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FAST FLUX TEST FACILITY
EVALUATION OF CONCEPTUAL FEATURES
FOR THE
REACTOR REFUELING SYSTEM

Evaluation Effort Directed by:

D. M. Walley
W. E. Cawley

Prepared by:

C. R. Nash
C. L. Peckinpaugh

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Approved by

W. B. McDonald

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INTRODUCTION

OBJECTIVE

In June, 1967 a conceptual evaluation effort was initiated to select the reactor refueling concept for FFTF. The objectives of this effort were:

- To identify and study alternate methods of fuel handling.
- To evaluate these concepts in sufficient detail to permit selection of a reference and backup concept.

PURPOSE

An evaluation of the conceptual features developed through this effort was deemed necessary because of the major impact on overall plant and testing capabilities exerted by refueling system design. These considerations warranted a full examination of system requirements and alternate concepts to assure a sound basis for the reference design choice.

SCOPE

The scope of the refueling concept evaluation effort included:

- Definition of functions and design requirements.
- Identification of promising concepts.
- Development of conceptual alternates.
- Definition of evaluation criteria.
- Evaluation of alternate concepts against this criteria.
- Recommendation of reference and fallback concepts.

The refueling concept evaluation effort was based on refueling the reference split conical core concept.⁽¹⁾

BACKGROUND

A committee of PNL personnel reviewed the requirements established in the original fuel handling studies and defined the initial functions and design requirements for the Reactor Refueling System. During the follow-on effort, these initial requirements were revised by PNL to guide concept development and employed in the concept development and evaluation effort as concurred in by RDT-AEC (Appendix A).

A committee of fuel handling specialists from throughout the country was convened by PNL to identify promising fuel handling concepts for the FFTF. The conclusions of this committee⁽²⁾ were adopted, along with internal PNL studies, to establish potential candidate concepts worthy of conceptual development.

The significant conceptual alternates identified by the concept identification studies were developed by two industrial contractors. Aerojet-General developed the concept of an unshielded, totally remote fuel handling machine (FHM)⁽³⁾ which operate in an inert atmosphere. Aerojet's studies, focused on a multiple special purpose FHM concept, considered both gas and sodium decay heat removal systems. Atomics International (AI) developed shielded manned access concepts, including both a sodium-cooled⁽⁴⁾ and a gas-cooled concept.⁽⁵⁾ AI also performed sensitivity studies on multiple special purpose versus single multiple purpose FHM concepts,⁽⁶⁾ and shielded versus unshielded concepts.⁽⁷⁾

Criteria were selected for evaluating the alternate concepts. These criteria (Appendix B) were reviewed by RDT-AEC and used by PNL to guide concept evaluation.

In September, 1967, a Concept Evaluation Task Force consisting of K. L. Berrett, D. C. Boyd, C. F. Gabel, R. A. Harvey, H. D. Lenkersdorfer, D. A. Munro, C. R. Nash, C. L. Peckinpaugh, and T. W. Withers, was organized at PNL to review and evaluate the results of the concept development studies. The Task Force evaluated the candidate concepts against the evaluation criteria established for this purpose. Results of the Task Force evaluation were presented to a Concept Selection Board consisting of senior PNL Staff Members W. E. Cawley, L. M. Finch, R. J. Hennig, W. B. McDonald, W. D. Richmond, F. H. Shadel, and D. M. Walley. The objective of the Concept Selection Board was to review the evaluation results and to recommend the conceptual features to be incorporated in a reference and backup reactor refueling system for conceptual design. The evaluation results, conclusions, and recommendations of both the Concept Evaluation Task Force and the Concept Selection Board are presented in this report.

RECOMMENDATIONS AND CONCLUSIONS

RECOMMENDATIONS SUMMARY

Four basic conceptual features of the Reactor Refueling System were identified for evaluation in terms of their ability to handle reference driver fuel assemblies and experiments of comparable specific decay power. These features were, (1) the number of Fuel Handling Machines (Multiple Fuel Handling Machines or Single Fuel Handling Machine), (2) the decay heat removal methods (sodium, gas, or combination), (3) the shielding (full, partial, or no shielding), and (4) the normal hot cell atmosphere (air or inert gas).

A summary of the recommendations resulting from the evaluation are as follows:

1. The basic reference reactor refueling system should be a Multiple Fuel Handling Machine (MFHM) concept consisting of indexing and transporter equipment capable of receiving and

carrying interchangeable fuel handling casks. The MFHM concept is recommended because initial casks may be supplied only for well defined conditions; and the inherent flexibility and versatility of multiple casks provides a variety of options to cope with unforeseen problems during design, development, procurement, and throughout plant operating life.

2. The reference concept should provide for the following fuel handling casks:

- Sodium-cooled cask with continuous heat removal capability in the range of 25 to 35 kW.
- Gas-cooled cask with non-continuous heat removal operation, cooling only when fuel is in cask (studies are in progress to determine the heat removal capability, expected to be in the range of 5 to 15 kW).
- Other casks with additional heat removal capabilities, as determined by future technical requirements.

The sodium-cooled cask is recommended for high decay heat loads because continuous cooling can be provided at the reactor interface without major reactor vessel design penalties, and because the excellent heat transfer properties of sodium provide inherently safe natural convection cooling and greater stretch capability. The gas-cooled cask is recommended for low decay heat loads because it provides, at minimum cost, an assured development cask which simplifies transfer cell interfaces and improves plant availability when operating in conjunction with the sodium cask (see Figure 1). The cask indexing and transporter system should be capable of handling fully shielded fuel handling casks to permit system flexibility by providing the option for both shielded and unshielded casks. Recommendations regarding shielding of the reference sodium and gas-cooled

FIGURE 1. Application Diagram of Fuel Handling Casks

casks should not be made until completion of sensitivity studies conducted to determine the effect of cask shielding on the decay heat cooling systems and the reactor secondary gamma shield.

No firm recommendation should be made concerning the normal hot cell atmosphere in view of an existing safeguards feasibility question regarding containment of a sodium spray fire within the hot cell.

The sodium-cooled cask is the only feature of the reference concept warranting development of a backup concept. The recommended backup concept for the sodium-cooled cask is a gas-cooled cask capable of heat removal in the range of 25 to 35 kW, and provisions for emergency cooling.

CONCLUSIONS AND FUTURE STUDIES

The following discussion summarizes findings and conclusions resulting from the Conceptual Features Evaluation and proposes, in general terms, a program for developing information additionally required in advancing the conceptual design of the Reactor Refueling Systems.

The major overall advantage of the sodium-cooled cask designed to the "radiator barrel" principle is its capacity to remove decay heat from a subassembly for an indefinite period of time by natural convection cooling.

A subassembly could not melt, even though all backup systems fail. The recommended 25-35 kW of heat removal capability is based on the decay heat curve shown in Figure 2.

The Sodium Cooling System would not impose severe interface problems on the reactor systems as does a continuous gas cooling system.

The excellent heat transfer properties of sodium permit greater stretch capability, so that subassemblies generating high

FIGURE 2. FTR Driver Fuel Conceptual Average Decay Heat Output

specific power or greater total power than reference assemblies could be handled and cooled if necessary.

Overall development and procurement schedules do not appear to conflict with present FFTF schedules, although a significant amount of development is required for the level control and sodium flooding system, the lower closure device, and the hoist and grapple assembly.

The noncontinuous gas-cooled cask has the principal overall advantage of the gas-cooled (5 - 15 kW) Hallam Fuel Handling Machine, and the limited development requirements would minimize disruptions to plant schedules. The closure valve and mechanisms are simpler for this low capacity gas-cooled cask so that fuel handling cycle times are shortened.

The nominal rating of 5 to 15 kW is stated only as a reference starting point. Studies must be conducted to determine where, in development of the gas-cooled system, that step-type increases in risks occur as heat removal capability is raised. Decay heat would not be permitted to exceed the level at which fuel could be melted by a loss of forced coolant circulation (see Figures 3 and 4). Determination of these heating values are needed in the FFTF project to provide accurate information on gas-cooling parameters, and because future experiments may need higher capability gas-cooled systems.

The interface problems at the reactor and the transfer cell would be simplified by using this gas-cooled cask to handle low heat subassemblies.

The need for continuous gas cooling of higher heat subassemblies would require the solution of serious problems in developing an adequate path to complete the gas cooling circuit. Gas must be returned either by (1) bubbling through the reactor sodium to create a gas entrainment potential in the sodium system, or (2) by flowing up the outside of the fuel element in a

FIGURE 3. FFTF Fuel Element Center Rod Clad Temperature

FIGURE 4. Transient Temperature for Center Pin
of FFTF Driver Fuel Assembly (600 °F
Heat Sink Surrounding Stagnant Sodium)

flow duct. The latter option would require increasing the diameter of the reactor nozzles and the length of the reactor vessel.

The noncontinuous gas-cooled cask avoids this problem by lifting subassemblies into the cask before the flow of cooling gas is started. The noncontinuous gas-cooled cask can be used whenever decay heat generation is too low to produce fuel melting in event of a cooling system failure during the lift-transport-lower cycle.

The combination cooling system, with all the faults of both cooling systems and with no significant advantages, should be dropped from further consideration.

The type of shielding recommended as a reference concept was based on an interim decision to begin conceptual design with provisions for full shielding. A firm basis for recommending the type of shielding requires determining the mode of operation for nozzle preparation and, therefore, the relative complexity of the secondary gamma shield. Determination of this operating mode is a high priority, near-term objective.

The principal overall advantage of full shielding would be to provide hot cell access for possible maintenance, and for other work more effectively accomplished by contact means. Various types of shields have application in the hot cell, including permanent shields or temporary shields erected for particular situations.

Partial shielding would permit contact maintenance at all times except when the FHM is carrying a subassembly. The hot cell must be vacated during fuel transfer, an operating mode that tends to reduce plant availability, weakening the case for partial shielding.

The most desirable type of hot cell atmosphere still awaits determination. The normal type of hot cell atmosphere does not inhibit FHM conceptual design because the equipment must be capable of operation in both inert and air atmosphere. With full shielding in the cell, an air atmosphere becomes highly desirable because it permits unencumbered access for maintenance work.

A serious feasibility question as to whether the hot cell can or should be required to withstand the pressures resulting from reaction of sodium with the oxygen in the cell remains to be answered. Comprehensive studies to determine both the feasibility limits and costs of the hot cell atmosphere must be completed before PNL can arrive at a final overall recommendation concerning this question.

DEFINITION OF CONCEPTUAL FEATURES EVALUATED

Concepts proposed by the contractors during their studies^(3,4,5,6,7) were developed for complete sets of equipment. Evaluation of each concept in its entirety was not necessary because of the commonality of elements among them. Only those features of greatest importance to the overall refueling system were evaluated. These are described under the following sub-headings.

TYPES OF FUEL HANDLING MACHINES

- Multiple Fuel Handling Machines
- Single Fuel Handling Machine

The Multiple Fuel Handling Machines (MFHM) concept discussed in this evaluation consists of an Indexing and Transporter System designed to receive and carry interchangeable fuel handling casks, a relatively simple, low capacity gas-cooled cask, and a high capacity sodium-cooled cask. Other casks would be supplied to meet special future conditions.

The Single Fuel Handling Machine (SFHM) concept also considered in this evaluation consists of one Fuel Handling Machine

mounted permanently on a gantry. This machine is able to cool and carry all core components routinely removed from the reference reactor.

DECAY HEAT REMOVAL METHODS

- Sodium (25 - 35 kW)
- Gas (continuous cooling 25 - 35 kW)
- Gas (noncontinuous cooling 5 - 15 kW)
- Combination Sodium/gas continuous cooling (25 - 35 kW)

Sodium flow in the sodium cooling system continuously cools the subassembly while it is being lifted or lowered either at the reactor or other ports in the hot cell, and while it is being transported. The sodium level in the FHM is raised by increasing pressure in the reactor system and reducing pressure in the fuel handling machine itself. The sodium level "tracks" the vertical position of the subassembly to keep the fuel portion submerged in sodium while simultaneously protecting the instrument connector at the upper end from sodium wetting. The sodium system provides 30 kW of heat removal capability continuously during the entire lift-transport-lower cycle.

The gas cooling system uses an inert gas as the cooling medium. For continuous cooling (25 - 35 kW), full gas flow is established through the subassembly before it is raised above the sodium level. Gas bubbles through the subassembly, into the bulk sodium, and discharges into the primary cover gas system. For noncontinuous gas cooling (5 - 15 kW), the fuel is raised into the machine before gas flow is established. Decay heat loads for the noncontinuous gas cooling system must be limited below the fuel melting level in the event cooling is interrupted between the FHM and the reactor sodium pool.

The "combination" cooling system, as in the sodium-cooled concept, enables the subassembly to remain submerged in sodium until it is pulled into the fuel handling machine. Then the sodium is replaced by continuous inert gas through the subassembly until the subassembly is released to a sodium cooling

system at one of the transfer ports in the hot cell. This combination system provides 30 kW of heat removal capability continuously during the entire lift-transport-lower cycle.

SHIELDING

- Full Shielding
- Partial Shielding
- No Shielding

Full shielding for the fuel handling machinery and the reactor nozzle region permits continuous unrestricted access to the hot cell, and thus contact operation and maintenance of the FHM. The shielding material is installed on the FHM and also over the reactor (secondary gamma shield). Refueling is accomplished by working through the shielding installed over the nozzle region.

Partial shielding of the fuel handling machinery and the reactor nozzle region permits access to the hot cell for remote operation and contact maintenance of the FHM except during movement of a subassembly. The thickness of shield material is sufficient only to protect against the radiation from the coating of residual sodium and fission products inside the FHM. Shielding over the nozzle region may or may not be in place during refueling.

Completely unshielded fuel handling machinery must be remotely operated in the hot cell. The shield over the nozzle region may be removed to permit access for fuel handling work. Personnel may enter the hot cell during reactor operation when the nozzles are shielded and the FHM is stored behind a shield. No contact with the FHM can be made until after its internals have been decontaminated.

NORMAL CELL ATMOSPHERE

- Air
- Inert Gas

Design of the fuel handling equipment to function in either an air or an inert gas atmosphere is a basic FFTF requirement

(Appendix A). This requirement was established to provide maximum flexibility of operation, including full plant testing capabilities. Specifically evaluated were conditions of the hot cell atmosphere to be established for normal activities in support of refueling operations. The air atmosphere permits manned access without breathing apparatus, while the inert gas atmosphere requires breathing apparatus. The type of atmosphere more directly affects maintenance activities rather than normal fuel handling operations as such.

EVALUATION CRITERIA

A detailed list of evaluation criteria (Appendix B) based primarily on the conceptual design requirements was developed. The four conceptual features discussed in the preceding section were evaluated in a detailed listing of advantages and disadvantages applicable to each particular criteria. The detailed criteria were reviewed to determine the relative importance of each in respect to corresponding advantages and disadvantages. The relative values of the criteria were qualitatively established by the use of two basic guidelines. First, it was desirable to highlight key differences in the conceptual features, and second, those differences of major effect on the project goals and requirements as stated in the Program Directive⁽⁸⁾ and the Overall CSDD⁽⁹⁾ were emphasized.

The criteria list was then summarized and simplified by condensing criteria and evaluation statements (advantages and disadvantages). The summary criteria resulting from this simplification process are shown in the following tabulation.

<u>Criteria</u>	<u>Capability Requirements</u>
1. Flexibility and versatility	Capability to adapt to changes and provide a variety of options for operation, maintenance, development, and cost

<u>Criteria (Contd)</u>	<u>Capability Requirements (Contd)</u>
2. Interfacing system compatibility	Capability to minimize complexity, development, and cost of interfacing systems
3. Experiment handling requirements	Capability to meet the functional testing requirements during fuel handling
4. Plant availability	Capability for high refueling rates, reliability, and maintainability
5. Safety	Capability to minimize consequence of cooling failure and other system malfunctions
6. Development risk	Capability to provide assured and timely development
7. Startup schedule	Capability to meet FFTF Project schedules
8. Cost	Capability to minimize FFTF Project costs

The evaluation process was primarily qualitative because of the conceptual nature of the concept development input. A quantitative evaluation, attempted to provide additional insight into relative performance of the conceptual features, did not provide additional clarification and, therefore, was not included in this report.

KEY ADVANTAGES AND DISADVANTAGES

The key advantages and disadvantages of each conceptual feature as evaluated are listed below. Advantages and disadvantages are listed only when meaningful information can be stated for the criteria of interest.

NUMBER OF FUEL HANDLING MACHINES

Multiple Fuel Handling Machines

Advantages

Flexibility and Versatility

- Adapts to changes, in that special casks can be provided for changing missions or requirements beyond the capacity of the basic driver fuel cask.
- Varies cooling medium because special casks can be provided if different cooling media are required.

Interfacing System Capability

- Simplifies reactor and transfer cell interface because casks can be used in sequences that minimize interface problems.

Plant Availability

- Improves plant availability because the gas-cooled cask with its simpler operating modes requires shorter cycle time.
- MFHMs can be used in partial redundancy when heat removal requirements overlap to ease outage problems from unscheduled maintenance.

Development Risk

- Minimizes development risks. Assured development cask, based on known technology, can be used for initial startup to allow more time for obtaining a cask meeting more stringent performance requirements.

Disadvantages

Cost

- Requires cask storage space in the hot cell.
- Increases total initial cost because the multiplicity of casks leads to higher capital cost.

Single Fuel Handling Machine (SFHM) ConceptAdvantagesCost

- No cask storage space as such is needed in the hot cell.
- Lowest initial cost if performance requirements remain within its capabilities.

DisadvantagesFlexibility and Versatility

- Difficult to adapt to changes. Where significant changes in mission develop, or nonroutine tasks are necessary, the SFHM may be incapable of the modification required.
- Restricts changes in cooling capacity and medium. Later requirements may develop with capacity beyond the SFHM, and adaptations to coolants other than sodium may prove to be impracticable.

Interfacing System Compatibility

- Complicates either reactor or transfer cell interface. A sodium-cooled SFHM complicates the transfer cell; a gas-cooled SFHM complicates the reactor.

Plant Availability

- Limits plant availability. The mechanisms needed for performing the most time consuming sequences must be used for tasks requiring only simple sequences.
- More complex equipment results in greater maintenance. Any malfunction of an SFHM interrupts fuel handling operations until repairs are completed.

TYPE OF DECAY HEAT COOLINGSodium Cooling (25 - 35 kW)AdvantagesFlexibility and Versatility

- Handles higher specific power (stretch capability). The excellent heat transfer properties of sodium permit removing not only higher heat fluxes but also greater total heat.

Interfacing System Compatibility

- Cooling is not disrupted at the reactor because the fuel assembly is kept submerged in sodium during the entire sequence of lift and transfer.

Experiment Handling Requirements

- Assures cooling of failed experiments and fuel assemblies because good conductivity of the sodium reliably cools sub-assemblies with partially plugged flow passages or warped pins.
- Minimizes thermal transients, in that continuous control over temperature is possible with the good thermal ballast of the bulk sodium in the FHM.

DisadvantagesInterfacing System Compatibility

- Requires reactor sodium level and pressure changes. When sodium is raised into the FHM, the level of sodium is also raised in other reactor nozzles. The level control system in the FHM must assure coolant as the subassembly is withdrawn from the reactor, and must reliably indicate any deviation from normal level changes.
- Requires complicated sodium system in transfer cell if the sodium-cooled FHM mates with the transfer cell. Receiver pots, sodium level control system, sodium cleanup system, etc., are necessary.

Experiment Handling Requirements

- Cannot handle gas-cooled experiments. Contamination of the test specimen will not be permitted.

Safety

- Potential exists for sodium leakage. Loss of the sodium volume in the FHM means loss of cooling and meltdown of the subassembly. Leakage from the FHM then would contaminate the hot cell.

Safety

- Provides inherently safe natural convection cooling. If the forced convection system in the FHM should fail, natural convection and conduction backup cooling would maintain the subassembly below the clad melting temperature.

Gas Cooling (continuous cooling 25 - 35 kW)AdvantagesDisadvantagesInterfacing System CompatibilityFlexibility and Versatility

- Permits simple gas-to-gas transition in the transfer cell because a sodium-filled receiver pot and sodium cleanup system are not required.

- Limits stretch capability. Continuous gas cooling is limited in ability to handle higher specific powers.
- Limits element configuration. The design of the coolant flow path through the assembly must be proof-tested to assure that gas cooling is feasible. This could compromise instrument lead passages and supports in the hanger assembly.

Safety

- Eliminates possibility of sodium leakage during transfer because no sodium is carried in the FHM. Leaks in the cask might reduce gas cooling but would not permit the complete loss of cooling that results when the sodium-cooled FHM develops a leak.

Interfacing System Compatibility

- Requires difficult sodium-to-gas cooling transition at the reactor. To assure removal of significant amounts of heat from a subassembly, gas flow must be established before the subassembly is withdrawn from the sodium.

Experiment Handling Requirements

- Cannot assure cooling of failed experiments. Partial flow blockage from bowed pins could reduce gas flow and result in local overheating.

Safety

- Cooling dependent on backup blowers and redundant electrical power supply. Forced convection cooling must be maintained at all times in the gas-cooled system.
- Low heat capacity available. The heat capacity of the gas system is low. Melting may occur with loss of gas circulation, as shown in Figures 3 and 4.

Gas Cooling (noncontinuous 5 - 15 kW)AdvantagesDisadvantagesInterfacing System CompatibilityFlexibility and Versatility

- Permits simple gas-to-gas transition in the transfer cell because a sodium-filled receiver pot and sodium cleanup system is not required.
- Permits simple interface with reactor. Gas is not bubbled through the reactor sodium, and complicated seals to establish a gas path are avoided.

- Limits stretch capability. Noncontinuous gas cooling is severely limited in ability to handle higher specific powers.

Experiment Handling

- Cannot assure cooling of failed experiments. Flow blocked sufficiently from bowed pins would result in local over-heating, though not in melting.

Safety

- Eliminates possibility of sodium leakage during transfer because no sodium is carried in the FHM. Leaks in the cask might reduce cooling but would not permit the complete loss of cooling that results when the sodium-cooled FHM develops a leak.

Development Risk

- Provides assured development. The system is a small extrapolation from existing gas cooling FHM equipment.

Schedule

- Shortest schedule. Simple system and small development requirements provide minimum development and fabrication time.

Combination Cooling (25 - 35 kW)AdvantagesInterfacing System Compatibility

- Cooling not disrupted at the reactor. Sodium, drawn up into the cask with the subassembly, maintains constant cooling. Gas bubbles into the FHM sodium system while gas flow is established.

Plant Availability

- Reduces plant availability. A 10-day decay period is required to handle average driver fuel with full exposure conditions (Figure 2).

Safety

- Limited to safe conduction cooling for backup. Conduction cooling must be sufficient to prevent clad melting if forced gas cooling fails. Decay heat must be reduced to a safe level.

DisadvantagesFlexibility and Versatility

- Limits stretch capability in that, during gas cooling modes, the lower heat removal capability limits the handling of higher specific powers.

Advantages

- Provides simple gas-to-gas transition at the transfer cell. Gas cooling is established while the FHM is still locked on to the reactor. Only gas cooling need be used throughout the rest of the fuel transfer cycle.

Safety

- Minimizes possibility of sodium leakage. The sodium is ejected from the FHM when gas cooling is established. Up to this point, loss of sodium would result in loss of cooling to the subassembly. Beyond this point, the leakage problem is the same as for the gas-cooled FHM.

Disadvantages

- Limits subassembly configurations. The subassembly design must assure adequate passage of the gas coolant.

Interfacing System Compatibility

- Requires reactor sodium level and pressure changes. Level control and leakage problems exist during withdrawal of the subassembly from the reactor.

Experiment Handling Requirements

- Cannot assure cooling of failed experiments or fuel. Partial flow blockage from warped pins seriously compromises heat removal in the gas-cooled mode.

Plant Availability

- Plant availability reduced. More complex equipment leads to higher failure rate and more maintenance time.

Safety

- Cooling dependent on backup blowers and electrical power. In the gas cooling mode, forced convection must be maintained.
- Low heat capacity available during gas cooling mode. If heat removal system fails, the potential of clad melting is the same as for the gas-cooled FHM.

Development Risk

- Transition from sodium to gas cooling is difficult. Flow of gas through subassembly requires bubbling gas through sodium.

TYPE OF SHIELDINGFully Shielded FHMAdvantagesPlant Availability

- Improves plant availability. Permits unrestricted manned access which, by facilitating manual troubleshooting and repairs, results in shorter downtime for maintenance and other work in the cell.

DisadvantagesCost

- Greatest capital cost for the FHM itself, both because of the approximately 130 tons of lead or its equivalent, and the support structures for the heavier equipment.

Partially Shielded FHMAdvantagesPlant Availability

- Helps to improve plant availability. Allows partially restricted manned access for manual repairs and troubleshooting when the FHM is empty, and thus reduces maintenance downtime.

DisadvantagesCost

- Capital cost is greater than the unshielded FHM, by an amount equal to approximately the additional 70 tons of lead or its equivalent, and the necessary support structures.
- Remote maintenance and a significantly greater time for maintenance operations is required if the FHM malfunctions while carrying a subassembly.

Unshielded FHMAdvantagesFlexibility and Versatility

- Simple, unshielded casks may be quicker to procure when adjusting to unplanned future situations.

DisadvantagesPlant Availability

- Remote maintenance and greater time for all troubleshooting and repair is required than for contact operations.

Cost

- Least capital cost for the FHM itself, but full capability for remote maintenance must be provided.

TYPE OF NORMAL HOT CELL ATMOSPHEREAirAdvantagesPlant Availability

- Increases plant availability because it permits unencumbered movement of personnel in the hot cell for maintenance work and for experiment setup. Remote or airsuit performance of this work materially increases the time required.

DisadvantagesSafety

- Sprays, spills, or leaks would create sodium fire hazards.

Cost

- Air medium least costly from operating standpoint.

Inert GasAdvantagesSafety

- Eliminates the sodium fire hazard.

DisadvantagesPlant Availability

- Encroaches on plant availability because of air-suit. Remote operations in the cell increase the time required to perform work.

Cost

- Inert gas is more costly because of expensive makeup and purification.

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APPENDIX A

REACTOR REFUELING SYSTEM FUNCTIONS AND REQUIREMENTS

APPENDIX A

REACTOR REFUELING SYSTEM FUNCTIONS AND REQUIREMENTSOVERALL FUNCTIONAL OBJECTIVE

The primary function of the Reactor Refueling System is to handle the routinely removable FFTF core components and experiments. The experiments will be handled in a controlled environment to permit maximum acquisition and preservation of data. The handling functions of the Reactor Refueling System are restricted to those operations to be performed within the reactor hot cell.

FUNCTIONS

The Reactor Refueling System inserts, removes, and transfers core components and experiments at the various refueling stations within the reactor hot cell.

Refueling stations lead to:

- Reactor
- Reactor containment transfer ports
- Interim irradiated decay heat storage
- Interim nonirradiated storage
- Transfer cell

The Reactor Refueling System provides interim storage for routinely removable core components and experiments. Trade studies will be performed to determine the location of interim decay storage in the fuel handling system. System 43 also will be identified.

REQUIREMENTS

1. The Reactor Refueling System shall be designed for the reference truncated, split conical core.
2. The Reactor Refueling System shall provide the capability to interface, and be compatible with, the reactor vessel nozzle configuration.

3. The Fuel Handling Machine shall be designed to be operated in a remote mode.
4. The Reactor Refueling Equipment shall be maintained in a contact and/or remote mode.
5. The Reactor Refueling System, Equipment, Mechanisms, and Process Systems shall be designed to fail in a fundamentally safe state.
6. The Reactor Refueling System shall be designed to handle only normal, undamaged driver fuel subassemblies.
7. The Reactor Refueling System shall be capable of initiating handling driver fuel subassemblies 24 hr after shutdown (approximately 30 kW decay heat load for average driver fuel used for concept development studies).
8. The Reactor Refueling System shall maintain the driver fuel cladding surface temperature below the specified design temperature (approximately 1200 °F maximum clad temperature used for concept development studies).
9. The Reactor Refueling System shall provide the capability to measure coolant temperature during transfer.
10. The Reactor Refueling System shall be designed to change out driver fuel and experimental trains at a rate that supports high plant availability (approximately one full transfer cycle in 4 hr used as a target for concept development studies).
11. Spills or leaks shall be prevented or contained, and adequate compatible backup cooling shall be provided when required without need for operator action. The Reactor Refueling System (Hot Cell) shall be designed to safely contain the fuel handling accident which results from loss of fuel cooling.
12. The Reactor Refueling System shall be designed with redundancy in mechanisms and process systems as required to assure that no single component or subsystems failure will render equipment incapable of completing functions leading to the next naturally safe state.
13. The Reactor Refueling System design will conform with such reactor standards, licensing conditions, and Federal Regulations as are determined to be applicable.

14. The Fuel Handling Machine grapple drive mechanism shall have controlled push-pull capability consistent with the mechanical strength characteristics of fuel assemblies and the reactor internals.
15. The Reactor Refueling System shall be designed to preserve the necessary experimental data acquired in the reactor for the experimental trains.
16. The Reactor Refueling System shall be capable of handling close-loop test specimens that have been tested to planned failure, and shall have proper safeguards for personnel, equipment, and facility.
17. The Reactor Refueling System inside the hot cell shall be designed to operate in an air or an inert atmosphere.

APPENDIX B

DETAILED EVALUATION CRITERIA
FOR REACTOR REFUELING SYSTEM CONCEPT SELECTION

APPENDIX B

DETAILED EVALUATION CRITERIAREACTOR REFUELING SYSTEM CONCEPT SELECTIONPERFORMANCE

1. Compatibility with the reference split conical core which includes integral full length core components (core element and attached hanger) positioned in individual reactor nozzles.
2. Capability to continue refueling operations after sodium or fission product leakage.
3. Capability to handle experiments which were planned for failure.
4. Capability to remove decay heat from driver and experimental fuel consistent with plant availability and maximum fuel temperature requirements (24 hr decay and 30 kW for concept development studies).
5. Capability to control and monitor environmental conditions of driver and experimental fuel and specimens during handling.
6. Capability of refueling rates for driver and experimental fuel consistent with high plant availability (one full transfer cycle in 4 hr for concept development studies).
7. Capability of connecting and disconnecting core component instrumentation.
8. Flexibility and adaptability to adjust to contingency situations or handle abnormal conditions.
9. Capability to maintain core components in a condition suitable for return to the reactor.

SAFETY

1. Capability to handle loss of primary cooling accident condition, and extent to which this possibility can be minimized or mitigated by proper design.
2. Capability of critical systems and features involving safety to fail to a naturally safe state or to a safe backup mode.

3. Capability to cool a fuel subassembly stopped in the nozzle region, and all other phases of handling.
4. Capability to minimize sodium and/or fission product leakage.

RELIABILITY

1. Complexity of mechanisms, valves, seals, and cooling equipment.
2. Capability to minimize consequences of individual component failure in terms of propagation of failure to other working parts.
3. Capability to use proven componentry.
4. Ability to use margins of safety (or safety factors).
5. Capability to de-rate performance of individual elements of the system.

MAINTAINABILITY

1. Capability to maintain system equipment.
2. Capability to recover economically and safely from malfunctions.
3. Capability to decontaminate equipment.
4. Capability to diagnose and correct malfunction (troubleshoot).
5. Capability for access to mechanisms.

COST

1. Ability to minimize fuel handling portion of the FFTF Project capital cost allocations.
2. Ability to minimize Fuel Handling System effect on overall FFTF cost.
3. Ability to minimize Fuel Handling System operations and maintenance cost.

SCHEDULE

1. Ability to meet FFTF Project Schedules.
2. Effect of development failure on project schedule.
3. Ability to adequately qualify Fuel Handling System equipment on project schedule.

DEVELOPMENT AND RISKS

1. Capability of using proven designs and equipment (State-of-the-Art).
2. Capability of using proven fabrication and assembly practices and contractors.
3. Capability to provide fall-back positions for critical development areas.

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