DATE: 6/30/94

# GT-MHR PROGRAM
# CONTROL ROD INSTRUMENTATION AND CONTROL VERIFICATION
# DDN C.11.01.01

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Programmable digital controllers in conjunction with brushless DC torque motor drive amplifiers are utilized in the control rod control system. The purpose of this DDN is to verify operational compatibility of the controlling drive amplifiers and control rod drive mechanisms. In addition, it is proposed to take advantage of this test to simultaneously verify the controller programming.

### 1.1 Summary of Function and Assumptions

"Move Control Rods," Assumption: The rod drive selection and control circuitry operation will be verified.

### 1.2 Current Data Base Summary

The use of programmable digital controllers and variable speed motor control for a rod control system is a new application configuration. This application in a nuclear plant has a potential impact on plant safety if selection, direction and speed control is inadequately controlled.

### 1.3 Data Needed

Data for the control rod instrumentation and control is needed to verify the following under the conditions in Section 1.4:

a. The control rod electronic control system is compatible with control rod drive mechanisms.

b. Performance characteristics (position versus time) and system response time of the control rod control system.

c. Verification of the following:

Drive selection capability (individual/group/automatic and manual).
Position indication/repeatability/selection capability.
Direction control selection.
Drive speed control.
Maximum withdrawal speed.
Ability of instrumentation to accurately read out rod position.

Quality Assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Data Parameters:

Drive selection capability: [Individual, Group, Sequence, Automatic Shim]
Direction selection capability: [Insert-Withdraw]
Drive speed: [0.4 to 1.2] in./s
Drive stroke: [366] in.
Control response time: [TBD]

Service Conditions:

Reactor Building Equipment:

Temperature: [104°F]
Pressure: Atmospheric
Humidity: [90% RH]
Radiation: Nil
Other:* [TBD]

2. DESIGNER'S ALTERNATIVES

2.1 Downgrade degree of automation of rod control system and use more conventional relay and selection techniques and install system without benefit of interface verification.

2.2 Install system without benefit of verification.

*Includes vibration, EMI, RFI, gas composition, etc.

3. SELECTED DESIGN APPROACH AND EXPLANATION

A programmable controller technique was selected to control the reactor control rod mechanisms because:

a. It better fits the distributed control architecture selected for the plant instrumentation and controls.

b. It is more reliable than conventional relay and switching mechanisms as it contains fewer moving parts.

c. It requires less physical space.

d. It requires less maintenance.

e. Significant operating flexibility is obtainable. Rods selected to be in one bank may be changed easily by reprogramming the controller for various core loadings.

A verification program has been selected to utilize the benefits of a more advanced design relative to capability for more complete automation and circuit flexibility as opposed to the use of more conventional relay/ selection's techniques. The verification program also assures proper operation of the rod control circuitry prior to plant startup, thereby reducing the risk of plant startup delays.

4. SCHEDULE REQUIREMENTS

The data will be needed by month [TBD], six months prior to start of component validation testing.

5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Use programmable controllers for control rod control without design verification testing.

Without design verification the use of programmable digital controllers and variable speed control could result in unavailability of performance data when needed and impacts mechanical design of rod drive systems, plant control system, and rod control system design.

[DDN C.11.01.01]

Additional plant startup delays could be encountered should adverse equipment interface problems or performance characteristics be uncovered during plant startup.

Originator Date 7/28/94

Task Manager Date 7/28/94

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# QUALIFICATION OF ELECTROMECHANICAL COMPONENTS OF NEUTRON CONTROL ASSEMBLY
# DDN C.11.01.02

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

All electromechanical components of the neutron control assembly must be highly reliable and perform repeatedly their required functions during their design lives. Related qualification testing in DDNs C.11.01.10 and C.11.01.11.

### 1.1 Summary of Function and Assumptions

"Move Control Rods," Assumption: Control rod drives can be controlled with a repeatable positional accuracy that is sufficient for control and the reliability of control rod drive operation is >99.5%.

"Execute Commands," Assumption: Control rod drives must respond correctly to shutdown command signals with a reliability of >99.5% and have a probability of spurious scram that is <0.5%.

### 1.2 Current Data Base Summary

The design of the neutron control assembly is based upon experience with designs developed for FSV and various large HTGR plants over the past 20 years. However, because performance requirements such as stroke and power are different for this design, they need verification.

### 1.3 Data Needed

Neutron Control Assembly electromechanical components reliability and performance data such as seismic response, operating speeds, effects of thermal aging (40 year design life), vibration and wear, accuracy and strength are needed under simulated operating conditions (see Section 1.4). Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Internal Atmosphere | Helium |
| Temperature: | |
| Components located above gamma shield | [200°F] |
| Pressure | [1025 psia] |
| Helium Oxidants | [TBD] |
| Radiation | [TBD] |
| Maximum horizontal acceleration (SSE) | [TBD] |
| Maximum vertical acceleration (SSE) | [TBD] |

## 2. DESIGNER'S ALTERNATIVES

Qualify design on the basis that sufficient prior data/experience exists without need for qualification testing.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

Components as-built on the production tooling will be tested. The tests will be in accordance with guidance from applicable codes, standards, and regulations. Alternative 2 was rejected in order to reduce risk of startup delays.

## 4. SCHEDULE REQUIREMENTS

Electromechanical component qualification testing to be completed by month [TBD], six months prior to the start of neutron control assembly qualification testing (DDN B.11.01.06).

## 5. PRIORITY

Urgency: 3
Cost benefit: H
Uncertainty in existing data: M
Importance of new data: H

[DDN C.11.01.02]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is alternative in Section 2. This approach is likely to lead to plant startup delays.

7/28/94

Originator Date

7/28/94

Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# CONTROL ROD DRIVE DESIGN VERIFICATION
# DDN C.11.01.03

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The control rod drive assembly must be highly reliable and perform repeatedly the required functions during its design life. Qualification testing of the neutron control assembly is described in DDNs C.11.01.10 and C.11.01.11,

### 1.1 Summary of Function and Assumptions

"Move Control Rods," Assumption: Control rod drives can be controlled with a repeatable positional accuracy that is sufficient for reactor control and with a reliability of control rod drive operation >99.5%.

"Execute Commands," Assumption: Control rod drives respond correctly to shutdown command signals with reliability of >99.5% and have a probability of spurious scram <0.5%.

### 1.2 Current Data Base Summary

The reference control rod drive design is significantly different from that of FSV because the rod is heavier, the stroke is longer, there is no orifice assembly, the entire assembly is within the primary system, and because of improvements due to FSV experience. Data on the proposed DC torque motor were gathered in experiments for the large HTGR, but no data on the other features are available.

### 1.3 Data Needed

Control rod drive (CRD) design features requiring validation testing are reliability, speed of rod motion under normal and rod trip conditions, accuracy of rod positioning and strength of the assembly under the conditions in Section 1.4.

Data on the reliability and performance of the CRD under long-term exposure (40-year design life) to the reactor environment are needed. Experimental data acquired should establish for the prototype design (1) operating speed versus electric load, (2) scram speed versus load resistor size, (3) change in internal friction with age, (4) positioning accuracy over active core, (5) nonlinearity of drum wrap-up,

(6) instrumentation and control operating characteristics, and (7) response time. Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Helium Pressure | 1025 psia |
| Impurity Level | <[10] ppmv oxidants |
| Temperature | 150-200°F |
| Control Rod Weight | 206 lb |

## 2. DESIGNER'S ALTERNATIVE

The following alternative is available:

2.1 Rely on analysis and test CRD during neutron control assembly qualification test.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

Performance data on a full-scale control rod drive assembly will be obtained for all expected conditions using simulated control rod channels and operating environment. The selected approach allows deficiencies in the reference design to be corrected in sufficient time to avoid expensive production line retooling. The full-scale test is reasonably achievable cost-wise and provides a high level of confidence in the applicability of the experimental data. Alternative 2.1 carries high risk of delays and expensive design changes if performance or reliability of the CRD were not confirmed until the qualification testing which occurs later in the design schedule.

## 4. SCHEDULE REQUIREMENTS

Data will be required by month [TBD], six months prior to the start of qualification testing (DDN C.11.01.10).

## 5. PRIORITY

Urgency: 3
Cost benefit: H
Uncertainty in existing data: M
Importance of new data: H

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is to validate performance and reliability of the CRD during the neutron control assembly qualification test. This would increase risk of schedule delays and/or cost

impact if design deficiencies were identified during the neutron control assembly qualification testing and major portions of the test had to be repeated.

| | |
|---|---|
| DW Letchan | 7-27-94 |
| Originator | Date |
| Carmelo Rodriguez | 7/28/94 |
| Task Manager | Date |
| | |
| Program Manager | Date |

DATE: 6/30/94

GT-MHR PROGRAM
RESERVE SHUTDOWN CONTROL EQUIPMENT DESIGN VERIFICATION
DDN C.11.01.04

PLANT: GT-MHR/System 11

1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The RSCE must perform its functions in a highly reliable and timely manner. Qualification testing of the neutron control assembly is described in DDNs C.11.01.10 and C.11.01.11.

1.1 Summary of Function and Assumptions

"Execute Commands," Assumption: Reserve shutdown control equipment (each hopper) responds correctly to shutdown signals with reliability of >99.5% and has a probability of spurious operation <0.5%.

1.2 Current Data Base Summary

The proposed design of the RSCE is different from the one tested for and used at Fort St. Vrain because the FSV rupture disk has been replaced by fuse links and the hopper is larger. Testing data on the fuse link design showed it could be used in place of the pneumatic rupture disk, thereby justifying the design change.

1.3 Data Needed

Operational performance data under the conditions of Section 1.4 on the fuse link release mechanism, linkage and gate valve operation controls, pellet flow, and channel configuration are needed to establish (1) response time, (2) material flow rates, (3) system reliability, and (4) power requirement for fuse link operation and periodic testing. Quality assurance must be in accordance with the requirements for experimental data or validation testing per safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Pressure | 1025 psia |
| Temperature | [150-200]°F |
| Atmosphere | Helium |
| Radiation level | [TBD] |

2. DESIGNER'S ALTERNATIVE

The following alternative is available:

2.1 Rely on verification of RSCE mechanism as part of the complete neutron control assembly qualification test.

3. SELECTED DESIGN APPROACH AND EXPLANATION

Performance data on the full scale prototype reserve shutdown control equipment will be obtained for all expected conditions and operating environment. Provisions will be made to simulate anticipated movements during operation and seismic events. The selected approach allows deficiencies in the reference design to be corrected in sufficient time to avoid expensive production line retooling. A full-scale test is reasonably achievable cost-wise and provides a high level of confidence in the applicability of the experimental data. Alternative 2.1 carries high risk of delays and expensive design changes if performance or reliability of the RSCE is not confirmed until the qualification testing which occurs later in the schedule.

4. SCHEDULE REQUIREMENTS

Data will be required by month [TBD], six months prior to the start of qualification testing (DDN C.11.01.10 and C.11.01.11).

5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: H
Importance of new data: H

[DDN C.11.01.04]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is to validate performance and reliability during neutron control assembly qualification test. This would increase risk of schedule delay if design deficiencies were identified during the neutron control assembly qualification testing and major portions of the test had to be repeated.

DW Ketchen 7-27-94

Originator Date

Camelo Rodriguez 7/28/94

Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# IN-CORE FLUX MAPPING UNIT (IFMU) DRIVE
# DESIGN VERIFICATION
# DDN C.11.01.05

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The in-core flux mapping unit drives must be reliable and perform repeatedly the required functions during its design life. Related DDN C.11.01.06.

### 1.1 Summary of Function and Assumptions

"Move IFMU Detector," Assumption: IFMU detector drive can be controlled with a repeatable positional accuracy that is sufficient for in-core flux mapping, and with a reliability of drive operation of >99.5%.

"Move Detector Guide Tubes," Assumption: Detector guide tube drives can be controlled with repeatable positional accuracy that is sufficient for refueling operations when withdrawn and provide the guidance necessary for the detector at the top of core interface when lowered.

"Measure Flux and Temperature," Assumption: Detector and thermocouple signals will maintain their electrical continuity during repeated flexing of cable assembly on a traveling sheave assembly.

### 1.2 Current Data Base Summary

The IFMU drives are completely new and there are no data even though the drive mechanisms are similar to other remote handling equipment.

### 1.3 Data Needed

There are several mechanisms within the IFMU which must be evaluated under conditions in Section 1.4. These include the guide tube drive and the detector vertical drive system including the sleeve and counterweight assembly.

Data are needed on functional performance including accuracy of positional readout, speed, and smoothness of travel in operating modes. Also, data on detector and thermocouple signals including: repeatability, linearity, drift, calibration, and signal

noise levels during operating modes. Reliability of overall drive operation is also required.

Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Radiation Level | [TBD] |
| Helium Pressure | 1025 psia |
| Temperature | [150-200] °F |
| Detector Weight | [TBD] |

## 2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Test the equipment at the site during preoperational checkout.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

Performance data on a full-scale IFMU drive assembly will be obtained for all expected conditions using a simulated detector channel and operating environment. The selected approach allows deficiencies in the reference design to be corrected prior to site installation. A full-scale test is reasonably achievable cost-wise and provides a high level of confidence in the applicability of the experimental data. The Alternative 2.1 was not selected due to the risk involved with the scheduled startup, if design changes are required.

## 4. SCHEDULE REQUIREMENTS

Data will be required by month [TBD], 12 months before completion of final design.

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

[DDN C.11.01.05]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Nonexecution of the preferred approach would lead to total dependence on Alternative 2.1 and failure at that time would certainly lead to schedule delays while the problems were investigated and corrected.

DW Ketchum 7-27-94
Originator Date

Camilo Rodriguez 7/28/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
IN-CORE FLUX MAPPING UNIT (IFMU) DESIGN VERIFICATION
DDN C.11.01.06

PLANT: GT-MHR/System 11

1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Axial neutron flux distribution data is required to monitor core performance. The purpose of this DDN is to confirm operability of a fission chamber and associated cabling in an HTGR operating environment for this application. Related DDN C.11.01.05.

1.1 Summary of Function and Assumptions

"Monitor Neutron Flux Distribution," Assumption: Axial neutron flux mapping in an HTGR environment can be made in-core with a traversing fission chamber.

1.2 Current Data Base Summary

Studies to date have indicated the most likely candidate for successful mapping of axial nuclear flux in an HTGR environment is a fission chamber.

Testing to date on readily available commercially available neutron detector is limited to LWR use.

A TOSHIBA fission chamber has been successfully tested at high temperature in the TRIGA reactor. The purpose of the TRIGA test was to prove the sensor could operate properly at high neutron flux levels ($10^{12}$ n/cm$^2$-s) and high temperatures. (The detector shows good linearity up to about 825°C above which signal degradation occurs).

1.3 Data Needed

Data for candidate in-core flux mapping detectors is needed to verify the following under the conditions in Section 1.4:

a. Acceptable operation at GT-MHR reactor core/reflector conditions.

b. The operating voltage selected for the fission chamber is valid for high radiation fields.

c. Gamma heating does not affect the fission chamber signal output.

d. The change in signal output or sensitivity due to temperature changes while traversing of the fission chamber.

e. Effect of exposure of the detector leadwire to high temperatures and coiling/uncoiling.

Quality Assurance must be in accordance with the requirements for experimental data or validation testing per nonsafety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Neutron Flux | $10^{12}$-$10^{14}$ n/cm$^2$-s (<.03 eV) |
| Gamma Flux | 1 x $10^6$ - 1 x $10^8$ R/hr |
| Temperature | [1200-1400]°F |
| Operating Environment | Helium |
| Pressure | [1 atm -1025 psia] |
| Moisture | [2-10 ppmv] |

2. DESIGNER'S ALTERNATIVES

Select and install a detector without the benefit of verification in a GT-MHR environment. This would necessitate more reliance on the analytical calculations of flux distribution.

3. SELECTED DESIGN APPROACH AND EXPLANATION

A detector design confirmation program consisting of testing a fission chamber has been recommended because considerable risk of encountering measurement difficulties is involved in not verifying detector performance in a GT-MHR environment.

4. SCHEDULE REQUIREMENTS

The data will be needed by month [TBD], 12 months prior to completion of final design.

5. PRIORITY

Urgency: 1
Cost benefit: H
Uncertainty in existing data: H
Importance of new data: H

[DDN C.11.01.06]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is to select and install a detector without the benefit of verification in an HTGR environment. This would necessitate placing more reliance on analytical calculation of the flux distribution and could necessitate a more conservative core design.

The consequences of nonexecution may result in a nonoperable system. Lack of axial power shape data could complicate core operation analysis and cause delays.

7/28/94

Originator Date

7/28/94

Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
NEUTRON CONTROL ASSEMBLY FLOW AND LEAK DESIGN VERIFICATION
DDN C.11.01.07

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Helium leakage flowing up through the neutron control assembly must not result in overheating of drive system components, and flow through the neutron control assembly must be held to acceptable levels during maintenance operations.

### 1.1 Summary of Functions and Assumptions

"Move Control Rods" Assumption: Control assembly does not allow helium to leak into upper region of penetration to the extent that causes overheating.

### 1.2 Current Data Base Summary

As a result of high temperatures in the upper head of the FSV PCRV due to leaks through the control assemblies, a series of tests was run to determine flow paths and resistances through the control assembly. The data gathered in these tests are not applicable to the current design which has no orifice and is intentionally more leaktight. However, the methods used for the FSV tests are applicable to this DDN.

### 1.3 Data Needed

Data must be obtained on the flow resistances of the flow paths under combinations of misalignments and pressure differentials for the Neutron Control Assembly design for conditions in Section 1.4. These data will be used in analysis to predict convective heating and contamination of the upper portion of the refueling penetration and gas flow through the penetration. Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Atmosphere | Helium |
| Ambient Temperature of Control Rod Drive (°F) | 150 |
| Core Inlet Pressure (psia) | 1025 |
| Core Inlet Temperature (°F) | 915 |
| Misalignments | [TBD] |
| Pressure Differentials | [TBD] |

## 2. DESIGNER'S ALTERNATIVES

The following alternatives have been considered:

2.1 Rely upon analysis until hot flow tests are performed during commissioning.

2.2 Add limited helium flow test capability to neutron control assembly prototype qualification test.

2.3 Small scale tests with data extrapolation to full size unit.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

A full-scale test rig will be instrumented to measure flow rates and pressure differentials. If necessary, results will be extrapolated to reactor conditions. Alternative 2.2 could cause substantial delay to the qualification test program. Alternative 2.1 could require substantial rework of all neutron control assemblies if design deficiencies are identified. Relying on small scale tests (Alternative 2.3) would increase the uncertainty in the test results.

## 4. SCHEDULE REQUIREMENTS

Data will be required by month [TBD], six months prior to the start of qualification testing (DDN C.11.01.11).

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

[DDN C.11.01.07]

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The preferred fallback position is Alternative 2.3. Nonexecution could result in increased risk of control rod drive mechanism overheating, excessive dose rates to personnel during maintenance operations, or schedule delays if problems were detected during hot flow testing.

7-27-94

Originator Date

7/28/94

Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# GUIDE TUBES FLOW INDUCED VIBRATION DESIGN VERIFICATION
# DDN C.11.01.08

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The effects of flow induced vibrations on the control rod guide tubes, plenum elements and related components, due to high velocity flow must not cause damage or excessive wear that will result in those components not being able to perform their functions over their design lives.

### 1.1 Summary of Function and Assumptions

"Move Control Rods," Assumption: Control assembly which passes through the upper plenum does not suffer unacceptable damage or operability problems as a result of flow induced vibrations.

### 1.2 Current Data Base Summary

British reactors have demonstrated that there is a potential for vibration damage of components in gas streams. Much work has been done on analytical evaluation of induced vibrations in gas streams. This general work will be used to analyze the proposed design, but the analysis should be verified by specific experimental data.

### 1.3 Data Needed

Data are needed on the frequency and magnitude of significant vibrations of the guide tubes, plenum elements and related components under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing per nonsafety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Core Inlet Pressure (psia) | 1025 |
| Core Inlet Temperature (°F) | 915 |
| Helium Flow Past Single Outer Guide Tube (lb/h) | [0 to 115,000] |
| Flow Velocities (ft/s) | [0 to 45] |

## 2. DESIGNER'S ALTERNATIVES

The following alternatives have been considered:

2.1 Depend only on results of flow induced vibration analysis.

2.2 Small scale tests with data extrapolation to full size unit.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to test a full scale air flow mockup of a group of guide tubes, plenum elements and related components. The test will allow interaction of the components to be evaluated. Testing will be at the upper core plenum inlet flow rates with various orientations of the components in the flow stream. Results will be extrapolated to reactor conditions as required by the modelling selected. Alternatives 2.1 and 2.2 were rejected because they cause significant increases in design uncertainty.

## 4. SCHEDULE REQUIREMENTS

Data will be required by month [TBD], six months prior to start of qualification testing (DDN C.11.01.11).

## 5. PRIORITY

Urgency: 3
Cost benefit: H
Uncertainty in existing data: M
Importance of new data: M

[DDN C.11.01.08]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is to rely on analysis to verify the acceptability of the design. This design approach might lead to a design with excessive wear with the consequential requirement for early replacements or design retrofits.

7-27-94

Originator Date

7/28/94

Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# DEMONSTRATION OF REMOTE HANDLING AND MAINTENANCE OF NEUTRON CONTROL ASSEMBLY
# DDN C.11.01.09

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Contamination and activation require that the neutron control assembly have features which permit remote handling and maintenance. These features must be tested to demonstrate adequacy. Qualification testing of the neutron control assembly is described in DDN C.11.01.10, CB.11.01.02, and C.11.01.11.

### 1.1 Summary of Function and Assumptions

"Perform Neutron Control Assembly Maintenance," Assumption: Equipment must satisfy the reliability function.

### 1.2 Current Data Base Summary

The proposed Neutron Control Assembly is significantly different from that of Fort St. Vrain. However, the conceptual design of the remote handling features was based on the experience gained at the Fort St. Vrain Hot Service Facility. Nevertheless, data on the handling features of the new control assembly design are not sufficiently complete.

### 1.3 Data Needed

Data on the remote handling and maintenance features of the Neutron Control Assembly and the procedures and tools used for its handling are needed. Operations for the removal, alignment, and installation in the reactor vessel and reactor service facilities must be performed and evaluated under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Internal Atmosphere | Air |
| Pressure | 14.7 psia |
| Temperature | 120°F |
| Offset (UPS and core), maximum | [TBD] |

## 2. DESIGNER'S ALTERNATIVES

2.1 Demonstrate remote handling capability on a prototype assembly.

2.2 Verify remote handling and maintenance at the plant site.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

Acceptability of the remote handling features of the control assembly will be verified by a series of tests in which the anticipated maintenance manipulations are performed on full-scale test components. The tests will be conducted on simulated reactor penetrations and in full scale mock-ups of the service facility. Neither of the alternatives considered was selected because each introduces significant risk of plant start up delays should either require modifications during late-in-schedule testing.

## 4. SCHEDULE REQUIREMENTS

Data will be required by month [TBD], 12 months prior to the completion of the final design phase.

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

[DDN C.11.01.09]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Alternative 2.1 is the leading fallback position if a prototype will be available on a timely basis. Nonexecution of the selected approach would increase the risk of having to make changes to the production units, thereby potentially causing delays in the safety review schedule, or requiring the development of new tools and procedures late in the plant schedule.

D W Kelsha 7-27-94
Originator Date

Carlo Rodriguez 7/28/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
NEUTRON CONTROL ASSEMBLY SEISMIC QUALIFICATION
DDN C.11.01.10

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The complete neutron control assembly including the reserve shutdown control equipment, control rod and control rod channel must maintain the ability to insert control material in a timely manner during and following a safe shutdown seismic event. In addition, there must be no degradation of any performance characteristic during or following an operating basis seismic event. Related qualification testing in DDNs C.11.01.11 and C.11.01.02.

### 1.1 Summary of Function and Assumptions

"Move Control Rods," Assumption: Control rod drives can be controlled with a repeatable positional accuracy that is sufficient for reactor control and with a reliability of control rod drive operation of >99.5%.

"Execute Commands," Assumption: Control rod drives respond correctly to shutdown command signals with reliability of >99.5% and has a probability of spurious operation that is <0.5%.

"Execute Commands," Assumption: Reserve shutdown equipment responds correctly (each hopper) to shutdown signals with reliability of >99.5% and has a probability of spurious operation (each hopper) that is <0.5%.

### 1.2 Current Data Base Summary

Configuration and components of the neutron control assembly are significantly different from those used in Fort St. Vrain. Also, data from tests of equipment for the large HTGR did not cover seismic events. Therefore, no seismic qualification data showing that the control assembly complies with IEEE-323 are available.

### 1.3 Data Needed

Data are needed to demonstrate the operability of the neutron control assembly during and following a seismic event in compliance with requirements specified in IEEE-323 and under conditions in Section 1.4. Data acquired should include the control system response time, control material insertion time, and reliability. Quality assurance must

be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Helium Pressure | 1025 psia |
| Impurity | <[10] ppm oxidants |
| Temperature | 150-200°F |
| Control Rod Weight | 206 lb |
| Maximum horizontal acceleration (SSE) | [TBD] |
| Maximum vertical acceleration (SSE) | [TBD] |

## 2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Perform seismic qualification of subassemblies in accordance with IEEE-323 and rely on analysis to predict response of the control assembly.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The complete neutron control assembly will be qualified for performance of its safety functions under seismic simulation. The selected approach provides a higher level of confidence than Alternative 2.1.

## 4. SCHEDULE REQUIREMENTS

Qualification testing to be completed by month [TBD], two months prior to start of qualification test (DDN C.11.01.11).

## 5. PRIORITY

Urgency: 3
Cost benefit: H
Uncertainty in existing data: M
Importance of new data: H

[DDN C.11.01.10]

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Fallback position is Alternative 2.1. However, seismic qualifications of subassemblies is not preferred based on safety considerations.

7-27-94

Originator Date

7/28/94

Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
NEUTRON CONTROL ASSEMBLY QUALIFICATION
DDN C.11.01.11

PLANT: GT-MHR/System 11

1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

A neutron control assembly must be highly reliable and perform repeatedly the required functions during the design life. Related qualification testing DDNs C.11.01.02 and C.11.01.10.

1.1 Summary of Function and Assumptions

"Move Control Rods," Assumption: Control rod drives can be controlled with a repeatable positional accuracy that is sufficient for reactor control and the reliability of control rod drive operation is >99.5%.

"Execute Commands," Assumption: Control rod drives must respond correctly to shutdown command signals with reliability of >99.5% and have a probability of spurious scram that is <0.5%.

1.2 Current Data Base Summary

The neutron control assembly design is significantly different from that of FSV because the rod is heavier, the stroke is longer, there is no orifice assembly, the assembly is entirely within the primary system, and because of improvements due to FSV experience. Therefore, the FSV data have limited applicability and there are no other data available.

1.3 Data Needed

Neutron Control Assembly reliability and performance data under reactor conditions (see Section 1.4) are needed. Design features requiring validation are reliability, speed of rod insertion under normal and scram conditions, accuracy of rod positioning, strength, and response to commands. The data must show that the control rod drive performance is not impaired when the control rod channel in the core is subjected to the representative movement of a seismic event. Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Helium Pressure | 1025 psia |
| Temperature | 150-200°F at CRD |
| | 915°F at lower guide tubes |
| Control Rod Weight | 206 lb |
| Relative Seismic Motion | [±1.5] in horizontally in any direction |

## 2. DESIGNER'S ALTERNATIVES

2.1 Demonstrate partial performance by acceptance test after installation in vessel and during hot flow tests.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to test a complete neutron control assembly built on production tooling over the entire range of anticipated reactor conditions, in a representative installation including a typical penetration, closure, and control rod channel. Provision will be made to simulate anticipated movements during operation and seismic events. Alternative 2.1 would increase schedule and cost risk from potential delays in achieving equipment qualification at a very late point in the plant schedule.

## 4. SCHEDULE REQUIREMENT

Completion of qualification testing, by [TBD] months after completion of final design.

## 5. PRIORITY

Urgency: 3
Cost benefit: H
Uncertainty in existing data: M
Importance of new data: H

[DDN C.11.01.11]

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Fallback position is Alternative 2.1. Unsatisfactory demonstration during hot flow tests in the plant due to inadequate test duration and scope may affect schedule and/or costs.

7-27-94

Originator Date

7/28/94

Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
CORE SUPPORT STRENGTH DATA
DDN C.11.02.01

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

In previous tests the ultimate failure load of the graphite core support structure was significantly different than predicted with stress analysis. Since that time the design of the core support posts has been revised so that the previous tests are not fully applicable. Therefore, testing is needed, in addition to analysis, to determine the actual load capacity of the graphite core support structure.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Graphite Core Support," Assumption: The use of simplified linear elastic stress analysis methods to show compliance with required stress limits can be validated.

### 1.2 Current Data Base Summary

Full-scale testing of FSV core support structure models (1968) confirmed adequate safety factors against vertical loads. A series of tests on LHTGR core support posts and seats (1976 and 1977) did not correlate well with analytical predictions. Specifically, in the first tests premature failure of the seats was experienced. In the second tests (after redesign of the seats), the experimental ultimate load exceeded the analytical predictions. For the GT-MHR, the post was redesigned so that failure is not expected at mid-height rather than at the base. Traditional stress analysis methods are used to predict failure, but their applicability must be confirmed.

### 1.3 Data Needed

Data are required to confirm that the ultimate load capacity of the graphite core support structure is adequate (see Section 1.4). Data are also required on the load at which initial cracking occurs, if different from the ultimate load. The effect of the load eccentricity on the ultimate strength must also be assessed. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

Maximum vertical design loads per core column are as follows:

| | |
|---|---|
| DW + DP | [3266] kg ([7200] lb) |
| DW + DP + OBE | [6320] kg ([13,900] lb) |
| DW + DP + SSE | [8500] kg ([18,700] lb) |

where DW is deadweight, DP is core pressure drop, OBE is operating basis earthquake, and SSE is safe shutdown earthquake.

Maximum offset of the applied load from the column axis is [0.10 m ([4] in.) during a seismic event.

## 2. DESIGNER'S ALTERNATIVES

2.1 Qualify the design on the basis of stress analysis alone.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to design the core support structure on the basis of stress analysis in combination with test results at ambient room temperature conditions, and to confirm the design by verifying the ultimate load capacity of the structure.

Stress analysis alone (Alternative 2.1) would leave considerable uncertainty as to the load capacity of the core support structure.

## 4. SCHEDULE REQUIREMENTS

Validate the design two years before the end of final design.

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

[DDN C.11.02.01]

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without test data, design alternative 2.1 would be employed, with increased risk that a satisfactory position on the structural integrity and reliability of this component might not be developed in time for the final design.

| | |
|---|---|
| Originator | Date |
| Task Manager | Date |
| Program Manager | Date |

DATE: 6/30/94

# GT-MHR PROGRAM
# HOT DUCT INTEGRITY VERIFICATION
# DDN. C.11.02.02

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

An insulated metallic duct has been selected to transport the primary coolant from the core outlet plenum to the power conversion inlet. In addition to high temperature, high velocity gas, and pressure differentials, the components of the hot duct are subjected to potentially detrimental flow-induced and acoustically induced vibration. The component most susceptible to the acoustically induced vibration environment is the thermal barrier. Limited applicable data is available on the effects of this vibration on thermal barrier, especially since the effects are configuration-sensitive. Hence, experimental validation testing of the thermal barrier component is required.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Hot Duct," Assumption: Hot duct components will satisfactorily sustain main circulator output acoustic energy levels up to [160 dB] and plant transients for the life of the plant.

### 1.2 Current Data Base Summary

A series of acoustic tests on flat and curved thermal barrier components were completed in 1984. During 1974-1975 a series of cyclic thermal tests were conducted on a scale model of a hot duct at CEA's Chela facility. More recently, development programs for hot gas ducts were performed in Germany and Japan. However, none of the tests to date are directly applicable to the current design.

### 1.3 Data Needed

Test data is needed to confirm the response of the thermal barrier to the acoustically induced vibration environment in order to give reasonable assurance that the thermal barrier integrity is maintained for the life of the plant under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing for non-safety related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Service Temperatures, °C (°F)

| | |
|---|---|
| Hot side (mixed mean) | 850 (1562) |
| Cold side | 490 (914) |
| Maximum hot streak surface temperature | [1030 (1886)] |

b. Operating Environment

| | |
|---|---|
| Primary coolant | Helium |
| Pressure | 7.07 MPa (1025 psia) |
| Velocity | [0 to 61 m/s (0 to 200 ft/s)] |
| Sound pressure level | Transient spectrum up to [160 dB] |
| Maximum fluence | [Thermal 1.0 x $10^{23}$ n/m$^2$ (E<3.05eV)] [Fast 3.9 x $10^{21}$ n/m$^2$ (E>0.1MeV)] |
| Maximum depressurization rate | [152 kPa/s (22 psi/s)] |

c. Startup/Shutdown Cycles [755]

2. DESIGNER'S ALTERNATIVES

2.1 Resize the thermal barrier insulation modules with rigid connections to minimize the vibrational movements, thereby decrease the damage potential.

2.2 Redesign from the existing available data on hot duct tests and data from the recently performed hot gas duct development programs in Germany and Japan, with consideration for the thermal barrier replaceability.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected design approach consists of four replaceable, annular, thermal barrier modules in the hot duct. A full size hot duct test model consisting of the thermal barrier module sections is recommended for the given design sound pressure spectrum. This will provide the desired thermal barrier acoustical vibration experimental data.

The design alternative 2.1 may make it difficult to remove and replace the thermal barrier sections, because of additional rigid connections and/or more modules. The design alternative 2.2 will result in multiple pieces of thermal barrier sections thus increasing component costs, and also increases the risk of component failure leading to missiles causing downstream damage.

It is judged that the selected design approach is the most cost effective means of the hot duct design with replaceablity feature.

[DDN C.11.02.02]

4. SCHEDULE REQUIREMENTS

For initial confirmation of the selected hot duct design, interim validation data would be desirable at the end of the preliminary design. However, the final test data shall be available at least 1½ years prior to the completion of the final design.

5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: M
Importance: H

6. FALLBACK POSITION AND CONSEQUENCE OF NONEXECUTION

Without the test data, confidence in the hot duct integrity would be reduced.

Design alternatives suggested in Section 2 may be employed with added risk that satisfactory assurance of the structural integrity and reliability of these hot duct components might not be developed in time for the final design.

| | |
|---|---|
| Originator | Date 7-25-94 |
| Task Manager | Date 7-26-94 |
| Program Manager | Date |

DATE: 6/30/94

# GT-MHR PROGRAM
# IRRADIATION EFFECTS ON METALLIC REACTOR INTERNALS (MRI) MATERIALS
# DDN C.11.02.11

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

A property data base is required for the design of the MRI Alloy 800H base metal and weldments, when exposed to neutron irradiation.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Metallic Reactor Internals," Assumption: In-service irradiation will not significantly degrade the design properties of the metal used for the metallic reactor internals.

### 1.2 Current Data Base Summary

Extensive tensile and creep rupture data are available for Alloy 800H at total fluences above $10^{24}$ n/m$^2$, which show that irradiation typically has little effect on tensile strength, but reduces ductility and creep rupture strength. These data indicate that if Alloy 800H is irradiated at temperatures below 593°C (1100°F), this effect will be acceptable if total fluence does not exceed $10^{24}$ n/m$^2$. At higher temperatures, the reduction in ductility becomes more pronounced. Limited data on Hastelloy X irradiated and tested at 649°C (1200°F) show that if the fluence exceeds $10^{21}$ n/m$^2$ thermal plus $10^{21}$ n/m$^2$ fast, there is a factor of two decrease in ductility. No similar data is available for Alloy 800H.

### 1.3 Data Needed

Data are needed on the effects of neutron irradiation during operating and conduction cooldown accident conditions on the following properties of Alloy 800H base metal and weldments (see Section 1.4):

a. Tensile strength
b. Low cycle fatigue strength
c. Fracture toughness
d. Creep and relaxation data (time to rupture, time to 1% strain, time to tertiary creep, creep ductility and constant length stress relaxation)
e. Creep-fatigue strength
f. High cycle fatigue strength

Sufficient data are needed to ensure at least 95% level of confidence to compare with the ASME BV&P Code. After compilation of all data, material property values will be compared to values defined in the ASME B&PV Code. As necessary, new design allowable material property values will be calculated and these allowables will be used to complete the final design of the metallic reactor internals. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Primary Coolant Helium Environment at 7.07 MPa (1025 psia). Estimated range of impurity concentrations is as follows:

Nominal (operating conditions)

[0.01-0.1] ppmv $H_2O$
[0.03-0.2] ppmv $CO_2$
[0.2-0.8] ppmv CO
[0.5-1.5] ppmv $H_2$
[0.05-0.2] ppmv $CH_4$

Off-Nominal

High methane, low moisture environment

[TBD] ppmv $H_2O$
[TBD] ppmv $CO_2$
[TBD] ppmv CO
[TBD] ppmv $H_2$
[TBD] ppmv $CH_4$

b. Maximum Temperature and Neutron Fluence Environment

Operating Conditions

| Item | Nominal Temp °C (°F) | Thermal Fluence (E < 3.05 eV) | Fast Fluence (E > 0.1 MeV) |
|---|---|---|---|
| UPS | [490] ([915]) | $1.2 \times 10^{22}$ n/m$^2$ | $8.4 \times 10^{22}$ n/m$^2$ |
| UCR Top | [490] ([915]) | $6.7 \times 10^{22}$ n/m$^2$ | $3.6 \times 10^{22}$ n/m$^2$ |
| UCR Bottom | [490] ([915]) | $3.4 \times 10^{24}$ n/m$^2$ | $8.7 \times 10^{22}$ n/m$^2$ |
| MCS (Floor) | [495] ([923]) | $8.4 \times 10^{21}$ n/m$^2$ | $1.0 \times 10^{20}$ n/m$^2$ |
| MCS (Barrel) | [495] ([923]) | $3.2 \times 10^{21}$ n/m$^2$ | $1.1 \times 10^{22}$ n/m$^2$ |
| MCS (Beltline) | [495] ([923]) | $1.0 \times 10^{22}$ n/m$^2$ | $5.8 \times 10^{21}$ n/m$^2$ |

Conduction Cooldown Events (Pressurized and Depressurized)

| Item | Maximum Temperature °C (°F) |
|---|---|
| Upper plenum shroud | [816] ([1500]) |
| Upper core restraint | [954] ([1750]) |
| Metallic core support: | |
| Floor | [549] ([1020]) |
| Barrel | [760] ([1400]) |

c. Load Cycles (for low and high fatigue strength)

| | |
|---|---|
| Plant cycles | $10^2$ to $10^6$ |
| For high cycle fatigue tests | $10^8$ (max) |

2. DESIGNER'S ALTERNATIVES

The alternative is to design conservatively to account for limited data available on irradiated Alloy 800H.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The proposed solution consists of using Alloy 800H and experimentally generating data needed to quantify the effects of irradiation at design temperatures.

In the absence of the experimental data, the alternative would be to design conservatively to account for limited data for irradiated Alloy 800H. This would require either additional shielding to limit the fluence to the MRI components based on the current data available or reduce the

allowables of the Alloy 800H in the design. This would make the metallic reactor internals more expensive and would increase the risk of delays in startup.

It is judged that the selected method is the most cost effective means to meet the schedule.

4. SCHEDULE REQUIREMENTS

In order to complete the design of the MRI components, interim material property data is required, six months prior to the end of preliminary design and final material property data, one year prior to completion of final design.

5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: M
Importance: M

6. FALLBACK POSITION AND CONSEQUENCE OF NONEXECUTION

Without test data, confidence in the metallic reactor internals integrity would be reduced.

Additional shielding could be used to reduce irradiation levels or the MRI components could be designed with lower Alloy 800H design allowables. In either cases, the consequences to the program would be higher cost and significant schedule delays.

| | |
|---|---|
| [signature] | 7-25-94 |
| Originator | Date |
| R.E. Vollmer | 7-26-94 |
| Task Manager | Date |
| | |
| Program Manager | Date |

Date: 6/30/94

# GT-MHR PROGRAM
# IRRADIATION EFFECTS ON HOT DUCT MATERIALS
# DDN C.11.02.12

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

A property data base is required for the design of the Hot Duct Alloy 800H base metal and weldments when exposed to neutron irradiation.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Hot Duct," Assumption: In-service irradiation will not significantly degrade the design properties of the metal used for the hot duct.

### 1.2 Current Data Base Summary

Extensive Alloy 800H tensile and creep rupture data exist at total fluences above $10^{20}$ n/m$^2$ which show that irradiation typically has little effect on tensile strength, but reduces ductility and creep rupture strength. These data indicate that if Alloy 800H is irradiated at temperatures below 593°C (1100°F), this effect will be acceptable if total fluence does not exceed $10^{24}$ n/m$^2$. At higher temperatures, the reduction in ductility becomes more pronounced. Limited data on Hastelloy X irradiated and tested at 649°C (1200°F) show that if the fluence exceeds $10^{21}$ n/m$^2$ thermal plus $10^{21}$ n/m$^2$ fast, there is a factor of two decrease in ductility. No similar data is available for Alloy 800H.

### 1.3 Data Needed

Data are needed on the effects of neutron irradiation during operating and conduction cool down accident conditions on the following properties of Alloy 800H base metal and weldments under the conditions in Section 1.4.

a. Tensile strength
b. Low cycle fatigue strength
c. Fracture toughness
d. Creep and relaxation data (time to rupture, time to 1% strain, time to tertiary creep, creep ductility and constant length stress relaxation)
e. Creep-fatigue strength
f. High cycle fatigue strength

The hot duct is currently a non-coded, non-safety related component of the Heat Transport System. However, sufficient data are needed to ensure that the duct will survive for the life of the plant. After compilation of all data, material property design allowables will be established and will be used to complete the final design of the Hot Duct. Quality assurance must be in accordance with the requirements for experimental data or validation testing of a non-safety related component.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Primary Coolant Helium Environment at 7.07 MPa (1025 psia) - Estimated range of impurity concentrations is as follows:

Nominal (operating condition)

[0.01-0.1] ppmv $H_2O$
[0.03-0.2] ppmv $CO_2$
[0.2-0.8] ppmv CO
[0.5-1.5] ppmv $H_2$
[0.05-0.2] ppmv $CH_4$

Off - Nominal

High methane, low moisture environment

[TBD] ppmv $H_2O$
[TBD] ppmv $CO_2$
[TBD] ppmv CO
[TBD] ppmv $H_2$
[TBD] ppmv $CH_4$

b. Maximum Temperature and Neutron Fluence Environment Operating Condition

| Item | Nominal Temp °C (°F) | Thermal Fluence (E < 3.05 eV) | Fast Fluence (E > 0.1 MeV) |
|---|---|---|---|
| Hot Duct | [850] ([1562])<br>[1030] ([1886])* | $1.0 \times 10^{23}$ n/m$^2$ | $3.9 \times 10^{21}$ n/m$^2$ |

*Maximum anticipated hot streaks from the core.

c. Conduction Cooldown Accident Condition

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

| | |
|---|---|
| Maximum Hot Duct Temperature: | |
| Average | [920]°C ([1688]°F) |
| Hot streak | Not Applicable |

Depressurized Conduction Cooldown (DCC):

| | |
|---|---|
| Maximum Hot Duct Temperature | |
| Average | [850]°C ([1562]°F) |
| Hot Streak | Not Applicable |

d. Load Cycles (for low & high fatigue strength)

| | |
|---|---|
| Plant cycles | $10^2$ to $10^6$ |
| For high cycle fatigue tests | $10^8$ (max) |

2. DESIGNER'S ALTERNATIVES

The alternatives are as follows:

2.1 Use alternative materials, such as graphite and carbon-carbon composites which are more resistant to damage from irradiation.

2.2 Design more conservatively to account for limited data for irradiated Alloy 800H.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The proposed solution consists of using Alloy 800H for the hot duct thermal barrier and experimentally generating data needed to quantify the effects of irradiation at design temperatures.

Alternative 2.1 involves uncertainties since these materials have not been used in this new application. This would require a separate set of DDNs which could be even more expensive. Alternative 2.2 would make the hot duct more expensive and would increase the risk of delays in startup.

It is judged that the proposed solution is the most cost effective means to meet the schedule.

4. SCHEDULE REQUIREMENTS

In order to complete the design of the hot duct, preliminary test data is required six months prior to the end of preliminary design and final material property data, one year prior to the completion of final design.

[DDN C.11.02.12]

5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: M
Importance: M

6. FALLBACK POSITION AND CONSEQUENCE OF NONEXECUTION

Without test data, confidence in the hot duct integrity would be reduced.

Additional shielding could be used to reduce irradiation levels. The consequences to the program would be higher cost and significant schedule delays.

Gallie 7-25-94
Originator Date

R.E. Vollmer 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# EFFECTS OF PRIMARY COOLANT CHEMISTRY AND TEMPERATURE ON HOT DUCT MATERIALS
# DDN C.11.02.13

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

A property data base is required for the design of the Hot Duct Alloy 800H base metal and weldments, when exposed to the coolant impurities and temperatures.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Hot Duct," Assumption: Exposure to primary coolant chemistry and temperature over the design life will not significantly degrade the design properties of the metal used for the hot duct.

### 1.2 Current Data Base Summary

The bounding primary coolant contains impurities [up to 2 ppmv $H_2O$, 7 ppmv CO, 7 ppmv $CO_2$, 10 ppmv $H_2$, and 2 ppmv $CH_4$] which can cause corrosion in the form of oxidation, decarburization and carburization. At the hot duct design temperature of about 816°C (1500°F), carbon transport has been shown to be the most potentially significant mode of corrosion with respect to bulk mechanical properties such as tensile and creep properties. Surface oxidation (and concurrent carbon transport) can also affect surface-sensitive properties such as fatigue and crack growth. Extensive data is available on the degree of Alloy 800H corrosion in HTGR primary coolant helium as a function of temperature, duration, and impurity level. However, little data is available on how this degree of corrosion affects selected properties of Alloy 800H.

Data is available on the effects of thermal aging to 30,000 h at temperatures to 816°C (1500°F) on tensile properties and room temperature CVN impact values.

### 1.3 Data Needed

Data are needed on the effects of elevated temperature corrosion from primary coolant helium impurities during operating and conduction cool down accident conditions on the following properties of hot duct Alloy 800H base metal and weldments under the conditions in Section 1.4.

a. Tensile strength
b. Low cycle fatigue strength
c. Fracture toughness

d. Creep and relaxation data (time to rupture, time to 1% strain, time to tertiary creep, creep ductility and constant length stress relaxation)
e. Creep-fatigue strength
f. High cycle fatigue strength

The hot duct is currently a non-coded, non-safety related component of the Heat Transport System. However, sufficient data are needed to ensure that the duct will survive for the life of the plant. After compilation of all data, material property design allowables will be established and will be used to complete the final design of the Hot Duct. Quality assurance must be in accordance with the requirements for experimental data or validation testing of a non-safety related component.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Primary Coolant Helium Environment at 7.07 MPa (1025 psia) - Maximum time-averaged impurity concentrations

Nominal (operating condition)

[0.01-0.1] ppmv $H_2O$
[0.03-0.2] ppmv $CO_2$
[0.2-0.8] ppmv CO
[0.5-1.5] ppmv $H_2$
[0.05-0.2] ppmv $CH_4$

Off-nominal

High methane, low moisture environment

[TBD] ppmv $H_2O$
[TBD] ppmv $CO_2$
[TBD] ppmv CO
[TBD] ppmv $H_2$
[TBD] ppmv $CH_4$

b. Maximum Temperature and Neutron Fluence Environment Operating Condition

| Item | Nominal Temp °C (°F) | Thermal Fluence (E < 3.05 eV) | Fast Fluence (E > 0.1 MeV) |
|---|---|---|---|
| Hot Duct | [850] ([1562])<br>[1030] ([1886])* | $1.0 \times 10^{23}$ n/m$^2$ | $3.9 \times 10^{21}$ n/m$^2$ |

*Maximum anticipated hot streaks from the core.

c. Conduction Cooldown Accident Condition

Pressurized Conduction Cooldown (PCC)

| | |
|---|---|
| Maximum Hot Duct Temperature: | |
| Average | [920]°C ([1688]°F) |
| Hot streak | Not Applicable |

Depressurized Conduction Cooldown (DCC)

| | |
|---|---|
| Maximum Hot Duct Temperature: | |
| Average | [850]°C ([1562]°F) |
| Hot Streak | Not Applicable |

d. Load Cycles (for low & high fatigue strength)

| | |
|---|---|
| Plant cycles | $10^2$ to $10^6$ |
| For high cycle fatigue tests | $10^8$ (max) |

2. DESIGNER'S ALTERNATIVES

The alternatives are as follows:

2.1 Lower the methane impurity level allowables in the primary coolant to minimize carburization.

2.2 Use alternate materials.

2.3 Redesign to reduce stress and accommodate additional allowance for changes in material properties.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The proposed solution consists of using Alloy 800H for the hot duct thermal barrier and experimentally generating data needed to quantify the effects of the primary coolant chemistry and temperature.

Alternative 2.1 would increase the potential for oxidation of graphite components during periods of high moisture (e.g., due to water ingress events); it could also constrain plant operation and increase the helium purification system requirements integrity due to the lower allowable methane level. Alternative 2.2 involves uncertainties which could require DDNs, which could be even more expensive. Alternative 2.3 would make the hot duct more expensive and would increase the risk of delays in startup.

It is judged that the selected method is the most cost effective means to support the design selection.

[DDN C.11.02.13]

4. SCHEDULE REQUIREMENTS

In order to complete the design of the hot duct, preliminary test data is required six months prior to the end of preliminary design and final material property data, one year prior to the completion of final design.

5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: M
Importance: M

6. FALLBACK POSITION AND CONSEQUENCE OF NONEXECUTION

Without test data, confidence in the hot duct integrity would be reduced.

Components could be redesigned to reduce stresses (Alternative 2.3), possibly in combination with the use of alternate materials (Alternative 2.2). The consequences to the program would be higher cost and significant schedule delays.

| | |
|---|---|
| [illegible] | 7-25-94 |
| Originator | Date |
| R. E. Vollman | 7-26-94 |
| Task Manager | Date |
| | |
| Program Manager | Date |

DATE: 6/30/94

# GT-MHR PROGRAM
# FIBROUS INSULATION MATERIAL PROPERTIES
# DDN C.11.02.14

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The hot duct carrying hot gas from the core outlet plenum to the steam generator employs fibrous insulation as a means of protecting the structural integrity of the duct. Similar insulation is used on the upper plenum shroud and the upper portion of the core barrel to protect the reactor vessel during conduction cooldown events. The insulation is required to retain its resiliency and physical characteristics during operating and conduction cool down accident conditions. Applicable data on isothermal and temperature differential effects on insulation resiliency is lacking. Hence, testing of sample materials is required to determine basic material properties.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Hot Duct," Assumption: Insulation characteristics will be maintained for the life of the plant, with exposure to temperatures up to 1030°C.

### 1.2 Current Data Base Summary

A series of cyclic and long-term thermal tests have been conducted on a variety of insulation materials at various temperatures and compressions to determine resiliency. Subsequently, representative acoustic vibration tests were conducted and many of the materials were found to be seriously affected. Short-term resiliency tests on high-temperature insulation materials were conducted with very promising results. However, the high temperature materials currently available are different than those previously tested.

### 1.3 Data Needed

Data on isothermal and temperature differential effects on insulation resiliency is needed to ensure that the selected material(s) is capable of lasting for the life of the plant under the conditions of Section 1.4.

Applicable safety related for upper plenum shroud and core barrel thermal barrier and non-safety related for hot duct thermal barrier quality assurance requirements must be met for experimental data or validation testing.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Service Temperatures, °C (°F)

| | |
|---|---|
| Hot side (mixed mean) | 805 (1562) |
| Cold side | 490 (914) |
| Maximum hot streak surface temperature | [1030 (1886)] |

b. Operating Environment

| | |
|---|---|
| Primary coolant | Helium |
| Pressure | 7.07 MPa (1025 psia) |
| Velocity | [0 to 61 m/s (0 to 200 ft/s)] |
| Sound pressure level | Transient spectrum up to [160dB] |
| Maximum fluence | [Thermal $1.0 \times 10^{23}$ n/m$^2$ (E<3.05eV)] [Fast $3.9 \times 10^{21}$ n/m$^2$ (E>0.1MeV)] |
| Maximum depressurization rate | [152 kPa/s (22 psi/s)] |

c. Startup/Shutdown Cycles [755]

2. DESIGNER'S ALTERNATIVES

2.1 Employ an active cooling system thereby eliminating the need for a passive thermal protection.

2.2 Employ thermal barrier using a non-fibrous insulation material.

2.3 Have testing performed by insulation material manufacturer after award of contract.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to obtain the material properties data needed to assure that a durable thermal barrier can be obtained. This data will be used to design the assemblies for the hot duct test (DDN. C.11.02.02) and to design the thermal barriers for the hot duct, the upper plenum shroud and the core barrel.

It is concluded that the confidence in the design gained by performing these tests is cost effective and viable relative to the alternatives given in Section 2. Specifically, alternative 2.1 was rejected because employing an active cooling system will increase the difficulty of inspecting the vessels and add complexity to the nuclear island; alternative 2.2 was rejected because a non-fibrous insulation thermal barrier would require a more extensive test program for verification of adequacy; and alternative 2.3 was rejected because the required data would not be obtained in a timely manner for economical design and procurement.

[DDN C.11.02.14]

4. SCHEDULE REQUIREMENTS

For initial confirmation of the selected design, interim validation data would be desirable by the end of the preliminary design. However, the final test data is required at least 1 year prior to the completion of the final design.

5. PRIORITY

Urgency: 2
Cost benefit: L
Uncertainty in existing data: M
Importance: M

6. FALLBACK POSITION AND CONSEQUENCE OF NONEXECUTION

Without test data, confidence in the hot duct integrity would be reduced. Alternative 2.3 could be employed which would provide the required data well after it is desired. While this data would be used to qualify and characterize the insulation, it would be also too late to optimize the design. This could lead to significant cost increases and delays in the hot duct test (DDN C.11.02.02) and the insulation material procurement.

Galli 7-25-94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# HARD CERAMIC INSULATION PROPERTIES DATA
# DDN C.11.02.15

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The hard ceramic insulation blocks under the graphite core support structure are made from brittle material and are susceptible to failures from fabrication imperfections as well as from the imposed working loads. Presently the data base for such large ceramic elements is small, and the design uncertainty is considerable.

To calculate the metallic core support and hard ceramic temperatures and the thermal stresses in these components, a hard ceramic thermal/mechanical properties data base is also needed.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Hard Ceramic Pad," Assumption: The production ceramic will have the same properties as the design data base.

### 1.2 Current Data Base Summary

The current GT-MHR ceramic insulation design is based on the FSV design, with modifications due to differences in grades of material, different loading conditions, and design criteria. Its use of alumina (Coors AD85) is an extension of the proven FSV design and provides a good temperature overshoot capability.

Four-point bend tests have been conducted in simulated reactor helium at different test temperatures and stress rates to provide input data for evaluating the consequences of thermally induced tensile stresses and to determine long-term environmental (primarily mois-ture) effects. Some room-temperature tests have been performed on other design configurations to provide structural response and acoustic emission data. Pre- and post-test NDE evaluations were also performed for the purpose of developing NDE capabilities for ceramic structures. There is a large data base on the defects formed in irradiated alumina and their effects on physical and mechanical properties. The effects are limited to high fluences, $>3$ to $4 \times 10^{25}$ n/m$^2$, and are therefore, considered insignificant for the exposure seen by the GT-MHR hard ceramic pads.

Other thermal and mechanical properties are currently estimated from vendor's data and from data available in the open literature.

1.3 Data Needed

Test data are needed to establish a design data base on the following properties for candidate hard ceramic materials under nominal and off-nominal reactor operating conditions (see Section 1.4):

a. Flexural strength
b. Compressive modulus
c. Elastic modulus
d. Fracture toughness (mode I)
e. Thermal expansion
f. Thermal conductivity
g. Specific heat

The data base must be valid for a billet size of [0.43] m ([17] in.) in diameter by [0.076] m ([3] in.) thick and must include data on the following:

a. Dependence on orientation and location in billet and variation from billet to billet.

b. Grain size effect.

The database must be sufficient to establish mean and minimum property values to a reasonably attainable accuracy and confidence level [TBD].

In addition, NDE capabilities are to be developed for production quality control assessment. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Primary Coolant Helium Environment at 7.07 MPa (1025 psia) - Estimated range of impurity concentrations is as follows:

Nominal

[0.01-0.1] ppmv $H_2O$
[0.03-0.3] ppmv $CO_2$
[0.2-0.8] ppmv CO
[0.5-1.5] ppmv $H_2$
[0.05-0.2] ppmv $CH_4$

Off-Nominal

High moisture, low methane environment

[TBD] ppmv $H_2O$
[TBD] ppmv $CO_2$
[TBD] ppmv CO
[TBD] ppmv $H_2$
[TBD] ppmv $CH_4$

High methane, low moisture environment

[TBD] ppmv $H_2O$
[TBD] 0.1 ppmv $CO_2$
[TBD] ppmv CO
[TBD] ppmv $H_2$
[TBD] ppmv $CH_4$

b. Temperature

Nominal

| | |
|---|---|
| Average | [900°C (1652°F)] |
| Hot streak | [1100°C (2012°F)] |

Off-Nominal

Event/Temperature*
Pressurized Conduction Cooldown (PCC)
[600°C (1220°F)]
Depressurized Conduction Cooldown (DCC)
[670°C (1238°F)]

c. Load Cycles

| | |
|---|---|
| Plant cycles | $10^2$ to $10^5$ |
| Seismic vibrations | $10^2$ to $10^5$ |

*Temperatures could be higher by 100°C

[DDN C.11.02.15]

2. DESIGNER'S ALTERNATIVES

The following alternatives have been considered:

2.1 Complete the design based on the available data in the open literature and add design margin for uncertainties.

2.2 Conduct trade study and analyze other design concepts (e.g., use of metallic supports or carbon bricks) in various design conditions.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to determine the strength and thermal/mechanical characteristics of large-size ceramic pads for use in the design analysis.

4. SCHEDULE REQUIREMENTS

Preliminary data are needed six months before the end of preliminary design, and the final data two years before the end of final design.

5. PRIORITY

Urgency: 2
Cost benefit: L
Uncertainty of existing data: M
Importance of new data: M

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without the required test data base, design alternatives 2.1 would be used. This may require different pad sizes and/or additional of insulation and could result in a crash technology program potentially causing delay in schedule.

Ta Ho 7/25/94
Originator Date

R. E. Vollman 7/26/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# EMISSIVITY ON METALLIC REACTOR INTERNALS (MRI) MATERIALS
# DDN C.11.02.16

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The emissivity during reactor operation of the MRI components is an important parameter in the removal of the residual and decay heat during core conduction cooldown events. An emissivity of 0.8 ± TBD is required of the MRI components throughout their operating life.

### 1.1 Summary Function and Assumptions

"Maintain Integrity of Metallic Reactor Internals," Assumption: Emissivity of 0.8 of the MRI components, during in-service irradiation has been assumed in the heat transfer calculations. Emissivity testing must confirm this assumption and also establish requirements on surface finish to control emissivity. In addition, the testing must conclude that the emissivity does not change by more than [TBD] with time.

### 1.2 Current Data Base Summary

No experimental or test data on the emissivity of the Alloy 800H material exists. Initial library research investigations on total emissivity have not uncovered any specific data on its effects on the selected material. Emissivity values on the material depend on the degree of surface oxidation and grain size. Thermal radiative properties of metallic elements and alloys appear to indicate a value in the range of 0.80 to 0.95 for stably oxidized stainless steel material at temperature ranging from 400°C (725°F) to 800°C (1472°F). However, no specific data is available for Alloy 800H.

### 1.3 Data Needed

Data are needed for Alloy 800H to verify the emissivity of 0.8 [± TBD] used in the temperature range (see Section 1.4) in the heat transfer calculations and also develop requirements for surface treatment to control the emissivity to the required value. All tests shall be conducted in the off-nominal high methane, low moisture helium environment. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

### 1.4 Data Parameters and Service Conditions

[DDN C.11.02.16]

Service conditions of interest are given below:

a. Primary Coolant Helium Environment at 7.07 MPa (1025 psia) - Estimated range of concentrations is as follows:

Nominal (operating conditions)

[0.01-0.1] ppmv $H_2O$
[0.03-0.2] ppmv $CO_2$
[0.2-0.8] ppmv CO
[0.5-1.5] ppmv $H_2$
[0.05-0.2] ppmv $CH_4$

Off-Nominal

High methane, low moisture environment

[TBD] ppmv $H_2O$
[TBD] ppmv $CO_2$
[TBD] ppmv CO
[TBD] ppmv $H_2$
[TBD] ppmv $CH_4$

b. Bounding Temperature Conditions

Operating Conditions

| Item | Maximum Temperature °C (°F) |
|---|---|
| Upper plenum shroud | [490] ([915]) |
| Upper core restraint (top) | [490] ([915]) |
| Upper core restraint (bottom) | [490] ([915]) |
| Metallic core support | |
| Floor | [495] ([923]) |
| Barrel | [495] ([896]) |
| Beltline | [480] ([896]) |

Conduction Cooldown Events (Pressurized and Depressurized)

| Item | Maximum Temperature °C (°F) |
|---|---|
| Upper plenum shroud | [816] ([1500]) |
| Upper core restraint | [954] ([1750]) |
| Metallic core support | |
| Floor | [549] ([1020]) |
| Barrel | [760] ([1020]) |

2. DESIGNER'S ALTERNATIVE

The alternative is to design the MRI components by conservatively estimating the extreme possibilities of emissivity of Alloy 800H based on the limited data available on the stably oxidized stainless steel materials at high temperature.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The proposed solution consists of testing the Alloy 800H material samples with selected surface conditions to determine their emissivity in a range of temperature [490°C (915°F)] to [1030°C (1886°F)]. This temperature range bounds the conduction cooldown events and meets the design requirements. The experimentally generated test data needed to quantify the effects of emissivity can be established at the required design temperatures.

It is judged that the selected method will result in the most cost effective design.

4. SCHEDULE REQUIREMENTS

In order to complete the design of the MRI components, interim emissivity data is required, six months prior to the end of preliminary design and final material property data, one year prior to completion of final design.

5. PRIORITY

Urgency: 2
Cost benefit: H
Uncertainty in existing data: H
Importance: H

6. FALLBACK POSITION AND CONSEQUENCE OF NONEXECUTION

Without test data, confidence in the metallic reactor internals and fuel integrity would be reduced. The fallback position is to assume a more conservative value for the emissivity in the

heat transfer calculations of the conduction cooldown events and ensure that the metal temperatures are within the acceptable limits of the Alloy 800H material. If this cannot be achieved, the components will have to be redesigned or the reactor module power rating will have to be reduced to achieve acceptable metal temperatures and fluence levels during all events. In either case, the consequences to the program would be higher cost and significant schedule delay.

Galli 7-25-94

Originator Date

R. E. Vollman 7-26-94

Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
CORE COLUMN VIBRATION DATA
DDN C.11.03.01

PLANT: GT-MHR/System 11

1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Confirm that there are no significant flow-induced vibrations of the core columns in the GT-MHR annular prismatic core.

1.1 Summary of Function and Assumptions

"Maintain Graphite Core Element Structural Integrity," Assumption: Flow-induced vibrations do not contribute significantly to graphite core element stresses.

1.2 Current Data Base Summary

Multi-column flow tests were performed in 1980 on an eight-block high core design. These tests showed that the columns were susceptible to flow-induced vibration at certain flow rates.

1.3 Data Needed

Data are required to confirm that the core columns have no significant flow-induced vibrations under any reactor operating conditions (see Section 1.4). Data shall also be obtained on the vibratory characteristics of core columns. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant

Helium

b. Maximum Temperature of Primary Coolant, °C (°F)

| | |
|---|---|
| At core inlet | 490 (914) |
| At core outlet (mixed mean) | 850 (1562) |

c. Pressure of Primary Coolant, MPa (psia)

At core inlet 7.07 (1025)

d. Core Pressure Drop, MPa (psia)

[Nominal + Design Evolution Margin] ± Tolerance
[0.052 (7.5) + 0.015 (2.2)] ± 15% = [0.067 (9.7)] ± 15%

e. Maximum Flow of Primary Coolant, kg/s (lbm/s)

| | |
|---|---|
| Flow through the core | 321 [708] |
| Gap flow | [21% max] |

2. DESIGNER'S ALTERNATIVES

2.1 Design the core and the supports to minimize the potential for vibrations, and continue to use the current design analysis methods and data base without further validation.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to validate the design with [1/4 and 1/2] scale model experimental data. The current data base is not considered adequate for the present 10-block high core design. Flow analyses are not considered significantly accurate to provide the necessary confidence that the core design will not be susceptible to flow-induced vibrations (Alternative 2.1).

4. SCHEDULE REQUIREMENTS

Data are needed by the end of preliminary design.

5. PRIORITY

Urgency: 1
Cost benefit: H
Uncertainty in existing data: H
Importance of new data: H

[DDN C.11.03.01]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The consequence of nonexecution could be that it would be necessary to redesign the core restraint system, if excessive vibration were encountered at reactor startup. This would result in schedule delays and cost increases. Design alternative 2.1 would be the fallback position.

Richard J Kapernick 7/25/94
Originator Date

R. E. Vollmer 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# CONTROL ROD VIBRATION DATA
# DDN C.11.03.02

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The design of the GT-MHR control rod has been revised to use high temperature carbon/carbon composite material as the reference material. Confirmation is required that flow-induced vibrations do not affect the integrity of the carbon/carbon composite control rods.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Control Rods," Assumption: Flow-induced vibrations do not contribute significantly to control rod stresses.

### 1.2 Current Data Base Summary

Control rod vibration tests were performed in 1975 on the Fort St. Vrain metallic control rod design. These tests showed that the control rods were susceptible to flow-induced vibration. These tests were of a limited nature and did not include the effect of crossflow. No data are available for the longer control rods in the 10-block high MHR core. Furthermore, for the GT-MHR, the control rod is redesigned using carbon/carbon composite material so that failure is not expected in a depressurized conduction cooldown event.

### 1.3 Data Needed

Data are required to confirm that the control rods have no significant flow-induced vibrations which would affect control rod operation under reactor operating conditions with and without crossflow under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant

Helium

b. Maximum Temperature of Primary Coolant, °C (°F)

| | |
|---|---|
| At core inlet | 490 (914) |
| At core outlet (mixed mean) | 850 (1562) |

c. Maximum Pressure of Primary Coolant, MPa (psia)

At core inlet 7.07 (1025)

d. Maximum Core Pressure Drop, MPa (psia)

[Nominal + Design Evolution Margin] ± Tolerance
[0.052 (7.5) + 0.015 (2.2)] ± 15% = {0.067 (9.7)] ± 15%

e. Maximum Flow of Primary Coolant, kg/s (lbm/s)

| | |
|---|---|
| Flow through the core | 321 (708) |
| Gap flow | [21% max] |
| Flow per control channel | 1.3 (0.6) |

2. DESIGNER'S ALTERNATIVES

2.1 Use analyses and current data base.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to validate the design based on experimental data.

Validation by analysis alone (2.1) is not believed to be sufficiently accurate to provide necessary confidence that vibrations will not occur.

4. SCHEDULE REQUIREMENTS

Data are needed before the end of preliminary design.

[DDN C.11.03.02]

5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: H
Importance of new data: H

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The consequence of nonexecution could be that it would be necessary to redesign the control rods, if excessive vibration was encountered at reactor startup. This would result in schedule delays and cost increases. The fallback position is to rely on analysis and the current data base.

Originator Date 7/25/94

R. G. Vollman 7/26/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# CORE ELEMENT DYNAMIC STRENGTH DATA
# DDN C.11.03.03

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The replaceable graphite core elements must withstand dynamic stresses due to seismic loads in combination with thermal/irradiation induced stresses.

### 1.1 Summary of Function and Assumption

"Maintain Replaceable Graphite Core Element Structural Integrity."

Assumption 1: The dynamic strength can be predicted with finite element methods.

Assumption 2: The coefficient of restitution and contact time of colliding blocks in the core during a seismic event can be predicted with finite element analysis.

### 1.2 Current Data Base Summary

To address the issue in the above assumptions, a series of dynamic tests of unirradiated fuel elements was performed in a pendulum rig. Those tests indicated that the dynamic strength (with a maximum relative impact velocity between two fuel blocks of 3 m/s or less) can be reasonably well predicted with static finite element methods. The contact time and coefficient of restitution were also determined in these tests. However, all the test specimens were control fuel elements which are of a different configuration than that used in the GT-MHR core and most of them were made of graphite grade H-327. Only two specimens were made from H-451 which is the GT-MHR reference material. No tests were conducted on H-451 irradiated core elements. No data exist for the GT-MHR core element designs.

### 1.3 Data Needed

The failure load and stiffness data of H-451 core elements subjected to dynamically applied forces is needed under the conditions in Section 1.4. The contact time and coefficient of restitution must be measured for correlation with analysis methods and input to seismic analysis. The nature of the forces and their duration must be representative of the type of loads imposed on the fuel elements during earthquakes.

The data base must be sufficient to establish that the mean values of the experimentally determined failure loads are higher than the corresponding analytical predictions. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters and Service Conditions

The following test conditions are acceptable:

The strength test will be performed at ambient conditions.

Maximum relative impact velocity: 1.5 m/s (59 in./s) between core elements.

## 2. DESIGNER'S ALTERNATIVES

These alternatives were considered:

2.1 Redesign the core to reduce the seismic impact loads on the core elements. This would require keying or clamping of the core.

2.2 Proceed on the basis of the present analytical methods with data from previous tests which were for different material and geometry.

2.3 Isolate the graphite core or reactor vessel to minimize the core seismic loads.

2.4 Perform strength and stiffness testing on both irradiated and unirradiated elements.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to validate by test using unirradiated core elements the dynamic strength and stiffness predicted by finite element analysis and obtain the properties of irradiated elements by scaling from irradiation tests on elemental material specimens (see DDN B.11.03.13). In addition, validate by test the contact time and coefficient of restitution. This is seen as the most cost effective approach. Alternative 2.1 would result in a costlier design and more complicated refueling. Alternative 2.2 would incur the risk of rejection during safety evaluations. Alternative 2.3 would result in additional development needs and higher cost. Alternative 2.4 was rejected because of the difficulty involved in obtaining irradiated elements for test purposes and also the costs and difficulty involved in testing.

## 4. SCHEDULE REQUIREMENTS

Data are required two years before the end of final design.

[DDN C.11.03.03]

5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: H
Importance of new data: M

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without dynamic test data, design Alternative 2.2 would be used, with the risk of rejection during safety evaluation which may result in either a crash technology program or a late design change.

Zu Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# CORE ELEMENT FAILURE MODE DATA
# DDN C.11.03.04

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The steps in the design process for meeting the plant availability and component safety and reliability requirements includes calculations of how a crack, if initiated, would progress until the core element is functionally damaged. The methods for performing these calculations need validation.

### 1.1 Summary of Function and Assumption

"Maintain Replaceable Graphite Core Element Structural Integrity," Assumption: The failure mode, i.e., the crack progression can be predicted with the TWOD finite element code.

### 1.2 Current Data Base Summary

The failure load and failure mode of virgin fuel elements under mechanical loads were measured in development programs. Some analytical correlations were performed, but these did not include crack progression analyses. Limited cracking under thermal/irradiation stresses have been observed in two FSV fuel elements, and reasonably good analytical correlations were achieved. The cracking was, however, far from extensive enough to represent failure in a functional sense. No data exist for failure under combined thermal and mechanical loads.

### 1.3 Data Needed

The failure loads and failure modes are needed for replaceable graphite core elements subjected to the combination of statically applied mechanical and thermal loads which simulate the most severe stress conditions for the service conditions given in Section 1.4. The static test is used as a basis for establishing crack initiation and progression correlations with the analytical TWOD finite element code. Testing shall be done with unirradiated elements, and failure loads shall be obtained based on creep effects and changes in mechanical properties as determined in irradiated specimens (see DDNs C.11.03.15 and C.11.03.13).

The specific data needed are:

a. Laterally applied mechanical load at crack initiation.

b. Location of crack initiation.

c. Mechanical load at ultimate failure based on the crack width and crack length failure criteria.

d. Crack path from initiation to ultimate failure.

The data base must establish that the mean values of the experimental data are higher than the corresponding analytical predictions. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters and Service Conditions

The following service conditions are bounding values:

| | |
|---|---|
| Material | H-451 |
| Normal operating condition service temperature range | 120 to 1200°C (248 to 2192°F) |
| Conduction cooldown condition maximum temperature | 1600°C (2912°F) |
| Maximum fast fluence | $4.5 \times 10^{25}$ n/m$^2$ |
| Operating environment | Helium at 7.07 MPa (1025 psia) |

The test will be performed at ambient conditions.

## 2. DESIGNER'S ALTERNATIVES

These alternatives were considered:

2.1 Validate the analytical predictions on the basis of the existing data.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to perform cracking analysis with the TWOD code as a part of the design process for showing compliance with the plant availability goal and component safety and reliability requirements and to validate the analytical methods by correlation with an expanded test data base. Alternative 2.1 would incur the risk of rejection during safety review.

## 4. SCHEDULE REQUIREMENTS

The data are needed [TBD] weeks before start of the final design phase.

[DDN C.11.03.04]

5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without an expanded test data base, design Alternative 2.1 would be used, with the risk that the validation would be deemed unacceptable, resulting in either a crash technology program or a late design change.

Jn Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# CONTROL ROD SHOCK ABSORBER DATA
# DDN C.11.03.05

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Crushable graphite shock absorbers are installed at the bottom of the control rod channel to protect the graphite core support structure in the event of an accidentally dropped control rod such as due to a broken drive cable. Data are needed to verify performance of the design.

### 1.1 Summary of Function and Assumptions

"Protect the Capability to Support Core," Assumption: A crushable graphite insert can absorb sufficient energy to protect the core support structure, in the event of an accidentally dropped control rod.

### 1.2 Current Data Base Summary

No data is available on the shock absorption characteristics of graphite in crushable form (e.g., perforated, honeycombed, etc.).

### 1.3 Data Needed

Data are needed to establish the absorption characteristics for three different variants, to be specified by the designer, of a crushable graphite shock absorber for the control rods. Test data shall be obtained using unirradiated material at ambient conditions, and the effects of temperature and irradiation (see Section 1.4) established from changes in mechanical properties determined for small scale specimens (see DDN C.11.03.13). (The absorption characteristic is the energy absorbed in crushing action, expressed as a percentage of the total kinetic energy in the falling body). For each of the three variants, a sufficient data base must be established to provide 90% confidence that the mean value of the data base is at most [20]% different from the true mean value. (Provided the data confirms that all three variants are adequate, the designer will select the most cost effective of the variants). Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

| | |
|---|---|
| Material | Graphite Grade H-451 |
| Service temperature range | 21° to [830]°C (70° to [1526]°F) |
| Maximum fast fluence | [1 x $10^{25}$] n/$m^2$ (E > 0.1 MeV) |
| Operating environment | Helium to 7.07 MPa (1025 psia) |
| Characteristics of Dropped Control Rod: | |
| Weight of Rod | [93.4] Kg ([206] lb) |
| Maximum Drop Height | [9.75] m ([32] ft) |

## 2. DESIGNER'S ALTERNATIVES

These alternatives were considered:

2.1 Improve the reliability of the control rod such that the unscheduled outage due to a dropped rod meets the allocations even without any shock absorbing features.

2.2 Use a FSV type metallic shock absorber connected to the lower end of the control rod.

2.3 Eliminate the shock absorber and accept the unscheduled outage resulting from a dropped rod.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to use shock absorbers of crushable graphite with validated characteristics. Validation is necessary because of the uncertainties in making analytical predictions. This approach was found to be more cost effective than the alternatives. Alternative 2.1 would increase the cost of the control rods and would also introduce the difficulties and expenses of proving that their reliabilities were adequate. Alternative 2.2 would require periodic replacements of the shock absorber due to embrittlement of the thin-walled metal structure. Irradiation testing would also be necessary to determine the degradation of the shock absorption characteristics as a function of the fast fluence. Alternative 2.3 would require an increase in the unscheduled outage allocation due to the extended shutdown for replacing potentially damaged core support components.

## 4. SCHEDULE REQUIREMENTS

The data are needed before the end of preliminary design.

[DDN C.11.03.05]

5. PRIORITY

Urgency: 2
Cost benefit: L
Uncertainty in existing data: M
Importance of new data: M

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Alternative 2.2 would be used. This would increase operating costs and also technology cost due to the need for irradiation testing.

H Ho 7/25/94
Originator Date

R. E. Vallman 7-26-94
Task Manager Date

Program Manager Date

[DDN C.11.03.06]

DATE: 6/30/94

GT-MHR PROGRAM
CONTROL ROD STRUCTURAL INTEGRITY DATA
DDN C.11.03.06

PLANT: GT-MHR/SYSTEM 11

[LATER]

[DDN C.11.03.11]

DATE: 6/30/94

# GT-MHR PROGRAM
# GRAPHITE MULTIAXIAL STRENGTH DATA
# DDN C.11.03.11

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The conceptual design of the graphite components has been performed on the basis of the maximum stress failure theory. This theory is an approximation whose uncertainty needs to be quantified on the basis of multiaxial strength data, and included in the ASME Subsection CE for permanent graphite core supports. The multiaxial strength data will also con-firm the probabilistic structural design criteria for replaceable graphite core elements. These criteria are being developed for showing compliance with the plant availability goal and the component safety and reliability requirements.

### 1.1 Summary of Function and Assumptions

"Maintain Graphite Component Structural Integrity," Assumption: The maximum stress failure theory is a reasonable approximation for HLM (permanent side reflector) and H-451 (core and core support) graphites under a multiaxial state of stress. This design approach is recommended in the ASME Subsection CE for graphite core supports and permanent side reflectors, and in the structural design criteria for graphite core elements.

### 1.2 Current Data Base Summary

Biaxial data are available on unirradiated ATJ, ATJ-S, Graphitite-G, IG-110, JTA, PGX, and 2020 graphites. The maximum stress failure theory as modified by the Coulomb-Mohr theory appears to most closely match the existing biaxial data. No biaxial or triaxial strength tests have as yet been performed on HLM and H-451 graphites.

### 1.3 Data Needed

Data are needed to determine the multiaxial strength surface of the core, core support, and permanent side reflector graphite under the conditions in Section 1.4. The data base must be adequate to determine the mean value failure surface and the associated variability as well as the specified minimum strength surface such that the survival probability is 99% with a confidence level of 95%.

The multiaxial strength data shall be obtained for unirradiated graphite at room temperature in air. Data for the effects of the service conditions on uniaxial strength are also needed for correlations with multiaxial strength (see DDN B.11.03.03). Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [1400°C(2552°F)/24 h |
| [TBD] ppmv $H_2$ | |

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

*Temperatures could be 100°C higher.

| Maximum Concentration | Maximum Graphite Temperature/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1630°C(2966°F)/30 h |

High Moisture Ingress - [TBD] events over reactor life

Helium at [TBD] MPa ([TBD] psia)

| Maximum Concentration | Maximum Graphite Temperature/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [TBD] |

b. Temperature*/Neutron Fluence

Nominal

| Element/Temperature* | Maximum Fast Fluence $10^{25}$ n/m$^2$ (E>0.18 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| [300 to 900°C] [(572 to 1652°F)] | 4.5 |
| [900 to 1300°C] (1652 to 2372°F) | 4.5 to 1.0** |
| [1300 to 1400°C] ([232 to 2552°F]) | 1.0 |
| Core Support Elements | |
| 120 to [1000]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 1.5 |

Off-Nominal (Conduction Cooldown)

| Element/Maximum Temperature*** (at DCC) | |
|---|---|
| Fuel, Reflector Elements | [1630°C (2966°F)] |
| Core Support Elements | [1000°C (1832°F)] |
| Permanent Side Reflector Elements | [1220°C (2228°F)] |

*Temperatures could be higher by 100°C.

**Linear variation between end points.

***Temperature could be higher by 100°C.

[DDN C.11.03.11]

2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Continue the use of the maximum stress failure theory and/or its derivative, the modified Coulomb-Mohr theory. Estimate the errors and uncertainties on the basis of the uniaxial data and the biaxial data available on other graphites. Also include sufficient design margin to account for the uncertainties from which the reliabilities can be estimated, and/or perform cracking analysis to assess the failure modes and effect.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to establish a "mean value" and/or a "specified minimum" failure surface as required for use in design. Alternative 2.1 was rejected due to the risk of not being acceptable for safety evaluations. It would also result in unnecessarily large structural cross sections, higher cost and a reduction in the quantity of nuclear grade material that would qualify for use in the reactor.

4. SCHEDULE REQUIREMENTS

Preliminary data are needed six months before the end of preliminary design, and final data 1-1/2 years before the end of final design.

5. PRIORITY

Urgency: 1
Cost benefit: L
Uncertainty in existing data: H
Importance of new data: M

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without statistical multiaxial strength test data, design alternative 2.1 would be used, with the risk of rejection during safety evaluations, resulting in either a crash technology program, a belated design change, or a reduction in the quantity of nuclear grade materials that would qualify for use in the reactor core.

Tu Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
GRAPHITE FATIGUE DATA
DDN C.11.03.12

PLANT: GT-MHR/System 11

1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Fatigue analysis is required for the graphite components. In this analysis, the fatigue strengths of graphite must be determined and the cumulative effects of varying stress amplitudes must also be accounted for.

Associated DDNs: DDN C.11.03.13.

1.1 Summary of Function and Assumptions

"Maintain Graphite Component Structural Integrity," Assumption: The cyclic fatigue strengths for H-451 graphite specified in the Graphite Design Handbook are valid, and Miner's rule for estimating the cumulative fatigue is applicable to H-451 graphite.

1.2 Current Data Base Summary

Some uniaxial push-pull fatigue tests in air at ambient temperature have been conducted on axial and radial specimens of H-451 graphite taken from a single billet. The stress amplitude was held constant during each test. The stress ratio, R (ratio between the minimum stress and the maximum stress during a cycle), varied between -1 and 0, and tests were conducted to a maximum of $10^5$ cycles. No tests in which the stress amplitude was changed have been conducted. The effect of irradiation fluence up to $8.5 \times 10^{25}$ n/m$^2$ (E > 0.1 MeV, HTGR) on the fatigue strength have been investigated for limited temperatures.

1.3 Data Needed

The following fatigue data are required under the conditions in Section 1.4:

a. Fatigue life for up to $10^5$ cycles of uniaxial stress as a function of stress amplitude for H-451 graphite under constant amplitude cyclic loading, including:

1. Dependence on stress ratio, R (ratio between the minimum and maximum stress during a cycle) ranging from [-1] to [+1].

2. Dependence on orientation and location in billet.

3. Variation from billet to billet and from lot to lot.

The data base must be sufficient to determine the mean value of the fatigue strength with [95]% confidence, to establish a specified minimum fatigue life as defined in the trial use edition of Subsection CE of the ASME Code, and to construct a Design Fatigue Diagram.

b. Fatigue life for H-451 graphite subjected to sequential series of uniaxial stress cycles with stress amplitude of 65% to 100% of mean ultimate strength. Sufficient data are needed to establish the difference between constant amplitude fatigue life and varying amplitude fatigue life with [95]% confidence.

The above data are primarily needed for unirradiated graphite at room temperature. In addition, a limited number of data points are needed to determine the effects of the operating environment (temperature and irradiation effects). The effects of oxidation on the fatigue properties of H-451 should also be evaluated. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1400°C (2552°F)]/24 h |

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1630°C (2966°F)]/30 h |

High Moisture Ingress - [TBD] events over reactor life

Helium at [TBD]

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [TBD] |

b. Temperature**/Neutron Fluence

Nominal

| Element/Temperature* | Maximum Fast Fluence $10^{25}$ n/m$^2$ (E>0.18 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| [300 to 900°C] ([572 to 1652]°F) | 4.5 |
| [900 to [1300°C] ([1652 to 2372°F) | 4.5 to 1.0 |
| [1300 to 1400°C] ([2372 to 2552°F]) | 1.0 |

*Temperatures could be higher by 100°C.

**Temperature could be higher by 100°C.

| | |
|---|---|
| Core Support Elements | |
| 120 to [1000]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 0.2 |

Off-Nominal (Conduction Cooldown)

Element/Maximum Temperature* (at DCC)

| | |
|---|---|
| Fuel, Reflector Elements | [1630°C (2966°F)] |
| Core Support Elements | [1000°C (1832°F)] |
| Permanent Side Reflector Elements | [1220°C (2228°F)] |

c. Load Cycles

Plant Cycles: $10^2$ to $10^5$
Seismic Vibrations: $10^2$ to $10^5$

## 2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Complete the fatigue analysis on the basis of the existing data base, assume Miner's rule to be valid without validation and include additional design margin to cover uncertainties.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to complete the fatigue strength data base for H-451 graphite, to perform fatigue analysis using Miner's rule and to validate the applicability of this rule to H-451 graphite.

Alternative 2.1 would incur the risk of rejection during safety evaluations.

## 4. SCHEDULE REQUIREMENTS

Final data are needed 1-1/2 years before the end of final design.

## 5. PRIORITY

Urgency: 2
Cost benefit: L
Uncertainty in existing data: L
Importance of new data: L

[DDN C.11.03.12]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without fatigue test data, design alternative 2.1 would be used with the risk of rejection during safety evaluations resulting in either a crash technology program or a belated design change, or reduction in the quantity of nuclear grade materials that would qualify for use in the reactor core.

| | |
|---|---|
| T. Ho | 7/25/94 |
| Originator | Date |
| R. G. Volkman | 7-26-94 |
| Task Manager | Date |
| | |
| Program Manager | Date |

DATE: 6/30/93

# GT-MHR PROGRAM
# GRAPHITE MECHANICAL PROPERTIES DATA
# DDN C.11.03.13

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Probabilistic stress criteria are used to ensure compliance with plant availability goals and safety and reliability component requirements. The statistical variability of the mechanical properties of permanent and replaceable graphite components is needed for the development of these criteria.

Associated DDNs: DDN C.11.13.20.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Graphite Components." Assumption: A statistically adequate data base will be established for H-451 (replaceable core and core support) and HLM (permanent reflector) graphites.

### 1.2 Current Data Base Summary

Tensile, compressive, flexural strengths, and elastic constants in air at ambient temperature have been measured on production HLM graphite. Axial and radial specimens were taken from two billets (45 in. in diameter and 72 in. long). The specimens were taken from six locations in the billets.

Tensile, compressive, and flexural strengths and elastic constants in air at ambient temperature have been measured on axial and radial specimens on approximately 100 billets (18 in. in diameter and 34 in. long) of preproduction and production H-451 graphite from six fabrication lots. For three billets, specimens were taken throughout the whole volume; for 12 billets, specimens were taken from four locations; and for the remainder of the billets specimens were taken from two locations. No strength tests have been made at elevated temperatures. Two production billets characterized by destructive testing have also been evaluated by nondestructive methods to obtain relative estimates of the overall strength. Volume effects were also identified by different strength specimen testings covering a range of over three orders of magnitude in stress volume.

A considerable body of data exists on the effects of irradiation on Young's modulus and tensile strength of H-451 graphite specimens irradiated in the Oak Ridge Reactor at 550°C (1022°F) through 1300°C (2372°F) to fluences between 1 x $10^{21}$ n/cm$^2$ and 1 x $10^{22}$ n/cm$^2$. Specimens were taken from five billets selected from three different production lots. Additional sonic modulus data on H-451 graphite irradiated at 600°C (1112°F) and 900°C (1652°F) to fluences up to 4 x $10^{22}$ n/cm$^2$ are available from HFIR capsule irradiations.

1.3 Data Needed

Data are needed, under the conditions in Section 1.4, to define the tensile and compressive strengths, elastic constants, and stress-strain relationship in accordance with appropriate ASTM standards for H-451 and HLM graphites, including the effects of:

a. Orientation and location in billet.

b. Variation from billet to billet and from lot to lot.

c. Temperature, ranging from shutdown conditions to the maximum service temperature.

d. Fast neutron fluence (H-451 only).

e. Specimen size (volume).

f. Irradiation creep (H-451 only).

g. Oxidation.

The data base must be sufficient to determine the statistical distribution of the required properties so that mean values and associated variabilities and the specified minimum strength (per ASME Subsection CE) can be established with [95]% confidence.

Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

[DDN C.11.03.13]

| Maximum Concentration | Maximum Graphite Temperature*/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [1400°C (2552°F)]/24 h for each event |
| [TBD] ppmv $H_2$ | |

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

| Maximum Concentration | Maximum Graphite Temperature/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [1630°C (2966°F)/30 h |
| [TBD] ppmv $H_2$ | |

High Moisture Ingress - [TBD] events over reactor life

Helium at [TBD]

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [TBD] |

*Temperatures could be higher by 100°C.

b. Temperature*/Neutron Fluence

Nominal

| Element/Temperature* | Maximum Fast Fluence $10^{25}$ n/m$^2$ (E>0.18 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| [300 to 900°C] ([572 to 1752°F]) | 4.5 |
| [900 to 1300°C] ([1652 to 2372°F]) | 4.5 to 1.0** |
| [1300 to 1400°C] ([2372 to 2552°F]) | 1.0 |
| Core Support Elements | |
| 120 to [1000]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 1.5 |

Off-Nominal (Conduction Cooldown)

| Element/Maximum Temperature* (at DCC) | |
|---|---|
| Fuel, Reflector Elements | [1630]°C ([2966]°F) |
| Core Support Elements | [1000]°C ([1832]°F) |
| Permanent Side Reflector Elements | [1220]°C ([2228]°F) |

2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Use the data base available at the time of the design analysis.

3. SELECTED APPROACH AND EXPLANATION

The selected approach is to meet the plant availability goals and component safety and reliability requirements through detailed probabilistic methods. This requires an adequate statistical data base.

Alternative 2.1 was rejected because the existing data base is inadequate for a probabilistic design approach.

4. SCHEDULE REQUIREMENTS

Final data are needed two years before the end of final design.

---

*Temperatures could be higher by 100°C.

**Linear variation between end points.

[DDN C.11.03.13]

5. PRIORITY

Urgency: 1
Cost benefit: H
Uncertainty of existing data: M
Importance of new data: H

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without a statistical test data base, design alternative 2.1 would be used. The consequences could be a reduction in the quantity of nuclear grade material that would qualify for use in the reactor and an increase in core size (component stress can be decreased by decreasing power densities, thus requiring a larger core to maintain the plant production goal), both resulting in higher cost and delay in schedule.

Th Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# GRAPHITE IRRADIATION-INDUCED DIMENSIONAL CHANGE DATA
# DDN C.11.03.14

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Probabilistic stress criteria are used to meet the plant availability goals and component safety and reliability requirements. Knowledge of the statistical variability of the irradiation-induced shrinkage of core and core support component graphite is needed for the development of these criteria. The mean value of the irradiation-induced shrinkage is used in the design analysis.

Associated DDN: DDN C.11.03.15.

### 1.1 Summary of Function and Assumptions

"Control In-Core Gap Flow," "Maintain Graphite Component Structural Integrity," "Control Material Degradation," "Protect the Capability to Maintain Graphite Component Structural Integrity," Assumption: A statistically adequate data base will be established for H-451 graphite.

### 1.2 Current Data Base Summary

A considerable body of data exists on the effects of irradiation on dimensional changes of H-451 graphite specimens irradiated in the Oak Ridge Reactor at 550°C (1022°F) through 1300°C (2372°F) to fluences between $1 \times 10^{21}$ n/cm$^2$ and $1 \times 10^{26}$ n/cm$^2$. Specimens were taken from five billets selected from three different production lots. Additional dimensional change data for H-451 graphite irradiated at 600°C (1112°F) and 900°C (1652°F) to fluences up to $4 \times 10^{26}$ n/cm$^2$ are available from HFIR capsule irradiations.

### 1.3 Data Needed

Data are needed, under the conditions in Section 1.4, to define the irradiation-induced shrinkage and the associated variabilities for graphite H-451 as a function of fluence and temperature, including:

a. Dependence on orientation and location in billet.

b. Variation from billet to billet and lot to lot.

c. Dimensional change covering a range of temperature conditions from 300° to 1600°C (572° to 2912°F).

d. Dependence on the state of oxidation of the graphite.

The data base must be sufficient to determine the mean values and standard deviations of the irradiation shrinkages to a reasonably attainable accuracy with [95]% confidence. Additional data are needed to establish the within billet correlation. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1110 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [1400°C (2552°F)/24 h for each event |
| [TBD] ppmv $H_2$ | |

*Temperatures could be higher by 100°C.

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1630°C (2966°F)/30 h |

High Moisture Ingress - [TBD] events over reactor life

Helium at [TBD]

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD]ppmv $H_2O$ | [TBD] |

b. Temperature/Neutron Fluence

Nominal

| Element/Temperature | Maximum Fast Fluence $10^{25}$ n/m$^2$ (E>0.18 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| [300 to 900°C] ([572 to 1652°F]) | 4.5 |
| [700 to 1300]°C ([1652 to 2372]°F) | 4.5 to 1.0 |
| [1300 to 1400°C] ([2372 to 2552]°F) | 1.0 |
| Core Support Elements | |
| 120 to [100]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 1.5 |

Off-Nominal (Conduction Cooldown)

| Element/Maximum Temperature* (at DCC) | |
|---|---|
| Fuel, Reflector Elements | [1630]°C ([2966]°F) |
| Core Support Elements | [1000]°C ([1832]°F) |
| Permanent Side Reflector Elements | [1220]°C ([2228]°F) |

*Temperatures could be higher by 100°C.

[DDN C.11.03.14]

## 2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Use the data base available at the time of the design analysis.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to meet the plant availability goal and component safety and reliability requirements through detailed probabilistic methods. This requires an adequate statistical data base.

Alternative 2.1 was rejected because the existing data base is inadequate for a probabilistic design approach. It would result in unnecessarily low and conservative stress limits.

## 4. SCHEDULE REQUIREMENTS

Final data are needed two years before the end of final design.

## 5. PRIORITY

Urgency: 1
Cost benefit: M
Uncertainty of existing data: M
Importance of new data: M

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without a statistical test data base, design alternative 2.1 would be used. The consequences may be a degradation in performance and a corresponding increase in core size (component stress can be decreased by decreasing power density, thus requiring a larger core). This would result in higher cost and schedule delays.

D. Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# GRAPHITE IRRADIATION-INDUCED CREEP DATA
# DDN C.11.03.15

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Probabilistic design criteria are used to meet the plant availability goal and safety and reliability requirements. Knowledge of the statistical variability of the irradiation creep properties of the replaceable core and core support graphite is needed for the development of these criteria.

### 1.1 Summary of Function and Assumptions

Maintain Graphite Component Structural Integrity," Assumption: A statistically adequate data base will be established for H-451 graphite.

### 1.2 Current Data Base Summary

Two compressive creep capsules without continuous strain registration operating at 600°C (1112°F) and three compressive creep capsules operating at 900°C (1652°F) have been completed at ORNL. Each capsule contained eight creep specimens of H-451 graphite stressed to 13.7 MPa (2000 psi) or 20.6 MPa (3000 psi) in compression. Two specimens of H-451 graphite were irradiated in tensile creep assemblies with continuous strain registration at Petten. The temperature was 820°C (1508°F) to 850°C (1562°F) and the stress was 5.5 MPa (870 psi). The ORNL experiments included measurements for the effect of creep strain on Young's modulus, Poisson's ratio, and thermal expansivity.

### 1.3 Data Needed

The following data are needed, under the conditions in Section 1.4, for H-451 graphite as function of fluence and temperature:

a. Steady state creep strain in tension and compression for up to 1% creep strain.

b. Transient (primary) creep strain.

c. Transverse-to-longitudinal strain ratios.

d. Creep under cyclic conditions covering a range of temperatures.

e. Creep with stress reversal from compression to tension.

The data base must be sufficient to establish the mean values and standard deviations of the creep properties to a reasonably attainable accuracy with [95%] confidence.

In addition to the statistical data base, data are also needed to establish the effect of creep on tensile strength, Young's modulus, thermal expansivity and thermal conductivity. Furthermore, data are needed to validate that the creep strain is not significantly affected by the flux level. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

*Temperaturs could be higher by 100°C.

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1400]°C ([2552]°F)/24 h for each event |

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1630]°C ([2966]°F)/30 h |

High Moisture Ingress - [TBD] events over reactor life

Helium at [TBD]

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [TBD] |

*Temperatures could be higher by 100°C.

b. Temperature*/Neutron Fluence

Nominal

| Element/Temperature* | Maximum Fast Fluence $10^{25}$ n/m$^2$ (E>0.1 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| 300 to [900]°C (572 to [1652]°F) | 4.5 |
| [700 to 1300]°C ([1652 to 2372]°F) | 4.5 to 1.0** |
| [1300 to 1400]°C ([2372 to 2552]°F) | 1.0 |
| Core Support Elements | |
| 120 to [1000]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 1.5 |

Off-Nominal (Conduction Cooldown)

| Element/Maximum Temperature* (at DCC) | |
|---|---|
| Fuel, Reflector Elements | [1630]°C ([2966]°F) |
| Core Support Elements | [1000]°C ([1832]°F) |
| Permanent Side Reflector Elements | [1220]°C ([2228]°F) |

## 2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Use the data base available at the time of the design analysis.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to meet the plant availability goal and component safety and reliability requirements through detailed probabilistic methods. This requires an adequate statistical data base.

Alternative 2.1 was rejected because the existing data base is inadequate for a probabilistic design approach.

*Temperatures could be higher by 100°C.

**Linear variation between end points.

[DDN C.11.03.15]

4. SCHEDULE REQUIREMENTS

Final data are needed two years before the end of final design.

5. PRIORITY

Urgency: 1
Cost benefit: M
Uncertainty of existing data: H
Importance of new data: H

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without a statistical test data base, design alternative 2.1 would be used. The consequences may be a reduced power density and a corresponding increase in core size (component stresses can be decreased by decreasing power densities, thus requiring a larger core) resulting in higher capital costs and schedule delays.

Tu Ho 7/25/94
Originator Date

R.E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# GRAPHITE THERMAL PROPERTIES DATA
# DDN C.11.03.16

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Thermal properties are needed to complete the thermal-hydraulic design of the core and to calculate the graphite temperatures and thermal stresses in permanent and replaceable graphite components. Knowledge of the statistical variability of these properties is needed to develop proba-bilistically based stress criteria for showing compliance with the plant availability goal and the component safety and reliability requirements.

### 1.1 Summary of Function and Assumptions

"Transfer Heat from Fuel to Heat Transfer Surface," "Maintain Core Coolant Passage Geometry," "Transfer Heat Through Core and Reflector," "Maintain Integrity of Graphite Components," Assumption: An adequate thermal property data base for candidate grades of permanent side reflector (HLM and H-451), core support (H-451), and core graphite (H-451) will be established.

### 1.2 Current Data Base Summary

Axial and radial thermal expansion measurements have been made on specimens from one billet of production HLM graphite. The specimens came from six locations in the billet. Measurements were made between room temperature and 500°C (932°F) and room temperature and 900°C (1652°F).

Thermal conductivity measurements in axial and radial directions have been made on specimens from one billet of production HLM graphite. Measurements were made between room temperature and 800°C (1472°F). Specimens were taken from one location in the billet.

Axial and radial thermal expansion measurements have been made on specimens from ten billets of production H-451 graphite. In most cases, specimens have been from four locations in the billet. Measurements were made between room temperature and 500°C (932°F).

Thermal diffusivity measurements in the axial and radial direction have been made on seven billets of production H-451 graphite between room temperature and 800°C (1472°F). Specimens were taken from one or two locations in the billet.

Data exists on the effects of irradiation on thermal diffusivity and thermal expansivity of H-451 graphite specimens irradiated in the Oak Ridge Reactor at 550°C (1022°F) through 1300°C (2372°F) to fluences between $1 \times 10^{25}$ n/m$^2$ and $1 \times 10^{26}$ n/m$^2$. Specimens were taken from five billets selected from three different production lots. Additional thermal expansivity data on H-451 graphite and some data on early subsize prototype H-451I graphite irradiated at 600°C (1112°F) and 900°C (1652°F)to fluences up to $4 \times 10^{26}$ n/m$^2$ are available from HFIR capsule irradiations.

1.3 Data Needed

Thermal expansivity, conductivity, emissivity, and specific heat are needed under the conditions in 1.4 for graphite H-451 and HLM, including:

a. Dependence on orientation and location in billet.

b. Variation from billet to billet and from lot to lot.

c. Temperature dependence.

d. Dependence on neutron fluence and irradiation temperature.

e. Effects of oxidation.

f. Effects of thermal annealing on thermal properties (during transients on irradiated H-451 only).

The data base must be sufficient to establish the mean values and standard deviations of the required thermal properties to a reasonably attainable accuracy with [95]% confidence.

Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

[DDN C.11.03.16]

| Maximum Concentration | Maximum Graphite Temperature*/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1025 psia)

Impurities affecting oxidation

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [1400]°C ([2552]°F)/24 h for each event |
| [TBD] ppmv $H_2$ | |

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [1630]°C ([2966]°F)/30 h |
| [TBD] ppmv $H_2$ | |

High Moisture Ingress - [TBD] events over reactor life

Helium at [TBD]

*Temperatures could be higher by 100°C.

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] | [TBD] |

b. Temperature/Neutron Fluence

Nominal

| Element/Temperature* | Maximum Fast Fluence $10^{25}$ n/m$^2$ (E>0.18 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| 300 to [900]°C (572 to [1652]°F) | 4.5 |
| [900 to 1300]°C ([1652 to 2372]°F) | 4.5 to 1.0** |
| [1300 to 1400]°C ([2372 to 2552]°F) | 1.0 |
| Core Support Elements | |
| 120 to [1000]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 1.5 |

Off-Nominal (Conduction Cooldown)

| Element/Maximum Temperature* (at DCC) | |
|---|---|
| Fuel, Reflector Elements | [1630]°C ([2966]°F) |
| Core Support Elements | [1000]°C ([1832]°F) |
| Permanent Side Reflector Elements | [1220]°C ([2228]°F) |

2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Use the existing data base, and add design margin to account for the uncertainties.

*Temperatures can be higher by 100°C.

**Linear variation between end points.

[DDN C.11.03.16]

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to complete the thermal properties data base for use in design and in probabilistic stress criteria development. Alternative 2.1 was rejected because the existing data base is inadequate for a probabilistic design approach.

4. SCHEDULE REQUIREMENTS

Final data are needed two years before the end of final design.

5. PRIORITY

Urgency: 1
Cost benefit: M
Uncertainty of existing data: M
Importance of new data: H

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without a statistical test data base, design alternative 2.1 would be used. The consequences may be a larger structural size, a reduced power density, and a corresponding increase in core size (component stresses can be decreased by decreasing power densities, thus requiring a larger core) resulting in higher costs and schedule delays.

Th Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
GRAPHITE FRACTURE MECHANICS DATA
DDN C.11.03.17

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

To meet the plant availability goal and the safety and reliability requirements of the replaceable graphite core components, it is necessary to calculate the probability of functional damage. Functional damage has been defined as a crack extending all the way across a fuel or reflector element or at least a significant distance into the element. So far, only vertical cracks have been addressed using existing continuum mechanics methods. Fracture mechanics methods are needed to address horizontal cracks and also to validate the continuum mechanics methods.

### 1.1 Summary of Function and Assumptions

"Maintain Graphite Component Structural Integrity," Assumption 1: The progression of vertical cracks (due to radial stresses) can be analyzed with continuum mechanics methods.

Assumption 2: Horizontal cracks which need fracture mechanics methods are less probable than vertical cracks due to (1) lower stresses in the axial direction, and (2) only vertical cracks have been observed in FSV fuel elements.

### 1.2 Current Data Base Summary

Some static $K_{IC}$ measurements have been made on production H-451 graphite using the chevron-notched short-rod specimen geometry. A few measurements have also been made on specimens from early subsize prototype H-451I billets. Changes in the static $K_{IC}$ have been measured on H-451 graphite specimens irradiated at 600°C (1112°F) and 900°C (1652°F) to fluences of $1.6 \times 10^{26}$ n/m$^2$ in HFIR.

### 1.3 Data Needed

A data base is needed to define the critical stress intensity factors ($K_{IC}$) and strain energy release rates ($G_{IC}$) for crack initiation, stable crack growth, and crack arrest for graphite H-451 at room temperature in air, including:

a. Dependence on orientation and location in billet.

b. Variation from billet to billet and from lot to lot.

The data base must be sufficient to establish the mean values of the above fracture mechanics properties to a reasonably attainable accuracy with [95]% confidence.

Additional data are also needed to establish the effects of the operating environment on the fracture mechanics properties (see Section 1.4). The environmental conditions whose effects need to be established are:

a. The effects of irradiation.

b. The effects of temperature within the service temperature range.

c. The effects of oxidation.

Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [1400°C (2552°F)/24 h] |
| [TBD] ppmv $H_2$ | |

*Temperatures could be higher by 100°C.

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1630°C (2966°F)/30 h] |

High Moisture Ingress - [TBD] events over reactor life

Helium at [TBD]

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] | [TBD] |

b. Temperature*/Neutron Fluence

Nominal

| Element/Temperature* | Maximum Fast Fluence $10^{21}$ n/cm$^2$ (E>0.1 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| 300 to [900]°C (572 to [1652]°F) | 4.5 |
| [900 to 1300]°C ([1652 to 2372°F]) | 4.5 to 1.0** |
| [1300 to 1400]° )[2372 to 2552]°F) | 1.0 |
| Core Support Elements | |
| 120 to [1000]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 1.5 |

Off-Nominal (Conduction Cooldown)

| Element/Maximum Temperature* (at DCC) | |
|---|---|
| Fuel, Reflector Elements | [1630°C (2966°F)] |
| Core Support Elements | [1000°C (1832°F)] |
| Permanent Side Reflector Elements | [1220°C (2228°F)] |

*Temperatures could be higher by 100°C.

**Linear variation between end points.

[DDN C.11.03.17]

## 2. DESIGNER'S ALTERNATIVES

The following alternative is available:

2.1 Use the existing finite element codes to examine crack initiation and progression based upon the maximum principal stress failure theory for vertical cracks and also for crack initiation for horizontal cracks.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to develop a fracture mechanics data base and methods and use these to study crack propagation as part of the analysis for showing compliance with plant availability goal and component safety and reliability requirements. Alternative 2.1 was rejected because it is theoretically unsound and thus would have been difficult to defend.

## 4. SCHEDULE REQUIREMENTS

Preliminary data are needed one year before the end of preliminary design, and final data two years before the end of final design.

## 5. PRIORITY

Urgency: 1
Cost benefit: M
Uncertainty of existing data: M
Importance of new data: M

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without a fracture mechanics test data base, design alternative 2.1 would be used. The consequences may be a reduced power density and a corresponding increase in core size (component stresses can be decreased by decreasing power densities, thus requiring a larger core to maintain the plant availability goals), resulting in higher costs and schedule delays.

Ta Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# GRAPHITE CORROSION DATA
# DDN C.11.03.18

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The graphite core and core support components may be corroded by coolant impurities, principally $H_2O$, with consequent deterioration of their integrity.

Associated data needs are in DDN C.11.03.19.

### 1.1 Summary of Function and Assumptions

"Maintain Graphite Core and Core Support Element Structural Integrity, and Geometry," "Maintain Controllable Geometry," Assumption: The correlations for H-451 graphite corrosion rate and profile are conservative within a factor of [2] at 95% confidence.

### 1.2 Current Data Base Summary

The corrosion of core and core support component graphite (H-451) by coolant impurities may be mass-transfer limited, chemical-reaction limited, or a combination of both; consequently, both processes must be characterized. The transport of coolant impurities is a combination of pore diffusion and permeation flow due to pressure gradients; the transport rates increase with increasing graphite burnoff. The former process is characterized by an effective diffusion coefficient; the reference correlation was obtained for $H_2O$ transport in H-451 graphite with 1% burnoff. The permeability and tortuosity of H-451 have not been well characterized.

The reference correlations for the kinetics of H-451 corrosion by coolant impurities are based primarily upon laboratory measurements on small unirradiated specimens in helium with high impurity levels at or near atmospheric pressure. Some data were obtained at elevated pressures (about 20 atmospheres) in the High Pressure Test Loop. Since the measurements were all made on unirradiated graphite, the effects of radiolysis and catalysis by fission metals on the graphite corrosion rate were not systematically investigated. The reaction of $H_2O$ with H-451 exhibits Langmuir-Hinshelwood type kinetics with significant product inhibition by $H_2$ but not by CO. The reference correlation for oxidation of H-451 by air was derived from lab measurements on H-327 graphite.

More recent data were obtained in capsule HFR-B1 of the high flux reactor at Petten under irradiation and temperature conditions close to those expected during normal operation of the GT-MHR. Test pressure was about 3.6 atmospheres. Although obtaining data for graphite corrosion was not a primary goal of the Petten experiment, the estimated loss in graphite mass showed reasonable agreement with approximate hand calculations.

## 1.3 Data Needed

Correlations describing the corrosion of H-451 graphite by coolant impurities during normal operation and $H_2O$ ingress events are needed under the conditions in Section 1.4. Data are needed to characterize both the transport of coolant impurities and graphite corrosion products in H-451 graphite and the intrinsic kinetics for the reaction of water with H-451 graphite. To characterize the transport of coolant impurities in graphite, the porosity, tortuosity, and permeability of the graphite must be determined. To characterize the reaction kinetics, the reaction rate must be determined as a function of temperature, impurity concentrations, system pressure, and time. In addition, the effects of radiolysis and catalysis by graphite impurities and by fission metals on the reaction kinetics must be determined. Finally, the effects of partial graphite burnoff on both the mass transfer processes and the intrinsic reaction kinetics must be quantified.

Sufficient data are needed to predict the burnoff rate and profile within a factor of [2] with [95]% confidence. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

## 1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

*Temperatures could be higher by 100°C.

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1400°C (2552°F)/24 h] |

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1630°C (2966°F)/30 h] |

High Moisture Ingress with Steam Generator Dump

Helium at [TBD]

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] | [TBD] |

b. Temperature*/Neutron Fluence

Nominal

| Element/Temperature* | Maximum Fast Fluence $10^{25}$ n/m$^2$ (E>0.18 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| 300 to [900]°C (572 to [1652]°F) | 4.5 |
| [900 to 1300]°C ([1652 to 2372]°F) | 4.5 to 1.0** |
| [1300 to 1400]°C ([2372 to 2552]°F) | 1.0 |

*Temperatures could be higher by 100°C.

**Linear variation between end points.

| | |
|---|---|
| Core Support Elements | |
| 120 to [1000]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 1.5 |

Off-Nominal (Conduction Cooldown)

Element/Maximum Temperature* (at DCC)

| | |
|---|---|
| Fuel, Reflector Elements | [1630]°C ([2966]°F) |
| Core Support Elements | [1000]°C ([1832]°F) |
| Permanent Side Reflector Elements | [1220]°C ([2228]°F) |

## 2. DESIGNER'S ALTERNATIVES

The following alternatives are available:

2.1 Use the current data base and add more margin to account for the uncertainties.

2.2 Impose tighter technical specification limits on primary coolant oxidant levels.

2.3 Use a higher purity, more corrosion-resistant graphite.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to determine the corrosion characteristics of H-451 graphite under normal operating and $H_2O$ ingress conditions. Design alternative 2.1 is rejected because the uncertainties in the current data base would necessitate unacceptably large design margins. Design alternative 2.2 is rejected because imposition of tighter technical specification limits on coolant impurities is expected to adversely impact plant availability. Design alternative 2.3 is rejected because development and qualification of a higher purity graphite would add significant development costs. (H-451 is already a graphite with high oxidation resistance.)

## 4. SCHEDULE REQUIREMENTS

Final data are needed two years before the end of final design.

## 5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty of existing data: M
Importance of new data: M

[DDN C.11.03.18]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without the required test data, a combination of alterna-tives 2.1 and 2.2 could be used, with the necessity of added margins in the design to compensate for uncertainties in the extent of core component corrosion. The consequence would be unnecessarily restrictive technical specification limits on primary coolant impurity levels which could have an adverse impact on plant availability.

| | |
|---|---|
| Ta Ho | 7/25/94 |
| Originator | Date |
| R. E. Vollman | 7-26-94 |
| Task Manager | Date |
| | |
| Program Manager | Date |

DATE: 6/30/94

# GT-MHR PROGRAM
# GRAPHITE CORROSION DATA FOR METHODS VALIDATION
# DDN C.11.03.19

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The design methods and codes used to predict the extent of corrosion of graphite components by coolant impurities must be validated to have the specified predictive accuracies for normal operating conditions and for moisture ingress events.

Associated data needs are in DDN C.11.03.18

### 1.1 Summary of Function and Assumptions

"Maintain Graphite Component Structural Integrity," Assumption: The existing design methods and computer codes for calculating graphite corrosion are accurate within a factor of [3] at 95% confidence.

### 1.2 Current Data Base Summary

Calculational methods have been developed to predict graphite corrosion in a HTGR environment. These methods include the computer codes OXIDE and HYDROBURN. The codes are based on the current data base on corrosion of various graphites developed in a laboratory environment. The validity of the models for graphite corrosion in the HTGR environment have not been thoroughly assessed although limited comparisons with surveillance data from FSV have been made with apparent good success.

### 1.3 Data Needed

Graphite-steam oxidation data for validation of the integrated models and computer codes used to predict graphite corrosion in the HTGR core under normal operation and during high moisture ingress events are needed, under the conditions in Section 1.4, in order to assure that the predictive methods are accurate to within a factor of [3] at 95% confidence. Particular attention must be given to transport of coolant impurities in fuel element graphite and to the effect of catalysis by graphite impurities and fission metals. The data base used for code validation must be independent from the data from which the individual correlations in the overall design method (effective diffusivities, reaction kinetics, etc.) were originally derived, in accordance with

software standard IEEE Standard 730-1984 and software definitions in NUREG-0856. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

The following service conditions are bounding values:

a. Primary Coolant Environment

Nominal

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration | |
|---|---|---|
| [0.1] ppmv $H_2O$ | Fuel/reflector elements | [1200°C]/12,000 h |
| [0.2] ppmv $CO_2$ | | [1100°C]/48,000 h |
| [0.8] ppmv CO | Core support elements | [1000°C]/480,000 h |
| [1.5] ppmv $H_2$ | Permanent side reflector elements | [650°C]/480,000 h |

Off-Nominal

Pressurized Conduction Cooldown (PCC) - 5 events over reactor life

Helium at 7.07 MPa (1025 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$ | [1400°C (2552°F)/24 h] |
| [TBD] ppmv $H_2$ | |

*Temperature could be higher by 100°C.

Depressurized Conduction Cooldown (DCC) - 2 events over reactor life

Helium at 0.1 MPa (14.7 psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] ppmv $H_2O$<br>[TBD] ppmv $H_2$ | [1630°C (2966°F)]/30 h |

High Moisture Ingress - [TBD] events over reactor life

Helium at [TBD] ([TBD] psia)

| Maximum Concentration | Maximum Graphite Temperature*/Duration |
|---|---|
| [TBD] | [TBD] |

b. Temperature*/Neutron Fluence

Nominal

| Element/Temperature | Maximum Fast Fluence $10^{25}$ n/m$^2$ (E>0.18 MeV) |
|---|---|
| Fuel, Reflector Elements | |
| [300 to 900]°C ([572 to 1652]°F) | 4.5 |
| [900 to 1300]°C ([1652 to 2372]°F) | 4.5 to 1.0** |
| [1300 to 1400]°C ([2372 to 2552]°F) | 1.0 |
| Core Support Elements | |
| 120 to [1000]°C (248 to [1832]°F) | 0.2 |
| Permanent Side Reflector Elements | |
| 120 to [650]°C (248 to [1202]°F) | 1.5 |

*Temperatures could be higher by 100°C.

**Linear variation between end points.

Off-Nominal (Conduction Cooldown)

Element/Maximum Temperature* (at DCC)

| | |
|---|---|
| Fuel, Reflector Elements | [1630]°C ([2966]°F) |
| Core Support Elements | [1000]°C ([1832]°F) |
| Permanent Side Reflector Elements | [1220]°C (2228]°F) |

## 2. DESIGNER'S ALTERNATIVES

The following alternatives have been considered:

2.1 Complete the design on the basis that the methods are acceptable without validation, and add sufficient design margin to account for the uncertainties.

2.2 Impose tighter technical specification limits on primary coolant oxidant levels.

2.3 Use a higher purity, more corrosion-resistant graphite.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to obtain a data base on the corrosion of graphite components and also to use the FSV graphite components and surveillance samples in support of code validation under conditions expected in a GT-MHR. Alternative 2.1 is rejected because it may require excessively large margins in the design to account for uncertainties in the design methods. Alternative 2.2 would have an adverse effect on plant availability. Alternative 2.3 would lead to large increases in graphite development costs.

## 4. SCHEDULE REQUIREMENTS

Preliminary data are needed one year before the end of preliminary design and final data two years before the end of final design.

## 5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

*Temperatures could be higher by 100°C).

[DDN C.11.03.19]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without the required data base, a combination of Alterna-tives 2.1 and 2.2 could be used, with the necessity of added conservatism in the design to compensate for calculational uncertainties. A weakened position during safety evaluation will result from this uncertainty. Another consequence of nonaccomplishment will likely be unnecessarily restrictive technical specification limits on primary coolant impurities with an attendant adverse impact on plant availability.

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|---|---|
| Tu Ho | 7/25/94 |
| Originator | Date |
| R. E. Vollman | 7-26-94 |
| Task Manager | Date |
| | |
| Program Manager | Date |

DATE: 6/30/94

GT-MHR PROGRAM
GRAPHITE DESTRUCTIVE AND NONDESTRUCTIVE EXAMINATION DATA
DDN C.11.03.20

PLANT: GT-MHR/System 11

1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Destructive and nondestructive examination (NDE) techniques are needed for product control during procurement of graphite for the core and core support components.

Associated data needs are DDN: DDN C.11.03.13.

1.1 Summary of Function and Assumptions

"Maintain Integrity of Graphite Core Components" "Maintain Graphite Core Support Component Structural Integrity," Assumption: The production graphite will have the same properties as characterized in the Graphite Design Handbook.

1.2 Current Data Base Summary

ORNL has developed NDE techniques and produced data on their accuracy and limitations for H-451 graphite grade. However, the data base is too small to sufficiently validate these techniques for use in product control of mass produced graphite.

1.3 Data Needed

A data base is needed to validate the NDE techniques which are to be developed and write acceptance test methods in material procurement specifications for the procurement of graphite for core and core support components under the conditions in Section 1.4. The NDE techniques must be sufficiently accurate to (1) detect flaws >[2 mm (0.08 in.)] in the billets, and (2) determine the tensile strength classification at a 95% confidence level. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

1.4 Data Parameters and Service Conditions

All NDE tests will be carried out at ambient conditions and room temperature in air.

[DDN C.11.03.20]

## 2. DESIGNER'S ALTERNATIVES

This alternative is available:

2.1 Control the strength of the production billet by conventional strength testing, and include additional design margin to account for lot-to-lot and log-to-log uncertainties in the production material.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to use nondestructive examination in combination with a minimum of destructive testing to ensure that the production graphite satisfies the specifications. This is the most cost effective approach since NDE is less expensive than conventional destructive testing (Alternative 2.1) and additional testing yields a higher confidence level for component material properties. Alternative 2.1 could also lead to a reduction in allowable stresses, a reduction in the quantity of nuclear grade material that would qualify for use in the reactor, and/or late design changes resulting in delay of schedule.

## 4. SCHEDULE REQUIREMENTS

The data are needed [TBD] weeks before beginning of final design.

## 5. PRIORITY

Urgency: 1
Cost benefit: H
Uncertainty of existing data: M
Importance of new data: H

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without sufficient NDE data base, alternatives 2.1 would be used which may result in higher cost of the graphite material.

Jin Ho 7/25/94
Originator Date

R. E. Volkman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# GRAPHITE COKE SOURCE QUALIFICATION DATA
# DDN C.11.03.21

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Cokes produced from new feedstocks need to be qualified for preproduction as well as production use.

### 1.1 Summary of Function and Assumptions

"Maintain Integrity of Graphite Components," Assumption: Preproduction and production of graphite with the required properties can be reproduced.

### 1.2 Current Data Base Summary

Within the last three to four years, Sigri Great Lakes Carbon (SGLC) manufactured sub-scale test billets with cokes produced from several feedstocks. Based on screening test results, SGLC has identified three candidate cokes for the production of graphite to meet the required properties of grade H-451 graphite.

### 1.3 Data Needed

Pre- and postirradiation data are needed to qualify the candidate coke(s) for later use in preproduction and production graphite (see Section 1.4). Data must cover sufficient properties to ensure that the candidate coke reproduces known H-451 graphite behavior. These data include dimensional changes, electrical resistivity, elastic and sheer modulus, Poisson's ratio, sonic attenuation, strength, and coefficient of thermal expansion. The data obtained need to be compared with FSV reload graphite and production H-451.

Quality assurance must be in accordance with the requirements for safety related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

Pre- and postirradiation nondestructive examinations and mechanical tests will be conducted in air at room temperature. Irradiation will be conducted at [600]°C ([1112]°F) and [900]°C ([1652]°F) to a fast fluence level sufficient to cause turn-around in the dimensional change.

## 2. DESIGNER'S ALTERNATIVES

2.1 Proceed to characterization of selected test billets without qualifying the coke sources.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to screen and to qualify coke sources by NDE, mechanical testing and irradiation experiments. This approach will ensure that the behavior of H-451 graphite can be reproduced. This is the most cost effective approach. Alternative 2.1 actually incurs a higher graphite development cost and is too risky to ensure a source of reference H-451 graphite for the core and core support components.

## 4. SCHEDULE REQUIREMENTS

Qualify the coke source by the end of preliminary design.

## 5. PRIORITY

Urgency: 1
Cost benefit: H
Uncertainty of existing data: H
Importance of new data: H

[DDN C.11.03.21]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Without coke source qualification data, design alterna-tive 2.1 would be used with the risk of rejection of the candidate graphites resulting in either a crash technology program or belated design change.

Ok Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# RESERVE SHUTDOWN PELLET PROCESS DEVELOPMENT DATA
# DDN C.11.03.22

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The $B_4C$ granules dispersed in the reserve shutdown control (RSC) pellets will be coated with pyrocarbon (PyC) to protect the $B_4C$ from oxidation during normal service and postulated moisture and air ingress events. The $B_2O_3$ phase which would form without the protective PyC coating is not refractory and could volatilize at temperatures as low as 300°C under moist conditions. Such a condition could lead to loss of reactivity control. Processes are needed to produce the PyC coated $B_4C$ granules and form them into the boronated graphite pellets without damage to the coating.

### 1.1 Summary of Function and Assumptions

"Control with Movable Poisons," Assumption: Processes are available to deposit a pyrocarbon coating on the $B_4C$ granules in the reserve shutdown pellets to protect them from chemical attack.

### 1.2 Current Data Base Summary

The current data base for boronated graphite oxidation consists of results from tests on uncoated $B_4C$ dispersed in graphite. Those tests confirm the preferential oxidation of $B_4C$ to form $B_2O_3$. The $B_2O_3$ layer forms around each $B_4C$ granule and then the rate of reaction slows unless the $B_2O_3$ layer is removed by vaporization. The boiling temperature for the $B_2O_3$ layer is 1250°C so vaporization near peak normal condition temperature would be rapid even in dry helium. In moist helium the $B_2O_3$ reacts with water to form boric acid ($H_3BO_3$) which is volatile at temperatures as low as 300°C.

The design correlation used in MHTGR design indicate that with a moisture level of 1000 ppm, 50 atm total pressure, and a temperature of 650°C, the rate of boron oxidation would approach 10% per day of exposure. Since the time of high moisture events could be as high as 40 days, the predicted extent of boron oxidation is very high.

In capsule R2-K13 $B_4C$ particles of about 200 $\mu$m diameter were coated with PyC and dispersed as a monolayer in graphite wafer compacts. The wafers were placed in the

capsule and irradiated to high burnup and fluence at 1000° and 1200°C. The $B_4C$ was coated first with a buffer and then a dense PyC coating to produce a BISO coating. The material performed very well with no observed coating failure or adverse dimensional change effects.

The basic material oxidation data indicate that the PyC is much less reactive than the $B_4C$ and the graphite matrix. Therefore, encapsulating the $B_4C$ in PyC is expected to provide the desired protection under normal conditions and less than the most severe accidents. However, under the most severe moisture ingress events the PyC coating may not provide adequate protection and the alternative of SiC coating may be needed.

## 1.3 Data Needed

A process is needed which is capable of depositing a coating of PyC on $B_4C$ granules under the conditions in Section 1.4. The granule size must cover a range appropriate for the RSC pellets. Granule diameter of 300 to 500 $\mu$m is anticipated. The coating thickness must be established so that it is thick enough to provide the required oxidation protection but not so thick that the required boron loading can not be obtained with current compact-making technology. Prior experience with coated $B_4C$ has been with spherical material, but for economic reasons the desired material form is fragmented as it comes from the crushing of $B_4C$ ingots.

The process coating development program must establish the allowable particle size, density, shape, coating batch size, and coating conditions producing an acceptable coating. It is anticipated that a buffer coating will not be needed so only the equivalent of the OPyC coating of the reference fuel coating (TRISO) will be deposited and characterized.

The compact development work must establish the optimum pellet fabrication process and the allowable quality control properties including dimensions, boron loading, matrix density and coating failure. The matrix composition must be also selected.

The program will produce process and product specifications for PyC coated $B_4C$ particles and RSC pellets. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety related components.

## 1.4 Data Parameters and Service Conditions

Test conditions will be elaborated in the applicable test specifications.

Coatings for $B_4C$ are needed which will provide the oxidation protection and be compatible with existing processes for manufacture of the RSC pellets:

| | |
|---|---|
| Boron loading | $\leq$40 wt % |
| $B_4C$ granule diameter | [300-500] $\mu$m |

| | |
|---|---|
| PyC coating thickness | [40] $\mu$m |
| Spherical pellet diameter | [10] mm |
| Pellet density | [<1.5] Mg/m$^3$ |

2. DESIGNER'S ALTERNATIVES

The following alternatives have been considered:

2.1 Coat the $B_4C$ granules with SiC.

2.2 Instead of coating the $B_4C$ granules with PyC or SiC, coat the entire RSC pellet with PyC to provide the needed oxidation protection.

2.3 Instead of $B_4C$, use oxidation resistant poisons such as rare earths, gadolinium, or hafnium oxides.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The use of PyC-coated $B_4C$ granules was selected because it promises a high probability of suitable protection against oxidation while still providing the favorable neutronic properties of boron. The use of a PyC coating eliminates the need for extensive process development since existing coating technology can be used. The thermal stability and irradiation performance of $B_4C$ in graphite has already been established, and the use of coated $B_4C$ would not alter physical properties significantly. Therefore, much of the existing data could be used to qualify the material for use in a reactor core.

Alternatives 2.1, 2.2, 2.3 were not chosen as the reference design because they represented higher costs for fabrication and qualification for use in the MHTGR.

4. SCHEDULE REQUIREMENTS

The process must be demonstrated before completion of Preliminary Design.

5. PRIORITY

Urgency 2
Cost benefit: H
Uncertainty in existing data: M
Importance of new data: H

[DDN C.11.03.22]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position would be to coat the $B_4C$ granules with SiC. The process parameters used for coating fuel with SiC would be modified to coat the $B_4C$ so the coating development effort would not be large. However, the coating time for SiC is about 10x longer than for PyC so the manufacturing cost will be higher for SiC.

| | |
|---|---|
| Originator | 7/27/94<br>Date |
| Task Manager | 7/28/94<br>Date |
| Program Manager | Date |

DATE: 6/30/94

# GT-MHR PROGRAM
# GRAPHITE OXIDATION DATA FOR POSTULATED ACCIDENTS
# DDN C.11.03.23

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The analysis methods and computer codes used for analyzing hypothetical accident scenarios that involve air ingress during the heat-up portion of a conduction cooldown event should be validated to the specified accuracies. Specifically, data are needed for air-graphite oxidation rates under low-frequency accident conditions that involve buoyancy-driven airflow. Oxidation effects on graphite mechanical strength are also needed.

Associated data needs: None.

### 1.1 Summary of Function and Assumptions

"Maintain Graphite Core and Core Support Structural Integrity and Geometry," "Maintain Controllable Geometry."

### 1.2 Current Data Base Summary

In several previous experiments, high airflow rates, electrical heaters, and preheated air were used, which precluded convective heat removal and supplied oxygen to the entire channel length. As expected, rapid temperature increases and oxidation rates were eventually obtained in these experiments. However, these conditions should not exist during GT-MHR conduction cooldown scenarios and the transient behavior is expected to be substantially less severe. Key parameters that affect temperatures and oxidation rates include the type of graphite, initial graphite temperature, inlet air temperature, air flow rate and oxygen content, channel length to diameter ratio, and the ratio of coolant surface area to graphite volume. For the GT-MHR, the graphite temperatures will be significantly higher than the values used in previous experiments. At sufficiently high temperatures, the effective reaction rate will be limited by the mass-transfer rate of oxygen from the gas flow to the graphite and will be only weakly dependent on temperature. Previous predictions indicate that the gas flow is buoyancy-driven and the mass-flow rates are relatively low. Essentially all of the oxygen is depleted from the gas flow well before exiting the core, and nearly all of the oxidation occurs in the lower reflector, lower portions of the active core, and core support structure. The predicted oxidation rates are relatively low and nearly constant with time. The predicted temperatures do not rapidly escalate with time and the

predicted behavior is not indicative of "runaway" oxidation. This behavior needs to be confirmed for GT-MHR accident conditions.

Oxygen diffusion rates through porous graphite as a function of graphite burnoff is not available for H-451 graphite.

A data base for intrinsic air graphite oxidation reaction rates is available for several other nuclear grade graphites, but not for H-451 graphite.

## 1.3 Data Needed

Analyses of air ingress during GT-MHR accident conditions should include the feedback of chemical heat-generation rates on temperatures with sufficient spatial resolution to determine local effects. Also, the effects of potential carbon monoxide combustion and the resulting high gas temperatures should be assessed. To estimate fuel failure and fission-product release, local temperatures and local oxidation rates must be predicted to within the required accuracy of 3 x at 95% confidence.

Data is needed for air-graphite intrinsic reaction rates for accident conditions. Data is needed for oxygen diffusion rates in graphite.

Data is needed for air-graphite reaction effects on graphite mechanical strength properties as a function of burnoff.

Data for gas temperatures and composition are needed to confirm graphite mass-loss rates, CO combustion models, and to assess the potential for flammable gas buildup. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

## 1.4 Data Parameters and Service Conditions

The services conditions are given below:

Maximum fast fluence (E> 29 fJ HTGR): $4.5 \times 10^{25}$ n/m$^2$
Maximum gamma flux: [TBD] MeV/m$^2$-s
Inlet gas mixture: normal air to depleted air
System pressure: 1 atm
Relative humidity: 10 - 90%
Inlet gas temperature: 30 - 300°C (86 - 572°F)
Graphite temperature: 500 - 1600°C (932 - 2552°F)
Reynolds No.: 5 - 100
External heating: nuclear decay heat

[DDN C.11.03.23]

## 2. DESIGNER'S ALTERNATIVES

The following alternatives have been considered:

2.1 Complete the analysis on the basis that the available data are acceptable.

2.2 Eliminate the need for additional data by including sufficient margin for uncertainties in the analysis.

2.3 Modify the design to further reduce the already extremely low possibility of air ingress during accidents due to multiple vessel failure.

## 3. SELECTED APPROACH AND EXPLANATION

The selected approach is to obtain additional data base on graphite oxidation under conditions expected during GT-MHR accidents. Alternative 2.1 and 2.2 may involve the risk of rejection during the safety-review process. Alternative 2.3 may result in increased capital costs.

## 4. SCHEDULE REQUIREMENTS

Preliminary data by the end of preliminary design. Final data 1 year after the start of final design.

## 5. PRIORITY

Urgency: 1
Cost benefit: H
Uncertainty of existing data: H
Importance of new data: H

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

A combination of alternatives 2.1 and 2.2, with the necessity of added conservatism in the design to compensate for uncertainties in the models. A weakened safety position may result from these uncertainties.

Kyle Cadwallader 7/25/94
Originator Date

T.D. Quinn 7/26/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# PROPERTIES OF HIGH TEMPERATURE CONTROL ROD MATERIALs
# DDN C.11.03.24

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

C/C composite is a candidate material for high-temperature control rods. The existing property database for this type of material is insufficient to cover all GT-MHR design conditions. This is especially the case for depressurized conduction cooldown events, when control rod design temperatures reach approximately 1381°C (2518°F).

### 1.1 Summary of Function and Assumptions

"Maintain Structural Integrity of Control Rod," Assumption: The C/C composite material will have the same, or better, high-temperature properties as have been extrapolated from the limited existing database.

### 1.2 Current Data Base Summary

The properties of C/C composites depend on fiber type and fiber architecture, type of matrix material, and processing conditions. Property data are currently available from the fusion energy reactor program on the behavior of a number of C/C composites irradiated at temperatures of 600°C to a maximum fast fluence ($E > 0.18$ MeV) of $5.5 \times 10^{25}$ n/m$^2$. Studies on corrosion of C/C composites under a full range of projected helium impurity environments in GT-MHR have not been conducted.

### 1.3 Data Needed

An expanded database is needed for C/C composites under nominal and off-nominal (pressurized and depressurized conduction cooldown) reactor operating conditions. The material properties sought are:

a. Thermal properties, including expansivity, conductivity, and specific heat.

b. Elastic moduli and stress-strain relationship.

c. Strengths, including tensile, compressive, flexural, and low cycle fatigue strengths.

d. Friction and wear characteristics.

e. Environmental effects:

- Irradiation effects on all of the above properties.
- Irradiation-induced dimensional change and creep.
- Effects of gas impurities, temperature, and pressure.

f. Fabricating characteristics, including machinability, weldability, joining, and hot-working temperature.

All thermal and mechanical properties of C/C composites must be effective values for representative component sections. The database must be valid for the product forms to be used for the control rod component.

The database must be sufficiently large to establish mean values and variability of properties to a reasonably attainable accuracy and the required confidence level [95%].*

In addition, NDE capabilities need to be developed for production quality control assessment.

Confirmatory data are also needed on the performance of control rod subassemblies under reactor operating and accident temperatures and pressures.

Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters/Service Conditions

Key service conditions and design basis events are summarized below; test requirements elaborated on in the test specification as appropriate:

a. Primary Coolant Helium Environment at 7.07 MPa abs (1025 psia)

Ranges of impurity concentrations (ppmv):**

| | Nominal | Off-Nominal |
|---|---|---|
| $H_2O$ | [0.01-0.1] | [TBD] |
| $CO_2$ | [0.03-0.2] | [TBD] |
| CO | [0.2-0.8] | [TBD] |
| $CH_4$ | [0.05-0.2] | [TBD] |

*Numbers given in brackets are tentative and subject to change.

**The range includes the maximum estimated time-averaged impurity concentration.

| | | |
|---|---|---|
| $H_2$ | [0.5-1.5] | [TBD] |
| Total oxidants < 1 ppmv | | |

b. Temperature and Neutron Fluence Environment

Nominal

| | |
|---|---|
| Maximum temperature, °C | [900] |
| Maximum fast fluences, $10^{25}$ n/m$^2$ (E > 0.18 MeV) | [8.4] |
| Maximum duration, h | [105, 120] |

Off-Nominal

Fast fluence

Negligible fast fluence is accumulated in an off-normal event. An off-nominal event can occur at any prior fast fluence up to the maximum value of [8.4] x $10^{25}$ n/m$^2$.

Pressurized Conduction Cooldown (PCC):

| | |
|---|---|
| Maximum temperature, °C | [1100] |
| No. of events over 60-year life, (Category 1 to 3 transients) | [6] |

Depressurized Conduction Cooldown (DCC):

| | |
|---|---|
| Maximum temperature, °C | [1281] |
| No. of events over 60-year life, (Category 3 transients) | [2] |

c. Load Cycles

| | |
|---|---|
| Plant cycles | [TBD] |
| Seismic inputs | [TBD] |

2. DESIGNER'S ALTERNATIVES

The alternatives are:

2.1 Use the existing control rod design, let the outer rods creep excessively or even break during the DCC event, retrieve the new rods, as needed. Note that broken control rods do not present a safety hazard,l since the neutron absorbing boronated graphite compacts remain in their proper position in the core during the conduction cooldown.

2.2 Redesign the GT-MHR to lower the peak outer control rod design temperature during the DCC event. This would most likely require lowering the power of the 102-column core below its current 600 MW(t) design value.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The proposed control rod design would use high-temperature materials capable of withstanding the DCC temperature conditions, and remain removable by normal means. Alternative 2.1 incurs excessive investment risk and significant downtime. Alternative 2.2 would not be possible without significantly increasing the cost per kWh of the energy produced.

4. SCHEDULE REQUIREMENTS

Interim data are needed for preliminary design as soon as they become available, but no later than one year before the end of preliminary design. Final data are needed no later than one year before the end of final design.

5. PRIORITY

Urgency: [TBD]
Cost benefit: H
Uncertainty of existing data: H
Importance of new data: H

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is to rely on alternative 2.1. However, without an expanded database, confidence in the structural integrity of the high temperature control rod would be reduced. The consequences to the program would be higher investment risk from greater reactor downtime to remove and replace failed control rods after a DCC event.

Th Ho 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# VERIFICATION OF NEUTRON DETECTORS AND CABLING
# DDN C.11.03.31

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The source range neutron monitoring requires the use of in-core neutron monitoring sensors (detectors). The purpose of this DDN is to confirm operability of a neutron detector and associated cabling in an GT-MHR environment.

### 1.1 Summary of Function and Assumptions

"Monitor Source Range Neutrons," Assumption: Neutron detection can be made in-core in an MHTGR environment for source range power levels.

### 1.2 Current Data Base Summary

The current data base for low level in-core neutron detectors (and cabling) capable of use in MHTGR source range neutron detection dates back to prior efforts on the LHTGR. Other more current data on high temperature, high pressure neutron detectors is available from neutron detector manufacturers for LWR and AGR applications.

### 1.3 Data Needed

Data on the source range neutron detector and cabling confirming operability, neutron sensitivity and detector/cable life at in-reactor GT-MHR conditions (see Section 1.4).

Quality Assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

### 1.4 Data Parameters and Service Conditions

Data Parameters: Neutron sensitivity signal to noise ratio, cable insulation resistance, response time, detector burnup.

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Service Conditions:

| | |
|---|---|
| Pressure | [0.7 MPa (100 psia)] (installation in re-entrant well) |
| Temperature | |
| at Detector | [700°C (1292°F)] at 100% power |
| | [815°C (1500°F)] peak |
| at Cable Splice | [TBD°F] |
| Gamma Field | [$10^7$] R/h |
| Neutron Field | From [4 x $10^4$] nv at source range |
| | to [2 x $10^{13}$] nv at 100% power |
| Atmosphere | Air |

2. DESIGNER'S ALTERNATIVES

Select and install neutron detectors (and cabling) without benefit of verification of operability at MHTGR conditions.

3. SELECTED DESIGN APPROACH AND EXPLANATION

A verification program is recommended to confirm operability at GT-MHR conditions because neutron detection for use in reactor source range neutron detection is an important measurement and in-core neutron measurements are difficult.

4. SCHEDULE REQUIREMENTS

The data will be needed by month [TBD], six months prior to end of final design.

5. PRIORITY

Urgency: 3
Cost benefit: H
Uncertainty in existing data: H
Importance of new data: H

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6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is to use in-core neutron detection without the benefit of verification of operability at GT-MHR conditions. Failure of adequate verification could cause startup delays, adversely impact plant availability (by requiring frequent replacement or longer restart times) and might require changes in installed equipment.

7/28/94

Originator Date

7/28/94

Task Manager Date

Program Manager Date

Date: 6/30/94

# GT-MHR PROGRAM
# FUEL ELEMENT CHANNEL FLOW DATA
# DDN C.11.03.41

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Thermal/hydraulic input parameters for computer codes are needed to calculate coolant channel pressure drop and heat transfer to meet the requirements for core exit hot and cold streaks, fuel and control rod temperatures, and fuel element stresses.

### 1.1 Summary of Function and Assumptions

"Transfer Heat from Fuel to Heat Transfer Surface," Assumption: Coolant channel friction factor correlation is valid.

### 1.2 Current Data Base Summary

Friction factor correlations currently used are based on tests performed at Commissariat A L'Energie Atomique (CEA) and at GA. These tests were performed on a different grade of graphite and a larger coolant channel. In addition, no tests were performed in the transition flow regime.

### 1.3 Data Needed

Friction factor data need to be obtained for representative drilled graphite coolant channels under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

### 1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Reynolds Number Range

500-100,000

The test may be conducted in any suitable gas, including air at ambient conditions.

[DDN C.11.03.41]

## 2. DESIGNER'S ALTERNATIVES

2.1 Continue to rely on the current data base.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to determine the friction factors by testing. Better knowledge of the coolant channel friction factor will reduce the uncertainty in the core pressure drop and distribution of flow between the coolant channels and control rod channels. Better data in the transitional flow regime will improve predictions of laminar flow instabilities which can result in fuel damage at low power operation. With this information the flow requirements at low power can be minimized.

## 4. SCHEDULE REQUIREMENTS

Data are required by the end of preliminary design.

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: L

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Rely on current data base and, use larger than necessary performance margins. Consequences are higher fuel tem-eratures and graphite stresses, and higher flow requirements during refueling, shutdown, and startup operation.

Richard J. Gerrard 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
CONTROL ROD CHANNEL FLOW DATA
DDN C.11.03.42

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Thermal/hydraulic input parameters for computer codes are needed to calculate coolant channel pressure drop and heat transfer to meet the requirements for core exit hot and cold streaks, fuel and control rod temperatures, and fuel stresses.

### 1.1 Summary of Function and Assumptions

"Control Flow in Control Rod Channel," "Maintain Fuel Element Structural Integrity," Assumption: Control rod channel entrance and exit pressure loss coefficients are valid.

"Maintain Integrity of Control Rods," Assumption: Control rod channel geometry provides >[2]% of the circulator flow rate in these channels.

### 1.2 Current Data Base Summary

Loss factors at the entrance and exit of the channels are available from tests performed at Commissariat a l'Energie Atomique (CEA) and at GA, but the control rod channel design (in particular through the lower reflector/core support) and the control rod channel flow requirements for the GT-MHR are different from the reactor designs which were modeled in these tests.

### 1.3 Data Needed

Flow loss coefficient data need to be developed for representative graphite control rod channels including the channel entrance and exit flow geometries, with and without the control rod in place under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Reynolds Number Range

1000 - 100,000, rod out
500 - 30,000, outer annulus, rod in

The test may be conducted in any suitable gas, including air at ambient conditions.

## 2. DESIGNER'S ALTERNATIVES

2.1 Continue to rely on current data base.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to determine the pressure loss coefficients by testing. These tests will ensure adequate flow, without excess flow. This will reduce the control rod channel flow requirement necessary to ensure acceptable control rod temperatures. Lowering the control rod channel flow requirement increases the fuel element coolant channel flow, thus reducing fuel temperatures. Lower control rod channel flow also reduces control block stresses and the potential for flow induced vibrations.

## 4. SCHEDULE REQUIREMENTS

Data are needed by the end of preliminary design.

## 5. PRIORITY

Urgency: 2
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

[DDN C.11.03.42]

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Rely on current data base and revert to larger than necessary performance margins. Consequences are greater potential for control rod flow-induced vibrations which must be considered in the control rod design, and increased stresses in the control rod blocks and temperatures in the fuel blocks.

Richard Hagrman 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# BOTTOM REFLECTOR/CORE SUPPORT
# PRESSURE DROP AND FLOW MIXING DATA
# DDN C.11.03.43

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Confirmation is required that the following limits are met: core pressure drop, maldistribution of coolant channel flows in the columns, the temperature of the coolant entering the hot duct, and the temperature of hot and cold streaks entering the steam generator.

### 1.1 Summary of Function and Assumptions

"Channel Primary Coolant Through Core," Assumption: Pressure loss coefficients through bottom reflector and graphite core support are valid.

"Transfer Heat from Heat Transfer Surface to Primary Coolant," Assumption: Flow geometries in the metallic elements/top reflector, lower reflector/core support, and core upper and lower plenums do not significantly affect the core coolant channel flow distribution.

"Channel Primary Coolant Through Core," Assumption: Coolant temperature attenuation coefficients in the bottom reflector and core support are valid.

### 1.2 Current Data Base Summary

No data for the pressure drop, flow distribution, or mixing through the lower reflector and core support blocks exist. Pressure loss coefficients are currently estimated from the data available from the general literature.

### 1.3 Data Needed

Data are needed for core pressure drop, coolant channel flow distribution in columns, and the coolant temperature distribution entering the hot duct and steam generator under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation for non-safety related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Reynolds Number Range

0 - ~~75,000~~ 100,000 in coolant channels

Various representative mixing configurations. The test may be conducted in any suitable gas, including air at ambient conditions.

## 2. DESIGNER'S ALTERNATIVES

2.1 Use the loss coefficient estimates based on data in the general literature. Estimate mixing.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to determine the pressure loss coefficients, flow distribution, and hot/cold streak attenuation by testing. Relying on estimates based on available data and engineering judgment would provide little confidence in the results (Alternative 2.1). Also, testing may identify modifications to reduce pressure drop and/or improve flow distribution or hot/cold streak attenuation.

## 4. SCHEDULE REQUIREMENTS

Data are needed by the end of preliminary design.

## 5. PRIORITY

Urgency: 1
Cost benefit: M
Uncertainty in existing data: H
Importance of new data: H

[DDN C.11.03.43]

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Use estimates based on data in the general literature and engineering judgment. Consequences are a less optimized design; allow for higher core pressure drop in the circulator design, higher hot/cold streaks exiting the core and greater flow maldistribution in the fuel columns.

Richard J. Kapustka 7/25/94
Originator Date

R. E. Vollmer 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# METALLIC PLENUM ELEMENT AND TOP REFLECTOR
# PRESSURE DROP AND FLOW DISTRIBUTION
# DDN C.11.03.44

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Confirmation is required that the following limits are met: core pressure drop and maldistribution of the coolant hole flows in the columns.

### 1.1 Summary of Function and Assumptions

"Channel Primary Coolant Through Core," Assumption: Pressure loss coefficients through metallic plenum element at the top reflector are valid.

"Transfer Heat from Heat Transfer Surface to Primary Coolant," Assumption: Flow geometries in the metallic plenum element/top reflector, bottom reflector/core support, and core upper and lower plenums do not significantly affect core coolant holes flow distribution.

### 1.2 Current Data Base Summary

No data exist for the flow geometry through the UCR at the top of the core. Estimates for pressure loss coefficients have been made based on the available data in the general literature.

### 1.3 Data Needed

Data are needed to establish the column average pressure loss coefficient and coolant hole flow distribution in columns as a function of channel Reynolds number under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing for non-safety related components.

### 1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

a. Reynolds Number Range

0 - 100,000 in the coolant holes

The test may be conducted in any suitable gas, including air at ambient conditions.

[DDN C.11.03.44]

2. DESIGNER'S ALTERNATIVE

2.1 The alternative is to use the estimates based on data in the general literature.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to determine the pressure loss coefficients and flow distribution by testing. Estimates based on available data for simple flow geometries are uncertain (Alternative 2.1). Also, the test may identify modifications to reduce pressure drop and/or improve flow distribution.

4. SCHEDULE REQUIREMENTS

Data are needed by the end of preliminary design.

5. PRIORITY

Urgency: 2
Cost benefit: L
Uncertainty in existing data: M
Importance: M

6. FALLBACK POSITION AND CONSEQUENCE OF NONEXECUTION

Without test data, estimates based on data in the general literature will be used. The consequences are, a less optimized design, greater uncertainty in the core pressure drop and hot/cold streaks exiting the core, the greater flow mal-distribution in the fuel columns.

Michael Hagerman 7/25/94
Originator Date

R. E. Volkman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# CORE CROSSFLOW TEST DATA
# DDN C.11.03.45

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Data are needed to characterize the flow exchange at core elements interfaces between the coolant channels and the surrounding gaps between columns (crossflow) to meet the requirements for control rod temperatures, fuel element stresses, and fuel temperatures.

### 1.1 Summary of Function and Assumptions

"Maintain Graphite Core Element Structural Integrity,"Assumption: Crossflow does not create unacceptable core element stresses.

"Maintain Integrity of Control Rods," Assumption: Control rod channel geometry provides >[2]% of the circulator flow rate in these channels.

### 1.2 Current Data Base Summary

Crossflow tests were performed on flat faced elements (eight row block) at Commissariat a l'Energie Atomique (CEA). Useful data were obtained only for basically one gap. In addition, these tests were not performed with differences in coolant channel pressures, thus crossflow from coolant channel to coolant channel was not measured. Also control rod channel blocks were not tested, so that crossflow to control rod channels is unknown.

Tests were performed at GA on single interfaces, but for flanged fuel elements (with end seals). Flat faced elements have been chosen for the MHTGR reactor.

### 1.3 Data Needed

Data are needed for loss coefficients for standard, RSC and reflector control rod block crossflow gaps as a function of expected crossflow pressure differentials, crossflow gaps, and coolant and bypass gap Reynolds numbers under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters and Service Conditions

The service conditions are:

| | Maximum | Minimum |
|---|---|---|
| Crossflow gap width, m (in.) | [0.005 (0.2)] | [0] |
| Gap Reynolds number | [15,000] | [0] |
| Channel/gap DP, MPa (psi) | [0.01 (2.0)] | [0] |
| Coolant channel Reynolds number | [100,000] | [0] |

## 2. DESIGNER'S ALTERNATIVES

Continue to rely on the currently available data and allow for greater design margins.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to extend the present data base. Relying on current data increases the uncertainty in predicted design stresses, decreasing margin between operating stresses and allowable stresses.

## 4. SCHEDULE REQUIREMENTS

Results are required by the end of preliminary design.

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: H
Importance of new data: H

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

Allow for greater uncertainties in the fuel element stress and fuel failure limits. Consequences are difficulty in meeting the stress limits, an increase in postulated fuel failure and difficulty in meeting fission product release limits.

Richard Hagenson 7/25/94
Originator Date

R. E. Vollmer 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# CORE FLUCTUATION TEST DATA
# DDN C.11.03.46

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Validate that the 10-block high active core and associated reflectors are stable to mechanical/thermal movements which would cause fluctuations in the outlet coolant temperatures.

### 1.1 Summary of Function and Assumptions

"Control Core Bypass Flow," Assumption: Absence of temperature fluctuations in core exit gas temperatures will be validated.

### 1.2 Current Data Base Summary

Analyses and tests were performed to resolve the temperature fluctuations experienced on the Fort St. Vrain reactor. The result of these efforts were the installation of region constraint devices which eliminated the problem.

A long-range testing program was initiated in 1981 on the LHTGR cylindrical prismatic core. Fluctuation testing was performed on a 1/14-scale, three-dimensional model; a 1/7-scale, two-dimensional model; and a 1/4-scale, single column, three-dimensional model. None of these had the same core configuration as the GT-MHR. Fluctuation testing was also performed on a 1/4-scale single column, three-dimensional model representative of the GT-MHR core. The data was insufficient to determine the temperature and pressure conditions necessary to initiate fluctuations.

### 1.3 Data Needed

Data are needed to validate that the core array will be stable or not adversely affected by the expected heating, flow, and pressure drop conditions under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing for safety-related components.

1.4 Data Parameters and Service Conditions

The following values are bounding service conditions:

a. Primary Coolant

Helium

b. Temperature of Primary Coolant, °C (°F)

| | |
|---|---|
| At core inlet | 490 (914) |
| At core outlet (mixed mean) | 850 (1562) |

c. Pressure of Primary Coolant, MPa (psia)

At core inlet 7.07 (1025)

d. Core Pressure Drop, MPa (psia)

[Nominal + Design Evolution Margin] ± Tolerance
[0.052 (7.5) + 0.015 (2.2)] ± 15% = [0.067 (9.7)] ± 15%

e. Flow of Primary Coolant, kg/s (lbm/s)

| | |
|---|---|
| Flow through the core | 321 (708) |
| Gap flow | [21% max] |

f. Core Power, MW 450

2. DESIGNER'S ALTERNATIVES

2.1 Design the core and the supports to minimize temperature fluctuations and rely on the current data base and analytical predictions for validation of the absence of core fluctuations.

3. SELECTED DESIGN APPROACH AND EXPLANATION

The selected approach is to validate the final design by experimentally demonstrating that the design, with [1/4 and 1/2] scale models, has no potential for significant fluctuations. There is insufficient confidence that validation can be obtained by analytical prediction alone (Alternative 2.1).

4. SCHEDULE REQUIREMENTS

Data are required before the end of preliminary design.

[DDN C.11.03.46]

5. PRIORITY

Urgency: 1
Cost benefit: H
Uncertainty in existing data: M
Importance of new data: H

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

One major consequence of nonexecution is that, if significant fluctuations were to occur after reactor startup, potentially high thermal stresses in the graphite core elements, and hot/cold streaks could result. The fallback position would be to rely on analysis and the current data base (Alternative 2.1).

Richard J Kapuvitz 7/25/94
Originator Date

R. E. Vollman 7-26-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# INTEGRAL NUCLEAR DATA MEASUREMENTS AT ELEVATED TEMPERATURES FOR GT-MHR PHYSICS METHODS VALIDATION
# DDN C.11.03.51

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA

Core physics requirements must be satisfied during normal operational and licensing basis events. Physics data must be obtained from experiments in facilities which are similar in design to the GT-MHR. This experimental data is needed to validate computational methods which are used to calculate the safety related physics parameters.

### 1.1 Summary of Function and Assumptions

"Maintain Shutdown," Assumptions: The core physics experimental data base is adequate to ensure that the core reactivity can be calculated at nominal full power conditions with an uncertainty of $\leq \pm 1.5\% \Delta\rho$.

"Control By Inherent Feedback," Assumptions: The core physics experimental data base is adequate to ensure that the temperature defect can be calculated with an uncertainty of $\leq \pm 20\%$.

### 1.2 Current Data Base Summary

The validity of the core physics methods used to calculate temperature coefficients for the MHTGR conceptual design have been assessed previously for high enriched uranium (HEU) fuel cycles. This assessment was based on measurements on the Peach Bottom reactor critical assembly, the operation of the Peach Bottom reactor, experiments on the HTGR critical assembly, FSV operation, AVR measurements, and the HTLTR critical assembly experiments. An evaluation has also been made of the sensitivity of operational events and design basis accident results to the uncertainties in the important MHTGR physics parameters. This study showed that, at least at the conceptual design level, quite large uncertainties in these parameters can be tolerated without unacceptable effects in the transients such as excessive fuel temperatures of fission product release.

While this sensitivity study provided adequate support for the validity of the MHTGR conceptual design methods for normal, transient, and accident analyses, an improvement in the core physics data base is needed for the preliminary and final design work. This enlarged data base is required primarily because of the scarcity of experimental data for low enriched uranium (LEU) fuel ($\leq$20% U-235) in graphite

moderated reactors, and the increased importance of U-238 and plutonium in the MHTGR core. Therefore, measurements of core physics parameters in an LEU-graphite critical are planned to supplement the existing data base. Specifically, a measurement of the temperature coefficient up to a temperature of 1000°C is needed.

### 1.3 Data Needed

Core physics experimental data in a graphite/LEU spectrum are needed to supplement the current data base for validation of the physics methods to calculate the temperature coefficient under the conditions in Section 1.4. The measurements to satisfy these data needs include:

- Reactivity changes as the core is heated up from room temperature to temperatures up to 1000°C.
- Reactivity worth measurements of plutonium and U-238 samples from room temperature to temperatures up to 1000°C.

Quality assurance must be in accordance with the requirements for experimental data or validation testing which is safety-related.

### 1.4 Data Parameters and Service Conditions

The test conditions of interest are given below:

- Graphite moderated assembly
- Graphite reflectors
- Small core with high neutron leakage
- Solid graphite core assembly
- LEU fuel (<20% enriched in U-235 in the form of fuel rods of coated particles in a graphite matrix)
- Capability for heating up the core, and small samples within the core from room temperature to 1000°C

## 2. DESIGNERS' ALTERNATIVES

The alternative is the reliance on existing HEU data and computer calculated benchmarks with increased risk that computational methods which are used to calculate temperature coefficients cannot be validated.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The validation of the core physics methods will be accomplished by successful comparison of calculated and measured physics parameters. Existing data from HEU facilities will be recalculated using the computational methods and cross sections which will be used for the final design of the MHTGR. Supplemental experimental data is also needed for the LEU fueled core in a small, high neutron leakage system. This supplemental data can be obtained from experiments performed and planned at the Compact Nuclear Power Source (CNPS) at the Los Alamos National Laboratories and at the Very High Temperature Reactor Critical (VHTRC) facility in Japan. In the completed experiment of VHTRC, the whole assembly was electrically heated and the reactivity change due to the 180°C temperature rise was measured. An additional experiment is planned for a temperature rise up to 1000°C. At CNPS the reactivity worth of a 60°C temperature increase of the core was measured. VHTRC and CNPS are graphite moderated, graphite reflected, and LEU-fueled assemblies. The measurements will be compared to calculations. The comparisons of measured and calculated physics parameters will provide sufficient information to supplement the existing data base such that the validity of the core physics methods used in the GT-MHR design analyses can be ensured.

## 4. SCHEDULE REQUIREMENTS

Data are needed prior to completion of final design. Additional information may be required for the PSSAR documentation.

## 5. PRIORITY

Urgency: 1
Cost Benefit: H
Uncertainty in Existing Data: M
Importance of New Data: H

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

If this data for graphite-moderated LEU systems is not available, then the accuracy limits for the temperature coefficient will have to be relaxed to accommodate the larger uncertainties in

the calculations. Further sensitivity studies will be necessary to determine the effect on plant safety. If safety is affected, then changes in the plant design will be required.

R.A. Rucker 7-25-94

Originator Date

R.K. Lane 7-25-94

Task Manager Date

Program Manager Date

DATE: 6/30/94

GT-MHR PROGRAM
CRITICAL EXPERIMENT DATA FOR GT-MHR PHYSICS METHODS VALIDATION
DDN C.11.03.52

PLANT: GT-MHR/SYSTEM 11

1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

Core physics requirements must be satisfied during normal operation and licensing basis events. Physics data must be obtained from experiments in facilities which are similar in design to the MHTGR. This experimental data is needed to validate computational methods which are used to calculate the safety related physics parameters.

1.1 Summary of Function and Assumptions

"Generate Nuclear Reactor Heat"

Assumption 1:

The core physics experimental data base is adequate to ensure that the core reactivity can be calculated at nominal full power conditions with an uncertainty of $\leq \pm 1.5\% \Delta\rho$.

Assumption 2:

The core physics experimental data base is adequate to ensure that the power distributions can be calculated at nominal full power conditions with an uncertainty of $\leq \pm 15\%$.

"Control Heat Generation Rate," Assumption: The core physics experimental data base is adequate to ensure that the water ingress effect can be calculated with an uncertainty of $\leq \pm 25\%$.

"Maintain Shutdown," Assumptions: The core physics experimental data base is adequate to ensure that the control rod bank reactivity worth can be calculated with an uncertainty of $\leq \pm 20\%$.

1.2 Current Data Base Summary

The validity of the core physics methods used for the MHTGR conceptual design have been assessed previously for high enriched uranium (HEU) fuel cycles. This

assessment was based on measurements on the Peach Bottom critical assembly, the operation of the Peach Bottom reactor, experiments on the HTGR critical assembly, FSV operation, DRAGON reactor operation, AVR measurements, and critical assembly experiments in HITREX, KAHTER, and CNPS. An evaluation has also been made of the sensitivity of operational events and design basis accident results to the uncertainties in important MHTGR physics parameters. This study showed that, at least at the conceptual design level, quite large uncertainties in these parameters can be tolerated without unacceptable effects in the transients such as excessive fuel temperatures or fission product release.

While this sensitivity study provided adequate support for the validity of the MHTGR conceptual design methods for normal, transient, and accident analyses, an improvement in the core physics data base is needed for the preliminary and final design work. This enlarged data base is required primarily because of the scarcity of experimental data for low enriched uranium (LEU) fuel ($\leq$20% U-235) in graphite moderated reactors, and the increased importance of U-238 and plutonium in the MHTGR core. Specifically, a clean measurement of material worths of U-238 and plutonium, a clean measurement of the worths of a reflector-located control rod, a clean measurement of the reactivity effects of water ingress, and measurements of flux distributions in a small, high leakage, graphite moderated, LEU-fueled core are needed.

## 1.3 Data Needed

Core physics experimental data in a graphite/LEU spectrum are needed to supplement the current data base for validation of the physics methods under the conditions in Section 1.4. The measurements to satisfy these data needs include:

- Reactivity worth measurements of a typical GT-MHR lumped burnable poison $B_4C$ rod.
- Reactivity measurements of a typical GT-MHR $B_4C$ control rod located in the side reflector.
- Radial and axial neutron flux distribution measurements through the active core and the reflectors.
- Reactivity worth measurements of Pu-239 and U-238 test elements.
- Reactivity worth measurements of the effects of varying amounts and distributions of water in the core and/or in the reflectors.

Quality assurance must be in accordance with the requirements for experimental data or validation testing which is safety-related.

1.4 Data Parameters and Service Conditions

The test conditions of interest are given below:

- Graphite moderated assembly
- Graphite reflectors
- Small core with high neutron leakage
- Solid graphite core assembly
- LEU fuel (≤20% enriched in U-235 in the form of fuel rods of coated particles in a graphite matrix)
- Room temperature conditions for measurements are acceptable test conditions
- Capability for control rod mock-up in graphite reflector
- Capability for neutron flux and material worth measurements.

## 2. DESIGNERS' ALTERNATIVES

The alternative is the reliance on existing HEU data and computer calculated benchmarks with increased risk that the computational methods can not be validated.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

The validation of the core physics methods will be accomplished by successful comparison of calculated and measured physics parameters. Existing data from HEU facilities will be recalculated using the computational methods and cross sections which will be used for the final design of the GT-MHR. Supplemental experimental data is also needed for the LEU fueled core in a small, high neutron leakage system. This supplemental data can be obtained from experiments performed at the existing critical facilities: Compact Nuclear Power Source (CNPS) at the Los Alamos National Laboratories, Very High Temperature Reactor Critical (VHTRC) in Japan, and PROTEUS in Switzerland. These facilities are graphite moderated, graphite reflected, and LEU-fueled assemblies. The measurements will be compared to calculations. The comparisons of measured and calculated physics parameters will provide sufficient information to supplement the existing data base such that the validity of the core physics methods used in the GT-MHR design analyses can be ensured.

## 4. SCHEDULE REQUIREMENTS

Data are needed prior to completion of final design. Additional information may be required for the FSSAR documentation.

[DDN C.11.03.52]

5. PRIORITY

Urgency: 1
Cost Benefit: H
Uncertainty in Existing Data: M
Importance of New Data: H

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

If this data for graphite-moderated LEU systems is not available then the accuracy limits for important physics parameters will have to be relaxed to accommodate the larger uncertainties in the calculations. Further sensitivity studies will be necessary to determine the effect of plant safety. If safety is affected, then changes in the plant design will be required.

R.A. Rucker 7-25-94
Originator Date

R.K. Lane 7-25-94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# REACTOR EQUIPMENT SERVICE FACILITY TOOLS DESIGN VERIFICATION
# DDN C.11.04.01

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The multipurpose machines, and equipment which perform the scheduled remote maintenance and service operations must accomplish their functions within a facility of specified size and layout.

### 1.1 Summary of Function and Assumptions

"Maintain Plant Performance Capability," Assumption: Machines and equipment will be available to remotely service Fuel Handling Equipment, Neutron control Assemblies, and other reactor equipment.

### 1.2 Current Data Base Summary

The conceptual design is based on experience gained from the Fort St. Vrain Hot Service Facility. However, the service facility equipment, machines and tools required for the neutron control assemblies and fuel handling equipment are unique to the proposed concept because of the taller core and other design changes. Therefore, no data exist for these unique features.

### 1.3 Data Needed

Data are needed to confirm the adequacy of the remote maintenance features built into the fuel handling equipment, the neutron control assemblies and other reactor equipment requiring remote maintenance under the conditions in Section 1.4. Data on tolerances and compatibility must be gathered. Also, data on the capability of the proposed tool designs to perform the required work in a timely manner must be collected. Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Atmosphere | Air |
| Pressure | 14.7 psia |
| Temperature | 120°F |
| Radiation | [TBD] |

## 2. DESIGNER'S ALTERNATIVES

2.1 Demonstrate the design adequacy of the tools within the finished facility at the site.

2.2 Do the necessary modeling on 3-D solid CAD to depict all handling operations and clearances required within facility.

## 3. SELECTED APPROACH AND EXPLANATION

It is necessary to assess the feasibility of the unique operations early in the design phase so that necessary changes can be made. Changes may be made to the facility or the service equipment where necessary and achievable, and it may be necessary to alter designs of the equipment to be serviced.

The reactor equipment service tools will be tested in a mock-up of the facility. This will provide early results on the capabilities of the equipment to perform the required service operations, provide early warning of problem areas, and will provide information to finalize the designs of components which must be serviced within the facility. Alternative 2.2, a complete reliance on drafting layout, was not chosen due to the weakness of this approach regarding visibility, equipment deflections, etc. Alternative 2.1 was rejected due to its potential for requiring changes to the components to be serviced after the plant is operating.

## 4. SCHEDULE REQUIREMENTS

Testing must be completed by month [TBD], one year prior to completion of final design.

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The preferred fallback position is Alternative 2.1. Should the selected approach not be conducted, there is increased risk of not being able to perform the required maintenance until

modifications are made to the already existing tools, facilities or components. This might lead to unscheduled downtime.

D W Kethley 7-27-94
Originator Date

Camelo Rodriguez 7/28/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# RESERVE SHUTDOWN VACUUM TOOL DESIGN VERIFICATION
# DDN C.11.04.02

PLANT: GT-MHR/System 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA ON VALIDATION TESTING

The Reserve Shutdown Vacuum Tool (RSVT) must successfully remove the reserve shutdown system pellets from a ten element high active core, which is four elements higher than Fort St. Vrain.

### 1.1 Summary of Functions and Assumptions

"Control With Movable Poisons," Assumption: A tool is available to remove the boron pellets used in the reserve shutdown system.

### 1.2 Current Data Base Summary

The RSVT conceptual design is based on existing equipment at Fort St. Vrain. The component has been revised to increase the storage capacity, provide dust filters and accommodate the increased core depth. No data are available on these new features.

### 1.3 Data Needed

Verification of satisfactory operation of the reserve shutdown vacuum tool design and/or identification of areas requiring redesign. Data on blower horsepower, most effective insertion rate for maximum blower life, the need for and the effects of filters, and performance limits in all operating modes, including maximum misalignment of channel with the material insertion holes are needed under the conditions in Section 1.4. Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Temperature | 250°F |
| Pressure | 14.7 psia |
| Internal atmosphere | Air or helium |
| Radiation | [TBD] |

## 2. DESIGNER'S ALTERNATIVES

2.1 Test the equipment at the reactor site.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

A test will provide early performance data and opportunity to correct deficiencies, so that the tool will function in all operating conditions. A full scale helium test rig with a variable speed hoist and a full depth core shutdown channel are required. Alternative 2.1 was not chosen because it might interfere with more critical activities at the site late in the schedule.

## 4. SCHEDULE REQUIREMENTS

Test to be completed by month [TBD], one year prior to completion of final design.

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is Alternative 2.1. Nonexecution of the proposed test would introduce the risk of the tool not being able to remove the shutdown material from the full depth of the reactor core causing a delay in plant startup.

D W Ketchen 7-27-94
Originator Date

Carlos Rodriguez 7/28/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# NEUTRON DETECTOR SERVICE EQUIPMENT DESIGN VERIFICATION
# DDN C.11.04.03

Plant: GT-MHR/System 11

## 1. REQUIREMENT OF DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OF VALIDATION TESTING

Activated neutron detector assemblies require that the detector service equipment provide remote handling features. These features must be tested to demonstrate adequacy.

### 1.1 Summary of Function and Assumption

"Perform Neutron Detector Assembly Maintenance," Assumption: Equipment must maintain performance capability.

### 1.2 Current Data Base Summary

The neutron detector service equipment is an entirely new machine for which there are no data.

### 1.3 Data Needed

Data are needed to verify the neutron detector service equipment design under the conditions in Section 1.4.

There are several mechanisms which must be evaluated including cutter configuration, force required to sever detector, performance of the drive roll system used to move the instrument vertically, tool required to remove detectors which have been severed from their support and lodged in place, and the shielded storage hopper. Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Internal atmosphere | Helium/air |
| Pressure | 14.7 psia |
| Temperature | [TBD] |
| Radiation | [TBD] |

## 2. DESIGNER'S ALTERNATIVES

2.1 Demonstrate the adequacy of the equipment at the site, or during manufacturing checkout.

## 3. SELECTED APPROACH AND EXPLANATION

A full-scale test article will be used to obtain early data on the performance capability of the equipment and its components. This will provide an opportunity to correct deficiencies prior to completion of final design. Alternate 2.1 was not chosen due to the potential for changes to the components after the plant is operating.

## 4. SCHEDULE REQUIREMENTS

Testing to be completed by month [TBD], one year prior to completion of final design.

## 5. PRIORITY

Urgency: 3
Cost benefit: M
Uncertainty in existing data: M
Importance of new data: M

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fall back position is Alternative 2.1. Should the selected approach not be conducted, there is increased risk of not being able to perform the required maintenance until modification are made to already existing tools or components.

DW Kethan 7-27-94
Originator Date

Camilo Rodriguez 7/28/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# METALLIC REACTOR INTERNALS (MRI) ISI AND SURVEILLANCE EQUIPMENT DESIGN VERIFICATION
# DDN C.11.04.04

PLANT: GT-MHR/SYSTEM 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The ISI equipment must be highly reliable and perform repeatedly the required functions during its design life. The purpose of this DDN is to confirm operability of this equipment in the GT-MHR during refueling conditions.

### 1.1 Summary of Function and Assumptions

"Perform a visual examination," Assumption: The ISI equipment can inspect the upper plenum shroud and core lateral restraint with a remotely operated moving TV camera.

"Retrieve material surveillance samples," Assumption: The ISI equipment can remove material samples of the core lateral restraint by use of a grappler mechanism.

### 1.2 Current Data Base Summary

Conditions of the GT-MHR are different than at Fort St. Vrain. Consequently, new equipment needs to be designed to perform the required operations. Commercially available TV camera equipment will be used to the maximum extent possible.

### 1.3 Data Needed

Data for candidate MRI ISI and surveillance equipment designs is needed to verify the following under the conditions in Section 1.4:

a. Acceptable installation and mechanical operation.

b. Acceptable image transfer.

c. Acceptable removal and transfer of material surveillance samples.

Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Temperature | 250°F maximum |
| Pressure | 14.7 psia |
| Atmosphere | Helium |
| Radiation | [TBD] |

## 2. DESIGNER'S ALTERNATIVE

2.1 Test the equipment at the reactor site.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

A test will provide early performance data and opportunity to correct deficiencies, so that the ISI equipment will function properly at the start of reactor operations. Alternative 2.1 was not chosen due to the potential of interference with more critical activities at the site late in the schedule.

## 4. SCHEDULE REQUIREMENTS

The test is to be completed at month [TBD] for coordination with the remote refueling equipment test (B.11.01.09).

## 5. PRIORITY

Urgency: 4
Cost benefit: L
Uncertainty in existing data: M
Importance of new data: L

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is Alternative 2.1. Nonexecution of the proposed test would introduce the risk of the ISI equipment not being able to perform to expectations, causing a delay during a refueling outage.

7-27-94
Originator Date

7/28/94
Task Manager Date

Program Manager Date

DATE: 6/30/94

# GT-MHR PROGRAM
# METALLIC CORE SUPPORT ISI AND SURVEILLANCE EQUIPMENT DESIGN VERIFICATION

DDN C.11.04.05

PLANT: GT-MHR/SYSTEM 11

## 1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The ISI equipment must be highly reliable and perform repeatedly the required functions during its design life. The purpose of this DDN is to confirm operability of this equipment in the GT-MHR during refueling conditions.

### 1.1 Summary of Function and Assumptions

"Perform a visual examination," Assumption: The ISI equipment can inspect the metallic core supports with a remotely operated moving TV camera.

"Retrieve material surveillance samples," Assumption: The ISI equipment can remove and transfer material samples of the metallic core support from the core support area to the hot cell by use of a portable cask with internal mechanisms.

### 1.2 Current Data Base Summary

Conditions of the GT-MHR are different than at Fort St. Vrain. Consequently, new equipment needs to be designed to perform the required operations. Commercially available TV camera equipment will be used to the maximum extent possible.

### 1.3 Data Needed

Data for candidate designs is needed to verify the following:

a. Acceptable installation and mechanical operation at GT-MHR refueling conditions.

b. Acceptable image transfer at GT-MHR refueling conditions.

c. Acceptable removal and transfer of material surveillance samples.

Quality assurance must be in accordance with the requirements for experimental data or validation testing per nonsafety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Temperature | 240°F maximum |
| Pressure | 14.7 psia |
| Atmosphere | Helium |

## 2. DESIGNER'S ALTERNATIVE

2.1 Test the equipment at the reactor site.

## 3. SELECTED DESIGN APPROACH AND EXPLANATION

A test will provide early performance data and opportunity to correct deficiencies, so that the ISI equipment will function properly at the start of reactor operations. Alternative 2.1 was not chosen due to the potential of interference with more critical activities at the site late in the schedule.

## 4. SCHEDULE REQUIREMENTS

The test is to be completed at month [TBD], the same completion time for the ISI equipment for the UPS and CLR.

## 5. PRIORITY

Urgency: [TBD]
Cost benefit: [TBD]
Uncertainty in existing data: [TBD]
Importance of new data: [TBD]

## 6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is Alternative 2.1. Nonexecution of the proposed test would introduce the risk of the ISI equipment not being able to perform to expectations, causing a delay during a refueling outage.

| | |
|---|---|
| [signature] | 7-27-94 |
| Originator | Date |
| [signature] | 7/28/94 |
| Task Manager | Date |
| | |
| Program Manager | Date |

DATE: 6/30/94

GT-MHR PROGRAM
GRAPHITE CORE SUPPORT ISI AND SURVEILLANCE DESIGN VERIFICATION
DDN C.11.04.06

PLANT: GT-MHR/SYSTEM 11

1. REQUIREMENT OR DESIGN FEATURE REQUIRING EXPERIMENTAL DATA OR VALIDATION TESTING

The ISI equipment must be highly reliable and perform repeatedly the required functions during its design life. The purpose of this DDN is to confirm operability of this equipment in the GT-MHR during refueling conditions.

1.1 Summary of Function and Assumptions

"Perform a visual examination," Assumption: The ISI equipment can inspect the graphite core supports with a remotely operated moving TV camera.

1.2 Current Data Base Summary

Conditions of the GT-MHR are different than at Fort St. Vrain. Consequently, new equipment needs to be designed to perform the visual examination. Commercially available TV camera equipment will be used to the maximum extent possible.

1.3 Data Needed

Data for candidate core support ISI and surviellance designs is needed to verify the following under the conditions in Section 1.4:

a. Acceptable installation and mechanical operation.

b. Acceptable image transfer.

Quality assurance must be in accordance with the requirements for experimental data or validation testing per non safety-related components.

1.4 Data Parameters and Service Conditions

Service conditions of interest are given below:

| | |
|---|---|
| Temperature | 250°F maximum |
| Pressure | 14.7 psia |
| Atmosphere | Helium |

[DDN C.11.04.06]

2. DESIGNER'S ALTERNATIVE

2.1 Test the equipment at the reactor site.

3. SELECTED DESIGN APPROACH AND EXPLANATION

A test will provide early performance data and opportunity to correct deficiencies, so that the ISI equipment will function properly at the start of reactor operations. Alternative 2.1 was not chosen due to the potential of interference with more critical activities at the site late in the schedule.

4. SCHEDULE REQUIREMENTS

The test is to be completed at month [TBD], the same completion time for the ISI equipment for the UPS and CLR (DDN C.11.04.04).

5. PRIORITY

Urgency: 4
Cost benefit: L
Uncertainty in existing data: M
Importance of new data: L

6. FALLBACK POSITION AND CONSEQUENCES OF NONEXECUTION

The fallback position is Alternative 2.1 Nonexecution of the proposed test would introduce the risk of the ISI equipment not being able to perform to expectations causing a delay in Service Inspection during a refueling outage.

7-27-94
Originator Date

7/28/94
Task Manager Date

Program Manager Date