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OAK RIDGE
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MARTIN MARIETTA

Operating Manual for the Critical Experiments Facility

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

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Operations Division
Technical Section

OPERATING MANUAL FOR THE CRITICAL EXPERIMENTS FACILITY

Compiled by
Critical Experiments Facility Staff

NOTICE: This document contains information of a preliminary nature. It is subject to revision or correction and, therefore, does not represent a final report.

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
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1. INTRODUCTION AND GENERAL PRINCIPLES OF OPERATION

The operation of the Critical Experiments Facility (CEF) requires careful attention to procedures in order that all safety precautions are observed. Since an accident could release large amounts of radioactivity, careful operation and strict enforcement of procedures are necessary. To provide for safe operation, detailed procedures have been written for all phases of the operation of this facility.

The CEF operating procedures are not to be construed to constitute a part of the Technical Specifications. In the event of any discrepancy between the information given herein and the Technical Specifications, limits set forth in the Technical Specifications apply.

All normal and most emergency operation conditions are covered by procedures presented in this manual. These procedures are designed to be followed by the operating personnel. Strict adherence to these procedures is expected for the following reasons.

1. To provide a standard, safe method of performing all operations, the procedures were written by reactor engineers experienced in supervising the operation of reactors and were reviewed by an organization with over 30 years of reactor operating experience.

2. To have an up-to-date description of operating techniques available at all times for reference and review, it is necessary that the procedures be written. In addition to reference by the operating personnel, the procedures furnish a valuable text for training new staff members, and it is absolutely essential that they represent the current practices. Various DOE and ORNL committees periodically review the CEF operation; and for these reviews to function constructively, it is necessary that an accurate description of the operating procedures be available.

1.1 GENERAL OPERATING POLICIES

1.1.1 Safety

Safe operation of the CEF will take precedence over other considerations.

1.1.2 Operating Personnel

The minimum number of operators for CEF operation will be two persons. One of these will be licensed as a senior reactor operator. The other may be a reactor operator or an operator-in-training.

1.1.3 Operating Log

A log will be maintained by the operating personnel to provide a detailed diary of CEF operation.

1.1.4 Changing Assembly Reactivity

Operations affecting changes in assembly reactivity, i.e., SPERT-plate and poison-strip additions/removals, etc., shall be directly supervised by a person qualified as a senior reactor operator.

1.1.5 Malfunction of Systems While Operating

Any malfunction or abnormal operation of the control or auxiliary systems should be immediately brought to the attention of the Senior Reactor Operator. The decision as to whether to continue testing depends upon the severity of the malfunction. It remains with the Senior Reactor Operator as to what immediate actions need to be taken. However, any operator is authorized, in the absence of the Senior Reactor Operator from the control room, to place the CEF in a safe shutdown mode if it is deemed necessary.

1.1.6 CEF Operating Parameters

The CEF shall be operated under conditions and limitations as set forth in the Oak Ridge Critical Experiments Facility Technical Specifications (ORNL/TM-9525).

1.2 DEFINITIONS

The terminology used in these procedures is defined as follows:

ASSEMBLY - the combination of various components (including the inner and outer fuel components, SPERT fuel plates and the SPERT box assembly, poison strips, and the water reflector/moderator) placed together in the CEF test tank for the purpose of measuring the <u>assembly</u> reactivity.

FUEL COMPONENTS - either the inner fuel annulus or the outer fuel annulus, usually placed together in the test tank but separated outside the test tank.

STARTUP - the daily initial use of the facility after the Daily Instrument Checklist and Startup Checklist are completed and approval is given to commence reactivity measurements.

RUN - The filling of the test tank with water after an assembly has been placed in the tank will constitute a <u>run</u>.

REACTIVITY MEASUREMENTS - Measurements performed on one matched set of fuel components with or without additional components (i.e., SPERT plates or poison strips) to determine assembly reactivity.

2. FUEL HANDLING

2.1 RESPONSIBILITIES

One senior reactor operator is assigned the responsibility for the overall safety of operation, including fuel handling. At least one senior reactor operator must be present during all handling of fissile material.

The Material Balance Area (MBA) Custodian is responsible for ensuring that all shipments and receipts are verified correctly and that documentation (waybills, inventories, receiving reports, shipping orders, etc.) is transmitted properly according to Y-12 regulations and DOE Order 5630.2.

2.2 PRECAUTIONS AND CONDITIONS FOR HANDLING

2.2.1 Fuel Assemblies

Operators shall wear clean cotton gloves while handling fuel components to ensure fingerprints and foreign contaminants (i.e., oil, grease, etc.) are not transferred to the surface of the components. During all phases of fuel component handling, the operators shall be careful to keep foreign articles from entering the coolant channels. All fuel components (inner and outer) shall be smeared after being emptied from the shipping containers and again before loading into the containers for shipment to ensure they are free from contamination.

2.2.2 Fuel Handling Tools

The fuel handling tools shall be stored in dust-free plastic bags during the time the CEF is not in operation. Prior to each series of tests, the tools shall be visually inspected for any damage that might have occurred since they were last used. The tools shall be smeared prior to and after each series of reactivity measurements to ensure that they are free from contamination.

2.2.3 Fuel Shipping Containers

Empty fuel shipping containers which are to be shipped must have two "EMPTY" tags attached. Any other non-applicable tags should be removed. The containers should be visually inspected after the fuel assemblies are removed. Any containers requiring repair should be reported by container number to the HFIR Quality Department representative.

2.3 HANDLING PROCEDURES

2.3.1 Unloading from Container

1. When the special vehicle containing the fuel components arrives, remove the fuel shipping containers individually using an approved fork lift operated by a licensed fork lift driver.

2. Place the container in the crane bay area of the West Cell.

3. Verify the container serial number and seal number.

4. Remove the seal.

5. Remove the bolts and nuts and lift the lid.

6. Carefully remove the fuel component plastic covering.

7. Lower the appropriate fuel handling tool by crane and attach it to the fuel component.

8. Engage the fuel handling tool by rotating the three cams 90° clockwise.

9. Slowly raise the fuel component out of the container up to the second floor.

10. Verify the fuel component number and visually inspect the component for damage and foreign particles.

11. Place the component on the acrylic stand and store as per NSR-8291.

12. Remove the fuel handling tool.

13. Inspect the interior of the container for damage, then replace the lid and store the empty container in a dry area.

2.3.2 Handling for Reactivity Measurement

2.3.2.1 Outer Fuel Component

1. Lower the outer-fuel handling tool into the outer fuel component, rotate the locking cams clockwise 90°, and verify proper engagement of the handling tool.

2. Slowly raise the component from the acrylic floor stand and transfer it to the test tank by positioning the crane to align with the pre-positioned markings. Precautions should be taken to ensure that the component does not collide with any objects while being handled.

3. Slowly lower the component onto the positioning disk in the bottom of the test tank and seat the component in the groove. Use a level to verify that the component is not tilted.

4. Disengage the handling tool by rotating the cams counterclockwise 90° and carefully raise the tool from the test tank to prevent unnecessary contact between the fuel component and the handling tool.

5. Reverse this order for component removal from the tank.

2.3.2.2 Inner Fuel Component

1. Follow the same component transferring procedures as described in 2.3.2.1. Use the inner-fuel handling tool. As the inner fuel component is lowered in its place, place two 3/8-in.-thick plastic spacers opposite each other on top of the outer fuel assembly's inner side plate. The spacers ensure that no air will be trapped between the fuel components as water fills the tank; failure to install these may affect the reactivity value by as much as $1.

2. Remove the handling tool.

3. Verify that no foreign objects have been left in the test tank.

4. Reverse this order for component removal from the tank.

2.3.3 Loading Into Container

1. Position an appropriate (i.e., inner or outer) empty container in the crane bay area with the fork lift.

2. Remove the lid and inspect the interior for damage.

3. Insert the appropriate fuel component handling tool into the component and engage it by rotating the cams 90° clockwise. Record the fuel component number.

4. Insert the fuel component slowly with the crane into the empty container.

5. Place a piece of non-clear plastic over the top of the fuel component to prevent dirt or other foreign matter from dropping into the coolant channels.

6. Place the lid on the container.

7. Place all bolts and nuts on the container and tighten.

8. Place a cup seal on the container and record the seal and container numbers in the Seal Log Book.

9. Move the container to temporary storage until it is picked up by the special vehicle for transport back to the storage vault.

3. REACTIVITY TEST PROCEDURE

3.1 INTRODUCTION

The test to determine how much reactivity is required to achieve criticality with a submerged HFIR fuel assembly is performed in steps. Prior to performing the reactivity tests on untested HFIR fuel assemblies, a reactivity test will be performed on a HFIR fuel assembly that has been previously tested. The results of this measurement should agree with previously obtained results to within ±15¢. Although all assemblies tested to date have been subcritical when submerged, a criticality test is made initially using the assembly only (i.e., without the addition of any SPERT plates or poison strips); this is primarily a safety precaution. After the initial test, the water is completely drained from the tank, two SPERT plates are added to the target region, and the criticality test is repeated. The HFIR assemblies tested to date have been from about $1.50 to $3.65 subcritical when submerged in water. Since the first two added SPERT plates are worth $2.40, some of the assemblies were critical during the second run. If they were not, the water was drained, two more SPERT plates and some poison strips were added, and the criticality test was repeated. Additional reactivity adjustments are made, if necessary, by adjusting the assembly reactivity until the assembly is only slightly supercritical with the water at the completely full level. No more than two SPERT plates are added to the assembly between attempts to achieve criticality. Procedures for performing the reactivity tests are given in Section 3.4.

3.2 PERSONNEL REQUIREMENTS

Approval for a reactivity measurement to be performed must be given by the Senior Reactor Operator in charge and noted on the Startup Checklist. A minimum of two persons, one of whom is a senior reactor operator, must be present during any reactivity measurement. The number of persons, including visitors, present in the control room during a reactivity measurement shall be at the discretion of the Senior Reactor Operator in charge. The Senior Reactor Operator in charge will direct the activities of all personnel in the control room and will assume the responsibility of making any necessary decisions. Any deviations from an established reactivity measurement program must be reviewed and approved by at least two senior reactor operators.

3.3 INSTRUMENTATION REQUIREMENTS

The minimum number of reliable instrument channels required to be in service for a reactivity measurement are: two safety channels, two measuring channels which may be the same as the safety channels, and the radiation-alarm channel. If this requirement cannot be met before reactivity measurements are to commence, the system must be shut down.

3.4 REACTIVITY MEASUREMENTS

3.4.1 First Run

1. Complete the Daily Instrument Checklist and the Startup Checklist as described in Section 4. Install the fuel components, without SPERT plates and poison strips, in the test tank and record the identifying number in the log. Check the logbook for any special instructions or conditions.

2. Ensure that the instrument-channel trips are reset.

3. Ensure that the recorder chart drives are energized and properly tracking.

4. Ensure that the range-selector dial for the IC-1 and IC-2 channels is set on "3×10^{-12}" and that no safety channels are bypassed.

5. Depress the "Scram Reset" button on the console.

6. Momentarily place the right-hand "Water" switch in the "Set" position and then return it to the "Hold" position. (The "Set" and "Hold" lights above the switch will turn on at this time.)

7. To insert the startup source, place the "Source" switch in the "In" position until the "In" light above the switch turns on. Verify by observing through the cell window that the source has been inserted. Enter the "Source Inserted" stamp in the logbook, and enter date, time, and signature in the log.

8. Place the left-hand "Water" switch in the "Feed" position. The "Pump" light above the switch will turn on, and after about 2 to 3 seconds, the adjacent "Feed" light will turn on indicating that the feed valve has opened. Hold the switch in the "Feed" position while observing the water level in the manometer tube. Observe the instrumentation for evidence of significant neutron multiplication.

   NOTE: As the water enters the test tank, there probably will be a slight increase in the ionization chamber readouts as the source neutrons are initially reflected; then, as the water starts to shield the source, the detected count rate will begin to decrease.

9. Remove entrapped air in the flexible hose connecting the test tank with the manometer.

10. Continue adding water to the test tank, while observing the nuclear instrumentation, until the water completely covers the fuel assembly (about 58.8 cm on the manometer). This should be observed through the viewing window.

11. Withdraw the neutron source from the test tank and verify that the assembly is subcritical by observing a decrease in neutron level as indicated on the chart recorders.

12. Completely drain the water from the test tank and record in the logbook that the assembly was subcritical for this test run.

13. Proceed with Section 3.4.2.

3.4.2 Second Run

<u>NOTE</u>: All operations within the test cell at the CEF shall be conducted in such a manner that personnel exposures to radiation are maintained at a level as low as reasonably achievable (ALARA). Radiation levels shall be monitored with a Cutie Pie upon each entry following a reactivity measurement run. Radiation exposure guidelines of the ORNL Health Physics Manual will be strictly adhered to.

1. Enter the test cell and add two SPERT plates (D-3224 and D-5495) to the target region of the assembly in accordance with Section 3.5.2. These two plates will add about $2.40 of reactivity to the assembly.

2. After positioning the SPERT plate box, ensure that all personnel have exited the cell prior to continuing the test run.

3. Commence the second test run by repeating Steps 2 through 10 of Section 3.4.1. If the assembly becomes supercritical with a short period (<30 s), immediately "dump" the water and enter the cell to insert poison strips.

4. If the assembly becomes critical at a water level significantly below 58.8 cm, withdraw the neutron source after significant neutron multiplication has been observed on the instrumentation.

5. Allow the neutron level to rise approximately one decade but normally no higher than N_L on the log-N recorder and level the power by adjusting the water level. Change the IC-1 and IC-2 range settings (<u>ALWAYS DEPRESS THE "OUTPUT BYPASS" BUTTONS WHEN CHANGING RANGES</u>), as needed, to maintain the readouts on the recorder scale and to prevent a scram from these channels.

<u>CAUTION</u>

<u>DO NOT EXCEED A RANGE SETTING IN EXCESS OF FIVE DECADES ABOVE THE BACKGROUND READING OBTAINED AFTER THE ASSEMBLY OF THE FUEL AND SPERT PLATES IN THE TANK WITH THE NEUTRON SOURCE INSERTED. DO NOT IN ANY CASE EXCEED A RANGE OF 10 x 10^{-7}.</u>

6. Record the "Critical" water level in the logbook and drain the water from the test tank. Compute the assembly reactivity as outlined in Section 3.6.

7. If the assembly becomes critical at a water level near but slightly below the completely full (58.8 cm on the manometer) level, follow the procedure in Section 3.4.3.

8. If the assembly is subcritical when the water is at the completely full level (58.8 cm on the manometer), which it will be for the majority of second test runs, record this fact in the logbook.

9. Allow the subcritical neutron multiplication effect to steady out with the source still inserted until a relatively stable period is obtained. Record the readings of both IC-1 and IC-2 in the logbook. Refer to Figs. A-1 and A-2 of Appendix A to determine the approximate subcritical reactivity worth of the assembly. These data have been determined from previous HFIR fuel assembly reactivity measurements. Using the subcritical reactivity worth of the assembly and Table 1, determine the number and reactivity worth of the poison strips, and two additional SPERT plates, necessary for a slightly supercritical (approximately 10¢) assembly.

10. Withdraw the neutron source and completely drain the water from the test tank. Enter the cell and adjust the reactivity by inserting the two additional SPERT plates (D-3242 and D-2870) and the poison strips in accordance with Section 3.5. Proceed with Section 3.4.3.

3.4.3 Third and Subsequent Runs

1. After positioning the SPERT plate box and the poison strips and reassembling the fuel assembly in the test tank, ensure that all personnel have exited the test cell prior to commencing the next run.

2. Commence the next run by repeating Steps 2 through 10 of Section 3.4.1. If the assembly does not reach criticality, repeat Steps 8 through 10 of Section 3.4.2, removing the poison strips as necessary. If the assembly becomes supercritical with a short period (<30 s), immediately "dump" the water and enter the cell to insert additional poison strips.

3. The assembly is expected to go critical at a water level slightly below the completely full level (58.8 cm on the manometer). Continue adding water to the test tank until the fuel assembly is completely covered with water. Withdraw the neutron source after significant neutron multiplication has been observed on the instrumentation.

4. While the neutron level is increasing, measure the time for the neutron level to rise from 20% scale to 54% scale (one period) on both IC-1 and IC-2. Record these times. Repeat this step as many times as possible until the assembly neutron level has increased one decade as observed on the log-N recorder. Change the IC-1 and IC-2 range settings (ALWAYS DEPRESS THE "OUTPUT BYPASS" BUTTONS WHEN CHANGING RANGES), as needed, to maintain the readouts on the recorder scale and to prevent a scram from these channels.

CAUTION

DO NOT EXCEED A RANGE SETTING IN EXCESS OF FIVE DECADES ABOVE THE BACKGROUND READING OBTAINED AFTER THE ASSEMBLY OF THE FUEL AND SPERT PLATES IN THE TANK WITH THE NEUTRON SOURCE INSERTED. DO NOT IN ANY CASE EXCEED A RANGE OF 10×10^{-7}.

5. Allow the neutron level to rise approximately one decade, but normally no higher than N_L on the log-N recorder, and level the power by adjusting the water level.

6. After it has been determined that the assembly is slightly supercritical and all readings are taken, completely drain the water from the tank and allow the fission products to decay before continuing operations in the cell.

7. Cut out the section of recorder paper from the log-N recorder which shows the neutron level increase of at least one decade. Measure the time it took the neutron level to increase one decade (one minute per division) and compute the period as follows:

   $\tau = t/\ln 10$,

   where

   τ = assembly period (s)

   t = time for neutron level to increase one decade.

   Tape this cutout section in the log, annotated with assembly number and period.

8. Average this result with those obtained in Step 4 to determine the period of the fuel assembly. Determine the reactivity worth of the period from Tables A-1 and A-2 of Appendix A. Calculate the reactivity worth of the element as shown in Section 3.6 and record that value in the logbook.

9. The difference between the computed reactivity and $2.40 is the amount the assembly was subcritical in the second run. Record this subcritical amount with the readings of IC-1 and IC-2 recorded in Step 9 of Section 3.4.2.

3.5 REACTIVITY ADJUSTMENTS

3.5.1 Introduction

To decrease reactivity, poison strips are inserted between the plates of the outer fuel component. There are two types of poison strips: stainless steel strips containing natural boron and stainless steel strips containing enriched boron. The strips containing enriched boron have two holes at the top; those containing natural boron have none. The reactivity worths of the poison strips are given in Table 1.

To increase reactivity, SPERT fuel plates are added, in pairs, to the flux-trap region, with or without the concurrent addition of poison strips. However, no more than two SPERT fuel plates will be added between attempts to achieve criticality. The reactivity worths of these plates are given in Table 1.

Reactivity adjustments in the positive direction, i.e., by the addition of SPERT fuel plates, are made while the complete fuel assembly is assembled in the test tank. Such adjustments are always made with the test assembly in the "dry" condition, i.e., with the water completely drained from the test tank.

Reactivity adjustments in the negative direction, i.e., by the addition of poison strips to the outer fuel component, are made with the outer fuel component outside the test tank primarily in order to ensure proper vertical alignment of the poison strips.

Table 1. Reactivity worth of SPERT plates and poison strips

SPERT plates:	Two plates (D-3224 and D-5495)	\$2.40 ± 0.07
	Four plates (two above and D-3242 and D-2870)	\$3.91 ± 0.15
	Each plate contains about 14 grams of enriched U-235.	
Poison Strips		Reactivity worth (cents)
Natural strips	#3	13.35
	#4	13.03
	#5	13.91
Enriched strips	#1	25.8
	#2	26.0
	#3	27.4
	#4	26.1
	#5	27.6
	#6	26.5
	#7	25.9

The ultimate "target" of all reactivity adjustments is to obtain an adjusted assembly reactivity of approximately 10¢ supercritical with the water at the completely full level (58.8 cm on the manometer). Experience has shown that assembly reactivities in this neighborhood permit complete filling of the tank before undesirably high power levels and/or short periods are attained.

3.5.2 Inserting SPERT Fuel Plates

NOTE: The SPERT fuel plates and SPERT box components are not stored at the CEF but are shipped in along with the fuel components. Upon receipt of the SPERT plates and components, they are transferred to the test cell work table where they are stored throughout CEF operations when not in use.

1. For the first addition, insert two SPERT plates in the extreme outer slots of the SPERT box at opposite sides from each other, and then install the box in the flux trap region of the drained fuel assembly. (There is a rod through the assembly which is threaded on the end; this end is screwed into the receptacle in the bottom of the test tank.)

2. Check the elevation of the fuel plates in the SPERT assembly relative to the elevation of the fuel plates in the HFIR inner fuel component; they should be within 1/16 in. of each other. A small 1 3/4-in.-long sleeve-type spacer is used on the securing rod to raise the SPERT plates as needed.

3. After the SPERT assembly is installed, place the acrylic cross over the securing hex nut of the SPERT assembly box to ensure that the SPERT assembly remains stationary and centered.

4. For the second addition, insert two SPERT plates, one next to each of the first two plates, and reinstall the assembly box as in Steps 2 and 3.

3.5.3 Inserting Poison Strips

1. If the SPERT plate box is installed, remove it.

2. Remove the inner fuel component from the test tank and transfer it to a floor storage stand.

3. Remove the plastic spacers.

4. Remove the outer fuel component from the tank; leave it suspended from the crane to allow a visual check for proper vertical alignment of the poison strips as they are inserted.

5. Select the desired poison strips from the test cell work table and insert them between the fuel plates (in the outer annulus only); distribute them evenly around the annulus and center them by moving them radially until they align with the holes in the top center of the fuel plates. Verify that the strips are fully inserted to the bottom of the black marking tape and that they are vertical. Check alignment from the bottom end of the annulus.

6. Reinstall the HFIR outer fuel component in the test tank.

7. Reinstall the HFIR inner fuel component in the test tank.

8. Reinstall the SPERT plate assembly, following the procedure given in Section 3.5.2.

3.6 COMPUTING ASSEMBLY REACTIVITIES

The reactivity of the fuel assembly is computed as follows:

$$\text{Reactivity} = -A + B + C \quad ,$$

where,

A = worth of added fuel plates,

B = worth of added poison strips, and

C = reactivity associated with positive period where C is computed as in Section 3.6.1.

3.6.1 Period Measurement Methods

1. Using a stopwatch, measure the time it takes the linear channel power level (IC-1 and IC-2) to increase from 20% scale to 54% scale (one decade) and record this time.

2. Determine the number of seconds it takes for the neutron level to increase by one decade on the log-N recorder chart (one division equals 60 seconds). Divide this value by the natural logarithm of 10. Record this time.

Average the period measurements obtained by methods 1 and 2 above. This is the period of the excess reactivity. Obtain the reactivity associated with this period from Tables A-1 and A-2 of Appendix A.

If the assembly reaches criticality at a water level significantly below 58.8 cm (as described in Section 3.4.2), the variable C above will be the reactivity associated with the difference between the "critical water level" and 58.8 cm. These values are recorded in Table A-3 of Appendix A.

4. INSTRUMENT CALIBRATION PROCEDURES

The procedures listed in Sections 4.1 through 4.4 will be performed by personnel from the Instrumentation and Control (I&C) Division. The results of these calibrations will be recorded on I&C forms and maintained in the CEF Instrument Surveillance Notebook which is kept in the CEF Control Room.

4.1 LINEAR SAFETY CHANNELS

4.1.1 Test Equipment

1. Current source providing currents ranging from 10^{-12} to 10^{-6} A (Keithley Model 261 or CEF Model SF-1, operated in current mode).

2. General purpose volt-ohm-milliammeter (VOM) (Triplett Model 630 or equal).

3. Meter stick.

4. Two neutron sources with neutron emission rates of the order of 10^6 and 10^7 neutrons/s (PU-BE-004(M-43) and PU-BE-018(M-525) or equal).

4.1.2 Signal Processing Unit (SPU) Operating Characteristics

1. Set SPU on least sensitive range.

2. Disconnect detector signal cable from SPU input and attach grounding plug to open end of cable.

3. Connect current source to SPU input.

4. Adjust source to provide a positive current signal of 10^{-12} A.

5. Switch SPU to range of 10^{-12} A full scale.

6. Record value of applied current, SPU range, panel meter deflection, corresponding current, and recorder deflection.

7. Repeat Step 6 for SPU range setting of 3×10^{-12} A full scale.

8. Repeat Steps 4 through 7 for signals of 10^{-11}, 10^{-10}, 10^{-9}, 10^{-8}, and 10^{-7} A, switching SPU ranges in decade steps to correspond to applied signals.

9. Tabulate data, noting deviations from linearity.

10. Compare data with previous operating characteristics. If nonlinearities are significantly greater than those of earlier observations, remove SPU for bench maintenance.

4.1.3 Scram Set Point

1. Set SPU to current range near low end of operating range, such as 3×10^{-12} A full scale.

2. Adjust source signal to produce full-scale deflection on panel meter.

3. Record SPU range, input current, panel meter deflection, and recorder deflection.

4. Change SPU to next higher current range.

5. Record SPU range, meter deflection, and recorder deflection.

6. Return SPU to setting of Step 1.

7. Increase applied current, driving meter off-scale, until output circuit trips. A trip condition is indicated by illumination of a red pilot lamp on the output panel.

8. Switch SPU to range of Step 4 and reset trip circuit.

9. Record SPU range, applied current, panel meter deflection, and recorder deflection. A value of current between 110% and 150% of that recorded in Step 3 is acceptable.

10. If trip point is outside of acceptable range, adjust trip level control and repeat Steps 6 through 9.

11. Repeat Steps 1 through 10 for mid-range current, such as 3×10^{-10} A full scale.

12. Repeat Steps 1 through 10 for high-range current, such as 10^{-7} A full scale.

13. Upon satisfactory completion of test, remove current source signal cable from SPU input, with SPU on least sensitive range.

14. Remove ground plug from detector signal cable and reconnect cable to SPU input.

4.1.4 Battery Condition

1. Remove HV cable to detector from battery box.

2. Using VOM, measure and record no-load battery voltage.

3. With VOM set to read dc current, measure and record current throughout limiting resistor.

4. If voltage and current readings are less than 95% of rated values marked on the battery box, faulty battery should be replaced.

5. Reconnect detector HV cable to battery box.

4.1.5 Ionization Chamber

1. Record identification number of ionization chamber.

2. Place chamber in paraffin; moderator can be mounted approximately 3 ft off the floor.

3. Measure and record background current as indicated on SPU readout. Area should be cleared of neutron and gamma sources. Presence of any such sources which cannot be removed should be noted.

4. Mount neutron source with emission rate of about 10^6 neutrons/s at 1 m from centerline of sensor.

5. Record current reading, source strength, and source distance.

6. Repeat Steps 4 and 5 with source having an emission rate of about 10^7 neutrons/s.

7. Calculate chamber sensitivity using the following equation:

$$S = 4\pi d^2 A/N = 12.57 \times 10^4 \, (I_n - I_b)/N \quad ,$$

where

S = sensitivity,

I_n = source current,

I_b = background current,

N = source strength (emission rate) in neutrons/s,

d = source distance in centimeters, and

A = chamber current in amperes.

4.2 SCINTILLATION DETECTOR SAFETY CHANNELS

4.2.1 Test Equipment

1. Variable voltage source providing dc voltage adjustable from 0.01 to 50 V, such as CEF SG-1, operating in the voltage mode.

2. FET-input VOM (Weston Model 666, or equal).

3. Electrostatic voltmeter (ESVM)(Sensitive Research Model ESD, or equal).

4. Gamma-ray source with strength of the order of 0.01 curie.

5. Dummy load - 1.5 megohm, 2-W resistor mounted in coax plug.

4.2.2 Signal Processing Unit (SPU)

1. Disconnect detector signal cable from SPU input.

2. Before connecting source, set SG-1 on minimum voltage range.

3. Attach T-conector to SPU input.

4. Check SPU "Zero." Adjust as needed, recording amount of zero offset and adjustment required to rezero.

5. Connect voltage-source signal cable and VOM leads to SPU input.

6. Adjust SG-1 for applied signal of 0.1 V, negative.

7. Record SG-1 settings, applied voltage, SPU panel meter readings, and recorder range and deflection (where applicable).

8. Repeat Step 7 for 0.1-V increments of applied signal until almost to full-scale deflection of the readout.

9. Adjust source to produce full-scale deflection on the readout.

10. Record SG-1 settings, applied voltage, panel meter readings, and recorder deflection and range (where applicable).

4.2.3 Scram Set Point

1. Increase applied voltage until output circuit indicates a trip condition.

2. Record SG-1 settings, applied voltage, and panel meter readings.

3. Reduce input signal to bring readout on scale and reset trip circuit.

4. Repeat Steps 1 through 3 until a minimum of five trip point readings has been recorded.

5. Acceptable level for trip signal is between 110% and 150% of that which produced full-scale deflection on the readout. If the trip point readings are not reproducible within this range, adjust the trip level setting and repeat Steps 1 through 4.

NOTE: Steps 6 through 9 apply to those channels having a secondary, backup trip point.

6. Increase applied voltage until secondary trip point is reached.

7. Record SG-1 settings, applied voltage, and panel meter readings.

8. Reduce signal level until secondary trip resets.

9. Repeat Steps 6 through 8 for a total of five sets of readings.

10. After completion of trip point determination, remove voltage source, VOM, and T-connector from SPU input.

11. Reconnect detector signal cable to SPU input.

4.2.4 High Voltage Power Supply (HVPS) Calibration

1. Reduce HVPS settings for minimal output.

2. Disconnect detector HV cable from HVPS output.

3. Attach T-connector to HVPS output.

4. Connect ESVM and dummy load to T-connector.

5. Adjust HVPS settings to produce a reading of 600 V on the ESVM.

6. Record value of dummy load, HVPS settings, and meter readings (if meter included) and ESVM reading.

7. Repeat Step 6 for 50-V increments as noted on ESVM up to a limit of 1400 V.

8. Plot HVPS setting vs output volts (ESVM).

9. Reduce HVPS settings for minimal output.

10. Remove test connections.

11. Reconnect detector HV cable to HVPS output.

12. Set HVPS to specified operating level.

4.2.5 Detector Sensitivity

1. Identify detector components.

2. Be sure the detector is in a position such that the gamma-ray source may be moved from a distance of 1 m to contact with face of light shield.

3. Set HV to 700 V.

4. With no source in the area, record background level from all readout devices.

5. Identify source to be used by number and strength.

6. Position source at a distance from the detector which produces a noticeable change of readout from background.

7. Record source distance and readout levels.

8. Reduce source distance in steps until in contact with detector or channel has tripped.

9. At each step, record source distance and readout levels.

10. Repeat Steps 4 through 9 for the following:

    HV = 800 V,
    HV = 900 V,
    HV = 1000 V,
    HV = 1100 V, and
    HV = 1200 V.

11. Plot relationship between dose and high voltage at trip point.

12. Plot readout levels vs source distance for each operating voltage.

13. Reset channel to operating conditions.

4.3 SCRAM TIME MEASUREMENT

4.3.1 Test Equipment

1. Safety Channel. Scintillation channel, chosen for fast response time and compatibility with test signal.

2. Signal Generator. Variable voltage source providing dc voltage adjustable from 0.01 to 50 V.

3. Dual-Trace Oscilloscope and Camera.

4. The dc Voltage Supply. Reference voltage for primary safety action monitoring circuit.

5. Contact probes. As needed to indicate time at which primary safety action occurs.

4.3.2 Test Signal Adjustment

1. Disconnect detector signal cable from safety channel SPU input.

2. Connect signal generator output to SPU input, one channel scope vertical input, and scope trigger input.

3. Set signal generator (SG-1) on 10-V range, vernier at 0, and polarity negative.

4. Increase signal to level at which channel trips.

5. Record range and vernier settings on SG-1, scope input sensitivity, and vertical deflection of scope trace.

6. Increase signal to level approximately ten times that recorded in Step 5.

7. Record range and vernier settings on SG-1, scope input sensitivity, and vertical deflection of scope trace.

8. Adjust scope trigger circuit so that negative input signal triggers sweep in SINGLE SWEEP mode.

9. Switch SG-1 off.

10. Reset safety channel.

4.3.3 Monitor Setup

1. Locate the probe assembly in the drain line opening below the bottom of the test tank.

2. Connect assembly to motor connector, M-3, on top of large cylindrical tank.

3. Connect jumper from CP-5 to second vertical input of scope.

4. Feed liquid until in contact with probe.

5. Record probe current.

6. Drain liquid in jogs, or raise probe slowly, until contact is broken.

7. Observe and record minimum probe current before drop to zero.

8. Adjust liquid level or probe position so that probe current is minimal for contact.

9. Adjust vertical sensitivity of scope to provide significant change in vertical position as probe and liquid break contact.

10. After final level adjustment, record input sensitivity of scope and probe current.

4.3.4 Test

1. Bypass scram for safety channel in use.

2. Recheck single sweep triggering of scope, Step 8, Section 4.3.2.

3. Check to be sure that SG-1 is off and channel trip is reset.

4. Remove scram bypass.

5. Check scope settings: SINGLE SWEEP mode reset; vertical amplifiers in CHOPPED mode; time base appropriately set, usually 50 ms/div; trace INTENSITY and grid line ILLUMINATION at levels to produce good quality double sweep photograph (done by internally triggering single sweep).

6. Open lens shutter in BULB mode, apply trip signal (see Step 7 in Section 4.3.2), observe sweep to be sure time mark is on trace, and close shutter at end of sweep.

7. Process film.

8. Determine scram time from photograph.

   a. Mark on input signal trace the point at which deflection is equivalent to that noted in Step 5, Section 4.3.2. This is channel trip level.

   b. Mark on second trace the point indicating specified displacement.

      NOTE: This is the point of initial change in vertical position of the trace.

   c. Measure time interval between the two marks. This is the scram time.

9. Check calibration of the time base by photographing 60-Hz signal and using this time reference (6 cycles = 100 ms) in comparison with grid line spacing (2 div = 100 ms = 6 cycles, for 50 ms/div time base).

4.3.5 Restoration of Normal Operating Conditions

1. Reset scram.

2. Remove all jumpers and probes used in test.

3. Disconnect signal generator from SPU input.

4. Reconnect detector signal cable to SPU input.

4.4 LOGARITHMIC MONITOR CHANNEL

4.4.1 Preliminary Channel Check

1. Check channel components, record the type, manufacturer, model number, and serial and/or property number of each unit, and verify that interconnecting cables are properly made up.

2. Check the condition of the battery source to verify its operability. If unit is faulty, replace with good unit, logging the condition and identity of this replacement bias supply (see Section 4.1.4 of this procedure for details).

3. Verify that ac power is applied to the signal processing unit ("POWER" switch is "ON" and pilot lamp is illuminated).

4. Verify that ac power has been applied to the strip chart recorder associated with this channel ("INSTRUMENT POWER" switch is "ON").

NOTE: Normally, the SPU and the recorder remain powered between runs in an experimental series. A unit is deenergized only when shut down for maintenance or for anticipated long periods between operations at the facility.

5. Turn "CHART DRIVE" switch "ON."

6. Verify that the recorder pen is inking properly and that there is an adequate supply of ink in the reservoir.

4.4.2 SPU Internal Calibration

1. Depress "CAL" toggle switch on the front panel to the "HI" position and hold down.

2. Note the readout on the panel meter and recorder. Panel meter should read "10^{-8}" and recorder should read "10," the level corresponding to an input signal of 10^{-8} A.

NOTE: Any adjustment to correct for error in the panel meter reading is internal to the instrument and should be performed only by qualified maintenance personnel.

3. If recorder reading is not equivalent to 10^{-8} A, adjust "RECORDER ADJ" pot on front panel to the left of the picoammeter so that level is "10."

4. Raise "CAL" toggle switch to the "LO" position and hold up.

5. Note the readout on the panel meter and the recorder. Panel meter should read "10^{-11}" and recorder should read "0.01," the level corresponding to an input signal of 10^{-11} A.

<u>NOTE</u>: Any adjustment to correct for error in the panel meter reading is internal to the instrument and should be performed only by qualified maintenance personnel. Normally, no adjustment is needed to obtain the correct calibration level in the "LO" setting.

6. Release "CAL" toggle switch, allowing it to return to neutral position. SPU is now reading signal applied to its input connector.

4.4.3 **SPU Response Check**

1. Remove signal input cable from receptacle in the rear of the unit and attach a shorting plug to the cable termination.

2. Connect a picoampere source to the SPU input.

3. Apply a signal of 1.0×10^{-12} A and record panel meter and recorder readings.

4. Repeat Step 3 with input of 1.0×10^{-11} A.

5. Repeat Step 3 with input of 1.0×10^{-10} A.

6. Repeat Step 3 with input of 1.0×10^{-9} A.

7. Repeat Step 3 with input of 1.0×10^{-8} A.

8. Repeat Step 3 with input of 1.0×10^{-7} A.

9. Compare readouts to input signal. Refer to instrument file for past calibration records to see if there is a significant shift in SPU linearity. If linearity is satisfactory, unit is ready for operations; otherwise, bench maintenance is required.

10. Remove picoampere source and reconnect signal cable.

4.4.4 **Channel Response**

1. Perform ionization chamber sensitivity check, according to Section 4.1.5 of this procedure.

2. Place gamma source which is used for the daily instrument response tests against the ionization chamber housing (detector should be mounted in its operating position beside the reflector tank) and move along the surface until a maximum signal level is noted on the channel readout. Mark source position on the housing and record

the maximum signal level with source in contact with the housing. This center of the sensor should be aligned with the midplane of the elements under test. Reposition housing, as needed.

4.5 RADIATION MONITORING SYSTEM TEST

This test shall be conducted on a monthly basis during CEF operation and on a quarterly basis when operations are not in progress. This test shall be conducted in such a way that the three monitor trip set points are each verified semiannually to be no higher than 40 R/h (normally set for 1 R/h).

1. Contact Y-12 PSS to arrange for a convenient time to conduct the test.

2. Upon signal from PSS ensuring that the test tape has been inserted into the PA system and that a PSS representative is stationed at the top of the hill to monitor the vehicular access warning lights, adjust the set point on one of the three monitors to lock in a trip at the background reading.

3. Enter the cell and place a radioactive source at the base of a second monitor detector. The trip of this monitor will cause a 2 of 3 coincidence trip to activate the building evacuation alarm. Ensure that the following actions occur:

    a. Alarm light lit on main monitor panel and on panel in Room 202.

    b. All air-handling equipment shuts down.

    c. Transmission of the alarm signal to Y-12 PSSO.

    d. Activation of the warning lights to limit vehicular access to the CEF including the remote light in the 9213 main passageway.

    e. Announcement of the radiation test on the 9213 PA system.

4. Following the test, the PSS will silence the alarm, remove the test tape, and arrange for the manual restart of all air-moving equipment. CEF operators will reset the tripped monitors to their original trip set points (1 R/h). Record the completion of the test in the operating log.

4.6 STARTUP CHECKS

Data obtained from the performance of the daily instrument checks and the startup checks will be recorded on Example 1, Daily Instrument Checklist, and Example 2, Startup Checklist. These checklists will be maintained in a notebook kept in the CEF Control Room.

4.6.1 Daily Instrument Checks

1. Energize all power supplies on the amplifiers located on the vertical instrument panels. (Normally these power supplies will be left on.)

2. Energize the recorder chart drives. (NOTE: It is not necessary to leave the temperature-recorder chart drive on except when obtaining data.)

3. Place the key-operated switch on the console in the "On" position; this will supply power to the system.

4. Calibrate the log-N channel, IC-3.

   a. Move the "Calibrate" toggle switch to the "Hi" position. The log-N recorder readout should drive to 10 and remain. If an adjustment is needed, use the "Recorder Adjust" dial to effect the necessary change.

   b. Move the "Calibrate" toggle switch from the mid position to the "Lo" position. The log-N recorder indicator should drive to 0.01 on the chart and remain.

   c. Return the toggle switch to the mid position.

5. Check the zero set points of the two Keithley amplifiers (IC-1 and IC-2).

   a. Depress the "Zero Check" button and hold, while observing panel meter reading. Make the necessary adjustments with the control at the right of the meters. Check "Zero" on two ranges anticipated for operation, such as 3×10^{-12} and 10×10^{-12} A full scale. Depress the "Output Bypass" button while changing the range settings.

   b. Turn the dial settings to 3×10^{-11}.

6. Verify that meter indicator settings on the PM-1 and PM-2 high voltage supplies (located on Panel No. 9) are 0.55 mA and 1.00 kV, respectively. Adjust by turning adjacent dials.

7. Check the response of the instrument channels to a radioactive source. [The source used for this purpose is a 10 mCi (May 1, 1974) cobalt-60 source.]

a. Place the toggle switches of those channels not to be tested for actual dumping of water in the "Off" position (switch up). Verify that the amber light above the switch has turned on indicating that the channel is bypassed. (NOTE: Usually, only one safety channel is checked each day to verify that an actual dumping of the water from the test tank occurs, and a different channel is selected each day.)

b. Establish audio communication between the operator in the control room and the operator in the cell.

c. Slowly move the radioactive source toward one of the ionization chambers. The control room operator will verify that the recorder is responding and will announce when the trip action occurs. The distance between the chamber and the source when the trip was actuated will be announced by the operator in the cell; record the value in the Daily Instrument Checklist.

d. Repeat the above step for each of the safety channels. In the case of the log-N channel, proper recorder response only is to be verified since there is no trip action from this channel.

e. Check the safety channel that was not "bypassed."

   (1) Reset any scram condition by depressing the individual trip buttons, depressing the "Scram Reset" button on the console, and momentarily placing the right-hand "Water" switch on the console in the "Set" position and then returning it to the "Hold" position.
   (2) Place the left-hand "Water" switch on the console in the "Feed" position and hold until water is observed in the test tank.
   (3) Approach the chamber with the source; when the trip occurs, verify that the water level drops immediately, that the "Hold" light extinguishes, and that the "Drain" light turns on.

f. Check the response of each of the three detectors in the radiation-protection channels. (NOTE: The three indicators for these channels are located on the wall, behind the console.) The control room operator will announce when the alarm is actuated on each channel and when the alarm clears as the source is withdrawn.

8. Verify that the neutron source is securely attached to the source drive.

9. Return all the toggle switches to the "On" (switch down) position and verify that each amber bypass light is extinguished.

10. Reset each trip and verify that the red trip lights are extinguished.

DAILY INSTRUMENT CHECKLIST

Date: ____________________

Instrument	Check range	Trip	Source distance	Reset (initial)	Startup range	Operational
IC-1	________	Meter	________	________	________	________
		Tube	________	________		
IC-2	________	Meter	________	________	________	________
		Tube	________	________		
PM-1	________	High	________	________	________	________
PM-2	________	Low	________	________	________	________
		High	________	________		

Log-N (IC-3) Calibrate: ____________________ Operate: ____________________

Radiation alarm: A: ______________ B: ______________ C: ______________

Source used: ________________________ Calculated curie content: __________

Neutron source installed and operations checked: ____________________

Trip used in dump check: ____

Instruments in trip circuit: ____

Remarks: ____

____

____

____

Control Room Operator: ____

Cell Operator: ____

Example 1.

11. Return the two Keithley range settings to 3×10^{-12} for startup.

12. Check the insertion of the neutron source by holding the "Source" switch on the console in the "In" position until the "In" light turns on and then withdraw the source.

4.6.2 Startup Checks

4.6.2.1 Measuring Fill and Drain Rates

Measure the rate at which water can be added and removed from the test tank by measuring the rate the water level rises and falls in the manometer. (NOTE: If the manually operated valves have not been readjusted, it is not necessary to perform this check each day.) This test will normally be performed prior to the initial reactivity test in each series; the valves will be set and not adjusted thereafter. The test will be performed first with no fuel assembly in the test tank and will be repeated at low neutron multiplication with a previously tested fuel assembly (no SPERT plates or poison strips installed) in the test tank.

1. Reset the scram conditions.

2. Place the left-hand "Water" switch in the "Feed" position. When the water level is on scale, stop the feed, read the level, start the feed again and time for one minute, read the level, and record the feed rate on the Startup Checklist. The feed rate must be such that the tank cannot be filled in less than 12 min.

3. Continue filling the tank to about 50 cm, read the level, place the switch in the "Drain" position, and time the normal drain rate for one minute; record the drain rate on the Startup Checklist. The drain rate must be such that the tank can be drained via the drain valve in less than 12 min.

4. Refill the tank so that the manometer level is about 50 cm, record the value, place the right-hand level "Water" switch in the center position, and time the decrease in level for approximately 10 s; record the dump rate on the Startup Checklist. The dump rate must be such that the tank can be drained via the dump valve in less than 2 min. (NOTE: The operating requirement is that the drain rate be greater than the feed rate and that the dump rate be greater than the drain rate. Actually, the drain and dump rates are normally considerably more than the feed rate; however, if an adjustment of the feed rate is required, the manually operated valves are provided for this purpose.)

4.6.2.2 Miscellaneous Startup Checks

1. Record the water temperature as the test tank is filled the first time each day. The temperature should be 20 ± 3°C. If the water temperature is outside this range, erroneous reactivity measurements will result due to the reactivity effect of the water density.

2. Check the availability and operability of all portable radiation monitoring equipment located in the control room.

3. Check the negative pressure in the cell; it should be >0.1 in. of water.

4. Turn on the red warning lights located at each personnel access door to the exclusion area by placing the light switch located by the wall safe in the "On" position. One of three red lights above this switch will also turn on to indicate that an experiment in the west cell is in progress. Record the time that these lights were turned on in the Startup Checklist.

5. Check all three access doors by momentarily opening each door and verifying that a local alarm sounds while the door remains open and that the red warning light remains on. The control room operator should verify that an alarm sounds in the control room as each door is opened. Ensure that the gate at the southwest wall is padlocked and the red light is on. Check to make sure there are no personnel in the exclusion area.

6. Check the three air-pressure gauges located on Panel No. 9. The normal readouts should be approximately 40 ± 5, 90 ± 10, and 70 ± 5 psig for the low-pressure, main pressure, and high-pressure lines, respectively. Record these pressures on the Startup Checklist.

7. The Daily Instrument Checklist will be reviewed by the Senior Reactor Operator who will certify, by signature, approval to commence reactivity measurements.

STARTUP CHECKLIST

Date: ____________________ **Initials**

1. Tank fill and drain rates measured. ________
   (NOTE: Only required prior to the initial reactivity test in each series.)

	Limit	Tank empty	Assembly installed
Fill rate	<6.0 cm/min	________	________
Drain rate	>6.0 cm/min	________	________
Dump rate	>36.0 cm/min	________	________

2. Water temperature ________ °C. ________

3. Radiation monitoring equipment checked. ________

4. Cell vacuum ________ . ________

5. Red warning light on at (time): ____________ ________

6. Exclusion area access alarms checked:

   a. Main passageway gate ________

   b. Door to fire escape ________

   c. Door to Room 102 ________

7. Gate at southwest wall padlocked and red light on. ________

8. Exclusion area checked free of personnel. ________

9. Air pressure: High (70 ± 5) ________
   Main (90 ± 10) ________
   Low (40 ± 5) ________ ________

10. Daily Instrument Checklist complete and reviewed by senior reactor operator. ________

11. All instruments reset and in operational mode. ________

12. Startup approval: ______________________________
    (Signature)

Example 2.

5. SHUTDOWN PROCEDURES

5.1 ACTIVITIES IN THE CONTROL ROOM

1. Drain the water from the test tank to the storage tank.
2. Withdraw the source.
3. Turn off the recorder chart drives and select the least sensitive scale on the linear channels.
4. Remove the key from the console and place it in the wall safe.
5. Turn off the warning lights.

5.2 ACTIVITIES IN THE WEST CELL

1. Monitor the radiation level from the just-tested fuel assembly.
2. If the tests on the assembly in the tank have been completed, remove the two fuel assembly components and transfer them to their floor stands. Place the cover over the drained test tank and extinguish the tank spotlight.
3. Remove the neutron source from the drive rod and place it in its approved storage container.
4. Contact the Y-12 security guards to secure the cell according to the Y-12 Security Plan.

6. EMERGENCY PROCEDURES

(Summarized from Y-DR-68, Rev. 1)

6.1 RADIATION ALARM

6.1.1 Immediate Action

1. Fuel assembly measurements shall be terminated by de-energizing the control panel.

2. All persons shall evacuate to assembly points along indicated and marked routes (Figs. 1 and 2) or as may be modified by knowledge of the emergency.

3. All persons shall be accounted for.

6.1.2 Subsequent Action

1. Local Emergency Director or representative shall contact the Y-12 Plant Shift Superintendent's Office. A flow of pertinent information shall be maintained.

2. The radiation field shall be established at the assembly station, and if it exceeds 100 mR/h, the personnel shall be relocated.

3. Search for missing personnel shall be initiated, guided by radiation fields.

4. Personnel dosimeters shall be read.

5. Occurrence and location of criticality accident shall be established.

6. Film badges shall be monitored as appropriate.

7. Personnel shall be evacuated to decontamination center and/or health centers as required.

6.1.3 Action During Unoccupancy of Building

If alarms sound, CEF staff shall respond to inquiry from the Plant Shift Superintendent.

7. RECORDS

7.1 LOG

A daily log shall be maintained by ORNL personnel performing the reactivity tests; the information that is to be recorded includes:

1. the identification of each HFIR fuel assembly tested;
2. the data obtained from the reactivity test (i.e., number of SPERT plates and/or poison strips added, reactivity values, etc.);
3. information regarding the auxiliary equipment at the CEF; and
4. any unusual occurrences that may have been encountered.

A Seal Log shall be maintained to keep a record of the E-type cup seal numbers and the corresponding shipping container they are placed on.

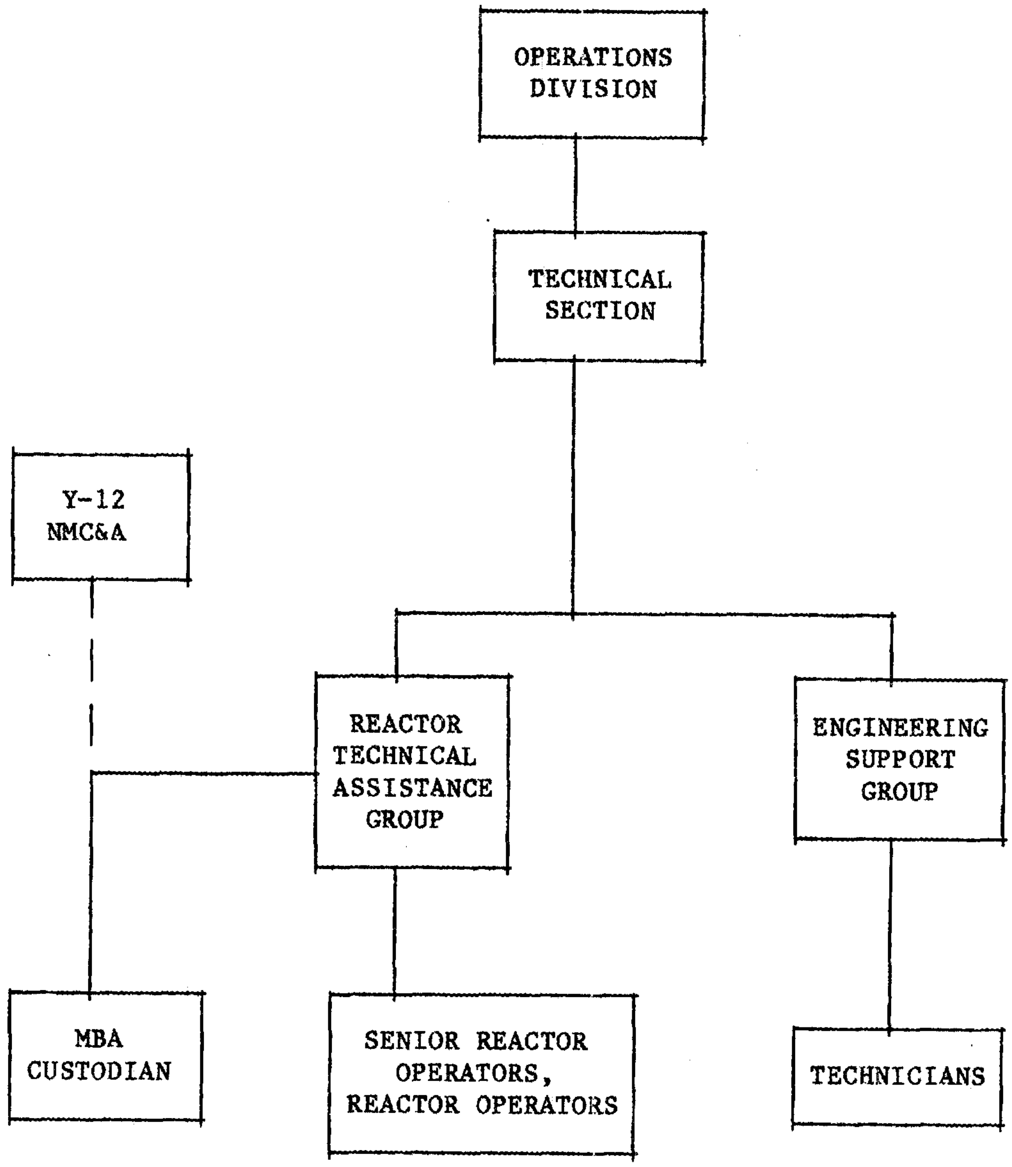
7.2 CHECKLISTS

A notebook shall be maintained containing the Daily Instrument Checklists and the Startup Checklists for reactivity measurement tests conducted at the CEF.

7.3 INSTRUMENT SURVEILLANCE

A notebook containing the periodic surveillance of the instrumentation relative to CEF operations shall be maintained.

8. ORGANIZATION



APPENDIX A

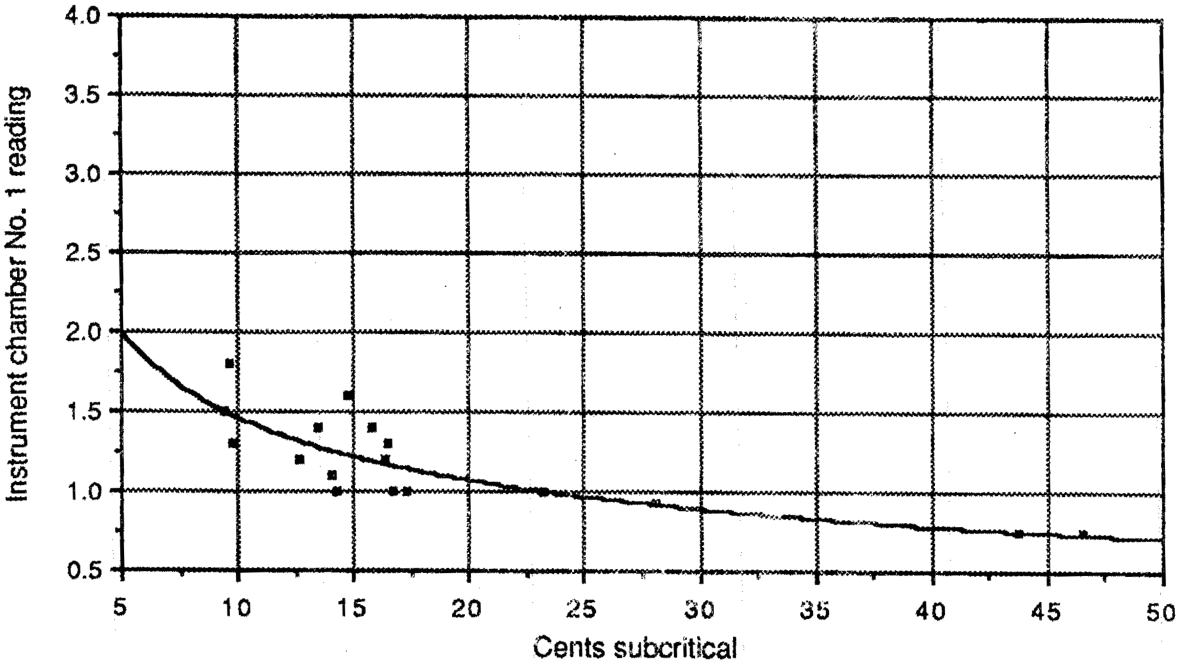


Fig. A-1. HFIR fuel assembly second run measurements - IC-1.

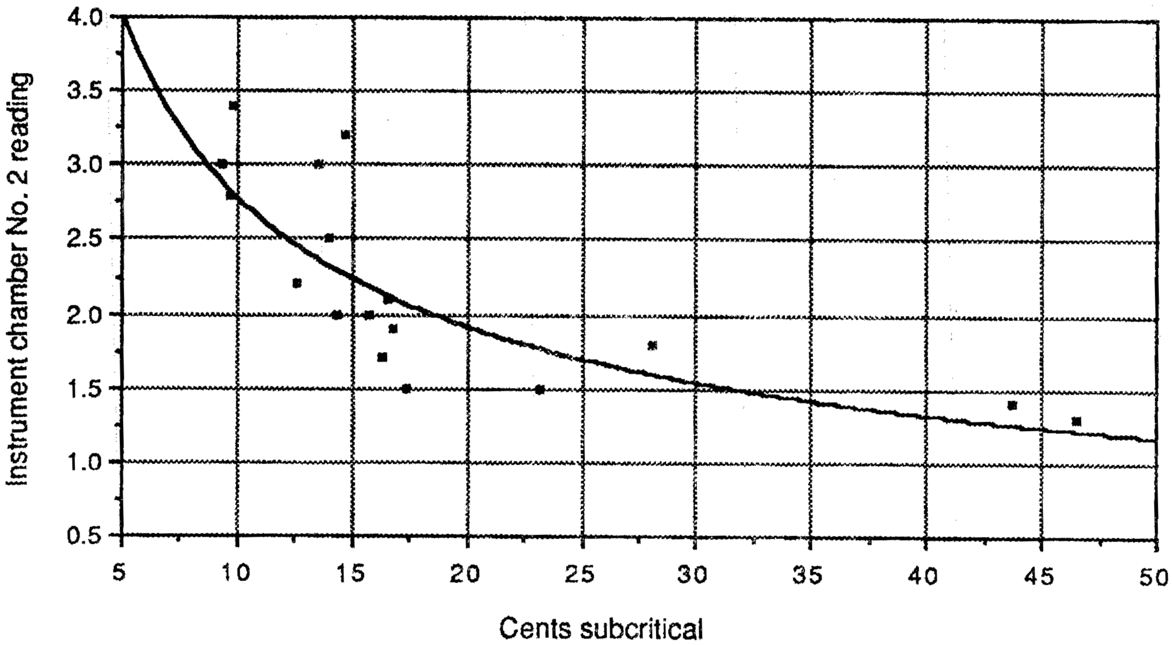


Fig. A-2. HFIR fuel assembly second run measurements - IC-2.

Table A-1. Excess reactivity vs. reactor period -- 10-200 s

Period (S)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	39.93	39.75	39.58	39.41	39.24	39.08	38.91	38.75	38.59	38.43
11	38.27	38.11	37.96	37.81	37.65	37.50	37.36	37.21	37.06	36.92
12	36.78	36.64	36.50	36.36	36.22	36.09	35.95	35.82	35.69	35.55
13	35.42	35.30	35.17	35.04	34.92	34.79	34.67	34.55	34.43	34.31
14	34.19	34.07	33.96	33.84	33.73	33.61	33.50	33.39	33.28	33.17
15	33.06	32.95	32.84	32.73	32.63	32.52	32.42	32.32	32.21	32.11
16	32.01	31.91	31.81	31.71	31.62	31.52	31.42	31.33	31.23	31.14
17	31.04	30.95	30.86	30.77	30.68	30.59	30.50	30.41	30.32	30.23
18	30.14	30.06	29.97	29.89	29.80	29.72	29.63	29.55	29.47	29.38
19	29.30	29.22	29.14	29.06	28.98	28.90	28.83	28.75	28.67	28.59
20	28.52	28.44	28.37	28.29	28.22	28.14	28.07	27.99	27.92	27.85
21	27.78	27.71	27.64	27.57	27.49	27.43	27.36	27.29	27.22	27.15
22	27.08	27.02	26.95	26.88	26.82	26.75	26.68	26.62	26.55	26.49
23	26.43	26.36	26.30	26.24	26.17	26.11	26.05	25.99	25.93	25.87
24	25.81	25.75	25.69	25.63	25.57	25.51	25.45	25.39	25.33	25.28
25	25.22	25.16	25.10	25.05	24.99	24.94	24.88	24.82	24.77	24.72
26	24.66	24.61	24.55	24.50	24.45	24.39	24.34	24.29	24.23	24.18
27	24.13	24.08	24.03	23.98	23.92	23.87	23.82	23.77	23.72	23.67
28	23.62	23.58	23.53	23.48	23.43	23.38	23.33	23.28	23.24	23.19
29	23.14	23.10	23.05	23.00	22.96	22.91	22.86	22.82	22.77	22.73
30	22.68	22.64	22.59	22.55	22.50	22.46	22.42	22.37	22.33	22.28
31	22.24	22.20	22.16	22.11	22.07	22.03	21.99	21.94	21.90	21.86
32	21.82	21.78	21.74	21.70	21.66	21.61	21.57	21.53	21.49	21.45
33	21.41	21.38	21.34	21.30	21.26	21.22	21.18	21.14	21.10	21.06
34	21.03	20.99	20.95	20.91	20.88	20.84	20.80	20.76	20.73	20.69
35	20.65	20.62	20.58	20.54	20.51	20.47	20.44	20.40	20.37	20.33
36	20.29	20.26	20.22	20.19	20.16	20.12	20.09	20.05	20.02	19.98
37	19.95	19.92	19.88	19.85	19.82	19.78	19.75	19.72	19.68	19.65
38	19.62	19.58	19.55	19.52	19.49	19.46	19.42	19.39	19.36	19.33
39	19.30	19.26	19.23	19.20	19.17	19.14	19.11	19.08	19.05	19.02
40	18.99	18.96	18.93	18.90	18.87	18.84	18.81	18.78	18.75	18.72
41	18.69	18.66	18.63	18.60	18.57	18.54	18.51	18.48	18.46	18.43
42	18.40	18.37	18.34	18.31	18.29	18.26	18.23	18.20	18.17	18.15
43	18.12	18.09	18.06	18.04	18.01	17.98	17.96	17.93	17.90	17.88
44	17.85	17.82	17.80	17.77	17.74	17.72	17.69	17.66	17.64	17.61
45	17.59	17.56	17.54	17.51	17.48	17.46	17.43	17.41	17.38	17.36
46	17.33	17.31	17.28	17.26	17.23	17.21	17.18	17.16	17.14	17.11
47	17.09	17.06	17.04	17.01	16.99	16.97	16.94	16.92	16.90	16.87
48	16.85	16.82	16.80	16.78	16.75	16.73	16.71	16.69	16.66	16.64
49	16.62	16.59	16.57	16.55	16.53	16.50	16.48	16.46	16.44	16.41
50	16.39	16.37	16.35	16.33	16.30	16.28	16.26	16.24	16.22	16.19
51	16.17	16.15	16.13	16.11	16.09	16.07	16.04	16.02	16.00	15.98
52	15.96	15.94	15.92	15.90	15.88	15.86	15.84	15.82	15.79	15.77
53	15.75	15.73	15.71	15.69	15.67	15.65	15.63	15.61	15.59	15.57
54	15.55	15.53	15.51	15.49	15.47	15.45	15.43	15.42	15.40	15.38
55	15.36	15.34	15.32	15.30	15.28	15.26	15.24	15.22	15.20	15.19

Table A-1. (Continued)

Period (S)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
56	15.17	15.15	15.13	15.11	15.09	15.07	15.05	15.04	15.02	15.00
57	14.98	14.96	14.94	14.93	14.91	14.89	14.87	14.85	14.84	14.82
58	14.80	14.78	14.76	14.75	14.73	14.71	14.69	14.68	14.66	14.64
59	14.62	14.61	14.59	14.57	14.55	14.54	14.52	14.50	14.49	14.47
60	14.45	14.44	14.42	14.40	14.38	14.37	14.35	14.33	14.32	14.30
61	14.28	14.27	14.25	14.23	14.22	14.20	14.19	14.17	14.15	14.14
62	14.12	14.10	14.09	14.07	14.06	14.04	14.02	14.01	13.99	13.98
63	13.96	13.95	13.93	13.91	13.90	13.88	13.87	13.85	13.84	13.82
64	13.81	13.79	13.77	13.76	13.74	13.73	13.71	13.70	13.68	13.67
65	13.65	13.64	13.62	13.61	13.59	13.58	13.56	13.55	13.53	13.52
66	13.50	13.49	13.47	13.46	13.45	13.43	13.42	13.40	13.39	13.37
67	13.36	13.34	13.33	13.32	13.30	13.29	13.27	13.26	13.24	13.23
68	13.22	13.20	13.19	13.17	13.16	13.15	13.13	13.12	13.10	13.09
69	13.08	13.06	13.05	13.04	13.02	13.01	12.99	12.98	12.97	12.95
70	12.94	12.93	12.91	12.90	12.89	12.87	12.86	12.85	12.83	12.82
71	12.81	12.79	12.78	12.77	12.75	12.74	12.73	12.72	12.70	12.69
72	12.68	12.66	12.65	12.64	12.63	12.61	12.60	12.59	12.57	12.56
73	12.55	12.54	12.52	12.51	12.50	12.49	12.47	12.46	12.45	12.44
74	12.42	12.41	12.40	12.39	12.37	12.36	12.35	12.34	12.33	12.31
75	12.30	12.29	12.28	12.27	12.25	12.24	12.23	12.22	12.21	12.19
76	12.18	12.17	12.16	12.15	12.13	12.12	12.11	12.10	12.09	12.08
77	12.06	12.05	12.04	12.03	12.02	12.01	11.99	11.98	11.97	11.96
78	11.95	11.94	11.93	11.91	11.90	11.89	11.88	11.87	11.86	11.85
79	11.84	11.82	11.81	11.80	11.79	11.78	11.77	11.76	11.75	11.74
80	11.72	11.71	11.70	11.69	11.68	11.67	11.66	11.65	11.64	11.63
81	11.62	11.61	11.59	11.58	11.57	11.56	11.55	11.54	11.53	11.52
82	11.51	11.50	11.49	11.48	11.47	11.46	11.45	11.44	11.43	11.42
83	11.41	11.39	11.38	11.37	11.36	11.35	11.34	11.33	11.32	11.31
84	11.30	11.29	11.28	11.27	11.26	11.25	11.24	11.23	11.22	11.21
85	11.20	11.19	11.18	11.17	11.16	11.15	11.14	11.13	11.12	11.11
86	11.10	11.09	11.08	11.07	11.06	11.05	11.04	11.03	11.02	11.02
87	11.01	11.00	10.99	10.98	10.97	10.96	10.95	10.94	10.93	10.92
88	10.91	10.90	10.89	10.88	10.87	10.86	10.85	10.84	10.84	10.83
89	10.82	10.81	10.80	10.79	10.78	10.77	10.76	10.75	10.74	10.73
90	10.72	10.72	10.71	10.70	10.69	10.68	10.67	10.66	10.65	10.64
91	10.63	10.63	10.62	10.61	10.60	10.59	10.58	10.57	10.56	10.55
92	10.55	10.54	10.53	10.52	10.51	10.50	10.49	10.48	10.48	10.47
93	10.46	10.45	10.44	10.43	10.42	10.41	10.41	10.40	10.39	10.38
94	10.37	10.36	10.35	10.35	10.34	10.33	10.32	10.31	10.30	10.30
95	10.29	10.28	10.27	10.26	10.25	10.25	10.24	10.23	10.22	10.21
96	10.20	10.20	10.19	10.18	10.17	10.16	10.16	10.15	10.14	10.13
97	10.12	10.11	10.11	10.10	10.09	10.08	10.07	10.07	10.06	10.05
98	10.04	10.03	10.03	10.02	10.01	10.00	9.99	9.99	9.98	9.97
99	9.96	9.96	9.95	9.94	9.93	9.92	9.92	9.91	9.90	9.89
100	9.89	9.88	9.87	9.86	9.85	9.85	9.84	9.83	9.82	9.82
101	9.81	9.80	9.79	9.79	9.78	9.77	9.76	9.76	9.75	9.74
102	9.73	9.73	9.72	9.71	9.70	9.70	9.69	9.68	9.67	9.67
103	9.66	9.65	9.64	9.64	9.63	9.62	9.62	9.61	9.60	9.59
104	9.59	9.58	9.57	9.56	9.56	9.55	9.54	9.54	9.53	9.52
105	9.51	9.51	9.50	9.49	9.49	9.48	9.47	9.46	9.46	9.45

Table A-1. (Continued)

Period (S)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
106	9.44	9.44	9.43	9.42	9.42	9.41	9.40	9.39	9.39	9.38
107	9.37	9.37	9.36	9.35	9.35	9.34	9.33	9.33	9.32	9.31
108	9.31	9.30	9.29	9.28	9.28	9.27	9.26	9.26	9.25	9.24
109	9.24	9.23	9.22	9.22	9.21	9.20	9.20	9.19	9.18	9.18
110	9.17	9.16	9.16	9.15	9.14	9.14	9.13	9.12	9.12	9.11
111	9.11	9.10	9.09	9.09	9.08	9.07	9.07	9.06	9.05	9.05
112	9.04	9.03	9.03	9.02	9.01	9.01	9.00	9.00	8.99	8.98
113	8.98	8.97	8.96	8.96	8.95	8.95	8.94	8.93	8.93	8.92
114	8.91	8.91	8.90	8.90	8.89	8.88	8.88	8.87	8.86	8.86
115	8.85	8.85	8.84	8.83	8.83	8.82	8.82	8.81	8.80	8.80
116	8.79	8.78	8.78	8.77	8.77	8.76	8.75	8.75	8.74	8.74
117	8.73	8.72	8.72	8.71	8.71	8.70	8.69	8.69	8.68	8.68
118	8.67	8.67	8.66	8.65	8.65	8.64	8.64	8.63	8.62	8.62
119	8.61	8.61	8.60	8.59	8.59	8.58	8.58	8.57	8.57	8.56
120	8.55	8.55	8.54	8.54	8.53	8.53	8.52	8.51	8.51	8.50
121	8.50	8.49	8.49	8.48	8.47	8.47	8.46	8.46	8.45	8.45
122	8.44	8.44	8.43	8.42	8.42	8.41	8.41	8.40	8.40	8.39
123	8.39	8.38	8.37	8.37	8.36	8.36	8.35	8.35	8.34	8.34
124	8.33	8.33	8.32	8.31	8.31	8.30	8.30	8.29	8.29	8.28
125	8.28	8.27	8.27	8.26	8.26	8.25	8.25	8.24	8.23	8.23
126	8.22	8.22	8.21	8.21	8.20	8.20	8.19	8.19	8.18	8.18
127	8.17	8.17	8.16	8.16	8.15	8.15	8.14	8.13	8.13	8.12
128	8.12	8.11	8.11	8.10	8.10	8.09	8.09	8.08	8.08	8.07
129	8.07	8.06	8.06	8.05	8.05	8.04	8.04	8.03	8.03	8.02
130	8.02	8.01	8.01	8.00	8.00	7.99	7.99	7.98	7.98	7.97
131	7.97	7.96	7.96	7.95	7.95	7.94	7.94	7.93	7.93	7.92
132	7.92	7.91	7.91	7.90	7.90	7.89	7.89	7.88	7.88	7.87
133	7.87	7.86	7.86	7.85	7.85	7.85	7.84	7.84	7.83	7.83
134	7.82	7.82	7.81	7.81	7.80	7.80	7.79	7.79	7.78	7.78
135	7.77	7.77	7.76	7.76	7.75	7.75	7.75	7.74	7.74	7.73
136	7.73	7.72	7.72	7.71	7.71	7.70	7.70	7.69	7.69	7.68
137	7.68	7.68	7.67	7.67	7.66	7.66	7.65	7.65	7.64	7.64
138	7.63	7.63	7.63	7.62	7.62	7.61	7.61	7.60	7.60	7.59
139	7.59	7.58	7.58	7.58	7.57	7.57	7.56	7.56	7.55	7.55
140	7.54	7.54	7.54	7.53	7.53	7.52	7.52	7.51	7.51	7.50
141	7.50	7.50	7.49	7.49	7.48	7.48	7.47	7.47	7.47	7.46
142	7.46	7.45	7.45	7.44	7.44	7.44	7.43	7.43	7.42	7.42
143	7.41	7.41	7.41	7.40	7.40	7.39	7.39	7.38	7.38	7.38
144	7.37	7.37	7.36	7.36	7.35	7.35	7.35	7.34	7.34	7.33
145	7.33	7.32	7.32	7.32	7.31	7.31	7.30	7.30	7.30	7.29
146	7.29	7.28	7.28	7.27	7.27	7.27	7.26	7.26	7.25	7.25
147	7.25	7.24	7.24	7.23	7.23	7.23	7.22	7.22	7.21	7.21
148	7.21	7.20	7.20	7.19	7.19	7.19	7.18	7.18	7.17	7.17
149	7.17	7.16	7.16	7.15	7.15	7.15	7.14	7.14	7.13	7.13
150	7.13	7.12	7.12	7.11	7.11	7.11	7.10	7.10	7.09	7.09
151	7.09	7.08	7.08	7.07	7.07	7.07	7.06	7.06	7.05	7.05
152	7.05	7.04	7.04	7.04	7.03	7.03	7.02	7.02	7.02	7.01
153	7.01	7.00	7.00	7.00	6.99	6.99	6.99	6.98	6.98	6.97
154	6.97	6.97	6.96	6.96	6.96	6.95	6.95	6.94	6.94	6.94
155	6.93	6.93	6.93	6.92	6.92	6.91	6.91	6.91	6.90	6.90

Table A-1. (Continued)

Period (S)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
156	6.90	6.89	6.89	6.88	6.88	6.88	6.87	6.87	6.87	6.86
157	6.86	6.86	6.85	6.85	6.84	6.84	6.84	6.83	6.83	6.83
158	6.82	6.82	6.82	6.81	6.81	6.80	6.80	6.80	6.79	6.79
159	6.79	6.78	6.78	6.78	6.77	6.77	6.76	6.76	6.76	6.75
160	6.75	6.75	6.74	6.74	6.74	6.73	6.73	6.73	6.72	6.72
161	6.72	6.71	6.71	6.70	6.70	6.70	6.69	6.69	6.69	6.68
162	6.68	6.68	6.67	6.67	6.67	6.66	6.66	6.66	6.65	6.65
163	6.65	6.64	6.64	6.64	6.63	6.63	6.63	6.62	6.62	6.62
164	6.61	6.61	6.60	6.60	6.60	6.59	6.59	6.59	6.58	6.58
165	6.58	6.57	6.57	6.57	6.56	6.56	6.56	6.55	6.55	6.55
166	6.54	6.54	6.54	6.53	6.53	6.53	6.52	6.52	6.52	6.51
167	6.51	6.51	6.50	6.50	6.50	6.49	6.49	6.49	6.49	6.48
168	6.48	6.48	6.47	6.47	6.47	6.46	6.46	6.46	6.45	6.45
169	6.45	6.44	6.44	6.44	6.43	6.43	6.43	6.42	6.42	6.42
170	6.41	6.41	6.41	6.40	6.40	6.40	6.39	6.39	6.39	6.39
171	6.38	6.38	6.38	6.37	6.37	6.37	6.36	6.36	6.36	6.35
172	6.35	6.35	6.34	6.34	6.34	6.33	6.33	6.33	6.33	6.32
173	6.32	6.32	6.31	6.31	6.31	6.30	6.30	6.30	6.29	6.29
174	6.29	6.29	6.28	6.28	6.28	6.27	6.27	6.27	6.26	6.26
175	6.26	6.25	6.25	6.25	6.25	6.24	6.24	6.24	6.23	6.23
176	6.23	6.22	6.22	6.22	6.22	6.21	6.21	6.21	6.20	6.20
177	6.20	6.19	6.19	6.19	6.19	6.18	6.18	6.18	6.17	6.17
178	6.17	6.17	6.16	6.16	6.16	6.15	6.15	6.15	6.14	6.14
179	6.14	6.14	6.13	6.13	6.13	6.12	6.12	6.12	6.12	6.11
180	6.11	6.11	6.10	6.10	6.10	6.10	6.09	6.09	6.09	6.08
181	6.08	6.08	6.07	6.07	6.07	6.07	6.06	6.06	6.06	6.05
182	6.05	6.05	6.05	6.04	6.04	6.04	6.04	6.03	6.03	6.03
183	6.02	6.02	6.02	6.02	6.01	6.01	6.01	6.00	6.00	6.00
184	6.00	5.99	5.99	5.99	5.98	5.98	5.98	5.98	5.97	5.97
185	5.97	5.97	5.96	5.96	5.96	5.95	5.95	5.95	5.95	5.94
186	5.94	5.94	5.94	5.93	5.93	5.93	5.92	5.92	5.92	5.92
187	5.91	5.91	5.91	5.91	5.90	5.90	5.90	5.89	5.89	5.89
188	5.89	5.88	5.88	5.88	5.88	5.87	5.87	5.87	5.86	5.86
189	5.86	5.86	5.85	5.85	5.85	5.85	5.84	5.84	5.84	5.84
190	5.83	5.83	5.83	5.83	5.82	5.82	5.82	5.81	5.81	5.81
191	5.81	5.80	5.80	5.80	5.80	5.79	5.79	5.79	5.79	5.78
192	5.78	5.78	5.78	5.77	5.77	5.77	5.77	5.76	5.76	5.76
193	5.75	5.75	5.75	5.75	5.74	5.74	5.74	5.74	5.73	5.73
194	5.73	5.73	5.72	5.72	5.72	5.72	5.71	5.71	5.71	5.71
195	5.70	5.70	5.70	5.70	5.69	5.69	5.69	5.69	5.68	5.68
196	5.68	5.68	5.67	5.67	5.67	5.67	5.66	5.66	5.66	5.66
197	5.65	5.65	5.65	5.65	5.64	5.64	5.64	5.64	5.63	5.63
198	5.63	5.63	5.62	5.62	5.62	5.62	5.61	5.61	5.61	5.61
199	5.60	5.60	5.60	5.60	5.60	5.59	5.59	5.59	5.59	5.58
200	5.58	5.58	5.58	5.57	5.57	5.57	5.57	5.56	5.56	5.56

Table A-2. Excess reactivity vs. reactor period -- 200-600 s

Period (S)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
200	5.58	5.56	5.53	5.51	5.49	5.46	5.44	5.42	5.39	5.37
210	5.35	5.33	5.31	5.28	5.26	5.24	5.22	5.20	5.18	5.16
220	5.14	5.12	5.10	5.08	5.06	5.04	5.02	5.00	4.98	4.96
230	4.94	4.92	4.90	4.88	4.87	4.85	4.83	4.81	4.79	4.78
240	4.76	4.74	4.72	4.71	4.69	4.67	4.66	4.64	4.62	4.61
250	4.59	4.57	4.56	4.54	4.53	4.51	4.49	4.48	4.46	4.45
260	4.43	4.42	4.40	4.39	4.37	4.36	4.34	4.33	4.31	4.30
270	4.29	4.27	4.26	4.24	4.23	4.22	4.20	4.19	4.18	4.16
280	4.15	4.14	4.12	4.11	4.10	4.08	4.07	4.06	4.05	4.03
290	4.02	4.01	4.00	3.98	3.97	3.96	3.95	3.93	3.92	3.91
300	3.90	3.89	3.88	3.86	3.85	3.84	3.83	3.82	3.81	3.80
310	3.79	3.77	3.76	3.75	3.74	3.73	3.72	3.71	3.70	3.69
320	3.68	3.67	3.66	3.65	3.64	3.63	3.62	3.61	3.60	3.59
330	3.58	3.57	3.56	3.55	3.54	3.53	3.52	3.51	3.50	3.49
340	3.48	3.47	3.46	3.45	3.44	3.43	3.43	3.42	3.41	3.40
350	3.39	3.38	3.37	3.36	3.36	3.35	3.34	3.33	3.32	3.31
360	3.30	3.30	3.29	3.28	3.27	3.26	3.25	3.25	3.24	3.23
370	3.22	3.21	3.21	3.20	3.19	3.18	3.17	3.17	3.16	3.15
380	3.14	3.14	3.13	3.12	3.11	3.11	3.10	3.09	3.08	3.08
390	3.07	3.06	3.06	3.05	3.04	3.03	3.03	3.02	3.01	3.01
400	3.00	2.99	2.98	2.98	2.97	2.96	2.96	2.95	2.94	2.94
410	2.93	2.92	2.92	2.91	2.90	2.90	2.89	2.89	2.88	2.87
420	2.87	2.86	2.85	2.85	2.84	2.84	2.83	2.82	2.82	2.81
430	2.80	2.80	2.79	2.79	2.78	2.77	2.77	2.76	2.76	2.75
440	2.75	2.74	2.73	2.73	2.72	2.72	2.71	2.71	2.70	2.69
450	2.69	2.68	2.68	2.67	2.67	2.66	2.66	2.65	2.64	2.64
460	2.63	2.63	2.62	2.62	2.61	2.61	2.60	2.60	2.59	2.59
470	2.58	2.58	2.57	2.57	2.56	2.56	2.55	2.55	2.54	2.54
480	2.53	2.53	2.52	2.52	2.51	2.51	2.50	2.50	2.49	2.49
490	2.48	2.48	2.47	2.47	2.46	2.46	2.46	2.45	2.45	2.44
500	2.44	2.43	2.43	2.42	2.42	2.41	2.41	2.41	2.40	2.40
510	2.39	2.39	2.38	2.38	2.37	2.37	2.37	2.36	2.36	2.35
520	2.35	2.34	2.34	2.34	2.33	2.33	2.32	2.32	2.32	2.31
530	2.31	2.30	2.30	2.29	2.29	2.29	2.28	2.28	2.27	2.27
540	2.27	2.26	2.26	2.26	2.25	2.25	2.24	2.24	2.24	2.23
550	2.23	2.22	2.22	2.22	2.21	2.21	2.21	2.20	2.20	2.19
560	2.19	2.19	2.18	2.18	2.18	2.17	2.17	2.17	2.16	2.16
570	2.15	2.15	2.15	2.14	2.14	2.14	2.13	2.13	2.13	2.12
580	2.12	2.12	2.11	2.11	2.11	2.10	2.10	2.10	2.09	2.09
590	2.09	2.08	2.08	2.08	2.07	2.07	2.07	2.06	2.06	2.06
600	2.05	2.05	2.05	2.04	2.04	2.04	2.03	2.03	2.03	2.02

Table A-3. Water level vs. reactivity worth for fuel assemblies

Water level (cm)	Reactivity (cents)	Water level (cm)	Reactivity (cents)	Water level (cm)	Reactivity (cents)
58.8	0.0	54.6	3.3	50.4	17.8
58.7	0.0	54.5	3.5	50.3	18.5
58.6	0.1	54.4	3.6	50.2	19.2
58.5	0.1	54.3	3.8	50.1	19.9
58.4	0.1	54.2	4.0	50.0	20.7
58.3	0.2	54.1	4.2	49.9	21.6
58.2	0.2	54.0	4.3	49.8	22.6
58.1	0.2	53.9	4.5	49.7	23.7
58.0	0.3	53.8	4.7	49.6	24.8
57.9	0.3	53.7	4.9	49.5	25.9
57.8	0.4	53.6	5.1	49.4	27.1
57.7	0.4	53.5	5.4	49.3	28.3
57.6	0.5	53.4	5.6	49.2	29.5
57.5	0.5	53.3	5.8	49.1	30.7
57.4	0.6	53.2	6.1	49.0	31.9
57.3	0.6	53.1	6.3	48.9	33.1
57.2	0.7	53.0	6.6	48.8	34.3
57.1	0.7	52.9	6.8	48.7	35.5
57.0	0.8	52.8	7.1	48.6	36.7
56.9	0.9	52.7	7.4	48.5	38.0
56.8	1.0	52.6	7.7	48.4	39.3
56.7	1.0	52.5	8.0	48.3	40.7
56.6	1.1	52.4	8.3	48.2	42.1
56.5	1.2	52.3	8.6	48.1	43.5
56.4	1.3	52.2	9.0	48.0	44.9
56.3	1.4	52.1	9.3	47.9	46.3
56.2	1.5	52.0	9.7	47.8	47.7
56.1	1.6	51.9	10.1	47.7	49.2
56.0	1.7	51.8	10.5	47.6	50.7
55.9	1.8	51.7	10.9	47.5	52.2
55.8	1.9	51.6	11.4	47.4	53.7
55.7	2.0	51.5	11.8	47.3	55.2
55.6	2.1	51.4	12.2	47.2	56.8
55.5	2.2	51.3	12.7	47.1	58.4
55.4	2.3	51.2	13.2	47.0	60.0
55.3	2.4	51.1	13.7	46.9	61.6
55.2	2.6	51.0	14.2	46.8	63.2
55.1	2.7	50.9	14.7	46.7	64.9
55.0	2.8	50.8	15.3	46.6	66.6
54.9	3.0	50.7	15.9	46.5	68.3
54.8	3.1	50.6	16.5	46.4	70.0
54.7	3.2	50.5	17.1	46.3	71.7

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