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STATUS OF SAFETY-RELATED QUALIFICATION AND DESIGN VERIFICATION AND SUPPORT PROGRAMS IN SUPPORT OF HTGR PSARs

BIANNUAL REPORT
FOR PERIOD ENDING JANUARY 31, 1975

by
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FOREWORD

This Licensing Topical Report (LTR) has been prepared by General Atomic Company (GA) to present to the Nuclear Regulatory Commission (NRC) the status of items cited in Section 1.5 of HTGR Preliminary Safety Analysis Reports (PSARs) as requiring further Design Verification and Support (DV&S). Certain items such as electronic components that must be qualified to IEEE-323-1974 requirements and those designated as Prototypal and requiring Qualification Programs are also included. This report is updated every 6 months.

Two prior reports in the series have been published:

GA-A12936 (GA-LTR-100), "Safety-Related Research and Development Programs Cited in Section 1.5 of HTGR PSARs, Biannual Report for Period Ending January 31, 1974."

GA-A13183 (GA-LTR-101), "Safety-Related Research and Development Programs Cited in Section 1.5 of HTGR PSARs, Biannual Report for Period Ending July 31, 1974."

INTRODUCTION

This report is the third in a series of biannual reports initially intended to cover the status of the programs called for in Section 1.5 of large HTGR PSARs that are docketed. This report covers the Delmarva Power & Light Summit Power Station, the Philadelphia Electric Fulton Generating Station, and the General Atomic Standard Plant as described in the General Atomic Standard Safety Analysis Report, GASSAR-6. Section 1.5 of the PSARs, entitled "Requirements for Further Technical Information," contains a description of a number of research and development (R&D) programs (or DV&S Programs), either planned or in progress, that will provide further technical information directly related to plant safety. This series of LTRs was intended to give the current status of these programs with emphasis on program, schedule, technical detail, and progress.

Beginning with this report, the scope of this series has been broadened to include Qualification Programs. This change reflects commitments made by GA to document program plans and progress for a number of items requiring Qualification Programs either because they are designated as Prototypal or because a Qualification Program is required. Operation or analytical methods, or a combination of both, may be used for qualification demonstration, depending upon the specific circumstances. The component performance must be measured against relevant design and acceptance criteria, and one of the primary purposes of this report is to state such criteria and describe the plans for demonstrating that they are met.

The principal class of components requiring Qualification Programs consists of electronic modules associated with various systems of the Plant Protection System (PPS). Other components designated Prototypal or that require Qualification Programs fall in classes already being reported under DV&S Programs in the LTR series. These include (1) the control rod drive system including orifice valves and the reserve shutdown system, (2) the

primary coolant moisture monitor system, and (3) the core auxiliary cooling system (to include the main loop coolant shutoff valve). The safety-related components of the main helium loop are now also included. The "R&D" programs planned for these classes of components, which have formed the basis for the previous reports in this series, are in practice DV&S Programs, a mixture of DV&S and Qualification Programs, or Qualification Programs only. The topics covered in this report and the type of coverage that has been designated are given in Table I.

Where both DV&S and Qualification Programs are designated, this report covers both types of programs under a single topical heading.

TABLE I
TOPICS AND TYPE OF COVERAGE

	Program	
	DV&S	Qualification
Core Seismic	X	
Core Support Posts	X	
Primary Coolant Moisture Monitor	X	X
Moisture Monitor Compressor		X
Control Rod System	X	X
Orifice and Drive Mechanism	X	X
Reserve Shutdown System	X	X
Main Loop Coolant Shutoff Valve	X	X
Auxiliary Loop Coolant Shutoff Valve	X	X
Core Auxiliary Heat Exchanger	X	X
Auxiliary Loop Coolant Circulator Assembly	X	X
Auxiliary Loop Coolant Circulator Motor Speed Controls	X	X
PPS Electronic Modules		X
Buffer Modules		
Bistable Trip Modules		
PPS Logic Modules		
Valve Control Modules		
Analog Test Modules		
Main Loop Helium Circulator (Safety- Related Components)	X

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SUMMARY

CORE SEISMIC PROGRAM

Experimental Testing

One test series was completed during the report period:

1. Core parameter studies were performed on 1/5- and 1/2-scale horizontal core sections, each with 73 elements.

There are presently seven areas in which tests are ongoing or planned:

1. Multibody collision tests of 1/1-scale graphite fuel elements are scheduled for completion in June 1975.
2. Basic rocking tests are being performed on 1/5- and 1/1-scale fuel elements with two, three, and four elements stacked on top of each other. They will be complete in February 1975.
3. Single column tests on 1/5-scale graphite elements on a core simulated support block supported by core support posts are scheduled for completion in May 1975.
4. Two-axis excitation tests on a 1/2-scale two-dimensional model are scheduled for completion in June 1975.
5. Additional 1/5-scale full-array tests are being performed. These tests include measurement of the shear forces in the dowel pins. They will be complete in March 1975.

6. Further tests on the 1/5-scale full-array model with simultaneous multiaxis inputs are tentatively planned for the third quarter of 1976.
7. Tests to demonstrate the workability of control rods and the reserve shutdown system in an earthquake are scheduled for completion in the fourth quarter of 1976 on the 1/5-scale full-array model.

Analytical Development

Of the seven codes being generated for seismic analysis, COSAM and CRUNCH 1-D are operable, although still undergoing development and improvement. The other codes are in various stages of development.

CORE SUPPORT POSTS

Two candidate graphites for core post material are being evaluated. Material testing and tests of post assemblies are scheduled for the second quarter of 1975. Following these tests, a complete full-scale assembly of one core support block with three posts will be tested to failure.

PRIMARY COOLANT MOISTURE MONITOR

The moisture monitor test program in the Peach Bottom HTGR has been concluded and the results are summarized herein. Tentative conclusions given in GA-LTR-101 were not altered. A test procedure for moisture monitors in an atmosphere that simulates large HTGR sample monitoring has been prepared, and testing is scheduled to commence in June 1976.

The moisture monitor system for the large HTGR includes a compressor for returning the helium from an accumulator to the reactor. The design, which originally called for a small axial flow compressor, has been revised to incorporate an off-the-shelf diaphragm compressor such as that used in the Peach Bottom HTGR. This proven component will require only the normal qualification.

CONTROL ROD DRIVE ASSEMBLY

A first test series established the adequacy of the torque motor, gear train, and grease lubrication for the drive bearings. During the report period, a parametric study to obtain design data from an orifice valve that did not perform to design criteria was completed. A prototype valve will be designed, tested in air, and then qualified, with its drive and a full-scale control rod and reserve shutdown system assembly, in a simulated reactor environment. Completion of these tests is scheduled for November 1976. In the first half of 1977, the complete assembly will be subjected to a prolonged moist atmosphere test.

CORE AUXILIARY COOLING SYSTEM (CACS) COMPONENTS

The auxiliary circulator motor tests are progressing as planned and will continue through 1975. The bearing lubrication and seal system tests are in progress and will also continue through the remainder of the year. The motor cooling system test rig is being fabricated. Testing is scheduled to commence in October 1975 with completion in March 1976. Initial tests of motor insulation have been completed. Preliminary results have shown the Dacron glass over enamel insulation construction is preferable. Further tests are in progress in this configuration. Motor insulation qualification testing is expected to be completed by March 1976.

Following the component tests, a complete prototype auxiliary circulator assembly including the CACS shutoff valve will be subjected to a series of qualification tests to demonstrate operational capabilities. Tests are scheduled to start in November 1977.

Core auxiliary heat exchanger (CAHE) development testing has begun. Currently, the gas-side inlet flow distribution test is in progress. The CAHE corrosion/erosion test is scheduled to start in September 1975.

Bench tests of the main helium shutoff valve actuator mechanism are currently scheduled for the first half of 1976. The complete valve performance qualification test is scheduled for the second half of 1976.

PPS ELECTRONIC MODULES

Five PPS systems have been designated as requiring Qualification Programs. The five systems are composed of nine different types of modules, and the modules will be qualified as a basis for qualifying the systems. Of the nine types of modules, design specifications have been prepared on five and are being prepared on two others. A test plan has been prepared for one type of module, the buffer module, and others are being prepared.

MAIN HELIUM CIRCULATOR

A program is being developed that will provide experimental/analytical verification that the safety-related circulator components (those with the potential to affect the primary coolant pressure boundary) will withstand a rotor burst and shaft seizure.

SCHEDULE SUMMARY

Table II presents an overall schedule for all the major tasks covered in this report.

TABLE II
SCHEDULE FOR DV&S AND QUALIFICATION PROGRAMS

Task	1975												1976												1977												1978				
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
Core Seismic																																									
Collision dynamics 1/5-, 1/2-, and 1/1-scale tests																																									
Single column test, 1/5 scale																																									
Two-dimensional, two-axis (73 x 1 element) test, 1/2 scale																																									
Full-array dowel force test, 1/5 scale																																									
Multiaxial test and control rod test, 1/5 scale																																									
Basic rocking tests, 1/5 and 1/1 scale																																									
Analytical																																									
CRUNCH 2-D																																									
COCO																																									
SECA																																									
Multicolumn COCO																																									
Multicolumn SECA																																									
Core Support Posts																																									
Materials evaluation																																									
Full-scale support block and three-post test																																									
Primary Coolant Moisture Monitor																																									
Evaluation of units in HTGR environment																																									

TABLE II (continued)

Task	1975												1976												1977												1978							
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M			
Control Rods and Associated Hardware																																												
Control rod drive mechanism																																												
Orifice valve environmental tests																																												
Reserve shutdown system environmental drop tests																																												
Control rod assembly in moist environment																																												
PPS Electronic Modules																																												
Buffer modules																																												
Bistable trip modules																																												
Logic modules																																												
Valve control modules																																												
Analog test module																																												
Digital test module																																												
Power supply																																												
Primary coolant flow measurement																																												
Special purpose modules																																												
Core Auxiliary Cooling System																																												
Auxiliary circulator components																																												
Bearing lubrication and seals																																												
First article motor																																												
Motor insulation																																												
Circulator prototype																																												

TABLE II (continued)

Task	1975												1976												1977												1978							
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M			
Motor control																																												
Auxiliary circulator shutoff valve																																												
Core auxiliary heat exchanger																																												
Main loop helium shutoff valve																																												
Auxiliary circulator assembly																																												
Main Helium Circulator																																												
Blade shedding																																												
Overspeed demonstration																																												

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1. CORE SEISMIC PROGRAM

1.1. INTRODUCTION AND BACKGROUND

1.1.1. Introduction

A core seismic DV&S Program is in progress. The purpose of the program is to determine the seismic response of the reactor core and core support system and to demonstrate that the design can safely withstand the specified earthquakes for the full range of potential site and soil conditions. In particular, the results of the program will be used to show the adequacy of the designs for the Summit and Fulton plants and for the standard plant, GASSAR-6.

The program involves both experimental and analytical studies of HTGR cores under conditions experienced during severe earthquakes. In addition to verifying the seismic adequacy of the core and core support system, the program will demonstrate the ability to insert the control rods to achieve and maintain core subcriticality. The Core Seismic Program is scheduled for completion by the end of 1976.

1.1.2. Background

The reactor core for the large HTGR is similar to the Fort St. Vrain (FSV) design, but the core support structure, both vertically and laterally, is different. From a seismic standpoint the main difference is that the FSV core is surrounded by a continuous core barrel into which the core support blocks and the top plenum layer are keyed. In the large HTGR design the core is laterally supported by springs connected directly to the sidewall of the prestressed concrete reactor vessel (PCRV).

The FSV reactor was designed for a site with very low seismic activity [the specified Operational Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE) were 0.05 and 0.08 g, respectively]. Because of this very low g-load, it was found acceptable to make simplifying and conservative assumptions such that the seismic design and analysis of the core and the core support system could be done by equivalent static load methods. For sites in higher seismic zones, this approach is not acceptable and a rigorous dynamic analysis must be performed.

The need for dynamic analysis of the core having been identified, the available multipurpose computer codes, such as NASTRAN and ANSYS, were surveyed. However, it was concluded that the problem is of such a special nature that it would be more practicable to develop separate computer codes for the specific purpose. The main objective of the core seismic program is to develop such computer codes and to verify the analytical methods by correlation with appropriate tests. The program also has a component strength phase for establishing the ability of the fuel elements to withstand impact loads.

1.2. OBJECTIVE

The primary objective of the Core Seismic Program is to develop analytical methods which can be used in the design of the core and the core support system and to verify these by comparison with test results. Since the tests are performed to provide information for the analytical computer codes, and not to directly confirm the design, the test results are not the end product. The end product of the Core Seismic Program will be the verified computer codes.

The specific information which is needed for the design and which will be determined during the program may be summarized as follows:

1. Impact load between adjacent fuel and reflector elements.

2. Shear forces in the dowel pins which connect the elements in a fuel column.
3. Displacements of the various components vertically, horizontally, and rotationally. This information will be used to evaluate control rod insertability and to study the potential for disarray.
4. Dynamic loads acting on the core support structure, the permanent side reflector, and the lateral restraint structure.
5. Impact strength of the core components, in terms of both failure under a single load application and fatigue failure under repeated loads.

1.3. DV&S PROGRAM

The Core Seismic Program consists of three phases:

1. Seismic tests.
2. Analytical development.
3. Fuel element impact tests.

The seismic design of the HTGR core and core support system is done according to the principle of "design by analysis." Therefore, the seismic loads in the core under the actual operating conditions are determined analytically. The development of analytical techniques for this purpose constitutes Phase 2 of the Core Seismic Program. Phase 1 consists of seismic tests on scaled models of full or partial reactor cores for verification of the analytical techniques. In Phase 3 the impact and fatigue strength of the fuel elements is established by testing full-scale elements.

1.3.1. Phase 1: Seismic Tests

Three types of tests are being performed within this phase:

1. Dynamic response tests of individual core components or small groups of components. These tests have two basic objectives:
 - a. Preparation for the more extensive tests of type 2 and 3.
 - b. Establishment of the basic dynamic properties needed for the analytical development, such as coefficient of restitution, dynamic stiffness, damping, etc.
2. Tests on scaled sections of the core. These tests are performed to study the effects of varying basic parameters such as in-core gaps, boundary spring rate, etc., and to provide data for analytical correlation.
3. Tests on scaled models of the entire core and core support system. The models are subjected both to harmonic vibration and to random excitation corresponding to real and artificial earthquakes. The test results are used to study the seismic response of the core in terms of loads, deflections, and velocities and for final analytical correlation.

A total of 14 tests will be performed. The first three are type 1, the next seven type 2, and the remaining four type 3. The tests are described below:

1. Pendulum collision tests between pairs of fuel elements in 1/5, 1/2, and 1/1 scale were performed to study the collision dynamics of graphite, that is, to obtain the force/time relationship of impact, coefficient of restitution, etc. These data have been employed as basic input to analytical collision models. The tests were completed in 1973 at the GA test facility.
2. Multibody collision tests on 1/5-, 1/2-, and 1/1-scale elements are being performed by sliding the graphite fuel elements on

frictionless rails. Interblock collisions with permutations of five blocks are performed as well as collisions off a support structure. The post-collision behavior is studied in all cases. The results are employed to establish basic dynamic properties for the analytical models. Tests with 1/5- and 1/2-scale blocks are completed, and the results from 1/1-scale tests are expected by June 1975. The tests are being performed at Harvey Mudd College, Engineering Division, Claremont, California.

3. Basic rocking tests are being performed on 1/5- and 1/1-scale fuel elements with two, three, and four elements stacked on top of each other. The blocks are displaced to a set configuration and then released. The rocking motion is recorded as well as the shear forces on the connecting dowel pins and the resulting vertical block force when one block rocks down on another. These tests are designed to yield further basic data for the analytical development phase, in particular for the mathematical modeling of the rocking phenomenon. The tests are being conducted at Approved Engineering Test Laboratories (AETL), Chatsworth, California, and will be complete in February 1975.
4. Vibration tests on stacked columns of scaled fuel elements were performed with sinusoidal excitations. A 1/8-scale graphite column, a 1/4-scale graphite column, and a 1/4-scale acrylic column were tested. An axial static force simulating the core pressure drop was applied to the top of the column. The input frequency ranged from 0 to 18 Hz, the input displacement from 1/16 to 1/4 in., and the amplitude of the input acceleration from 0 to 1 g. The data obtained were used to study the "column effects" on a planar array as part of the effort to assess how the three-dimensional core can be described by a two-dimensional model. These tests were completed in 1971 at the GA test facility.
5. Further single column tests are being performed with 1/5-scale graphite elements situated on a simulated core support block

supported by simulated support posts. Uniaxial excitation horizontally and vertically will provide column frequency and damping characteristics. Measurements of column deflection, fuel element rocking angles, dowel shear forces, and support post forces will provide data for correlation with the analytical computer codes, both for uniaxial tests and for combined horizontal and vertical tests. Test completion is scheduled for May 1975 at Wyle Laboratories, Norco, California.

6. A model representing a simulated horizontal layer of fuel elements was subjected to harmonic vibrations at the GA test facility. The model consisted of a two-dimensional array of 3-1/2-in.-diameter, 1-in.-high pucks resting on a base and contained within a rigid hexagonal-shaped boundary. Boundary displacement and acceleration, as well as puck accelerations and velocities, were measured for various excitation frequencies and amplitudes. The tests were completed in 1971, and the data correlated well with the results from PIC, an early (now obsolete) computer code.
7. Hydromechanical shaker tests were conducted on ninety-one 1/5-scale graphite elements representing a two-dimensional planar section of the core. These tests provided a checkout for the 1/5-scale full-array systems:
 - a. Hydromechanical shaker control system.
 - b. Instrumentation.
 - c. Computerized data acquisition system.

These tests, which were completed at Wyle Laboratories in 1972, concluded an extensive instrumentation development program designed to measure displacements, velocities, and forces on elements in the core and displacements and forces in the lateral restraint.

8. As part of the core parametric studies and correlation of two-dimensional analytical computer codes, tests were performed at AETL on 1/5- and 1/2-scale horizontal core sections, each with 73 elements. A wide range of core gap values and their influence on the resonance and lumping characteristics were studied. Fuel element impact forces, relative velocities, and boundary support forces were measured to provide data for correlation with results from two-dimensional analytical models. Both the 1/5- and 1/2-scale tests were completed in January 1975.
9. The test scope for the 1/2-scale two-dimensional model has been expanded to include two-axis excitation along orthogonal directions in the horizontal plane. The objectives are to study two-dimensional core behavior and provide data for correlation with analysis. These tests are scheduled for completion in July 1975 at AETL.
10. Tests on a 1/4-scale model of a partial core were undertaken in cooperation with the French Atomic Energy Commission (Commissariat a l'Energie Atomique) at their research facilities in Saclay near Paris. The model was built of graphite and consisted of 91 fuel columns in full (scaled) height, as compared with 300 to 500 columns in the HTGR core. Two horizontal boundaries were tested, one flexible and one rigid. Boundary forces and in-core velocities were measured. The tests were completed in March 1974.
11. A 1/5-scale model of the full core representing the 3000-MW(t) reference design was built at Wyle Laboratories. The model contains graphite elements and was designed to be an accurately scaled reproduction of the core and the core support structures, incorporating all design details that might affect the dynamic response. It represents the core in its cold and fully irradiated state. Briefly, the 1/5-scale test objectives were to obtain the following information under earthquake conditions:

- a. Core motion characteristics.
 - (1) Core lumping.
 - (2) Natural frequencies and mode shapes.
 - (3) System damping.
- b. Force and deflection of lateral supports.
- c. Core deflection and forces.
 - (1) Fuel column and reflector column deflections.
 - (2) Fuel element impact forces.
- d. Number of repetitious loadings of fuel elements.

In addition to harmonic boundary excitation, real and artificial earthquakes were applied at g-levels ranging from 0.075 to 0.75 equivalent ground intensity. The core was tested uniaxially in two orthogonal directions: across the flats of a fuel element and across the corners. Two side support designs were studied: (1) a soft spring support with 20,000 lb/in. equivalent full-scale stiffness and (2) a combination soft spring and hard stop support, which represents the HTGR lateral restraint structure. These studies were completed in January 1974.

- 12. An extension of the 1/5-scale full-array tests includes the measurement of the shear forces in the dowel pins which constitute the connecting link between adjacent elements within a column. Selected dowel pins in the model are instrumented with strain gages and load washers. Dowel shear forces are determined at numerous locations throughout the core. The excitation of the test rig is uniaxial across the flat faces of the elements. The test is scheduled for completion in March of 1975 at Wyle Laboratories, and the results will be used for comparisons with predictions from the analytical codes.
- 13. Further tests with the 1/5-scale model (modified partial or full array) with simultaneous multiaxis input are tentatively planned. The multiaxis input will include excitation in one horizontal and

one vertical axis, both separately and simultaneously. Test specifications for multiaxis testing of the 1/5-scale full-array model and the alternative partial array are scheduled for completion in the second quarter of 1975. The test objectives are similar to those described above for the uniaxial tests. In addition, dowel forces and vertical support forces will be obtained. Completion of these tests is tentatively scheduled for the third quarter of 1976. The contract for this work has not yet been awarded.

14. The test scope also includes further tests with the 1/5-scale full-array model to determine the effect of the control rods on core behavior and to demonstrate the insertability of the control rods and the ability of the reserve shutdown system to function during an earthquake. This safety-related program, which also includes parametric analysis of the core, is sponsored by ERDA. Analytical modeling of the core, including control rod models to interact with the core, is in progress. Work on test specifications that will describe the substantial modifications required to the 1/5-scale test rig and the design and manufacture of a 1/5-scale control rod are also under way. The control rod tests are scheduled for completion in the fourth quarter of 1976 in conjunction with the multiaxis test described above. The contract for this work has not yet been awarded.

With the exception of tests No. 4, 7, and 10, which were scoping-type tests, the following instrumentation is used in all the seismic tests:

1. Strain gages and load cells are used to measure impact forces between adjacent fuel elements. The strain gages are attached to the surface of one of the vertical holes through the test elements and are calibrated to give impact loads resulting from collision of the instrumented element with a rigid bumper mounted on a pair of Kistler load cells. Kistler load cells are also used to measure the impact loads directly, in which case they are

mounted on the side face and on the bottom face of the elements. Those on the bottom face are used to measure vertical collision force when the elements rock on top of each other.

2. Boundary loads are measured with Kistler load cells.
3. Distances between adjacent elements are measured with eddy current gages and recorded as a function of time. Relative velocities are computed from these measurements and are assumed to be constant within the very closely spaced recording intervals.
4. Deflections at the boundary are measured with liner velocity displacement transducers (LVDTs), which can measure accurately over a larger range than the eddy current gages.
5. Contact devices are used to determine when the elements are in contact and when they are separated. These are small metal strips, wired to conduct electrical current and attached to the hexagonal side faces of selected elements. Current flows in the circuit only when the elements are in contact.
6. Dowel forces are measured by providing special dowels instrumented with strain gages in selected elements. The strain gage values are calibrated statically by suspending weights from the dowel pins.

1.3.2. Phase 2: Analytical Development

This phase of the Core Seismic Program includes the development of computer codes which can be used to predict the seismic loads in the core and its support system, to establish numerical values for the basic dynamic properties by "tuning" with the type 1 tests of Phase 1, and to verify the codes by correlating their predictions with the results of the type 2 and type 3 tests.

Seven computer codes are under development or in the planning stage. This number of codes is felt necessary for the following reasons:

1. Because of the great complexity of the problem, it is desirable to start with relatively simple geometrical models, correlate them with experiments, and then proceed to more complex models with the experience gained.
2. Simple design tools are needed for use in parametric studies. The codes with the more complex geometrical models are inconvenient for this purpose because they require extensive computer time.
3. Two alternative techniques for the mathematical modeling of the interelement collisions are used: spring-damper and impulse-momentum.

The main features of the seven codes are described below:

1. COSAM models a one-dimensional horizontal "strip" diametrically across the core. The fuel and reflector elements contained in this strip are described as discrete masses connected to the PCRV by springs and dampers to simulate the "column effect." Collisions between adjacent elements are modeled by special nonlinear collision springs. Mathematically, the problem is solved by numerical integration of the differential equation of motion. The output gives velocities, displacements, interelement collision forces, and boundary forces. Good correlation with the 1/5-scale full-array test has been achieved (reported in Summit Power Station PSAR, Q 3.17a, Amendment 16, April 6, 1974; Fulton Generating Station PSAR, Q 3.7.2-4, Change 9, May 1974).
2. CRUNCH 1-D is similar to COSAM except that the collisions are modeled mathematically by the impulse-momentum technique. The impulsive force is a function of the coefficient of restitution

and the contact time, both of which are established from the collision tests already described. Spring rates and damping values for the springs which simulate the column effects are established from the column shake tests. The code has been correlated with the 1/5-scale full-array tests with good results (reported in Summit Power Station PSAR, Q 3.17a, Amendment 16, April 6, 1974; Fulton Generating Station PSAR, Q 3.7.2-4, Change 9, May 1974). Correlation with the 1/5- and 1/2-scale two-dimensional tests will be completed during June 1975. CRUNCH 1-D requires significantly less computer time than COSAM and is therefore better suited for design purposes. The results predicted by the two codes are being compared in order to use the more standard spring-damper approach to confirm the less common impulse-momentum technique.

3. CRUNCH 2-D models a horizontal array, including the core, the permanent side reflector, and the lateral restraint structure. The solution technique is the same as in CRUNCH 1-D, extended to two directions. The code will be used to determine the effects of simultaneous ground acceleration in two horizontal directions and to obtain a more detailed distribution of collision forces, both internally and around the boundary. Programming has started, and the code is scheduled for preliminary completion by December 1975.
4. COCO is a code to analyze a stacked column of fuel elements subjected to horizontal and/or vertical boundary excitation. Horizontal collisions with the boundary, as well as the vertical collisions that take place when the elements rock on top of each other, are described by springs and dampers. Mathematically, the code is based on deriving the governing nonlinear differential equations by a Lagrangian approach. These equations are solved numerically by a modified Runge-Kutta process. The output gives displacements (horizontally, vertically, and rotationally), dowel shear forces, and horizontal and vertical collision forces. The preliminary version of COCO will be completed during March 1975,

but like all the other codes, COCO will undergo continued development and improvement.

5. SECA uses the impulse-momentum approach to the analysis of a stacked column; otherwise, it is quite similar to COCO. The impulse-momentum method allows a large integration step to be used, so computer time is considerably less than for COCO. Completion of a preliminary version is scheduled for September 1975. Correlation will be undertaken with the single column test and with the dowel force test.
6. Multicolumn COCO models a series of stacked columns side by side, including the core support blocks and posts and the lateral restraint structure. The output will give more detailed dowel forces, horizontal and vertical collision forces, and displacements. The displacements will be used to show that disarray cannot take place. The code will also compute the dynamic forces applied to the support blocks and the posts. Formulation of the basic equations has begun. A preliminary version is scheduled for completion in September 1975.
7. Multicolumn SECA analyzes a series of stacked columns by the alternative impulse-momentum technique. Geometrically, the code is similar to Multicolumn COCO, and it provides the same information. One reason for developing Multicolumn SECA is that Multicolumn COCO may be so expensive to operate that only a limited number of runs can be made. Correlation will be made with the 1/5-scale full-array tests, in particular with the multiaxis test. A preliminary version is scheduled for completion in March 1976.

1.3.3. Phase 3: Fuel Element Impact Tests

Fuel element fatigue tests are being conducted at the GA test facility to gather basic design information for determination of the fatigue behavior of the graphite fuel elements. These data will be used to develop appropriate seismic acceptance criteria.

The impact fatigue behavior of the fuel elements is determined by subjecting them to repetitive two-body collisions. The fuel elements are supported by ballistic pendulums and impacted at specified orientation and force until fatigue failure occurs. Instrumentation enables determination of impact velocity, contact time, impact force, and number of impacts. Elements are inspected for cracks or other damage. The cracks are recorded as a function of impact force and number of impacts.

Fuel element fatigue testing, scheduled for completion by August 1975, will include determination of the fatigue lives of H-327 and H-451 graphite fuel elements in various impact orientations.

Present fatigue test results include determination of the impact fatigue life of H-327 graphite control fuel elements in flat-face configuration. The mean control element impact fatigue life N can be expressed by the relation

$$N = \alpha(F - F_e)^{-\beta} ,$$

where F = impact force in pounds,

F_e = endurance limit,

α and β = constants.

Experimental results give the following estimated values:

$$F_e = 21,250 \text{ lb}_f ,$$

$$\log \alpha = 18.01 ,$$

$$\beta = 3.68 .$$

As an example, this relation indicates that H-327 fuel elements can survive 25 impacts of 54,000 lb_f , 10 impacts of 63,000 lb_f , or one impact of 99,600

1b_f. Standard fuel elements have been shown to have fatigue strengths at least as great as those of control fuel elements.

1.4. ACCEPTANCE CRITERIA

The acceptance criteria for the design of the HTGR core are:

1. OBE: No core element disarray or damage shall occur such that normal full-power operation cannot be maintained or resumed.
2. SSE: The core elements shall retain their structural configuration to allow sufficient control poison to be inserted into the core to ensure safe shutdown and allow sufficient coolant flow to be maintained through the coolant channels to remove the reactor core decay heat.

The core seismic program provides the tools in the form of computer codes to assure that these acceptance criteria are met. The computer codes are considered acceptable when good correlation with the test results has been demonstrated.

In general, it is required that all the instrumentation used in the tests be accurate within $\pm 10\%$.

1.5. DESIGN ALTERNATIVES

If any HTGR design deficiencies should become apparent from results obtained during the various stages of the Core Seismic Program, the design will be modified. The program has already led to a change in the lateral restraint system, from a single to a bilinear spring configuration. The need for this change became apparent after the 1/5-scale full-array test had been completed.

1.6. STATUS AND SCHEDULE

The status and schedule of each test and each analytical code are given in Section 1.3. The status and schedule are summarized in Tables 1-1 and 1-2.

TABLE 1-1

SCHEDULE FOR CURRENT AND PLANNED SEISMIC TESTS

○ CONTRACT AWARD

□ SCHEDULED COMPLETION

△ TEST COMPLETED

● TEST REPORT

(a) TEST NUMBERS CORRESPOND TO NUMBERS USED IN TEXT.

TABLE 1-2
SCHEDULE FOR DEVELOPMENT OF SEISMIC CODES

○ PRELIMINARY COMPLETION, CODE READY FOR USE.

□ FINAL COMPLETION, CODE FULLY DOCUMENTED.

2. TEST OF CORE SUPPORT POSTS

2.1. INTRODUCTION

Testing of the core support posts is a DV&S program only. It applies directly to the 2000-, 3000-, and 3800-MW(t) reactors, since the same core support post design will be employed in all large HTGR projects.

The core of the large HTGR rests on a number of core support blocks which are supported by graphite posts. Since the post geometry, and perhaps material, differs from that tested and used in the FSV reactor, a program has been implemented to demonstrate that the support posts for the large HTGR meet all necessary requirements.

The posts are solid graphite rods with hemispherical ends that fit into slightly larger matching holes in seats at both ends. For the large HTGR the core support posts will be about 74 in. long and 7-3/4 in. in diameter, or almost twice the length of and 1-3/4 in. greater in diameter than the FSV core support posts. In addition, the unit loading is higher for the large HTGRs since their cores are deeper than the FSV core. These two differences and the possibility that a different grade of graphite may be used in the large HTGRs make it necessary to demonstrate that the new posts meet the relevant criteria.

2.2. OBJECTIVE

The objective of this program is to ensure that the design and material specification for the core support posts and blocks result in an assembly that meets the basic design criteria of a load safety factor of 5. Candidate material properties will be determined, representative post assemblies tested, and a reference material selected. A core support block assembly will then be tested to determine its safety factor.

2.3. DV&S PROGRAM

2.3.1. Design Features and Materials

Post assemblies fabricated from material made to plant specifications will be evaluated. The purpose of these tests is to demonstrate that the new post geometry and the different candidate materials exhibit the required ultimate load safety factor of 5.

Tests are conducted by stressing a full-scale post and end assembly configuration to failure. The top end of the test specimens is displaced laterally relative to the bottom end, with the center line of the post support and post seat insert aligned vertically. The lateral displacement represents the maximum movement due to thermal expansion of the support floor tolerances and spring-back compression caused by seismic loads. The assemblies are tested in compression by loading the posts axially in a testing machine and recording the loads, the axial displacement, and two lateral displacements. Loads are read off the loading machine and are also measured by use of a load cell under the post support. The vertical and lateral deflection of the test specimen is measured using linear motion transducers.

Because of the modest length-to-diameter ratio ($\ell/D = 9.5$), buckling failure of the posts is precluded and the load-carrying capacity is governed by local failure due to high Hertzian stresses in the spherical ends. Tests were conducted to verify this mode of failure and to establish the ultimate load capacity of the post/seat assembly. The posts tested so far had a length of 77-3/4 in. and a diameter of 6 in. ($\ell/D = 13$), which represented an initial design configuration prior to allowances for loss of strength of the posts due to oxidation effects. For the design where the radius of curvature of the spherical ends was 5.753 in. and the radius for the seats was 6.312 in., tests showed a failure load of 155,000 lb with failure occurring in the post seat insert. This gave a safety factor on a typical core support post of $155,000/12,600 = 12.3$ during normal operating conditions.

The material (Great Lakes Carbon Company GLCC H-359) used for the core support post in the aforementioned tests is no longer available. One candidate post material (Stackpole Carbon Company Grade 2020) is on hand for the material evaluation program and another (GLCC H-439) is scheduled for delivery in March 1975.

2.3.2. Assembly Test

A complete full-scale assembly of one core support block with three posts will be fabricated from the material selected based on the above tests. This test is to demonstrate the margin of safety in the prototype design, since the anisotropic nature and complex geometry of the graphite core support structure make it difficult to analyze.

The core support block will be displaced laterally relative to the bottom end of the posts to represent the maximum movement of a core support block during OBE conditions. An ultimate load safety factor greater than 5 is required.

2.3.3. Test Facilities

Test of single posts with end seats are being performed at Testing Engineers Incorporated. Material property tests are being performed at GA. The core support block three-post assembly requires a large test unit, and the contract for the tests has not yet been awarded. There are at least two or three suitable laboratories in California in which the assembly can be tested.

2.4. ACCEPTANCE CRITERION

The basic acceptance criterion is that the assembly have an overall safety factor greater than 5. This safety factor is to be demonstrated on a production design with material as specified for plant use. One core support block assembly will be tested to failure. Any break, spall, crack or abnormal occurrence will be considered as failure.

2.5. DESIGN ALTERNATIVES

If test results are unsatisfactory, the load capacity of this component may be improved easily by (1) changing the radius of the spherical end, (2) increasing the diameter of the post, (3) increasing the thickness of the post support and post seat insert, or (4) using higher-strength graphite.

2.6. STATUS AND SCHEDULE

2.6.1. Design Features and Materials

Tests of the two available post materials, including tests of post assemblies, are scheduled for completion in September 1975, at which time the core support post end seat materials will be selected.

2.6.2. Assembly Test

A test procedure document is currently being written. The unit assembly test is scheduled for completion in March 1976.

2.6.3. Reports

The current status of the test programs will be reported every 6 months in the LTR-100 series. A summary report will be issued when the post tests are completed, and a second report will be issued when the assembly test is completed.

3. PRIMARY COOLANT MOISTURE MONITOR TEST PROGRAM

3.1. INTRODUCTION AND BACKGROUND

The moisture monitor program is a DV&S Program that phases into a Qualification Program.

3.1.1. Reasons for Program

The HTGR employs helium at 725 psia as the primary coolant to transfer heat from the reactor core to the steam generators. As pressures up to 2500 psig are reached on the steam side of the steam generators, a leak could allow moisture to enter the primary coolant system. The presence of excessive moisture in the hot graphite environment of the core could result in an increase in the operating pressure, erosion of the graphite moderator, and a reaction that could liberate hydrogen and carbon monoxide.

To eliminate the possibility of excessive moisture in the primary coolant, a moisture monitor system is used. The system must provide a reliable and redundant means of rapidly detecting moisture in any of the cooling loops at all normal and abnormal operating conditions. It should also identify the loop with the excessive moisture so that it can be isolated and the steam generator dumped.

Moisture monitors designed for use at Fort St. Vrain (FSV) are ruggedized optical dew point units. They are quite complex owing to the special design requirements of a double closure. (Fort St. Vrain has no secondary containment building.) Accordingly, a program to develop a simpler detector has been initiated.

The moisture monitor system for the large HTGR includes a compressor for returning the helium from an accumulator tank to the reactor. This

component, which is not used in the FSV system, was originally conceived as a small axial flow compressor which would have required a developmental and qualification program. The design has since been modified to incorporate an off-the-shelf diaphragm compressor of a design similar to that used in the Peach Bottom moisture monitor system. This compressor will therefore not require the type of Qualification Program associated with a component of new design.

3.1.2. Moisture Monitors in U.S. HTGRs

3.1.2.1. Peach Bottom Unit 1. Beckman electrolytic hygrometers were used in the 40-MW(e) Peach Bottom Unit 1 HTGR. During the first year of operation their performance was adequate, but problems were then encountered in deterioration of response time and in obtaining replacement cells of assured high quality. Some system changes, an improvement in quality by the vendor, and a more stringent periodic test program finally resulted in satisfactory performance. A mean cell life of about 6 weeks was established in the test program that was conducted to determine the causes of the problem. Beckman cells were also found to be degraded in response time by the presence of excessive hydrocarbons in the coolant. A hydrocarbon concentration, other than for methane, of less than 1 to 2 ppmv did not affect the cells.

A more detailed account of Peach Bottom moisture monitor experience is given in Ref. 3-1.

3.1.2.2. Fort St. Vrain. General Atomic Company optical dew point moisture detectors are installed in the FSV HTGR. These instruments are used in both the trip and indicating modes. Liquid nitrogen is used to achieve the appropriate temperatures on the mirrors.

Qualification tests performed on prototype detectors established the integrity of the system, the adequacy of the temperature control system, and the negligible effects of fission product plateout and of graphite dust. The FSV Qualification Program is described in more detail in Refs. 3-1 and 3-2.

3.1.3. The Large HTGR

3.1.3.1. System Description. Each main loop of the HTGR is instrumented with three independent moisture detection instruments. Each of the instruments monitors a sample of primary coolant flow from the steam generator cavity. If two of three instruments associated with a given main loop indicate a moisture content exceeding the preset limit, the reactor is tripped, the loop is isolated, and the steam is dumped into a low-pressure tank. At the same time, the moisture trip signals from the other loops are locked out so that cooling continues on the main loops.

Each auxiliary loop has three instruments which continuously sample at the heat exchanger inlet and outlet. The PPS logic is designed to allow only one auxiliary loop to be isolated due to moisture; the other auxiliary loops will be inhibited automatically from isolation. Also, if any main loop is isolated due to moisture, all auxiliary loops will be inhibited from isolation.

3.1.3.2. Potentially Suitable Types of Moisture Monitors. Of the many moisture monitors available, optical dew point devices, infrared detectors, thermal conductivity bridges, and variable capacitance devices seem particularly well suited to HTGR requirements. These four types are described in Ref. 3-2 and short descriptions are given below.

3.1.3.2.1. Optical Dew Point Device. The dew point sensor, which is the type used at FSV, typically contains a cooled mirror, an optical bridge, a temperature sensor, and readout electronics. With minor modifications, the instrument may be operated in either the indicating or the trip mode.

This type of instrument offers flexibility, high accuracy, and rapid response in the trip mode. It is comparatively slow in the indicating mode. It is also very complex in that it requires support systems, such as

a liquid nitrogen cooler or Freon refrigeration, if measurements as low as 1 ppm are required.

3.1.3.2.2. Infrared Detector. Infrared detectors typically contain an infrared source, a filter (either rotating or stationary), a sample cell, an infrared detector, and associated electronics.

The response of this system is proportional to the sample cell volume and sample flow rate. Consequently, an instrument with a fast response has a relatively low sensitivity and vice versa.

3.1.3.2.3. Thermal Conductivity Bridge. This unit consists of a four-element bridge, a process delay line, a power supply, and detector electronics. Four hot-wire elements form the electric bridge. The resistance of an element changes with the conductivity of the gas, which is a function of its moisture content. By means of a delay of a portion of the sample stream, the sets of bridge elements can be adjusted to detect any imbalance due to change in moisture content. This unit operates only in the trip mode.

3.1.3.2.4. Variable Capacitance Device. This type of device uses a sensor consisting of an aluminum strip which is anodized to provide a porous oxide layer. A thin coating of gold is then evaporated over this structure to give a set of gold and aluminum electrodes. When water vapor is transported through the gold layer, it equilibrates on the pore walls, determining the conductivity. Conductivity measurements are then directly related to moisture content.

3.2. PROGRAM OBJECTIVES

The objective of this program is to select a moisture monitor for use in large HTGRs and to demonstrate that the unit selected meets the necessary criteria by means of a Qualification Program.

3.3. PROGRAM DESCRIPTION

The program is divided into three phases:

1. Tests in the Peach Bottom HTGR.
2. Evaluation of candidate units in a test loop under HTGR conditions.
3. Qualification of the selected unit in a test loop under HTGR conditions.

3.3.1. Tests in Peach Bottom HTGR

Four types of monitors were installed in the Peach Bottom Unit 1 HTGR in 1972. Their performance was evaluated in a test program which continued until the reactor was shut down for decommissioning late in 1974. These instruments were subjected to sample gas at a pressure of 2 atm at 80°F. Radiation exposure was negligible.

The instruments evaluated were:

1. Optical dew point hygrometer.
2. Infrared absorption analyzer.
3. Aluminum oxide capacitance hygrometer.
4. Thermal conductivity trip device.

Utilizing a National Bureau of Standards traceable dew point hygrometer and a moist gas generator, tests were conducted to determine the following instrument characteristics:

1. Accuracy.
2. Repeatability.
3. Drift.
4. Response time.
5. Reliability.

3.3.1.1. Performance Criteria. Operation and performance of the moisture monitors were based on the following criteria:

1. Response time: less than 10 sec, including sample transport time, to the generation of a trip signal with the insertion of 600 parts per million by volume (ppmv) of water vapor.
2. Accuracy: ± 60 ppmv, or $\pm 2^{\circ}\text{F}$ dew point.
3. Range: 0.1 to 4000 ppmv, or -86° to $+140^{\circ}\text{F}$ dew point at 725 psia.
4. Reliability: No adverse effects from continuous exposure to dry helium environments containing less than 0.1 ppmv moisture.

3.3.1.2. Test Results. Information pertaining to the instruments and a summary of the calibration and response time tests are given in Table 3-1. The test results are summarized below.

3.3.1.2.1. Accuracy. Calibrations were performed by inserting moist gas samples into the units under test with moisture concentrations of less than 1 ppmv (reactor gas) and 200, 500, and 1000 ppmv.

None of the instruments tested meet the accuracy requirement of ± 60 ppmv, with the apparent error becoming greater at higher moisture levels for most instruments. The EG&G dew point hygrometer and the Wilkes infrared analyzer both show far better accuracy and repeatability than the Panametrics aluminum oxide capacitance hygrometer. No calibrations were performed on the thermal conductivity device since this is not an indicating unit.

3.3.1.2.2. Response Time. The time indicated in Table 3-1 is the elapsed time from the insertion of a 4000 ppmv gas sample to the generation of an output signal with the set point at 200 ppmv.

TABLE 3-1
SUMMARY OF MOISTURE MONITOR TEST PROGRAM IN PEACH BOTTOM UNIT 1

	Type of Instrument			
	Optical Dew Point	Variable Capacitance	Infrared	Thermal Conductivity
Manufacturer	EG&G	Panametrics	Wilkes	GA
Model	992	D2567B	Miran II	1
Number of units	1	1	1	1
Mode	Indicating/Trip	Indicating/Trip	Indicating/Trip	Trip
Summary of Calibration Tests				
No. of tests	15	13	9	--
Nominal moisture in He (ppmv)	200, 500, 1000	200, 500, 1000	200, 500, 1000	--
Average Δ of reading (%)	3.6, 5.1, 9.2	47, 45, 55	Not applicable	--
Summary of Response Time Tests				
No. of tests	28	25	22	24
RMS at 6.5 scfh $\pm \sigma$ (sec) ^(a)	2.32 ^{+4.18} -1.72	13.1 ^{+6.5} -5.3	13.81 ^{+4.7} -4.46	1.37 ^{+0.93} -1.27
RMS at 14.7 scfh $\pm \sigma$ (sec)	1.28 ^{+2.47} -1.05	16.0 ^{+6.2} -7.2	9.55 ^{+3.51} -1.15	--
Drift and repeatability	Good	Poor	Fair	Fair
Conclusion	Generally satisfactory	Unsatisfactory	Possible for use with modifications	Flow sensitive, but promising

(a) Root mean square time to trip after introduction of 4000 ppmv moisture with trip level set at 200 ppm.

The GA thermal conductivity device exhibits the fastest RMS (root mean square) response time, 1.16 sec, of all units tested. This device is nonselective as far as contaminants are concerned and is very sensitive to flow and pressure changes resulting in spurious output signals large enough to cause channel trips. The EG&G hygrometer also shows a rapid response time of 1.28 sec (RMS). The response times of the Panametrics hygrometer and the Wilkes infrared analyzer are considerably longer than those of the GA and EG&G units, being 13.1 and 9.55 sec, respectively. The long response time of the infrared unit was partly due to the inability of the system to supply the recommended flow and partly due to the longer lines required for installation. The Panametrics unit had the greatest variance in response time.

3.3.1.2.3. Instrument Drift. The dew point hygrometer exhibited the least drift of the units tested, while the infrared analyzer showed intermittent periods of excessive drifting. The aluminum oxide hygrometer calibration shift was large enough to mask any evidence of other possible drifting in the instrument. A small change in the output signals from the thermal conductivity device may possibly be the result of aging or contamination.

3.3.1.2.4. Instrument Reliability. All the instruments undergoing tests failed at one time or another. The EG&G dew point hydrometer experienced a loss of Freon in the mirror cooling refrigeration unit on two occasions, and the light source in the sensor failed once. The Wilkes infrared analyzer had a continuous malfunction in the motor starting circuit. The manufacturer is aware of this problem and claims it has been remedied in new models. This device had several instances of intermittent operation and drifting, requiring disassembly to clear switches, etc.

The Panametrics aluminum oxide hygrometer showed a continual shift of calibration and response time probably owing to continuous exposure to dry helium. This unit was rebuilt by the manufacturer and returned with a sensor of a new design that exhibited little, if any, improvement in operation.

The instruments will also be subjected to step changes of moisture level to determine response time. Their effectiveness as trip instruments will be evaluated by this test.

After several months of the above type of operation, the candidate sensors will be exposed to radiation to simulate a 5-yr exposure to gaseous and plateout radioactivity. After the exposure the sensors will be reinstalled on the loop, and their preirradiation and postirradiation operating characteristics will be compared.

3.3.3. Qualification in Test Loop

Based on the program outlined above, one type of unit (and backup units, if considered necessary) will be selected and subjected to a 6-month qualification test program in accordance with IEEE-323-1974 (Ref. 3-3).

3.3.4. Test Facility

A helium test assembly will be constructed at GA to provide means for the simultaneous installation and testing of eight moisture detection instruments. Under dry gas conditions, the sensors will be connected in series with the same gas flowing through all units. Also included as part of the test assembly will be a system to generate, insert, and remove helium gas samples of discrete moisture content for calibrations and response time measurements. The test loop assembly will be designed so that the gas sample transit time from the moisture source to the sensor is either negligible (0.1 sec) or can be calculated to within ± 0.1 sec. Provision will be made for the injection of other contaminants, such as hydrocarbons or graphite, at the test ports.

3.4. ACCEPTANCE CRITERIA

The operating and performance criteria of moisture monitors for large HTGRs are as follows:

1. Response time: less than 20 sec, including sample transport time, to the generation of a trip signal with the insertion of 1000 ppmv of water vapor (dew point 87°F) at full helium inventory.
2. Accuracy: $\pm 1^\circ\text{F}$ dew point.
3. Range: 10 to 2000 ppmv at 725 psia.
4. Reliability: no adverse effects on detection from continuous exposure to dry helium environments containing less than 0.1 ppmv moisture.

3.5. DESIGN ALTERNATIVES

If none of the detectors tested in the program prove to be satisfactory, the schedule provides the time to select and qualify suitable alternatives. Monitors similar to those designed and qualified for the FSV reactor could be used in large HTGRs.

3.6. STATUS AND SCHEDULE

3.6.1. Peach Bottom Tests

Testing in Peach Bottom Unit 1 has been completed. The results are given in Section 3.3.1.

3.6.2. Test Program for Large HTGR

A test plan covering the tests outlined in Section 3.3.2 has been prepared, and testing is scheduled to start in June 1976 and to result in the selection of an instrument in December 1976.

Based on Issue B of the Moisture Detection Instrument Specification, No. 900103 (the current specification), requests for quotation for test

units have been sent to vendors of moisture monitor instruments. Response to these requests for quotation is expected by the end of August 1975.

3.6.3. Reports

During the test program, monthly status reports will be issued by the test engineer. These reports will contain, as a minimum, the number and type of instruments undergoing tests, test results on all instruments, and test deviations such as malfunctions and instrument failure. Significant results will be reported in the LTR-100 series.

Final test reports will be issued at the end of the selection program and at the end of the Qualification Program. These reports will contain summaries of all relevant aspects of the tests.

References

- 3-1. Tully, G. R., Jr., and G. L. Stiehl, Jr., "Safety-Related Research and Development Programs Cited in Section 1.5 of HTGR PSARs, Biannual Report for Period Ending January 31, 1974," General Atomic Report GA-A12936 (GA-LTR-100), February 28, 1974.
- 3-2. Tully, G. R., Jr., and G. L. Stiehl, Jr., "Safety-Related Research and Development Programs Cited in Section 1.5 of HTGR PSARs, Biannual Report for Period Ending July 31, 1974," General Atomic Report GA-A13183 (GA-LTR-101), November 15, 1974.
- 3-3. "IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-323-1974.

4. CONTROL AND ORIFICING ASSEMBLY TESTS

4.1. INTRODUCTION AND BACKGROUND

Testing of the control and orificing (C&O) assembly is a combination DV&S and Qualification Program.

4.1.1. System Description

The C&O assembly consists of a pair of control rods with their drive mechanism, the reserve shutdown hopper with shutdown material and a release mechanism, and the related guide tubes. These components are installed as a common assembly that also includes the orifice valve and its drive mechanism. The assembly incorporates gamma radiation shielding which is penetrated by the control rod drive cables immediately below the control rod drive mechanism. The control assembly housing extends to the lower end of the refueling penetration. The lower section of the housing contains both neutron and thermal shielding. Guide tubes are provided through the assembly into the core to allow for insertion of the in-core instrumentation, control rods, and reserve shutdown material.

The control rod drives are essentially electrically powered winches, each of which raises and lowers a pair of control rods by means of flexible steel cables. The principal components of the mechanism are the drive motor, reduction gearing, rod-position transmitters, slack-cable indicators, cable drums, and suspension cables. The rods can be inserted or withdrawn under drive motor power (shim) or velocity-controlled gravity insertion with the motor de-energized (trip). There are 49 control rod assemblies in a 2000-MW(t) HTGR and 73 in a 3000-MW(t) HTGR. Both large HTGRs use the same assembly.

The reserve shutdown system provides a means of introducing negative reactivity into the core entirely independent of the normal reactor control system. Cylindrically shaped pellets containing neutron-absorbing material are stored in a hopper located in the lower section of each C&O assembly housing. The material is retained in the hopper by a cylindrical gate suspended by a flexible drive cable from redundant actuation mechanisms. The actuation mechanism for the 2000/3000 MW(t) reactors consists of a single-turn cable pulley, a stepping motor, a speed reducer, and a position transmitter.

The orifice valve consists of a cylindrical shell connected to the output shaft of the valve drive mechanism by a flexible steel cable. The mechanism regulates flow by raising and lowering the shell relative to the region plenum elements and a fixed plate attached to the C&O assembly guide tubes. Telescoping and articulating guide tubes allow the orifice valve to rest on top of the core during all conditions of reactor operation. The drive mechanism consists of a single-turn cable drum driven by a stepping motor through a speed reducer. The mechanism also contains a position transmitter.

4.1.2. Difference From FSV Design

In the early stages of large HTGR design, many of the components were similar in configuration and use to the control rod drive mechanism for FSV. However, some new design concepts were incorporated, and the tests that had been conducted for the FSV equipment were not entirely applicable. The basic design changes involved the use of a torque motor in place of the induction motor used in the FSV drive, the use of a different gear train, and the use of grease-lubricated bearings rather than dry-lubricated bearings. The last change was made because of advances in helium environment grease technology, accumulation of more operating experience in the Dragon Project (Ref. 4-1), and test experience gained at GA since the inception of the FSV design.

The large HTGR orifice valve and drive mechanism also differs from the FSV design in that the actuating mechanism has been changed from an Acme screw drive mechanism to a drum and cable drive mechanism.

The reserve shutdown system for the 2000/3000 MW(t) HTGRs differs from the FSV design in that the method of actuation has been changed from a pneumatic force shattering a retaining membrane to an electrically controlled gate.

4.2. PROGRAM OBJECTIVES

The main objective of the overall test program is to prove the ability of the C&O assembly to function over the standard service period of 8 yr (2 yr regulating duty and 6 yr shim duty) without exceeding the maximum allowable downtime allocated to the equipment. The number of test cycles performed during the first series of tests (Section 4.3) was based on a maximum allocation of 84 hr/yr for a 3000-MW(t) plant. Presently, the downtime allocations are being reassessed and as a result the required number of test cycles to be performed during the second series of tests (Section 4.4) will be re-evaluated accordingly. These test cycle requirements will be available prior to the start of testing in April 1976.

Additional functional tests are to be performed on the individual components of the C&O assembly in order to verify their performance to design criteria and to improve the design, if necessary.

In addition, a test program is required for the qualification of various C&O assembly components that are classified as Seismic Category I and Class IE equipment. A detailed description of the goals of these tests is presented in Sections 4.4.7 and 4.4.8.

The overall test program is comprised of the following tests which are described in detail in this report:

1. C&O assembly checkout and installation and moist environmental tests.
2. Control rod drive mechanism cycling in a controlled environment.
3. C&O assembly grease lubrication tests.
4. Orifice valve air flow tests.
5. Orifice valve cycling in a controlled environment.
6. Reserve shutdown hopper tests.
7. Reserve shutdown environmental cycling.
8. Seismic qualification of Category I components.
9. Qualification of Class IE electromechanical components.

4.3. DESCRIPTION OF FIRST TEST SERIES

4.3.1. Reasons for Program

Beginning in 1970, a test program was started to demonstrate the ability of the control rod drive mechanism to satisfy its particular design criteria. Only the control rod drive mechanism was subjected to testing, since at the time the control rod drive and reserve shutdown assembly was very similar to the FSV C&O assembly. The only differences were in the control rod drive mechanism and in the lack of a requirement for a variable orifice valve. Orificing of the coolant flow was to be accomplished by fixed orifices located in the core column plenum blocks. The reserve shutdown system was the same as employed in the FSV design, and as a result no further testing was planned.

4.3.2. Criteria

The basic design criteria that were verified by the first series of tests were as follows:

1. Control rods and drives will provide reactivity control during normal and upset operating conditions. There will be no loss of reactor trip capability during emergency and faulted conditions.
2. Control rods will be automatically released and allowed to drop into the core in the event of a power failure.
3. The rate of control rod insertion during reactor trip will be controlled by the rod drive mechanism under all normal, upset, emergency, and faulted conditions.
4. Control rod guidance will be such that the rod insertion into the core will be unaffected by any credible misalignment of the core as a result of expected core displacement or seismic disturbances.
5. Those portions of the C&O assembly located within the core plenum will be capable of functioning in, and will not be adversely affected by, a helium environment at reactor conditions of temperature, pressure, and purity.
6. Those portions of the C&O assembly located within the refueling penetration will be capable of functioning in the environment described in (5) above, except that the ambient temperature is 150°F (maximum) for normal conditions and 200°F (maximum) for abnormal conditions.
7. The C&O assembly will be capable of functioning in, and will not be affected by, periods of storage up to 1 yr in an air environment with a relative humidity of up to 100%.

8. The C&O assembly will be capable of being installed in a core region having a core-to-penetration center line misalignment of 1-3/4 in. (maximum).
9. The C&O assembly will be capable of accommodating vertical displacements of its seating face relative to the top of the core of 4.7 in. upward and 9.3 in. downward.
10. An electric motor will be utilized to insert and withdraw the control rod pair at an average shim speed of 1 in./sec. Travel may be continuous over the full rod travel in either direction or intermittent (jog) travel in either direction.
11. A gravity trip mode of insertion of the rods into the core will be provided. The velocity will be controlled to a value consistent with the allowable maximum deceleration of less than 2 g. The insertion time will be 22 ± 3 sec for both the 2000- and 3000-MW(t) cores.
12. The drive mechanism will maintain its rod pair at any preset position within the specified rod travel without drift in either direction.
13. The C&O assembly will have a service life of 8 yr (2 yr in regulating duty, 6 yr in shim duty) and will be tested to a minimum reliability of 0.65 in shim duty and 0.995 for an individual scram.

4.3.3. Test Configuration and Sequence

For test purposes, a full-scale prototype control rod drive mechanism was constructed using materials, parts, and fabrication and inspection processes equivalent to those planned for production. The prototype mechanism was installed in a modified FSV C&O assembly housing for testing in the

autoclave. The overall test program for this version of the control rod drive mechanism was divided into three phases as described below.

4.3.3.1. Phase 1: Checkout in Air

4.3.3.1.1. Test Description. The first phase of this test series was a general checkout of the drive mechanism in an air environment at room temperature. This phase included a thorough checkout of the ease of assembling the unit, after which the drive characteristics were verified by a complete system of mechanical and electrical checkouts of components during the various modes of operation.

4.3.3.1.2. Test Facility and Instrumentation. The testing was performed in an air test stand which allowed accessibility to all components on the mechanism for test measurements and adjustments. The test stand provided support to the mechanism in a manner similar to that provided by the refueling penetration. Adjustable steel weights were used to simulate various control rod sizes. The test stand height permitted operation of these simulated control rods through the nominal control rod travel (303 in.).

The test measurements were made with calibrated instrumentation consisting of torque wrenches, thermocouples, control system electrical panel meters (voltmeter and ammeter), and high-speed Visicorder and strip-chart recorders.

4.3.3.1.3. Test Performance and Results. With the C&O assembly in the test stand and the dummy control rods attached, the following tests were conducted:

1. Mechanical efficiency and limit switch tests.
2. Control rod position meter calibration.
3. Torque-voltage tests.
4. Drive motor transfer voltage tests.
5. Shim and jog tests.
6. Scram tests.

These tests established the basic drive characteristics such as scram speed (sizing of system resistance) and rod holding voltage. The tests also established the operability of the overall mechanism as well as the drive motor power supply. Measurements taken during this series of tests were used as the operational basis for the environmental cycling tests described in Section 4.3.3.2.

4.3.3.2. Phase 2: Environmental Endurance Test

4.3.3.2.1. Test Description. Phase 2 of the test program was an environmental test involving endurance testing in an environment simulating reactor conditions of helium purity and temperature. The radiation environment was not simulated because the mechanical drive components are located in a shielded area where the radiation level is sufficiently low that radiation damage is not a consideration. The high pressure was also not simulated since it has no effects on the operational characteristics of the mechanisms. The test was performed at an autoclave pressure of 10 to 15 psig. The assembly test atmosphere was helium gas containing less than 10 ppm of oxidizing impurities. The reactor physical surroundings of the C&O assembly were also simulated.

4.3.3.2.2. Test Facility and Instrumentation. The test facility used for all C&O tests, except seismic tests, is located at GA in San Diego, California. It is housed in a building designed to accommodate a full-scale HTGR control rod and the environmental control and performance monitoring instrumentation required to support control rod testing programs.

The test vessel is rated for 100 psig at 600°F and is 50 ft high. The lower half is 36 in. in diameter and contains a simulated core section with control rod and reserve shutdown channels. The simulated core can be externally adjusted to investigate drive assembly installation and control rod motion with a misaligned and disturbed channel. The core channel is heated, and temperatures up to 1200°F can be obtained in the graphite core blocks.

The upper half of the test vessel is 20 in. in diameter and its internal configuration simulates the reactor refueling penetration. The area of the upper plenum surrounding the orifice valve is heated for maintaining the valve at 750°F. The upper portion of the C&O assembly is maintained at 150° to 200°F by installed heaters.

The control and instrumentation system for the test article was designed to functionally test and automatically cycle the C&O assembly. Test-article performance was recorded on a 36 channel oscillograph and strip-chart recorder. Measurements on test articles were available on 30 signals that could be connected to the oscillograph through a computer-type patch panel. Each channel had its own calibration circuit.

4.3.3.2.3. Test Cycle and Results. Phase 2 testing consisted of installing the test specimen in the autoclave and operating the mechanism in the shim, jog, and scram modes before closing the autoclave. The autoclave was then pumped down, purified, and heated. Pre-cycling tests were then performed and recorded for the various operational modes.

Cycling consisted of 630,000 jogs and 5400 scrams. A rest period of 3 sec was used after each jog cycle, and a scram was conducted after every 120 jog cycles. The rods were initially jogged and scrambled from the 80% inserted position until approximately 70,000 jogs were completed. Thereafter, the rods were cycled for approximately 70,000 jogs at each inserted position of 70%, 60%, 50%, 40%, 30%, 20%, 10%, and ROD OUT until the required test cycles were achieved. The electrical characteristics of the drive were recorded on a Visicorder after each 10,000 jogs. Typical test measurements monitored and recorded were as follows:

1. Rod speed.
2. Rod position.
3. Slack cable actuation.
4. Rod-in and rod-out actuation.
5. Drive motor voltage.
6. Drive motor current.

7. Scram command.
8. dc holding voltage.
9. dc holding current.
10. Test temperatures.
 - a. Drive mechanism.
 - b. Drive motor stator.
 - c. Motor bearings.
 - d. Cable drum bearing.
 - e. Vessel temperatures.

The performance of the mechanisms was satisfactorily demonstrated over the extensive testing cycle.

4.3.3.3. Phase 3: Lubricant Test

4.3.3.3.1. Test Description. The third phase of testing consisted of an environmental test to establish the adequacy of the grease lubrication and to demonstrate that the control rod drive mechanism would be capable of providing a trip after an extended period of essentially static operation.

4.3.3.3.2. Test Facility and Instrumentation. The lubrication qualification testing was conducted in a simulated reactor environment of helium at reactor temperature and purity in the autoclave used for the environmental endurance testing described in Section 4.3.3.2.2.

4.3.3.3.3. Test Performance and Results. Following the environmental cycling tests, the test specimen was removed from the autoclave for inspection and refurbishment. It was then replaced in the facility for the environmental grease testing. The test cycles were derived on the basis of the rod exercise practice at Peach Bottom with the addition of several trip tests. The mechanism was maintained in the fully withdrawn position with no rod motion for a month at a time. Following the first month of inactivity, the rods were tripped and then shimmed out to ROD OUT. The rods were then maintained in the static mode for another month, after which they were exercised

by being shimmed in and out five times over a distance of 6 in. This cycle was repeated over a period of 2 yr. Facility temperatures, helium purity, and motor holding voltages were monitored regularly. Each month during the exercising, the drive characteristics (i.e., trip time, shim voltage and current, and holding voltage) were recorded on the Visicorder.

This testing was successfully completed with all trips meeting the time requirements (22 ± 3 sec). No significant time changes were discovered during the course of testing. No significant changes in drive characteristics were recorded. Following testing, the drive was removed from the autoclave and inspected for wear. The bearings and grease were sent to the grease manufacturer for analysis. The results of these inspections showed no significant wear or changes in the grease configuration. The grease is therefore considered qualified for use in the large HTGR.

4.4. DESCRIPTION OF SECOND TEST SERIES

4.4.1. Reasons for Program

The configuration of the test article used in the first series of tests did not include an orifice valve and drive mechanism. Also, the intent at the time of those tests was to use the same reserve shutdown system as the FSV reactor.

During the period that the first series of tests was being performed, some design evolution was taking place. The requirement for variable orificing was introduced, with the valve and drive mechanism being added to the C&O assembly. Also, a design study was performed to determine any features of the FSV design that could be eliminated. As a result of this study, the shutdown actuation system was changed from a pneumatic to an electric release type, a new valve and drive mechanism design was developed, some minor changes were made to the control rod drive mechanism configuration, and some unnecessary structural components carried over from the FSV design were eliminated. A test program has been started to verify that the design with these changes incorporated meets all requirements of the

design criteria and to determine performance criteria and demonstrate performance reliability. This is a combined DV&S and Qualification Program.

4.4.2. Test Program Configuration

The second test series is divided into four parts:

1. C&O assembly installation and moist-environment tests.
2. Control rod drive mechanism tests.
3. Orifice valve tests.
4. Reserve shutdown system tests.

Where applicable, these tests will be performed with the same equipment, in the same manner, and against the same criteria as related tests in the first series. The primary objective of demonstrating that all the components function with less than the allowable downtime as described in Section 4.2 remains unchanged.

4.4.3. C&O Assembly Installation and Moist-Environment Tests

4.4.3.1. Objectives. These tests will be performed on a full-scale prototype large HTGR C&O assembly. The purpose of the tests is (1) to demonstrate the capability of the assemblies to function under normal and maximum core offset conditions (lateral and rotational) and to be installed and removed under limits of maximum constructional tolerances, and (2) to check the overall efficiency and operational characteristics of the assembly components.

The program also includes a test to demonstrate the ability of the C&O assembly to function in a moist-air environment and, further, to function properly after prolonged exposure to the moist environment to which it is expected to be subjected during shipping and storage at a reactor site prior to plant start-up.

4.4.3.2. Test Stand Requirements. An air test stand to accommodate the full-scale C&O assembly will have the following capabilities:

1. It must be capable of testing the insertability of the C&O assembly into the refueling penetration and reactor core. The stand must simulate the minimum penetration dimension.
2. The reactor core must consist of the top two or three layers. The plenum is simulated by a ring whose inside diameter will be equivalent to the inside diameter of the opening of the plenum elements.
3. The stand must provide the capability of offsetting the core to the penetration center line in both the lateral (up to 3 in. in any direction) and rotational (up to $\pm 6^\circ$) directions. The refueling penetration portion of the stand must also be capable of being tipped with respect to true vertical up to 5° .
4. The core position must also be capable of being varied vertically to permit checkout of the telescoping feature of the C&O assembly. Vertical variations of 14 in. are required.
5. The moist-environment test rig requires a place to store the C&O assembly in a moist-air environment for a period of 6 months. The air test stand will be utilized with the addition of a temporary sealed container (for example, a sealed polyethylene or barrier paper cocoon) capable of maintaining a 100% relative humidity environment. The rig must be capable of periodic monitoring of the environmental moisture.

4.4.3.3. Instrumentation. Specific instrumentation will be detailed in a test procedure to be issued in the first quarter of 1976. Additional instrumentation presently identified will be provided for in the prototype mechanism. This will include a tachometer to monitor motor or cable drum speed and thermocouples to monitor motor winding temperatures and bearing

temperatures. A scale or load cell for determining the friction in sliding surfaces of telescoping guide tubes and C&O assembly housing in penetrations will also be provided.

4.4.3.4. Installation Capability Tests. The following tests will be performed to verify C&O installation capability:

1. Install the C&O assembly into simulated penetration dimensions with the reactor core (i.e., the top two or three layers of the region) offset 1-3/4 in. radially. Check to make certain that the valve leads in and seats properly. Check the installation with the offset in several different directions and the orientation of the C&O assembly rotated $\pm 6^\circ$ from the orientation of the control plenum element.
2. Check the insertion of the reactor design control rod into the simulated core when it is at the maximum allowable radial offset (3 in. during seismic conditions) and rotational orientation ($+6^\circ$). It is necessary to check the insertion into the top two layers of blocks.
3. Check the installation at several different core heights to assess the effects of the telescoping feature on installation. The orifice valve is capable of 14 in. of telescoping travel. Measure the load at the interface of the valve and reactor core. A load in excess of the valve and lower guide tube assembly weight indicates binding or friction in the telescoping tubes.

4.4.3.5. Moist-Environment Tests. Following the C&O installation tests, the assembly will be tested (see Section 4.4.4) under a simulated reactor environment. When these tests are completed, the assembly will be subjected to moist-environment tests that include the operations described below:

1. Pre-test inspection. A detailed record of the condition of the C&O assembly components, including the status of both the bearing and gearing lubrication, will be compiled.

2. Pre-test efficiency tests

- a. Control rod drive mechanism. Repeat the mechanical efficiency measurements and record data.
- b. Orifice valve mechanism. Repeat the mechanical efficiency measurements and record data.
- c. Reserve shutdown system. With a fully loaded reserve shutdown hopper, determine and record the force required to raise and lower the hopper gate a small distance (i.e., approximately 1/2 in., not enough to drop the material).

3. Pre-test exercising. After assembling the C&O assembly and mounting it in the test rig, perform the following series of electrically operated motions of the control rod drive mechanism and the orifice valve and record the results:

a. Control rod drive mechanism

- (1) With the rods at the 100% withdrawn position, initiate a scram sequence. Record the following data after measurement to $\pm 1\%$ accuracy:

- (a) Scram response.
- (b) Rod displacement.
- (c) Total scram time to end of motion.

- (2) After the completion of the scrams in step (1), shim out the rods to the 100% withdrawn position. During this shim cycle, record the following data after measurement to $\pm 1\%$ accuracy:

- (a) Motor current per winding.
- (b) Motor voltage.

- (c) Rod travel.
- (d) Total shim time.

(3) Shim the rods to the 0% withdrawn position and record the data listed in step (2).

(4) Shim the rods to the 100% withdrawn position per step (2).

(5) Repeat the cycle [steps (1) through (5)] five times.

b. Orifice valve and mechanisms. Operate the orifice valve in an open-closed-open cycle five times and record the following data to $\pm 1\%$ accuracy:

- (1) Motor current.
- (2) Motor voltage.
- (3) Time to complete one cycle.

c. Reserve shutdown system. With a full load of reserve shutdown material in the hopper, actuate the release mechanism and record the total time required from actuation until the hopper is emptied. Record the time and any unusual flow characteristics.

Reload the hopper and rearm the actuation device in preparation for the moist-environment test.

4. Moist-environment test. Enclose the C&O assembly in the moist-environment test rig. After producing an air environment of 100% relative humidity, seal the rig.

Periodically (once a day), monitor and record the C&O assembly environment temperature and relative humidity. The C&O assembly will be maintained in this condition for a period of 6 months.

5. Post-test efficiency tests. Repeat the tests described in step 2.
6. Post-test exercising. Repeat the exercising described in step 3.
7. Post-test disassembly and inspection. After completion of the above tests, completely disassemble the C&O assembly, recording all conditions and noting all deviations from the conditions recorded in the pre-test inspection records of step 1. Pay specific attention to corrosion and/or other deleterious effects resulting from the exposure to the environment. Disassemble the bearing shields and visually inspect the grease lubrication. Visually inspect the gear dry-lubricant condition. Weigh all bearings and compare the results with pre-test data.

4.4.4. Control Rod Drive Mechanism Tests

This series of tests will be a repetition of the first test series described in Section 4.3. The same test facility will be used with slight modifications to meet the current design of the penetration, mechanism, and controls. The test environment and duration are identical.

The test specimen will be a full-scale C&O assembly fabricated to production drawings and manufacturing procedures and processes.

4.4.5. Orifice Valve Tests

The purpose of this test is to demonstrate the ability of the orifice valve and mechanism to meet the design criteria and perform during the 8-yr service life with a maximum unavailability as described in Section 4.2.

Testing will be separated into valve flow characteristics tests and mechanical tests including environmental cycling.

4.4.5.1. Flow Tests. Flow testing has been performed at the GA test tower using wood, acrylic, and steel mock-ups of the proposed valve configurations.

The test rig is a full-scale mock-up of the cross section of one fuel region (seven fuel elements) of the HTGR core, upon which the valve and plenum blocks are mounted. Since the test rig does not have full-length coolant channels, the coolant holes are sized to give a pressure drop across the rig equal to the ΔP across the full-length core. Air is the test medium, and the system exhaust fans are capable of drawing about 9 lb of air per second through the rig.

Measurements taken during the flow tests included pressure, ΔP , temperature, gas flow rate, and flow distribution. The types of instruments used and their locations and functions are described below.

Twenty-one pitot-static probes were mounted in sleeves which friction-fit on and off at the exit of any desired tube. With this arrangement, the probe measures center-line total and static pressures, approximately 7/8 in. above the exit end of the tube. Twelve static taps were located in the valve plenums. Six static taps in the exhaust plenum were headered together, since they all read approximately the same under any condition. These taps gave a measure of the overall rig ΔP and were used to achieve the same rig ΔP s (during testing) over the full range of valve positions.

The overall flow rate through the rig is measured with an orifice plate in the ducting upstream of the blowers. A water manometer is used to measure orifice plate ΔP , a mercury manometer for orifice plate inlet static pressure, and a thermocouple-voltmeter for orifice plate inlet temperature.

Other instrumentation includes a barometer (and an associated thermometer) and a thermocouple directly above the inlet to the valve for measuring air temperature into the rig.

All pressures except those for the orifice plate and barometer are read on a bank of forty-four 5-ft water manometers with atmospheric references for each bank. Switching valves permit any one tube to read two or

three pressures alternately. In almost all data runs, the bank is photographed with a fitted Polaroid camera and the negatives are read later.

The air flow tests involved several different configurations of the two basic valve designs to be studied. The tests were devised to assess the flow distribution, valve pressure drop, and flow linearity characteristics of the two valves. The test results showed that the original valve design exhibited better performance than the proposed valve design in terms of valve loss coefficient and flow distribution. However, the choice between the designs was less clearcut with regard to valve pressure drop and flow linearity.

It was therefore decided to pursue the optimization of the original valve design. A new series of tests was performed using the same test rig and instrumentation as in the initial test series. The purpose of these tests was to evaluate the effect of one flow parameter on the others. The same criteria stated earlier were used in judging valve performance. These tests resulted in the determination of the position of the fixed plate and the limits on the valve stroke.

As a result of the information obtained during the second test series, the design of an orifice valve which will meet the previously stated criteria is in progress. Once the design has been finalized and released (scheduled for October 1, 1975), a prototype unit will be fabricated using the production drawings and manufacturing procedures and processes. This final prototype valve (i.e., equal to the production design) will be subjected to confirming flow tests which will essentially be a repetition of those just discussed. The same rig and instrumentation techniques will be used. The data will be used to confirm the acceptability of the valve characteristics to meet the criteria stated earlier. This will qualify the actual valve design to be used in the reactor.

4.4.5.2. Environmental Tests. Using a prototype valve of the design derived from the flow testing described above, a series of tests will be performed to establish the mechanical and functional characteristics of the valve

as well as to demonstrate the reliability of the valve when operating in a simulated reactor environment.

The basic criteria to be verified by the flow tests and environmental tests are as follows:

1. The orifice valve mechanism located within the refueling penetration will be capable of functioning in a helium environment at reactor conditions of temperature, pressure, and purity. The environmental temperatures surrounding the valve mechanism are 150°F (maximum) for normal conditions and 200°F (maximum) for abnormal conditions.
2. The orifice valve and telescoping guide tubes located within the core plenum will be capable of functioning in, and will not be adversely affected by, a helium environment at reactor conditions of temperature, pressure, and purity.
3. The design of the mechanism will be such that the orifice setting will remain unchanged as a result of fuel column vertical expansion or contraction due to temperature variations or irradiation-induced contraction of the graphite.
4. The design of the mechanism will be such that an electrical failure will not cause the orifice to close or move from its preset position.
5. A position transmitter provided in the mechanism will indicate the relative orifice position.
6. The torque capability of the mechanism will be sufficient to move the orifice under maximum pressure drop conditions with a substantial allowance for frictional losses in the system.

7. Flow control will be provided over the standard service period of 8 yr without exceeding the maximum allowable downtime for the overall assembly as described in Section 4.2.

For test purposes a full-scale valve and mechanism fabricated from production drawings will be tested in conjunction with the control rod drive mechanism tests described in Section 4.4.4. The test will employ the same test rig and the same type of instrumentation and will expose the valve to the same environmental conditions as described in Section 4.3.3.2.

The initial testing will be conducted in the air stand simultaneously with the C&O assembly air tests and will consist of verification of drive characteristics by a series of mechanical and electrical checks. Following insertion of the C&O assembly into the test autoclave, the valve and drive mechanism will be cycled over a predetermined number of cycles concurrently with the control rod drive mechanism tests. The number of valve cycles will be based on demonstrating that the valve will not exceed the maximum allowable downtime as described in Section 4.2. The actual number of cycles required will be determined prior to the start of testing in April 1976.

4.4.6. Reserve Shutdown System Tests

Two tests have been planned for the reserve shutdown system. The first test series, which has been completed, was used to establish the configuration of the hopper and gate to promote efficient material flow. The second test series consists of demonstrating that the overall system will reliably meet the desired design criteria (discussed below). Reliability and the required number of drop tests are based on the main objective of the overall test program, as stated in Section 4.2, to establish the maximum allowable downtime for the overall C&O assembly.

The basic design criteria to be verified by this testing are as follows:

1. Those portions of the reserve shutdown hopper and gate located within the lower portion of the refueling penetration will be capable of functioning in, and will not be adversely affected by, a helium environment at reactor conditions of temperature, pressure, and purity.
2. Those portions of the reserve shutdown actuator mechanism located within the upper portion of the refueling penetration will be capable of functioning in the same environment as in (1) above, except that the ambient temperature is 150°F (maximum) for normal conditions and 200°F (maximum) for abnormal conditions.
3. The neutron absorber material will be sized to eliminate the possibility of bridging, and the materials will be selected to avoid agglomeration.
4. The reserve shutdown system, including the hoppers, guide tubes, and channels within the core regions, will be designed to enclose and retain the absorber material and to avoid any significant release of absorber material into the primary coolant system.
5. The reserve shutdown system will be designed such that all absorber material will be inserted within the core channel within a maximum time limit of 60 sec following actuation of the "dump" switch.

4.4.6.1. Hopper Tests. A plexiglass and metal mock-up of the hopper and gate was constructed. The gate was manually operated since it was not intended to test the actuation mechanism during these tests. During performance of initial drop tests in air, the configurations of the hopper and hopper gate were modified to optimize material flow. Following this series of tests, 60 drops in air were performed for each of the two sizes of absorber material (i.e., 9/16-in.-diameter by 9/16-in.-long and 7/16-in.-diameter by 7/16-in.-long pellets) which are being considered for use in the reactor. In both cases the drop tests were successfully completed.

4.4.6.2. Environmental Drop Tests. This series of tests will be conducted using a prototype reserve shutdown system which has been fabricated using production drawings, materials, protective coatings, and fabrication procedures. The test article will consist of a redundant actuation mechanism which will be mounted in a position equivalent to its actual position within the C&O assembly. The reserve shutdown hopper portion of the C&O assembly neutron and thermal shielding housing will be reproduced for the test.

The test facility will be capable of containing the test article within a simulated reactor environment. The facility autoclave will provide a helium environment of 15 psig with a hopper/gate environment temperature of 610°F and an actuation mechanism environment temperature of 150° to 200°F. The bottom of the autoclave will simulate the diameter and length of the reserve shutdown core channel.

These tests will demonstrate the ability of the system to function properly in the reactor environment, including vibration and long-term static effects. Sixty drop tests will be conducted in helium at the above environmental conditions to demonstrate system performance without exceeding the maximum allowable downtime. Following these tests a hopper load of material will be vibrated prior to system actuation. These tests will be conducted five times each in an air and helium environment. Also, a long-term static test will be performed. Three hoppers will be loaded and maintained in a static state at reactor conditions for a period of a year prior to actuation. These tests will be used to assess any tendency of the reserve shutdown material to compact and bridge.

Instrumentation will be provided to monitor motor actuation current, actuation and material flow times, and material fill height and weight. The actual instrumentation and the step-by-step procedures to be employed have not yet been detailed. These details will be completed by June 1976.

4.4.7. Qualification of Seismic Category I Components

The purpose of these tests is to qualify all Category I components of the C&O assembly. The electromechanical equipment of the C&O assembly will be qualified per the requirements of IEEE-344-1975 (Ref. 4-2) to withstand the postulated SSE. The operability of the remaining components of the C&O assembly during and subsequent to an SSE will be justified by shake tests performed at an outside laboratory. Details of these qualifying tests are scheduled to be available by March 1976.

4.4.8. Qualification of Class IE Electromechanical Components

All safety-related Class IE electromechanical components of the C&O assembly (the control rod drive motor, reserve shutdown actuator motor, control rod drive and reserve shutdown system position transmitters, control rod drive trip velocity controlling resistors, control rod drive slack cable load cells, etc.) will be qualified per the requirements of IEEE-323-1974, IEEE-334-1974, and IEEE-117-1973 (Refs. 4-3, 4-4, 4-5). Qualification includes accelerated aging of the components to their design life followed by exposure to typical DBDA environmental conditions. These tests will most likely be performed at an outside laboratory. Details of the qualifying tests are presently being formulated and are scheduled to be available by March 1976.

4.5. ACCEPTANCE CRITERIA

4.5.1. Installation Tests

These tests will be acceptable if the C&O assembly is capable of being installed in a refueling penetration and core which are offset up to 1-3/4 in. radially and 6° rotationally. If the tests reveal any areas of excessive friction, these areas will be modified and the tests rerun.

4.5.2. Moist-Environment Tests

These tests are designed to pinpoint any potential problems resulting from long-term (up to 1 yr) exposure to a moist-air environment. The objective of these tests is to assess any propensity toward corrosion of the C&O assembly and its components. Special attention will be given to the more critical components within the assembly, in particular, bearings, gears, motors, potentiometers, slack cable load cells, electrical connectors, etc. Any problems resulting from the moist environment will be corrected, and the item will be proved acceptable either by rerunning the entire test or by qualifying the specific area of concern.

4.5.3. Control Rod Drive Mechanism Tests

Since the purpose of these tests is to demonstrate the ability of the control rod drive mechanism to operate reliably, the acceptance criteria will be based on successful operation over a specific number of cycles. Any failure of the control rod drive mechanism to initiate or complete a scram or to be driven in the shim or jog mode will constitute a failure of the control rod drive mechanism tests.

The mechanism must operate successfully for over 630,000 jogs, 5400 scrams, and 80,000 ft of shim travel.

4.5.4. Orifice Flow Tests

The performance of the valves is judged according to relevant design criteria, the more critical of which are summarized below (for reactor conditions):

1. The stagnation pressure drop across the valve will be less than or equal to 1.92 psi at the fully open design flow rate of 76 lb_m/sec of helium per region. The stagnation pressure drop is defined as the difference between the core upper plenum pressure (directly upstream of the valve) and the average stagnation pressure in a horizontal plane immediately above the coolant channels.

2. The flow maldistribution between coolant holes will be less than or equal to 10%. Percent maldistribution is defined as the percent difference between minimum coolant channel flow and average coolant channel flow (for coolant channels of equal diameter).
3. Maximum region flow will be $76 \text{ lb}_m/\text{sec}$ and the minimum region flow will be $11.5 \text{ lb}_m/\text{sec} \pm 5\%$ with a valve ΔP of 10 psi.
4. The maximum permissible percent change in region mass flow rate per increment of orifice position will be 5% for the full range of orifice travel.

4.5.5. Reserve Shutdown System Tests

The primary function of the reserve shutdown system is to provide a means for shutdown of the reactor in the improbable event of a failure of the control rod drive system. Acceptance of the design will be based on successful flow of the material from the hopper to the core channel within the maximum allowable time of 60 sec. Any stoppage of flow or partial flows due to material bridging or other means will be considered a failed test.

4.5.6. Qualification of Seismic Category I Components

The acceptance criteria for these tests will be available after the test procedures have been formulated. See Section 4.4.7.

4.5.7. Qualification of Class IE Electromechanical Components

The acceptance criteria for these tests will be available after the test procedures have been formulated. See Section 4.4.8.

4.6. DESIGN ALTERNATIVES

Although the designs of the FSV and large HTGR C&O assemblies are different, the basic design philosophies now being used are similar to those

in use since the inception of the FSV design. Additionally, the current design concepts have been revised to include the experience gained during FSV construction and start-up. Therefore, none of the large HTGR C&O assembly designs are new concepts, and adequate engineering experience is available. For example, the use of the dc torque motor in the large HTGR control rod drive mechanism has already been proven by testing (see Section 4.3). Also, the designs of the reserve shutdown system and orifice valve incorporate the use of stepping motors and cable drives which have been used previously in the FSV control rod drive and orifice valve drive mechanisms.

As a result, it is expected that this developmental and qualification test program will pose no problems that will require major changes in the existing design concepts. It is expected that any problems encountered during testing will be corrected on the existing components and that the testing will be completed successfully. Therefore, no alternative design concepts have been deemed necessary at this time.

4.7. STATUS AND SCHEDULE

The current status and schedule for the C&O assembly test program are given below. Progress will be reported on all C&O assembly programs through the LTR-100 series of reports. Final reports will be prepared as each of the individual programs is completed.

4.7.1. First Series of Tests

These tests have been completed. Summaries of the tests and results are given in Section 4.3.3.

4.7.2. Second Series of Tests

4.7.2.1. C&O Assembly Installation and Moist-Environment Tests. This test phase is presently in the facility design and planning stages. The installation tests will be performed as part of the control rod drive Phase 1 air

tests and is scheduled for April and May 1976. The moist-environment test will be performed immediately following the hot helium cycling tests on the control rod drive and orifice valve mechanisms. This test is scheduled for 6 months beginning in December 1976.

4.7.2.2. Control Rod Drive Mechanism Tests. These tests are currently in the planning stage with facility rework and prototype fabrication planning in progress. These tests, which will be essentially a rerun of the first test series, are currently scheduled for June through November 1976.

4.7.2.3. Orifice Valve Flow Tests. These tests have been completed, and a summary of the tests and results is given in Section 4.4.5. Design of an optimum valve is now in progress. A rerun of the air flow tests on a valve fabricated to production specifications is scheduled to commence in June 1976.

4.7.2.4. Orifice Valve Environmental Tests. These tests are presently in the planning stages, concurrently with fabrication of the prototype unit. These tests, which will be conducted simultaneously with the control rod drive mechanism tests, are scheduled for June through November 1976.

4.7.2.5. Reserve Shutdown Hopper Tests. These tests have been completed, and the resulting design changes to the hopper and gate have been incorporated into the production drawings. A report of the test results will be included as part of the environmental drop test report.

4.7.2.6. Reserve Shutdown Environmental Drop Tests. These tests are presently in the planning stage. Testing is scheduled to begin in June 1976, with completion expected in December 1977. The report of the results is scheduled for July 1978.

4.7.2.7. Qualification of Seismic Category I Components. These tests are presently in the early stages of planning. Shake testing is planned to be performed following the C&O assembly environmental testing and will therefore be performed in late 1976 or early 1977.

4.7.2.8. Qualification of Class IE Components. The qualification test program for all C&O assembly electromechanical equipment is presently being developed. Qualification tests are planned to be completed during 1976.

References

- 4-1. Horsley, G. W., and H. Fricker, "The Selection of Greases for Lubrication of Bearings in the Dragon Reactor," Dragon Project Report 51, September 1961.
- 4-2. "IEEE Recommended Practices for Seismic Qualification of Class IE Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-344-1975.
- 4-3. "IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-323-1974.
- 4-4. "Trial-Use Guide for Type Tests of Continuous Duty Class I Motors Installed Inside the Containment of Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-334-1974.
- 4-5. "Test Procedure for Evaluation of Systems of Insulating Material for Random-Wound AE Electrical Machinery," Institute of Electrical and Electronics Engineers Standard IEEE-117-1973.

5. CORE AUXILIARY COOLING SYSTEM TESTS

5.1. INTRODUCTION AND BACKGROUND

5.1.1. Introduction

Certain components of the CACS will be subjected to DV&S and Qualification Programs that involve testing under simulated accident conditions to assure conformance with design specifications for performance under accident loads and stresses. The components for which the emphasis is on the DV&S studies are:

1. Auxiliary circulator components, including the bearing lubrication and seal system and the motor cooling system.
2. The CAHE.

Specific components of the auxiliary circulator for which the emphasis is on the Qualification Program testing are:

1. Motor insulation.
2. Motor.
3. Auxiliary circulator (assembly).
4. Coolant shutoff valve.
5. Motor drive control.

In this section of this report, the DV&S and Qualification Programs are discussed under separate headings corresponding to the two major component categories listed above. Equipment descriptions and other background information are presented below.

5.1.2. Background

5.1.2.1. System Description. The function of the CACS is to remove fission product decay heat from the reactor under either normal or abnormal conditions when the main loop cooling is not operating. The principal components of the system are an electric-motor-driven axial flow compressor, a primary-coolant-to-water heat exchanger, and a closed circuit helium loop that includes a primary coolant shutoff valve. A primary coolant shutoff valve in the main loop is also essential to the CACS. In operation the compressor circulates hot gas through the heat exchanger for cooling and back through the core. The CACS shutoff valve, which must be closed during normal main loop cooling must open automatically when the CACS is activated. The main loop shutoff valve, which is open during main loop cooling, must be closed during CACS operation.

Two CACS loops are provided for the 2000-MW(t) reactor and three loops are provided for both the 3000-MW(t) and 3800-MW(t) reactors.

5.1.2.2. Auxiliary Circulator. The main elements of the auxiliary circulator machine assembly consist of an electric-motor-driven axial flow compressor mounted on a single shaft supported by oil-lubricated rolling contact bearings. These elements are of conventional design and do not require an extensive development test program.

Because the circulator operates in a helium environment inside the PCRV, various aspects of the design that could be affected by this environment will be evaluated by testing. The tests will demonstrate the margins in the design. Specific features are being evaluated on special-purpose component test stands.

Component tests in progress include motor insulation evaluation and circulator bearing lubrication and seal system tests. Motor cooling system tests are scheduled to begin in July 1975.

Following the component tests, a complete first article (prototype) auxiliary circulator assembly, including ducting and a CACS shutoff valve, will be subjected to a series of qualification tests to demonstrate operational capability.

5.1.2.3. Auxiliary Circulator Motor Control. The auxiliary circulator motor control is a solid-state, variable frequency unit with characteristics integrally compatible with those of the electric motor drive. The total power requirement is supplied by combining smaller-capacity modules of a standard industrial design into a single specially designed and qualified package. The design utilizes state-of-the-art components which have been used commercially. A first article control will be tested by the control manufacturer and then shipped to San Diego, where it will be used during the auxiliary circulator qualification test and also for all production circulator acceptance tests.

The motor control tests include seismic qualification and overall performance and endurance operation concerned with demonstrating the margins in the design.

5.1.2.4. Core Auxiliary Heat Exchanger. In conformance with the overall CACS requirements, each CAHE module is designed to remove core residual heat under all credible accident conditions. The design provides for and is restrained by requirements on removability, water inleakage limit, and in-service inspection of the primary closure welds and bolts. Each heat exchanger has a single heat transfer section consisting of helically coiled tubes. The shrouds, headers, insulation, supports, valves, and primary closure and flow restriction are part of the heat exchanger.

Cooling water enters the heat exchanger via the inlet manifolds which distribute the water to lead-in tubes. These lead-in tubes penetrate the upper end of the cavity penetration and the primary coolant pressure boundary (primary closure) and terminate in a subheader to which heat transfer tubes are connected. The heating surface consists of a helically coiled tube bundle arranged in countercurrent flow with the helium flow.

From the bottom of the tube bundle, the heat transfer tubes are routed to the top of the bundle via the center duct, where they are again collected into subheaders. Lead-out tubes penetrate the primary closure and convey the water from the subheaders to the exchangers.

5.1.2.5. Auxiliary Circulator Shutoff Valve. The auxiliary circulator shutoff valve concept is similar to that utilized in the FSV plant. The test program will further demonstrate the margin of conservatism of the design.

The shutoff valve will be tested as part of the auxiliary circulator verification and qualification test program. These tests will demonstrate the capability of a proven design concept as adapted for the present application. The FSV experience is summarized below.

5.1.2.5.1. FSV Design. The original design was conceived in 1966. A prototype valve was built in 1967 and subjected to tests in a special rig using atmospheric air. The design of this valve is described in Ref. 5-1.

5.1.2.5.2. Bench Tests. Static tests of the original assembly revealed deficiencies in the hinge performance caused by fabrication problems. The hinge area was bored out for the subsequent prototype tests in air and was redesigned for the production version. The present design ensures that loading of the hinge-pin region will not occur either during assembly or during the operational life of the valve. The bench tests provided information on the static moment characteristics of the valve components.

5.1.2. .3. Air Tests. Valve performance was evaluated by mounting the prototype valve in a duct and passing atmospheric air through the valve assembly. The following information was obtained from the air tests:

1. Valve free position and stability for various flow rates were determined.

2. Moment coefficients were measured, and it was established that the valve position was a function of velocity head and independent of Reynolds number.
3. Pressure drop (loss) across the valve was determined.
4. Different "spoilers" were evaluated. The spoiler provides added lift in maintaining the valve in the open position and also produces a drag to assist closure when reverse flow is present. An "intermediate" size spoiler was selected for the final design because it provided the best combination of opening/closing assist with negligible effect on the free flow past the open valve.

5.1.2.5.4. Production Valve Tests. A FSV production valve was installed within the circulator test loop at the Valmont test facility. This valve was cycled throughout the testing of the five production circulators. Test conditions included simulated reactor helium conditions (full temperature and pressure) and circulator tests at 137% of design speed. The test assembly included all circulator components: machine assembly, inlet, diffuser, and valve.

Acceptable shutoff valve mechanical and aerodynamic performance encompassed:

1. 1915 hr of operation associated with the total testing of the five production circulators.
2. 225 opening and closing cycles as a function of circulator starting and stopping conditions.

5.1.2.5.5. FSV Reactor Tests. Shutoff valve experience during pre-operational tests at FSV has included operation of the circulators in the helium environment. Specific histories are currently being tabulated and

brought up to date for each circulator/valve assembly. However, each of the four circulator assemblies has been operated for at least 2000 hr, and each of the four valves has experienced approximately 50 open/close cycles.

5.1.2.6. Main Helium Shutoff Valve. Each main circulator is provided with a shutoff valve which limits backflow through a primary loop when the associated main circulator is shut down. When core cooling is provided by use of the auxiliary circulators, the main shutoff valve for each main circulator is closed. These valves are therefore discussed in conjunction with the auxiliary circulator components.

The valve ring, which fits in the annular space at the circulator diffuser exit, is closed and positioned by three motor-driven linear actuators with attachments equally spaced around the circumference of the ring. A secondary means of closing the valve is provided by a solenoid-operated release device in each actuating rod which, when operated, allows the valve ring to drop aided by the forces generated by the springs.

5.2. DV&S PROGRAM

5.2.1. Auxiliary Circulator Components

5.2.1.1. Bearing Lubrication and Seal System. The auxiliary circulator bearing lubrication and seal system consists of a dynamic/gravity seal combined with a buffer-helium seal. This system prevents leakage of circulator lubricating oil into the PCRV and, at the same time, helps to ensure that primary coolant and oil vapor do not enter the circulator motor cavity.

5.2.1.1.1. Objectives. The main objectives of the bearing lubrication and seal system tests are:

1. Verification of thrust bearing system functional capability over the entire speed and load range.

2. Verification of seal system performance at all required conditions.
3. Verification of the lubrication supply, scavenge, and cooling system under all operating conditions.

The operation of the bearing lubrication and seal system under simulated normal and abnormal reactor operating conditions is being demonstrated in a full-size test rig at the GA Experimental Engineering Facility in San Diego. The shaft, seal system, thrust bearing, and oil reservoir configuration have been duplicated in the test rig. Verification of seal system, bearing lubrication system, and thrust bearing performance is being accomplished. These tests are being used to check out design alternatives and optimize the configuration for the prototype design.

5.2.1.1.2. Test Description. The test rig for the thrust bearing system consists of a full-size test bearing set, an oil reservoir with cooling coils, an oil recirculation impeller, and a shaft assembly driven by a variable speed ac test motor.

The test rig is being used to optimize the oil pumping system, which is similar in both upper and lower bearing systems. It is constructed with both steel and Lucite oil reservoirs. Three different oil pump impellers and two different flow restrictor orifices are being tested with the Lucite oil reservoir installed. After the oil system visualization tests, the steel reservoir will replace the Lucite reservoir and the oil pump impeller and flow restrictor orifice giving optimum performance will be installed.

The test rig has a built-in hydraulic thrust system. Hydraulic oil pressurized by an external supply system acts on an annular area to provide downward thrust on the shaft.

Except when the Lucite oil reservoir is installed in the thrust bearing system, thermal parameters will be controlled by electric heating elements, insulation, and heating of the incoming buffer helium as well as

by the cooling water in the simulated cooling coils. All boundaries external to the bearing system will be maintained at $200^{\circ} \pm 20^{\circ}\text{F}$. The test program will include the following:

1. Orifice calibration. The orifice regulates flow from the oil reservoir to the bearings. Two different orifice configurations have been tested to determine flow versus pressure drop characteristics for high, intermediate, and low oil levels. Final selection of an orifice configuration will depend on the results of the impeller tests outlined below.
2. Impeller performance. The impeller is installed as part of the bearing assembly and recirculates oil from the bearing cavity to the oil reservoir when the shaft is rotated. Three different impeller configurations are being evaluated in conjunction with the two orifice configurations. Impeller performance for different shaft speeds and oil levels is being determined.
3. Thrust bearing and seal performance. Operation of the thrust bearing and seal system over the range of expected required operating conditions will be performed. "Worst case" conditions will be simulated, and the capability of the sealing system will be demonstrated. The oil evaporation loss rate will be determined during operation.

The following data are being recorded:

1. Flows.
 - a. Gas flow to the labyrinth.
 - b. Gas flow from the oil reservoir.
 - c. Water flow to the oil cooling coils.
 - d. Hydraulic oil flow rate (thrust loading).

2. Pressures.

- a. Simulated buffer helium pressure.
- b. Gas pressure in the vent line.
- c. Gas pressure in the bearing cavity.

3. Temperatures.

- a. Gas temperature upstream of the labyrinth.
- b. Gas temperature leaving the oil reservoir.
- c. Water temperature into the cooling coils.
- d. Water temperature out of the cooling coils.
- e. Bearing outer race temperature, upper bearing (two places 180° apart).
- f. Bearing outer race temperature, lower bearing (two places 180° apart).
- g. Oil temperature in the oil reservoir.
- h. Oil temperature leaving the bearing cavity.
- i. Radial support bearing race temperature.
- j. Hydraulic oil temperature.
- k. Bearing cavity temperature.

4. Shaft speed.

5. Thrust (pressure on piston).

6. Oil vapor concentration (when using helium).

7. Oil reservoir oil level.

5.2.1.1.3. Instrumentation. All data will be measured utilizing appropriate instrumentation consistent with the parameters to be measured. The instruments are all state of the art and require no special techniques or procedures during operation.

5.2.1.1.4. Acceptance Criteria. These are DV&S tests and thus the results will be used to optimize the design. This optimum design, having gone through an extensive endurance test, will instill greater confidence prior to the overall bearing qualification test planned with the final machine assembly.

5.2.1.1.5. Status and Schedule. The bearing lubrication and seal system tests are in progress and are expected to be completed in December 1975. The test report is scheduled to be released by June 1976.

5.2.1.1.6. Design Alternatives. Any deficiencies determined by the test program will be corrected by suitable design and/or specification changes.

Final production hardware will consist of configurations that have demonstrated acceptable performance characteristics as indicated by the results of the test program.

5.2.1.2. Motor Cooling System. The auxiliary circulator motor cooling system consists of motor cooling fans incorporated in the motor rotor and a water-cooled heat exchanger around the motor stator. During motor operation, the motor cooling fans circulate helium gas in a closed loop through the motor and then through the water-cooled heat exchanger. Because the cooling medium is helium gas, the fans and cooling loop are different from those for conventional air-cooled motors, and the performance of the system will therefore be demonstrated in a full-size test rig prior to first article qualification tests.

5.2.1.2.1. Objectives. The motor cooling system tests will provide information to verify the design and demonstrate the margins in the design. Specific objectives are:

1. To determine the velocity profile of the gas leaving the stator plenum.
2. To determine the performance of the fan and motor rotor combination in terms of pressure rise versus flow for various speeds.
3. To verify the performance of the heat exchanger.

5.2.1.2.2. Test Description. Tests using air will be performed on a full-size mock-up of the motor and casing assembly including fan blades, motor rotor and motor stator flow paths, and cooling coils. Measurements of flow distributions and temperatures will verify the motor cooling system performance. These tests will be conducted at the GA Experimental Engineering Facility in San Diego.

All flow passages inside the frame will simulate the production assembly as closely as possible, including the mounting of the stator and heat exchanger. The test rig rotor will be driven by an electric motor. Speed variation will be obtained with different sheaves and belts. The rotor fans will draw atmospheric air into the frame. After passing through the stator and heat exchanger, the air will discharge into two ducts, which include a flow-measuring device. The flow will then converge into a single line in which a restrictor valve is located.

The following tests will be conducted:

1. Rotor fan performance. To verify the performance of the motor cooling fans and determine the performance of the motor rotor-stator combination, the following test sequence will be accomplished:

- a. Assemble the rig without the motor heat exchanger for this part of the test program.
 - b. Open the restrictor valve all the way, and with the appropriate sheave/belt combination, accelerate the rotor to 1200 rpm using the largest sheave on the driven end.
 - c. Upon reaching equilibrium, record all data as indicated below.
 - d. While maintaining speed, close the restrictor valve sufficiently to decrease the flow rate by 10%. Upon reaching equilibrium, again record data.
 - e. Repeat step (d) until the restrictor valve is fully closed.
 - f. Depending on the shape of the performance curve, additional flow increments may be required.
 - g. Repeat steps (b) through (f) for speeds of 2400 and 3600 rpm by assembling the required sheave/belt combination onto the driver and driven ends of the shafts.
2. Heat exchanger performance. The following steps will be performed to verify the performance of the motor heat exchanger:
- a. Assemble the heat exchanger into the test rig. All external surfaces of the rig will be insulated with at least 4 in. of fiberglass.
 - b. Open the flow restrictor valve all the way.
 - c. With the appropriate sheave/belt combination, accelerate the motor rotor to 3550 rpm.

- d. Upon reaching equilibrium, i.e., less than $1/2^{\circ}\text{F}$ variation in temperature after a period of 1 min, record all data.
 - e. Admit 100°F (or at least 20° higher than ambient air) water into both sets of heat exchanger coils. A total flow of 30 gpm should be divided equally between the two sets.
 - f. Upon reaching equilibrium, i.e., less than $1/2^{\circ}\text{F}$ variation in temperature after a period of 1 min, record all data.
 - g. Repeat step (e) for total water flows of 25, 20, 15, and 10 gpm.
 - h. Increase the water temperature to 120°F and repeat step (e) for water flows of 30, 25, 20, 15, and 10 gpm.
 - i. Repeat step (h) for water temperatures of 140° and 160°F .
 - j. For each data point, obtain sufficient readings of the temperatures to provide good statistical data.
 - k. Repeat steps (e) through (j) with one of the heat exchanger loops isolated and water flows of 20, 15, 10, and 5 gpm in the operating loop.
 - l. Repeat steps (e) through (k) for circulator speeds of 2400 and 1200 rpm.
3. Data. The following information will be recorded for every test point:
- a. Atmospheric pressure.
 - b. Fan inlet pressures.

- c. Fan pressure rise.
- d. Stator end turn pressure.
- e. Heat exchanger gas inlet static pressure.
- f. Heat exchanger gas outlet pressure.
- g. Flow-measuring device inlet pressure.
- h. Flow-measuring device pressure drop.
- i. Atmospheric temperature.
- j. Fan inlet temperature.
- k. Fan outlet temperature.
- l. Motor stator outlet temperature.
- m. Flow-measuring device temperature.
- n. Stator temperature.
- o. Speed.
- p. Flow restrictor valve position.
- q. Velocity profile of the air leaving the motor stator shroud at 3600 rpm.

In addition, the following information will be recorded for every test point when the heat exchanger is installed:

- a. Heat exchanger water inlet pressure.

- b. Heat exchanger water pressure drop.
- c. Heat exchanger gas outlet temperature.
- d. Heat exchanger water inlet temperature.
- e. Heat exchanger water outlet temperature.
- f. Heat exchanger water flow.

5.2.1.2.3. Instrumentation. All data will be measured utilizing appropriate instrumentation consistent with the parameters to be measured. The instruments are all state of the art and require no special technique or procedures during operation.

5.2.1.2.4. Acceptance Criteria. These tests are part of the overall DV&S tests to be performed prior to the complete qualification tests planned for the machine assembly. Test results will either be used to confirm the design or as a basis for design modification. Qualification testing will proceed only after data extrapolation confirms a maximum gas outlet temperature from the heat exchanger of 75°C.

5.2.1.2.5. Status and Schedule. The motor cooling system test rig is being fabricated. Testing is scheduled to commence in August 1975 with completion in March 1976. The final test report is scheduled to be released in September 1976.

5.2.1.2.6. Design Alternatives. Any deficiencies determined by the test program will be corrected by suitable design and/or specification changes.

Final production hardware will consist of configurations that have demonstrated acceptable performance characteristics as indicated by the results of the test program.

5.2.2. Auxiliary Circulator Assembly

Following the component tests previously described and the tests described in Sections 5.3.1.1 and 5.3.1.2, a complete first article

auxiliary circulator assembly, including ducting and the CACS shutoff valve, will be subjected to a series of design verification and qualification tests as described in Section 5.3.1. DV&S tests are scheduled to start in July 1977, with a test report scheduled for release in October 1978.

5.2.3. Core Auxiliary Heat Exchanger

5.2.3.1. Objective. The objective is to verify the function and design of various components of the CAHE by performing both gas- and water-side flow tests. These tests include a gas-side inlet plenum flow distribution test and a water-side corrosion/erosion test of the manifolds, subheaders, and tubes.

5.2.3.1.1. Gas-Side Inlet Flow Distribution. The purpose of this test is to determine the flow distribution at the entrance to the CAHE tube bundle and to establish required modifications if excessive maldistribution exists in the as-designed configuration.

The program includes the design and fabrication of a scale-model of the CAHE helium inlet and partial tube bundle:

1. To experimentally determine the velocity distribution at, and upstream of, the tube bundle inlet plane for both the 2000- and 3000-MW(t) models.
2. To establish design modifications which will provide a velocity distribution at the bundle inlet with a variation from the average not exceeding 20%.

5.2.3.1.2. Corrosion/Erosion. The primary objective of the corrosion/erosion test program is to assess the potential corrosion/erosion damage in the inlet to the CAHE water inlet manifold, lead tubes, subheaders, and heat transfer tubes.

The program is therefore designed to (1) identify the critical areas for erosion and corrosion damage in the CAHE water system and (2) provide quantitative data on erosion and corrosion rates at these critical areas for the three types of materials selected for testing. This information will be used to verify materials selected for application in the CAHE.

5.2.3.2. Test Description

5.2.3.2.1. Gas-Side Inlet Flow Distribution. The gas flow into the CAHE emerges from a lower cross duct which is perpendicular to the direction of flow through the CAHE. This configuration requires the gas to undergo both a sudden expansion into the plenum below the CAHE and a 90° bend before entering the tube bundle.

An air flow test on a scale model of the CAHE is being conducted to evaluate the gas flow distribution at the entrance to the helical tube bundle. The results of this test will be used to verify performance of the full-scale CAHE with respect to inlet flow distribution by verification of the peak-to-average velocity distribution at the inlet to the tube bundle.

This test is being performed on a 1/4-scale model of the lower cross duct, the inlet plenum, and the first ten rows of the CAHE tube bundle, using air as the test fluid. The basic laws of dynamic similarity are being followed so that the test will accurately represent full-scale conditions. The test is being conducted over a range of Reynolds numbers representative of CAHE operation.

Performance will be measured by velocity traverses across the bundle inlet, which will be a direct indicator of the flow distribution. The shell of the model is fabricated from a transparent material (plexiglass) to allow full visibility for flow visualization studies.

The basic model will represent the CAHE for the 3000-MW(t) reactor and will be fabricated and tested initially in the "as designed" configuration. If necessary, the model will be retested with guide vanes installed in the

inlet plenum to improve the flow distribution. The model will then be modified to represent the 2000-MW(t) design by simply installing a smaller pipe inside the cross duct. This will allow the existing model to be reused for the 2000-MW(t) CAHE design by changing the scaling factor. The model will then be retested (with turning vanes if required in the 3000-MW(t) model), and the data will be compared with the previous results. If the results are dramatically different, refinement of the design and scaling of the 2000-MW(t) flow model will be accomplished and additional testing conducted. Modification and testing will continue until a satisfactory flow distribution is established at the tube bundle inlet for both the 2000- and the 3000-MW(t) designs.

All tests will be conducted at the GA experimental engineering facility.

5.2.3.2.2. Corrosion/Erosion. It has been postulated that corrosion/erosion damage may potentially occur under certain conditions as flow encounters abrupt changes in sections, such as at the entrance to tubes, and in tube bends. The combination of operating conditions of the CAHE, such as velocity, water temperature, and pH, falls outside the data in published literature. Hence, a test to evaluate the effects of the specific CAHE operation conditions and configuration on corrosion/erosion damage was formulated to demonstrate the acceptability of the design.

This demonstration calls for a test of approximately 3000-hr total duration. The basic test parameters are (1) tube materials (SA-213, T-2, T-22, and Incoloy 800), (2) water chemistry consistent with CAHE water system specifications, (3) flow and temperature ranges consistent with worst operating conditions for the CAHE, and (4) full-size CAHE manifold, sub-header, and tube geometry.

The metal loss rates will be measured directly after 1000- to 3000-hr test times. Two distinct time-dependent mass loss values will be obtained which, when extrapolated to the lifetime of the HTGR plant, can be compared with the standard corrosion allowance of 30 mils/lifetime.

Data from a similar test program for the steam generators will also be available to complement the CAHE erosion/corrosion test results.

5.2.3.3. Instrumentation

5.2.3.3.1. Gas-Side Inlet Flow Distribution. For qualitative flow observation, thread tufts will be used extensively throughout the model. The tufts of baby wool or multistrand cotton threads, approximately 1 in. long, are fastened to wire grids.

Test measurements will be centered on the following three parameters:

1. Flow visualization studies.
2. Velocity surveys.
3. Pressure drop measurements.

In addition, air flow rates and ambient temperature and pressure measurements will be taken.

The velocity surveys will be taken with three-dimensional probes in conjunction with fast response transducers to determine flow directions as well as flow velocities for each configuration and flow condition tested. Care will be exercised to use the smallest-diameter velocity probe practical to assure the least amount of disturbance to the flow fields. The velocity surveys will consist of radial traverses at angular intervals of 30°. One-inch increments will be sufficient at the other planar locations. Total pressure probes mounted on a fixed rake may be used for the velocity surveys downstream of the partial bundle.

Static pressure measurements will be made in the cross duct at the same planar location as the velocity surveys by means of wall static pressure taps. Wall static taps will also be located at each velocity survey plane within the model. Four static pressure taps located 90° apart at each planar location will be used.

For flow visualization, video tapes will be taken during the flow tests of the tufts described above. The tapes will record the behavior of all tufts for each flow conditions. Additional flow visualization studies, such as the injection of bubbles or smoke, will be considered if necessary.

Using standard instrumentation, ambient conditions of air temperature and barometric pressure as well as air flow rate through the model are recorded before and after each test. During velocity surveys, the above measurements will also be made at 2-hr intervals.

The measurement accuracies will be $\leq \pm 2\%$ for velocity ratios and pressure drops and on the order of 5% of absolute values. These accuracy requirements apply only to the high-flow-rate condition.

5.2.3.3.2. Corrosion/Erosion. Test specification TS-037 (Ref. 5-2) calls for the following type instrument to be used in the corrosion/erosion studies:

<u>Parameter</u>	<u>Instrument</u>
Temperature	Thermocouples
Pressure	Pressure gage
Flow rate	Venturi meter
Turbulence	Hot film anemometer

The corrosion/erosion studies will be performed in the GA experimental engineering facility.

5.2.3.4. Acceptance Criteria

5.2.3.4.1. Gas-Side Flow Distribution. The acceptance criterion for successful completion of the inlet flow test will be that flow maldistribution at the entrance to the tube bundle will not exceed the design allowable maximum of 1.2:1, peak to average.

5.2.3.4.2. Corrosion/Erosion. Acceptance criteria will be based on comparison of measured material loss of the candidate tubing materials (carbon and low-alloy steels) with the standard corrosion allowance of 30 mils for the 40-yr plant life. Where the combined effects of both erosion and corrosion exceed this metal loss rate, that material will be deemed unacceptable. Special consideration will be given to such problem areas as local pitting caused by excess erosion/corrosion wear at the tube entrances where excess material is present.

5.2.3.5. Status and Schedule

5.2.3.5.1. Gas-Side Flow Distribution. The tests are about 50% complete. The final phase is scheduled to start in July 1975 and to be complete by October 1975.

5.2.3.5.2. Corrosion/Erosion. The CAHE erosion/corrosion program is presently in the equipment procurement and test specimen fabrication stage. Testing is scheduled to start in September 1975. Intermediate results at 1000 hr will be obtained in November 1975, and a test program completion date of February 1976 is planned.

5.2.3.6. Design Alternatives

5.2.3.6.1. Gas-Side Flow Distribution. If the test reveals unacceptable flow distributions, the same test rig will be used to assess turning vanes or other flow distribution devices as necessary to provide acceptable conditions.

5.2.3.6.2. Corrosion/Erosion. The current design of the CAHE includes the use of either SA-213, T-2, or T-22 material for the manifolds, sub-headers, and tubes. If this test reveals that any or all of these materials are unacceptable, local redesign will be done to incorporate Incoloy 800 (which is undergoing testing concurrently with the other materials). All indications from power plant experience show that Incoloy 800 will not undergo the corrosion/erosion phenomena for the CAHE operating conditions.

5.3. DESIGN QUALIFICATION

5.3.1. Auxiliary Circulator and Components

5.3.1.1. Motor Insulation

5.3.1.1.1. Objective. The objective of the combined DV&S and qualification test program for the motor insulation is to optimize the design and demonstrate the margin of conservatism of that design.

5.3.1.1.2. Test Description. Auxiliary circulator motor insulation qualification tests are being conducted at the Westinghouse Research Laboratory, Pittsburgh, Pennsylvania. Motorettes constructed by Westinghouse are being subjected to accelerated aging in helium within a specially constructed pressure vessel. Phase-to-phase and phase-to-ground electrical tests are being used to detect sample failures.

The motorette samples will also be subjected to radiation and to helium depressurization cycles. Corona testing techniques will be utilized to evaluate the capability of the insulation to resist depressurization damage.

The results of the motorette tests will be used to determine the time-temperature relationships required to simulate 40-yr life by oven aging the stator, per IEEE-334-1974 (Ref. 5-3). The stator will also be irradiated by an independent testing laboratory. Potential and resistance tests will be conducted on the aged stator prior to assembly into the first article auxiliary circulator at GA.

The motor insulation life test procedures are summarized below:

1. Preliminary Coil Tests (completed)

The following coils were tested:

- a. Two fully insulated coils with Dacron glass over enamel insulation.
- b. Two fully insulated coils with Dacron glass insulation.

The 11-in.-i.d. by 48-in. pressure tank from Westinghouse was used for the tests.

Each set of coils was lashed together and tested at 13.6 psia helium and 2040 V for phase-to-phase insulation breakdown and turn-to-turn insulation breakdown. This test was performed after elevating coils to 155°C for 24 hr.

The tests were performed to establish that either or both basic insulations would be suitable for exposure to helium with its low dielectric value. Based on the results of these tests, Dacron glass over enamel insulation was selected for the final design.

2. Coil Decompression Test

Use the Dacron glass-over-enamel insulated coils. Place the specimen in the helium tank and elevate pressure to 725 psig at 155°C. Age for 24 hr minimum and then decompress the tank to 23.2 psia in 150 sec. Check the dielectric strength at 13.6 psig. This test will verify research experience which indicates that the insulation using Micanite II will withstand this decompression.

3. Final Motorette Test

Obtain two motorettes with two coils each from Westinghouse. Two of these units can be inserted in the available pressure tank.

Cycle 1

- a. Heat age the models in helium at 725 psig and 210°C for 3 days. Cool to 155°C while maintaining pressure.
- b. While at 155°C, lower the pressure in 150 sec to 23.2 psia and cool to room temperature.
- c. Vibrate the models at 1.6 g, 60 Hz in accordance with IEEE-275-1966 (Ref. 5-4) (models may be removed from the pressure vessel for this test).
- d. Replace the models in the test vessel, heat to 60°C, and evacuate for 4 hr to 1 mm Hg. Fill with pure helium to 50 psia and soak 4 hr. Evacuate to 1 mm Hg. Fill with pure helium to 10.2 psia. Soak for 4 hr while cooling to 25°C at 9.2 psia, which is equivalent in gas density to 13.2 psia at 150°C.
- e. Apply a voltage test of 2000 V ac (rms), 60 Hz to ground, 2000 V ac (rms), 60 Hz phase-to-phase, 115 V ac turn-to-turn. After completion of the tests, evacuate the vessel through a sample analyzer to assure maintenance of the helium purity level.
- f. Measure the corona threshold voltage. Measure the total corona charge per cycle with a capacitance bridge and calculate apparent void content.

Cycle 2

Reexpose the specimen to 725 psia helium at 210°C and heat age for 3 days. Cool to room temperature slowly and repeat steps (c) through (e).

Cycles 3, 4

- a. Repeat cycles 1 and 2.

Cycle 5

- a. Repeat cycle 1.
- b. Irradiate the specimen to 10^8 rad.

Cycles 6, 7, 8, 9, 10

- a. Repeat cycles 1, 2, 1, 2, and 1.

The test data compiled under this test procedure will be analyzed in accordance with the method specified in IEEE-101-1972 (Ref. 5-5).

The external leads on the motorettes will be taped with glass-reinforced silicone rubber per Westinghouse specification.

The criterion of breakdown failure of the motorette insulation will be consistent with ASTM.D149-64 (Ref. 5-6). In addition, there will be a high-impedance voltmeter connected in parallel with the specimen to determine whether the specimen is withstanding the required test voltage.

Also, the steady current through the specimen at the test voltage will be determined. A failure will be considered to have occurred if this current exceeds twice the capacitance charging current based on the initial capacitance of the specimen prior to any aging.

No failures are expected in this test. However, if a coil failure should occur, the failure will be analyzed to determine its cause.

An additional motorette will then be aged at the same temperature levels through the ten-cycle plan defined above.

After all tests are completed, the time and temperature required to age the first article motor for 40 yr will be determined.

Aging will be performed in air or helium at the designated time and temperature (estimated as 430 hr at 210°C or 160 hr at 220°C).

5.3.1.1.3. Instrumentation. The pressure vessel used during the aging of the motorettes will be instrumented with pressure gauges to measure the pressure during evacuation (1 mm Hg) and pressurization (725 psia). In addition, thermocouples will be placed on the outside of the pressure vessel to assure that the aging temperature is maintained at 210°C.

A capacitance bridge will be used to measure the total charge per cycle of the motorettes to calculate the apparent void content. A high-impedance voltmeter will be used during the voltage stress tests to assure that the motorette is withstanding the applied voltage [2000 V ac(rms)].

5.3.1.1.4. Acceptance Criteria. The motorette tests must demonstrate by means of an extrapolated life curve that the insulation system will adequately meet the 40-yr service requirement, i.e., 34,000 hr at 140°C and 316,400 hr at 70°C. This requirement will be satisfied if there are no failures of the four motorettes during the ten aging cycles, or if one failure occurs that can be satisfactorily explained and another motorette substituted which subsequently survives the ten aging cycles. The justification of this aging argument is contained in Ref. 5-7.

5.3.1.1.5. Status and Schedule. Preliminary results from the initial tests have shown that Dacron glass over enamel insulation is the preferable configuration. Further tests are in progress on this configuration, with completion planned for March 1976. The test report is scheduled to be released in September 1976.

5.3.1.1.6. Design Alternatives. Any deficiencies determined by the test program will be corrected by suitable design and/or specification changes.

Final production hardware will consist of configurations that have demonstrated acceptable performance characteristics as indicated by the results of the test program.

5.3.1.2. First Article Motor

5.3.1.2.1. Objective. Prior to installation in the prototype auxiliary assembly, the first article motor will be subjected to a series of tests to demonstrate acceptable performance capability. Compliance of the design with design specifications will be the main objective of these tests.

5.3.1.2.2. Test Description. The following tests will be performed on the first article motor at the Westinghouse facility in Buffalo, New York:

1. Coil Tests Before Treatment

- a. Perform a turn-to-turn surge test between groups before connecting them, using a surge comparator at 3500 V. Use a visual scope picture to compare all phases for capacitor charge and decay voltage. If this test discloses a phase imbalance, check for an incorrect winding connection and correct.
- b. Perform a 1-sec, 60-Hz stator ground test before connecting groups. Apply 3300 V. If ground occurs during the test, rework the stator and retest.
- c. Perform a 1-sec, 60-Hz stator ground test after connecting groups. Apply 3300 V. If ground occurs during the test, rework the stator and retest.

- d. Measure the terminal-to-terminal resistance on a Kelvin bridge and check against minimum, maximum, and nominal computer values.
- e. Perform a 1-sec, 60-Hz Resistance Temperature Detector (RTD) ground test from RTD leads to the core and winding. Ground the motor winding to the core before applying voltage. Apply 2000 V ac. If ground occurs during the test, rework the stator and retest.

2. Water Test After Epoxy Resin Treatment

- a. Record data and instrument serial numbers.
- b. Measure the stator in air with a 500-V Meggar and record megohms after 1 min.
- c. Record the water temperature in °C.
- d. Submerge the stator vertically with the external leads not submerged but the connections submerged (connection end up).
- e. After a 1-min submersion, measure the insulation resistance between the winding and stator frame. Values must not be less than 4.5 megohms at 25°C or 6.4 megohms at 20°C.
- f. If the stator does not pass the test, dry out, reimpregnate, and rebake it and repeat the tests.
- g. After the stator passes test (e), apply 600 V ac, 60 Hz between the terminals and stator frame for 1 min while the stator is immersed.
- h. If the stator fails the ground test, return it for repair or rewinding.

- i. If the stator passes the ground test, step (g), repeat the insulation resistance test, step (e).
- j. Take an insulation resistance recovery Meggar reading in air after the stator has dripped over the tank for 1 min.

3. 60-Hz Commercial Test

- a. Winding Resistance - Terminal to Terminal - Cold. Measure and record the winding resistance. The standard limit is the theoretical average $\pm 5\%$.

Record the Kelvin bridge serial number.

Record ambient temperature.

- b. No Load Amperes. Measure and record data after a minimum of 1/2 hr running at 1800 rpm. The standard limit is the theoretical average $\pm 20\%$.

Record the instrument serial numbers and calibration dates plus the instrument transformer type and accuracy class.

- c. No Load Watts. Measure and record data after a minimum of 1/2 hr running at 1800 rpm. The standard limit is the computed theoretical value $\pm 25\%$. Record the instrument serial numbers and calibration dates plus the instrument transformer type and accuracy class.
- d. Rotation Direction. Check that the rotation is counter-clockwise facing the lead end and the phase sequence is T1-T2-T3. Check the phase rotation with a scope or phase rotation meter. Retag the lead if necessary.

- e. Current Input - Rotor at Standstill. Perform this test when the unit is set up in a dynamometer. Measure and record data. Apply 3-phase power at 50% voltage ≈ 130 V ac. The standard limit is the computed theoretical value +15%, -10%.

Record the instrument serial numbers and calibration dates plus the instrument transformer type and accuracy class.

- f. Insulation Resistance (all insulated windings). Measure the insulation resistance with a 500-V Meggar with the unit cold and record the value. The standard limit is 1.6 megohms minimum at 40°C. Correct the value of the "cold" reading to 40°C per IEEE-43-1961 (Ref. 5-8). Record the Meggar serial number.

- g. Insulation High-Potential Test. Perform this test after all other tests. The insulation must withstand for 1 min an ac, 60-Hz voltage equal to 2040 V applied successively between each electric circuit and the frame. RTDs not under test should be connected to the frame.

Tie the windings to the frame when testing RTDs with 2000 V ac. Record the ground tester serial number.

- h. RTD Resistance. Use a Wheatstone bridge or digital voltmeter to read each RTD resistance "cold." Record the ambient temperature. The element resistance at 0°C should be 100 ohms. Record the Wheatstone bridge or digital voltmeter serial number.

4. Tests on Dynamometer (60-Hz supply).

- a. Current Input - Rotor at Standstill. Apply 3-phase power at 50% voltage ≈ 130 V ac. Read the voltage, amperes for each leg, 3-phase watts, and torque. The standard limit on the computer calculation is +15%, -10%.

Record the instrument serial numbers and calibration dates plus the instrument transformer type and accuracy class.

- b. Performance Test (current-speed curve). Run the motor to full load at 260 V ac, 60 Hz. Run it until the resistance of the RTDs stabilizes such that temperatures are the same, $\pm 1\%$, at 15-min intervals.

Then read the frequency, voltage, current for each line, 3-phase watts, torque, and slip for six load points from 150% to 25% of full load torque. Measure the winding resistance at the end of the performance test. After the test, make dynamometer torque corrections and calculate both the efficiency and power factor curves per IEEE-112A-1964 (Ref. 5-9).

Performance test standard curves of current, watts, efficiency, power factor, and rpm versus torque or horsepower will be plotted.

Record the instrument serial numbers and calibration dates plus the instrument transformer type and accuracy class.

- c. Speed-Torque Curve. At 130 V ac, 60 Hz, 1677 rpm, increase the load in 10 steps to pull-out rating. Read the rpm, volts, line amperes, and dynamometer torque. Correct the readings to rated values at 260 V ac, 60 Hz. Plot both speed-torque and current-speed curves.

Record the instrument serial numbers and calibration dates plus the instrument transformer type and accuracy class.

5. First Article Performance. This test will be run on dynamometer No. 4 at the manufacturing site using the first article motor

control for input power. A special air flow test tool will be used to measure cooling air flow and motor temperature rise.

- a. Torque-Speed Curves. Perform this test to the controller maximum rating of 100% full load and at the following speeds:

	<u>Speed (rpm)</u>	<u>Motor Torque (ft-lb)</u>	<u>Controller Output Frequency (Hz)</u>
1.	216	40	7.2
2.	1200	1335	40
3.	1800	1335	60
4.	3600	1335	120
5.	3600	1600	120 (20-min run)

- b. Current-Speed Curves. Perform this test at speeds listed in "a," above.

- c. Efficiency and Power Factor Curves. Perform this test at speeds listed in "a."

- d. Air Flow Rate Tests. Unlike tests "a," "b," and "c," take temperature readings every 15 min until temperature readings are stable. (Stability is reached when four 15-min readings are constant $\pm 1^{\circ}\text{C}$.) Record these tests for the four key speeds of 216, 1200, 1800, and 3600 rpm. At each speed, record the following data:

- (1) rpm.
- (2) Torque.
- (3) Air flow (cfm).
- (4) Voltage.
- (5) Frequency.
- (6) Current.

- (7) Inlet (ambient) air temperature (°C).
 - (8) Outlet air temperature (°C).
 - (9) Inlet air pressure (psi - gauge).
 - (10) Outlet air pressure (psi - 0 gauge).
 - (11) Room temperature (°C).
 - (12) All motor RTDs resistance to temperature (°C).
 - (13) Winding resistances to temperature (°C) (per IEEE-112A-1964, Ref. 5-9).
- e. Vibration Test. Measure and record at 1800 and 3600 rpm for comparison with 60-Hz commercial test.
- f. Permissible Variations

<u>Parameter</u>	<u>Variation from Calculated Value</u>
Temperature rise	+5°C, -15°C. Unit must not exceed nameplate rise.
No load amperes - average	+10%, -20%
No load amperes - balance	Highest ÷ lowest = 1.10
No load watts	±25%
Cold winding resistance - average	±5%
Cold winding resistance - balance	Highest ÷ lowest = 1.05
Locked amperes	+15%, -10%
Full load amperes	±2%
Full load efficiency	±1%
Full load power factor	±1%
Full load slip	±10%

All malfunctions, failures, and corrective actions will be documented for review and agreement by buyer.

- g. Certified Commercial Test Report. The test report will identify the test shop order, test instrument serial numbers and calibration dates, and test limits.
 - h. Insulation Test. After all tests are completed, apply 2040 V ac, 60 Hz for 1 min between each electrical circuit and the frame. RTDs not under test are to be connected to the frame.
- 6. Stator Aging Test. Age the stator according to the procedure previously determined by the motorette tests (Section 5.3.1.1).
 - 7. Stator Irradiation Test. Irradiate the stator or apply the results of the motorette tests as required per IEEE-344-1975 (Ref. 5-3).
 - 8. Dielectric Overload Test. Conduct normal dielectric tests at 2/3 of twice rated voltage plus 1000 V ac for 1 min.

Following the above tests, the motor will be installed into the prototype auxiliary circulator assembly and tested as outlined in Section 5.3.1.3.

5.3.1.2.3. Instrumentation. The voltmeters, ammeters, Kelvin bridge, and Meggers used during the commercial tests will be within their calibration period and will have been calibrated with standards traceable back to the National Bureau of Standards. During the performance tests, the air flow pressure drops will be measured with a manometer. The temperature of the cooling air flow will be measured by thermocouples. When the first article motor control is used to power the motor, the panel-mounted meters on the control itself will be used to measure the applied voltage, current, and power.

5.3.1.2.4. Acceptance Criteria. The tests outlined in Subsection 5.3.1.2.2(1)&(2) are normal commercial production checks used by the manufacturer to verify the manufacturing process. If the motor fails any these tests, it will be reworked and retested until it passes.

The tests outlined in Subsection 5.3.1.2.2(3)&(4) are further production checks which are being conducted to establish a baseline for comparing all future production motors. If the measured data fall out of range of the theoretical values, this will indicate a potential problem. The data will be examined by the motor designers and appropriate corrective action taken.

The tests outlined in Subsection 5.3.1.2.2(5) are the true performance tests which the motor must pass to demonstrate design compliance. The unacceptable failures which could occur during this testing are as follows:

1. Insulation resistance and strength degradation below specified limits.
2. Mechanical failure of the rotor assembly.
3. Electrical failure of the rotor winding.
4. Any RTD failures.
5. Lead failures.
6. Exceeding the insulation temperature rating.
7. Failure to meet the torque-speed performance specification.
8. Excessive machine noise or unbalance.
9. Failure to meet the following criterion: the restriction to the cooling flow represented by the motor rotor and stator shall not

exceed 1.0 in. of water pressure differential at 3180 cfm total flow rate with 75°C, 14.7 psia air.

Any unacceptable functional or material degradation will be cause for corrective action and retest as necessary.

5.3.1.2.5. Status and Schedule. The first article motor tests at Westinghouse will commence in October 1975, with delivery to GA scheduled during January 1976. The test report is scheduled to be released in April 1976.

5.3.1.2.6. Design Alternatives. Any deficiencies determined by the test program will be corrected by suitable design and/or specification changes.

Final production hardware will consist of configurations that have demonstrated acceptable performance characteristics as indicated by the results of the test programs.

5.3.1.3. Prototype Auxiliary Circulator

5.3.1.3.1. Objective. The prototype auxiliary circulator qualification test will demonstrate the overall performance capability of the auxiliary circulator assembly during and following typical postulated reactor plant operating conditions. The margins in the design will be demonstrated.

5.3.1.3.2. Test Description. A series of qualification tests will be performed on a prototype auxiliary circulator. These tests will demonstrate operational capability as outlined in IEEE-334-1975 (Ref. 5-3). Testing will include normal no-load and load conditions up to full power and speed. Planned transients include simulation of the Design Basis Depressurization Accident (DBDA) conditions. Satisfactory aerodynamic, electrical, and mechanical performance will be established. Details of

typical auxiliary circulator performance tests are given below. After the prototype qualification tests, acceptance tests on all production auxiliary circulators will be carried out prior to shipment to the sites. A motor control unit will be installed in the test facility and qualified in conjunction with the prototype circulator. The same unit will be used for the production circulator acceptance tests.

The auxiliary circulator test facility will be located adjacent to the main helium circulator test facility, and common use will be made of test pits and the control area. Certain service systems will be connected with both facilities for contingency purposes.

The facility will be capable of testing all planned HTGR circulators at all reactor operational conditions of interest. Facility capability includes the following:

Type of helium loop.	Closed loop with Dowtherm cooler, electric heater, and modulating control restrictor valves
Prime mover.	900-hp variable speed electric motor
Power supply	Static frequency converter with 0 to 100% frequency modulation
Helium temperature	850°F
Helium pressure.	750 psia
Capability of testing auxiliary cooling loop shutoff valve	Yes
Capability of testing service modules concurrently with auxiliary circulator	Yes
Capability of producing full compressor map	Yes
Capability of testing during the rapid depressurization (DBDA) simulated accident conditions.	Yes

Capability of achieving the
reactor helium purity level (less
than 10 ppm impurities). Yes

Testing capability (single
helium vessel) 18 to 24 circulators per year

The performance characteristics test is described below:

1. Procedure

- a. Backfill the vessel with pure helium, establishing a density of 0.02 lb/ft^3 .
- b. Accelerate the circulator to maximum obtainable speed (3550 rpm at this density) with the loop flow restrictor valve wide open.
- c. Record data as described in item (2), below.
- d. Reduce flow by 10% by closing the loop flow restrictor valve, and record data as in item (2).
- e. Repeat step (d) until the loop flow restrictor valve is fully closed.
- f. Repeat steps (a) through (e) for speeds 80%, 60%, 40%, and 20% of the maximum obtained in step (b).
- g. Determine the loop flow restrictor valve position yielding the maximum power to the motor.
- h. Backfill the vessel with additional helium to establish a density of 0.05 lb/ft^3 .
- i. Set the loop restrictor valve to the position determined in step (g) and accelerate to the maximum obtainable speed for this gas density.

- j. Open the loop restrictor valve while maintaining speed and record data as described in item (2).
- k. Reduce flow by 10% and again record data as described in item (2).
- l. Repeat step (k) until the loop restrictor valve is fully closed.
- m. Repeat steps (k) and (l) for speeds of 80%, 60%, 40%, and 20% of the maximum obtained in step (i).
- n. Repeat steps (h) through (m) for densities of 0.1, 0.15, 0.20, and 0.25 lb/ft³.
- o. Note any conditions in step (m) under which the shutoff valve is not open. During any of these conditions, omit that portion of the test and proceed to the next condition.
- p. Remove all the helium from the vessel and backfill with nitrogen to a density of 0.07 lb/ft³.
- q. Repeat the circulator performance as described in steps (b) through (e) and repeat it again for speeds of 80%, 60%, 40%, and 20% of maximum.
- r. Repeat step (q) for densities of 0.15, 0.30, and 0.60 lb/ft³.
- s. Operate through various simulated plant transients including the DBDA (using IEEE-334-1975 requirements).
- t. Operate through the various conditions associated with the auxiliary shutoff valve tests (see Section 5.3.1.4).

2. Data to be Recorded

- a. Gas inlet pressure to circulator.
- b. Gas inlet temperature to circulator.
- c. Gas flow rate.
- d. Circulator speed.
- e. Circulator pressure rise.
- f. Circulator electrical power.
- g. Vessel heat rejection system flow rate.
- h. Vessel heat rejection system temperature rise.
- i. Restrictor valve position.
- j. Motor stator hot spot temperature, two each phase.
- k. Motor rotor gas inlet temperature.
- l. Bearing oil temperature.
- m. Motor casing vibration.
- n. Motor cooling water flow.
- o. Motor cooling water pressure drop.
- p. Motor cooling water temperature rise.
- q. Motor cavity buffer helium flow.

- r. Vessel helium purity.
- s. rms line voltage (line-to-line Δ stator; line-to-neutral Y stator).
- t. rms line current.
- u. Motor controller frequency.
- v. Motor stator insulation resistance to ground (after testing).

5.3.1.3.3. Instrumentation. All data will be measured utilizing appropriate instrumentation consistent with the parameters to be measured. The instruments are all state of the art and require no special techniques or procedures during operation. Instrument accuracies are described in the Qualification Test Specification.

5.3.1.3.4. Acceptance Criteria. Qualification of the auxiliary circulator will be based on the acceptance criteria as described in the Qualification Test Specification. The qualification specification is in preparation and is scheduled for final release in July 1976.

5.3.1.3.5. Status and Schedule. Prototype auxiliary circulator tests are scheduled to begin in November 1977 and continue through May 1978. These dates are later than previously reported mainly owing to delays in test facility construction. The test report is scheduled to be released in October 1978.

5.3.1.3.6. Design Alternatives. Any deficiencies determined by the test program will be corrected by suitable design and/or specification changes.

Final production hardware will consist of configurations that have demonstrated acceptable performance characteristics as indicated by the results of the test program.

5.3.1.4. CACS Shutoff Valve

5.3.1.4.1. Objective. Tests of the CACS shutoff valve will demonstrate the margin of conservatism of the design and the compatibility of the combined operation of the circulator and valve. Opening, closing, and operating characteristics will be determined.

5.3.1.4.2. Test Description. A production valve assembly will be installed in the GA auxiliary circulator test facility in a configuration duplicating the planned reactor geometry.

In order to predict the valve and compressor operating characteristics during multiloop operation in the reactor, a special test sequence will be established at the test facility. Since it is impossible to set up a multiloop operation in the single loop vessel, the test will be divided into two phases.

First, there will be an overall compressor performance determination as outlined in Section 5.3.1.3. During this phase, the compressor characteristics will be determined from the zero flow condition to the maximum flow for various speeds and gas conditions. From this information, plus the pressure drop across the valve and the gas conditions, the speed and power required to equalize the pressure difference across the valve can be predicted.

The test valve will have position indicators for each plate capable of monitoring any position from full closed to full open. Since each plate will be monitored, variations in their positions can be detected.

The second phase will be an extended series of tests on the valve. The differential pressure and circulator power required to open the valve and maintain it in different open positions will be determined. These tests will cover the range of full closed to full open valve positions for different gas conditions and will be repeated many times to allow a meaningful statistical determination of the valve characteristics.

From these two phases, the overall circulator and valve performance can be predicted. From the first series of tests, the pressure rise and circulator power required to overcome the differential pressure established by another circulator will be determined. Then the valve opening and closing performance data will enable prediction of the circulator speed and power required to initiate opening of the valve and maintaining it in the open position.

The valve performance characteristics test is described below:

1. Procedure

- a. Backfill the vessel with pure helium, establishing a density of 0.02 lb/ft^3 .
- b. Based on the compressor performance curves and the expected reactor operating flow resistance lines, set the loop flow restrictor valve to the required position.
- c. Slowly accelerate the compressor until the shutoff valve just opens, and record data as described in Section 5.3.1.3.2.
- d. Increase speed in 50-rpm increments until the shutoff valve is wide open, recording the speed and valve positions for each case and the data for the full open case.
- e. Decrease speed slowly until the valve starts to close, and record data.
- f. Decrease speed in 50-rpm increments, recording the speed and valve position for each increment, until the valve is fully closed. Record data for the valve fully closed condition.
- g. Repeat steps (c) through (f) 50 times.

- h. Repeat steps (c) through (g) for helium densities of 0.05, 0.1, 0.15, 0.20, and 0.25 lb/ft³.
- i. Repeat steps (c) through (g) for nitrogen densities of 0.07, 0.15, 0.30, and 0.60 lb/ft³.

2. Data to be Recorded

See Section 5.3.1.3.2.

5.3.1.4.3. Instrumentation. The instrumentation is the same as for the auxiliary circulator qualification tests (see Section 5.3.1.3.3).

5.3.1.4.4. Acceptance Criteria. Qualification of the auxiliary circulator shutoff valve will be based on the acceptance criteria as described in the Qualification Test Specification. The specification is in preparation and is scheduled for release in October 1975.

5.3.1.4.5. Status and Schedule. The status and schedule are the same as for the auxiliary circulator qualification tests (see Section 5.3.1.3.5).

5.3.1.4.6. Design Alternatives. Any deficiencies determined by the test program will be corrected by suitable design and/or specification changes.

Final production hardware will consist of configurations that have demonstrated acceptable performance characteristics as indicated by the results of the test program.

5.3.1.5. Auxiliary Circulator Electric Motor Drive Control. The test program for the auxiliary circulator electric motor drive control is a combined DV&S and Qualification Program.

5.3.1.5.1. Objectives. The objective of the test program is to demonstrate that the motor control meets design and performance specifications under normal and abnormal conditions. Design and specification

requirements are given in detail in Section 2 of Ref. 5-10. Those to be verified and subjected to qualification testing are described below:

1. Environment. The control is outside the radiation area, and there are no unusual environmental conditions other than the temperature and seismic requirements. The humidity requirement will not pose a problem because this equipment is always kept in an energized standby condition, and therefore its dew point will always be above ambient.

The temperature requirement states that the equipment must function during an abnormal condition when the dry bulb temperature is 120°F.

The seismic considerations require all components essential to the continued operation of the motor control to be designed to operate without damage due to simultaneous input of both horizontal and vertical OBE response spectra for a time duration equal to five combined OBEs (each of 30-sec duration). The components must also operate without loss of function due to simultaneous input of both horizontal and vertical SSE response spectra for a time duration equal to one SSE (40-sec duration).

2. Input power. The control is designed to operate under a degraded power network condition which would cause the input supply voltage to be minus 15% of its nominal value. If the input supply voltage drops below this value, the unit will initiate shutdown procedures to protect itself and then be capable of being restarted following restoration of normal conditions.
3. Power requirements. The control must regulate the speed of a 900-hp induction-type electric motor over a synchronous speed range from 216 to 3600 rpm to within $\pm 4\%$ at any point over the entire speed range under conditions of no change in input variable.

4. Effect on input power quality. The full load power factor of the control will be 0.8 or better.

The control will be designed to limit the transients reflected back to the input power system. Line transients will be limited to $\pm 10\%$ peak-to-peak (of the supply voltage), as measured on an oscilloscope.

The control system will be designed to limit the motor starting current, as viewed from the controls, to 100% full load plus current to provide acceleration torque.

5. Cubicle cooling. The control will be designed with forced air cooling and will consist of redundant fans, filters, and detectors.
6. Radiofrequency interference (RFI). The interference level limits will conform to MIL-STD-461A (Ref. 5-11), test method RE02 with 60-db relief and test method CE03 with 80-db relief.

5.3.1.5.2. Test Description. The test plan for the control is as follows. The seller is to carry out a test program and submit to GA for approval a program that demonstrates compliance with IEEE-323-1974 (Ref. 5-12) and IEEE-344-1975 (Ref. 5-13), where applicable. In addition, the program must contain provisions for demonstrating compliance with all special design specifications, with emphasis on performance, reliability, environmental, and seismic requirements. The seller-conducted performance tests will utilize the motor control and the motor, which will be loaded with a calibrated dynamometer to demonstrate that the system will perform to the design performance specifications. A reliability test will next be performed which will consist of 5 days of cyclic loading of the motor control to demonstrate its ability to withstand this stress. A seismic test will then be performed on the motor control while it is operating to demonstrate the unit's ability to perform its safety function during a seismic event.

Figure 5-1 presents all the steps in the qualification program. This figure will be used in this report as the base from which the relevance, order, scheduling, and status of the different steps of the program are given perspective.

The overall program calls for the seller to supply GA with the first article unit, which will be coupled with the first article motor and used in a qualification test consisting of three parts:

1. A test to measure the ability of the motor control to limit conducted and radiated RFI to those limits specified in Section 2.10 of Ref. 5-10.
2. A system test in which the motor control will power the first article motor, which will drive a compressor wheel within a helium environment and under simulated reactor gas/pressure conditions.
3. The ongoing use of the motor control to power each production auxiliary circulator assembly. This will further demonstrate the reliability of the motor control unit under the accelerated use conditions.

The control design verification tests (except seismic) will be conducted at the supplier's testing area in Buffalo, New York. The reliability tests and the combination motor and control tests for verifying the adequacy of motor performance (described in Section 5.3.1.2) will also be conducted at this site.

The control will then be shipped to the seismic test laboratory, where the control will be seismically tested. Because of the size and weight of this equipment, the input transformer/rectifier and inverter sections will be tested separately on a biaxial shake table.

*The specification contains the design and acceptability requirements, test plan, standards and codes compliance, and quality assurance requirements.

Fig. 5-1. Qualification program for auxiliary circulator electric motor drive control

The control will then be shipped to San Diego, where it will be installed in the circulator test facility in a manner similar to that used for installation in a nuclear power plant. Following installation, the RFI tests will be conducted per procedures of MIL-STD-461A, test methods RE02 and CE03. The control will subsequently power the auxiliary circulator during its qualification tests. The control will then be available to power all future production circulators during acceptance tests.

5.3.1.5.3. Instrumentation. Since the control test programs have not yet been prepared and approved, the control instrumentation to be used has not yet been identified. When test programs are submitted to GA for approval, GA will consider the suitability of the instruments suggested. The test programs are scheduled to be approved by September 1975, and the instruments involved will be reported in the next issue of the LTR-100 series.

5.3.1.5.4. Acceptance Criteria. The motor speed control must meet the design and specification requirements given in Section 2 of Ref. 5-10. Safety-related aspects of the program emphasize the performance and reliability characteristics of the control under normal and degraded network power supply conditions, environmental effects, and the ability of the unit to function properly during a seismic event.

A preliminary version of the acceptance criteria to be used during the seismic testing is given in Table 5-1.

5.3.1.5.5. Design Alternatives. Any deficiencies determined by the test programs will be corrected by suitable design and/or specification changes.

Final production hardware will consist of configurations that have demonstrated acceptable performance characteristics as indicated by the results of the test programs.

TABLE 5-1
ACCEPTANCE CRITERIA FOR CACS CIRCULATOR MOTOR CONTROL DURING SEISMIC TESTING

<u>Unacceptable Failures</u>	<u>Allowable Failures</u>	<u>Conditionally Acceptable Failures</u>
1. Input transformer	1. Input ammeter	1. Pre-charging supply during operation
2. Rectifier breaker failing open	2. Rectifier ammeter	2. Input breaker failing closed and no overload or overspeed trip required
3. Rectifier failure that faults all rectifier sections	3. Rectifier breaker failing closed	3. (Later) number of parallel inverter stages (number will depend on plant condition)
4. Inductor	4. dc bus voltmeter	4. Input breaker false trip and reclose except during initial cooldown
5. Inverter logic	5. Output voltmeter or ammeter	
6. Firing circuit	6. Reverse rotation sensor or indication	
7. All inverter stages	7. False indication of over-temperature, fuses blown, or fans off	
8. Output contactor open	8. Current limit circuit (rate settings of process control have similar effect)	
9. Overspeed trip on false signal	9. One-half of cooling fan system	
10. Both sets of redundant cooling fans	10. Portion of capacitor bank	
11. Input buffer	11. One phase to ground	
12. Wire, cable, or bus failure that faults components or functions of this column	12. Structural failure that faults components or functions of this column	
13. Structural failure that faults essential components or functions of this column		

5.3.1.5.6. Status and Schedule. The design review of the control system will be completed in May 1975, and production of the first article control will begin in August 1975. The design verification testing for loading and stressing the control is scheduled to be completed in October 1975. The combination motor and control tests are scheduled to be completed by November 1975. The seismic tests are scheduled to start in December 1975 and are expected to be completed by February 1976. The schedule for powering the first article auxiliary circulator during its qualification testing is given in Section 5.3.1.3.5.

All reports are scheduled to be released 6 months following the completion of testing.

All test plans as submitted by the supplier are currently under review by GA and will be published following their approval.

5.3.2. Main Helium Shutoff Valve

5.3.2.1. Objectives. These tests will demonstrate the adequacy of the valve designed for the large HTGR. The capability of the valve closure and sealing features will be confirmed.

5.3.2.2. Test Description. The qualification tests of the main shutoff valve and actuators are described below. Evaluation will include monitoring of valve performance during tests and disassembly and inspection of the valve and actuator.

The main shutoff valve qualification tests outlined in items (2), (3), and (4) below will be conducted in the GA circulator test facility in San Diego. The main circulator machine assembly, inlet, diffuser, and shutoff valve will be installed in a special (approximately 13 ft in diameter) test vessel. The main shutoff valve tests will be accomplished in conjunction with the design verification tests on the first production main circulator.

The present main circulator test facility will be capable of testing all planned 2000/3000 MW(t) HTGR circulators. The reactor vessel and all necessary operational characteristics will be simulated. The test facility capability includes the following:

Type of helium loop	Closed loop with Dowtherm cooler and modulating control restrictor valves
Type of steam loop.	Noncondensing superheated steam loop with makeup water injection
Steam conditions.	176,000 lb/hr of 726°F/128 psi steam
Prime mover, 800 hp	Electric-motor-driven steam compressor
Standby mode, prime mover, 250 hp . . .	Electric-motor-driven steam compressor
Type of steam loop control.	Throttle/bypass valve with surge control
Helium temperature.	100% rated (624°F)
Rotational speed.	100% rated (7120 rpm)
Steam temperature	100% rated (723°F)
Helium density.	20% rated
Helium pressure	20% rated (140 psia)
Steam compressor/prime mover (rated power).	8000 hp
Circulator steam turbine power.	22% rated (3700 hp)
Capability of testing primary coolant shutoff valve in helium (at design temperature).	Yes
Capability of testing bearing water module concurrently with circulator . .	Yes
Capability of producing full compressor and turbine maps	Yes
Circulator speed control system	By predialing desired rpm with automatic rpm rate increase
Electrical substation	1 each, 69 kV/4160 kV 1 each, 4160 kV/480 V
Testing capability (single helium vessel)	18 to 24 circulators per year

Specific main shutoff valve qualification tests include the following:

1. Actuator mechanism bench tests. A typical production actuator will be structurally tested by subjecting it to loads and dynamic conditions at least as severe as expected during reactor operation. The performance of the actuator will be demonstrated by operating the actuator through several times the number of operational cycles that would be expected during reactor operation.
2. Normal valve operation tests. During the main circulator endurance tests, the valve will be operated through 1000 open and closed cycles using the motor operator. The cycles will be performed in hot helium while actual main circulator stop and start sequences are simulated.
3. Failure of one motor operator test. Two of the three motor operators will be lowered all the way. Then the third actuator will be lowered using the secondary release solenoid, and the valve will be checked to determine that it is fully closed. This test will be conducted 20 times for each combination of actuators. The test will be conducted in hot helium with the main circulator at free spinning speed.
4. Valve closure with secondary releases. The valve will be dropped 100 times by simultaneously actuating the secondary release solenoids. The test will be performed in hot helium with the main circulator at free spinning speed.

The following data will be recorded:

1. Valve position.
2. Valve actuator motor voltage.
3. Valve release solenoid electrical continuity.
4. Valve closing time with actuator.
5. Helium temperature.

6. Helium pressure.
7. Circulator speed.

5.3.2.3. Instrumentation. All data will be measured utilizing appropriate instrumentation consistent with the parameter to be measured. The instruments are all state of the art and require no special techniques or procedures during operation.

5.3.2.4. Acceptance Criteria. Qualification of the primary coolant shutoff valve actuator will be based on the acceptance criteria as described in the Qualification Test Specification. The specification is in preparation and is scheduled for release in October 1975.

5.3.2.5. Status and Schedule. The actuator mechanism bench tests are scheduled to commence in February 1976. The complete valve performance qualification test is scheduled for completion in November 1976. The test report is scheduled to be released in May 1977.

5.3.2.6. Design Alternatives. Any deficiencies determined by the test program will be corrected by suitable design and/or specification changes.

Final production hardware will consist of configurations that have demonstrated acceptable performance characteristics as indicated by the results of the test program.

References

- 5-1. Tully, G. R., Jr., and G. L. Stiehl, Jr., "Safety-Related Research and Development Programs Cited in Section 1.5 of HTGR PSARs, Biannual Report for Period Ending July 31, 1974," General Atomic Report GA-A13183 (GA-LTR-101), November 15, 1974.
- 5-2. "SG and CAHE Corrosion-Erosion Tests," Specification No. TS-037, Issue B, September 27, 1974, General Atomic unpublished data.

- 5-3. "Trial Use Guide for Type Tests of Continuous Duty Class I Motors Installed Inside the Containment of Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-334-1975.
- 5-4. "Test Procedure for Evaluation of Systems of Insulation Material for AC Electric Machinery Employing Self-Wound Preinsulated Stator Coils," Institute of Electrical and Electronics Engineers Standard IEEE-275-1966.
- 5-5. "Guide for Statistical Analysis of Thermal Life Test Data," Institute of Electrical and Electronics Engineers Standard IEEE-101-1972.
- 5-6. "Standard Methods of Test for Dielectric Breakdown Voltage and Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies," ASTM.D149-64, American Society for Testing Materials, reapproved 1970.
- 5-7. "Preliminary Description of Representative Qualification Test Programs for HTGR Control and Electrical Equipment," General Atomic Report GA-A13392, March 31, 1975, Sections III.E and III.F.
- 5-8. "Guide for Testing Insulation Resistance of Rotating Machinery," Institute of Electrical and Electronics Engineers Standard IEEE-43-1961.
- 5-9. "Test Procedures for Polyphase Induction Motors and Generators," Institute of Electrical and Electronics Engineers Standard IEEE-112A-1964.
- 5-10. "Auxiliary Circulator Electric Motor Control," Document No. 900685, General Atomic unpublished data.
- 5-11. "Electromagnetic Interference Characteristics Requirements for Equipment," U.S. Department of Defense Document MIL-STD-461A, August 1, 1968.
- 5-12. "IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-323-1974.
- 5-13. "IEEE Recommended Practice for Seismic Qualification of Class IE Equipment for Nuclear Generation Stations," Institute of Electrical and Electronics Engineers Standard IEEE-344-1975.

6. PLANT PROTECTION SYSTEM ELECTRONIC MODULES

6.1. INTRODUCTION AND BACKGROUND

6.1.1. Introduction

All programs for Plant Protection System (PPS) electronic modules are Qualification Programs only.

The function of the PPS is to prevent an unacceptable release of radioactivity which would constitute a hazard to the health and safety of the public by initiating action to protect the fission product barriers and by initiating action to limit the release of radioactivity if failures occur in the barriers.

Qualification Programs will be performed on the electronic components of five PPS systems to demonstrate that the systems meet design requirements. Qualification of the components will serve as a basis for qualification of the systems. The PPS systems for which qualification demonstrations will be performed are:

1. Reactor trip system.
2. Steam generator isolation and dump system.
3. Main loop shutdown system.
4. CAHE isolation system.
5. Single rod withdrawal interlock system.

6.1.2. Background

The basis for qualification of a system can be achieved by qualification of the individual components or modules. Since the PPS systems listed above contain many common modules, qualification of each different module, to

meet the most severe criteria, provides a basis for qualification of the individual systems. Table 6-1 lists the systems and their associated modules and shows the grouping of modules by specifications containing similar components. In this report, the components are considered by the module specification (rather than individually for each system), and to relate a component to a system, or vice versa, the reader should refer to Table 6-1. Buffer-amplifiers were designated as a separate qualification item for this report. However, since they are a module common to all PPS electronic systems, they are reported in the same manner as the other modules.

The modules listed in Table 6-1 include all the equipment between the sensors and the input terminals of those actuation devices of the PPS systems that are involved in providing actions that lead to a function which provides protection to the public.

6.1.3. Definitions

6.1.3.1. Terminology. The electrical terminology of the nuclear industry used in this report is consistent with the terminology of IEEE-323-1974, IEEE-380-1972, and IEEE-100-1972 (Refs. 6-1, 6-2, 6-3).

6.1.3.2. Test Plan. A test plan outlines the testing to be conducted to demonstrate that the design and performance requirements of the procurement specification have been achieved.

6.1.3.3. Test Procedures. A test procedure gives a step-by-step outline of a test. It includes items such as test equipment descriptions, explanations of how parameters are controlled and measured, data recording procedures, etc. Test procedures are to be prepared by the organization conducting the tests that have been specified by the test plan. The content of test procedures is the subject of a section of a reference specification entitled "Purchase of Safety Related Instrumentation, Control and Electrical Equipment" (Ref. 6-4).

TABLE 6-1
PPS SYSTEMS AND MODULES

PPS System					Module	Item No.	Spec.
Reactor Trip	S.G. Isolation and Dump	Main Loop Shutdown	CAHE Isolation	Single Rod Withdrawal Interlock			
X	X	X	X	X	Buffer type 1	001	900991, buffer modules
X	X	X	X		Buffer type 2	002	
X	X	X	X		Buffer type 3	003	
		X			Bistable trip type 1	001	900992, bistable trip modules
X					Bistable trip type 2	002	
X					Bistable trip type 3	003	
X		X			Bistable trip type 4	004	
X					Bistable trip type 5	005	
X					Bistable trip type 6	006	
X	X				Reactor trip 2/3 logic trip detection	001	900994, PPS logic modules
X					Type 1 2/3 logic trip detection	002	
					Type 2 2/3 logic trip detection	003	
		X	X		Main loop shutdown	004	
		X			Main loop manual shutdown	005	
			X		CAHE isolation control	006	
		X			CPP/CACS manual initiation	007	
				X	Control rod withdrawal control	008	
X					Reactor trip relay power control	009	
X					Reactor trip logic	010	
					PCRVR relief block valve interlock control	011	
		X			CACS initiation	012	
	X				Dump control	013	

TABLE 6-1 (Continued)

PPS System					Module	Item No.	Spec.
Reactor Trip	S.G. Isolation and Dump	Main Loop Shutdown	CAHE Isolation	Single Rod Withdrawal Interlock			
	X		X		CAHE isolation valve control	001	901586, PPS valve control modules
		X			Dump valve control	002	
					Helium shutoff valve release actuator	003	
		X			Trim valve control	004	
		X			Hydraulic valve control, type 1	005	
		X			Hydraulic valve control, type 2	006	
		X			Primary coolant shutoff valve	007	
X	X	X	X		Analog test module	001	901557
	X	X	X		Digital test module	001	901558
X	X	X	X	X	Power supply		901618
X					Primary coolant flow measurement (several types of modules in a drawer)		902392
X		X			I/E converters		902311, special purpose modules
X					Instrument isolation switch module		
		X			Feedwater flow averager		
		X			Steam generator inlet temp averager		
		X			Primary coolant flow averager		

6.1.3.4. Design Report/Qualification. The Design Report/Qualification is a controlled document containing all pertinent information for equipment qualification. It includes information such as procurement specifications, test plans, test procedures, test results, stress analysis, ongoing qualification, and a final summary report. A final summary report will be published at the conclusion of each module test program.

6.2. OBJECTIVE

The objective of all the programs involving PPS electronic modules is to qualify the modules, and hence the PPS systems in which they are used, for use in all large HTGRs. Qualification is defined as "demonstration that equipment meets design requirements" and will comply with IEEE-323-1974 (Ref. 6-1) and with special environmental, seismic, and operational requirements.

6.3. SUMMARY OF PRESENT STATUS OF QUALIFICATION PROGRAMS

Specifications for the modules and their status are tabulated below:

	<u>Specification</u>			<u>Test Plan</u>
	<u>Number</u>	<u>Issue</u>	<u>Status</u>	<u>Status</u>
Buffer modules	900991*	C	Complete	Complete
Bistable trip modules	900992*	A	Complete	**
Logic modules	900994*	A	In release cycle	**
PPS valve control modules	901586*	A	Complete	**
Analog test module	901557*	A	Complete	**
Digital test module	901558		Being prepared	--
Power supply	901618		Being prepared	--
Primary coolant flow measurement	902342		Due July 1976	--

*References 6-5 through 6-9.

**A formal test plan has not been written for this module but the specification contains the base for the plan.

	<u>Specification</u>			<u>Test Plan Status</u>
	<u>Number</u>	<u>Issue</u>	<u>Status</u>	
Special purpose modules	902331		Due August 1976	--
I/E converters				
Instrument isolation switch module				
Feedwater flow averager				
Steam generator inlet tem- perature averager				
Primary coolant flow averager				

6.4. TEST FACILITY

The vendor of each module is to specify the test facility in his program plan, which is to be approved by GA. No test facilities have yet been designated, but it is presently planned that all the testing except the seismic excitation will be done in the GA electronics manufacturing facility. The seismic testing will probably be done at one of a number of suitable sites, such as Wyle Laboratories.

6.5. SCHEDULE

6.5.1. Test Schedule

As indicated in Table II in the Summary of this report, the start and finish dates for the nine electronic module qualification programs cover a period beginning in early 1975 and ending with the completion of the last module type in the first quarter of 1978.

6.5.2. Report Schedule

The status and progress of each module qualification program will be reported every 6 months in future editions of the LTR-100 series. At the end of each program, a final report will be issued (see Section 6.1.3 and Table II).

6.6. DESIGN ALTERNATIVES

If any unit tested does not meet all design specification performance requirements, the vendor will be required to alter the module until it meets specification or until the vendor can demonstrate that the deficiency lies in the design concept. In the latter event, more conventional means of implementing the required functions will be used. For the buffers, this could include relay isolation or other similar techniques. For the other modules, a more conventional solid-state logic family could be selected to replace the Complementary Metal Oxide Semiconductor (CMOS) logic currently specified.

6.7. INDIVIDUAL PROGRAM SUMMARIES

6.7.1. Buffer Modules

6.7.1.1. Application to PPS Systems. Buffer modules are used in the reactor trip system, the steam generator isolation and dump system, the main loop shutdown system, the CAHE isolation system, and the single rod withdrawal interlock system.

6.7.1.2. Design and Specification Requirements. Buffering devices are used in extracting signals from PPS equipment for monitoring and display functions while isolating the equipment from faults that may occur in non-PPS equipment. Buffering devices are also used for certain internal functions within the PPS systems.

The modules are Class IE, QAL I, and Seismic Category I (Ref. 6-10). Detailed design specifications are given in Ref. 6-5. There are three types of buffer modules:

1. Buffers, Analog, Type 1 (Top Assembly Dwg. No. ELD 327-0000-1). These solid-state devices will be used for analog signal transfer from PPS instrumentation to monitoring and display equipment in other systems. Each double-width NIM module will contain four separate buffer amplifiers and an associated power supply unit.

2. Buffers, Digital, Type 2 (ELD 327-1000-1). These solid-state devices will be used to isolate digital signals that travel between PPS systems or logic channels within the boundary of the PPS, as well as for digital signal transfer to other systems from the PPS. Each single-width NIM module will contain 12 separate digital buffer circuits and a common dc-to-dc converter isolation power supply.
3. Buffers, Digital, Type 3 (ELD 327-1000-2). These devices will be used primarily for digital signal transfer to the data acquisition and processing system from the PPS. Each single-width NIM module will contain 12 separate digital buffer circuits.

Buffer modules will be designed so that there is electrical isolation between input and output, and no failure mode of the buffer will provide an electrical path between input and output that is not detectable by testing.

Buffer modules will be designed to function without any in-service adjustments.

Buffer module calibration will be performed by removing the module containing the buffer from service. Buffer modules will be designed to function without calibration for a minimum of 3000 hr.

Buffer modules will be capable of on-line replacement in less than 1 min.

Buffer modules will be capable of operation without any on-line maintenance.

Buffer modules will be designed so that they can be periodically tested to comply with the following requirements of IEEE-336-1971 (Ref. 6-11):

1. Testing the operation availability with the buffer module in the control board.
2. Testing the input and output isolation with the buffer module removed from the control board.

Buffer modules will be designed to warm up in less than 1 min.

Buffer modules will be designed for continuous operation in the plant control room and reactor service building locations, under the humidity, pressure, radiation, and temperature conditions given in Ref. 6-12.

The equipment will be mounted in an instrument board which will have an internal temperature range of 60° to 104°F during normal plant conditions and 40° to 120°F during specified upset/emergency/faulted plant conditions.

6.7.1.3. Test Plan. The general specification (Ref. 6-5) requires the seller to perform or have performed tests in accordance with a buyer-approved test procedure prepared by the seller in full compliance with IEEE-323-1974 (Ref. 6-1) and IEEE-344-1971 (Ref. 6-13). Test procedures are to be submitted to the buyer for approval at least 8 weeks prior to planned testing.

A test plan for buffer modules has been prepared (Ref. 6-14). In addition, the design specification for buffer modules (Ref. 6-4) contains a table (Table 6-2 of this report) relating the various requirements for the module to five general specifications (Refs. 6-4, 6-10, 6-12, 6-15, 6-16). Many of the items labeled "No" in this table are quality assurance (QA) functions covered in QA procedures and are not discussed in this report.

The objective of the tests in the test plan is to demonstrate the operability of each buffer type before, during, and after application of expected seismic, temperature, atmospheric pressure, and humidity conditions

TABLE 6-2
SUPPLIER REQUIREMENTS FOR SAFETY-RELATED INSTRUMENTATION, CONTROL, AND ELECTRIC EQUIPMENT

Description	900300 Purchase Specification		900304 Seismic Specification		900305 Gen'l Reqmts Specification		900307 Qualification Specification		900763 Environmental Specification	
	Reqd	Section	Reqd	Section	Reqd	Section	Reqd	Section	Reqd	Section
Normal operating conditions							Yes	3.2.5	Yes	3.1
Upset/emergency/ faulted conditions							Yes	3.2.6	Yes	3.2
Malfunction/design limit conditions							Yes	3.2.8	Yes	3.3
Storage conditions					Yes	3.2.11			Yes	3.4
Radiation tests and conditions							No	3.2.7	No	3.5
Requalification test							Yes	3.4		
Quality assurance requirements	No	5.2					No	4.1		
Test procedures	No	5.3.1					No	5.1.1		
Test reports	No	5.3.2					No	5.1.2		
Certificate of compliance	No	5.3.2								
Inspection report	No	5.4.1								

TABLE 6-2 (continued)

Description	900300 Purchase Specification		900304 Seismic Specification		900305 Gen'l Reqmts Specification		900307 Qualification Specification		900763 Environmental Specification	
	Reqd	Section	Reqd	Section	Reqd	Section	Reqd	Section	Reqd	Section
Operation and maintenance manual	Yes	5.5								
Performance specification	Yes	5.6								
Workmanship manual/reqmts	No	5.7	No	3.10						
Spare parts list	No	5.8								
Equipment logging	Yes	5.9	Yes	3.2.9						
Cleaning specification	Yes	5.10	Yes	3.10.6						
Material certification	Yes	5.11	No	3.2.7						
Eqpt or module assembly drawing	Yes	5.12.1								
Schematic diagram	Yes	5.12.3.1								
Interconnection wiring diagram	No	5.12.3.1								
Connection wiring diagram	No	5.12.3.1								

TABLE 6-2 (continued)

Description	900300 Purchase Specification		900304 Seismic Specification		900305 Gen'l Reqmts Specification		900307 Qualification Specification		900763 Environmental Specification	
	Reqd	Section	Reqd	Section	Reqd	Section	Reqd	Section	Reqd	Section
Packing and shipping procedure	Yes	6.	Yes	3.2.11.1						
Unpacking instructions	Yes	6.3.2								
Seismic mathematical analysis					No	3.2				
Seismic equipment testing					Yes	3.3			Yes	3.6
Seismic fragility test					Yes	3.4				
Enclosures			Yes	3.1						
Cable			No	3.2.1						
Contact ratings			No	3.2.2						
Fuses and circuit breakers			No	3.2.3						
Indicator lamps			No	3.2.4						
Instruments			No	3.2.5						

TABLE 6-2 (continued)

Description	900300 Purchase Specification		900304 Seismic Specification		900305 Gen'l Reqmts Specification		900307 Qualification Specification		900763 Environmental Specification	
	Reqd	Section	Reqd	Section	Reqd	Section	Reqd	Section	Reqd	Section
Terminals			No	3.2.6						
Nameplates			Yes	3.2.8						
Wireways			No	3.2.10						
Grounding/shielding/ electric noise			Yes	3.3						
Calibration			Yes	3.4						
Power quality			Yes	3.5						
Reliability			Yes	3.6						
Standardization			Yes	3.7						
Protection of equipment			Yes	3.8						
Safety of personnel			Yes	3.9						

specified for the installation location under both normal and abnormal conditions. Margin for design specification requirements will be demonstrated for seismic and temperature effects.

Two units of each of the three buffer types will be tested. Prior to qualification tests, the units will be QA inspected, functionally tested, burned in, and calibrated. The test units will be mounted in a standard NIM bin in a manner simulating expected installation conditions as closely as possible.

To simulate aging, buffers will be subjected (non-operating) for 30 days to a temperature of 150° to 158°F and a humidity of 50% to 100%. At least five times during this aging cycle, the modules will be removed from the test environment and tested at normal ambient conditions.

For simulated service conditions, the modules will be tested to expected normal (60° to 104°F, 10% to 90% RH) and abnormal (40° to 120°F, 10% to 90% RH) temperature and humidity conditions. Alternating current power quality tests (rated voltage $\pm 10\%$, normal; and $+15\%$, -25% for 15 sec, abnormal) will also be conducted on the analog buffers. In addition, tests will be run at higher temperatures (130° and 140°F) to assess the degree of design margin.

Seismic testing will be performed on the NIM-bin-mounted buffer modules. Biaxial broadband excitations will be applied to the equipment mounted on a shake table with the actual input spectrum tailored by required response spectra for the OBE and SSE given in Ref. 6-10. Buffer performance will be monitored before, during, and after the seismic excursions. Fragility tests will also be run up to response spectra zero period acceleration levels of 12, if electrical malfunction or physical damage has not occurred at lower levels. These fragility tests will provide a reasonable assurance of design margin.

6.7.1.4. Acceptance Criteria. All three types of buffers must be capable of isolating their outputs from their inputs for the following output fault conditions:

1. Short circuit across output terminals.
2. Short to ground.
3. Open circuit.
4. Application of ± 1000 V dc from output to input, across the output terminals, or from output high to chassis ground.
5. Application of 120 V ac from output low to input low, across the output terminals, or output high to chassis ground.

In items (4) and (5) above, application of voltage across the output terminals may destroy the buffer output circuitry but must not disturb the output-to-input isolation characteristics.

For type 1 buffers, the isolation must be sufficient to prevent the source of input signal or any other input signal from deviating by more than 0.2% of input voltage span under fault conditions given in items (1) through (5).

For type 1 and 2 buffers, the listed output fault conditions must not cause the input signal, or any other input signal, to deviate by more than 2.0 V.

All three types of buffers must be capable of isolating their outputs from their inputs for the following input fault conditions:

1. Short across input terminals.
2. Short to ground.
3. Open circuit.

4. Application of ± 1000 V dc from output to input, across the input terminals, or from input high to chassis ground.
5. Application of 120 V ac from output to input, across the input terminals, or from input high to chassis ground.

In items (4) and (5) above, the application of voltage across the input terminals may destroy the input circuitry to some degree but must not disturb the input-to-output isolation characteristic.

For type 1 buffers, the input faults listed above must not cause the output signal, or any other output signal, to be less than the negative internal power supply voltage or greater than the positive internal power supply voltage.

For type 2 and 3 buffers, the input faults listed above must not cause the output signal, or any other output signal, to be less than zero volts or more than the positive supply voltage to the buffer.

The foregoing description of the test plan and associated criteria considers the safety-related aspects of the buffer and omits performance characteristics such as accuracy, linearity, stability, drift, etc., which are also required and specified. It also does not include a test sequence laid out in the test plan.

In the context of the test plan, failure is defined as the inability of any buffer channel within a module to perform its required function within the environmental and performance characteristic constraints designated.

6.7.2. Bistable Trip Modules

6.7.2.1. Application to PPS Systems. Bistable trip modules are used in the PPS reactor trip system and the PPS main loop shutdown system.

6.7.2.2. Design and Specification Requirements. The design and specification requirements for the bistable trip modules are detailed in Ref. 6-6. The bistable trip modules accept analog voltage or current signals from field sensors or signal conditioners and convert these signals into digital signal level information for use in their associated logic systems. In addition, the bistable trip modules transmit analog and digital information to buffer modules. They are Class IE, QAL I, and Seismic Category I (Ref. 6-10).

Bistable trip modules are designed for continuous operation in the plant control room, under the humidity, pressure, radiation, and temperature conditions specified in Ref. 6-12. Logic output is required to change state in 0.5 msec or less from the time the input signal exceeds the setpoint by 1.1X (where X is the setpoint) over the entire range of the setpoint. The input voltage at which the bistable changes state is to remain constant to $\pm 0.25\%$ at full-scale input for any setpoint and over the temperature range specified for a minimum of 3000 hr. The equipment is to be designed for a useful life of 40 yr. Maintenance may be performed when necessary.

There are six different types of bistable trip modules, which differ primarily in the type of signal input and in the number and type of output signal. The six module types are described below:

Type 1 (Part No. 19101-001). The bistable trip module (018550 I&L Diagram, PPS - General Bistable Trip Module) accepts either a 0- to 10-V or a 4- to 20-ma input signal and, upon reaching a predetermined setpoint, causes the associated logic signals to change state. The digital signal level information is then fed to the appropriate logic systems or channels. In addition, type 1 bistable trip modules transmit one analog signal and one digital signal to associated buffer modules.

Type 2 (Part No. 19101-002). The bistable trip module (015835 I&L Diagram, PPS Type 2 Bistable Trip Module) accepts a 0- to 10-V input

signal and, upon reaching a predetermined setpoint, causes the associated logic signals to change state. The digital signal level information is then fed to the appropriate logic system. In addition, type 2 bistable trip modules transmit one analog signal and two digital signals to associated buffer modules.

Type 3 (Part No. 19101-003). The bistable trip module (018551, I&L Diagram, PPS - Helium Flow Programming Bistable Trip Module) accepts a 0 to 10-V input signal and, upon reaching a predetermined setpoint, causes the associated logic signal to change state. The digital signal level information is then fed to the appropriate logic systems or channels. In addition, type 3 bistable trip modules transmit one analog signal to an associated buffer module.

Type 4 (Part No. 19101-004). The bistable trip module (015836 I&L Diagram, PPS Type 4 Bistable Trip Module) accepts either a 0- to 10-V or a 4- to 20-ma input signal and, upon reaching either (or both) of the predetermined setpoints, causes the associated logic signals to change state. The digital signal level information is then fed to the appropriate logic system or channel. In addition, type 4 bistable trip modules transmit one analog signal and two digital signals to associated buffer modules.

Type 5 (Part No. 19101-005). The bistable trip module (015837 I&L Diagram, PCRVP Pressure Bypass Bistable Trip Module) accepts a 0- to 10-V input signal and, upon reaching a predetermined setpoint, causes the associated logic signal to change state. The digital signal level information is then fed to the appropriate logic system. In addition, the type 5 bistable trip modules transmit one digital signal to an associated buffer module.

Type 6 (Part No. 19101-006). The bistable trip module (018552 I&L Diagram, PPS - Steam Generator Helium Inlet Temperature Bistable Trip Module) accepts a 0- to 10-V input signal and, upon reaching a programmed setpoint, causes the associated logic signals to change state.

The digital signal level information is then fed to the appropriate logic system. In addition, type 6 bistable trip modules transmit one analog signal and one digital signal to associated buffer modules.

6.7.2.3. Test Plan. A formal test plan has not yet been prepared for these modules. Specification 900992 (Ref. 6-6) contains the following test requirements relevant to performance or safety:

1. General requirements. The seller will perform or have performed tests in accordance with a buyer-approved test procedure prepared by the seller. Test procedures will be submitted to the buyer for approval at least 8 weeks prior to planned testing.
2. Design compliance testing. The design compliance testing will be performed with the first article and will include any tests that are required to indicate that the performance and construction comply with the specified design requirements, referenced drawings, and associated data sheets.
3. Logic operations. Tests will be performed to demonstrate that all logical operation requirements are satisfied with the bistable trip module in the untripped and tripped conditions. Inhibit of bistable trip conditions will be verified where applicable.
4. Analog controls. Operation of all controls and indicators (both internal and external) will be verified over the specified ranges or conditions.
5. Input/output signals. Input and output analog signal characteristics will be determined to verify correct operation within the correct signal ranges.

Table 6-2, which lists the sections of five general specifications to which the buffer modules must be tested, also applies to bistable trip

modules. The environmental tests and test criteria, for both operating and seismic conditions, are the same as those described for the buffer module.

6.7.2.4. Acceptance Criteria. The acceptance criteria for bistable trip modules are separated into four categories: (A) operating characteristics, (B) adjustable controls, (C) switches, and (D) indicators. Requirements for each of these categories are given below:

A. Operating Characteristics

1. Inputs. For all bistable trip modules, each type of input signal described below will have the specified characteristics defined.

4-20 ma Input Signal. Differential input operating in the ungrounded mode, input impedance 50 ohms minimum and 150 ohms maximum, common mode rejection 80 dB minimum, common mode voltage +65 V dc.

4-20 ma Test Signal. Differential input operating in the ungrounded mode, input impedance 50 ohms minimum and 150 ohms maximum, common mode rejection 80 dB minimum, common mode voltage +65 V dc.

0-10 V Input Signal. Differential input operating in the ungrounded mode, input impedance greater than or equal to 100 ohms, common mode rejection 90 dB minimum, common mode voltage +15 V dc.

0-10 V Test Signal. Differential input operating in the ungrounded mode, input impedance greater than or equal to 100 ohms, common mode rejection 80 dB minimum, common mode voltage +15 V dc.

Test Selection Control Signal. Control relay energized by high signal (interface circuitry acceptable if required), high 9 to 12 V, low 0 to 3 V, input impedance one standard CMOS load.

Logic Level Input Signal. High 9 to 12 V, low 0 to 3 V, input impedance one standard CMOS load.

2. Outputs

0 to 10-V Output Signal to Analog Buffer. Maximum drive capability 1 ma, linearity $\pm 0.25\%$ of full-scale input relative to the input signal applied to the bistable trip module input.

Logic Level Output Signal. High 9 to 12 V, low 0 to 3 V, capable of driving 50 standard CMOS loads.

3. Response Time. For all bistable trip modules, logic outputs will change state in less than or equal to 0.5 msec from the time the input signal exceeds the setpoint by $1.1X$ (where X is the setpoint) over the entire range of the setpoint.
4. Trip Point Stability. For all bistable trip modules, the input voltage at which the bistable changes state will remain constant to within $\pm 0.25\%$ of full-scale input for any setpoint and over the temperature range specified for the duration of the tests.
5. Linearity. Analog outputs to buffer modules must demonstrate a maximum drive capability of 1 ma, with linearity to within $\pm 0.25\%$ of full-scale output relative to the input signal applied to the bistable trip module input.

6. Logical Operations. Tests will be performed to confirm that all logical operation requirements are satisfied with the bistable trip module in the untripped and tripped conditions. Inhibit of bistable trip conditions will be verified where applicable.

B. Adjustable Controls

1. Hysteresis Adjustment. Bistable trip modules will have an internally mounted control to allow a hysteresis adjustment of 10% of full scale or less. Operation of this control over its entire range will be verified during testing.
2. Trip Point Setting. Bistable trip module trip point settings will be verified as adjustable from 1% to 100% of the full-scale input range.
3. Zero and Span Adjustments. Any zero and span adjustments will be verified over their entire range.

C. Switches

All switch operations defined below will be verified during testing.

1. Manual Trip Switch. This front panel switch trips the bistable when depressed, illuminates the "Manual Trip" light, and holds the trip condition until reset.
2. Output Test Switch. This front panel switch momentarily clears a bistable trip caused by energization of a trip control relay, which is necessary to perform a complete analog test of the bistable trip module.

3. Reset Switch. This front panel switch performs the following functions (assuming the tripped parameter has returned to normal operating range):
 - a. For a bistable trip module in the latch mode, it returns logic outputs to the untripped condition and extinguishes and reset lights.
 - b. For a bistable trip module in the nonlatch mode, it extinguishes the reset light.
4. Latching Switch. This internally mounted switch performs the following functions:
 - a. For the latch mode, it holds the bistable trip module in the tripped condition until the tripped parameter has returned to the normal operating range and the reset switch has been depressed.
 - b. For the nonlatch mode, the bistable trip module will return to the untripped condition as soon as the tripped parameter has returned to the normal operating range.
5. Test Control Input Switch. When energized, this switch disconnects normally utilized analog input signal lines and connects analog signal lines from the analog test module.

D. Indicators

Correct functioning of all indicators will be verified during testing.

1. Manual Trip Light (Red). This light, which is part of the manual trip switch assembly, illuminates when a manual trip is activated.

2. Inhibit Light (Red). This light, which is part of the manual trip switch assembly, illuminates when an inhibit signal is present and blocking bistable trip action.
3. Bistable Tripped Light (Red). This light, which is part of the reset switch assembly, illuminates when a bistable trip module is tripped for any reason.
4. Reset Light (Yellow). This light, which is part of the reset switch assembly, illuminates when a bistable trip module has been tripped (see Reset Switch, above).
5. Indicators (color as specified on reference drawings). These are single or split screen indicators for various functions.
6. Meters. These front panel meters display analog information on parameters being measured. In all cases, a meter is driven by a 0 to 10-V signal.

6.7.3. PPS Valve Control Modules

6.7.3.1. Application to PPS Systems. The PPS valve control modules are used in the steam generator isolation and dump system, the main loop shutdown system, and the CAHE isolation system.

6.7.3.2. Design and Specification Requirements. The design and specification requirements for the PPS valve control modules are detailed in Ref. 6-8. The modules are designed for continuous operation in the control room during normal/upset/emergency/faulted plant conditions. They are Class IE, QAL I, and Seismic Category I per Ref. 6-10.

Seven different types of valve control modules are used in the PPS systems cited above. Their functions range from providing a simple "close"

valve" signal to the control of an electrically operated valve with three motors. A brief description of the function of each of the seven control modules is given below:

Type 1 (Part No. 019372-001). The PPS CAHE isolation valve control module generates a close valve signal for an electro/hydraulically actuated valve. The close valve signal is generated after either of two externally generated close signals is received. The close signal remains on until an externally generated open valve signal is received.

Type 2 (Part No. 019372-002). The PPS dump valve control module generates an open valve signal for an electro/hydraulically actuated valve. The open valve signal is generated after either of two externally generated open signals is received. The open signal remains on until an externally generated close valve signal is received.

Type 3 (Part No. 019372-003). The PPS helium shutoff valve release actuator module generates a drive mechanism release signal for a helium shutoff valve. The release signal is generated in response to any of four externally generated release signals.

Type 4 (Part No. 019372-004). The PPS trim valve control module generates a close valve operation signal for a modulating valve, which is otherwise controlled by an analog signal from the overall plant control system. The close signal is generated in response to any one of four externally generated close signals. The close signal remains on until an externally generated reset-to-normal control signal is received.

Type 5 (Part No. 019372-005). The PPS hydraulic valve control module, Type I, generates a close valve signal for an electro/hydraulically actuated valve, which is otherwise controlled by an open/close signal

from the operational protection system. The close signal remains on until an externally generated open control signal is received.

Type 6 (Part No. 019372-006). The PPS hydraulic valve control module, Type II, generates a close valve signal for an electro/hydraulically actuated valve, which is otherwise controlled by an open/close signal from the operational protection system. The close signal is generated upon receiving any one of four externally generated close signals. The close signal remains on until an externally generated open control signal is received.

Type 7 (Part No. 019372-007). The motor drive control module for the PPS primary coolant shutoff valve switches forward- and reverse-drive electrical circuits to fully close, 10% close, latch, or open an electrically operated valve. This valve has three motors, each with four position detectors which generate signals to open the motor circuits when the selected opening is achieved. The latch position is past the fully closed position and is used to mechanically engage the valve drive mechanism.

6.7.3.3. Test Plan. A formal test plan and acceptance criteria have not been prepared for these modules. However, specification 901586 (Ref. 6-8) contains the basis for the test plan outlined below.

The seller is required to prepare a test plan and test procedure and, after approval by GA, to perform or have performed the tests agreed upon.

Design compliance testing will be conducted on the first article and will include the following tests and any other tests needed to show that the performance and construction requirements are met:

1. Logical operations tests which indicate that all logical operations requirements are satisfied.

2. Input/output signal tests of input signal characteristic limits, including threshold voltages, common mode rejection, and switch contact bounce effects as applicable, to verify correct operation within the specified values. The voltages of all output signals will be measured under the specified load conditions to verify correct operation within the specified signal values.

Parts of five general reference specifications are used to closely define the test requirements of the valve modules. Table 6-2 lists the sections of each of these general specifications that apply to the different aspects of the valve module specification. The environmental tests and test criteria, for both operating and seismic conditions, are the same as those described for the buffer module.

6.7.3.4. Acceptance Criteria. Functional acceptance criteria will be supplied in the next issue of the LTR-100 series.

6.7.4. PPS Logic Modules

6.7.4.1. Application to PPS Systems. PPS logic modules are used in the reactor trip system, the steam generator isolation and dump system, the main loop shutdown system, the CAHE isolation system, and the single rod withdrawal interlock system.

6.7.4.2. Design and Specification Requirements. The design and specification requirements for the PPS logic modules are detailed in Ref. 6-7. Fourteen different types of modules are used in the five PPS systems cited above. The logic modules accept digital signals from other modules and switches and combine these signals in specific patterns to generate certain functional logic signals used to control valve control modules, control rod power supplies, and other equipment. In addition, the logic modules transmit digital information to buffer modules. The modules include such features as 2-out-of-3 logic, 1-out-of-6 inputs to activate a system, and complex conditional inputs with multiple varied outputs.

Logic modules are designed for continuous operation in the plant control room under the humidity, pressure, radiation, and temperature conditions specified for that location. The modules are Class IE, QAL I, and Seismic Category I per specification 900304.

Logic modules utilized in the reactor trip section of the PPS utilize "hindrance logic." The failure mode provides action on loss of power, module removal or replacement, or loss of circuit continuity. Removal of a logic module from the system changes the logic state of any signals to other downstream modules interfaced to the removed module.

A brief description of the function of each of the 14 modules is given below:

Type 1 (Part No. 020175-001). This module (I&L Diagram 018809, PPS - Reactor Trip 2-out-of-3 Logic Trip Detection Module) accepts three logic level input signals. When two or three of these inputs change state, the module outputs change state. Each of the three logic inputs may be manually tripped by means of a front panel switch.

Type 2 (Part No. 020175-002). This module (I&L Diagram 018810, PPS - Type 1, 2-out-of-3 Logic Trip Detection Module) accepts three input signals. When two or three of these inputs change state, the module outputs change state. Each of the three logic inputs may be manually tripped by means of a front panel switch.

Type 3 (Part No. 020175-003). This module (I&L Diagram 018811, PPS - Type 2, 2-out-of-3 Logic Trip Detection Module) accepts three logic level input signals. When two or three of the inputs change state, the module outputs change state. Each of the three logic inputs may be manually tripped by means of a front panel switch or pulse tested from an associated digital test module.

Type 4 (Part No. 020175-004). This module (I&L Diagram 018842, PPS - Main Loop Shutdown Module) accepts six logic level input signals.

When one of these inputs changes state, the module outputs change state.

Type 5 (Part No. 020175-005). This module (I&L Diagram 018843, PPS - Main Loop Manual Shutdown Module) accepts one input from a manual shutdown handswitch. Upon receipt of a shutdown signal, the output signal of this module changes state.

Type 6 (Part No. 020175-006). This module (I&L Diagram 018844, PPS - CAHE Isolation Control Module) accepts a logic level input from a Type 2, 2-out-of-3 logic module. When the input changes state, the module outputs change state. The trip action is inhibited when a lockout signal from another loop is present. A manual isolate input will cause a trip whether a lockout signal is present or not.

Type 7 (Part No. 020175-007). This module (I&L Diagram 018845, PPS - CPP*/CACS Manual Initiation Module) accepts input signals from two remote switches. Sequential depression of these two switches will cause the module outputs to change state, generating trip signals. Both input signal lines may be pulse tested from an associated digital test module.

Type 8 (Part No. 020175-008). This module (I&L Diagram 018846, PPS - Control Rod Withdrawal Control Module) accepts 13 logic level inputs. When two or more of these inputs change state, the outputs (14 through 16) change state. Clearing of the tripped condition returns outputs 14 and 15 to the untripped state. Output 16 remains in the tripped state until the reset switch is depressed. A front panel test switch is available for trip testing various combinations of the input signals.

Type 9 (Part No. 020175-009). This module (I&L Diagram 018847, PPS - Reactor Trip Relay Power Control Module) accepts a logic level input

*Containment Pressure Protection.

signal from the reactor trip 2-out-of-3 logic trip detection module. When the logic level input changes state, the two output signals change state and deenergize the associated reactor trip relays. Depressing the associated manual reactor trip switch opens the input signal line to this module, causing the outputs to change state and deenergize the reactor trip relays.

Type 10 (Part No. 020175-010). This module (I&L Diagram 018848, PPS - Reactor Trip Logic Module) is essentially a multiple input OR gate. A change of state on one or more of the inputs will result in a change of state to the outputs of this module. The reactor trip logic module transmits logic level output signals to four reactor trip 2-out-of-3 logic modules (through digital buffers). In addition, this module transmits digital signal level information to associated buffer modules.

Type 11 (Part No. 020175-011) (I&L Diagram 018850, PPS - PCRVR Relief Block Valve Interlock Control Module). Upon receipt of a valve closed signal, the solid-state relay will be energized and energize the coil in the associated PCRVR relief block valve interlock module. The INTERLOCK IN light will be extinguished, the INTERLOCK OUT light will illuminate, and the VALVE OPEN light will be extinguished.

Type 12 (Part No. 020175-012). This module (I&L Diagram 015870, PPS - CPP/CACS Initiation Module) accepts five inputs signals from bistable trip modules measuring various plant parameters. A trip signal on input 3 enables the manual bypass controls. The manual bypass can be used to inhibit CACS initiation on trips of inputs 1 and 2. If the manual bypass is not enabled, the module works as follows: (a) a trip on input 1 or 2 will cause outputs 9, 10, 11, and 12 to change state; (b) a trip on input 7 will cause outputs 9, 10, 11, 12, and 8 to change state; (c) a trip on input 6 will inhibit a trip on input 7 from causing a state change on outputs 9, 10, 11, 12, and 8. In any condition, the channel manual trip switch will cause outputs 9, 10, 11, and 12 to change state.

Type 13 (Part No. 020175-013). This module (I&L Diagram 015875, PPS - Logic Trip Detection Module) accepts three logic level input signals. When two or three of the inputs change state, the module outputs change state. Each of the three logic level inputs may be pulse tested from an associated digital test module.

Type 14 (Part No. 020175-014). This module (I&L Diagram 015995, PPS - Dump Control Module) accepts a logic level input from a type 2, 2-out-of-3 logic module. When the input changes state, the module outputs change state. The trip action is inhibited when a lockout signal from another loop is present. A manual dump input will cause a trip whether a lockout signal is present or not.

6.7.4.3. Test Plan. Parts of five general reference specifications are used to closely define test requirements for the PPS logic modules. Table 6-2 lists the sections of each of these general specifications that apply to different aspects of the PPS logic module specification. The environmental tests or test criteria, for both operating and seismic conditions, are the same as those described for the buffer module.

6.7.4.4. Acceptance Criteria. The acceptance criteria for logic modules are separated into three categories: (A) operating characteristics, (B) switches, and (C) indicators. These categories are further defined below:

A. Operating Characteristics

1. Inputs. For all logic modules, each type of input signal described below will have the specified characteristics defined unless specified differently on the individual data sheet associated with a particular logic module.

Logic Level Input Signal. High 9 to 12 V; low 0 to 3 V; input impedance one standard CMOS load, driven from bistable trip modules, logic modules, buffer modules, and remote switches.

Input Signal. Logic signals with levels other than 12 V, in most cases 24 V, require signal conditioning prior to interfacing with the CMOS logic of the module receiving the signal.

Pulse Input. Pulse input from digital test module.

Pulse width:	100 to 750 μ sec, 450 μ sec nominal
Pulse height:	12 V dc $\pm 1\%$
Repetition rate:	100 to 200 pulses/sec $\pm 5\%$
Rise time:	10 μ sec

2. Outputs. For all logic modules, each type of output signal will have characteristics defined on the individual data sheet associated with a particular logic module type.
3. Response Time. All output signals will respond to associated logic input signal changes in 20 μ sec or less (exclusive of specified time delays in the signal path).
4. Logic Operations. All logic operations will function as specified.
5. Time Delays. All the time delays will be as specified on the associated drawings. Tolerances will be $\pm 10\%$ of specified value unless otherwise defined.
6. Noise Immunity. Tests will be performed to demonstrate that the logic modules perform acceptably when subjected to a noise source.
7. Fail Safe Operation. Logic modules will be tested to verify fail safe operation.

B. Switches

Tests will be performed to demonstrate that all switches (front panel mounted) perform as specified.

C. Indicators

Tests will be performed to demonstrate that all indicators (front panel mounted) perform as specified.

6.7.5. Analog Test Module

6.7.5.1. Application to PPS System. Analog test modules are used in the reactor trip system, the steam generator isolation and dump system, the CAHE isolation system, and the main loop shutdown system.

6.7.5.2. Design and Specification Requirements. The analog test modules (Ref. 6-9) will be used to perform on-line testing (operating and trip points) and calibration of bistable trip modules. Each module contains three independently variable test sources, two voltage sources variable from 0 to 10 V, and one constant current source variable from 4 to 20 ma. Front panel control is provided for source variation and to select bistables individually or in groups. Positive keylock control is provided to prevent inadvertent module operation.

The modules are designed for continuous operation in the control room. The modules are Class IE, QAL I, and Seismic Category I. Important operating parameters are given below:

1. Fail Safe Operation. Analog test modules will be designed so that bistable trip modules can be placed in the test configuration only with the analog test module keyswitch in the ON position. Loss of power to the analog test module will not place any bistable trip modules in the test configuration.

2. Adjustment. Analog test modules will function without any in-service adjustments.
3. Calibration. Modules will function without calibration for a minimum of 3000 hr.
4. Maintainability. Modules will operate without on-line maintenance.
5. Performance. Removal or insertion of an analog test module from the system will not cause any of the associated bistable trip modules to be placed in the test mode.

6.7.5.3. Test Plan. A separate test plan for the analog test module has not been prepared. Reference 6-9 contains the following relevant test requirements:

1. General. The seller is required to perform tests in accordance with a buyer-approved test plan and test procedure prepared by the seller.
2. First Article Testing. The design compliance testing will be made with the first article and will include any tests that are required to indicate that the performance and construction comply with the specified design requirements.
3. Logical Operations. Tests will be performed which indicate that all logical operation requirements are satisfied with the analog test module in the ON and OFF positions.
4. Analog Controls. Operation of all controls and indicators (both internal and external) will be verified over the specified ranges or conditions.

5. Output Signals. Output analog signal characteristics will be determined to verify correct operation within the correct signal values.

Table 6-2 lists the sections of the five second-level specifications that apply to the analog test modules. The environmental tests and test criteria, for both operating and seismic conditions, are the same as those described for the buffer module.

6.7.5.4. Acceptance Criteria. The acceptance criteria for the analog test module are separated into four categories: (A) operating characteristics, (B) adjustable controls, (C) switches, and (D) indicators. Each of these categories is defined below:

A. Operating Characteristics

1. Inputs: None.

2. Outputs

- a. Voltage Generator Outputs (V1 and V2)

Polarity: Positive dc.

Amplitude: Variable from 0 to 10 V dc.

Load: Capable of driving bistable trip module with differential input operating in the ungrounded mode with input impedance greater than or equal to 100 kohm, common mode rejection 80 dB minimum, and common mode voltage +15 V dc.

Linearity and Accuracy: $\pm 0.1\%$ of full-scale voltage for a minimum of 3000 hr over the temperature range specified

relative to the input signal indicated on the rotary thumbwheel switch controlling the signal.

b. Current Generator Output

Range: 4 to 20 ma dc.

Load: Capable of driving bistable trip module with differential input operating in the ungrounded mode with input impedance of 50 ohms minimum, 150 ohms maximum, common mode rejection 80 dB minimum, and common mode voltage +65 V dc.

Linearity and Accuracy: $\pm 0.25\%$ of full-scale current for a minimum of 3000 hr over the temperature range specified relative to the input signal indicated on the rotary thumbwheel switch controlling the signal.

c. Bistable Trip Module Test Enable Lines. Analog test modules will be tested to verify that the following conditions are met:

- (1) With the keyswitch in the ON position and power applied only to the analog test module, the selected enable line(s) applies a high logic level signal to the selected bistable trip module(s).
- (2) With the keyswitch in the ON position and loss of power to the analog test module, all enable lines will have a low logic level signal present on their outputs.
- (3) With the keyswitch in the OFF position, all enable lines will have a low logical level signal present

on their outputs with or without power applied to the module.

(4) All enable lines will meet the following conditions:

Normal state: 0 to 3 V dc.

Enable state: 9 to 12 V dc.

Load: Output capable of sinking or sourcing at least five standard CMOS gate inputs.

(5) Removal or insertion of an analog test module from the system will not cause any of the associated bistable trip modules to be placed in the test mode.

d. Fail Safe Operation. Analog test modules will be tested to verify fail safe operation.

B. Adjustable Controls

1. The analog test modules have two separately variable voltage sources (0 to 10 V dc) with the characteristics defined in (a) above. Operation of their controls over their entire range will be verified.
2. The analog test modules have one variable current source (4 to 20 ma dc) with the characteristics defined in (b) above. Operation of their control over its entire range will be verified.

C. Switches

Operation of switches listed below will be verified:

1. V1 Voltage Control Switch. Four-digit rotary thumbwheel switch.
2. V2 Voltage Control Switch. Four-digit rotary thumbwheel switch.
3. I1 Current Control Switch. Four-digit rotary thumbwheel switch.
4. G-T Switch. Group-test four-digit rotary thumbwheel switch.
5. ON-OFF Keyswitch. Multiple deck ON-OFF keyswitch.

D. Indicators

The test-on indicator illuminates when the ON-OFF keyswitch is placed in the ON position.

References

- 6-1. "IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-323-1974.
- 6-2. "Definitions of Terms Used in IEEE Standards on Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-380-1972.
- 6-3. "Dictionary of Electrical and Electronic Terms," Institute of Electrical and Electronics Engineers Standard IEEE-100-1972.
- 6-4. "Specification for Purchase of Safety Related Instrumentation, Control, and Electrical Equipment," Issue A, Document No. 10300, July 20, 1973, General Atomic unpublished data.

- 6-5. "Buffer Modules," Specification I0991, Issue C, Document No. 900991, May 12, 1975, General Atomic unpublished data.
- 6-6. "Bistable Trip Modules," Specification I0992, Issue A, Document No. 900992, October 16, 1974, General Atomic unpublished data.
- 6-7. "Specification for PPS Logic Modules," Issue A-1, Document No. 900994, General Atomic unpublished data.
- 6-8. "Specification for PPS Valve Control Modules (Safety-related)," Issue A, Document No. 901586, December 30, 1974, General Atomic unpublished data.
- 6-9. "Specification for Analog Test Module," Issue A-1, Document No. 901557, General Atomic unpublished data.
- 6-10. "Seismic Qualification, Category I, Instrumentation, Control and Electric Equipment," Specification I0304, Issue B, Document No. 900304, December 18, 1974, General Atomic unpublished data.
- 6-11. "Installation, Inspection, and Testing Requirements for Instrumentation and Electric Equipment During the Construction of Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-336-1971.
- 6-12. "Specification for Environmental Conditions for Instrumentation, Control & Electric Equipment," Issue A, Document No. N0763, June 22, 1973, General Atomic unpublished data.
- 6-13. "Trial Use Guide for Seismic Qualification of Class I Electric Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronics Engineers Standard IEEE-344-1971.
- 6-14. Robert, G. V., "Qualification Test Plan for Class IE Buffer Modules, Revision B," April 21, 1975, General Atomic unpublished data.
- 6-15. "General Requirements for Instrumentation, Control and Electric Equipment," Issue C, Document No. 900305, February 25, 1975, General Atomic unpublished data.
- 6-16. "Specification for Qualification of Instrumentation, Control and Electric Equipment," Issue A, Document No. I0307, May 11, 1973, General Atomic unpublished data.

7. MAIN HELIUM CIRCULATOR (SAFETY-RELATED ASPECTS)

7.1. INTRODUCTION AND BACKGROUND

The safety-related part of the main circulator consists of the helium pressure boundary, the stationary structure that works in conjunction with the main shutoff valve, and the PPS sensors located in the circulator inlet.

These components must not be functionally affected by a failure of the main circulator rotor resulting from either a rotor burst or a rapid seizure of the shaft. Verification will be accomplished by a combination of analytical techniques, the application of previous experimental data, and supplementary test programs if necessary. The failure modes being investigated are rotor burst and shaft seizure.

The following sections describe the program only in general terms. Details will be provided in the next issue of the LTR-100 series.

7.2. OBJECTIVES OF PROGRAM

The program is intended to verify the safeguards against rotor burst and shaft seizure. The design criteria are:

1. The rotor speed will be limited to a safe level regardless of any other component malfunction that might otherwise produce dangerous rotor overspeed.
2. The damage caused by a rapid shaft seizure in any of the shaft support bearings will be limited to circulator components having no safety-related function.

To ensure that the design criteria are met, the following design features have been adopted and will be verified in this program:

1. The rotor speed will be limited by designing the turbine blades to shed at 155% speed.
2. The 155% speed will be verified to be a safe speed for the rotor.
3. The compressor and turbine structures are designed to contain a rotor burst at 160% speed.
4. The rotor and rotor supporting structure are designed to withstand the peak torque developed during a rapid shaft seizure.

7.3. DESCRIPTION OF PROGRAM

The DV&S and Qualification Program, as currently conceived, will provide analytical verification that the safety-related circulator components will withstand a rotor burst and shaft seizure. Turbine blade shed will be verified by an experimental program, and production rotor assemblies will be acceptance tested at 140% speed at room temperature. Post-test examination for permanent deterioration and flaw growth will verify that the disks will not rupture at 155% speed.

Details of the program are currently being developed. Preliminary schedules are given in Table II.