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ENGINEERING SERVICES FOR THE NEXT GENERATION NUCLEAR PLANT (NGNP) WITH HYDROGEN PRODUCTION

Test Plan – Fuel Handling and Storage System

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ACRONYMS

ASC	Auxiliary Service Cask
DDN	Design Data Need
EHGA	Element Hoist and Grapple Assembly
FHEP	Fuel Handling Equipment Positioner
FHESS	Fuel Handling Equipment Support Structure
FHM	Fuel Handling Machine
FHSS	Fuel Handling and Storage System
FSIP	Fuel Sealing and Inspection Facility
FTC	Fuel Transfer Cask
FSV	Fort Saint Vrain
GA	General Atomics
GT-MHR	Gas Turbine Modular Helium Reactor
HTGR	High-Temperature, Gas-Cooled Reactor
I&C	Instrumentation and Controls
INL	Idaho National Laboratory
LRSF	Local Refueling and Storage Facility
NGNP	Next Generation Nuclear Plant
MHR	Modular Helium Reactor
MHTGR	Modular HTGR
NP-MHTGR	New Production Modular HTGR
PC-MHR	Plutonium Consumption – Modular Helium Reactor
TRL	Technology Readiness Level

1 INTRODUCTION

1.1 Purpose

This Test Plan provides a high-level description of a test program to support design, fabrication, and deployment of the Fuel Handling and Storage System (FHSS) for the Next Generation Nuclear Plant (NGNP). Startup of the NGNP is currently scheduled for 2021, so the test program must be well coordinated with an FHSS design and fabrication schedule that supports this startup date.

1.2 Scope

GA has assigned a baseline Technology Readiness Level (TRL) of 4 to the FHSS based on GA's large experience base from designing, building, testing and operating fuel handling equipment for the Peach Bottom and Fort St. Vrain (FSV) reactors. The required design and testing activities to advance the TRL of the FHSS from 4 to 8 are as follows:

TRL 4 → 5

- Component and Integrated Verification in the air and helium environment.
- FHESS material and component qualification, functional and endurance
- FSIF component verification for packaging, sealing and inspection processes

TRL 5 → 6

- FHEP speed, accuracy and extended cyclic verification with and without load
- EHGA Operability and reliability of the vertical drive system for the grapple
- FHM Functional and Performance limits in anticipated operating modes and conditions
- FTC Operability and reliability of the hoist grapple, horizontal transfer, table drive and the whole complete grapple system

TRL 6 → 7

- The operability and reliability of the integrated FHSS, working in simulated plant operating conditions

TRL 7 → 8

- A cyclic test of FHSS in simulated plant operating conditions.

These activities ate outlined in Sections 3 through 6 of this Test Plan. A summary of the cost and schedule for the overall design/technology development program is provided in Section 7.

Given that adequate design details for the FHSS are not currently available to precisely define design support and verification testing requirements, this Test Plan is intended primarily to identify the design and testing activities that are likely to be needed and to provide cost and schedule estimates, which are based primarily on engineering judgment at this point in time. It is assumed that this Test Plan will be updated periodically as the FHSS design progresses and that detailed test plans and test procedures will be prepared by the testing organizations for the specific tests that need to be conducted.

1.3 System Description and Operation

1.3.1 System Equipment

The FHSS is used to refuel the reactor and for all transfers of fuel and reflector elements between the reactor and local storage facilities and between the local storage facilities and the packaging and shipping facility. The system is also used to manipulate special tools for in-service inspection of reactor components. The major fuel handling and storage components (subsystems) include the fuel handling machine (FHM), the fuel transfer cask (FTC), the fuel handling equipment positioner (FHEP), the fuel handling equipment support structure (FHESS), the element hoist and grapple assembly (EHGA) in the local fuel storage facility, and the fuel sealing and inspection facility (FSIF).

The arrangement of fuel handling equipment is shown in Figure 1. In-core fuel handling is performed by the FHM and the FTC working together. The functions of the various major FHSS components are summarized below:

- The FHM is a shielded, gas tight structure containing all the necessary mechanisms required to transfer fuel and reflector elements between the reactor core and the upper plenum
- The FTC is a shielded structure which transfers fuel and reflector elements between the fuel handling machine (inside the upper plenum) , and the FSIF and/or the Local Refueling and Storage Facilities (LRSF)
- The FHESS receives and supports fuel handling equipment over the reactor vessel during refueling
- The FHEP transfers and positions the FHM, FTC, FHESS, and auxiliary service cask between storage locations, reactor vessel and fuel/target processing facilities floor valves
- The EHGA robot is a remotely operated bridge robot used in the LRSFs and FSIF to handle fuel and reflector elements and storage well plugs
- The FSIF equipment loads spent fuel elements into shipping containers, seals the container lid, and inspects the resulting container integrity.

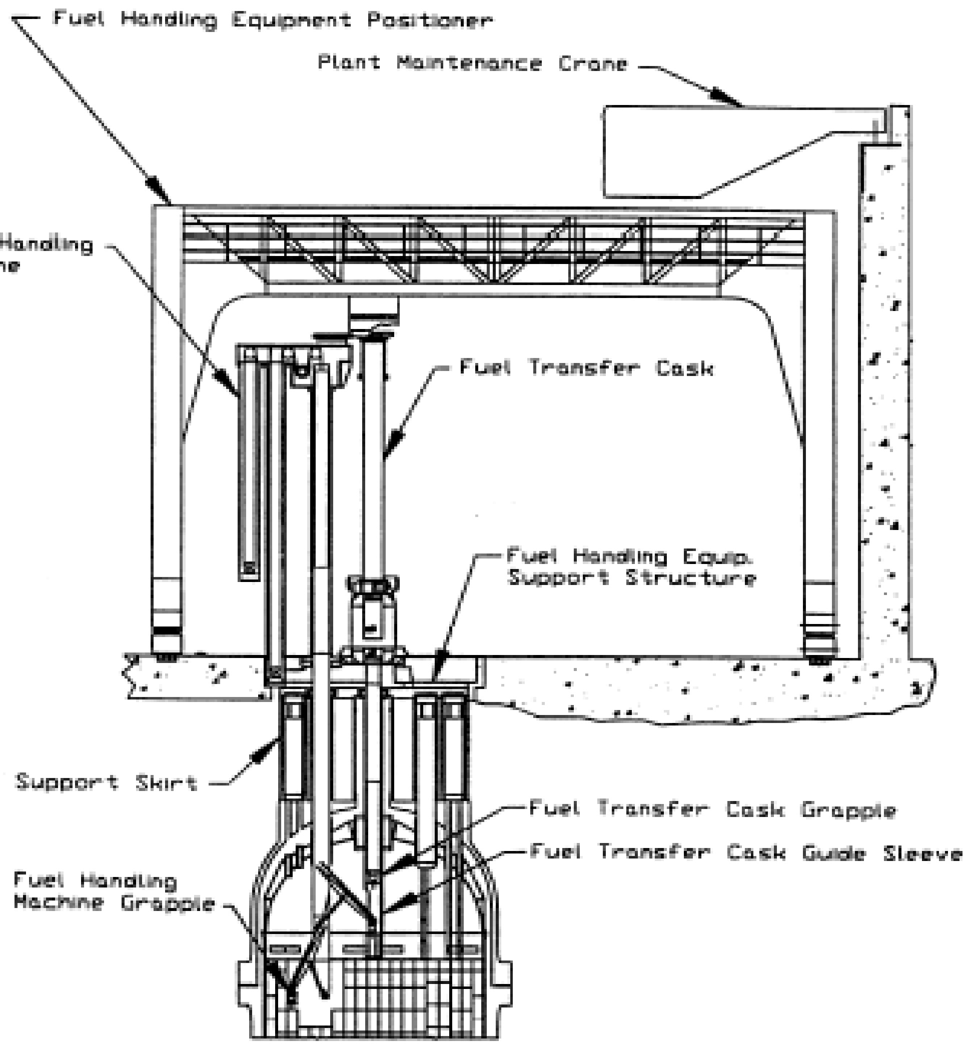

Figure 1. General Arrangement of Fuel Handling Equipment

A key component of the system is the grapple head design that is used in several of the FHSS machines to engage and release fuel and reflector elements. A picture of the FSV grapple head is shown in Figure 2. Key features of the FSV grapple head include:

- Antifriction ball systems to allow the grapple system to translate horizontally. These systems allowed for up to 7/8-inch horizontal misalignment between the grapple head and the element to be grappled

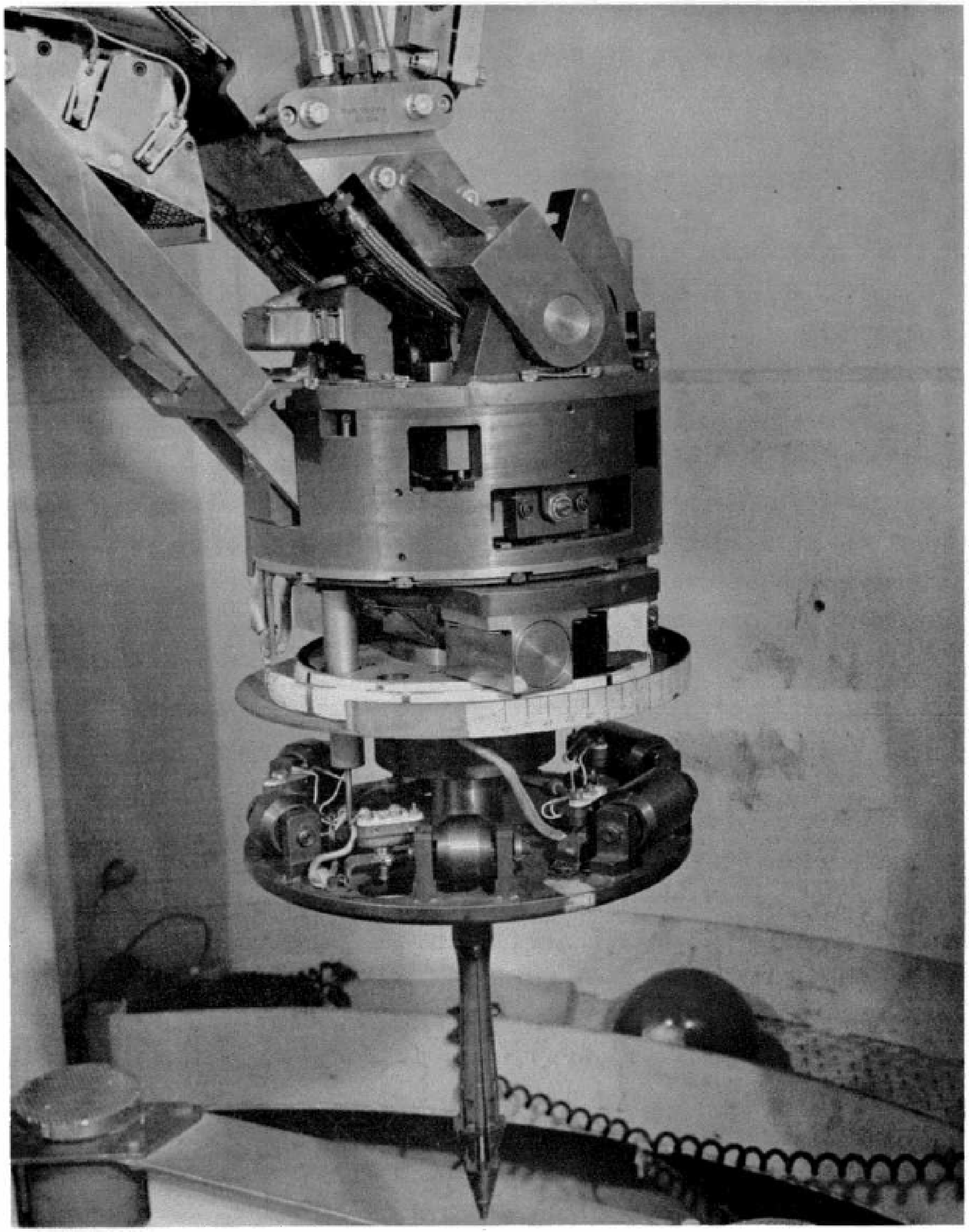

Figure 2. Fuel Handling Machine Grapple Head Assembly

- A rotation system capable of ± 39 degrees rotation and allowing for handling operations under misaligned core conditions was used to grapple some of the outer reflector elements.
- The grapple collet and lower plate were supported to allow for 2 inches of vertical overtravel. This overtravel allowance is sufficient to allow the FHM to stop safely after impacting an object at vertical speeds of 12 inches/second or less.
- Limit switches were mounted on the lower plate to sense the element dowel pins. To ensure proper orientation of the elements with respect to the grapple head
- An element weight system to weigh elements and detect element binding to adjacent surfaces
- An expandable grapple collet that support the elements by engaging a ledge inside the handling hole of the elements. This grapple system was spring-actuated and fail-safe

A more detailed description of the FHSS can be found in Section 3.3 of GA's NGNP Preconceptual Design Studies Report, Document 911107.

Operation of the FHSS is a key factor contributing to plant availability. The system must be highly reliable with sufficient redundancy to accommodate upset conditions and equipment failures. The equipment must minimize complexity and be readily maintainable. These are all important requirements that require a comprehensive confirmation and endurance test program. The FHSS provides radiation protection to workers and public during refueling operations. The reactor containment is opened for refueling and the refueling equipment must be securely fastened and sealed to the pressure vessel. The equipment is designed to appropriate seismic requirements to maintain integrity with the reactor pressure vessel. Leakage of primary coolant from the reactor is prevented by maintaining the interior pressure slightly below atmospheric. In addition, the equipment is sealed to the reactor with elastomeric seals. In the event of upset conditions, such as an interior water leak, the equipment and seals are designed for the maximum pressure rise (approximately plus 25 psig). Machine controls and fail safe mechanisms are provided for the handling of fuel elements. Mislocating of blocks, dropping or damaging blocks, or runaway machinery, etc., are concerns.

1.3.2 Design Data Needs

The design data needs (DDNs) for the GT-MHR FHSS are provided in document DOE-GT-MHR-100217, draft. Table 1 summarizes the DDNs and the proposed design support tasks.

Table 1. GT-MHR FHSS DDNs and Design Support Tests

DDN Title	Required Data and Testing	DDN #
Fuel Handling Machine (FHM)/Handling Mechanism Design Verification	Perform full-scale rig test to acquire data for FHM on functional and performance limits in anticipated operating modes and operating conditions Phase 1: Automated checkout of grapple head Phase 2: Automated checkout of element transfer mechanisms over a full core sector Phase 3: Automated cycle test in 250F helium	C.21.01.0 1
Fuel Transfer Cask (FTC) Component Design Verification	Use a full-scale test rig and test article to conduct tests in air (Phase 1) and helium (Phase 2) to establish the operability and reliability of the FTC and its components under expected environmental conditions. Key components include the vertical drive system for the hoist grapple, horizontal transfer table drive, and the complete grapple system. Test Phase 3 will be a separate cyclic test of the automated hold-downs and remote connections	C.21.01.0 2
Element Hoist and Grapple Assembly (EHGA) Design Verification	Conduct tests using a full-scale test rig and test article to acquire data on the operability and reliability of the vertical drive system for the grapple, the two independent grapple systems, and the positioning capability of the overhead crane under expected environmental conditions	C.21.01.0 3
Verify Fuel Handling System Instrumentation and Controls	Phase 1: Conduct tests in air to qualify element identification components Phase 2: Conduct tests in helium to qualify electronic instrumentation, viewing systems, etc. Demonstrate that the fuel handling control system, including software, meets its design requirements and is compatible with the fuel handling mechanism.	C.21.01.0 4
Fuel Handling Equipment Positioner (FHEP) Design Verification	Perform speed, accuracy, and extended cyclic endurance and structural testing to verify the design and ensure reliability and accuracy of the FHEP to retrieve, transport and place large, heavy machines and structures. The testing will include measurement of the four-axis acceleration and velocity capabilities of the FHEP under static and dynamic load conditions to acquire the data needed to validate process speed and performance predictions.	C.21.01.0 6
Fuel Handling Equipment Support Structure (FHESS) Design Verification	Conduct material qualification, functional and endurance testing with prototypic test articles and simulated interfaces. Obtain reliability and maintenance data for valve actuators, seal quality (leakage), and anchoring mechanisms to validate the performance of the valve and seal leakage with and without the load of the supported equipment with misalignment of NCA housings.	C.21.01.0 7
Fuel Sealing and Inspection Equipment Design Verification	Perform tests to verify the automated packaging, sealing and inspection process including extended cycle endurance tests under the expected service conditions	C.21.01.0 8
Integrated Fuel Handling System Test Data	Acquire operability and reliability data for the components of the handling system operating together by testing full-scale fuel handling and control equipment with simulated fuel elements in an environment representative of the operational environment	C21.01.05

1.3.3 Refueling Operation

It is anticipated that the refueling procedure for the NGNP will be essentially the same as that developed for the GT-MHR, except that the actual in-core refueling operation for the NGNP reactor will be executed on a column-by-column basis rather than using a layer-by-layer procedure as originally intended for the GT-MHR. Refueling takes place on a specific schedule, and involves the entire 1020 fuel element inventory in the reactor core, plus certain replaceable reflector elements as may be required.

A routine refueling commences with depressurization of the vessel system and installation of the FHESS above the reactor vessel. The FHESS is moved and handled using the FHEP. Using the auxiliary service cask, the nuclear instrumentation equipment is removed from the reactor vessel centerline penetration. A fuel element guide sleeve and support plate assembly is then inserted into this penetration, also using the auxiliary service cask. This equipment item is needed to support movement of fuel and reflector elements between the FHM and the FTC during the refueling procedure. Under controlled conditions, a neutron control assembly (control rod drive) is removed from one of the vessel top head inner penetrations using the auxiliary service cask. Using the FHEP, the FHM is installed over that same penetration. Also using the FHEP, a FTC is mounted over the reactor vessel centerline penetration, immediately adjacent to the fuel handling machine. Both machines are anchored to the FHESS to ensure seismic integrity.

Fuel and reflector elements are removed from the reactor in a specific order and placed in the FTC, one by one. When full, this cask is moved to the spent fuel storage area where all or a portion of these elements are placed in a helium-filled spent fuel storage well for interim cooling. New fuel elements are then loaded into the FTC and moved to the reactor where they are placed into the core, also in a specific order.

Replacement of certain fuel and reflector elements near the outer edges of the core requires that the control rods (and guide tubes) and reserve shutdown guide tubes associated with the neutron control assemblies in the outer penetrations be withdrawn to allow access into this area by the FHM. All such control rod withdrawals must be fully approved prior to withdrawal, and carefully controlled and monitored during the actual withdrawal. When all element moves are completed in this outer area, the rods and guide tubes are re-inserted.

When the current one-sixth region of the reactor has been refueled, the FHM is removed and the neutron control assembly is replaced in that penetration. The FHESS is then rotated as needed to obtain access to the next inner top head penetration for continuation of the refueling procedure. This process continues until the entire reactor core has been refueled in accordance with a predetermined sequence of fuel and reflector movements, after which the

FHESS is removed and the reactor is prepared for resumption of operations. A diagram of the one-sixth refueling sector is shown in Figure 3.

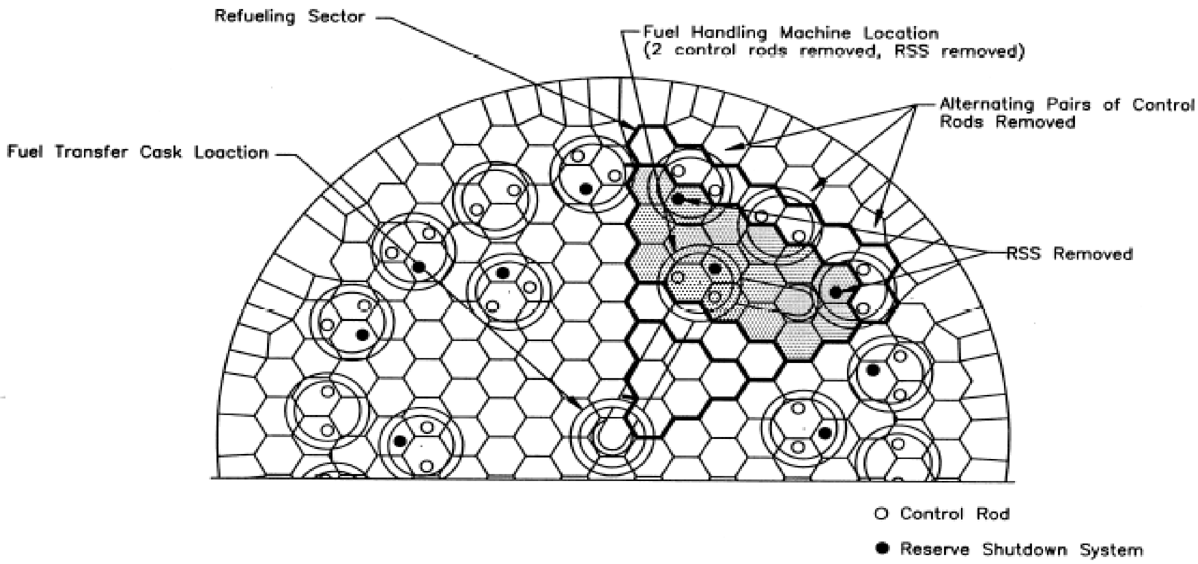

Figure 3. Refueling Sector

1.4 Background

A large experience base exists from designing, building, testing and operating fuel handling equipment for the Peach Bottom and Fort St. Vrain (FSV) reactors. Although the Peach Bottom fuel handling machine was manually operated, important technology was developed in the areas of: (1) electrical power and signal cables for operation in 450°F helium with high gamma background; (2) lubricants for use in the same harsh environment; (3) electronic sensors for use on the grapple head; (4) grapple head floating plate technology for light touch in horizontal and vertical directions; and (5) general purpose manipulator technology adapted for special use in the reactor.

The FSV FHM was designed and built in the late 1960's during the time that programmed machine tools were being developed for numerical control. This machine advanced from the Peach Bottom 1 technology in areas of: (1) computer control of multiple positioning systems in automatic mode or direct operator control in manual operation mode; (2) the use of electric motors, brakes, and position feedback instrumentation in a helium environment; (3) The use of a radiation-hardened television camera and lighting in helium; (4) programming techniques to safely operate the FHM within limits set by hard-wired interlocks and, (5) elementary inventory control, which was greatly enhanced in a 1989 control system upgrade.

The current design for the FHSS has evolved from the FSV technology. Years of experience with the FSV FHM have demonstrated both reliable features of the design and some features which could be improved. The current FHM design is based on the FSV FHM, but includes some mechanisms that differ from the FSV FHM:

- Shorter grapple probe
- Electrically controlled grapple mechanism rather than pneumatic
- Electrically controlled grapple head mechanism rather than pneumatic
- Increased handling mechanism linkage radial displacement
- Viewing system and electronic control system revised to incorporate more current technology
- Telescoping tube guide sleeve is transported and inserted by the FHM rather than an auxiliary service cask
- Vertical travel requirement is greater in order to operate in a deeper core

The FHSS also includes several new automated machines that must operate in concert. The simultaneous operation of these machines is necessary to refuel a reactor module within the allocated time.

The FTC and the EHGA robot are new designs required to operate in a helium environment. These machines incorporate proven technology where applicable. For example, the FTC will use grapple head, telescopic guide tubes, and isolation valve designs similar to those used in the FHM. The FHEP is similar to a commercially available, computer operated gantry crane with position control of the x, y, z, and load rotation axes. The EHGA robot and its end effectors are similar to the gantry robots applied by GA in the U.S. Army chemical weapons demilitarization development program. GA has developed the robotics for the remote handling of munitions in a lethal agent environment. The particular relevant expertise gained and "lessons learned" in the design, use and control of multiple gantry robots, end-effectors, and decontamination compatible hardware is available and applicable to the gantry robots to be used in the LRSFs and the FSIF. The computer control and element accountability system will utilize background data derived from the FSV project, commercial HTGR designs, the GA Demil program and industrial applications of computer controlled equipment. The FSV and Demil projects provide tested data bases for the FHSS computer architecture which include automated serialized accounting of fuel elements and target assemblies.

The baseline TRL assigned to the FHSS is 4 based on (1) the lowest TRL for the subsystems that comprise the FHSS and (2) the need to conduct tests to confirm the performance and environmental compatibility of instrumentation and control components and systems, and to firm up their design prior to overall system development and verification. A TRL of 4 is assigned to both the FHESS and the FSIF for the reasons given below. A TRL of 5 is assigned to the other FHSS subsystems based on the state of the technology as discussed above.

The FHESS with its multiple interfaces (i.e., the reactor isolation valves and neutron control assembly housing seals) is a first-of-a-kind unit. Although design of the FHESS is a routine structural task based on loads, deflections, and stability of the structure, consideration must also be given to the radiation shielding needed to prevent unnecessary personnel radiation exposure. Adequate vendor documentation is expected to be available for the seals and valves to warrant a TRL of 4, but testing is needed to validate the performance of these components.

Little design information is currently available for the FSIF and the equipment will be first-of-a-kind; however, the fuel handling and packaging mechanisms and procedures used in this facility will be based on those employed in FSV and in other HTGRs. Further, as noted above, the relevant expertise gained and "lessons learned" in the design, use, and control of multiple gantry robots, end-effectors, and decontamination compatible hardware is available and applicable to the gantry robots to be used in the FSIF. Thus, an initial TRL of 4 is judged appropriate for this FHSS subsystem.

It is also important to note that the conceptual designs of the current FHSS components were developed in the early 1990’s and were based on the technology available at that time. Further, the “technology development” activities defined for the FHSS in the technology development road map (TDRM) and supporting TRL rating sheets are primarily design verification tests. Thus, an important first step in NGNP FHSS technology development will be to review the current designs of the FHSS components and ascertain the extent to which previous design selections should be updated based on new technologies that have become available since the current designs were developed. It is not anticipated that any new technology will be need to be developed for the FHSS components; rather it is a matter of ensuring optimal utilization of currently available technology, particularly in the area of FHSS I&C.

2 APPLICABLE DOCUMENTS

Table 2. Documents Applicable to FHSS Technology Development

Document Number	Title	Date
911107, Rev. 0	NGNP and Hydrogen Production Preconceptual Design Studies Report	July 2007
GA Report PC-000396	PC-MHR Engineering Development Plan	November 1995
CEGA-002712	Engineering Development Plan for the New Production Modular High-Temperature Gas-Cooled Reactor Program	October 2008
DOE-GT-MHR-100217 draft	600 MW(t) Gas Turbine – Modular Helium Reactor Design Data Needs	July 1994

3 TEST PLAN TO ADVANCE FROM TRL 4 TO TRL 5

A TRL of 5 is achieved when components have been demonstrated at an experimental-scale in a relevant environment. For the FHSS, these requirements will be met by a combination of design and engineering analysis, testing of instrumentation and control components common to the entire FHSS, and testing of specific components of the FHESS and the FSIP. Specifically, the following activities will be conducted to advance the TRL of the FHSS from 4 to 5.

1. Conceptual design of the FHSS components.
2. Perform a survey of the supply network for the types of equipment required for the FHSS and select vendors for the various components.
3. Complete preliminary design of the FHSS
4. Perform testing as necessary to verify the accuracy and reliability of the instrumentation and control components under a variety of operating conditions and after frequent use.
5. Perform testing to demonstrate proper operation of the FHESS with its four built-in reactor isolation valves and inflatable seals.
6. Perform tests of FSIF components to verify the automated packaging, sealing, and inspection processes (including leak-tightness testing capabilities).

These activities are discussed in the following sections. An overall schedule and cost estimate summary is provided in Section 7.

3.1 Develop FHSS Design Requirements and Conceptual Design

The first part of this activity will be to define the design requirements for the FHSS based on the requirements and conceptual design of the NGNP. Once the design requirements have been defined, the FHSS conceptual design will be developed. As discussed in Section 1.3, it is expected that the design of the various FHSS machines and facilities for the NGNP will be similar to the FHSS design conceptualized for the GT-MHR. However, the conceptual design of the FHSS for the GT-MHR was developed in the early 1990's, and the design could potentially benefit from subsequent advances in the relevant technologies. Therefore, the conceptual design effort will include a review of the current designs (developed in the early 1990's) and the current state of relevant technologies to ascertain the need for design changes to better utilize current technologies. Design improvements will be made based on the results of this review. The level of the design activity and supporting calculations will be sufficient to demonstrate a high probability that the FHSS will satisfy all design requirements.

The design requirements will be developed by GA. The conceptual design will be developed by GA, a GA NGNP team member, or by a designated subcontractor(s) using computer codes that have been verified and validated in accordance with the applicable requirements of ASME NQA-1.

This activity should start at the beginning of the NGNP conceptual design phase. It is estimated that it will take about 18 months to complete this activity. The estimated cost is about $1.9M.

3.2 Perform Survey of Supply Network

The first part of this activity will be to conduct a survey of the supply network for the types of equipment required for the FHSS. It is anticipated that this will be a continuation of the technology review started in the conceptual design task (Section 3.1.1). The second part of this activity will be to select vendors for the various FHSS. The market survey and vendor selection will be performed by GA, by a GA NGNP team member, or a designated subcontractor.

This activity will start upon completion of the FHSS conceptual design and will require about six months. The estimated cost is $350K.

3.3 FHSS Preliminary Design

The preliminary design of the NGNP FHSS will be developed by GA (or a GA NGNP team member or designated subcontractor) working with the FHSS equipment vendor(s). As part of this activity, a review of the FHSS DDNs defined for the GT-MHR (and assumed herein to be applicable to the NGNP FHSS) will be performed to determine their applicability in view of any FHSS design changes and advances in technology that have occurred since the GT-MHR FHSS design and DDNs were developed in the early 1990's. A revised set of DDNs specific to the NGNP FHSS will be prepared. A design support and verification program plan that is responsive to the NGNP FHSS DDNs will also be prepared.

This activity will start upon completion of conceptual design and will require about 18 months. The cost is estimated to be about $3M.

3.4 Verification of FHSS Instrumentation and Controls (DDN C.21.01.04)

3.4.1 Test Objective

The objective of this testing is to verify the accuracy and reliability of the instrumentation and control components under a variety of operating conditions and after frequent use.

3.4.2 Test Description

The identification equipment will be tested under a range of operating conditions including element motion, velocity, size of identification markings, lighting conditions, etc. Other instrumentation will also be tested under various operating speeds and environmental conditions to verify its performance characteristics. The testing will be conducted in two phases. Phase 1 tests will be conducted in air to qualify element identification components. Phase 2 tests will be conducted in helium to qualify electronic instrumentation, viewing systems, etc.

3.4.3 Test Conditions

Anticipated NGNP FHSS service conditions applicable to the testing are:

Console and Electronics Cabinets	
Pressure	Atmospheric
Temperature	Room temperature
Atmosphere	Air
Relative Humidity	10% to 90%
In-Reactor Components	
Pressure	Atmospheric
Temperature	250°F
Atmosphere	Helium

3.4.4 Test Configuration

The testing will be conducted in two phases. Phase 1 tests will be conducted in air to qualify element identification components. Phase 2 tests will be conducted in helium to qualify electronic instrumentation, viewing systems, etc. The test configurations for the various tests will be defined in the detailed test plans and test procedures that will be prepared for the individual tests.

3.4.5 Required Data

The required data for the FHSS control system includes:

- Performance of instrumentation and control components including limiting values for factors (e.g., element motion, direction, velocity, size of identification marking, temperature, etc) which could cause failures in serial number identification under the conditions of Section 3.4.1

- Demonstration that the FHSS control system, including software, meets its design requirements and is compatible with the fuel handling mechanisms

3.4.6 Test Location

Testing can be done at facilities located at General Atomics, vendor plants, or other suitable facilities. One such facility is Wyle Laboratories. Another is Hazen Research. Information for Wyle Laboratories and Hazen Research is provided below.

Wyle Laboratories
128 Maryland St.
El Segundo, Ca 90245
(310) 563-6662
john.shimada@wylelabs.com

Wyle Laboratories is headquartered in El Segundo, Calif. and employs approximately 4,200 employees at more than 40 facilities nationwide. Wyle is one of the nation's leading providers of specialized engineering, scientific, and technical services to the Department of Defense, NASA, and a variety of commercial customers. Wyle has been designing and building unique test fixtures, equipment and entire test facilities for industry and government use for more than 50 years. These facilities include centrifugal and linear accelerators, vibration systems with up to six axes of motion, high intensity acoustic chambers, dynamic shock devices like crash barriers, plus rail dynamics test facilities and numerous combined-environment test systems. In the nuclear sector, Wyle has qualified more equipment than anyone else in the industry.

Hazen Research Inc
4601 Indiana Street
Golden, Colorado 80403
Phone: (303) 279 4501
www.hazenusa.com

Hazen services include laboratory-scale research on new processes or adaptation of known technology to new situations, followed by pilot plant demonstration, preliminary engineering, and cost analysis. Projects range from beaker-scale experiments, material testing and analyses to multimillion-dollar continuous pilot or demonstration plants. Activities began at the present location in Golden, Colorado, in 1961 and the staff has since grown to over 120. Sixteen buildings containing an extensive inventory of laboratory and process equipment provide the flexibility for evaluating different unit operations.

3.4.7 Data Requirements

Quality assurance must be in accordance with experimental data or validation testing per non-safety-related components. Further, all work performed to support the NGNP R&D Program must be in accordance with The Next Generation Nuclear Plan (NGNP) Quality Assurance Program, INEEL/EXT-04-01776. This program invokes the national consensus standard ASME NQA 1997, "QA Program Requirements for Nuclear Facilities Applications," and Subpart 4.2 of ASME NQA 2000, "Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development."

3.4.8 Test Evaluation Criteria

The conditions for successful completion of the FHSS instrumentation and controls testing are: (1) the required data as identified in Section 3.4.4 has been obtained and (2) the data satisfies the data quality requirements as defined in Section 3.4.7.

3.4.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing.

3.4.10 Schedule, Cost, and Risk

3.4.10.1 Schedule

The testing will start at the beginning of FHSS final design and will require about 9 months.

3.4.10.2 Cost

The estimated cost is $900K.

3.4.10.3 Risk

The fallback position should the testing of the instrumentation components subsystems described in Section 3.4 not be performed would be to defer verification of these systems to the testing of the FHSS subsystems (e.g., the FHM, FTC, FHEP, etc.) and the integrated FHSS system. This could result in schedule delays and a likely need for control system redesign during these tests.

3.5 FHESS Component Design Verification Testing (DDN C.21.01.07)

3.5.1 Test Objective

The active components of the FHESS are the reactor isolation valves and the neutron control assembly housing seals. The objective of this testing is to demonstrate proper operation of the FHESS with its built-in reactor isolation valves and inflatable seals.

3.5.2 Test Description

Conduct material qualification, functional and endurance testing with prototypic test articles and simulated interfaces. Obtain reliability and maintenance data for valve actuators, seal quality (leakage), and anchoring mechanisms to validate the performance of the valve and seal leakage. The inflatable seals that seat to the nuclear control assembly housings will be tested against offset (nonconcentric) housing locations to simulate expected plant construction tolerances. Valve operators and all seals will be cycled to represent 10 refueling outages. Interlocks will be demonstrated.

3.5.3 Test Conditions

All testing will be performed in air at ambient temperature. Testing will exclude the effects, if any, of applied loads and possible deflections imposed by the fuel; handling equipment because these are considered to be a low design risk that can be reasonable calculated and validated during integrated system testing.

3.5.4 Test Configuration

Testing of the FHESS isolation valves and inflatable seals will be performed with prototypic test articles and simulated interfaces. The inflatable seals that seat to the nuclear control assembly housings will be tested against offset (nonconcentric) housing locations to simulate expected plant construction tolerances. The test configurations for these tests will be defined in the detailed test plan and test procedure that will be prepared for this test.

3.5.5 Required Data

The required data for the FHESS includes:

- FHESS mispositioning limits relative to each of the interfaces which permit the valves, seals, and mechanical interfaces to perform to design specifications under the conditions noted in Section 3.5.3
- Reliability and maintenance data for valve actuators, seal quality (leakage), and anchoring mechanisms

3.5.6 Test Location

It is expected that this testing would be performed at the FHESS vendor's plant. However, it could be performed at other suitable testing facilities such as Wyle Laboratories or Hazen Research (see Section 3.4.5).

3.5.7 Data Requirements

Quality assurance must be in accordance with experimental data or validation testing per non-safety-related components. Further, all work performed to support the NGNP R&D Program must be in accordance with The Next Generation Nuclear Plan (NGNP) Quality Assurance Program, INEEL/EXT-04-01776. This program invokes the national consensus standard ASME NQA 1997, "QA Program Requirements for Nuclear Facilities Applications," and Subpart 4.2 of ASME NQA 2000, "Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development."

3.5.8 Test Evaluation Criteria

The conditions for successful completion of FHESS component verification testing are: (1) the required data as identified in Section 3.5.4 has been obtained and (2) the data satisfies the data quality requirements as defined in Section 3.5.7.

3.5.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data

- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing.

3.5.10 Schedule, Cost, and Risk

3.5.10.1 Schedule

The testing will start at the beginning of FHSS final design and will require about 1 year.

3.5.10.2 Cost

The estimated cost is $600K.

3.5.10.3 Risk

Failure to perform the testing described in Section 3.5 would eliminate the potential benefits to isolation valve and seal design and/or production. It could also result in failure of the FHESS isolation valves and seals to meet performance and reliability requirements during integrated system testing of the FHSS, which could significantly impact the schedule and cost of FHSS qualification and deployment in NGNP.

3.6 FSIF Equipment Design Verification Testing (DDN C.21.01.08)

3.6.1 Test Objective

Verify the automated packaging, sealing, and inspection processes that will be carried out within the FSIF.

3.6.2 Test Description

Tests will be performed for the various equipment within the FSIF, including the equipment used for remote closing, sealing, and inspection of the canisters used for 0containment of spent fuel for subsequent storage or disposal. The test will demonstrate proper operation of the equipment for sealing allowing for mechanical tolerances of the component items to be sealed.

3.6.3 Test Conditions

The test conditions cannot be defined at this time because sufficient design information to define the service conditions for the FSIF is not currently available. The test conditions will be defined in the design support and verification test plan to be prepared during FHSS preliminary design (see Section 3.3).

3.6.4 Test Configuration

Test configurations cannot be defined at this time because sufficient information on the FSIF equipment and processes is not currently available. Test configurations for these tests will be defined in the detailed test plans and test procedure that will be prepared for these tests.

3.6.5 Required Data

Extended cycle endurance test data under FSIF service conditions is needed to verify the FSIF automated packaging, sealing, and inspection processes, including leak-tightness testing capability (in the FSIF).

3.6.6 Test Location

It is expected that this testing would be performed at the FSIF equipment vendors' plants. However, the testing could also be performed at other suitable testing facilities such as Wyle Laboratories or Hazen Research (see Section 3.4.5).

3.6.7 Data Requirements

Quality assurance must be in accordance with experimental data or validation testing per non-safety-related components. Further, all work performed to support the NGNP R&D Program must be in accordance with The Next Generation Nuclear Plan (NGNP) Quality Assurance Program, INEEL/EXT-04-01776. This program invokes the national consensus standard ASME NQA 1997, "QA Program Requirements for Nuclear Facilities Applications," and Subpart 4.2 of ASME NQA 2000, “Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development.”

3.6.8 Test Evaluation Criteria

The conditions for successful completion of FSIF equipment and process verification testing are: (1) the required data as identified in Section 3.6.4 has been obtained and (2) the data satisfies the data quality requirements as defined in Section 3.6.7.

3.6.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data

- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

3.6.10 Schedule, Cost, and Risk

3.6.10.1 Schedule

The testing will start at the beginning of FHSS final design and will require about 1 year.

3.6.10.2 Cost

The estimated cost is $900K.

3.6.10.3 Risk

Failure to perform the testing described in Section 3.6 could result in failure of the FSIF equipment to meet performance and reliability requirements in the FSIF. This could have a negative impact on the operation of the NGNP.

4 TEST PLAN TO ADVANCE FROM TRL 5 TO TRL 6

A TRL of 6 is achieved when components have been integrated into a subsystem and demonstrated at pilot-scale in a relevant environment. For the FHSS, these requirements will be met by testing the various subsystems (e.g., the FHM, FTC, FHEP, etc) that comprise the FHSS. Specifically, the following activities will be conducted to advance the TRL of the FHSS from 5 to 6.

1. FHEP design verification testing
2. EHGA robot design verification testing
3. FHM design verification testing
4. FTC design verification testing
5. Complete final design of the FHSS based on the results of all component testing. Issue final procurement specifications for all equipment.

These activities are discussed in the following sections. An overall schedule and cost estimate summary is provided in Section 6.

4.1 FHEP Design Verification Testing (DDN C.21.01.06)

4.1.1 Test Objective

The objective of the testing is to validate the axes kinematics and accuracy of the FHEP under expected load conditions.

4.1.2 Test Description

The FHEP automatically connects and disconnects the fuel handling equipment by a command sequence issued by the control computer. The FHM, FTC, ASC and FHESS adapter have different physical parameters, particularly weight and height, which may affect the performance of the automatic sequence. The interface coupling will be repeatedly join-and-release tested with applied loads simulating the essential physical parameters of the fuel handling equipment.

Speed, accuracy, and extended cyclic endurance and structural testing of the FHEP will be performed to verify the design and to ensure the reliability and accuracy of the FHEP to retrieve, transport and place large, heavy machines and structures. FHEP kinematic testing will be performed to develop stable, smooth motion control for all payload conditions. Positioning tests will be run with the developed set of servo gain and compensation parameters to obtain mean and standard deviation repeatability data under all load conditions to validate that the error band is within the range of the mechanical guides and structural compliance of the several payloads. The safety interlocks of the FHEP control system will be validated in the course of these tests.

4.1.3 Test Conditions

The following service conditions for the FHEP are given in DDN C.21.01.06 for the GT-MHR. The applicability of these conditions to the NGNP FHEP must be confirmed during NGNP FHSS design.)

Transport Payload	100 tons
Travel Distances	
X-axis	100 feet
Y-axis	70 feet
Z-axis	6 feet
Rotation	350 degrees
Velocities:	
Trolley, bridge	Slow: 50 feet/minute
	Medium: 100 feet/minute
Hoisting	Slow: 4 feet/minute
	Medium: 7 feet/minute
Environment	Room temperature
Desired accuracy	± 0.25 in. (x, y, or x direction)
	± 0.25 degrees (rotational)

4.1.4 Test Configuration

The FHEP testing requires a high-bay building with capability to add floor crane rails. It is anticipated that the tests will be conducted at the FHEP vendor’s facility using a production prototype of the FHEP. The test configuration will be defined in the detailed test plan and test procedure that will be prepared for the FHEP testing.

4.1.5 Required Data

Data is needed on the positioning certainty of the FHEP control axes under the service conditions identified in Section 4.1.3. The testing should also include measurements of the four-axis acceleration and velocity capabilities of the FHEP under static and dynamic load conditions. The point-to-point positioning time for each axis and load condition will be measured. This data is needed for comparison with system simulation models to validate process speed and performance predictions.

4.1.6 Test Location

It is anticipated that the FHEP design verification testing will be conducted at the FHEP vendor's facility.

4.1.7 Data Requirements

Quality assurance must be in accordance with experimental data or validation testing per non-safety-related components. Further, all work performed to support the NGNP R&D Program must be in accordance with The Next Generation Nuclear Plan (NGNP) Quality Assurance Program, INEEL/EXT-04-01776. This program invokes the national consensus standard ASME NQA 1997, "QA Program Requirements for Nuclear Facilities Applications," and Subpart 4.2 of ASME NQA 2000, "Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development."

4.1.8 Test Evaluation Criteria

The conditions for successful completion of FHEP design verification testing are: (1) the required data as identified in Section 4.1.4 has been obtained, (2) the data satisfies the data quality requirements as defined in Section 4.1.7, (3) the test results verify that the FHEP meets positioning precision requirements, and (4) the test results validate the process speed and performance predictions of the system simulation model.

4.1.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

4.1.10 Schedule, Cost, and Risk

4.1.10.1 Schedule

The testing will start at the beginning of FHSS final design and will require about 18 months.

4.1.10.2 Cost

The estimated cost is $1.9M.

4.1.10.3 Risk

Failure to verify the design of the FHEP prior to testing of the integrated FHSS could significantly impact the schedule and cost of FHSS qualification and deployment in NGNP should significant deficiencies in the performance of the FHEP be detected during the integrated FHSS testing.

4.2 EHGA Robot Design Verification Testing (DDN C.21.01.03)

4.2.1 Test Objective

The objective of the testing is to verify that the EHGA robot has the capability to perform all fuel element and reflector element handling operations with the required accuracy within the cycle time allocation. A further objective is to demonstrate that the EHGA meets endurance requirements under all service conditions.

4.2.2 Test Description

Testing will be conducted using a full-scale test rig and test article to acquire data on the operability and reliability of the vertical drive system for the grapple, the two independent grapple systems, and the positioning capability of the overhead crane under expected environmental conditions. Environmental endurance testing in both air and helium will be performed. Local controllers, production software, recovery manipulation controls and closed circuit television visibility will be tested for safe, practical operation.

The EHGA robot is a bridge robot with end effectors on a single trolley. The EHGA robot, the element trolley, and the end effector will be tested for at least 10,000 cycles in air and helium over the maximum expected cycle path. This will exercise all motion axes and the end effector to validate accuracy and endurance over the service range and at required speeds.

A set of upset conditions will be simulated to test the general ergonomics of the EHGA robot manual and computer aided controls, television viewing, manipulator and gantry robot. The test objects will be broken, jammed or misplaced fuel elements and well plugs.

4.2.3 Test Conditions

Anticipated EHGA service conditions applicable to the testing are:

Atmosphere	Helium or air
Temperature	Ambient
Pressure	Atmospheric

4.2.4 Test Configuration

The testing will be conducted using a full-scale test rig and test article. A room or cell with an inert atmosphere at room temperature is required.

4.2.5 Required Data

Data are needed to verify the EHGA design under the conditions in Section 4.2.3. Specifically, data is needed on functional and performance limits for the operating modes to establish the operability and reliability of components under the expected environmental conditions.

4.2.6 Test Location

Testing can be done at facilities located at General Atomics, the EHGA vendor's plant, or other suitable facilities. Such facilities likely include Wyle Laboratories and Hazen Research. Information for Wyle Laboratories and Hazen Research is provided in Section 3.4.6.

4.2.7 Data Requirements

Quality assurance must be in accordance with experimental data or validation testing per non-safety-related components. Further, all work performed to support the NGNP R&D Program must be in accordance with The Next Generation Nuclear Plan (NGNP) Quality Assurance Program, INEEL/EXT-04-01776. This program invokes the national consensus standard ASME NQA 1997, "QA Program Requirements for Nuclear Facilities Applications," and Subpart 4.2 of ASME NQA 2000, “Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development.”

4.2.8 Test Evaluation Criteria

The conditions for successful completion of EHGA design verification testing are: (1) the required data identified in Section 4.2.4 has been obtained, (2) the data satisfies the data quality requirements defined in Section 4.2.7, and (3) the test results verify that the EHGA robot meets the endurance requirements under all service conditions and has the capability to perform all fuel element and reflector element handling operations with the required accuracy within the cycle time allocation.

4.2.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

4.2.10 Schedule, Cost, and Risk

4.2.10.1 Schedule

The testing will start at the beginning of FHSS final design and will require about 18 months.

4.2.10.2 Cost

The estimated cost is $850K.

4.2.10.3 Risk

Failure to verify the design of the EHGA prior to testing of the integrated FHSS could significantly impact the schedule and cost of FHSS qualification and deployment in NGNP should significant deficiencies in the performance of the EHGA be detected during the integrated FHSS testing.

4.3 FHM Design Verification Testing (DDN C.21.01.01)

4.3.1 Test Objective

The objective of the testing is to verify that the FHM has the capability to perform all fuel element and reflector element handling operations with the required accuracy within the cycle time allocation. A further objective is to demonstrate that the FHM meets endurance requirements under all service conditions.

4.3.2 Test Description

The FHM design verification tests will be performed to demonstrate that element handling operations for all required conditions are done safely to prevent damage to core blocks or equipment and reliably within the FHM element handling cycle time allocation. The testing will be performed in three phases and will progress from checkout of subassemblies in air to testing of the entire FHM in hot helium.

In Phase 1, the FHM grapple head will be tested in ambient air for grapple cycles equivalent to five refueling outages. This will exercise all motions (x, y, z, and rotation), grapple operation, and the weighing system to demonstrate proper operation. Electric motor drives will be used for rotation and grapple operation replacing the pneumatic systems used on the FSV FHM. Safety interlocks will be demonstrated.

In Phase 2, the entire FHM will be tested in ambient air for a number of element-handling cycles equivalent to five refueling outages. This test will verify the positioning accuracy, dependability, and cycle time for the four closed loop servos used to position the grapple head. Simultaneous motion of drive systems is allowed and will be demonstrated to assure safe operation. Removal and replacement of a core support post for ISI will be demonstrated. Safety interlocks and failed equipment removal techniques will be demonstrated.

In Phase 3, the FHM will be tested in 250°F dry helium for a number of element handling cycles equivalent to 25 refueling outages. The testing will be designed to verify proper operation of lubricants, seals, and electrical and remote viewing systems exposed to the challenges of a hot, dry helium environment.

4.3.3 Test Conditions

Phase 1 and Phase 2 testing will be performed in air at ambient temperature. Phase 3 testing will be performed in helium at 250°C. All testing will be performed at atmospheric pressure. The in-service hoist speed range that will be tested is 2 to 24 inches/second.

4.3.4 Test Configuration

As described in Section 4.2.2, the testing will progress from checkout of automated operation of the grapple head in air to testing of the entire FHM in air and then in hot helium. A high-bay area enclosure with an overhead crane and helium atmosphere autoclave is required fore the Phase 3 testing. The high cycle test of the FHM inside an autoclave will be performed using techniques and software verified during the in-air test. Because it is not planned to combine a FTC or other element removal system in this test, a limited number of simulated core elements will be available for handling within the closed autoclave. These elements may be transferred to different locations within the autoclave to simulate all necessary element handling locations.

4.3.5 Required Data

Data are needed for the FHM on functional and performance limits in the anticipated operating modes to establish the operability and reliability of components under the expected environmental conditions identified in Section 4.3.3.

4.3.6 Test Location

Testing can be done at the FHM vendor's plant or at a suitable testing facility such as Wyle Laboratories. Information on Wyle Laboratories is provided in Section 3.4.6.

4.3.7 Data Requirements

Quality assurance must be in accordance with experimental data or validation testing per non-safety-related components. Further, all work performed to support the NGNP R&D Program must be in accordance with The Next Generation Nuclear Plan (NGNP) Quality Assurance Program, INEEL/EXT-04-01776. This program invokes the national consensus standard ASME NQA 1997, "QA Program Requirements for Nuclear Facilities Applications," and Subpart 4.2 of ASME NQA 2000, "Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development."

4.3.8 Test Evaluation Criteria

The conditions for successful completion of FHM design verification testing are: (1) the required data identified in Section 4.3.4 has been obtained, (2) the data satisfies the data quality requirements defined in Section 4.3.7, and (3) the test results verify that the FHM meets the endurance requirements under all service conditions and has the capability to perform all fuel element and reflector element handling operations with the required accuracy within the cycle time allocation.

4.3.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

4.3.10 Schedule, Cost, and Risk

4.3.10.1 Schedule

The testing will start at the beginning of FHSS final design and will require about 18 months.

4.3.10.2 Cost

The estimated cost is $1,250K.

4.3.10.3 Risk

Failure to verify the design of the FHM prior to testing of the integrated FHSS could significantly impact the schedule and cost of FHSS qualification and deployment in NGNP should significant deficiencies in the performance of the FHM be detected during the integrated FHSS testing.

4.4 FTC Design Verification Testing (DDN C.21.01.02)

4.4.1 Test Objective

The objective of the testing is to verify that the FTC has the capability to perform all fuel element and reflector element handling operations with the required accuracy within the cycle time allocation. A further objective is to demonstrate that the FHM meets endurance requirements under all service conditions.

4.4.2 Test Description

FTC design verification testing will be performed to demonstrate that element handling operations for all required conditions are done safely to prevent damage to core blocks or equipment and reliably within the FTC element handling cycle time allocation. Key components include the vertical drive system for the hoist grapple, horizontal transfer table drive, and the complete grapple system. The testing will be performed in three phases.

In Phase 1, FTC will be tested in ambient air for a number of element handling cycles equivalent to five refueling outages. This test will verify the positioning accuracy, dependability, and cycle time for the servos used to position the grapple head and the fuel element translating tables. Coordinated, sequential motion of the grapple and table drive systems will be cycle tested to assure safe and reliable operation. Safety interlocks, fault recovery software diagnostics, and recovery and equipment removal methods will be developed.

In Phase 2, the FTC will be tested in 250°F dry helium for a number of element handling cycles equivalent to 25 refueling outages. This test assures proper operation of lubricants, seals and electrical systems exposed to the challenges of a hot, dry helium environment.

Test Phase 3 will be a separate cyclic test of the automated hold-downs and remote connections.

- The '"T" bolts that secure the FTC to the FHESS base and floor valves are set and released by a hydraulically powered, computer controlled sequence. This hardware will be set-and-release cycle tested (3,000 minimum) with the joint loaded in excess of the seismic induced working load on each of the 3000 cycles.
- The service interface that couples the electrical power and data signals to the FTC from the FHESS base and floor valve is mechanically joined when the FTC is placed by the FHEP. This interface will be engaged and disengaged at least 3,000 cycles and the electrical continuity and pneumatic sealing will be measured on each cycle.

4.4.3 Test Conditions

Phase 1 and Phase 3 testing will be performed in air at ambient temperature. Phase 2 testing will be performed in helium at 250°C. All testing will be performed at atmospheric pressure. The in-service hoist speed range that will be tested is 2 to 24 inches/second.

4.4.4 Test Configuration

As described in Section 4.2.2, the FTC will first be tested in air and then in hot helium. For the Phase 2 testing in hot helium, a high-bay area enclosure with an overhead crane and helium atmosphere autoclave is required. The high cycle test of the FTC inside an autoclave will be performed using techniques and software verified during the in-air test. Because it is not planned to combine a FHM or other element removal system in this test, a limited number of simulated core elements will be available for handling within the closed autoclave. Detailed test configurations for all testing, including the Phase 3 tests, will be given in the detailed test plans prepared by the testing organization(s).

4.4.5 Required Data

Data are needed for the FTC on functional and performance limits in the anticipated operating modes to establish the operability and reliability of components under the expected environmental conditions identified in Section 4.4.3.

4.4.6 Test Location

Testing can be done at the FTC vendor's plant or at a suitable testing facility such as Wyle Laboratories. Information on Wyle Laboratories is provided in Section 3.4.6.

4.4.7 Data Requirements

Quality assurance must be in accordance with experimental data or validation testing per non-safety-related components. Further, all work performed to support the NGNP R&D Program must be in accordance with The Next Generation Nuclear Plan (NGNP) Quality Assurance Program, INEEL/EXT-04-01776. This program invokes the national consensus standard ASME NQA 1997, "QA Program Requirements for Nuclear Facilities Applications," and Subpart 4.2 of ASME NQA 2000, “Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development.”

4.4.8 Test Evaluation Criteria

The conditions for successful completion of FTC design verification testing are: (1) the required data identified in Section 4.4.4 has been obtained, (2) the data satisfies the data quality requirements defined in Section 4.4.7, (3) the test results verify that the FTC meets the endurance requirements under all service conditions and has the capability to perform all fuel element and reflector element handling operations with the required accuracy within the cycle time allocation, and (4) the test results verify that the automated hold-downs and remote connections between the FTC and FHESS meet endurance requirements.

4.4.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

4.4.10 Schedule, Cost, and Risk

4.4.10.1 Schedule

The testing will start at the beginning of FHSS final design and will require about 18 months.

4.4.10.2 Cost

The estimated cost is $1,250K.

4.4.10.3 Risk

Failure to verify the design of the FTC prior to testing of the integrated FHSS could significantly impact the schedule and cost of FHSS qualification and deployment in NGNP should significant deficiencies in the performance of the FHM be detected during the integrated FHSS testing.

4.5 Finalize FHSS Design and Issue Equipment Procurement Specifications

The design of the NGNP FHSS will be finalized based on the results of the design support and verification testing on FHSS components and subsystems. The final design work and analyses will be performed using computer codes that have been verified and validated in accordance with the applicable requirements of ASME NQA-1. Upon completion of final design procurement specifications will be prepared for all of the FHSS subsystems (e.g., FHM, FTC, FHEP, etc.). All procurement documents will be issued in accordance with the GA QA Program requirements applicable to procurement control.

This activity will start about 18 months into NGNP final design and will require about two years to complete. The estimated cost is $1.5M.

5 TEST PLAN TO ADVANCE FROM TRL 6 TO TRL 7

To achieve a TRL rating of 7, the system must complete integrated engineering-scale demonstration in a relevant environment. For the FHSS, this requirement will be met by performing an integrated test of the FHSS. The testing will involve full-scale fuel handling and control equipment with simulated fuel elements in an environment representative of the operational environment.

5.1 Integrated Fuel Handling System Test (DDN C.21.01.05)

5.1.1 Test Objective

The objective of the integrated FHSS test is to verify that all of the machines and structures that comprise the system function together and that system operations can be performed safely and reliably within the allocated time. This includes verification of physical compatibility, alignment requirements, tolerances, and coordination by the control system. Human factors data on the control station are also needed.

5.1.2 Test Description

Full-scale fuel handling and control equipment will be tested with simulated fuel elements. The FHM and FTC will be mounted on a full-scale FHESS and the upper plenum and the first two layers of the core will be simulated. Refueling of the first two layers of the core will be simulated using the automated control system. Two full refueling sequences will be simulated to assure the dependability and reliability of the system. A full-scale FHEP will be utilized in testing the integrated system. Two full refueling sequences should be simulated to assure the dependability and reliability of the system.

5.1.3 Test Conditions

The testing will be performed under the expected operating conditions in NGNP. The simulated in-core fuel handling operations will be conducted in 250°F helium at atmospheric pressure. Testing will cover the in-service hoist speed range of 2 to 24 inches/second.

5.1.4 Test Configuration

Full-scale fuel handling and control equipment will be tested with simulated fuel elements. A full-scale FHM and full-scale FTC will be mounted on a full-scale FHESS and the upper plenum and the first two layers of the core will be simulated. The simulated core will be contained within a helium atmosphere autoclave. The test configuration should include a simulated reactor module with a local fuel storage area and a computer control room to emulate fuel and reflector element handling operations.

5.1.5 Required Data

Operability and reliability data are required for the components of the fuel handling system when they are operating together under the expected operating conditions in the NGNP. This includes verification of physical compatibility, alignment requirements, tolerances, and coordination by the control system. Human factors data on the control station are also needed.

5.1.6 Test Location

A high-bay area enclosure with an overhead crane and helium atmosphere autoclave is required. Testing can be done at the FHM vendor's plant or at a suitable testing facility such as Wyle Laboratories. Information on Wyle Laboratories is provided in Section 3.4.6.

5.1.7 Data Requirements

Quality assurance must be in accordance with experimental data or validation testing per non-safety-related components. Further, all work performed to support the NGNP R&D Program must be in accordance with The Next Generation Nuclear Plan (NGNP) Quality Assurance Program, INEEL/EXT-04-01776. This program invokes the national consensus standard ASME NQA 1997, "QA Program Requirements for Nuclear Facilities Applications," and Subpart 4.2 of ASME NQA 2000, "Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development."

5.1.8 Test Evaluation Criteria

The conditions for successful completion of the integrated FHSS test are: (1) the required data identified in Section 5.1.5 has been obtained, (2) the data satisfies the data quality requirements defined in Section 5.1.7, and (3) the test results verify that all of the machines and structures that comprise the FHSS function together and that system operations can be performed safely and reliably within the allocated time.

5.1.9 Test Deliverables

A final Test Report shall be provided which includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

5.1.10 Schedule, Cost, and Risk

5.1.10.1 Schedule

The total duration of the integrated FHSS test, including fabrication of the prototype machines, fabrication of the test rig, set up of the test facility, and conduct of the test is about 2.5 years (see schedule in Figure 4 in Section 7). The test should be completed approximately six months before installation of the equipment in the NGNP.

5.1.10.2 Cost

The estimated cost is $6,000K, not including the cost of the prototype FHSS equipment.

5.1.10.3 Risk

If this test is not performed, the fallback position would be to wait to test the integrated FHSS at the NGNP during NGNP startup testing. This approach would increase the risk of a delay in the operation of the NGNP should the FHSS fail to meet performance requirements. However, given the high cost of the integrated FHSS test, this option should be strongly considered if the results of the design verification testing of the individual machines comprising the FHSS provide a reasonable level of confidence that the integrated FHSS will meet overall system performance requirements.

6 TEST PLAN TO ADVANCE FROM TRL 7 TO TRL 8

A TRL of 8 is achieved by demonstrating an integrated prototype of the system in its operational environment with the appropriate number and duration of tests and at the required levels of test rigor and quality assurance. All NGNP systems, structures, and components must have a TRL of 8 as a prerequisite for hot startup of the NGNP. TRL 8 will be achieved for the FHSS via testing of the actual NGNP FHSS during NGNP startup testing. The details of the FHSS test program will be defined in the NGNP startup plan.

6.1 Test Objective

Conduct the appropriate number and duration of tests of the FHSS in the actual operating environment (i.e., in the NGNP) to verify that the system meets all operational and reliability requirements.

6.2 Test Description

TRL 8 will be achieved for the FHSS by operating the NGNP FHSS in the NGNP during NGNP start-up testing. This will be accomplished before hot startup of the reactor. The first part of this activity will be to prepare the Test Specification (or alternately to define the test in the NGNP startup plan).

6.3 Test Conditions

The test conditions will be defined in the Test Specification or the NGNP startup plan.

6.4 Test Configuration

The tests will be performed on the as-installed FHSS in the NGNP.

6.5 Required Data

The required data will be defined in the Test Specification or the NGNP startup plan.

6.6 Test Location

Testing will be performed in the NGNP.

6.7 Test Evaluation Criteria

The test evaluation and acceptance criteria will be defined in the Test Specification or the NGNP startup plan.

6.8 Test Deliverables

The test results will be included in the NGNP startup testing report. The information to be provided for the test includes:

- Detailed discussion of test method
- Equipment employed
- Equipment calibration verification
- Detailed test procedures
- Original test data
- Summarized and reduced test data
- A detailed discussion of test results, observations, and calculations that were completed throughout the course of testing

6.9 Schedule, Cost, and Risks

6.9.1 Schedule

This test will be performed as part of NGNP startup testing.

6.9.2 Cost

The incremental cost of this test on the overall cost of the NGNP startup program should be negligible.

6.9.3 Risks

Not applicable.

7 COST AND SCHEDULE SUMMARY

Figure 4 provides an integrated schedule for FHSS system technology development and design, and a summary of the estimated costs.

TRL	Activity	Estimated Cost ($K)	Calendar Year 2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	NGNP Schedule														
	Common Conceptual Design														
	Common Preliminary Design														
	NHSS Conceptual and Prelim. Design														
	Final Design														
	Site Work and Construction														
	Startup and Testing														
	FHSS Design, Fab, & Installation Schedule														
	Conceptual Design														
	Preliminary Design														
	Final Design														
	Prepare/issue procurement docs for FHSS components														
	Fabricate FHSS equipment for NGNP														
	Install FHSS equipment in NGNP														
	FHSS Technology Development														
4→5	Prepare conceptual design for NGNP FHSS	1900													
	Survey supply network and select vendors	350													
	Complete FHSS preliminary design	3000													
	Perform I&C testing	900													
	Perform testing of Fuel Handling Equip. Support Structure	600													
	Perform testing of Fuel Sealing and Inspection Facility	900													
5→6	Perform testing of Fuel Handling Equipment Positioner	1900													
	Perform Testing of Equipment Hoist and Grapple Assembly	850													
	Perform testing of Fuel Handling Machine	1250													
	Perform testing of Fuel Transfer Cask	1250													
	Complete final design of FHSS and procurement specs	1500													
6→7	Integrated FHSS	6000													
	Prepare test specification														
	Fabricate prototype equipment and test rig														
	Set up test facility and equipment														
	Conduct testing														
	Evaluate test data and complete test report														
7→8	FHSS testing in NGNP	TBD													
	Total	20400													

Figure 4. Schedule and Cost Estimate Summary for NGNP FHSS Development

GENERAL ATOMICS
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