DOE-HTGR-86-051
Revision 1

HTGR

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# NSSS CONTROL SUBSYSTEM DESIGN DESCRIPTION




**AUTHORS/CONTRACTORS**

GA TECHNOLOGIES INC.



ISSUED BY GA TECHNOLOGIES INC.
FOR THE DEPARTMENT OF ENERGY
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# NSSS CONTROL SUBSYSTEM DESIGN DESCRIPTION



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GA Project 6300

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GA 1485 (REV. 10/82)

# GA Technologies Inc.

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|---|---|---|---|
| NSSS CONTROL SUBSYSTEM DESIGN DESCRIPTION | ☐ R & D<br>☐ DV & S<br>☒ DESIGN | APPROVAL LEVEL 5 | |

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*See List of Effective Pages

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908437
(HFD-33700)
(DOE-HTGR-86-076)

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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ANSI | American National Standards Institute |
| ASME | American Society of Mechanical Engineers |
| CRT | Cathode Ray Tube |
| DMS | Data Management System |
| ECA | Energy Conversion Area |
| EMI | Electromagnetic Interference |
| FW | Feedwater |
| HTS | Heat Transport System |
| HVAC | Heating, Ventilating, and Air Conditioning |
| IEEE | Institute of Electrical & Electronic Engineers |
| IB | Instrument Block |
| MHTGR | Modular High-Temperature Gas-Cooled Reactor |
| MTBF | Mean Time Between Failure |
| MTR | Mean Time to Repair |
| NSSS | Nuclear Steam Supply System |
| NSSSCS | NSSS Control Subsystem |
| PCDIS | Plant Control, Data, and Instrumentation System |
| PPIS | Plant Protection and Instrumentation System |
| PSCS | Plant Supervisory Control Subsystem |
| QA | Quality Assurance |
| QAL | Quality Assurance Level |
| ROM | Read Only Memory |
| SCS | Shutdown Cooling System |
| SDD | System Design Description |
| SSDD | Subsystem Design Description |
| TBD | To be determined |

# DEFINITIONS

Activity: An identifiable set of human actions undertaken to accomplish a particular task within one of the more general industry activities of Design, Construction, Operation, Maintenance, and Decommissioning.

Design Criterion: A basis for judging the acceptability of a particular quantity, action, procedure, or design solution.

Design Value: The nominal value of a plant or system operating parameter plus an appropriate margin.

Energy Conversion Area: That portion of the plant not included within the Nuclear Island.

Equilibrium Plant: A commercial plant that incorporates a design that has matured through construction of replicate facilities and has accrued the benefits of standardization, learning, and optimal use of associated manufacturing facilities.

Equivalent Availability: Equivalent availability is mathematically defined as:

$$Ae = \int_{o}^{T_p} \frac{Pa(t)}{T_p} dt$$

where: $Pa(t)$ = available net electrical power expressed as a percentage of design power as a function of time (t)

$t$ = time

$T_p$ = time period (operational lifetime)

DEFINITIONS (Continued)

Function: A statement of what is to be achieved.

Functional Analysis: A systems engineering technique or method used to develop (1) functions required to meet established goals, (2) the relationship between functions and related requirements, and (3) the basis and justification for design selections through which the prescribed goals are met. [Functional analysis is one part of the Integrated Approach.]

Functional Independence: Design provisions which ensure that the safety-related functions of a system do not rely in whole or in part on another system to provide the design function.

Functional Requirement: A bounding quantification that is derived from a functional need versus being imposed by an institutional standard.

Goal: An endpoint or accomplishment towards which an effort is directed. The Integrated Approach has identified the following specific goals supporting the overall objective:

1. Safe economical power (top level - Goal 0).
2. Maintain plant operation (Goal 1).
3. Maintain plant protection (Goal 2).
4. Maintain control of radionuclide release (Goal 3).
5. Maintain emergency preparedness (Goal 4).

Institution: A significant practice, relationship, or organization in a society. Institutions include the utility/user, the federal government, industry codes and standards, the Department of Energy, and state and local governments.

Institutional Requirement: A bounding quantification that is imposed by an institution as opposed to a quantification derived from a functional need.

DEFINITIONS (Continued)

Integrated Approach: A systems engineering technique for establishing and defending a well-developed nuclear plant design.

Interface Requirement: A requirement imposed by a system, subsystem, or component on another system, subsystem, or component, which must be accomplished to facilitate satisfaction of a function(s) of the imposing system, subsystem, or component.

Nominal Value: Value of a quantity in name only, and thus not actual. Generally rounded for this usage.

Nuclear Island: That portion of the plant that has within its boundary the following:

1. The standard reactor modules and "safety-related" buildings, structures, systems, portions of systems, and components dedicated to ensuring reactor shutdown, decay heat removal, fission product retention, and security of vital areas including new (unirradiated) fuel.

2. At the designer's discretion, buildings, structures, systems, portions of systems, and components that support reactor operation or investment protection, and are not "safety-related."

Operating Basis-Earthquake (OBE): The earthquake which could reasonably be expected to affect the plant site during the operating life of the plant.

Operating Life: The calendar time from receipt of the operating license to completion of plant power production.

DEFINITIONS (Continued)

Plant: All buildings, structures, systems, and components that together accomplish the process of energy production and conversion and support the human activities of administration, operation, and maintenance.

Plant Life: The calendar time from construction permit issuance to completion of plant power production.

Parameter: A specific measurable and quantifiable aspect of a physical item.

Plant State: The condition of the physical plant (or module) at a particular time and place, as described by a set of appropriate variables associated with a plant goal.

Principal Design Criteria: Qualitative statements which specify the design commitments made to ensure that the dose criteria of 10CFR100 will be met and, therefore, that public health and safety will be protected under accident conditions.

Rated Value: The nominal value of a parameter at 100% plant energy conditions.

Requirement: The bounding quantification (limits) of a function.

Safe Shutdown Earthquake (SSE): That earthquake for which those structures, systems, and components required to meet 10CFR100 are designed to remain functional with a high degree of confidence.

"Safety-Related": Identifier on equipment necessary to perform the functions required to limit releases under accident conditions to those allowed by 10CFR100.

DEFINITIONS (Continued)

Standard Reactor Module: That portion of the Nuclear Island which is duplicated with the addition of each reactor. This would include, in part, the reactor, steam generator, helium circulator, Reactor Building, Reactor Cavity Cooling System, etc.

System: A collection of electrical, mechanical, and/or structural components and associated software and human actions treated as a unit for technical, administrative, or contractual purposes.

# PREFACE

The objective of the MHTGR plant project is to produce safe, economical power. Supporting this objective, four major goals and their associated plant states are identified as follows:

1. Maintain Safe Plant Operation.
1.1 Maintain Safe Energy Production (State 1).
1.2 Maintain Safe Plant Shutdown (State 2).
1.3 Maintain Safe Plant Refueling (State 3).
1.4 Maintain Safe Plant Startup/Shutdown (State 4).

2. Maintain Plant Protection.
2.1 Protect the capability to maintain safe energy production.
2.2 Protect the capability to maintain safe plant shutdown.
2.3 Protect the capability to maintain safe plant refueling.
2.4 Protect the capability to maintain safe plant startup/shutdown.

3. Maintain Control of Radionuclide Release.
3.1 Control radiation.
3.2 Control personnel access.

4. Maintain Emergency Preparedness.

The Overall Plant Design Specifications (OPDS) is the top-level technical document for the MHTGR plant. The OPDS (based on Utility/User and regulatory requirements) establishes the overall performance, functional, institutional, operational, safety, maintenance, inspection and decommissioning requirements for design of the plant.

In response to the OPDS, a series of lower tier documents, System Design Description (SDDs), Subsystem Design Descriptions (SSDDs), Buildings and Structures Design Descriptions (BSDDs), Component Design Specifications

PREFACE (Continued)

(CDSs), and Interface Control Documents (ICDs), describe and control the individual designs. Traceability of requirement source from plant-level requirements to equipment-level requirements shall be maintained throughout this hierarchy of design documents.

# SUMMARY

The NSSS Control Subsystem (NSSSCS) is one of the systems comprising the MHTGR. The design of this system has been developed through the Integrated Approach toward safe and economical production of electrical power.

This document defines the functions of the NSSSCS, system design requirements derived from the functional analysis, and institutional requirements from the Overall Plant Design Specification (Ref. 2). A description of the subsystem design which satisfies the requirements is presented. These lower-tier requirements are derived at the system level and passed down to the NSSSCS. This document also includes information on aspects of system construction, operation, maintenance, and decommissioning.

The NSSSCS controls NSSS systems and monitors and evaluates the state of the NSSS modules. There are four (4) independent NSSSCS modules in the MHTGR plant. The system automatically controls the NSSS during energy production, shutdown, refueling, and startup/shutdown. The scope of the system starts with and includes the electronic interfaces with other MHTGR systems. These include input of the NSSSCS commands to the actuated equipment in the NSSS. The NSSS systems interface stations, which are located near the Reactor Buildings and which are part of the NSSSCS, physically attach to these electronic interfaces. The scope of the system ends with the NSSS operations stations which perform other functions including exchange of control and status information with a plant supervisory control system and interface with plant operating personnel at locations outside of the control room.

The NSSSCS monitors selected process variables through its data system and controls the state of the NSSS through command of actuated equipment. The process instrumentation is contained in the other NSSS systems. The NSSSCS provides continuous monitoring and automatic control of NSSS systems and reports information to a Plant Supervisory Control System (PSCS). Each NSSSCS module independently receives command information from the PSCS and

SUMMARY (Continued)

responds independently to PSCS commands. The NSSSCS and PSCS, along with the other subsystems shown below, make up the Plant Control Data and Instrumentation System. The complete document structure for the controls is shown below.

| System | System No. | Document No. |
|---|---|---|
| Plant Control Data and Instrumentation | 3700 | HFD-33700 |

| Subsystem | Subsystem No. | Document No. |
|---|---|---|
| Plant Supervisory Control | 3707 | HFD-43707 |
| NSSS Control | 3701 | HFD-43701 |
| Tech. Operation Support | 3708 | HFD-43708 |
| Data Management | 3735 | HFD-43735 |

# SECTION 1
# NSSS CONTROL SUBSYSTEM DESIGN DESCRIPTION

## 1.1 SUBSYSTEM FUNCTIONS

The NSSS Control Subsystem consists of four identical sets of controls - one for each NSSS module. These operate under the supervision of the Plant Supervisory Control Subsystem or the operators.

The NSSS Control Subsystems functions are:

1. Accept Direction - Supervisory control commands are accepted from the supervisory Control Subsystem or the operators. These commands tell the NSSS module its state set point, such as for example, load level. Information requests are also received by the NSSS Control Subsystem.

2. Observe Status - Process information is acquired by each NSSS Control Subsystem from its NSSS module, converted to alternate forms, and stored.

3. Make Decisions - Based on the observed status and the accepted direction, the NSSS Control Subsystem makes control decisions about the actions that it needs to take on its NSSS module in order to reach or maintain its state set point.

4. Effect Control - The NSSS Control Subsystems outputs analog and digital control signals to carry out control decisions.

5. Report Information - Information about the status of the NSSS module is communicated to data highways for output to operator interfaces.

## 1.2 SUBSYSTEM DESIGN REQUIREMENTS

### 1.2.1 Subsystem Configuration and Essential Features Requirements

The NSSS Control Subsystems shall be functionally independent from major component and equipment monitoring and protective features. The NSSS control subsystem shall be functionally independent of the PPIS. (3701.0102.001)*

NSSSCS alarm points to the control room shall be restricted to those critical parameters which can lead to initiation of protective action for major plant components or the loss of electrical production. (3701.0102.002)

NSSSCS features shall be included to facilitate operation of the reactor module at different power levels. (3701.0102.003)

The design of structures, systems, and components (SSCs) within the Nuclear Island shall be standardized. (3701.0102.004)

The NSSSCS shall be designed for a Nuclear Island that contains four (4) standard reactor modules. (3701.0102.005)

Human/machine interfaces and machine/machine communication interfaces shall be provided for the NSSSCS equipment outside the control room requiring human interaction during energy production, shutdown, refueling, and startup/shutdown. (3701.0102.006)

Features of the NSSSCS (e.g., intersystem communication performance or data highway cable configuration) shall not impose limiting or restrictive requirements on the physical location of equipment and device interfaces. (3701.0102.007)

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*Requirement traceability number

The NSSSCS design shall permit the addition of new control and data communication interfaces, including signal input/output field wiring, without necessitating de-energizing electronics or affecting the operation of other electronic equipment. (3701.0102.008)

Base the NSSSCS design on proven technology or on new technology expected to be demonstrated in time to support the construction licensing process. (3701.0102.010)

### 1.2.2 Operational Requirements

The NSSSCS shall provide the capability to control and regulate the conditions of the nuclear steam supply so as to deliver 2400 psig, 1000°F steam to the high-pressure turbine admission valves. (3701.0102.011)

The NSSSCS shall provide the capability for roving operators to control, under supervision from the control room, selected processes and subsystems during energy production, shutdown, refueling, and startups/shutdowns not requiring direct control room operator interfacing and interaction. Communications and status information shall be made available at the locations involved in the operations outside the control room. (3701.0102.012)

The NSSSCS shall be designed to operate through the design transients specified in the MHTGR Plant Design Basis Transient Analysis Report for the number of cycles specified in Table 5.1-1 of Ref. 2. (3701.0102.013)

The NSSSCS design shall accommodate the performance and transient characteristics of the following reactor/turbine-generator combinations:

1. Two (2) reactor modules operating in parallel supplying steam to a single turbine-generator.

2. Four (4) reactor modules operating in parallel supplying steam to a single turbine-generator.

3. Four (4) reactor modules operating in parallel supplying steam to two turbine-generators. (3701.0102.014)

The NSSSCS design shall permit for reloading at 5% of rated load per minute following:

1. Load rejection from full generator electric output to house electrical load without a reactor trip.

2. Turbine trip (except on low condenser vacuum) from any load level without a reactor trip, without the necessity for a mandatory hold except for those associated with the turbine-generators. (3701.0102.015)

The NSSSCS design shall provide sustained and controlled operation for the conditions listed below:

1. Step changes of ±15% in plant output caused by utility electrical transmission grid upsets. (3701.0102.016)

NSSSCS features shall be included as required to limit recovery time to resumption of reactor power operation when a protection trip occurs consistent with meeting the plant availability goal. (3701.0102.017)

The NSSSCS shall be capable of changing reactor output under automatic control at a rate of up to and including 5% of rated output per minute. (3701.0102.018)

The NSSSCS shall include features to enable automatic control during startups. (3701.0102.518)

The NSSSCS shall be designed to operate from 25% to 100% feedwater flow for the performance parameters specified in Table 1-1. (3701.0102.019)

The NSSSCS shall control circulator speed not to exceed a speed 10% above the nominal value. (3701.0102.020)

The NSSSCS shall be designed to maintain the SG primary coolant inlet bulk temperature and primary coolant flow rate within the envelope shown in Figures 1-1 through 1-3. (3701.0102.021)

The NSSSCS shall maintain the circulator speed/feedwater flow schedule between 25% and 100% feedwater flow between ±15% of nominal values. (3701.0102.022)

The NSSSCS shall be designed to maintain the primary coolant cold leg temperature below 288°C (550°F). (3701.0102.023)

The NSSSCS control shall maintain long-term, stable steam generator outlet temperature below 557°C (1035°F). (3701.0102.024)

The NSSSCS shall accept PPIS signals and initiate control adjustments in response to trips. (3701.0102.405)

The NSSSCS shall provide setpoint signals to the neutron flux controller for use in automatically controlling the rods. (3701.0102.415)

The system shall be designed to control the helium mass flow through the active steam generator bundle between 25% and 100% of nominal feedwater flow for steady-state operation as specified in Table 1-1 and Table 5.12-2 of Ref. 2. (3701.0102.025)

Table 1-1
DESIGN POINT NSSS PERFORMANCE AT RATED (100%) FEEDWATER FLOW

| | |
|---|---|
| NSSS Heat Balance, MW(t) | |
| Heat generated by core | 350.00 |
| Heat added by circulators | 3.13 |
| Total heat to helium | 353.13 |
| Loss to environment from helium | 0.73 |
| Loss of SCHE from helium | 0.25 |
| Net steam generator power | 352.15 |
| Reactor | |
| Inlet helium flow rate, lb/h | 1,246,397.0 |
| Inlet helium temperature, °F | 497.4 |
| Inlet helium pressure, psia | 924.5 |
| Loss to vessel from core, MW(t) | 0.62 |
| Outlet helium temperature, °F | 1,267.7 |
| Helium pressure drop, psi | 8.00 |
| Steam Generator | |
| Inlet helium flow rate, lb/h | 1,248,100.0 |
| Inlet helium temperature, °F | 1,266.0 |
| Inlet helium pressure, psia | 915.8 |
| Outlet helium temperature, °F | 490.6 |
| Helium pressure drop, psi | 3.70 |
| Inlet feedwater flow rate, lb/h | 1,089,736.0 |
| Inlet feedwater temperature, °F | 380.0 |
| Inlet feedwater pressure, psia | 3,000.0 |
| Inlet feedwater enthalpy, Btu/lb | 357.60 |
| Regenerative heat loss, MW(t) | 0.33 |
| Outlet steam temperature, °F | 1,005.3 |
| Outlet steam pressure, psia | 2,515.0 |
| Steam pressure drop, psia | 485.0 |
| Main Circulator | |
| Circulator helium flow rate, lb/h | 1,254,372.0 |
| Bypass helium flow rate, lb/h | 6,272.0 |
| Inlet helium temperature, °F | 490.7 |
| Inlet helium pressure, psia | 911.8 |
| Helium temperature rise, °F | 6.85 |
| Helium pressure rise, psi | 13.20 |
| Circulator speed ratio | 1.00 |

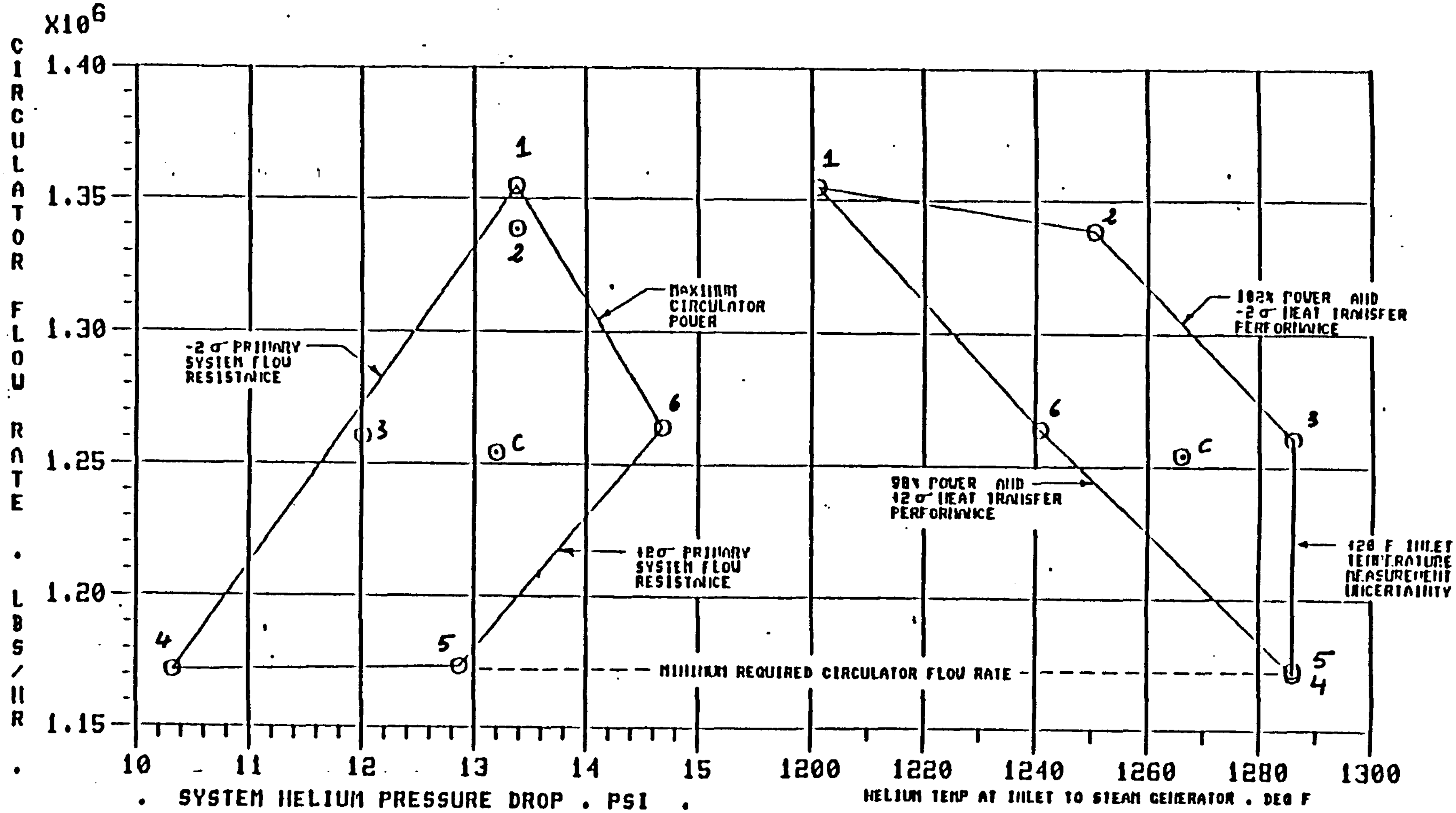


Figure 1-1 HTS OPERATING ENVELOPES AT 100% FEEDWATER FLOW

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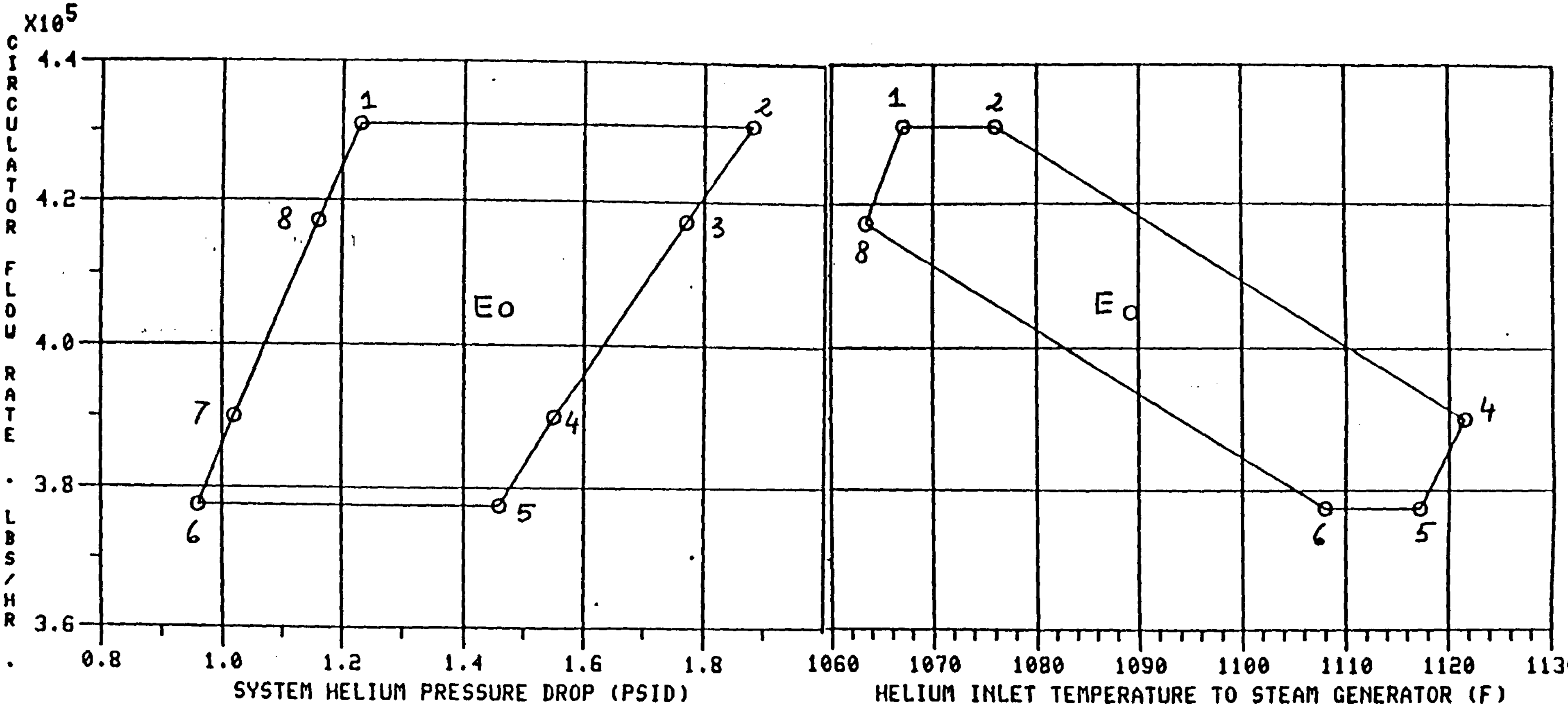
X10^5
CIRCULATOR FLOW RATE, LBS/HR
4.4
4.2
4.0
3.8
3.6
0.8
1.0
1.2
1.4
1.6
1.8
SYSTEM HELIUM PRESSURE DROP (PSID)
1060
1070
1080
1090
1100
1110
1120
1130
HELIUM INLET TEMPERATURE TO STEAM GENERATOR (F)
Eo
E o
1
2
3
4
5
6
7
8

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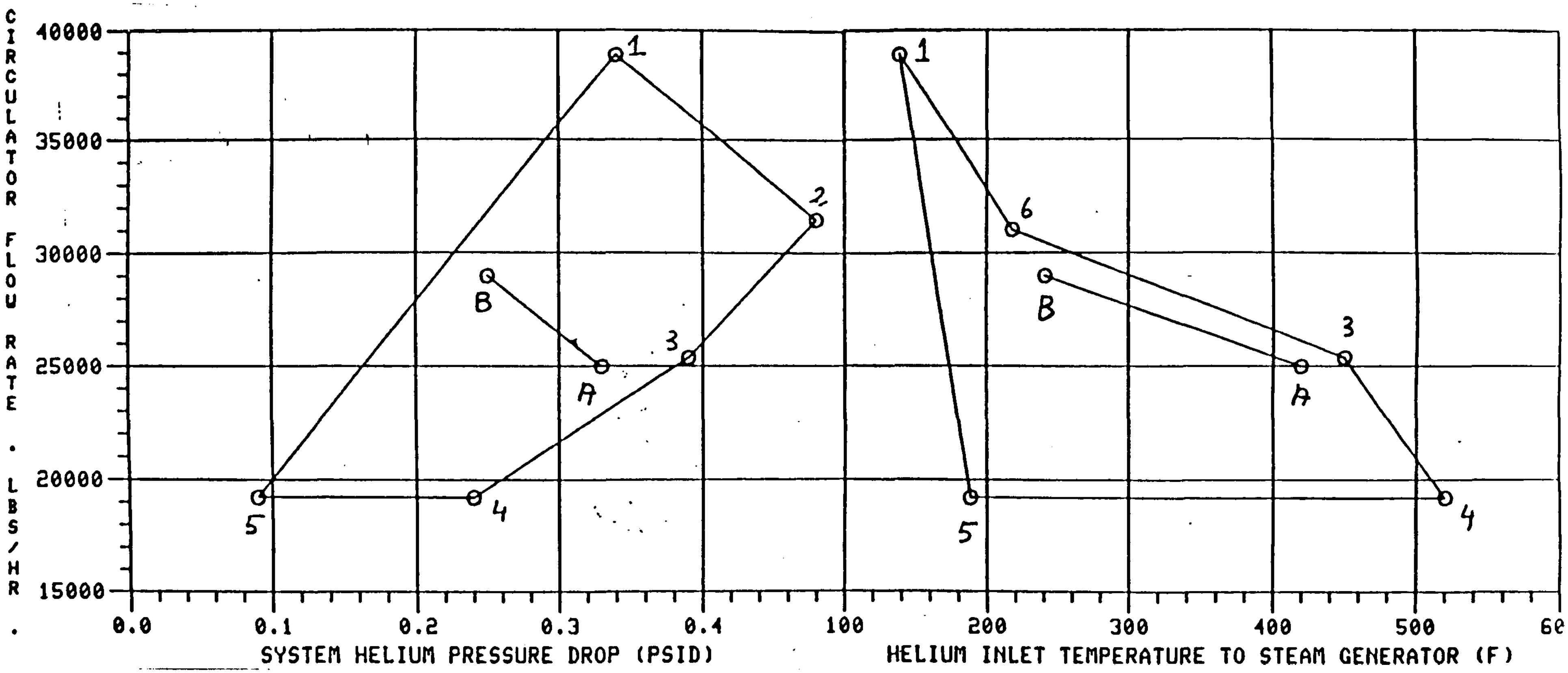


Figure 1-3 HTS OPERATING ENVELOPES AT REFUELING

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Each individual reactor module shall be capable of continuous operation under automatic control between 25% and 100% of nominal module feedwater flow. (3701.0102.026)

The NSSSCS shall be designed to sustain continuous operation at reduced electrical output through and following transients associated with the loss or failure of a major component, system, or train, including an individual reactor. (3701.0102.027)

The NSSSCS shall be designed to measure and control the performance of the NSSS parameters at any point between 25% and 100% rated feedwater flow for steady-state operation as specified in Table 1-2. (3701.0102.028)

The NSSSCS shall include features to enable automatic control during plant operation. (3701.0102.029)

Reactor module startup shall range between 0% and 25% rated feedwater flow rate on a per reactor module basis. (3701.0102.030)

The NSSSCS shall be designed to accommodate one or more reactor modules starting up. (3701.0102.031)

Reactor module shutdown shall range between 25% and 0% rated feedwater flow rate on a per reactor module basis. (3701.0102.032)

The NSSSCS shall include features to enable automatic control during orderly shutdowns. (3701.0102.033)

The plant shall be designed to accommodate one or more modules shutting down. (3701.0102.034)

Provisions shall be made to remove a reactor from service, perform refueling, and return it to service with the remaining reactors and the turbine plant in operation. (3701.0102.035)

Table 1-2
STEAM/FEEDWATER CONTROL AND INSTRUMENT UNCERTAINTIES

| | |
|---|---|
| Steam outlet temperature | ±9°F |
| Steam outlet pressure | ±1% |
| Feedwater inlet temperature | ±2°F |
| Feedwater flow rate | ±2% |

The NSSSCS shall be designed for a plant operating life of 40 calendar years. (3701.0102.036)

Features shall be included in the NSSSCS to facilitate continual NSSS operation through the transients shown in Table 1-3 (except for shutdown) and at reduced electrical output upon loss of function of major subsystem components where more than one is employed. (3701.0102.037)

The NSSSCS shall be designed for base load operation and be capable of accommodating the weekly load cycle in Figure 1-4 over its design life. (3701.0102.038)

### 1.2.3 Structural Requirements

Nonsafety-related systems shall be designed for ANSI A58.1 seismic load requirements, as a minimum. (3701.0102.039)

Failure of SSCs that are not "safety-related" shall not cause failure of "safety-related" SSCs during an SSE. (3701.0102.597)

OBE seismic response spectrum load level specifications for the NSSSCS shall be based on the plant seismic response spectra provided in the FY-86 MHTGR plant seismic assessment. (3701.0102.040)

The NSSSCS shall be designed to withstand the mechanical and thermal loads resulting from the design transients specified the MHTGR Plant Design Basis Transient Analysis Report for the number of cycles specified in OPDS Table 5.1-3. (3701.0102.041)

### 1.2.4 Environmental Requirements

Environmental qualification requirements pertaining to NSSSCS operation and structural design shall be based upon relevant plant site characteristics as specified in Table 1-4. (3701.0102.042)

Table 1-3 DESIGN DUTY CYCLES[a]

| | Design Number of Occurrences for Plant Lifetime |
|---|---|
| 1. Reactor/plant startup from cold conditions | 160 |
| 2. Reactor/plant shutdown to cold conditions | 160 |
| 3. Rapid load ramp (5%/min) (25% to 100%)/(100% to 25%) | 1,000/1,000 |
| 4. Normal load ramp (0.5%/min) (100% to 25%)/(25% to 100%) | 17,500/20,800 |
| 5. Step load changes (±15%) | 2,000 |

[a]Additional duty cycle events and their frequency of occurrence are to be determined by the responsible designers for concurrence by the Utility/User (see Section 5.1, Ref. 2).

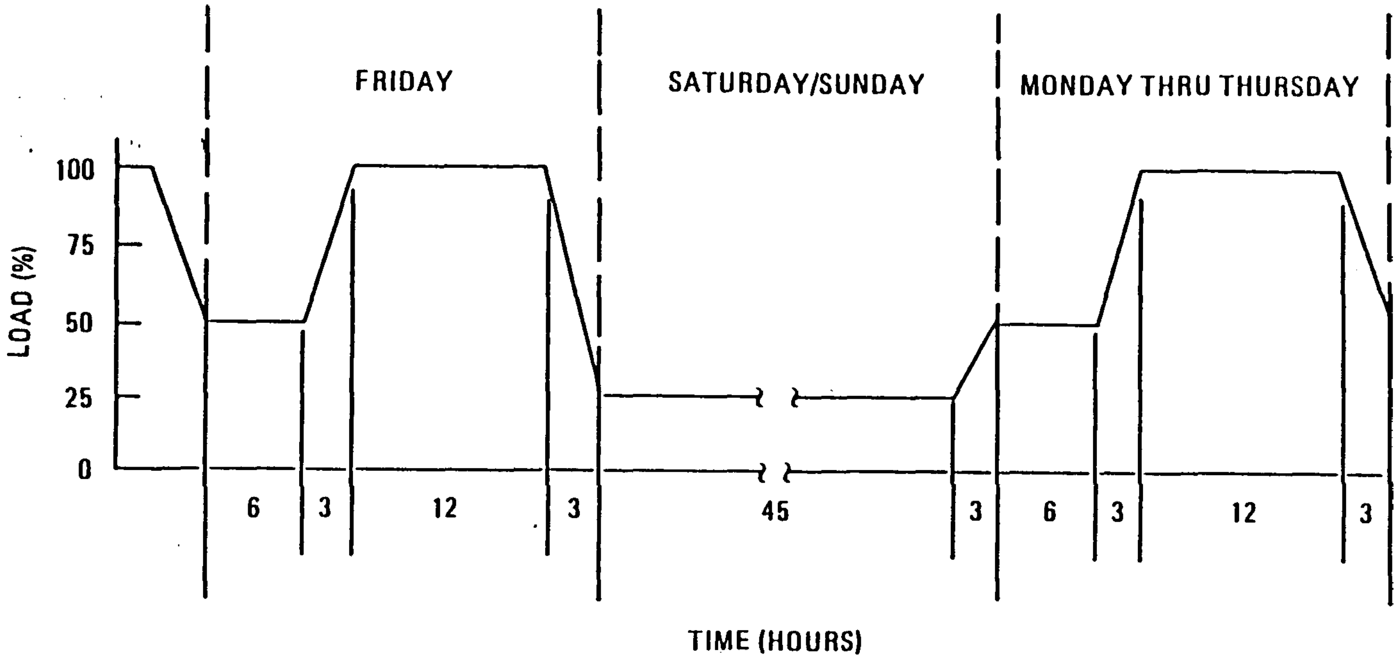


Fig. 1-4 WEEKLY LOAD FOLLOWING CYCLE

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## Table 1-4 SITE CHARACTERISTICS

This table provides the site characteristics to be used as a basis for the plant design. The characteristics include site parameters, which envelope 85% of the available U.S. sites.

| | |
|---|---|
| 1. Site Conditions | |
| 1.1 Soil Characteristics[(a)] | |
| Shear wave velocity (fps) | 1000 - 8000 |
| Allowable static bearing capacity (KSF) | 10[(b)] |
| 1.2 Water Table | Normal groundwater elevation is approximately 8 ft below grade. |
| 1.3 Precipitation (Snow)[(a)] | Snow load: 50 psf per ANSI A58.1. |
| 1.4 Wind Velocity[(a)] | 110 mph at and above a height of 33 ft (10 m) above grade per ANSI A58.1. |
| 1.5 Air Temperature[(a)] | Dry Bulb: 110°F, -45°F; Wet Bulb: 82°F, N/A |
| 1.6 Meteorological[(a)] | |
| Atmospheric dispersion X/Q values | Annual average at EAB: equivalent ground level release is $2 \times 10^{-5}$ s/m$^3$.<br>Accident evaluations are per NRC Regulatory Guides as appropriate. |
| 1.7 Demography | |
| Population density | Uniform 500 people/mi$^2$ out to 30 miles, consistent with Reg. Guide 4.7 (tentative). |

(a)Site characteristics which envelope 85% of prospective U.S. sites. Other characteristics are reference values.

(b)Value applicable to large mat foundations, not isolated footings.

Table 1-4 (Continued)

| | |
|---|---|
| 1.8 Boundaries[a] | |
| Exclusion area boundary (EAB) | 425 m, minimum from reactor release point. |
| Protected area boundary (PAB) | To be determined by site layout. |
| Low population zone (LPZ) | 425 m (same as EAB). |
| Emergency planning zone (EPZ) | 425 m (same as EAB). |
| 1.9 Water Sources | |
| Water | Nonbrackish river water (see Table 2.1-3 for analysis). |
| 1.10 Elevation | |
| Nuclear Island[a] | 100 to 6000 ft above mean sea level. |
| Energy Conversion Area | 100 ft above mean sea level. |
| 2. Site Events | |
| 2.1 Seismic[a] | |

| Maximum ground acceleration: | Horizontal | Vertical |
|---|---|---|
| Safe shutdown earthquake | 0.3 g | 0.3 g |
| Operating basis earthquake | 0.15 g | 0.15 g |

| | |
|---|---|
| 2.2 Tornado[a] | |
| Designation (RG 1.76) | Region I |
| Maximum wind speed | 360 mph |
| Rotational speed | 290 mph |
| Translational velocity | 70 mph |
| External pressure drop | 3.0 psi at 2.0 psi/s |
| 2.3 Flooding | No special provisions required. Maximum probable flood level below plant grade. |
| 2.4 Aircraft hardening | No specific provisions required. Plant considered to be outside of commercial flight paths. |

[a] Site characteristics which envelope 85% of prospective U.S. sites. Other characteristics are reference values.

## 1.2.5 Instrumentation and Control Requirements

Provisions shall be made to automatically detect and document the sequence of significant events (e.g., control inputs, changes in operation of major systems and components, protective trips, etc.) that occur during plant operation. (3701.0102.043)

Portions and/or derivations of those observations required for controlling NSSS energy production, shutdown, refueling and startup/shutdown from a single control room shall be made available for use by the PSCS and the operators. (3701.0102.044)

The NSSS control subsystem shall be capable of evaluating and determining the state of the NSSS and the corresponding module-level control state maneuvers required for energy production, shutdown, refueling and startup/shutdown control. (3701.0102.045)

The NSSS control subsystem shall provide the capability to automatically regulate conditions (e.g., pressure, flow, temperature, etc.) of the steam produced and delivered by each reactor module. (3701.0102.046)

The NSSS control subsystem shall provide the capability to control those actuators and devices required to effect a change in state in the NSSS during energy production, shutdown, refueling and startup/shutdown. (3701.0102.047)

The NSSS control subsystem shall be designed to accept directions corresponding to energy production and conversion load demand changes at rates anywhere from a minimum of [TBD % per minute] to a maximum of 5%/minute. (3701.0102.048)

The NSSSCS shall be capable of accepting plant energy production, shutdown, refueling and startup/shutdown instructions from the control room operators and operator workstations. (3701.0102.049)

The NSSS control subsystem shall acknowledge and process other subsystem variables, states, modes, performance limits, conditions, etc., in the energy production, shutdown, refueling and startup/shutdown analysis and decision making process. (3701.0102.050)

The NSSSCS shall provide the capability to communicate digital control and monitoring signals using non-hardwired, signal transmission techniques. (3701.0102.051)

The NSSSCS shall be designed to accept startup directions corresponding to rated load demand changes at rates anywhere from a minimum of [+TBD] % per minute to a maximum of [+TBD] % per minute. (3701.0102.052)

The NSSSCS shall be designed to accept shutdown directions corresponding to rated load demand changes at rates anywhere from a minimum of [-TBD % per minute]. (3701.0102.053)

Provisions shall be made for monitoring NSSS status, configuration, and performance as a basis for maintenance diagnostics and decision making. (3701.0102.054)

The NSSSCS shall provide the capability to sense, process, and analyze those variables, states, modes, limits, conditions, etc., required for the NSSS to be observable. (3701.0102.055)

The NSSSCS shall monitor the SFSF temperature and report to the main control room if temperature exceeds [TBD]. (3701.0102.410)

The NSSSCS shall perform [TBD] calculations utilizing the signals from the neutron detection equipment. (3701.0102.420)

The NSSSCS shall monitor the number of control rods withdrawn during shutdown and issue an alarm report to the main control room if more than three are withdrawn. (3701.0102.425)

The NSSSCS shall monitor and report steam generator feedwater inlet temperatures in excess of 371°C (700°F) to the main control room. (3701.0102.450)

The NSSSCS shall monitor and report steam generator feedwater inlet pressure in excess of 25.4 MPa (3685 psia). (3701.0102.460)

The NSSSCS shall monitor and report steam generator outlet pressure in excess of 18.9 MPa (2750 psia). (3701.0102.465)

Human engineering techniques shall be employed in the design of the NSSSCS to enhance operator response and reduce the probability of human error as specified in the Human Factor Engineering Plan [TBD]. (3701.0102.056)

Supporting controls and instrumentation for systems, structures, or components whose failure would not have an immediate impact on plant output shall be located outside the control room in the proximity of the systems, structures, or component with status indication provided to the control room. (3701.0102.057)

### 1.2.6 Surveillance and In-Service Inspection Requirements

This subsystem does not perform a "safety-related" function and, therefore, no "safety-related" surveillance and/or in-service inspection is required.

Requirements in this category, needed to satisfy the Integrated Approach Goals 1, 2, and 3, are covered under "Maintenance Requirements" in Section 1.2.8.

### 1.2.7 Availability Assurance Requirements

The Effective Forced Outage Hour (EFOH) values specified for the NSSSCS in Reliability Allocations for the Standard MHTGR shall not be exceeded when using a model employing equipment mean time to failure and mean time to repair data for like type or similar systems and/or components. The NSSSCS shall be designed to meet a planned outage allocation of [TBD] hours. (3701.0102.060)

The NSSSCS shall be designed to meet the reliability requirements specified in Reliability Allocations for the Standard MHTGR and the Investment Protection Performance Requirements for the Standard MHTGR. The NSSSCS shall be designed to meet an overall reliability allocation of [TBD]. (3701.0102.061)

### 1.2.8 Maintenance Requirements

Internal diagnostic monitoring to detect malfunctions shall be incorporated within the NSSSCS. (3701.0102.058)

Malfunctions within major plant control and electric systems shall be alarmed in the main control room. (3701.0102.059)

The NSSSCS shall provide self-test capabilities (i.e., monitoring, checking, and diagnosing) for key functional components. (3701.0102.560)

Provisions shall be made for monitoring NSSS status, configuration, and performance as a basis for maintenance diagnostics. (3701.0102.570)

The NSSSCS shall be designed and arranged, and equipment and components located in the plant to facilitate on-line maintenance. (3701.0102.062)

The NSSSCS components shall be designed to facilitate hands-on maintenance. (3701.0102.063)

The NSSSCS shall be configured to enable maintenance of NSSSCS equipment within a plant total scheduled outage time of less than 876 h per year averaged over the plant lifetime as defined in OPDS Table 5.1-4. (3701.0102.064)

NSSSCS components shall be classified to reduce the number of different types, sizes, and temperature and pressure ratings in order to reduce the cost of spare parts inventory. (3701.0102.065)

Special NSSSCS maintenance and installation tools not commercially available shall be provided by the NSSSCS equipment vendor. (3701.0102.066)

The NSSSCS shall make provisions for removing a reactor from service, performing maintenance and returning it to service with the remaining reactors and the turbine plant in operation. (3701.0102.580)

### 1.2.9 Safety Requirements

[The NSSSCS is not a "safety-related" subsystem. Therefore, it has no nuclear "safety-related" requirements.]

The NSSSCS shall be designed to meet applicable top-level regulatory criteria. (3701.0102.590)

### 1.2.10 Codes and Standards Requirements

NSSSCS design, analysis, fabrication, and construction shall comply with applicable codes and standards that are needed to meet the four goals of the Integrated Approach. All such applicable codes and standards shall be identified and documented in component design specifications and other appropriate documentation during the design effort. Applicable state and local government regulations, codes and standards shall be identified and documented subsequent to the time a specific site is identified. Use of all codes and standards shall be justified in appropriate lower level design documents. The specific codes and standards that have been selected to date as being applicable to the overall plant are as follows:

ANSI/ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities.

DOE NE F2-10, Quality Assurance Program Requirements (Supplement to ANSI/ASME NQA-1). (3701.0102.067)

1.2.11 Quality Assurance Requirements

Items that are not "safety-related" shall come under a Quality Assurance Program which complies with selected basic requirements and supplements of ANSI/ASME NQA-1 and the four additional supplements from DOE NE F2-10 regarding Management Assessment (NE 02-4.3.0), Engineering Holds (NE 03-1.3.2), Design Reviews (NE 03-1.3.4), and Engineering Drawings Lists (NE 03-1.3.5). (3701.0102.068)

1.2.12 Construction Requirements

Shop, factory, or field fabricated, assembled, and erected components and subsystems shall be utilized as appropriate to reduce costs and enhance quality control. (3701.0102.069)

The NSSSCS design shall be based upon parallel construction of the complete plant; features shall be included that facilitate construction and startup in increments of two standard reactor modules and one turbine.

(3701.0102.070)

1.2.13 Decommissioning Requirements

The NSSSCS shall include features that accommodate decommissioning or refurbishment of one reactor while maintaining others in operation.

(3701.0102.080)

# SECTION 2

# DESIGN DESCRIPTION

## 2.1 SUMMARY DESCRIPTION

The NSSS Control Subsystem (NSSSCS) is a complete control, display, and information system. The MHTGR plant contains four such subsystems, each being a part of a particular NSSS module, and each being able to control the module steam conditions and flow independently of the other modules. Each subsystem contains redundant control processing hardware and software. Each subsystem provides distributed digital process control, information processing, display, and data storage capabilities. The scope of supply includes sensors for control and monitoring, hardware and software that provide control logic and outputs to final control elements, and equipment necessary to process, display, and store plant data. The NSSSCS communicates with a plant supervisory control system (PSCS) through an interface between the NSSSCS and the PSCS data highway. The NSSS data highway system, local microprocessors and cabinets are all part of the NSSSCS. Figure 2-1 shows the buildings where the NSSS control equipment is located. Signal processing, control logic execution and data processing for each NSSS module is performed in each reactor building. Limited operator interfaces are located in each reactor building. NSSS module operator interfaces are located in a separate building close to the reactor building.

Each NSSSCS processes approximately 1100 analog and digital variables as explained in Section 2.2.

The architecture within the Plant Control Data and Instrumentation system is shown in Figure 2-2. The architecture within the NSSSCS and its interface with the PSCS are shown in Figure 2-3.

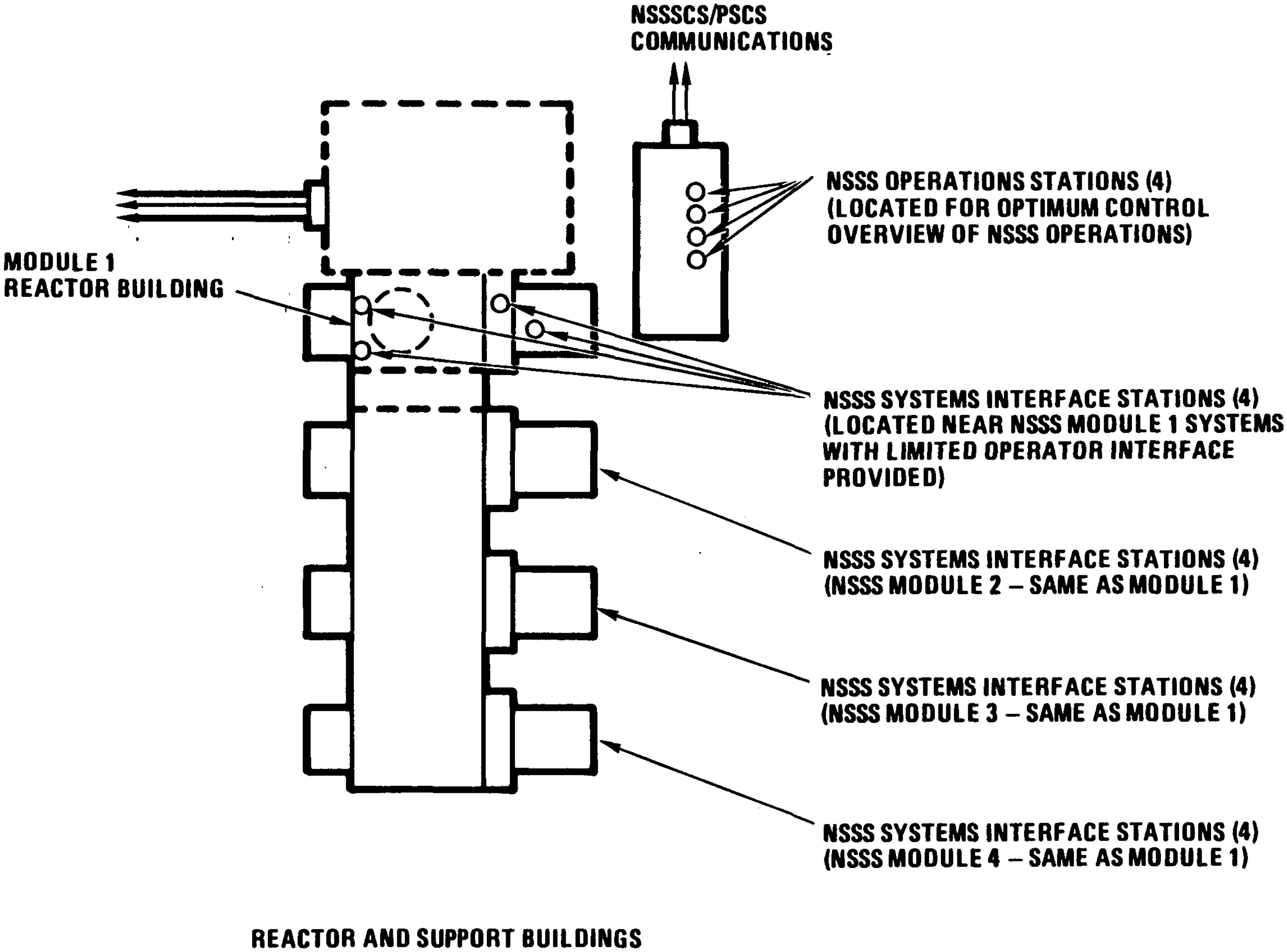


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Fig. 2-1. MHTGR BUILDINGS AND NSSS CONTROL SUBSYSTEM

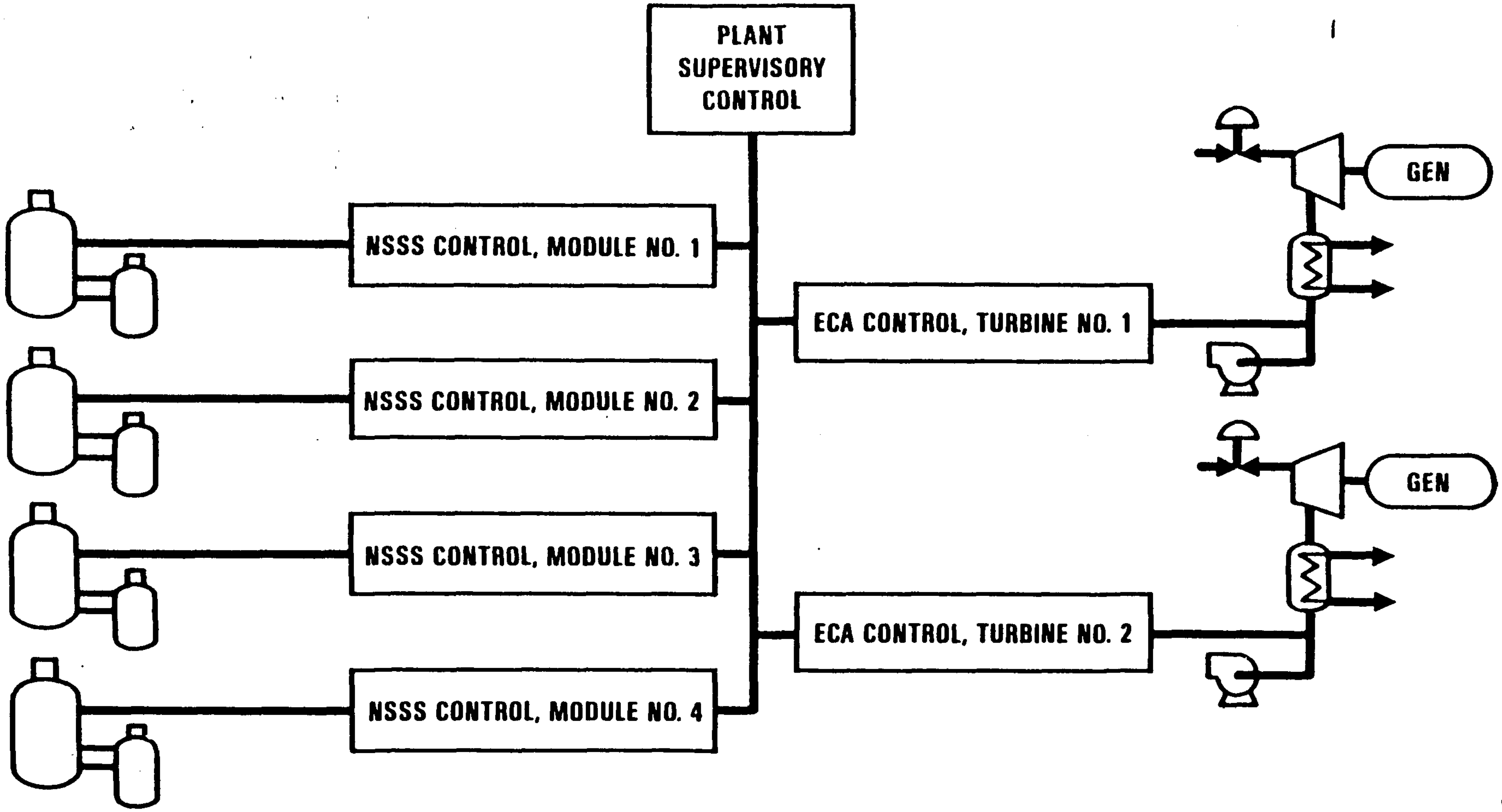


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Fig. 2-2. CONTROL SYSTEMS WITHIN PCDIS

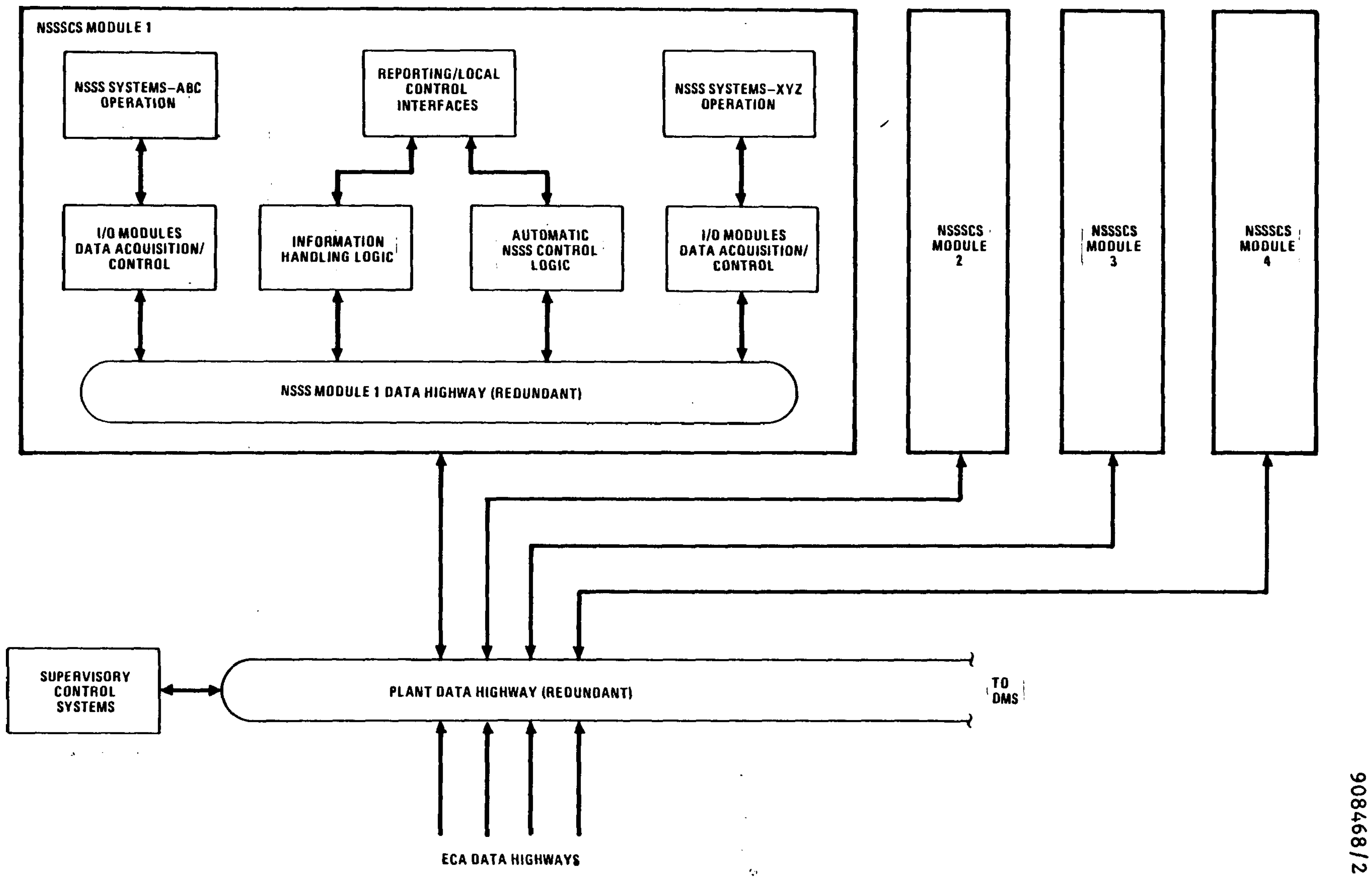


Fig. 2-3. NSSS CONTROL SUBSYSTE CHITECTURE AND INTERFACES

The NSSSCS is functionally independent of the PPIS except that it is notified by the Plant Protection System via a unidirectional isolator of any equipment trips so that the NSSSCS can continue to adjust its parameters within acceptable operating ranges outside of trip ranges.

## 2.2 SUBSYSTEM CONFIGURATION

The five major functions of each NSSSCS are:

1. Accept direction from the PSCS or from operator.
2. Observe the status of the NSSS.
3. Make all control decisions for automatic NSSS response.
4. Provide output command signals to NSSS actuators and hardware control units.
5. Report information.

The design selections to perform these functions and the requirements they satisfy are discussed in the following sections.

### 2.2.1 Direction Acceptance

To follow direction from the plant supervisory control system or the operators, the NSSSCS automatically accepts load setpoints in the power operating range, or HOLD setpoints in the startup and shutdown range. These HOLD setpoints define the startup and shutdown sequences of the NSSS. Load setpoints and HOLD points are communicated over the data highways depicted in Figure 2-3.

### 2.2.2 Status Observation

The NSSSCS automatically detects and documents the sequence of significant operational events (e.g., changes in operation of major systems and components), that occur during plant operation. It acknowledges and processes other NSSS system variables, states, modes, performance limits, conditions, etc., in the energy production, shutdown, refueling and startup/shutdown modes.

Table 2-1 shows the data parameters in each NSSS module that are monitored or controlled. There are about 1100 of these parameters in each module. The control variables are processed through control algorithms, and outputs are sent to the control actuators. The fastest cycle time required for this process is 500 ms.

Many of the parameters in Table 2-1 are measured, calculated, or actuated by devices that are part of other NSSS systems. However, they have been included in Table 2-1 for completeness in the total count of NSSS parameters to be monitored or controlled. For example, the Shutdown Cooling Control Subsystem is dedicated to and part of the Shutdown Cooling System; however, it has a reporting line to the NSSSCS. Therefore, Shutdown Cooling System information is passed to the NSSSCS via the Shutdown Cooling Control System Subsystem. Thus, there is a hierarchy of control which supports the modularity of the fluid and mechanical systems.

### 2.2.3 Automatic Control Decision Making

Based on the sensed data and the direction from the PSCS or the operator, the NSSS Control Subsystem automatically decides what control actions are used within each NSSS module to produce steam. The definition of these actions forms the control scheme. These actions are:

1. Control steam production process in accordance with plant electrical output and allocation of the total demand to each NSSS module.

Table 2-1 NSSS CONTROL AND DATA SIZE

| | Monitored and Controlled Analog Variables | Monitored Analog Variables | Monitored On-Off Variables | Controlled On-Off Variables |
|---|---|---|---|---|
| 1. Reactor: | | | | |
| Core support deflection. | | 25 | | |
| Vessel temperature. | | 30 | | |
| Helium inlet temperature. | | 4 | | |
| Helium outlet temperature. | | 4 | | |
| Core pressure differential. | | 6 | | |
| Rod in. | | | 60 | |
| Rod out. | | | 60 | |
| Rod position. | | 60 | | |
| Cable tension. | | 60 | | |
| Rods motor on-off. | | | 60 | 30 |
| Rod holding voltage. | | 4 | | |
| Mechanism temperature. | | 36 | | |
| Wide range log power. | | 18 | | |
| Linear power. | 1 | 12 | | |
| 2. Steam Generator: | | | | |
| Circulator motor exciter temperature. | | 6 | | |
| Circulator shaft vibration/displacement. | | 16 | | |
| Rotor axial position. | | 2 | | |
| Motor exciter voltage. | | 6 | | |
| Motor exciter current. | | 6 | | |
| Circulator buffer helium supply flow. | | 2 | | |
| Motor Cooling water flow. | | 2 | | |
| Motor control breaker position. | | | 2 | 1 |

Table 2-1 (Continued)

| | Monitored and Controlled Analog Variables | Monitored Analog Variables | Monitored On-Off Variables | Controlled On-Off Variables |
|---|---|---|---|---|
| Magnetic bearing current. | | 10 | | |
| Magnetic bearing voltage | | 2 | | |
| Circulator compressor ΔPs. | | 4 | | |
| Cooling water temperature, outlet. | 1 | 1 | | |
| Cooling water temperature, inlet. | | 2 | | |
| Cooling water shutoff valve position. | 2 | | | |
| Module main steam temperature. | 1 | 3 | | |
| Module steam pressure. | 1 | 3 | | |
| Circulator RPM. | 2 | 2 | 4 | |
| FW flow, inlet. | 1 | 3 | | |
| Primary coolant helium flow rate. | | 3 | | |
| Helium pressure, inlet | 1 | 3 | | |
| Helium pressure, outlet. | | 3 | | |
| Helium temperature, circulator inlet | | 3 | | |
| Helium temperature, outlet | | 6 | | |
| Feedwater flow control valve position. | 1 | 3 | | |
| Main loop shutoff valve position. | | 4 | | |
| Main loop shutoff valve actuation pressure | | 1 | | |
| Main loop shutoff valve actuation valve position | | 1 | | |
| FW header pressure, inlet. | | 4 | | |
| ΔP FW/steam. | | 4 | | |
| FW temperature, inlet. | | 4 | | |
| Isolation and startup valve positions. | | | | 20 |
| Isolation and startup breaker positions. | | | | 20 |
| 3. Shutdown Cooling System: | | | | |
| Helium pressure, inlet. | | 3 | | |
| Helium pressure, outlet. | | 3 | | |
| Flow ΔP. | | 3 | | |
| Motor bearing temperature. | | 3 | | |

Table 2-1 (Continued)

| | Monitored and Controlled Analog Variables | Monitored Analog Variables | Monitored On-Off Variables | Controlled On-Off Variables |
|---|---|---|---|---|
| Cooling water, temperature, inlet. | | 2 | | |
| Cooling water, temperature, outlet. | 1 | 2 | | |
| Cooling water flow. | | 2 | | |
| Helium temperature, inlet | | 3 | | |
| Oil reservoir level. | | 3 | | |
| Cooling water pressure. | | 3 | | |
| SCS motor RPM. | 1 | 3 | | |
| Shutdown loop shutoff valve position. | 1 | 2 | | |
| CW valve position, inlet. | | | 2 | |
| Motor current. | | 2 | | |
| CW valve position, outlet. | | | 2 | |
| Motor control breaker position. | | | 2 | 1 |
| Motor voltage. | | 2 | | |
| Isolation and start-up valve positions. | | | | 20 |
| Isolation and start-up breaker positions. | | | | 20 |
| 4. Helium Purifications System: | | | | |
| Water temperature. | | 2 | | |
| Pressure, $N_2$. | | 2 | | |
| Water level. | | 2 | | |
| Heater status (on/off). | | | 4 | 1 |
| Relief valve position. | | | 4 | 1 |
| $N_2$ inlet valve position. | | | 2 | 1 |
| Water inlet valve position. | | | 4 | 1 |
| Helium storage pressure. | | 2 | | |
| Helium shutoff valves. | 2 | | 2 | 1 |

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Table 2-1 (Continued)

| | Monitored and Controlled Analog Variables | Monitored Analog Variables | Monitored On-Off Variables | Controlled On-Off Variables |
|---|---|---|---|---|
| 5. Service Water System: | | | | |
| Valve position, inlet. | | | 4 | 1 |
| Valve position, outlet. | | | 4 | 1 |
| Water flow. | | 2 | | |
| Water pressure. | | 2 | | |
| Service water temperature, inlet. | | 2 | | |
| Service water temperature, outlet. | | 2 | | |
| Isolation and startup valve, position. | | | | 20 |
| Isolation and startup breaker position. | | | | 20 |
| 6. Reactor Cavity Cooling System: | | | | |
| Air temperature, inlet duct. | | 12 | | |
| Air temperature, outlet duct. | | 12 | | |
| Flow, outlet duct. | | 6 | | |
| Air temperature in top of cavity. | | 6 | | |
| Air temperature on middle of cavity. | | 3 | | |
| Air temperature on floor of cavity. | | 3 | | |
| Pressure in cavity. | | 3 | | |
| 8. Miscellaneous: | | | | |
| Cross duct temperatures. | | 20 | | |
| Concrete temperatures pressures. | | 40 | | |
| Cross duct pressure. | | 20 | | |
| Helium purification pressures. | 1 | 8 | | |
| Helium purification temperatures. | | 6 | | |
| Fuel handling, equipment position. | 12 | 32 | 60 | 40 |
| TOTALS | 30 | 597 | 276 | 199 |

2. Adjust NSSS operating conditions to accommodate plant configuration changes.

3. Stabilize the NSSS module under transient conditions.

The design selections to accomplish the above three actions are discussed in the following sections. (Table 3-3 shows the design selection for automatic control. Since these design selections translate into component-level requirements, the table has been located in the component requirements section of this document.)

### 2.2.3.1 Regulation of Steam Conditions

Each NSSS module is required to deliver 2400 psig, 1000°F steam to the high pressure turbine admission valves. In order to meet this requirement, each NSSS control subsystem regulates circulator speed (helium flow), reactor power and module feedwater flow. By providing automatic and continuous control adjustment of these parameters, the NSSS control system meets its required capability to deliver the demanded amount of steam at the required temperature and pressure (1000°F, 2400 psig). The command signals for adjusting these parameters are the output of the control subsystem.

The plant is required to change reactor and plant output under automatic control at a rate of up to and including 5% of rated output per minute of those reactors on line: Therefore, each NSSS module is able to change its output at a rate up to and including 5% per minute of rated output.

Additionally, in order to enter or leave the power production mode, each reactor module must be controlled automatically through the range of 0% to 25% of rated feedwater flow. This control is accomplished also by adjusting module feedwater flow, circulator speed and reactor power, plus additional parameters which include the steam generator isolation valve positions (inlet and outlet), startup bypass valve positions, and control rod and control rod bank configurations.

Figure 2-4 shows the basic NSSS control scheme and the major interfaces with other systems. For simplicity, the diagram shows a single reactor control unit. The heavier lines show the process system.

The primary control outputs from the NSSS are the circulator motor speed setpoint, the reactor flux setpoint, the module feedwater flow setpoint and control valve position (in lower part of fluid flow system), the steam generator exit isolation valve position (directly above feedwater flow control valve) and the startup bypass valve (to right of exit isolation valve). The turbine throttle valve control referred to on Figure 2-4 is part of the ECA (see Ref. 7). The primary control input to the NSSS from the PSCS is the load index shown by the downward arrow at the top of Figure 2-4. The primary control sub-modules are identified by name in the boxes shown on Figure 2-4.

2.2.3.2 Adjustment to Plant Configuration

The control system must be able to operate reactor modules independently of one another. The plant Supervisory Control Subsystem or the operators can schedule the desired even or uneven load distribution, and each NSSS Control Subsystem drives its NSSS module to its allocated load regardless of the status of the other modules. Module-to-module control independence is achieved by manipulating module feedwater flow individually in each module and using module feedwater flow as a module load index. Figure 2-5 illustrates this feedback control concept, which passes throttle pressure feedback requirements to the ECA in Section 4 of this document. Decoupling of interactions between the ECA and the NSSS module via this method of control contributes to plant stability. As Figure 2-5 shows, control of each module is independent of other modules and the ECAs.

Similarly, the NSSS control design makes provisions for the automatic removal and return of one or more reactor modules from service to perform maintenance or refueling, and return it to service with other reactors and turbines in operation. This removal and return is through a sequence of hold points discussed in Section 2.3.1.1.

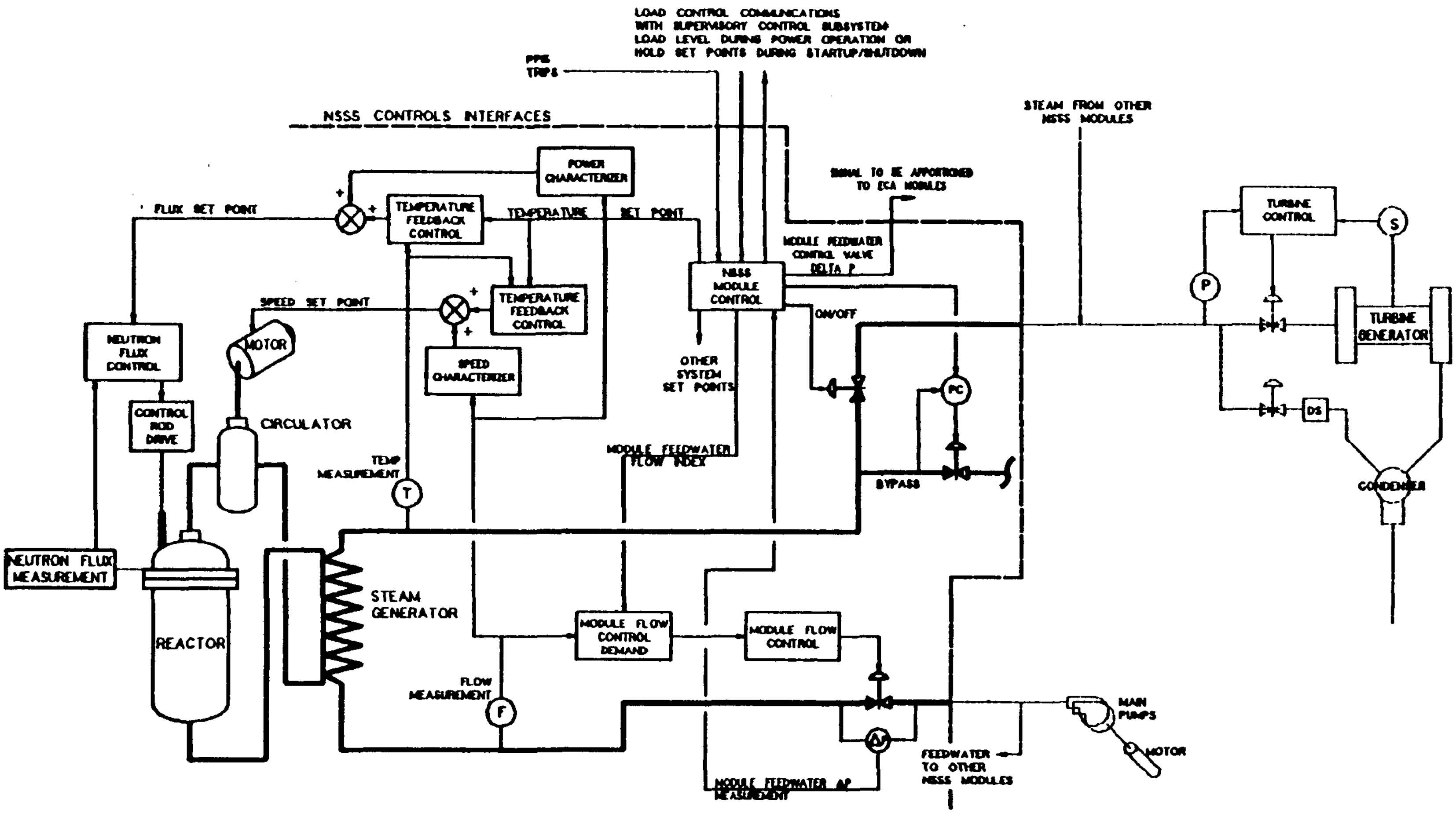


Fig. 2-4 NSSS CONTROL SCHEME AND INTERFACES

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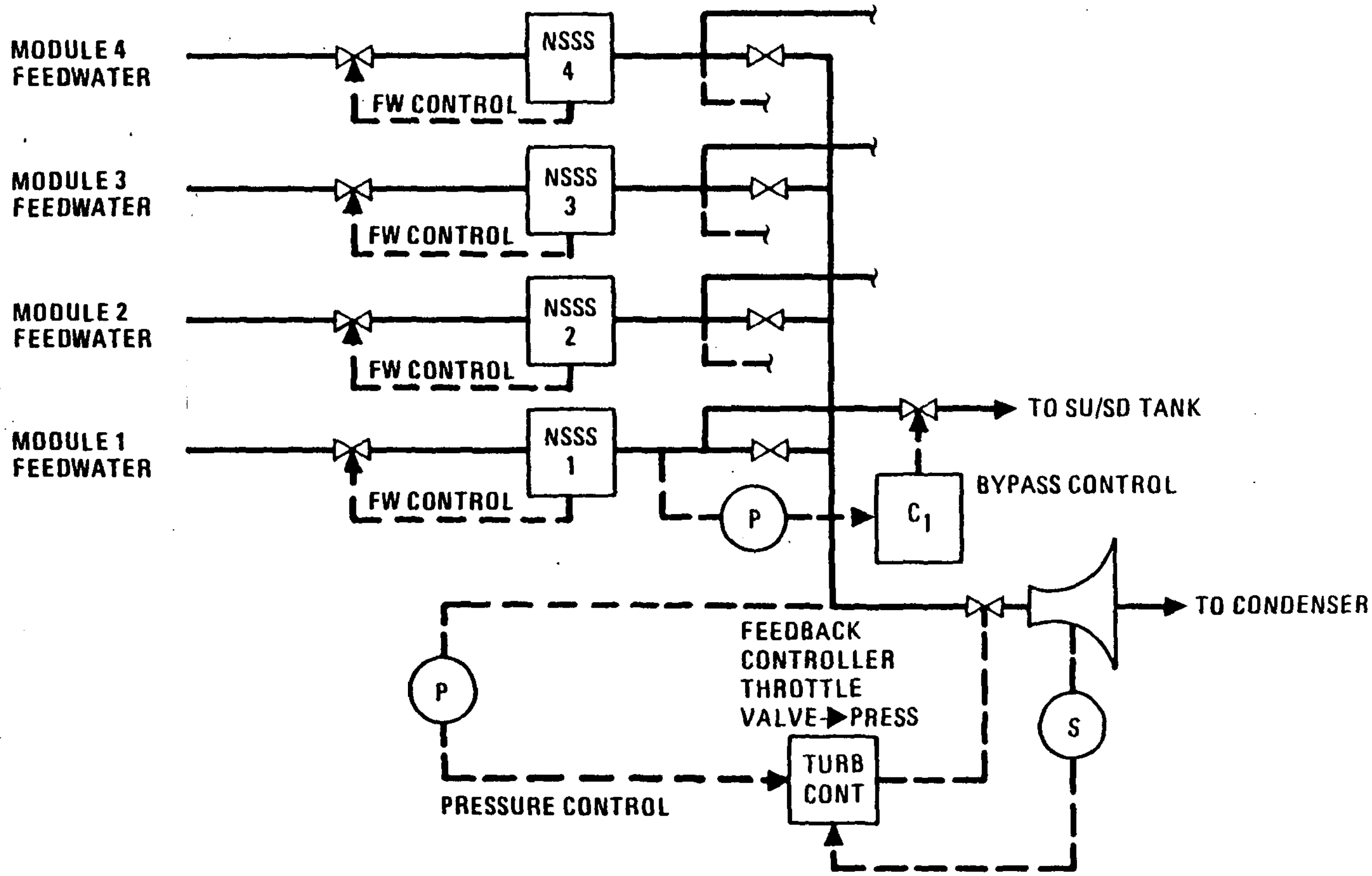


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Fig. 2-5. INDEPENDENT MODULE FEEDWATER CONTROL, AND THROTTLE PRESSURE FEEDBACK TO THROTTLE VALVE.

2.2.3.3 Control System Stability

A detailed assessment of control system design selection trade-offs regarding true control stability provided by the control algorithms was provided during the conceptual design. The NSSS control scheme of Figure 2-4, along with specific control algorithms discussed in Section 3.0 and the interfacing ECA controller actions (Figure 2-5) provide the basic stability for the NSSS under any condition of change. The ability of the plant to provide sustained and controlled operation for the conditions below has been investigated and documented as part of the design process. Reference 1 contains the transient calculations which show plant stability with the NSSS Control Subsystem. The following specific requirements are satisfied by the NSSS control scheme:

1. Load rejection from full generator electric output to house electrical load without receiving a reactor trip signal.

2. Turbine trip (except on low condensor vacuum) from any load level without receiving a reactor trip signal. Continuous reactor operation at reduced output must be provided.

3. Step changes of ±15% of plant output caused by utility electrical transmission grid frequency impacts.

Additionally, the NSSS controls are designed to operate through the design transients specified in the MHTGR Plant Design Basis Transient Analysis Report.

In meeting the above requirements, the NSSS performs within the transient limitations specified in Table 2-2. These limitations are design selections which become requirements (see Section 3.2.3). The system is also designed to control the helium mass flow through the active steam generator bundle between 25% and 100% of nominal feedwater flow for steady-state operation as specified in Table 2-3 whenever a transient event

Table 2-2 NSSS TRANSIENT CONTROL REQUIREMENTS

| Controller | Max Error from Setpoint | Range Limits | Rate Limits |
|---|---|---|---|
| Steam temperature | ±40°F | 25%-105% | -- |
| Steam pressure | ±50 psi | 2200-2700 psia | -- |
| Reactor power | ±20% | 10%-110% | 4%/s |
| Circulator speed | ±15% | 5%-110% | 4%/s |
| Turbine throttle valve | -- | -- | 7.5%/s |
| Feedwater flow rate | [TBD] | 15%-110% | 2%/s |

Table 2-3 CIRCULATOR CHARACTERIZER FUNCTION

| Feedwater (% Design) | Circulator[a] Speed (% Design) |
|---|---|
| 100 | 100.00 |
| 85 | 88.58 |
| 62.5 | 69.44 |
| 40 | 47.85 |
| 25 | 32.12 |

[a]Helium density correction = -2 rpm/% change in helium density at circulator inlet. Correction = 0.0 rpm at design condition.

occurs. These accommodations allow other plant systems to operate for the number of cycles specified in Table 5.1-3 of Ref. 2.

Each individual reactor module is capable of continuous operation under automatic control between 25% and 100% of nominal module feedwater flow and this supports the plant design requirement to sustain continuous operation through and following transients associated with the loss or failure of a major component, system, or train, including an individual reactor or turbine-generator.

### 2.2.4 Command Outputs

On the basis of the control decisions made, the NSSS Control Subsystem effects final control element action to bring steam conditions to desired levels. Figure 2-4 also shows the major NSSS control outputs: module feedwater flow control valve position, circulator motor speed input, and control rod position.

A preliminary design phase goal will be to develop detailed software interface requirements for the NSSS command/control hardware. Primary concerns will be maintenance and availability. The following design selections are directly applicable to requirements for the MHTGR design.

1. Systems will be designed and arranged and equipment and components located in the plant to facilitate on-line maintenance.

2. Systems and components will be designed to facilitate hands-on maintenance.

### 2.2.5 Information Reporting/Data System

The NSSS Control Subsystem generates display information regarding NSSS status and conditions, and provides it to the supervisory control system and the operator stations. Communications and status information made available at NSSS locations outside the control room as shown in Figure 2-1 allow for roving operators to control, under supervision from the control room, selected processes and control subsystems during energy production, shutdown, refueling, and startup/shutdown not requiring direct control room operator interfacing and interaction. The presentation formats for the data displays support the following activities:

1. Operations.
2. Test and Calibration.
3. Engineering Reporting.
4. Maintenance (hardware and software).
5. Management Reporting.

Each NSSS control subsystem module provides its own redundant data highway network which is be linked to the plant data highway network as shown in Figure 2-3. All failures of the data processing and control functions are automatically detected and reported.

NSSS information processing equipment includes computers for performance monitoring, status assessment, operator guidance, historical data base logs, calibration and equipment testing. Design selection trade-off studies to determine the hardware configuration were completed during the conceptual design. Two types of NSSS control system cabinets were determined and the functions of each are shown below.

| | Display | Control | Print | Removable Magnetic Storage |
|---|---|---|---|---|
| NSSS Module Operator Interfaces | X | X | X | X |
| Limited Operator Interfaces (Four Locations per Module) | X | X | | |

The basic features described above meet the following top-level requirements from Section 1.

1. Capability of evaluating and determining the state of the NSSS and the corresponding module-level control state maneuvers required for simultaneous energy production, shutdown, refueling and startup/shutdown control.

2. Incorporation of internal diagnostic monitoring within the NSSS control subsystem to detect malfunctions.

3. Main control room alarming of malfunctions within major plant control and electric systems.

The NSSSCS concept supports the requirement to develop a reporting scheme that limits control room alarms to critical parameters leading to protective action for major plant components or loss of electrical production. This effort will incorporate the following utility/user goals for plant staffing determined in Ref. 2, Section 2.1.1.

1. Administration, operation, and maintenance by minimum plant staff consistent with the plant availability and safety goals.

2. Permanent operating staff maximum of 50 full-time personnel. This staff would include first line supervisors, operating, and operations maintenance support personnel.

3. Maximum shift staff of:

   a. 1 - senior licensed supervisor.
   b. 2 - licensed reactor operators in the control room.
   c. 4 - roving operators.

4. Evaluation of required operator response for each anticipated operating staff position. This evaluation shall be used to confirm that operator staffing is consistent with anticipated work loads and response times for normal, off-normal, and emergency conditions.

5. Permanent technical and security staff (excluding administrative and clerical staff) maximum of 70 full-time personnel. This staff would include first line supervisors and other personnel assigned in the categories of engineering, health physics, water and helium chemistry, laboratory staff, security, and other technical disciplines.

6. Permanent maintenance staff maximum of 75 full-time personnel. This staff would include first line supervisors and personnel assigned in the categories of mechanical, electrical, electronic and instrument maintenance, quality control, and stores and warehouse activities.

## 2.3 SUBSYSTEM PERFORMANCE CHARACTERISTICS

### 2.3.1 Subsystem Operating Modes

The NSSS control subsystem is in service during the following operations:

1. Startup and shutdown.
2. Normal operation.
3. Refueling.
4. Shutdown.
5. Abnormal operation.

The primary function is to control the NSSS to the required conditions during each of these operations.

2.3.1.1 Startup and Shutdown. Startup and shutdown covers the range of operating conditions encountered in the 0% to 25% module feedwater flow range. (See Table 5.3-3 of Ref. 2. Level of service "A" events 1 through 4.)

Dedicated equipment and provisions are used in the NSSS to startup and shutdown a module. For example, wide range nuclear flux instrumentation is provided to monitor and control core power from the source range up to the design power range. The total flux range spans several orders of magnitude (decades). Interfacing ECA actions are performed to startup and shutdown a reactor module. For example, the module steam bypass system allows hot water and steam produced during the startup and shutdown sequences to bypass the main steam header. To route the hot water and steam into this bypass, the module isolation valve, and bypass valve operate in a synchronized fashion. In order to allow independent operation of reactor modules, each module is equipped with its own bypass.

During startup or shutdown, the module main steam isolation and check valve is closed. This allows other reactor modules that may be on line to continue supplying steam to the turbine for power generation. Steam from the isolated module is passed via the module startup bypass valve to a flash tank. The bypass valve is modulated to control system pressure at the steam generator outlet through a pressure range of 700 to 2600 psia at the steam generator outlet.

The hot steam generator water and steam outlet temperatures during startup (and shutdown) ranges from 80°F subcooled liquid to rated 1005°F superheated steam. This temperature is controlled by the NSSS Control Subsystem by varying module feedwater flow, reactor power, and circulator speed. Feedwater inlet temperature is controlled by the ECA. During startup, the feedwater temperature ranges from 80°F to 380°F, while other modules operate with feedwater at the design temperature of 380°F. A startup feedwater system (part of the ECA) generates the appropriate feedwater temperature as demanded by the NSSS Control. The requirements for ECA control of this temperature are a control system interface which is identified in Section 4.

When a module reaches rated steam conditions in the startup sequence and it is requested by the Supervisory Control System to transfer its flow of steam into the main steam header for use by the turbines, the NSSS Control Subsystem raises the module steam pressure via the startup bypass control valve control, above the main steam header pressure. This results in a slow closure of the module startup bypass valve and opening of the isolation check valve.

Table 2-4 shows the current planned startup sequence of a reactor module from depressurized helium conditions. The module is controlled automatically through a set of HOLD points that define the startup and shutdown sequences. During shutdown, special control gains are selected to allow automatic control of temperature with outlet steam conditions below rated values and feedwater flow less than 25%.

### 2.3.1.2 Normal Operation

Normal operation takes place in the load range between 25% and 100%. (See Table 5.1-3 of Ref. 2. Level of service "A" events 5 through 12 and level of service "B" events 15 and 16.) A brief description of steady state performance is contained in Section 2.3.2 and a description of response to plant transients is contained in Section 2.3.3. Reference 1 may also be consulted for information on transient events.

During normal operation, the NSSS load level setpoint is under continuous command from the PSCS. The NSSS Control Subsystem will respond automatically to this command. The NSSS control subsystem also allows operator command through consoles located within the nuclear island (see Section 2.4). This mode is under administrative control from the control room operators.

### 2.3.1.3 Shutdown

The NSSS Control Subsystem can enter one of two module shutdown modes; pressurized decay heat removal or depressurized decay heat removal. In the pressurized shutdown mode, the NSSS Control Subsystem automatically holds

Table 2-4
NSS MODULE STARTUP SEQUENCE FROM DEPRESSURIZED CONDITIONS

| Time (h) | Action |
|---|---|
| STARTING POINT INITIATED FROM MAIN CONTROL ROOM | |
| 0-0.5 | Establish secondary pressure (startup bypass setpoint) to 1200 psia (17 psi/min) |
| 0-5 | Pressurize primary coolant vessel, perform precritical checks, and bring reactor to critical (0.5% power) |
| 5-5.8 | Increase feedwater flow to 15% (0.25%/min)<br>Increase reactor power to 3% (0.053%/min)<br>Increase circulator speed from 5% (minimum value) to 12.5% (0.16%/min) |
| 6-10 | (Hold at about 400°F steam generator secondary outlet temperature for feedwater cleanup and reactor vessel warmup as necessary) |
| HOLD TO ALLOW OPERATOR CLEARANCE TO CONTINUE | |
| 10-10.5 | Increase secondary pressure to 1800 psia (20 psi/min) |
| 11.1-13.8 | Increase feedwater temperature from 220°F to 380°F (1.0°F/min) |
| 11.1-12.8 | Increase power to 7% (0.039%/min) |
| HOLD TO ALLOW OPERATOR CLEARANCE TO CONTINUE | |
| 12.8-13.3 | Increase power to 16% (0.30%/min). Increase circulator speed to 30% (0.58%/min) |
| 13.0-13.6 | (Transition to boiling) |
| 14.3-16.3 | Decrease reactor power to 14.7% (0.011%/min) |
| 14.5-18.6 | (Hold at about 800°F main steam temperature for secondary component warm-up as necessary) |
| HOLD TO ALLOW OPERATOR CLEARANCE TO CONTINUE | |
| 18.1 | Place reactor power and circulator speed in automatic main steam temperature control (setpoint at 826°F) |
| 18.6-20.1 | Ramp main steam temperature setpoint to 1005°F (2.0°F/min) |

Table 2-4 (Continued)

| Time (h) | Action |
|---|---|
| 19.1-20.1 | Increase secondary pressure setpoint to 2450 psia (11 psi/min) |
| HOLD TO ALLOW OPERATOR CLEARANCE TO CONTINUE | |
| 20.1-20.8 | Stabilize module parameters and transfer steam flow from startup bypass to main steam header. Place feedwater flow in automatic control |

circulator speed at 20% of design and feedwater flow at 15% of design. These conditions are sufficient to avoid core recirculation and to maintain subcooled conditions at the steam generator outlet.

In the depressurized shutdown mode, the NSSS Control Subsystem automatically holds circulator speed at 100% of design and supplies enough feedwater flow so boiling does not occur in the steam generator. The NSSS Control Subsystem is configured to allow core decay heat removal at subatmospheric reactor pressure. Helium is circulated through the module main loop in a balance with feedwater flow so that no boiling occurs in the steam generator and core outlet helium temperature remains less than 240°F. This is accomplished automatically by the NSSS Module Control Subsystem after reactor depressurization and on receipt of a refueling mode enable.

#### 2.3.1.4 Refueling

The NSSS is configured to allow core decay heat removal via the SCS during refueling at subatmospheric reactor pressure. Helium is circulated and heat is extracted through the SCS heat exchanger. The SCS is placed on-line automatically by the NSSSCS after reactor depressurization and on receipt of a refueling mode enable.

When a reactor module is in the refueling mode, the primary function of the NSSSCS is data acquisition and information reporting to the PSCS. Many monitoring and control functions are administratively allowed at the reactor area. Most of the human interface are through the NSSS control console near the refueling area.

#### 2.3.1.5 Abnormal Operation

Abnormal operation includes all operation not described above. Section 2.3.3 contains a brief description of NSSS control response to several abnormal events (e.g., B and C events identified in Table 5.3-3 of Ref. 2).

Reference 1 contains additional information on transient response to abnormal events.

In this mode of operation, the control hierarchy of the PSCS and the NSSCS can be reversed. The NSSSCS responds directly to keep the affected module within its operating range when it is notified of an abnormal event through the PPIS data interface (see Section 4). However, the PSCS is informed by the NSSCS of the situation simultaneously, and it may cause other unrestricted NSSS modules to make up for any loss of load in the affected module. The control system actions are entirely independent of the PPIS, and are not part of or necessary to the safety-related features of the plant.

Two additional features of the NSSSCS design address response to abnormal events. These are as follows:

1. Design features are included to facilitate continued plant operation if a control failure occurs.

2. Features are included to limit recovery time when a protection trip occurs.

The above features are necessary to meet the NSSSCS availability allocation discussed in Section 3.

### 2.3.2 Subsystem Steady-State Performance

The NSSSCS controls steam conditions within the tolerances listed in Table 5.12-1 of Ref. 2 during all steady state operation. The system also monitors the NSSS performance based on the measurements listed in Table 2-1. Each NSSS Control Subsystem module provides information regarding the NSSS module performance through the data highways. The operators have access to this information, as well as other plant information. The

NSSS information is also available at local operator interfaces within the reactor operations area.

### 2.3.3 Subsystem Response to Plant Transients

Control of module main steam temperature is accomplished by the NSSS Control Subsystem by manipulating reactor power and circulator speed. Steam temperature is kept between 990°F and 1014°F during a 100% to 25% load ramping maneuver. One hour after initiation of this maneuver, main steam temperature deviations are negligible and reactor power deviations are within the control algorithm deadband. (See transient response Figure 2-5 through 2.8 of Ref. 1.) During a 15% step load change from full load, module main steam temperature control maintains temperature between 99°F and 1025°F (e.g., see transient response Figure 2.10a of Ref. 1). Special steam temperature controls used following a module reactor trip significantly limit thermal transients in the steam generator: by ramping down main steam temperature setpoint at rates beginning at 1.0°F/s from 1005°F to saturation, then returning circulator speed to feedforward demand through a 30 s time constant, the NSSS Control Subsystem tightly controls the removal of stored heat from the core and heat transfer into the secondary fluid. Runback and steam bypass functions allow individual operation of the remaining, untripped MHTGR reactor modules by the NSSS Control Subsystems. Reference 1 shows examples of reactor trip response. In load range operation, if one or more reactor trips occur, the feedwater flow to each tripped module is ramped back on a schedule by its NSSS Control Subsystem to 15%. The schedule is given in Table 3-3. Simultaneously, the Supervisory Control System is notified, and it causes the other reactor modules or the turbine load to adjust on a matching schedule to make the turbine load compatible with available flow from the untripped modules.

Compatible ECA settings for bypass and relief valves are required to obtain the predicted response for turbine trip. (See Figure 2.15a in Ref. 1.) The turbine bypass and startup bypass setpoints for load range operation are set for 2475 psig and 2575 psig, respectively in this example. The turbine bypass acts during turbine side upsets such as turbine trip, while the startup bypass acts during events such as startup, shutdown, and reactor trip. The isolation valve separates the module(s) from the main steam header on startup or shutdown.

### 2.3.4 Subsystem Failure Modes and Effects

Parts of the NSSS Control Subsystem are redundant and single failure proof. Therefore, a failure in one of these subsystem parts allows the system to respond correctly. A failure within the system is alarmed or identified during the routine surveillance testing of the system. The NSSS Control Subsystem is designed to operate correctly on disconnection of any failed parts of the system or loss of power.

Table 2-5 shows the preliminary failure modes and effects analysis for the major NSSS Control Subsystem loops.

## 2.4 SUBSYSTEM ARRANGEMENT

The location of NSSS control hardware and resulting requirements for access, HVAC, etc. which are imposed on nuclear island buildings come from the following requirements.

1. Location of controls in proximity of the system being controlled.
2. Controls and instrumentation/operator interface design to enhance operator response.
3. Individual personnel access for 40 h per week performance.
4. Seismic, site, and environmental requirements.

Based on the above requirements, plus the reliability and maintainability requirements of Section 1, the architecture design selection for the NSSS Control Subsystem is of the distributed digital type.

Table 2-5
FAILURE MODES AND EFFECTS ANALYSIS

| Failure Mode | Failure Effect | Detection Method | Remarks |
|---|---|---|---|
| Module Main Steam Temperature Control Output Fails: | | | |
| High: | Reactor power or circulator speed increases. Possible PPIS reactor module trip on high power to flow ratio. | Measured neutron flux, circulator speed and primary coolant flow. High main steam temperature alarm in NSSS control system. | Possible loss of one reactor module output. Remaining modules can operate at full output. Control hardware and software fault tolerance may allow minimum decrease in affected module output. |
| Low: | Reactor power or circulator speed decreases. Possible circulator speed to feedwater flow mismatch trip or main turbine trip on low steam temperature. | Measured neutron flux, circulator speed and main steam temperature. Low main steam temperature alarm in NSSS control system. | Possible loss of one reactor module output. Remaining modules can operate at full output. Control hardware and software fault tolerance may allow minimum decrease in affected module output. |
| Module Feedwater Flow Control Output: | | | |
| High: | Reactor module output increases beyond load allocated by the supervisory control system. Possible PPIS action on exceeding module load output limits. | High module load alarm in the supervisory control system. High feedwater flow alarm in NSSS control system. | Possible loss of one reactor module output. Remaining modules can operate at full output. Control hardware and software fault tolerance may allow minimum decrease in affected module output. |

Table 2-5 (Continued)

| Failure Mode | Failure Effect | Detection Method | Remarks |
|---|---|---|---|
| Low: | Reactor module output decreases to less than load allocated by the supervisory control system. Possible PPIS action on module parameters decreasing to less than investment or safety limits. | Low module load alarm in the supervisory control system. Feedwater flow error high alarm in NSSS control system. | Possible loss of one reactor module output. Remaining modules can operate at full output. Control hardware and software fault tolerance may allow minimum decrease in affected module output. |
| Reactor Power Control Command Output Fails: | | | |
| High: | Module reactor power increases. Group rod insertion occurs on high neutron flux. Possible PPIS action to trip module when parameters increase to investment or safety limits. | High measured neutron flux and main steam temperature alarm in the NSSS control system. | Possible loss of one reactor module output. Remaining modules can operate at full output. Control hardware and software fault tolerance may allow minimum decrease in affected module output. |
| Low: | Module reactor power decreases. Module primary and secondary coolant temperatures decrease. Possible PPIS action to trip module when parameters decrease to investment or safety limits. | Low measured neutron flux and main steam temperature alarm in the NSSS control system. | Possible loss of one reactor module output. Remaining modules can operate at full output. Control hardware and software fault tolerance may allow minimum decrease in affected module output. |

Table 2-5 (Continued)

| Failure Mode | Failure Effect | Detection Method | Remarks |
|---|---|---|---|
| Circulator Speed Control Output Fails: | | | |
| High: | Module circulator speed increases. PPIS speed-to-primary coolant flow mismatch trip. | Measured circulator speed high alarm in the NSSS control system. | Possible loss of one reactor module output. Remaining modules can operate at full output. Control hardware and software fault tolerance may allow minimum decrease in affected module output. |
| Low: | Module circulator speed decreases. PPIS speed-to-primary coolant flow mismatch trip. | Measured circulator speed low alarm in the NSSS control system. | Possible loss of one reactor module output. Remaining modules can operate at full output. Control hardware and software fault tolerance may allow minimum decrease in affected module output. |
| Load Following Command Signal Failure: | | | |
| Load increase not received: | No change in module steam flow or steam conditions. | Measured feedwater flow. | Modules will stay on-line. Software may detect condition. |
| Load decrease not received: | No change in module steam flow or steam conditions. | Measured feedwater flow. | Modules will probably stay on line. Software may detect condition. |

### 2.4.1 NSSS Systems Interface Stations

Four control stations are used for each reactor module for NSSS control. One of the four stations is used for SCS interface. (The SCS is provided with its own control systems.) All of these stations are connected to the NSSS data highway. Table 2-6 shows the distribution of data and command variables, and each of the locations is explained as follows:

1. The HTS station is located near the main circulator motor control. It provides command and instrumentation interfaces for the main circulator motor, the magnetic bearings, the motor cooling system and other HTS subsystems.

2. The Reactor System station is located in the reactor auxiliary building near the PPIS equipment. This station interfaces with the nuclear instrumentation cabinets and the PPIS. It sets reactor power levels in the power operating range and schedules rod run-in or withdrawal sequencing for startup or shutdown. It also acquires data from the PPIS via a unidirectional isolation

3. The NSSS Feedwater and Steam Bypass Station is located near the feedwater and main steam grade level entry/exit points of each reactor building.

4. The SCS station is located near the SCS circulator motor power supply. It interfaces with the SCS control and acquire SCS information.

### 2.4.2 NSSS Operations Stations

Each reactor module has an operator control station. The DMS interface for a particular reactor module is located at this station.

Table 2-6 DISTRIBUTION OF CONTROL STATIONS

| Data Highway Station Description | Interfacing Systems | Command I/O Variables | Data I/O Variables |
|---|---|---|---|
| NSSS Operations Station | Plant Supervisory Control System Data Highway (PSCS) | 100 | 250 |
| HTS Station | Heat Transport System (HTS) | 3 | 110 |
| | Service Water System | -- | 60 |
| | Other NSSS Systems | -- | 40 |
| Reactor Systems Station | Reactor System | 4 | 520 |
| | Helium Purification System | 8 | 220 |
| | PPIS | -- | 100 |
| NSSS Feedwater and Startup Bypass Station | Feedwater Supply System | 4 | 40 |
| | Turbine System | 2 | 10 |
| | Startup Bypass System | 1 | 10 |
| SCS Control Station | Shutdown Cooling System | 3 | 80 |

This station provides the data management features necessary to accept direction from and report information to roving operators and to the PCDIS data highway. It also drives the redundant NSSS data highways, which carry data and control information to the four NSSS control stations discussed in Section 2.4.1.

Figure 2-1 shows the general arrangement of the reactor and support buildings where the NSSSCS stations are located.

## 2.5 INSTRUMENTATION AND CONTROL

The NSSS Control Subsystem is itself an instrumentation and control system. Therefore, it is described throughout this entire document.

# SECTION 3

# COMPONENT FUNCTIONS AND DESIGN REQUIREMENTS

## 3.1 COMPONENT FUNCTIONS

The functions that the NSSSCS components provide are:

1. Interfacing the operation of a particular NSSS module with the operation of other parts of the plant. This includes interfacing with Nuclear Island local operators, the PSCS, and ECA controls.

2. Controlling and communicating with NSSS module systems and subsystems, including acquiring the necessary data for reporting status of each NSSS module.

The control selection studies determined two types of distributed control hardware components and one software component for accomplishing these functions. These components are discussed next.

### 3.1.1 NSSS Operations Station

The NSSS operations station (one station provided for each NSSS module) provides the following functions.

1. Communicating with the plant data highway, the ECA controls, and the PPIS. (The PPIS is not part of the NSSSCS.)

2. Controlling data flow within the connecting control stations which comprise the distributed control system for a particular NSSS module.

3. Maintaining a reportable data base reflecting the state of the NSSS and the corresponding module-level control state maneuvers.

4. Accepting PSCS commands through the plant data highway and assurance of continuous operation through design transients and other events.

5. Interfacing and interacting with operators outside the control room during energy production, shutdown, refueling, and startup/shutdown.

### 3.1.2 NSSS Systems Interface Station

The NSSS systems interface station (four stations per module) provides the following functions:

1. Connection of digital or analog data sources from adjacent NSSS systems with the NSSSCS and processing these signals for control and for transmission to the NSSS data highway.

2. Automatic regulation of NSSS outlet conditions through command of actuators and devices under the control of adjacent NSSS subsystems.

### 3.1.3 NSSS Control Software

The NSSS control software provides all of the software features necessary to perform the NSSS operations station and NSSS system interface station functions. This includes NSSS information reporting, storage and display, and automatic NSSS control response to transients or energy production demands.

The software contains logic and algorithms which perform the functions described in Section 2.2.3.

## 3.2 COMPONENT DESIGN REQUIREMENTS

Component requirements for this subsystem arise from the system design requirements in Section 1.2, from design selection in Section 2, and from trade-off studies, which lead to those design selections.

### 3.2.1 NSSS Operations Station Component Design Requirements

#### 3.2.1.1 Component Configuration and Essential Features Requirements

The NSSS operations station shall be independent of the PPIS. It shall receive protection information via a unidirectional isolator. (3701.0302.101)

Components shall be of solid state, standardized, modular, plug-in design. Any module may be easily removed from the system and replaced without breaking or making solder-type connections and without recourse to alteration, force selection, or wiring changes. (3701.0302.102)

Physically separated interconnecting cables shall be plug-connected at both ends wherever possible. (3701.0302.103)

A communication protocol that is recognized by the PCDIS data highway and by the distributed NSSS systems interface stations. (3701.0302.104)

The NSSS operations station shall operate the NSSS Control Subsystem data highway, which ties together a particular NSSS Control System. The data highway shall not be susceptible to electromagnetic noise or interference. (3701.0302.105)

3.2.1.2 Operational Requirements

The NSSS operations station shall provide the capability for operator control of its NSSS module outside of the control room during energy production, shutdown, refueling, and startup/shutdown. (3701.0302.106)

The NSSS operations station shall maintain a data base which is adequate for evaluating and determining the state of the NSSS and the corresponding module-level control state maneuvers. Design requirements shown in Table 3-1 shall be met during all possible combinations of events or plant states. (3701.0302.107)

3.2.1.3 Structural Requirements

Nonsafety-related systems shall be designed for ANSI A58.1 seismic load requirements, as a minimum. (3701.0302.108)

3.2.1.4 Environmental Requirements

The NSSS operations station shall be designed and built for continuous service under the environmental conditions shown in Table 3-2. (3701.0302.109)

The NSSSCS shall be configured to enable maintenance of NSSSCS equipment within a plant total scheduled outage time of less than 876 hours per year averaged over the plant lifetime as defined in OPDS Table 5.1-4. (3701.0302.110)

3.2.1.5 Instrumentation and Control Requirements

The NSSS operations station is an instrumentation and control component. Its requirements are distributed over the entire Section 3.2.1.

Table 3-1 NSSS OPERATIONS STATION DESIGN REQUIREMENTS

| | |
|---|---|
| Control command acknowledge time | 0.5 s |
| Maximum sampling period | 0.5 s |
| Maximum control action period | 0.5 s |
| Minimum automatic data storage time span | (TBD) |
| Data processing (mass, energy, nuclear balances, etc.) | 5000 algebraic equations |
| Real time displays | 20 pages |

Table 3-2 NSSS OPERATIONS STATION OPERATING REQUIREMENTS

Power sources needed:

120 V, 60 Hz, 15 kVA

Equipment operating limits:

40°F to 120°F ambient temperature
10% to 90% relative humidity
≤0.15 g seismic acceleration at ground level

Nominal working conditions:

70°F to 80°F service building
65°F to 85°F reactor building
<(TBD) dB noise level
<(TBD) r/h radiation exposure level
>(TBD) lighting

(NOTE: TBD levels allow O&M access.)

3.2.1.6 Surveillance and In-Service Inspection Requirements

Refer to Section 1.2.6.

3.2.1.7 Availability Assurance Requirements

The NSSS operations station shall be designed to meet NSSSCS reliability requirements specified in Reliability Allocations for the Standard MHTGR and the Investment Protection Performance Requirements for the Standard MHTGR. The NSSSCS shall be designed to meet an overall reliability allocation of <12 equivalent forced outage hours per year.
(3701.0302.113)

The NSSS operations station shall utilize diversity, redundancy, functional partitioning, or single failure proofing to meet its availability allocation. (3701.0302.114)

3.2.1.8 Maintenance Requirements

The NSSS operations station shall have automatic surveillance and announcement features. (3701.0302.112)

The NSSS Control Subsystem shall provide uninterruptible operation while equipment is serviced. This shall include redundant measurement inputs and equipment, and emergency standby units that bypass controllers for servicing without losing indication or ability to manipulate the final control elements. The NSSS operations station shall comply with this requirement. (3701.0302.115)

The NSSS operations station shall be serviceable with the plant on-line.
(3701.0302.116)

The NSSS operations station shall be provided with easy to follow preventive maintenance and equipment repair documentation, subsystem/equipment failure clearing procedures, all spare parts needed to assure the required level of subsystem availability and training requirements. (3701.0302.117)

The NSSS operations station, components, and parts shall provide for interchangeability. This includes mechanical and electrical interchangeability. (3701.0302.118)

Special maintenance tools shall be provided by the equipment vendor. (3701.0302.119)

### 3.2.1.9 Safety Requirements

There are no safety requirements for the NSSS operations station.

### 3.2.1.10 Codes and Standards Requirements

NSSSCS design, analysis, fabrication, and construction shall comply with applicable codes and standards that are needed to meet the four goals of the Integrated Approach. All such applicable codes and standards shall be identified and documented in system design descriptions and other appropriate documentation during the design effort. Applicable state and local government regulations, codes, and standards shall be identified and documented subsequent to the time a specific site is identified. Use of all codes and standards shall be justified in appropriate lower level design documents. The specific codes and standards that have been selected to date as being applicable to the overall plant are as follows:

ANSI/ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities.

DOE NE F2-10, Quality Assurance Program Requirements (Supplement to ANSI/ASME NQA-1). (3701.0302.120)

3.2.1.11 Quality Assurance Requirements

The NSSS operations station shall come under the quality assurance program stated in Section 1.2.11. (3701.0302.122)

3.2.1.12 Construction Requirements

The NSSS operations station shall be constructed using materials and workmanship at least equal to the highest grade of industrial control equipment. (3701.0302.123)

Grounding, shielding, cabling, and wiring will not be susceptible to external electromagnetic and electrostatic interference and will not generate electromagnetic noise. (3701.0302.124)

All cabinets, racks, modules, cables, and terminal blocks shall be labeled in accordance with the schematics, wiring, an constructions drawings. (3701.0302.125)

The NSSS operations station design shall be based upon parallel construction of the complete plant as described in Section 5.1.2 of Ref. 2, however, features shall be included that facilitate construction and startup in increments of two standard reactor modules and one turbine. (3701.0302.126)

3.2.1.13 Decommissioning Requirements

[Later]

### 3.2.2 NSSS Systems Interface Station Component Design Requirements

#### 3.2.2.1 Component Configuration and Essential Features Requirements

The NSSS systems interface station shall be independent of the PPIS. It shall receive protection information via a unidirectional isolator. (3701.0302.201)

Components shall be of solid state, standardized, modular, plug-in design. Any module shall be easily removed from the system and replaced without breaking or making solder-type connections and without recourse to alteration, force selection, or wiring changes. (3701.0302.202)

Physically separated interconnecting cables shall be plug-connected at both ends wherever possible. (3701.0302.203)

A communication protocol that is recognized by the distributed NSSS systems interface stations and by the NSSS operations station shall be utilized. (3701.0302.204)

The NSSS systems interface station shall provide the capability to handle high- and low-level analog and digital I/O as required for NSSS system interfacing under all modes of plant operation. (3701.0302.205)

Data shall reference a common time base. (3701.0302.206)

The hardware configuration of every NSSS systems interface station shall be identical. (3701.0302.207)

#### 3.2.2.2 Operational Requirements

The NSSS systems interface station shall provide the capability for limited operator interaction outside of the control room during energy production, shutdown, refueling, and startup/shutdown. (3701.0302.208)

### 3.2.2.3 Structural Requirements

Nonsafety-related systems shall be designed for ANSI A58.1 seismic load requirements, as a minimum. (3701.0302.209)

### 3.2.2.4 Environmental Requirements

The NSSS systems interface station shall be designed and built for continuous service under the environmental conditions shown in Table 3-2. (3701.0302.210)

The NSSSCS shall be configured to enable maintenance of NSSSCS equipment within a plant total scheduled outage time of less than 876 h per year averaged over the plant lifetime as defined in OPDS Table 5.1-4. (3701.0302.212)

### 3.2.2.5 Instrumentation and Control Requirements

The NSSS systems interface station is an instrument and control component. Its requirements are distributed over the entire Section 3.2.2.

### 3.2.2.6 Surveillance and In-Service Inspection Requirements

Refer to Section 1.2.6.

### 3.2.2.7 Availability Assurance Requirements

The NSSS systems interface station shall be designed to meet NSSSCS reliability requirements specified in Reliability Allocations for the Standard MHTGR and the Investment Protection Performance Requirements for the Standard MHTGR. The NSSSCS shall be designed to meet an overall reliability allocation of <12 equivalent forced outage hours per year. (3701.0302.214)

The NSSS systems interface station shall utilize diversity, redundancy, functional partitioning, or single failure proofing to meet its availability allocation. (3701.0302.215)

3.2.2.8 Maintenance Requirements

The NSSS systems interface station shall have automatic surveillance and announcement features. (3701.0302.213)

NSSS systems interface station design shall provide uninterruptible operation while equipment is serviced. This shall include redundant measurement inputs and equipment, and emergency standby units that bypass controllers for servicing without losing indication or ability to manipulate the final control elements. (3701.0302.216)

The NSSS systems interface station shall be serviceable with the plant on-line. (3701.0302.217)

The NSSS systems interface station shall be provided with easy to follow preventive maintenance and equipment repair documentation, subsystem/equipment failure clearing procedures, all spare parts needed to assure the required level of subsystem availability and training requirements. (3701.0302.218)

The NSSS systems interface station, components, and parts shall provide for interchangeability. This includes mechanical and electrical interchangeability. (3701.0302.219)

Special maintenance tools shall be provided by the equipment vendor. (3701.0302.220)

3.2.2.9 Safety Requirements

There are no safety requirements for the NSSS systems interface station.

3.2.2.10 Codes and Standards Requirements

NSSSCS design, analysis, fabrication, and construction shall comply with applicable codes and standards that are needed to meet the four goals of the Integrated Approach. All such applicable codes and standards shall be identified and documented in system design descriptions and other appropriate documentation during the design effort. Applicable state and local government regulations, codes, and standards shall be identified and documented subsequent to the time a specific site is identified. Use of all codes and standards shall be justified in appropriate lower level design documents. The specific codes and standards that have been selected to date as being applicable to the overall plant are as follows:

ANSI/ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities.

DOE NE F2-10, Quality Assurance Program Requirements (Supplement to ANSI/ASME NQA-1). (3701.0302.221)

3.2.2.11 Quality Assurance Requirements

The NSSS systems interface station shall come under the quality assurance program stated in Section 1.2.11. (3701.0302.223)

3.2.2.12 Construction Requirements

The NSSS system interface station shall be constructed using materials and workmanship at least equal to the highest grade of industrial control equipment. (3701.0302.224)

Grounding, shielding, cabling, and wiring will not be susceptible to external electromagnetic and electrostatic interference and will not generate electromagnetic noise. (3701.0302.225)

All cabinets, racks, modules, cables, and terminal blocks shall be labeled in accordance with the schematics, wiring, an constructions drawings. (3701.0302.226)

The NSSS system interface station design shall be based upon parallel construction of the complete plant as described in Section 5.1.2 of Ref. 2, however, features shall be included that facilitate construction and startup in increments of two standard reactor modules and one turbine. (3701.0302.227)

3.2.1.13 Decommissioning Requirements

[Later]

3.2.3 NSSS Control Software Component Design Requirements

3.2.3.1 Component Configuration and Essential Features Requirements

The software shall be of a standardized design. (3701.0302.301)

Four (4) identical software packages shall be utilized in the design. One software package shall be provided for each NSSSCS. (3701.0302.302)

The software shall provide data for other plant control algorithms. A calculated value of flow control valve $\Delta P$ shall be provided to the ECA. (3701.0302.303)

3.2.3.2 Operational Requirements

[Table 3-3, should be referenced for further explanation of the design requirements given below.]

Table 3-3
4 x 350 MW(T) MHTGR
REFERENCE CONTROL SYSTEM ALGORITHM GAINS FOR NSSS CONTROL SYSTEM

| | Proportional | Integral | Derivative |
|---|---|---|---|
| Throttle pressure (Valve-fract/psia) | -0.0015[a] | 0.025 | 0.0 |
| Main steam temperature (PWR-fract/°F) | 3E-3 + 4E-3*FWN[b] | 4E-4 + 4.3E-3*FWN | 151.5 - 106*FWN |
| Main steam temperature (rpm/°F) | 4.04+4.0*FWN | 0.0 | 93.3-53.3*FWN |
| Main steam temperature (reactor trip) (rpm/°F) | 3.33+6.67*FWN | 0.0069 | 16.667 |
| Neutron flux | On-off control | On=±0.004*VA | Off=±0.001*VA |
| Shim rod insertion | On-off control | On=-0.015 | Off=-0.008 |
| Auto control rod shim | Regulating rod bank is reshimmed if position is less than 15% inserted or more than 85% inserted | | |
| Circulator speed | Equal to demand unless torque or power limited | | |
| Steam temperature meas. time const. | 17.5667-2.667*FSN | | |

FWN = FW/FWD (1.0 < FWN < 0.25)
FW = feedwater flow rate (lbm/s)
FWD = design feedwater flow rate
FSN = FS/FSD
FS = SG outlet flow rate (lbm/s)
FSD = design main steam flow rate
VA = load index (fract) (0.25 < VA < 1.0)

(a)The negative sign on the proportional gain in the throttle pressure control loop accounts for the phase reversal inherent in valve closing resulting in increased throttle pressure and valve opening resulting in decreased throttle pressure.

(b)If temperature control of circulator inactive (i.e., loop open, control limited, or circulator motor power limited), gain is attenuated by 3.5 dB.

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Table 3-3 (Continued)

| | AFF | FFSIG | CAL | TCDEP (s) | TCF (s) | TCMESI (s) | TCF2 | VCONS | VMIN | VMAX | VRATE | FCT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Throttle-press./admission valve | 0.95 (fract) | VA (load index) | 25.0[7] | 0.0 | 0.0 | 0.0 | 0.0 | 2415 (psia) | 0.0 (valve-fract) | 1.0 (valve-fract) | 0.075[6] (valve-fract/s) | ∞[7] |
| MS temp.-reactor power | Funct | FV2(1) + VCONC(5) | 0.5 | 5.0 | 20.0 | 14.9 (Adapt)[5] | 30.0 | 1005°F (Sched)[4] | 0.1 (Fract) (Adapt)[1] | 1.10 (Fract) (Adapt)[1] | 0.04 (Fract/s) | 5.0 |
| MS temp.-circulator speed | Funct | FL(1,1,1) | 0.0 | 2.0 | 20.0 | 14.9 (Adapt)[5] | 30.0 | 1005°F (Sched)[4] | 286.0 (rpm) (Adapt)[2] | 6292.0 (rpm) (Adapt)[2] | 228.8 (rpm/s) | N/A |
| Feedwater flow | 302.46 (lbm/s) | VA[3] | 0.0 | 3.0 | 0.0 | 2.0 | 0.0 | Sched | 45.37[3] (lbm/s) | 332.71 (lbm/s) | 6.049 ($lbm/s^2$) | N/A |

Definitions:

- AFF = feedforward gain characterizer
- FFSIG = feedforward signal
- CAL = deadband fcr gain attenuaton
- FCT = deadband, gain attenuation factor
- TCDEP = actuator time constant
- TCF = FFSIG filter time constant
- TCMES1 = measurement time constant
- VCON/VCONS = design/setpoint
- VMIN/VMAX = control algorithm output range
- VCONC = char. coeff.
- VRATE = rate limit
- FL(1,1,1) = module feedwater flow
- TCF2 = feedforward lead time constant
- FSN = normalized steam flow fraction

(1)Controller output limited to ±20% of nominal reactor power (= ±0.2 fract.) in addition to VMIN and VMAX absolute limits.

(2)Controller output limited to ±15% of nominal circulator speed (= ±858 rpm) in addition to VMIN and VMAX absolute limits.

(3)Load runback rate following a reactor trip: 0.7%/s (= 2.1 $lbm/s^2$) to 25%, then 0.1% (= 0.3 $lbm/s^2$) to min. Runback held at 25% until MS measured decreases below 950°F. Load runback rate following a turbine trip: 0.25% (= 0.756 $lbm/s^2$). Feedwater minimum setpoint following reactor trip: 15% (= 45.37 lbm/s); feedwater minimum setpoint following turbine trip: 25% (75.615 lbm/s).

(4)MS temperature setpoint schedule following reactor trip: = -1.0°F/s from 1005°/F to 920°F, then = -0.30°F/s to saturation. Runback at first ramp rate is held at 920°F until MS measured decreases below 950°F. Second ramp is continuous to saturation. The runback is delayed until a SG helium inlet temperature tracker has released. The tracker is engaged when the SG helium inlet temp. rises within 20°F of PPIS trip. It releases when the temperature drops 10°F below a peak condition. When demand reaches saturation, speed is returned to feedforward setpoint through a 30 s time constant.

(5)17.5667-2.667*FSN.

(6)Fast valving (e.g., unit trip) rate limit is 5.0.

(7)Note: CAL = 10.0; FCT = 10 in FY87 design basis analysis. Table shows FY87 agreements for ECA control interface which have not been evaluated.

The control algorithms shall use integral control with accuracy sufficient to regulate the NSSS steam conditions required in Table 1-2. Column 2 of Table 3-3 gives the integral terms required in the control algorithms. (3701.0302.304)

The control algorithms shall be tested using simulation under each of the [TBD] design basis events given in Table 5.1-3 of Ref. 2. (3701.0302.305)

The module feedwater flow shall be commanded in proportion to the module load and used by the NSSSCS as a lead parameter in scheduling other NSSS control parameter load changes and plant configuration changes. (3701.0302.306)

The NSSS control software shall utilize scheduling algorithms to accommodate load rejection, turbine trip, or step changes in plant output up to ±15% per notes 1 through 6 on Table 3-3. The NSSS reactor module shall normally be controlled to avoid reactor trip if one of these events occurs. (3701.0302.307)

The recovery strategy shall allow resumption of reactor power following a protection trip within [TBD]. (3701.0302.308)

The NSSS control software shall maintain hardware scheduling rates (and hardware interface requirements) capable of meeting the maximum load scheduling rate (5%/min). (See VRATE and other data in Table 3-3.) (3701.0302.309)

The NSSS control software shall include limiters and other appropriate means to allow NSSS systems to meet the transient control requirements given in Table 2-2. This requirement has two purposes during normal operation with module feedwater flow between 25% and 100% as follows:

1. The NSSS shall operate within protection system trip settings.

2. The NSSS shall operate within design basis transient limitations needed to achieve the number of operating cycles specified in Table 5.1-3 of Ref. 2.
(3701.0302.310)

The NSSS control software shall schedule the relationship between module feedwater flow and helium flow for steady-state operations given in Table 2-3. (3701.0302.311)

The NSSS control software shall utilize feedforward and feedback control to assure continuous automatic control between 25% and 100% of nominal module feedwater flow. (3701.0302.312)

The NSSS control software shall utilize the scheme defined in Table 3-3 to assure continuous operation of the HTS following a reactor trip.
(3701.0302.313)

The NSSS control software shall utilize adjustment of gains based on module feedwater flow rate and shall combine the effects of circulator control and reactor control and assure continuous stability of the main steam temperature in all modes of operation. (See main steam temperature control, Table 3-3). (3701.0302.314)

The NSSS control software shall have design features which allow transition to a stable condition following a reactor or turbine trip. A reactor trip control for main steam temperature shall provide cooling rates satisfactory to the HTS and other NSSS systems during shutdown. Table 3-3 specifies the reactor trip control algorithms for main steam temperature.
(3701.0302.315)

3.2.3.3 Structural Requirements

The NSSS control software has no structural requirements.

#### 3.2.3.4 Environmental Requirements

The NSSS control software has no environmental requirements.

#### 3.2.3.5 Instrumentation and Control Requirements

The NSSS control software is an instrumentation and control component. Therefore, requirements are distributed over this entire section.

#### 3.2.3.6 Surveillance and In-Service Inspection Requirements

Refer to Section 1.2.6.

#### 3.2.3.7 Availability Assurance Requirements

The NSSS control software has no availability assurance requirements.

#### 3.2.3.8 Maintenance Requirements

The NSSS control software shall support the self-checking and announcement features of the NSSS operations station and the NSSS system interface station. (3701.0302.317)

The NSSS control software shall support all of the maintenance requirements in Sections 3.2.1.8 and 3.2.2.8. (3701.0302.318)

#### 3.2.3.9 Safety Requirements

The NSSS control software has no safety requirements.

#### 3.2.3.10 Codes and Standards Requirements

NSSSCS software design analysis shall comply with applicable codes and standards that are needed to meet the four goals of the Integrated

Approach. All such applicable codes and standards shall be identified and documented in system design descriptions and other appropriate documentation during the design effort. Applicable state and local government regulations, codes, and standards shall be identified and documented subsequent to the time a specific site is identified. Use of all codes and standards shall be justified in appropriate lower level design documents. The specific codes and standards that have been selected to date as being applicable to the overall plant are as follows:

ANSI/ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities.

DOE NE F2-10, Quality Assurance Program Requirements (Supplement to ANSI/ASME NQA-1). (3701.0302.319)

3.2.3.11 Quality Assurance Requirements

The NSSS control software shall come under the quality assurance program stated in Section 1.2.11. (3701.0302.320)

3.2.3.12 Construction Requirements

The NSSS control software shall be based upon parallel construction of the complete plant as described in Section 5.1.2 of Ref. 2, however, features shall be included that facilitate construction and startup in increments of two standard reactor modules and one turbine. (3701.0302.321)

3.2.3.13 Decommissioning Requirements

The NSSSCS software shall include features that accommodate decommissioning or refurbishment of one reactor while maintaining others in operation. (3701.0302.322)

# SECTION 4
# SUBSYSTEM AND COMPONENT INTERFACES

The NSSS Control Subsystem receives direction from the Plant Supervisory Control Subsystem (PSCS) or operator, senses conditions within its NSSS module, makes control decisions and effects control actions within the module, and reports status within the NSSS module to the Supervisory Control System or to operators. In performing these functions, the NSSS Control Subsystem has top interfaces with the Supervisory Control System and the Plant Control Data Highway, horizontal interfaces with ECA control system, and interfaces with NSSS fluid and mechanical systems and components. Also, it receives protection action information from the Plant Protection and Instrumentation System via a unidirectional isolator, so that the NSSS Control Subsystem can independently adjust to changes brought on by the Plant Protection and Instrumentation System and maintain conditions in the NSSS module systems that are not affected by the PPIS.

## 4.1 SUBSYSTEM INTERFACE REQUIREMENTS

### 4.1.1 Interface Requirements Imposed on Building and Structures and on Other Systems and Subsystems Within Other Systems

Each NSSS Control Subsystem requires space in four locations of the buildings associated with the particular NSSS module that it controls. In each of these locations, 200 $ft^2$ of space is required for signal conditioning, multiplexing, control logic, and command sending units. The ambient temperature is required to be in the 40°F to 120°F, and the relative humidity in the 10% to 90% range.

In addition, 500 $ft^2$ of space for complete operator overview of the NSSS at a location outside of the main control room is required, as shown in Figure 2-1, for the four local man-machine interfaces for each NSSS Control Subsystem. Temperature and humidity ranges are above.

Interfaces with other systems and subsystems within those systems and listed on Table 4-1.

Table 4-1
NSSS CONTROL SUBSYSTEM INTERFACES WITH OTHER SYSTEMS AND SUBSYSTEMS

4.1.1 <u>Identification of Interfaces</u>

| Interfacing System (With Subsystem/ Identification) | Nature of Interface | Interfacing Component | Interface Requirements |
|---|---|---|---|
| 4.1.1.1 Reactor System (1000) | | | |
| Neutron Control Subsystem (1012) | Provides capability for measurement and command of neutron flux level | Electrical signals | NSSS data and control information shall be exchanged with the NSSSCS through a compatible data interface (3701.0401.020) |
| | Provides instrumentation listed in Table 2.0-1 under group 1 and group 8 | Electrical signals | Instrumentation for evaluating and determining the state of the NSSS shall be provided and made available to the NSSSCS through a compatible data interface (3701.0401.030) |
| | | | Instrumentation shall allow detection of changes in operation of major systems and components that occur during plant operation (3701.0401.040) |
| 4.1.1.2 Heat Transport System (2100) | | | |
| Main Circulator Subsystem (2101) | Provides capability for measurement and command of circulator speed | Electrical signals | NSSS data and control information shall be exchanged with the NSSSCS through a compatible data interface. (3701.0401.020) |
| | Provides instrumentation listed in groups 2 and 5 of Table 2.0-1 | Electrical signals | Instrumentation for evaluating and determining the state of the NSSS shall be provided and made available to the NSSSCS through a compatible data interface. (3701.0401.030) |

Table 4-1 (Continued)

| Interfacing System (With Subsystem/ Identification) | Nature of Interface | Interfacing Component | Interface Requirements |
|---|---|---|---|
| | | | Instrumentation shall allow detection of changes in operation of major systems and components that occur during plant operation. (3701.0401.040) |
| 4.1.1.3 Shutdown Cooling System (5700) | | | |
| Shutdown Heat Removal Control Subsystem (5703) | Provide instrumentation listed in Table 2.0-1 under group 3 | Electrical signals | Instrumentation for evaluating and determining the state of the NSSS shall be provided and made available to the NSSSCS through a compatible data interface (3701.0401.030) |
| | | | Instrumentation shall allow detection of changes in operation of major systems (3701.0401.040) |
| | Provides control command interface | Electrical signals | NSSS data and control information shall be exchanged with the NSSSCS through a compatible data interface. (3701.0401.020) |
| 4.1.1.4 Reactor Cavity Cooling System (5600) | | | |
| | Provides instrumentation listed in Table 2.0-1 under group 6 | Electrical signals | Instrumentation for evaluating and determining the state of the NSSS shall be provided and made available to the NSSSCS through a compatible data interface. (3701.0401.030) |
| | | | Instrumentation shall allow detection of changes in operation of major systems and components that occur during plant operation. (3701.0401.040) |

Table 4-1 (Continued)

| Interfacing System (With Subsystem/ Identification) | Nature of Interface | Interfacing Component | Interface Requirements |
|---|---|---|---|
| 4.1.1.5 Vessel System | | | |
| No interfaces identified at this time (see instrumentation under 4.1.1.8 below). | | | |
| 4.1.1.6 Plant Protection and Instrumentation System (3200) | | | |
| | Provides detection of PPIS actions | Electrical signals | NSSS data and control information shall be exchanged with the NSSSCS through a compatible data interface (3701.0401.020) |
| 4.1.1.7 Fuel Handling and Storage System (3400) | | | |
| No interfaces identified at this time. | | | |
| 4.1.1.8 Reactor Service Group (2000) | | | |
| Helium Purification Subsystem (2023) | Provides instrumentation listed in Table 2.0-1 under group 4 | Electrical signals | NSSS data and control information shall be exchanged with the NSSSCS through a compatible data interface (3701.0401.020)<br><br>Instrumentation for evaluating and determining the state of the NSSS shall be provided and made available to the NSSSCS through a compatible data interface (3701.0401.030)<br><br>Instrumentation shall allow detection of changes in operation of major systems and components that occur during plant operation. (3701.0401.040) |

Table 4-1 (Continued)

| Interfacing System (With Subsystem/ Identification) | Nature of Interface | Interfacing Component | Interface Requirements |
|---|---|---|---|
| 4.1.1.9 Power Conversion Group (5000) | | | |
| Turbine Generator and Auxiliaries Subsystem (5001) | Transmission of turbine load droop caused by electric grid frequency variations | Optical or electrical interface into module data highways | Turbine control information shall be made available to the NSSSCS for use in NSSS module control during load changes or turbine trip. (3701.0401.060) |
| | Provides control stability | Pressure control algorithm | Main steam pressure control shall be maintained by action of the throttle valve. (3701.0401.070) |
| Feedwater and Condensate Subsystem (5002) | Provides capability for measurement and command of feedwater flow rate under controlled feedwater flow valve pressure drop | Electrical signals | Data and control information shall be exchanged with the NSSSCS through a compatible data interface (3701.0401.025) |
| | Provides capability for module feedwater temperature control while module starts up/shuts down | Electrical signals | Instrumentation for evaluating and determining the state of the NSSS shall be provided and made available to the NSSSCS through a compatible data interface (3701.0401.030) |
| | | | Instrumentation shall allow detection of changes in operation of major systems and components that occur during plant operation (3701.0401.040) |

Table 4-1 (Continued)

| Interfacing System (With Subsystem/ Identification) | Nature of Interface | Interfacing Component | Interface Requirements |
|---|---|---|---|
| Main and Bypass Steam Subsystem (5004) | Provides steam pressure to NSSSCS | Electrical signals | Instrumentation for evaluating and determining the state of the NSSS shall be provided and made available to the NSSSCS through a compatible data interface (3701.0401.030) |
| | Provides thermocouple wells for main steam temperature sensors | Instrumentation and attachment fixtures | Main and bypass steam subsystem shall provide thermocouple wells for instrumentation of control parameters for individual reactor modules (3701.0401.050) |

4.1.1.10 Heat Rejection Group (5200)

No interfaces identified at this time.

4.1.1.11 Plant Control, Data, and Instrumentation System (3700)

| Interfacing System (With Subsystem/ Identification) | Nature of Interface | Interfacing Component | Interface Requirements |
|---|---|---|---|
| PSCS (3707) | Transmits NSSS control information to the main control room operators | Data link between the NSSS module data highways and the PSCS | PSCS command and control information shall be passed to NSSSCS through a compatible data interface (3701.0401.010) |

4.1.1.12 Electrical Group (9200)

| Interfacing System (With Subsystem/ Identification) | Nature of Interface | Interfacing Component | Interface Requirements |
|---|---|---|---|
| | Provides compatible electrical power to NSSS controls | Electric feeders | Redundant power circuits with UPS backup shall be provided for NSSSCS. (3701.0401.100) |

4.1.1.13 Miscellaneous Control and Instrumentation Group (3000)

No interfaces identified at this time.

Table 4-1 (Continued)

| Interfacing System (With Subsystem/ Identification) | Nature of Interface | Interfacing Component | Interface Requirements |
|---|---|---|---|
| 4.1.1.14 Plant Service Group (9000) | | | |
| No interfaces identified at this time. | | | |
| 4.1.1.15 Buildings, Structures, and Building Service Group (7000) | | | |
| | Provides Nuclear Island building space, structural and environmental support to accommodate NSSSCS | Equipment cabinets and communication hardware | Controls and instrumentation shall be located in proximity of system being controlled. Specific locations [TBD]. (3701.0401.080) |
| | Provides operational space | Control consoles | Space shall be provided to allow operator capability for NSSS operations outside the main control room (3701.0401.090) |

4.1.2 Interface Requirements Imposed on Subsystem Within the Plant Control, Data, and Instrumentation System

The NSSS Control Subsystem interfaces with the other subsystems via communication interfaces to each of their data highways.

Specifically, the NSSS Control Subsystem receives direction from the Supervisory Control Subsystem or operators in the form of a load allocation and a load allocation weighting factor for the NSSS module when the module is in the power range (25% to 100% load, and module steam flowing to the main steam header). In the startup or shutdown range (0% to 25% reactor power level, and module steam flowing only to the startup bypass), the NSSS Control Subsystem receives direction from the same sources in the form of predefined HOLD points (or states) to which the NSSS Control Subsystem drives its NSSS module and holds.

The NSSS Control Subsystem reports states within the NSSS module to the Supervisory Control Subsystem and to operators via the system data highway.

Each NSSS Control Subsystem sends the pressure drop across the feedwater flow control valve in its module to the two feedwater trains in the ECA. The ECAs are required to maintain the lowest of the four pressure drops at 100 psid.

The NSSS Control Subsystem receives from the ECAs the turbine load droops caused by electric grid frequency variations.

4.2 COMPONENT BOUNDARY DEFINITION

Sensors: The boundary for each sensor that monitors or controls process conditions shall be the point at which the sensor touches or penetrates the process pipe or vessel. For temperature or other measurements requiring thermowells, the thermowells may be specified with the process pipe or vessel. Each case will be treated individually.

Communications Transmission Boundaries: There are two types of communication boundaries. One is a multiplexing panel that connects the NSSS Control Subsystem data highway to the Plant Control Data and Instrumentation data highway. The other type connects the NSSS Control Subsystem data highway to other NSSS systems. In these cases, the boundary is the connector at the data highway or at the system where the wires or digital communication lines are connected to the NSSS Control Subsystem.

Other: Other boundaries are defined by the brackets and mechanical attachments of electronic or optical cabinets to building floors or walls, and by electric power connectors.

# SECTION 5
# SUBSYSTEM CONSTRUCTION

The NSSS Control Subsystem architecture generally matches the modularity of the fluid and mechanical systems. Therefore, the subsystem is fabricated and packaged in a set of modules that are delivered to the plant with prefabricated.

## 5.1 PACKAGING AND SHIPPING

The NSSS Control Subsystem signal conditioning, control logic, man-machine interfaces, etc., is packaged as follows: for each NSSS module there are four cabinets of local signal conditioning and control logic, plus a fifth cabinet for man-machine function. There are four sets of these five cabinets, one for each reactor.

1. Sensors and data highways are packaged separately.
2. Software that is not burned in ROM is also packaged separately.
3. Environmental limitations for shipping are TBD.

The design of the NSSS Control Subsystem includes consideration for special packaging including as necessary handling fixtures for the packages and for the components to be inserted and removed from the packages. The packages and components are designed for handling, storage, and movement both horizontally and vertically with considerations for impact loading and shock absorbers due to inadvertent truck accidents. Shipping fixtures, attachments, welded lifting lugs, slings, etc., where provided on large items, receive the same design review, including materials and process approval prior to fabrication, as is applied to the component itself. The design of the initial shipping/handling fixtures on large items will be coordinated with the plant constructor to ensure that they are compatible with his lifting equipment which is not necessarily the plant equipment to be used after construction completion.

## 5.2 HANDLING AT DELIVERY

A specification/procedure will be written to describe the procedure for handling the components of the NSSS Control Subsystem from the delivery point to the storage or installation location, including appropriate inspections at specified intervals. These instructions shall be followed.

## 5.3 RECEIVING INSPECTION

The equipment as delivered will have been thoroughly shop tested and inspected during fabrication.

Thorough receiving inspection shall be made for the entire NSSS Control Subsystem. Inspection includes damage assessment, accounting for all items with or without tags, determining if any protective packaging is deteriorating, proper positioning, QA checks, etc. Such inspections shall be planned and documented on a receiving inspection plan which shall be retained in the quality assurance record system for the plant.

## 5.4 STORAGE

All NSSS Control Subsystem equipment/components shall be stored in closed temperature controlled buildings out of the weather. All components regardless of location shall be inspected weekly in accordance with the specification/procedure described under Section 5.2.

## 5.5 ACCESS

Access to the reactor building is required for NSSS Control Subsystem components located in the reactor building. Access requirements in other buildings and lifting equipment requirements are [TBD].

## 5.6 INSTALLATION AND/OR FIELD FABRICATION

The installation of the NSSS Control Subsystem will be described in several specifications/procedures. In addition to handling and inspections (see Sections 5.2 and 5.3), procedures are required for connecting piping, electrical power and instrumentation leads to the components of the NSSS Control Subsystem. These connections are preferably prefabricated with connectors, flanges, etc., to make for easy installation with a minimum of field fabrication.

## 5.7 CONSTRUCTION TESTING

A construction test procedure is required for the NSSS Control Subsystem to describe visual and mechanical inspection, cleaning, pressure/leak testing, electrical continuity, insulation integrity, phase sequence, operability of moving equipment, etc. The procedure includes specific pressure levels, voltage levels, and boundaries for application of these test levels with specific precautions (such as double block and bleed valves) to prevent leakage or misapplication during cleaning and testing. If construction cleaning is required of components to be installed in the reactor vessel and to be operated in primary coolant helium, such cleaning shall conform to GA Reference Specification RC-2-2. A specific site acceptance test will be conducted to determine that the NSSSCS is installed and configured correctly. This test will repeat and be expected to duplicate a similar factory acceptance test that will be completed before the NSSSCS is shipped to the site. The results of construction testing will be reported for a record of test performance and results.

## 5.8 AS-BUILT DRAWINGS

Permanent changes will be recorded for the master reproducible drawings of the NSSS Control Subsystem for record purposes. All changes will be subject to the normal design review process for approval or restoration to the original design configuration.

# SECTION 6
# SUBSYSTEM OPERATION

## 6.1 SUBSYSTEM LIMITATIONS, SETPOINTS, AND PRECAUTIONS

The NSSS Control Subsystem is designed to operate the NSSS module within the operating ranges of all NSSS components. Any deviations from these ranges are detected and corrected by the independent Plant Protection and Instrumentation System. The operating limits and setpoints required for NSSS operations are given in Table 3-3. The NSSSCS itself has electronic equipment settings such as power supply voltage levels, etc., which are factory set and checked during periodic maintenance of the equipment.

### 6.1.1 Subsystem Limitations and Setpoints

Limitations and setpoints for control of NSSSCS equipment are entered through the NSSS operations station. The required setpoints or setpoint schedules, min/max limits, rate limits, and deadband range limits shown in Table 3-3 must be entered prior to any operation of the NSSS using the NSSSCS. Controller gains settings which must also be put into the NSSSCS data base before operating the plant, are specified in Table 3-3 as well.

Equipment calibration procedures for setting voltage regulators and other similar equipment in the NSSSCS will be developed during the preliminary and final design. These procedures are also executed before using the NSSSCS to operate the plant.

### 6.1.2 Precautions

The procedures for NSSSCS operation should be followed, especially when on-line maintenance is being done. Design features to assist the operator in verifying the system degree of redundancy are also included. These features, combined with administrative control of maintenance activities, protect the plant against loss of <u>both</u> redundant control channels in one of the NSSS modules.

## 6.2 PREOPERATIONAL CHECKOUT

### 6.2.1 Initial Preoperational Checkout

After completion of the construction testing, a series of initial preoperational tests will be performed to verify the proper operation of the NSSSCS prior to nuclear fuel loading and power operation.

Initial preoperational test procedures will be written to demonstrate operational capability for at least the following:

1. Main steam temperature control logic.
2. Feedwater flow control logic.
3. Neutron flux command logic.
4. Circulator speed command logic.
5. Load following control logic.
6. Control logic following a turbine trip.
7. Control logic following a reactor trip.

In addition, the following instrumentation and operator interfaces will be tested:

1. NSSS/PSCS operations interface and control.
2. Reactor instrumentation and operations interface.
3. HTS instrumentation and operations interface.
4. Feedwater and main steam instrumentation.
5. SCS instrumentation and operations interface.

6.2.2 Routine Preoperational Checkout

The following are required for routine preoperational checkout of the control system prior to placing the control system online after a shutdown.

1. Control Room operable.
2. Reactor Building Equipment operable.
3. Uninterruptible power sources operable.
4. Annunciator System operable.
5. Voice communication systems operable.
6. Reactor Operations Facility operable.
7. Neutron Control System operable.
8. SCS instrumentation and control operable.
9. Heat Transport System Instrumentation operable.
10. Feedwater and Steam System Instrumentation operable.
11. Reactor Systems Instrumentation operable.
12. Control system status to be placed on-line.

6.3 STARTUP/SHUTDOWN

6.3.1 Startup to 25% Steam Flow

When the preoperational checkout is completed, the NSSS Control Subsystem is placed in service. Then, the NSSS module is automatically started through the NSSS startup sequence shown in Table 2-3. Operator action is required to verify that each HOLD point has been successfully reached, and to release the NSSS Control Subsystem to take the NSSS module to its next HOLD point.

6.3.2 Shutdown from 25% Steam Flow

Normal shutdown is done automatically through the sequence of HOLD points in Table 2-3 in reverse, with operator participation to verify that each

HOLD point has been successfully reached, and to release the NSSS Control Subsystem to take the NSSS module to its next HOLD point.

The control system automatically regulates feedwater flow rate, steam temperature and steam pressure during shutdown. Special control gains (see Table 3-3) are selected automatically in order to stabilize the steam conditions and slow the cooling rates in the steam generator tubesheet and elsewhere when the shutdown is due to module isolation or reactor trip. The control system operates the circulator and FW flow valves to satisfy the requirements in Section 3.2.3. If the reactor vessel is depressurized the circulator speed is automatically increased to 100%. The NSSSCS continues to monitor data from NSSS subsystems and, if necessary, interact with the NSSS operators.

## 6.4 NORMAL OPERATION

Normal operation takes place in the load range between 25% and 100%, also known as the load range, or power range since this is the range in which the NSSS module actively contributes steam to the main steam header for turbine-generator operation. (See Table 5.1-3 of Ref. 2, Level of service "A" events 5 through 12 and level of service "B" events 15 and 16). In this range, the NSSS automatically follows the load demand allocated by the Supervisory Control Subsystem or the operator. References 1 and 7 may be consulted for NSSS performance information on these transient events. Appendix C contains control system information regarding control system transient performance that is typically expected during normal operation.

## 6.5 REFUELING

The NSSS is configured to allow core decay heat removal via the SCS during refueling at subatmospheric reactor pressure. Helium is circulated and heat is extracted through the SCS heat exchanger. The SCS is placed online automatically by the NSSSCS after reactor depressurization and on receipt of a refueling mode enable. The NSSSCS monitors NSSS systems during this period and accomplishes its data reporting function.

## 6.6 SHUTDOWN

The transition to the reactor subcritical conditions in shutdown mode is described in Section 6.3. Beyond that, the NSSS Control Subsystem operates the other NSSS subsystems within their decay heat removal operating ranges.

## 6.7 ABNORMAL OPERATION

The NSSSCS is responsive to abnormal events and will respond in a particular fashion to such events. Abnormal operation pertaining to the NSSSCS itself includes all events involving control system failures which cause abnormal plant operation. The NSSSCS design includes features that enhance plant availability and minimize abnormal control operation. These are as follows:

1. Redundant processing of all data and control algorithms -- single failures of processing hardware do not disrupt normal operation of the plant other than within the affected control module. Maintenance design features, in turn, allow recovery from such an event.

2. Range limiting of controller outputs -- the ranges are generally satisfactory to provide load following but limit the outputs if a sensor or processing hardware component fails. In some cases, the energy production process is not interrupted because the NSSS is maintained within its operating range without challenging the independent PPIS. Also, the capability to adjust unaffected modules to accommodate abnormal operation of one NSSS module is assured by the module-to-module independence required of the NSSSCS design.

3. Feedforward synchronization of primary control elements -- module feedwater flow is controlled within the NSSS module and is the only index command input to other primary control loops. If the load level inputs to the NSSSCS from other plant controls are mismatched or incorrect, the NSSSCS still maintains reactor power consistent with NSSS heat removal through feedwater-flow-based feedforward command.

## 6.8 CASUALTY EVENTS AND RECOVERY PROCEDURES

### 6.8.1 Casualty Events

Casualty events for the NSSS Control Subsystem include the following:

1. Events that cause PPIS protective action.

2. Events that cause the NSSS to drop below the energy production range (25% to 100% of rated output).

### 6.8.2 Design Features to Mitigate Effects of Casualty Events

The design features to reduce the frequency of casualty events are:

1. NSSSCS preventive maintenance and surveillance features to assure satisfactory capability for control component maintenance while the NSSSCS is on-line.

2. Module-to-module independence of NSSSCS control functions.

3. Automatic rate and range limiting of primary control variables.

Features which mitigate the effect of casualty events are:

1. Automatic reconfiguration of the control to retain HTS heat removal following a reactor trip. This feature reduces recovery

time that would be lost if NSSS/ECA feedwater supplies had to be replaced then reinstated following the event.

2. Module-to-module independence during startup/shutdown. This feature prevents loss of more than one module if the trip was initiated by an NSSS parameter and allows restart of the module independently of load adjustments in other modules following the event.

### 6.8.3 Recovery Procedures

Detailed recovery procedures are to be prepared in the preliminary and final design phases based on the features of Section 6.7.

In general, this will involve developing detailed procedures to place the NSSS module in one of the states defined as a HOLD point in the startup/ shutdown regime, accomplishing heat removal to allow required maintenance to be performed, and allowing the NSSS Control Subsystem to take the NSSS module through the sequence of HOLD points in the startup range with operator acknowledge and release of each HOLD point.

# SECTION 7
# SYSTEM MAINTENANCE

## 7.1 MAINTENANCE APPROACH

The NSSSCS is designed to reduce or minimize the mean time to repair (MTR). One-half hour has been established as the design goal for MTR. A nominal level of expertise is required by operating and maintenance personnel when maintenance or calibration activities are performed. Only standard electronic equipment and very few special tools are required.

The NSSS Control Subsystem maintenance approach utilizes a modular instrumentation system construction, standardized modules to the extent practical, and a minimum of spare part diversity.

In both the NSSS operations station and the NSSS systems interface station all replaceable modules and subassemblies are made accessible from the front of the equipment enclosure. All terminal blocks and connectors are accessible without removal of modules, subassemblies, or chassis because of the use of swing-away panels or other electrical equipment construction techniques. Additionally, diagnostic programs have been incorporated into the software design to aid in detecting faults in communication channels or power supplies.

Due to the subsystem configuration and redundancy provided, it is possible to perform a considerable amount of maintenance and repair with the plant operating; however, it is preferred that, where possible, routine maintenance be performed during NSSS module outages scheduled for maintenance of other systems or for refueling. The subsystem design considers maintenance activities in the following order of preference:

1. Adjust in place.

2. Replace component with spare unit (and then repair the disabled unit).

3. Repair components in place by available means to the extent permissible (consistent with personnel radiation exposure and availability requirements).

# SECTION 8
# SUBSYSTEM DECOMMISSIONING

The primary support of the decommissioning requirement is the independence of each NSSS control module. One control system can be removed without affecting the others.

# SECTION 9
# REFERENCES

1. "MHTGR Plant Design Basis Transient Analysis," DOE-HTGR-86-121, Rev. 1, (GA Document 908754/1), April 1987.
2. "Overall Plant Design Specification Modular High-Temperature Gas-Cooled Reactor," HTGR-86-004, Rev. 4, (HFS-20100, Rev. 4), (GA Document 908397/4), May 1987.
3. "NSSS Thermal Performance Requirements for the Modular High-Temperature Gas-Cooled Reactor," DOE-HTGR-86-030, Rev. 2, (GA Document 908755/2), June 1987.
4. "FY86 Seismic Assessment Report," 4 x 350 MW(t) Modular HTGR Plant," HTGR-86-119, Rev. 0, September 1986.
5. "Reliability Allocations for the Standard MHTGR," DOE-HTGR-87-008, Rev. 0, (GA Document 909279/0), February 1987.
6. "Plant Control, Data, and Instrumentation System Design Description," DOE-HTGR-86-076/2, (HFD-33700, Rev. 2), (GA Document 908437/2), July 1987.
7. "Main and Bypass Steam System Design Description," HFD-45004, Rev. 1, (GA Document 908516/1), September 1986.

# APPENDIX A

## Table A-1
## NSSS CONTROL SUBSYSTEM DESIGN REQUIREMENTS TRACEABILITY SUMMARY

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0102.001 | NSSS functionally independent of PPIS. | 2/3.2.2/3700.0322.490 |
| 3701.0102.002 | Audible alarms restricted to critical parameters. | 2/3.2.2/3700.0322.220 |
| 3701.0102.003 | Control features to operate reactors and turbines at different power levels. | 2/3.2.2/3700.0322.080 |
| 3701.0102.004 | Systems in Nuclear Island of standardized design. | 2/3.2.2/3700/0322.015 |
| 3701.0102.005 | Each NSSS module has independent control system. | 2/3.2.2/3700.0322.129 |
| 3701.0102.006 | Human-machine interfaces for NSSSCS equipment outside control room. | 2/3.2.2/3700.0302.030 |
| 3701.0102.007 | Data communications not restricted to location. | 2/3.2.2/3700.0302.040 |
| 3701.0102.008 | New control and data communication interfaced allowed. | 2/3.2.2/3700.0302.050 |
| 3701.0102.009 | One percentage increase in capital investment allowance versus 7/10 percentage availability. | 2/3.2.2/3700.0302.070 |
| 3701.0102.010 | Base design on proven technology. | 2/3.2.2/3700.0302.090 |
| 3701.0102.011 | Nuclear steam supply shall deliver 2400 psig, 1000°F steam. | 2/3.2.2/3700.0322.285 |
| 3701.0102.012 | Provide capability to control NSSS modules outside the control room. | 2/3.2.2/3700.0322.110 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0102.013 | Design control to operate through specified design transients. | 2/3.2.2/3700.0322.160 |
| 3701.0102.014 | Design control to accommodate reactor/turbine-generator combinations. | 2/3.2.2/3700.0302.010 |
| 3701.0102.015 | Controlled operation allowing load rejection or turbine trip without reactor trip. | 2/3.2.2/3700.0322.330 |
| 3701.0102.016 | ±15% load step in plant output. | 2/3.2.2/3700.0322.340 |
| 3701.0102.017 | Features to limit recovery time after protection trip occurs. | 2/3.2.2/3700.0322.320 |
| 3701.0102.018 | Each NSSS module able to change output at rate up to 5% per minute. | 2/3.2.2/3700.0322.320 |
| 3701.0102.518 | Features to enable automatic startup. | 2/3.2.2/3700.0322.148 |
| 3701.0102.019 | NSSS transient control requirements to meet NSSS thermal requirements. | 2/3.2.2/3700.0322.120 |
| 3701.0102.020 | Maximum circulator speed requirement. | 7/4.1.1/2100.0401.090 |
| 3701.0102.021 | NSSSCS design maintain hot helium temperature. | 7/4.1.1/2100.0401.091 |
| 3701.0102.022 | NSSSCS control speed to flow ratio. | 7/4.1.1/2100.0401.092 |
| 3701.0102.023 | NSSSCS design maintain cold helium temperature. | 7/4.1.1/2100.0401.093 |
| 3701.0102.024 | NSSSCS maintain stable steam generator outlet temperature regulation. | 7/4.1.1/2100.0401.094 |
| 3701.0102.025 | Control of helium mass flow through steam generator bundle. | 2/3.2.2/3700.0322.115 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0102.026 | Continuous automatic control between 25% and 100% feedwater flow. | 2/3.2.2/3700.0322.310 |
| 3701.0102.027 | Ability to sustain continuous operation following failure of major component. | 2/3.22/3700.0322.170 |
| 3701.0102.028 | NSSSCS steady-state control accuracy. | 2/3.2.2/3700.0322.117 |
| 3701.0102.029 | NSSSCS automatic control during plant operation. | 2/3.2.2/3700.0322.125 |
| 3701.0102.030 | Startup -- 0% to 25% of rated feedwater flow. | 2/3.2.2/3700.0322.150 |
| 3701.0102.031 | Accommodate one or more modules starting up. | 2/3.2.2/3700.0322.145 |
| 3701.0102.032 | Shutdown -- 25% to 0% of rated feedwater flow. | 2/3.2.2/3700.0322.130 |
| 3701.0102.034 | Accommodate one or more modules shutting down. | 2/3.2.2/3700.0322.129 |
| 3701.0102.035 | Capability for removal of a reactor from service for refueling and return to service with remaining plant in operation. | 2/3.2.2/3700.0322.140 |
| 3701.0102.036 | 40-yr operating life. | 2/3.2.2/3700.0322.420 |
| 3701.0102.037 | Design duty cycles. | 2/3.2.2/3700.0322.190 |
| 3701.0102.038 | Weekly load cycle. | 2/3.2.2/3700.0322.300 |
| 3701.0102.039 | Seismic design requirement. | 2/3.2.2/3700.0322.200 |
| 3701.0102.040 | OBE seismic response spectrum. | 2/3.2.2/3700.0322.205 |
| 3701.0102.041 | Operation of NSSS systems by NSSSCS within transient margins for total duty cycles. | 2/3.2.2/3700.0322.195 |
| 3701.0102.042 | Site environmental table. | 2/3.2.2/3700.0322.207 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0102.043 | Provide automatic detection and documentation of significant events. | 2/3.2.2/3700.0322.225 |
| 3701.0102.044 | NSSSCS provide data to control room. | 2/3.2.2/3700.0322.260 |
| 3701.0102.045 | NSSSCS capable of evaluating and determining control action for module-level maneuvers. | 2/3.2.2/3700.0322.270 |
| 3701.0102.046 | NSSSCS automatic control capability. | 2/3.2.2/3700.0322.280 |
| 3701.0102.047 | NSSSCS control actuators and devices required for change in NSSS state. | 2/3.2.2/3700.0322.290 |
| 3701.0102.048 | NSSSCS follow PSCS load demand at rates up to ±5%/minute. | 2/3.2.2/3700.0322.350 |
| 3701.0102.049 | Ability to control NSSS at work stations outside control room. | 2/3.2.2/3700.0322.360 |
| 3701.0102.050 | NSSSCS ability to process data from NSSS systems and subsystems. | 2/3.2.2/3700.0322.370 |
| 3701.0102.051 | NSSSCS use of digital communication techniques to interface with PSCS. | 2/3.2.2/3700.0322.400 |
| 3701.0102.052 | Accept startup directions corresponding to rated load demand change. | 2/3.2.2/3700.0322.380 |
| 3701.0102.053 | Accept shutdown directions corresponding to rated load demand change. | 2/3.2.2/3700.0322.390 |
| 3701.0102.054 | Provisions for monitoring NSSS status. | 2/3.2.2/3700.0322.240 |
| 3701.0102.055 | NSSSCS capability to sense, process, and analyze. | 2/3.2.2/3700.0322.250 |
| 3701.0102.410 | Report excessive SFSF temperature to control room. | 8/4.1.1/3400.0401.048 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0102.420 | Perform neutron calculations. | 6/4.1.1/1012.0401.080 |
| 3701.0102.425 | Issue alarm to control room if more than three control rods. | 6/4.1.1/1012.0401.081 |
| 3701.0102.450 | Report excessive SG feedwater inlet temperature. | 7/4.1.1/2100.0401.094 |
| 3701.0102.460 | Report excessive SG feedwater inlet pressure. | 7/4.1.1/2100.0401.096 |
| 3701.0102.465 | Report excessive steam pressure. | 7/4.1.1/2100.0401.097 |
| 3701.0102.056 | Reduction of human error through design of operator interface. | 2/3.2.2/3700.0322.060 |
| 3701.0102.057 | Locate controls outside control room in proximity of system. | 2/3.2.2/3700.0322.020 |
| 3701.0102.058 | Provide internal diagnostic monitoring to detect malfunctions. | 2/3.2.2/3700.0322.230 |
| 3701.0102.059 | Malfunction alarming in control room. | 2/3.2.2/3700.0322.060 |
| 3701.0102.560 | NSSSCS have self-test capability | 2/3.2.2/3700.0322.470 |
| 3701.0102.510 | Provisions for monitoring NSSS status, configuration and performance. | 2/3.2.2/3700.0322.480 |
| 3701.0102.060 | Meet reliability allocation for MHTGR. | 2/3.2.2/3700.0322.410 |
| 3701.0102.061 | NSSSCS reliability design requirement. | 2/3.2.2/3700.0322.430 |
| 3701.0102.062 | Design, arrange, and locate components to facilitate on-line maintenance. | 2/3.2.2/3700.0322.450 |
| 3701.0102.063 | Design for hands-on maintenance. | 2/3.2.2/3700.0322.440 |
| 3701.0102.064 | NSSSCS configured to maintain within availability hours. | 2/3.2.2/3700.0322.445 |
| 3701.0102.065 | Reduction of spare parts inventory. | 2/3.2.2/3700.0322.530 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0102.066 | Special maintenance tools provided by vendor. | 2/3.2.2/3700.0322.447 |
| 3701.0102.580 | Provisions for removing reactor from service. | 2/3.2.2/3701.0102.580 |
| 3701.0102.590 | Top-level regulatory criteria. | 2/3.2.2/3700.0322.590 |
| 3701.0102.067 | Codes and standards requirement. | 2/3.2.2/3700.0322.510 |
| 3701.0102.068 | QAL requirements. | 2/3.2.2/3700.0322.520 |
| 3701.0102.069 | Shop fab/assembly requirement. | 2/3.2.2/3700.0322.540 |
| 3701.0102.080 | Parallel construction requirement. | 2/3.2.2/3700.0322.550 |
| 3701.0102.081 | Decommissioning requirement. | 2/3.2.2/3700.0322.560 |
| 3701.0302.101 | NSSS operations station independent of PPIS. | 4/1.2.1/3701.0102.001 |
| 3701.0302.102 | NSSS operations station components of standardized electronic design. | 4/1.2.1/3701.0102.004 |
| 3701.0302.103 | Plug-connected cables. | 4/1.2.1/3701.0102.004 |
| 3701.0302.104 | Consistent communication protocol between connected control hardware. | 4/1.2.5/3701.0102.051 |
| 3701.0302.105 | Data communications not susceptible to electromagnetic noise or interference. | 4/1.2.1/3701.0102.061 |
| 3701.0302.106 | NSSSCS provide capability to control NSSS modules outside of control room. | 4/1.2.2/3701.0102.012; 4/1.2.2/3701.0102.035 |
| 3701.0302.107 | Maintain data base adequate for evaluating and determining state of NSSS. | 4/1.2.2/3701.0102.012; 4/1.2.5/3701.0102.045 |
| 3701.0302.108 | NSSS operations station seismic design requirement. | 4/1.2.3/3701.0102.039 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0302.109 | NSSS operations station designed and built for continuous service. | 4/1.2.3/3701.0102.042 |
| 3701.0302.110 | NSSSCS configured for maintenance within scheduled outage time. | 4/1.2.4/3701.0102.064 |
| 3701.0302.112 | NSSS operations station automatic surveillance and announcement features. | 4/1.2.5/3701.0102.058 |
| 3701.0302.113 | NSSS operations station meet [TBD]% of NSSSCS reliability allocation. | 4/1.2.7/3701.0102.060 |
| 3701.0302.114 | NSSS operations station reliability design methods. | 4/1.2.7/3701.0102.060 |
| 3701.0302.115 | Uninterruptible operation while equipment is serviced. | 4/1.2.8/3701.0102.062 |
| 3701.0302.116 | Serviceable with plant on-line. | 4/1.2.8/3701.0102.062 |
| 3701.0302.117 | NSSS operations station service and spare parts plan. | 4/1.2.8/3701.0102.063 |
| 3701.0302.118 | Parts interchangeability. | 4/1.2.1/3701.0102.065 |
| 3701.0302.119 | NSSS operations station special tools provided by vendor. | 4/1.2.8/3701.0102.066 |
| 3701.0302.120 | Codes and standards requirement. | 4/1.2.10/3701.0102.067 |
| 3701.0302.122 | QAL requirement. | 4/1.2.11/3701.0102.068 |
| 3701.0302.123 | General quality of materials requirement. | 4/1.2.11/3701.0102.067<br>4/1.2.9/3701.0102.069 |
| 3701.0302.124 | External electromagnetic and electrostatic interference requirement. | 4/1.2.11/3701.0102.056<br>4/1.2.11/3701.0102.050 |
| 3701.0302.125 | General equipment labeling requirement. | 4/1.2.11/3701.0102.067<br>4/1.2.11/3701.0102.069 |
| 3701.0302.126 | Parallel construction requirement. | 4/1.2.12/3701.0102.070 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0302.201 | NSSS systems interface station independent of PPIS. | 4/1.2.1/3701.0102.001 |
| 3701.0302.202 | NSSS systems interface station components of standardized electronic design. | 4/1.2.1/3701.0102.004 |
| 3701.0302.203 | Plug connected cables. | 4/1.2.1/3701.0102.004 |
| 3701.0302.204 | Consistent communication protocol between connected control hardware. | 4/1.2.1/3701.0102.051 |
| 3701.0302.205 | Capability to handle analog and digital I/O. | 4/1.2.5/3701.0102.045 |
| 3701.0302.206 | Common time base. | 4/1.2.5/3701.0102.044 |
| 3701.0302.207 | Hardware configuration of stations identical. | 4/1.2.1/3701.0102.051 |
| 3701.0302.208 | NSSS systems interface station limited operator interaction capability. | 4/1.2.2/3701.0102.012 |
| 3701.0302.209 | NSSS systems interface station seismic design requirement. | 4/1.2.3/3701.0102.039 |
| 3701.0302.210 | NSSS systems interface station designed and built for continuous service. | 4/1.2.3/3701.0102.042 |
| 3701.0302.212 | NSSSCS configured for maintenance within schedule outage time. | 4/1.2.4/3701.0102.064 |
| 3701.0302.213 | NSSS systems interface station automatic surveillance and announcement features. | 4/1.2.5/3701.0102.058 |
| 3701.0302.214 | NSSS systems interface station meet [TBD]% of NSSSCS reliability allocation. | 4/1.2.7/3701.0102.060 |
| 3701.0302.215 | NSSS systems interface station reliability design methods. | 4/1.2.7/3701.0102.060 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0302.216 | Uninterruptible operation while equipment is serviced. | 4/1.2.8/3701.0102.062 |
| 3701.0302.217 | Serviceable with plant on-line. | 4/1.2.8/3701.0102.062 |
| 3701.0302.218 | NSSS systems interface station service and spare parts plan. | 4/1.2.8/3701.0102.063 |
| 3701.0302.219 | Parts interchangeability. | 4/1.2.1/3701.0102.065 |
| 3701.0302.220 | NSSS systems interface station special tools provided by vendor. | 4/1.2.8/3701.0102.066 |
| 3701.0302.221 | Codes and standards requirement. | 4/1.2.10/3701.0102.067 |
| 3701.0302.222 | QAL requirement. | 4/1.2.11/3701.0102.068 |
| 3701.0302.224 | General quality of materials requirement. | 4/1.2.11/3701.0102.067<br>4/1.2.11/3701.0102.069 |
| 3701.0302.225 | External electromagnetic and electrostatic interference requirement. | 4/1.2.11/3701.0102.067<br>4/1.2.11/3701.0102.069 |
| 3701.0302.226 | General equipment labeling requirement. | 4/1.2.11/3701.0102.067<br>4/1.2.11/3701.0102.069 |
| 3701.0302.227 | Parallel construction requirement. | 4/1.2.12/3701.0102.070 |
| 3701.0302.301 | Software of standardized design. | 4/1.2.1/0100.0102.004 |
| 3701.0302.302 | Software provided for each NSSSCS. | 4/1.2.1/3701.0102.005 |
| 3701.0302.303 | Software functions to calculate ECA control inputs. | 4/1.2.1/3701.0102.011 |
| 3701.0302.304 | Control algorithm integral gains. | 4/1.2.2/3701.0102.046 |
| 3701.0302.305 | Software testing via simulation. | 4/1.2.2/3701.0102.013<br>4/1.2.2/3701.0102.037 |
| 3701.0302.306 | Feedwater flow versus load command requirement. | 4/1.2.2/3701.0102.014<br>4/1.2.2/3701.0102.021<br>4/1.2.2/3701.0102.023 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0302.307 | Control algorithms to accommodate load rejection, turbine trip or load step change. | 4/1.2.2/3701.0102.015<br>4/1.2.2/3701.0102.022 |
| 3701.0302.308 | Recovery strategy following protection trip. | 4/1.2.2/3701.0102.017 |
| 3701.0302.309 | Hardware scheduling rates compatible with ±5% per minute load change. | 4/1.2.2/3701.0102.018 |
| 3701.0302.310 | Operation of NSSS within (1) protection trip settings and (2) within ranges needed for total duty cycles. | 4/1.2.2/3701.0102.518<br>4/1.2.2/3701.0102.041<br>4/1.2.2/3701.0102.021 |
| 3701.0302.311 | Coordination of feedwater flow and helium flow. | 4/1.2.2/3701.0102.025<br>4/1.2.2/3701.0102.021 |
| 3701.0302.312 | Control design methods to maintain continuous automatic control. | 4/1.2.2/3701.0102.026<br>4/1.2.2/3701.0102.029 |
| 3701.0302.313 | Reactor trip control. | 4/1.2.2/3701.0102.027 |
| 3701.0302.314 | Adjust gains automatically to maintain control stability. | 4/1.2.2/3701.0102.028<br>4/1.2.2/3701.0102.024 |
| 3701.0302.315 | Reactor or turbine trip control stable, with main steam cooling rates satisfactory for NSSS systems. | 4/1.2.2/3701.0102.041<br>4/1.2.2/3701.0102.024 |
| 3701.0302.317 | Software provide NSSSCS self-checking and failure announcement features. | 4/1.2.5/3701.0102.058<br>4/1.2.5/3701.0102.059 |
| 3701.0302.318 | Software support maintenance functions. | 4/1.2.7/3701.0102.060 |
| 3701.0302.319 | Software codes and standards requirement. | 4/1.2.10/3701.0102.067 |
| 3701.0302.320 | QAL requirement. | 4/1.2.11/3701.0102.068 |
| 3701.0302.321 | Parallel construction requirement. | 4/1.2.11/3701.0102.080 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0302.322 | Accommodate decommissioning one reactor while others in operation. | 4/1.2.13/3701.0102.080 |
| 3701.0401.010 | Command/data exchange with PSCS. | 2/1.2.5/3700.0322.260 |
| 3701.0401.020 | Command information sent to NSSS control actuators. | 2/1.2.5/3700.0322.290 |
| 3701.0401.025 | Command information sent to feedwater actuators. | 2/1.2.5/3700.0322.270 |
| 3701.0401.030 | Instrumentation for evaluating and determining state of NSSS. | 2/1.2.5/3700.0322.270 |
| 3701.0401.040 | Instrumentation to detect changes in major systems and components. | 2/1.2.5/3700.0322.225 |
| 3701.0401.050 | Main steam and bypass steam instrumentation for NSSSCS. | 2/1.2.5/3700.0322.280<br>2/1.2.5/3700.0322.290 |
| 3701.0401.060 | Turbine system control information sent to NSSSCS. | 2/1.2.5/3700.0322.320<br>2/1.2.5/3700.0322.330<br>2/1.2.5/3700.0322.340 |
| 3701.0401.070 | Capability to automatically regulate conditions of steam produced. | 2/1.2.5/3700.0322.290 |
| 3701.0401.080 | Location of controls and instrumentation in proximity of system. | 2/1.2.5/3700.0322.020 |
| 3701.0401.090 | Capability for operators to control outside of control room. | 2/1.2.5/3700.0322.110 |
| 3701.0401.100 | NSSSCS required to meet overall reliability allocation. | 2/1.2.5/3700.0322.430 |
| 3701.0102.405 | NSSSCS response to PPIS trip. | 5/4.1.1/3200.0401.050 |
| 3701.0102.410 | NSSSCS monitor and report SFSF temperature. | 8/4.1.1/3400.0401.048 |
| 3701.0102.415 | NSSSCS issue setpoint command to NCSS. | 6/4.1.1/1012.0401.079 |
| 3701.0102.420 | NSSSCS perform neutron flux calculations. | 6/4.1.1/1012.0401.080 |

Table A-1 (Continued)

| Traceability No. | Summary Description of Requirement | Source Reference/Section/ Traceability No. |
|---|---|---|
| 3701.0102.425 | NSSSCS monitor and alarm if more than three control rods withdrawn. | 6/4.1.1/1012.0401.081 |
| 3701.0102.430 | NSSSCS control circulator speed below maximum. | 7/4.1.1/2100.0401.090 |
| 3701.0102.435 | NSSSCS designed to maintain helium temperature at SG inlet within envelope. | 7/4.1.1/2100.0401.091 |
| 3701.0102.440 | NSSSCS control circulator speed to feedwater flow ratio. | 7/4.1.1/2100.0401.092 |
| 3701.0102.445 | NSSSCS designed to limit maximum temperature at SG outlet. | 7/4.1.1/2100.0401.093 |
| 3701.0102.450 | NSSSCS monitor and report feed-water temperature too high at SG inlet. | 7/4.1.1/2100.0401.094 |
| 3701.0102.455 | NSSSCS maintain stable steam outlet temperature below 1035°F. | 7/4.1.1/2100.0401.095 |
| 3701.0102.460 | NSSSCS monitor and report feedwater pressure too high at SG inlet. | 7/4.1.1/2100.0401.096 |
| 3701.0102.465 | NSSSCS monitor and report steam pressure too high at SG outlet. | 7/4.1.1/2100.0401.097 |

## TRACEABILITY STUDY SUMMARY REFERENCE LIST

1. This reference number not used.
2. "Plant Control, Data, and Instrumentation System Design Description," DOE-HTGR-86-076/2, (HFD-33700, Rev. 2), (GA Document 908437/2).
3. This reference number not used.
4. "NSSS Control Subsystem Design Description," DOE HTGR-86-051, Rev. 1, (HFD-43701, Rev. 2), (GA Document 908468/2), July 1987.
5. "Plant Protection and Instrumentation System Design Description," DOE-HTGR-86-047/1, (HFD-33200, Rev. 2), (GA Document 908444/2).
6. "Neutron Control Subsystem Design Description," DOE-HTGR-86-100/1, (HFD-41012, Rev. 2), (GA Document 908472/2).
7. "Heat Transport System Design Description Modular HTGR Plant," DOE-HTGR-86-020/3, (HFD-32100, Rev. 4), (GA Document 908441/4).
8. "Fuel Handling and Storage System Design Description," DOE-HTGR-86-098/1, (HFD-33400, Rev. 2), (GA Document 908445/2).

# APPENDIX B

## DRAWING LIST

| Drawing No. | Title |
|---|---|
| GA 029900 | Communications Between NSSS and ECA Control Modules |
| GA 029993 | NSSS Control Scheme and Interfaces IB Diagram |

# APPENDIX C
# TRANSIENTS

This appendix shows typical NSSS control system transient response during the following design events:

1. Load Ramp -- The NSSS control changes the output of the module at rates up to 5% per minute in order to change plant output. Load can change up to 75% (100% to 25% or 25% to 100%).

2. Load Step -- The NSSS control adjusts module steam flow up to 15% of the total design flow to change plant output automatically following a change in grid frequency.

3. Turbine Trip -- The NSSS control automatically reduces NSSS module steam flow at a rate of 15% per minute following a turbine trip. The reactor does not trip and the NSSS module continues to supply steam at rated temperature after the trip. If both turbines trip, the total NSSS steam flow will be reduced to 25%.

4. Reactor Trip -- The NSSS control automatically reduces feedwater flow and steam temperature following a reactor trip. The steam temperature feedback loop for circulator speed control is opened when the steam temperature reaches the saturation value and HTS cooling is continued via feedforward control of feedwater flow and circulator speed.

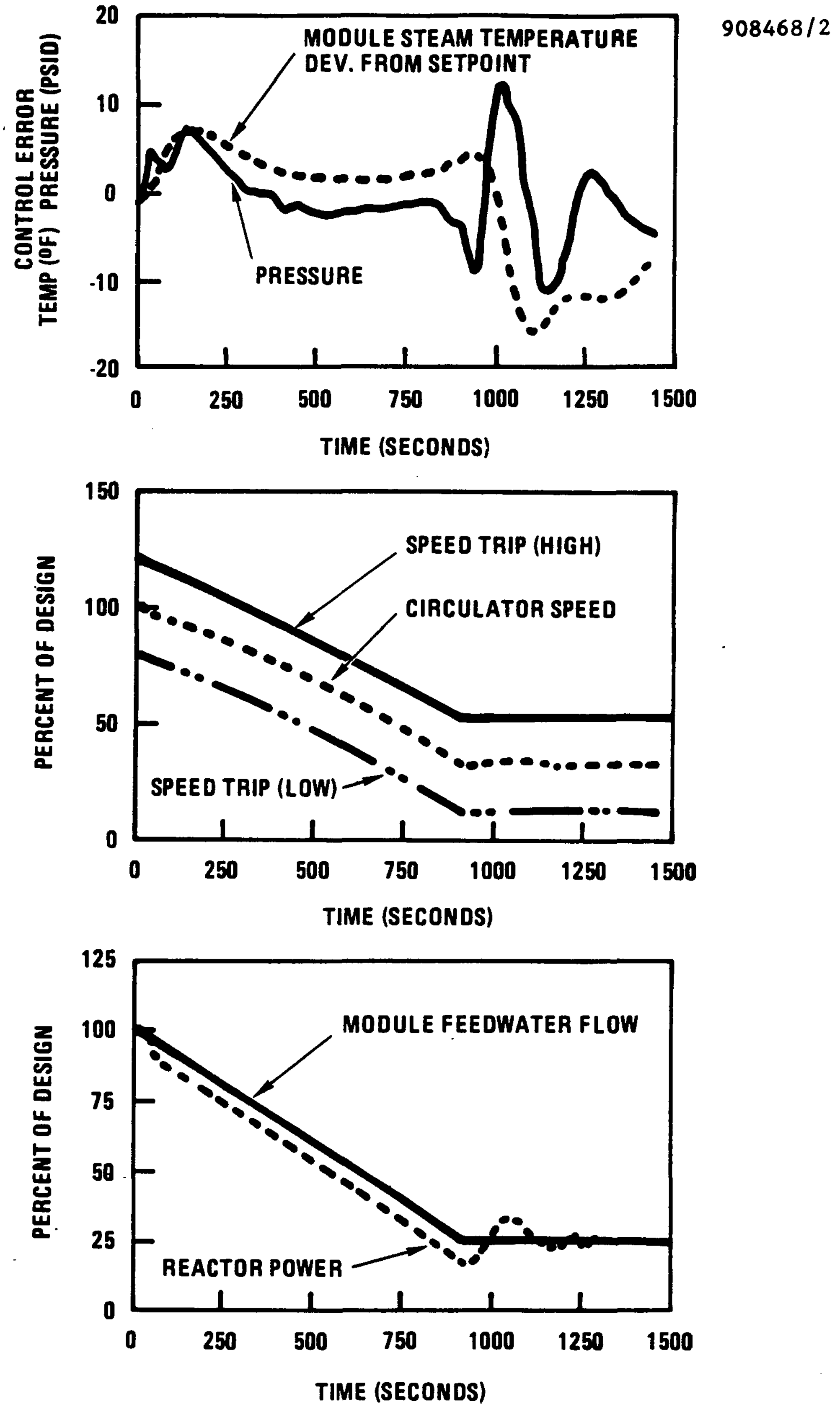


Fig. C-1. FIVE PERCENT PER MINUTE LOAD RAMP - 100% LOAD TO 25% LOAD

908468/2

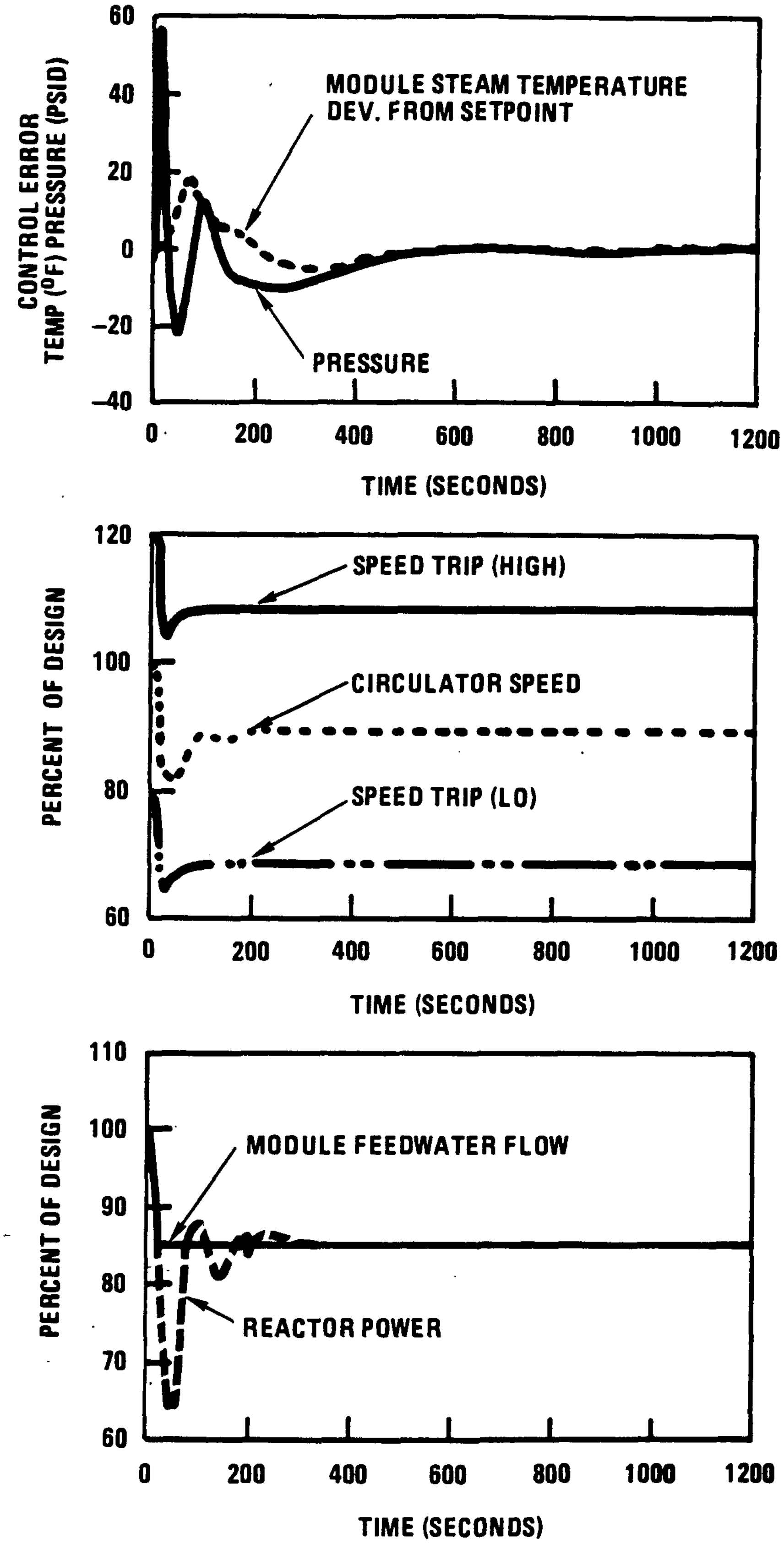


Fig. C-2. FIFTEEN PERCENT LOAD STEP - 100% LOAD TO 85% LOAD

908468/2

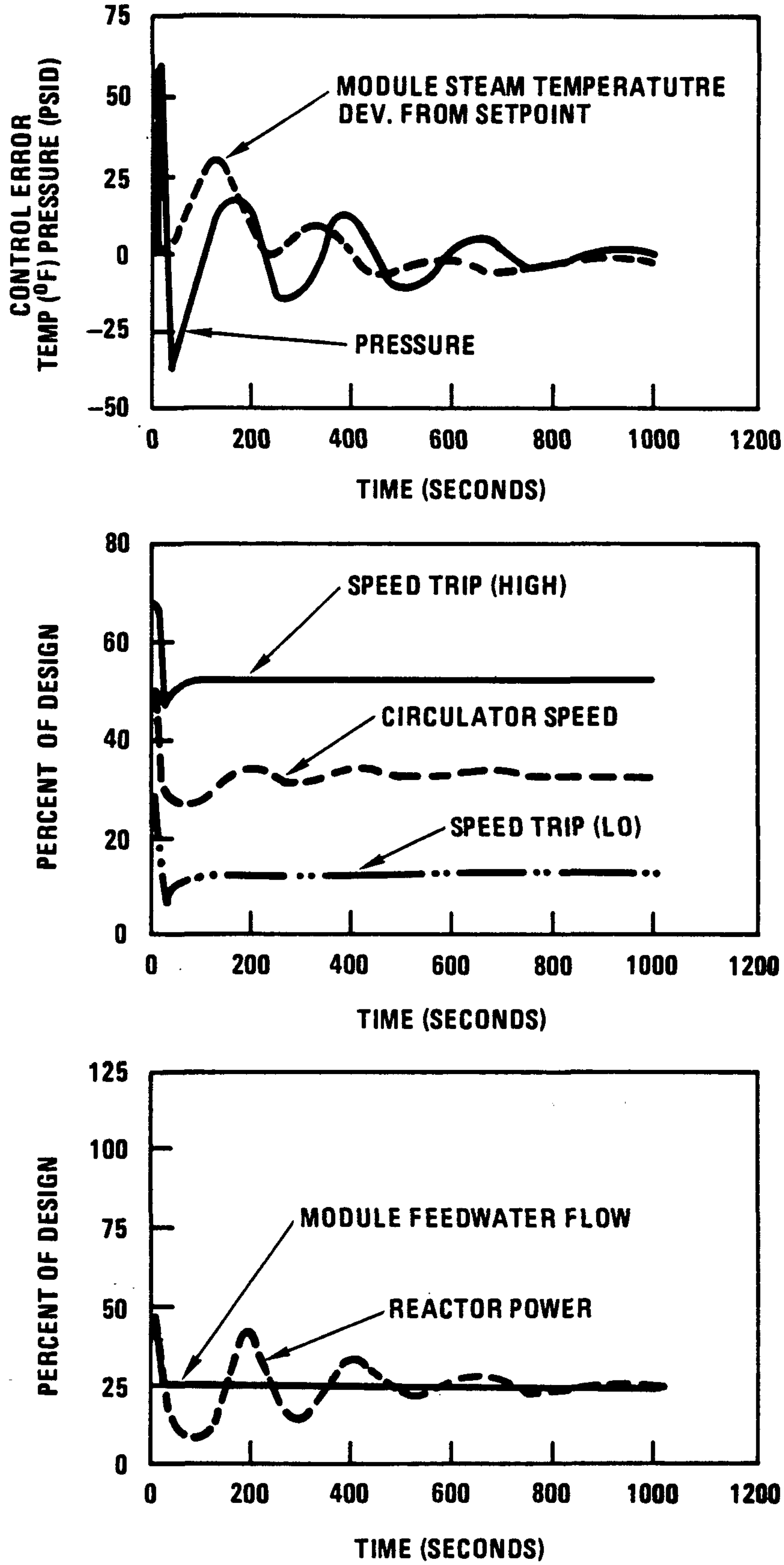


Fig. C-3. FIFTEEN PERCENT LOAD STEP - 40% LOAD TO 25% LOAD

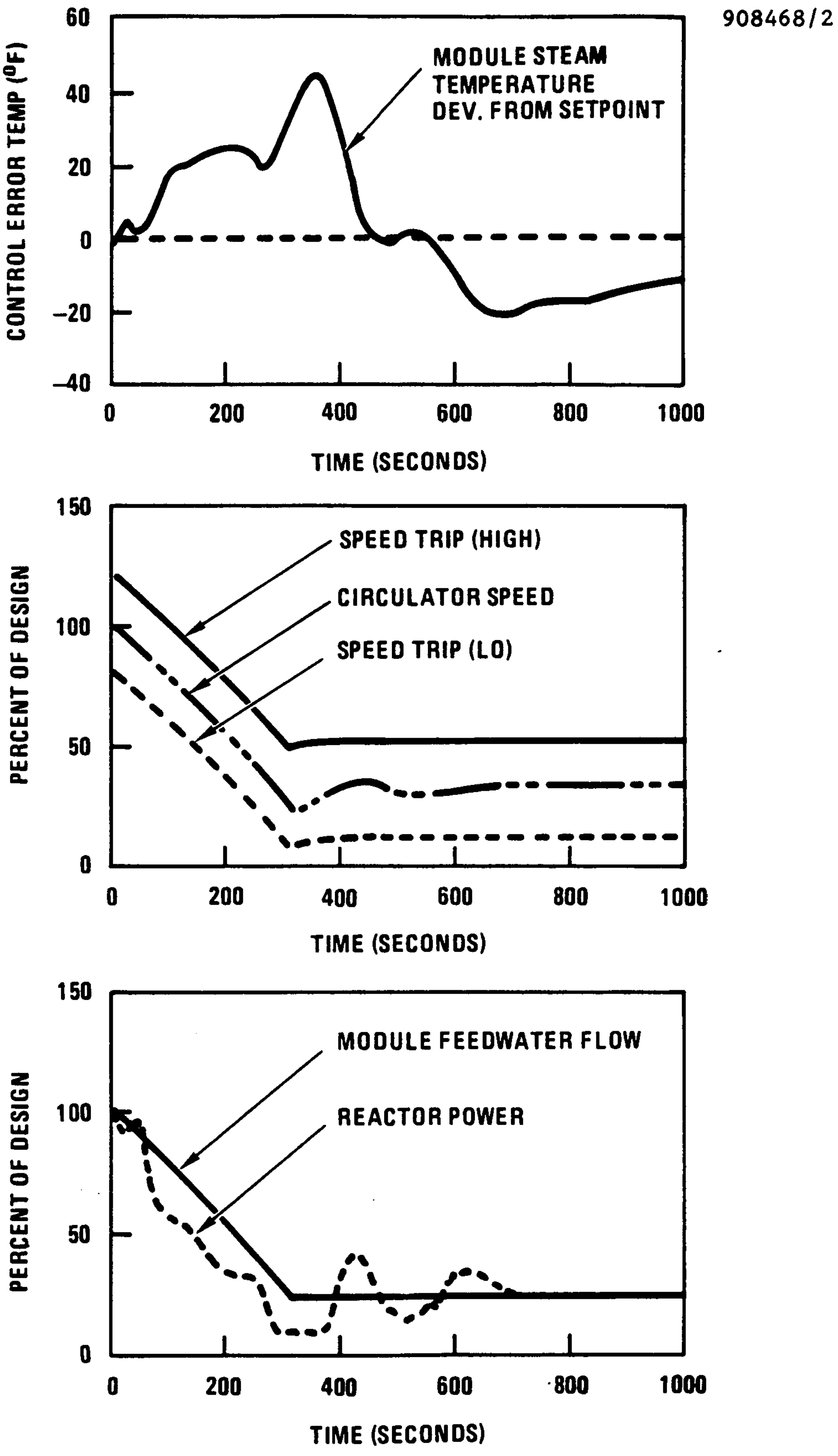


Fig. C-4. TURBINE TRIP RESPONSE OF NSSS MODULE FROM 100% LOAD TO MINIMUM STEAM FLOW

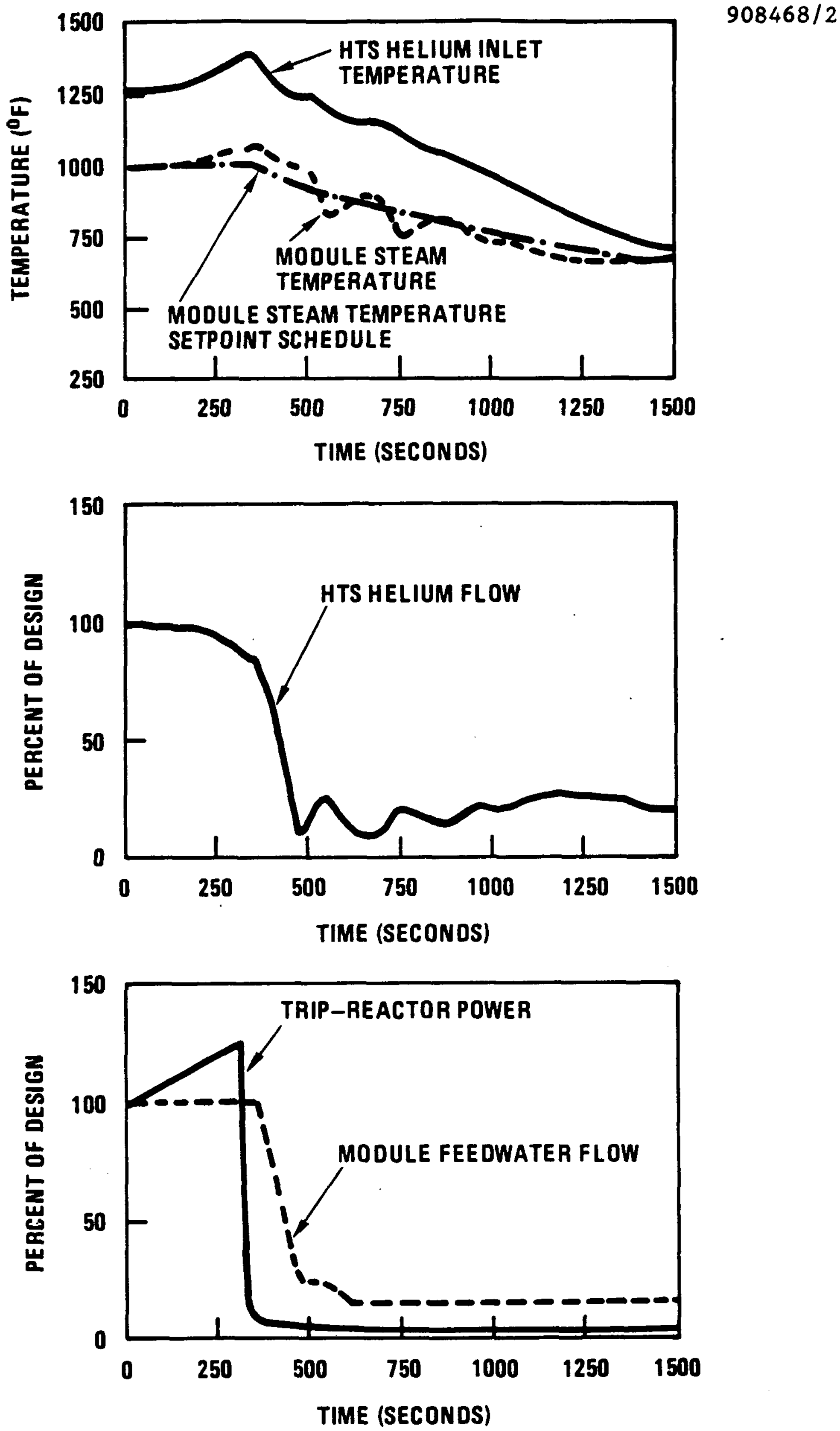


Fig. C-5. REACTOR TRIP RESPONSE AFTER POWER INCREASES ABOVE 100%

# APPENDIX D

[LATER]

# APPENDIX E
## EQUIPMENT LIST

The following is a list of major equipment contained in the NSSS Control Subsystem (NSSSCS) equipment module. One NSSSCS equipment module is supplied with each NSSS module.

| Equipment | Quantity |
|---|---|
| NSSS Operations Station | (1) |
| cables | |
| consoles | |
| cabinets | |
| printer | |
| operation manuals | |
| service equipment package | |
| maintenance tools | |
| maintenance manuals | |
| NSSS Control Software | (1) |
| disks | |
| manuals | |
| NSSS Systems Interface Station | (4) |
| cables | |
| consoles | |
| cabinets | |

# APPENDIX F
# PARAMETER LIST

The following is a list of major parameters utilized by the NSSS Control Subsystem for control of its NSSS module.

Primary measurements:

Module feedwater flow.
Helium flow.
Circulator speed.
Reactor power.
Control rod positions.
Module main steam temperatures.
Helium pressure.
Circulator motor cooling water temperature.

Other measurements:

Isolation and shutoff valve positions.
Isolation and startup control breaker positions.
Analog valve positions.
Status of SCS and HPS systems.

A count of parameters at the next level of detail is included in Section 2.2.2.