ornl

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

ORNL/M-4609

Basis for Requirements for Advanced Neutron Source Control Element Test Facility

W. R. Hendrich
G. T. Yahr
J. L. Anderson
R. E. Battle
P. S. Litherland
L. S. Oakes
H. R. Payne
A. B. Poole

August 1995

Advanced Neutron Source

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/M-4609

ornl

OAK RIDGE
NATIONAL
LABORATORY

MARTIN MARIETTA

Basis for Requirements for Advanced Neutron Source Control Element Test Facility

W. R. Hendrich
G. T. Yahr
J. L. Anderson
R. E. Battle
P. S. Litherland
L. S. Oakes
H. R. Payne
A. B. Poole

August 1995

Advanced Neutron Source

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/M-4609

BASIS FOR REQUIREMENTS FOR ADVANCED NEUTRON SOURCE (ANS) CONTROL ELEMENT TEST FACILITY

W. R. Hendrich
G. T. Yahr
J. L. Anderson
R. E. Battle
P. S. Litherland
L. S. Oakes
H. R. Payne
A. B. Poole

August 1995

Prepared by
OAK RIDGE NATIONAL LABORATORY
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

CONTENTS

TABLES

ACRONYMS

ANS	Advanced Neutron Source
CETF	Control Element Test Facility
DBE	design basis event
HFIR	High Flux Isotope Reactor
I&C	Instrumentation and Control
ICR	inner control rod
ORR	Oak Ridge Research Reactor
SDDs	System Design Descriptions
TBD	to be determined

ABSTRACT

The process used to determine the requirements for the Advanced Neutron Source (ANS) Control Element Test Facility (CETF) is explained. The requirements for the CETF are tabulated.

1. BACKGROUND

Flow-induced vibrations of the inner control element system were an early and major concern as discussed in ref. 1. The long, slender rods were found to be susceptible to subcritical vibrations that might result in poor control characteristics or structural damage to the control element system. The Control Element Test Facility (CETF) was envisioned as a test to evaluate the flow-induced vibration response and to provide a developmental facility for the evaluation of any design changes that might be required as the Advanced Neutron Source (ANS) design developed.

As the dynamic analyses of ref. 1 progressed, it became clear that having the fluid properly represented was of vital importance. It also became clear that many engineering data, such as the modal frequencies of the system, were critical to understanding what steps could be taken to prevent flow-induced vibrations. The scope of the CETF was expanded to provide engineering data for the evaluation of the performance functions of the inner control element system.

As a result, the CETF was expanded into an assembly and a flow module so that two complete sets of rods could be evaluated simultaneously. The flow test stand would be primarily dedicated to the verification of the semiempirical equation being used to predict flow-induced vibration. The assembly stand would be dedicated to modal and other engineering parameter evaluations.

As the dynamic analysis and CETF objectives continued to develop, it was apparent that many of the performance functions of the inner control rods should be evaluated in the CETF. The scram, control, cooling, and structural response functions were all interrelated and should be evaluated as a system. It was then decided that a comprehensive study should be undertaken to determine what testing the full-scale system facilities of the CETF must have.

2. DISCUSSION

The strategy adopted to develop a comprehensive test plan for the inner control rod (ICR) system utilized the following steps to determine the tests and test facilities required to eliminate uncertainties and verify requirements of the system:

1. Identify all functions to be performed.
2. Identify the requirements of each function.
3. Identify the actual hardware designed to perform the function.
4. Identify uncertainties in the hardware meeting the requirements.
5. Identify actions necessary to eliminate uncertainties and verify that hardware meets the functional requirements. (This could include tests, analyses, literature searches, etc.)
6. Describe tests required, data needed, and facility requirements.
7. Define test facilities, combining tests where possible.
8. Schedule tests and facilities.
9. Estimate test and facility costs.

Functions to be performed were taken from System Design Descriptions (SDDs) 31 and 33 and consisted of the following:

I. Control reactivity
  A. Normal operation
    1. Regulate
    2. Shim
  B. Scram
    1. Decouple from drive system
    2. Accelerate into scram configuration
    3. Decelerate into scram configuration
    4. Recouple to the drive system

II. Detect absorber position
  A. Normal operation
    1. Continuous position indication
  B. Scram
    1. Detect down position of absorber

III. Limited subpile room volume
  A. High-pressure seal

These functions were divided among the authors for evaluation. This resulted in nine separate documents, each of which addresses requirements, hardware, uncertainties, and actions, including tests, for a particular function. Each of those documents is included in Appendix A.

Tests identified in the nine documents were reviewed and assigned to distinct test facilities. In most cases, test facilities accommodate several individual tests. Test facilities presently identified are listed as follows.

1. Magnet Test Facility—a bench-top test to verify design and develop data on latch magnet performance and operating parameters.

2. Wet Latch Wear Test Facility—a bench-top test to develop data on latch part wear and alternate latch materials.
3. Corrosion Product Buildup Test—a test to determine if aluminum corrosion products from fuel elements can be deposited in the cracks and crevices of the latch mechanism and cause problems.
4. Seal Test Facility—a test of the lower control rod seal into the subpile room to determine leak properties and tolerance to rod misalignment (possibly performed at seal vendor).
5. Spring Heat Transfer Test Facility—a bench-top test of the acceleration springs in a flooded annulus to determine heat transfer coefficients.
6. Damper Test Facility—a bench-top wet test to determine the design of damper holes for hydraulic damping during scram deceleration.
7. Down Position Indicator Test Facility—a bench-top wet test to verify proof of principle of hydraulic down indicator switch.
8. ICR Assemble Test Stand—a full-scale static wet test of one control rod subassembly to verify integrated unlatch, accelerate, decelerate, and relatch requirements and to get preliminary single rod modal characteristics.
9. Control Element Test Facility (CETF)—a full-scale wet test of the complete ICR system with flowing and pressurized water to verify vibration characteristics, integrated three-rod operation, seismic reliability, and operation under near-prototypic conditions.

Only the CETF is discussed in this report. The worksheets in Appendix A primarily covered the control system functions and the high-pressure seals of the system. The hydraulic and flow-induced vibration were added later into the compiled data.

It was apparent from the worksheets in Appendix A that several of the functional requirements could be tested in a single systems test such as in the CETF. The evaluation team met to combine the worksheets in Appendix A and to identify tests that were appropriate for the CETF. Table 1 presents 40 tests in the CETF that should be run to evaluate the uncertainties associated with performance requirements. These tests would verify the structural integrity of the rods in the turbulent flow environment and evaluate the ability of the rods to control the reactor under normal and adverse conditions. This list of 40 items was somewhat unmanageable as far as clearly defining the CETF requirements; several of the items are redundant.

The 40 items in Table 1 were then grouped into four main categories:

- Flow-Induced Vibration,
- Scram Performance,
- Operational Performance, and
- Hydraulic Performance,

where the hydraulic performance was an addition to the original 40 items. Table 2 summarizes the tests under these four main categories. The first column of Table 2 references the 40 items in Table 1 as the Table 1 item number. This column indicated that several of the uncertainties can be resolved by a single system test. The emphasis on system interaction dictates that much of the performance testing be done with the actual system hardware. By scramming under flow test conditions, this interaction will be present during the tests. Since several of the performance uncertainties must be evaluated under flow conditions, many of the tests identified in Table 1 can be accomplished simultaneously with a single scram test under flow conditions. In the assembly stand, a single scrammable rod and

Table 1. Forty tests in Control Element Test Facility

No.	Test description
1.	Measure the flow-induced vibration response and develop a suspension system.
2.	Demonstrate ability of drive to operate for extended periods with continuous dither. Observe performance and wear.
3.	Confirm that withdrawal and insertion rates are within specifications and are proportional to input error under all operating conditions.
4.	Determine that system backlash and coasting are small enough that they will not cause instabilities in regulation.
5.	Determine if motor reversal causes drive or gear problems, rod stress, vibration, or bending.
6.	Make sure that the rods are immobilized when requested by the limit switches.
7.	Assure that the drive or gearbox will not overheat in subpile room. Measure temperature.
8.	Connect to a reactor simulator to evaluate stability, backlash, coasting, and friction.
9.	Confirm mounting structure and mechanical stop ability to withstand peak forces.
10.	Demonstrate ability to function over expected lifetime under simulated environmental and load conditions.
11.	Confirm that the shim drive is limited to 7.5 mm/s (0.25% $\Delta k/k{\circ}s$) under all conditions.
12.	Confirm that mechanical stop will positively stop the rod at a position of maximum negative worth.
13.	Confirm proper relatching operation over lifetime.
14.	Connect to reactor simulator to evaluate speed, stability, backlash, and coasting.
15.	Demonstrate that the shim motor can be reversed without causing drive or gear problems, rod stress, vibration, or bending.
16.	Demonstrate that the rods will not move without being driven by shim or regulation drives (no backdriving).
17.	Confirm that scram may be initiated from any shim position without rod damage.
18.	Demonstrate magnet integrity and performance in operating environment.
19.	Test effect of rod bowing on release time.
20.	Determine total response time from various positions for life of rods.
21.	Determine whether thermal effects may cause delatching or inhibit delatching.
22.	Demonstrate ability of magnet to support vertical load of weight and pressure.

Table 1 (continued)

No.	Test description
23.	Demonstrate that required insertion rate is met from all positions throughout lifetime, including effects of spring rate, fluid friction and pressure, mechanical friction, misalignment, and bowing.
24.	Verify performance of damper.
25.	Determine if flow-induced vibrations influence the deceleration profile or inhibit complete insertion.
26.	Determine if friction keeps the rods from stopping in the fully inserted position.
27.	Determine if rebound spring will return the rods.
28.	Determine if the rebound spring rate is so high that it will cause the rods to buckle.
29.	Determine whether deposits will form that increase deceleration or cause incomplete insertion.
30.	Determine if inadvertent rod release at any position could cause buckling to occur.
31.	Verify that air supply pressure and flow rate requirements are met.
32.	Life-cycle performance validation.
33.	Measure overtravel required for relatching.
34.	Demonstrate that deadband/backlash is < 1 mm.
35.	Confirm that flow rate is sufficient to provide an acceptable flow and ΔP signal.
36.	Demonstrate ability to replace control rod assembly with the hydraulic transition assembly attached to the control rod shock absorber.
37.	Demonstrate reliability of seat switch over lifetime.
38.	Measure pressure pulse during scram from various positions.
39.	Measure leakage through high-pressure seal under operating conditions.
40.	Determine effects of misalignment, side loads, bowing, pressure, and vibration on leakage rate.

Table 2. Summary of Control Element Test Facility requirements

Design/ Operational Uncertainty	Table 1 Item No.	Test Requirements: Water	Flow Velocity (m/s)	Pressure (MPa)	Geometry	Special	Schedule Requirements	Data Requirements	Required Accuracy or Confidence Level
Flow-Induced Vibrations									
Natural frequency	1	X	0	0	Assembly stand	Prototypic mock-up	Sept. '96	Orthogonal modes and natural frequencies up to 20 Hz	
Vibration amplitude	1	X	1-6	TBD	Flow test	Actual 3-rod system	Sept, '97	Flow-induced vibration amplitude at critical locations	
Scram Performance									
Insertion rate	19,20,23,35	X	1-6	0	Flow test	Control simulator		Position vs time	3%/95%
Deceleration effects	1,24,28,30	X	0	0	Assembly stand	1 rod	Nov. '96	Acceleration vs time, forces	3%/95%
Deceleration effects	1,9,17,24,28,30	X	0-4	0	Flow test	3 rods		Acceleration vs time, forces	3%/95%
Rod position after scram	12,25,26,27	X	1-6	0	Flow test			Position	3%/95%
Hydraulic Performance									
Flows and pressure drops		X	1-6	3.2	Flow test	Actual system		Flow in and around rods, pressure drops, forces over rods	
Drag force on free rod		X	1-6	3.2	Flow test	Actual system with one rod free		Flow rate when rod levitates	
Operational Performance									
Lifetime performance	2,7,10,23,29,32	X	1-6	3.2	Flow test	Actual system, control simulator		Position vs time, acceleration, force	3%/95%
Withdrawal/insertion rate	3,8,11,14	X	1-6	3.2	Flow test	Actual system		Position vs time, forces	3%/95%
Direction reversal	4,5,7,15,34	X	1-6	3.2	Flow test	Actual system		Position vs time, forces	3%/95%
Steady operation	2,6,16	X	1-6	3.2	Flow test	Actual system		Position vs time, forces	3%/95%
Latch	13,21,33	X	1-6	3.2	Flow test	Actual system		Push-rod position vs time	3%/95%
Seat switch	31,35,37,38	X	1-6	3.2	Flow test	Actual system		Pressure flow	3%/95%
Magnet	22		0	0	Assembly stand			Holding force, release time	3%/95%
Magnet	18,22	X	1-6	3.2	Flow test	Actual system		Armature position vs time	3%/95%
High-pressure seal	39,40	X	1-6	3.2	Flow test	Actual system		Leak rate	3%/95%

two mockup rods were sufficient. The deceleration effects tests must be performed with and without flow because the maximum deceleration occurs for the no-flow condition. The remainder of the table defines the test and data requirements for each of the four major categories. Finally, the accuracy requirements are defined because many of these tests deal with critical safety issues. These basic requirements form the basis for the specifications and drawings for the CETF.

3. CONCLUSIONS

A comprehensive study was completed by a multiple-discipline task force to determine the tests and analyses that would be required to resolve the uncertainties related to the inner control element system of the ANS reactor. The study concluded that analyses or bench tests could provide adequate information for some functions, while subsystem or full-scale system testing in the CETF would be required for the larger systemic uncertainties. Consideration was given to the interaction between the major categories and to what extent the system mock-up must be prototypic or actual hardware to minimize cost of test hardware. Since the inner control rods were identified as a safety system, the confidence level needed from each test was identified.

4. REFERENCE

1. W. R. Hendrich, *Summary of Dynamic Analyses of Advanced Neutron Source Inner Control Rods*, ORNL/M-4629, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., August 1995.

APPENDIX A

Summary of Functional Requirements Worksheets

Functions to be performed (Table A.1)

1. Control reactivity
   a. Normal operation
      1. **Regulate**

Purpose

The regulating stroke of the rod drive system provides instantaneous power-level regulation by means of fast, limited-stroke of the rod. The regulating drive speed is faster than the shim speed, and the stroke of the regulating drive is positively limited to a reactivity worth that can be tolerated by the Reactor Protection System.

Requirements

1. Perform as required by the servo system to maintain steady-state flux within $\pm 1\%$.
2. Add or remove reactivity at a maximum rate of 0.5% $\Delta k/k \cdot s$ (15 mm/s) and a minimum rate of 0.025% $\Delta k/k \cdot s$ (0.75 mm/s) or less. The rate shall be proportional to the error signal to the motor.
3. Withdraw and insert the rod at the same rate for the same magnitude error signal only with reversed polarity.
4. Reversing forces of the system shall not damage the mechanisms.
5. Perform for extended periods of time at the same nominal position with continuous rod dither.
6. Limit the total reactivity available to less than 0.8% $\Delta k/k$ (50 mm).
7. Meet the seismic requirements (NRS-3 or Category I-L).
8. Provide interface (gearbox) between the regulation motor and the rod. Minimize reactivity effects of backlash and coasting.
9. The drive shall include five limit switch functions and continuous position indication (described separately).
10. The regulating drive motor shall not backdrive due to load.
11. Load changes from static to sliding friction shall not cause abrupt changes in rod speed.
12. Operate in the subpile room environment (temperature, humidity, aging).

Hardware

1. Gearing and mechanical stop assembly.
2. Electrical limit switch and position indication assembly.
3. Servomotor with integral tachometer.
4. Support and restraint structure.

Table A.1. Control reactivity, normal operation, *regulate*
Uncertainties and test functions

Requirement	Item	Uncertainties	Action	Description of action
5	1	Operate at steady state, near one position continuously without damaging gears.	a. Analysis b. Cycle tests	Operate for an extended period under various conditions and observe performance and wear. Perform test in Control Element Test Facility.
2	2	Confirm that the drive motor cannot add reactivity faster than 15 mm/s (0.5% $\Delta k/k \cdot s$).	a. Analysis b. Test	Analysis. Perform test in Control Element Test Facility.
6	3	Assure that the drive has positive mechanical stops that will prohibit adding greater than 25 mm (0.8% $\Delta k/k$).	a. Analysis b. Failure mode tests	Confirm the integrity of mechanical stops. Perform test in Control Element Test Facility.
3	4	Assure that the withdrawn and insert speeds are within specification and at a rate proportional to the input error.	a. Analysis b.	Test under all appropriate operating conditions. Perform test in Control Element Test Facility.
8	5	Determine that system backlash and coasting are small enough that they will not cause regulation instability.	a. Analysis b. Test	Performance testing in Control Element Test Facility.
4	6	Confirm that the motor can reverse from full speed in one direction to full speed in the opposite direction rapidly and that this will not cause drive or gear problems, rod stress, vibration, or bending.	a. Analysis b. Test	Performance testing in Control Element Test Facility.
8,10	7	Confirm that the rod will not insert or withdraw when the servo rod has zero error signal or is turned off (and the shim drives are off).	a. Test	Design confirmation test in Control Element Test Facility.
7	8	Continue to function without damage during and after an NRS-3 seismic event and do not damage the rods for an SSE.	a. Analysis b.	Analysis. Seismic testing is not currently planned.
12	9	Assure that the drive or gearbox will not overheat, and that it operates in the subpile room environment, for continuous operation.	a. Analysis b. Cycle test	Perform qualification and life-cycle testing. Perform test in Control Element Test Facility.

Table A.1. (continued)
Uncertainties and test functions

Requirement	Item	Uncertainties	Action	Description of action
1, 5, 11	10	Connect to a reactor simulator to evaluate stability, backlash, coasting, and stiction.	a. Test	Operate under appropriate conditions simulated with computer-based simulator. Perform test in Control Element Test Facility.
4, 6, 8	11	Confirm that mounting structure and mechanical stops are able to withstand peak forces.	a. Analysis b. Test	Performance testing in Control Element Test Facility.
2, 6	12	Confirm that rod speeds are in accordance with final rod worth calculations.	a. Analysis	Final analysis of rod worths from neutronics designers.

These tests must be done in an integrated test facility because of the difficulty of establishing conditions for testing. The full rod drive assembly is required, and the tests require loading conditions that can be realistically created only in an integrated test facility.

Functions to be performed (Table A.2)

1. Control reactivity
   a. Normal operation
      1. Regulate
      2. **Shim**

Shim Purpose

Provide full-stroke adjustment of the inner rods to adjust reactivity for startup and compensation for fuel burnup, xenon, and other slow reactivity changes.

Requirements

1. Add or remove reactivity at a rate less than or equal to 0.25% $\Delta k/k \cdot s$ (7.5 mm/s).
2. The drive motor shall not backdrive due to load.
3. Operation of the high-speed air motor shall not damage the electric shim or regulating drive mechanisms.
4. Insert (only) reactivity with a unidirectional air motor at a rate of 5–10 times the normal electric motor speed.
5. Meet the seismic and environmental requirements. The rods, guides, drives, and support structures must have sufficient stiffness to resist buckling, wrinkling, or binding under all design forces over the rod lifetime, considering radiation damage, chemical changes, vibration fatigue, and temperature.
6. Provide interface (gearbox) between the shim, motor, and the rod threads. Control backlash and coasting to within specifications.
7. The shim function shall not cause the scram function to operate improperly.
8. The shim drive shall position the lower end of the absorber from 600 mm below to 600 mm above the core midplane, and it shall provide for overtravel to re-engage the latch.
9. The electric shim drive motor shall be incapable of being reversed by any influence external to the motor control system (e.g., a three-phase induction motor must not be used).
10. Provide positive mechanical stops at the ends of travel to assure that the rod cannot be inserted beyond the position of maximum negative reactivity or withdrawn beyond a position of acceptable minimum differential worth.

Hardware

1. Shim drive electric motor and accessories.
2. Shim drive pneumatic turbine-motor and associated gearing.
3. Shim drive gearing and support assembly.
4. Regulating stroke drive and support assembly.
5. Position and limit indication hardware (described separately).
6. Interface with scram latch assembly.
7. Pressure seals and bearings.
8. Shim drive air motor and associated support and gearing.

Table A.2. Control reactivity, normal operation, *shim*
Uncertainties and test functions

Requirement	Item	Uncertainties	Action	Description of action
5	1	Confirm that system will operate without overheating or damaging gears. Consider vibration, temperature, humidity.	a. Analysis b. Cycle tests	Operation under simulated environmental and load conditions for many cycles to determine performance and wear, etc. Perform test in Control Element Test Facility.
1	2	Confirm the control of reactivity at a rate limited to less than 7.5 mm/s (0.25% $\Delta k/k \cdot s$).	a. Analysis b. Test	Operate under all appropriate conditions of load, pressure, etc., to determine limiting speeds. Perform test in Control Element Test Facility.
8, 10	3	Confirm that mechanical stops will positively stop the rod at a position of maximum negative worth.	a. Analysis b. Failure mode testing	Operate under worst-case conditions to verify limiting performance. Perform test in Control Element Test Facility.
8	4	Confirm sufficient torque and overtravel to engage latch.	a. Analysis b. Test	Confirm proper relatching operation with repeated cycles. Perform test in Control Element Test Facility.
1, 6	5	Confirm that withdraw and insert speeds are acceptable. Evaluate coasting and backlash effects on reactivity.	a. Analysis b. Test	Test with connection to reactor simulator to confirm performance with servo action and simulated signal noise. Perform test in Control Element Test Facility.
5, 6	6	Determine that the motor can reverse from full speed in one direction to full speed in the opposite direction without causing drive or gear problems, excessive rod stress, vibration, or bending.	a. Analysis b. Test	Test operating performance. Perform test in Control Element Test Facility.
2, 9	7	Determine that the rods will not move without being driven by shim or reg drives (no backdriving).	a. Test	Test under all appropriate conditions. Perform test in Control Element Test Facility.
Class 1E	8	Confirm function during and after an NRS-3 seismic event.	a. Analysis	Seismic testing is not planned.
5, 7	9	Confirm that scram may be initiated from any shim position without rod damage.	a. Analysis b. Test	Test to ensure that mechanisms and rods will not be damaged by scram from any shim position. Perform test in Control Element Test Facility.

Table A.2 (continued)
Uncertainties and test functions

Requirement	Item	Uncertainties	Action	Description of action
3, 4	10	Confirm that the air motor will insert reactivity at the required speed with no possibility of withdrawing and with no ill effects on drive or rods.	a. Analysis	Design analysis.
1	11	Confirm that rod speeds are in accordance with final rod worth calculations.	a. Analysis	Final analysis of rod worths from neutronics designers.
5	12	Evaluate potential for radiation damage to lubricants, windings, insulation, etc.	a. Analysis	Evaluate subpile room radiation and effectiveness of shielding.

These tests must be done in an integrated test facility because of the difficulty of establishing conditions for testing. The full rod drive assembly is required, and the tests require loading conditions that can be realistically created only in an integrated test facility.

Delatch Functional Test Plan

Functions to be performed (Table A.3)

1. Control reactivity
   a. Scram
      1. **Decouple**

Requirements

1. Delatch in 25 ms.
2. Survive any design basis event.
3. Sense magnet armature position.
4. Operate for 2000 cycles.

Hardware

1. Latch magnet, housing, armature, and sensing switches.
2. Latch release rod internal to drive rod.
3. Latch mechanism cylinders, slots, and discs.

Table A.3. Control reactivity, scram, *decouple*
Uncertainties and test functions

Requirement	Item	Uncertainties	Action	Description of action
2	1	Magnet integrity and performance in operating environment	a. I&C investigation	
			b. Test	Full-scale integrated test with heat and liquid (CETF).
1	2	Armature motion times	a. Analysis	
			b. Test	Bench test of magnet with applied loads, armature switches, and current switch.
1		Magnet release times	a. Analysis	
			b. Test	Bench test of magnet with applied loads, armature switches, and current switch.
1, 3	3	Armature location tolerance	a. Analysis	
			b. Test	Bench test with applied loads and setting the armature gap to different settings.
2, 4	4	Magnet winding cooling	a. Analysis	
			b. Test	Bench test w/temp sensors followed by full-scale test w/sensors for life cycle.
1, 2, 3, 4	5	Mechanical part wear	a. Literature search	
			b. Analysis	
			c. Test	Wet bench test of latch with post-test measurements followed by full-scale test measurements.
1, 2, 4	6	Rod bowing effects	a. Analysis	
			b. Test	Full-scale tests in single rod or full-scale facility, ATS
1	7	Total response time (vs rod position)	a. Analysis	Magnet and latch response time in bench-top component tests.
			b. Component test	Acceleration times in single-rod test.
			c. Integrated test	Total response time in full-scale three-rod test facility, CETF.
1	8	Thermal effects (delta L)	a. Analysis	
			b. Investigate HFIR, ORR experience	
			c. Test	Test of single rod or full three-rod test with heat applied to latch rod or drive.

Table A.3 (continued)
Uncertainties and test functions

Requirement	Item	Uncertainties	Action	Description of action
1, 2, 4	9	Loading effects	a. Analysis	
			b. Test	Bench test of rods and rod connectors under compression. Full-scale test of load-carrying integrity of complete.
1, 2, 4	10	Corrosion product buildup (Al_2O_3 in water)	a. Analysis	
			b. Investigation	
			c. Test	Static latch test in corrosion test loop.
1, 2	11	Ability to delatch while under seismic acceleration	a. Analysis	
			b. Test	Full-scale test under seismic accelerations (defer).
1, 2, 4	12	Operation of current interrupt switch	a. Test	Bench test of switch with magnet to determine lifetime and effects of backdriven current.
2, 4	13	Ability of magnet housing to support vertical load of weight and pressure	a. Analysis	
			b. Test	Bench test of magnet housing under load, followed by CETF test.

Accelerate Functional Test Plan

Functions to be performed (Table A.4)

1. Control reactivity
   a. Scram
      1. Accelerate

Requirements

1. Each rod must insert a minimum of $.50 of negative reactivity in 100 ms with the initial position at the maximum withdraw limit and near the end of neutron absorber life. Rod travel is tentatively allocated 70 ms. (1.2.1.1.2.2).
2. Full-stroke insertion time from initiation of scram motion until rod is fully inserted must not exceed 250 ms from any acceptable starting position (1.2.1.1.2.3).
3. Each rod shall scram individually.
4. Must be capable of meeting above requirements after two years of operation in ANS with reliability of TBD.
5. Must be capable of meeting above requirements under all ''design basis conditions'' including:
   a. earthquake,
   b. vibrations, and
   c. single failure modes.

Constraints

1. Must be replaceable in <TBD days.
2. Must fit within available space.
3. Rods cannot be ejected from core due to accidents.
4. Minimize neutron flux depression when not scramming (minimum weight design).
5. Minimize activation for handling.

Hardware

1. Three control rods supported at the bottom via bearings and by rollers at the top.
2. Three independent control systems providing scram initiation.
3. Three sets of scram and push springs.
4. Fasteners are provided to remove remotely out the top.

Table A.4. Control reactivity, scram, *accelerate*
Uncertainties and test functions

Requirement	Item	Uncertainties	Actions to eliminate uncertainties
1	1	Are the springs adequate to provide the required insertion rate?	a. Simulation programs to predict insertion times. b. CETF flow test[a] will measure response.
4	2	Will the springs overheat?	a. Thermal analyses being performed. b. Test to determine heat transfer coefficients.
4	3	Will springs maintain adequate preload under irradiation?	a. Review existing data. b. Expose springs to irradiation under stress.
2	4	Will fluid friction/pressure force improve/hamper insertion rates?	a. Analysis to provide scoping values. b. CETF will simulate flow and pressure.
5	5	Will mechanical friction cause a reduction in performance?	a. Design with as large a clearance as possible. b. Assembly stand[b] and CETF to check scram.
3	6	Will misalignment cause a reduction in performance?	a. Tolerance analysis will define misalignment. b. Assembly stand will induce misalignment.
4	7	Can asymmetric thermal loading and/or irradiation-induced swelling cause bowing that will decrease insertion rates?	a. Thermal and structural analyses. b. Heated scram in assembly test stand.
4	8	Will the springs suffer unacceptable embrittlement due to irradiation exposure?	a. Literature review. b. In-reactor tests. c. Fracture assessment.
4	9	Determine potential for stress corrosion cracking in X750.	a. Autoclave testing.

[a]CETF test is a complete wet mock-up of the three control rods under prototypic flow conditions.
[b]Assembly test is a complete dry mock-up of a single control rod including latch, acceleration and deceleration mechanisms, magnets, and seals.

Decelerate Functional Test Plan

Functions to be performed (Table A.5)

1. Control reactivity
   a. Scram
      1. **Decelerate**

Requirements

1. Provide controlled deceleration of each rod for all extraction distances.
2. Provide controlled deceleration for certain failure modes that involve transient pressure and flow.
3. Maintain the dynamic load levels below the buckling limit.
4. Maintain position of control rod after scram is completed.
5. Provide no or very little deceleration during first portion of travel.
6. Must scram during a severe accident and/or DBE but does not need to operate afterward.
7. Limit rebound and overshoot.
8. Must be capable of meeting above requirements after two years of operation in ANS with a reliability of TBD.

Hardware

1. Fluid piston attached to bottom of control rod acts as a damper.
2. Slotted holes in cylinder around piston provides damper vs distance profile.
3. Push spring, pressure, and gravity provide a net downward force to hold rods in place after scram.
4. Rebound or catch spring to provide final deceleration and positioning of control rods after full insertion.

Table A.5. Control reactivity, scram, *decelerate*
Uncertainties and test functions

Requirement	Item	Uncertainties	Actions to eliminate uncertainties
1	1	Is there a damper profile that will provide the quick insertion and still decelerate the rod in time?	a. Analysis—Provide simulation of nonlinear deceleration profile for all critical extraction distances. b. Assembly[a] and CETF[b] test to verify performance.
2	2	Can we maintain tight enough tolerances on the piston to prevent leakage and yet not bind during acceleration?	a. Analysis—Simulation to get required profile. b. Bench test[c] to measure profile. c. Assembly stand, CETF tests to verify.
3	3	How much eccentric bending should be expected due to thermal, vibrations, manufacturing tolerances? Impact on buckling?	a. Buckling analysis of bent configuration including post-buckled shapes. b. Assembly stand with off-nominal tolerance and possible heated test.
5	4	Will the flow-induced vibrations influence the deceleration profile or cause incomplete insertion?	a. CETF test.
4	5	Will friction in the scram system cause the rods to not be fully inserted.	a. Simulation will scope rebound spring rate. b. Analyze system forces for off-nominal insertion. c. CETF testing.
4	6	Is the rebound spring rate high enough to return the rods to inserted position within tolerances?	a. Simulation will scope rebound spring rate. b. Analyze system forces for off-nominal insertion. c. CETF testing.
7	7	Is the rebound spring rate too high so that buckling at the end of travel occurs?	a. Buckling analysis gives max deceleration using peak velocity. b. The spring rate will be sized to stay below maximum deceleration. c. Check in CETF.
8	8	Can deposits form during the rod lifetime on the piston, cylinder, and bearings that will increase deceleration and cause incomplete insertion?	a. Corrosion study of components. b. Life-cycle testing.
8	9	Will irradiation cause significant damage to the push or rebound springs?	a. Review existing data. b. Expose springs to irradiation under stress and measure relaxation and embrittlement.

Table A.5 (continued)
Uncertainties and test functions

Requirement	Item	Uncertainties	Actions to eliminate uncertainties
6	10	Can false scrams prior to being critical cause buckled damage to control rods?	a. Reinvestigation of requirements. b. Test for these extraction distances.
8	11	Brittle fracture of aluminum components.	a. Literature search. b. HFIR capsules. c. Fracture analysis.

[a]Assembly test is a complete dry mock-up of a single control rod including latch, acceleration and deceleration mechanisms, magnet, and seals.
[b]CETF test is a complete wet mock-up of the three control rods under prototypic flow conditions.
[c]This bench test must include the piston/cylinder arrangement of the rods. An appropriate mass loading and acceleration mechanism must also be provided.

Recouple Functional Test Plan

Functions to be performed (Table A.6)

1. Control reactivity
   a. Normal operation
      1. Regulate
      2. Shim
   b. Scram
      1. Decouple
      2. Accelerate
      3. Decelerate
      4. **Recouple**

2. Detect absorber position
   a. Normal operation
      1. Continuous position indication
   b. Scram
      1. Down position of absorber detection

3. Limited subpile room volume
   a. High-pressure seal
   b. Detect leaks
   c. Contain leaks

Requirements

1. Drive system must lower magnets and drive shafts to relatch position.
2. Relatch assist from fingers must reposition latch release rod (magnet armature) for latching.
3. Magnet relatch switch must indicate armature is in relatch position.
4. Drive system must return control rods to "0" withdraw position with latch release rod latched.
5. Lifetime equal to or greater than 10 years.

Hardware

1. Control rod drive and magnet assembly with air motors, armature position switches and rod position indicators.
2. Control rod assembly with shock absorbers and guide tubes.
3. Primary system mock-up from and including the high-pressure seal to the top of the reflector vessel.
4. Instrumentation for switches, motors (air and electric), magnet and position indicators.

A full-scale mock-up of the control drive system including the high-pressure seals with a high-pressure container having an ID equal to the reactor system ID operating at the ANS pressure and temperature is need for this test.

Table A.6. Control reactivity, scram, *recouple*

Requirement	Item	Uncertainties	Actions to eliminate uncertainties
1,2,3,4	1	Ability of electric and air motors to position accurately rods for relatching and restarting.	a. Analysis of design (design review). b. Test prototype of control rod drive system, including magnets, as part of a full-scale mock-up operating as the system is expected to operate.
1,2	2	Air-supply pressure and flow rate required to drive the air motor.	a. Analysis. b. Vendor information on air motors. c. Review of HFIR system. d. Test prototype air motor as part of the full-scale mock-up operating as the system is expected to operate.
5	3	Meeting the requirements of a ten-year or greater lifetime.	a. Life-cycle test of prototype components as part of the full-scale mock-up operating as the system is expected to operate.
5	4	Life of electric motor and magnet insulation.	a. Analysis to determine radiation level at these components. b. Shielding where practical. c. Selection of the best available electrical insulating materials for radiation service.
1,5	5	Electric motor problems resulting from high-speed rundown of the air motor.	a. Use a gearing system that is very similar to or the same as that now used in the HFIR.

Continuous Position Functional Test Plan

Functions to be performed (Table A.7)

1. Detect absorber position
   a. Normal operation
      1. **Continuous position indication**

Provide continuous position indication over the total shim stroke, including overtravel for relatching if necessary.

Provide limit switches at fully inserted and fully withdrawn positions.

Provide continuous position indication over the regulating stroke of 25 mm.

Provide limit switches at designated (TBD) positions in regulating stroke.

Requirements

1. Position indication over full shim stroke of 1200 mm.
2. Position indication over full regulating stroke of 25 mm.
3. Resolution of shim readout ± 1 mm.
4. Resolution of regulation readout ± 0.5 mm.
5. Limit switches adjustable over 25 mm.
6. Deadband/backlash of shim drive < 1 mm.
7. Deadband/backlash of regulating drive < 0.5 mm.
8. Reference position (0 mm) adjustable over 25 mm.
9. Operational lifetime $>$ 10 years.
10. Overtravel indication for relatching.

Hardware

1. Digital encoder(s) or selsyn transmitters.
2. Gearing and shafting from motor to encoder.
3. Adjustable limit switches.
4. Power and signal transmission wiring.
5. Support and mounting structure.
6. Signal conditioning electronics.

Table A.7. Detect absorber position, normal operation, *continuous position indication*
Uncertainties and test functions

Requirement	Item	Uncertainties	Action	Description of actions to eliminate uncertainties
10	1	Overtravel required for relatching	a. Test (to measure)	Single-rod full-scale test or full three-rod test.
6,7	2	Deadband/backlash < 1 mm.	a. Test (to measure)	Single-rod full-scale test or full three-rod test.
1,2,9	3	Effects of neutrons on encoder operation.	a. Investigation b. Analysis	
1,2,9	4	Encoder and electronics reliability	a. Investigation	
1,2,8	5	Latch locks absorber cylinder to drive rod in the wrong place by wedging discs other than at the latch points.	a. Analysis	
3,4	6	Encoder resolution	a. Investigation w/vendors b. past experience	
9	7	Lifetime of encoder light source.	a. Investigation w/vendors b. past experience	
8	8	Definition of "0" reference point and how is it ensured?	a. Investigation	

Absorber Down Functional Test Plan

Functions to be performed (Table A.8)

1. Control reactivity
   a. Normal operation
      1. Regulate
      2. Shim
   b. Scram
      1. Decouple
      2. Accelerate
      3. Decelerate
      4. Recouple

2. Detect absorber position
   a. Normal operation
      1. Continuous position indication
   b. Scram
      1. **Down position**

3. Limited subpile room volume
   a. High-pressure seal
   b. Detect leaks
   c. Contain leaks

Requirements

1. Detect position of rod's lower end at the fully inserted position ("0" withdraw position).
2. Detect position of rod's lower end when within ± 10 mm of "0" withdraw position.
3. Provide continuous indication when the rod is seated.
4. Parts inside the high-pressure containment replaceable with the control rod assembly.
5. Operate 2000 (or TBD) cycles.
6. Survive DBEs.

Hardware

1. Full-scale scrammable inner control rod assembly including shock absorbers, magnets, and complete drive system.
2. Containment for the control rod assembly including the high-pressure seals with ID same as the reactor system ID and capable of being operated at the temperature and pressure of the ANS.
3. Seat switch hydraulic transition assembly located outside of and between the shock absorber's spring housing and the high-pressure containment.
4. Hydraulic (D_2O) system with pump, valves, flow indicators, pressure indicators, delta P indicators, and other instrumentation similar to that required for the ANS seat switch system.

A full-scale mock-up of the control rod drive system, including the high-pressure seals with a high-pressure container having an ID equal to the reactor system ID operating at the ANS pressure and temperature, is needed for this test.

Table A.8. Detect absorber position, scram, *down position* (rod seat switch)
Uncertainties and test functions

Requirement	Item	Uncertainties	Actions to eliminate uncertainties
1,2,3	1	Stopping position of the scrammed rod.	a. Analysis of the design.
1,3	2	D_2O (H_2O in test facility) flow rate to provide an acceptable flow and delta P signal.	a. Analysis of the hydraulic system. b. Testing of the hydraulic system and instrumentation.
1,3	3	Magnitude of FI and delta PI signal required.	a. Analysis. b. Investigation of available instruments. c. Testing prototype instruments. d. Expertise of I&C Division personnel.
4	4	Ability to replace control rod assembly with the hydraulic transition assembly attached to the control rod shock absorbers.	a. Analysis of design. b. Testing—Removing and reinstalling the control rod assembly in the full-scale mock-up.
5,6	5	Ability of seat switch system to operate 2000 (or TBD) times without failure.	a. Life-cycle test 2 times the required life.
5	6	High-pressure pulse during scram that may damage flow and pressure transducers.	a. Hydraulic analysis. b. Testing of transducers during life-cycle test.

High-Pressure Seal Functional Test Plan

Functions to be performed (Table A.9)

1. Limited subpile room volume
   a. **High-pressure seal**

Requirements

1. Ensure minimum leakage through seal ($\leq$TBD ml/s).
2. Provide for seal lifetime of TBD stokes at TBD mm/stroke.
3. Provide backup seal protection until core depressurization (seal at TBD MPa and TBD°C for TBD minutes).
4. Ensure ease of maintenance and seal replacement.
5. Ensure that erosion/corrosion is not a problem.
6. Ensure that seal functions do not degrade with temperature and neutronic heating.
7. Seal must pass a design hydrostatic test at TBD times core pressure and maximum coolant temperature at seal location. Hold pressure TBD minutes with total leakage less than TBD liters.

Hardware

1. Primary seal
2. Secondary seal
3. Rod wipe
4. Upper seal plate
5. Middle seal plate
6. Lower seal plate
7. Rod tube
8. D_20 supply system
9. Gas supply system
10. D_20 gas collection system
11. Leak-off storage and collection system as required.

Table A.9. Limited subpile room, volume *high-pressure seal*
Uncertainties and test functions

Requirements	Item	Uncertainties	Action to eliminate uncertainties	Test requirements/comments
1,2,3	1	Sealing capability of single primary seal for all failure modes (normal, upset, faulted)	a. Analysis b. Test (seal design development and materials)	Full-scale heated and pressurized test, rod motion and off-normal loadings.
2	2	Mechanical part wear	a. Analysis b. Material (wear test development test)	Laboratory test both wet and dry. Measure friction and wear of various materials.
5,6	3	Corrosion/erosion, breakdown of seal materials	a. Literature survey b. Autoclave test	Laboratory test at temperature and wet conditions over 2 years.
2,5,6	4	Galling or wear of seal on rod tube	a. Literature survey b. Wear test	Uncertainties Nos. 2 and 3 will guide test needs.
6	5	Thermal expansion/cooling between two materials (rod, seal, base plate)	a. Analysis (design to minimize ΔT effects) b. Test? (depends on analysis)	Analysis and uncertainties Nos. 2 and 3 will determine test requirements.
2,7	6	Deformation of rod and tubes (e.g., misalignment, side loads, bowing, pressure, vibration)	a. Analysis b. Mechanical tests	Full-scale wet test with prototypic conditions.
5	7	Crud buildup on seal surface (e.g., potential for denting tube, corrosion, pitting)	a. Analysis, literature survey b. Autoclave test	Analysis and uncertainty No. 3 will establish need and test requirements.
4	8	Maintenance of seals (e.g., ease of removal, draining of refueling stack)	a. Analysis b. Mock-up	Same component parts may be used here and in major tests.
6	9	Irradiation effects on seals (e.g., material/ breakdown, swelling, loss of strength)	a. Literature search b. Tests in HFIR may be required	Based on choice of material, capsule tests in HFIR may be needed.
6	10	Radiation-induced heating of seal and/or housing parts	a. Analysis (determine need for additional cooling) b. Thermal exponential coefficient test	Material test may be needed based on analysis.

Internal Distribution

1. R. E. Battle
2-6. J. H. Campbell
7. S. J. Chang
8. J. M. Corum
9. W. G. Craddick
10. G. F. Flanagan
11. R. G. Gilliand
12. R. C. Gwaltney
13-17. W. R.Hendrich
18. R. O. Hussung
19-22. R. L. Johnson
23. P. S. Litherland
24. C. R. Luttrell
25. J. A. March-Leuba
26. L. S. Oakes
27. F. J. Peretz
28. A. B. Poole
29. C. C. Queen
30. D. L. Selby
31. W. F. Swinson
32. C. D. West
33. G. T. Yahr
34. ORNL Patent Office
35-36. Central Reserach Library Document Reference Sect.
37. Y-12 Technical Library
38-39. Laboratory Records Dept.
40. Laboratory Records, RC

External Distribution

41. J. L. Anderson, 1041 W. Outer Drive, Oak Ridge, TN 37830.
42. U.S. Department of Energy, ANS Project Office, Oak Ridge Operations Office, FEDC, MS-8218, P.O. Box 2009, Oak Ridge, TN 37831-8218.
43-44. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, Tennessee 37831.
45. H. R. Payne, 836 Roderick Road, Knoxville, TN 37923.