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AEROJET-GENERAL NUCLEONICS INDUSTRIAL REACTOR (AGNIR)

# CRITICAL EXPERIMENTS AND POWER CALIBRATION

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# AGNIR CRITICAL EXPERIMENTS AND POWER CALIBRATION

## I. INTRODUCTION

The procedures to be followed during the initial critical experiments and power calibration of the AGNIR Facility are delineated below. The operating procedures, technical specifications and the hazard report appear in separate documents to allow revision of each document with relative ease as the reactor equipment and procedures are changed. The following procedures are to be followed during the initial reactor startup and at such times that major changes in the core arrangement necessitate a new set of critical experiments and power calibrations.

## II. SIMULATED REACTOR LOADING AND UNLOADING PROCEDURES

Before attempting fuel transfer operations, all personnel involved with the initial critical experiment will become familiar with the techniques and procedures required for the reactor critical assembly. The detailed procedures for reactor loading and fuel handling are presented in Section III. C.

Familiarization with the techniques required to transfer fuel elements to the reactor core from the fuel element storage rack, located in the reactor pool tank, (or) from fuel element shipping containers (to the reactor core), or from the storage pits will be developed by performing a mock transfer. Dummy elements will be used for training to develop fuel-transfer proficiency.

## III. REACTOR CRITICAL ASSEMBLY PROCEDURES

The critical assembly of the reactor shall be performed in a manner that will ensure the maximum safety to all personnel involved. The procedures described below include all phases of the critical assembly. Reactor operation procedures are presented in a separate document.

The transferring of fuel elements for the critical assembly from the temporary storage area to the reactor room shall be performed in a manner that will comply with recommendations of the AGN Radiological Safety Officer. The following restrictions will apply to all transfer operations:

No more than one fuel element may be transferred to the reactor core at a time. Only one fuel storage container (or storage pit) shall be opened at any one time.

The following five people will be required for the critical experiment: the engineer-in-charge (a licensed senior operator); fuel handler; data analyst; instrument specialist and a health physicist.

A. REQUIRED STARTUP INSTRUMENTATION

The minimum instrumentation required during the initial critical assembly is shown in Table 1. All normal instrumentation shall remain operative, thereby providing reactor period scrams from Channels A and B, and reactor level scrams from Channels C and D. Sub-critical multiplication measurements will be obtained primarily from the Auxiliary Pulse Channels E, F, and G; however, plots of all the channels will be maintained during the initial criticality measurements.

TABLE 1

INSTRUMENTATION REQUIRED DURING CRITICAL ASSEMBLY

| Startup Channel No. | Detector | Readout | Reactor Channel |
|---|---|---|---|
| A | Proportional Counter | LOG CRM/scaler | 1 |
| B | Compensated Ion Chamber | LOG Pico Ammeter | 2 |
| C | Uncompensated Ion Chamber | Pico Ammeter | 3 |
| D | Uncompensated Ion Chamber | Pico Ammeter | 4 |
| E | Uncompensated Ion Chamber | Pico Ammeter | --- |
| F | Proportional Counter | Scaler | --- |
| G | Proportional Counter | Scaler | --- |

B. RESUME OF REACTOR CONDITIONS

Prior to critical assembly, the integrity of all mechanical and electrical components shall be demonstrated. A neutron check on all the detectors will be performed by checking and calibrating detectors on the AGN 201 reactor. The nuclear scram and annunciator circuits that are to remain operative are listed in Table 2.

Channels 3 and 4 will be set in a range not to exceed 6 decades above source level during foil irradiations associated with initial critical power calibrations. The source will be removed and reinserted to check the source interlock system. The addition of fuel elements to the reactor core during the critical assembly may be performed <u>only</u> when:

1. The reactor safety and interlocking systems are functioning, and,
2. The safety rod is fully withdrawn and both the shim and regulating rods are fully inserted.

C. FUEL LOADING TECHNIQUES

To ensure that all personnel are completely familiar with the techniques required to perform the critical assembly, a simulated reactor loading will be conducted prior to the actual fuel transfer. The fuel element handling tool will be used to transfer dummy elements from the shipping containers (or fuel storage pits) to various positions in the reactor core.

To maintain control of all fuel element transfers to the reactor core and to comply with fuel transfer procedures, a fuel inventory check shall be continuously made during the critical assembly. The AGNIR Fuel Inventory Chart, Figure 1, shows the fuel element locations in the reactor core. Using 23 graphite-filled aluminum dummy elements and a source element located in Rings F and G, two control rods located in Ring C and one in Ring E, the estimated number of standard aluminum-clad TRIGA fuel elements required for criticality is 64 located in the remaining unfilled positions in Rings A through F.

## TABLE 2

## SCRAM AND ANNUNCIATOR CIRCUITS OPERATIVE DURING CRITICAL ASSEMBLY

| Channel No. | Condition Monitored | Trip Setting |
|---|---|---|
| 1 | Period | 4 $\pm$ 1 sec |
| 1 | Low Level (source interlock) | 60 $\pm$ 5 cpm |
| 2 | Period | 4 $\pm$ 1 sec |
| 2 | Power Supply Low | 510 $\pm$ 10 volts |
| 2 | Instrument Power | - |
| 3 | Low Level | 4 $\pm$ 2% of full scale |
| 3 | High Level | 98 $\pm$ 2% of full scale |
| 3 | Power Supply Low | 510 $\pm$ 10 volts |
| 3 | Instrument Power | - |
| 4 | High Level | 98 $\pm$ 2% of full scale |
| 4 | Power Supply Low | 510 $\pm$ 10 volts |
| 4 | Instrument Power | - |
| - | Low Pool Water Level | 1 ft below building floor level |
| - | Earthquake | Modified Mercalli IV |
| - | Pool Water Temperature | 125 $\pm$ 5$^{o}$F |

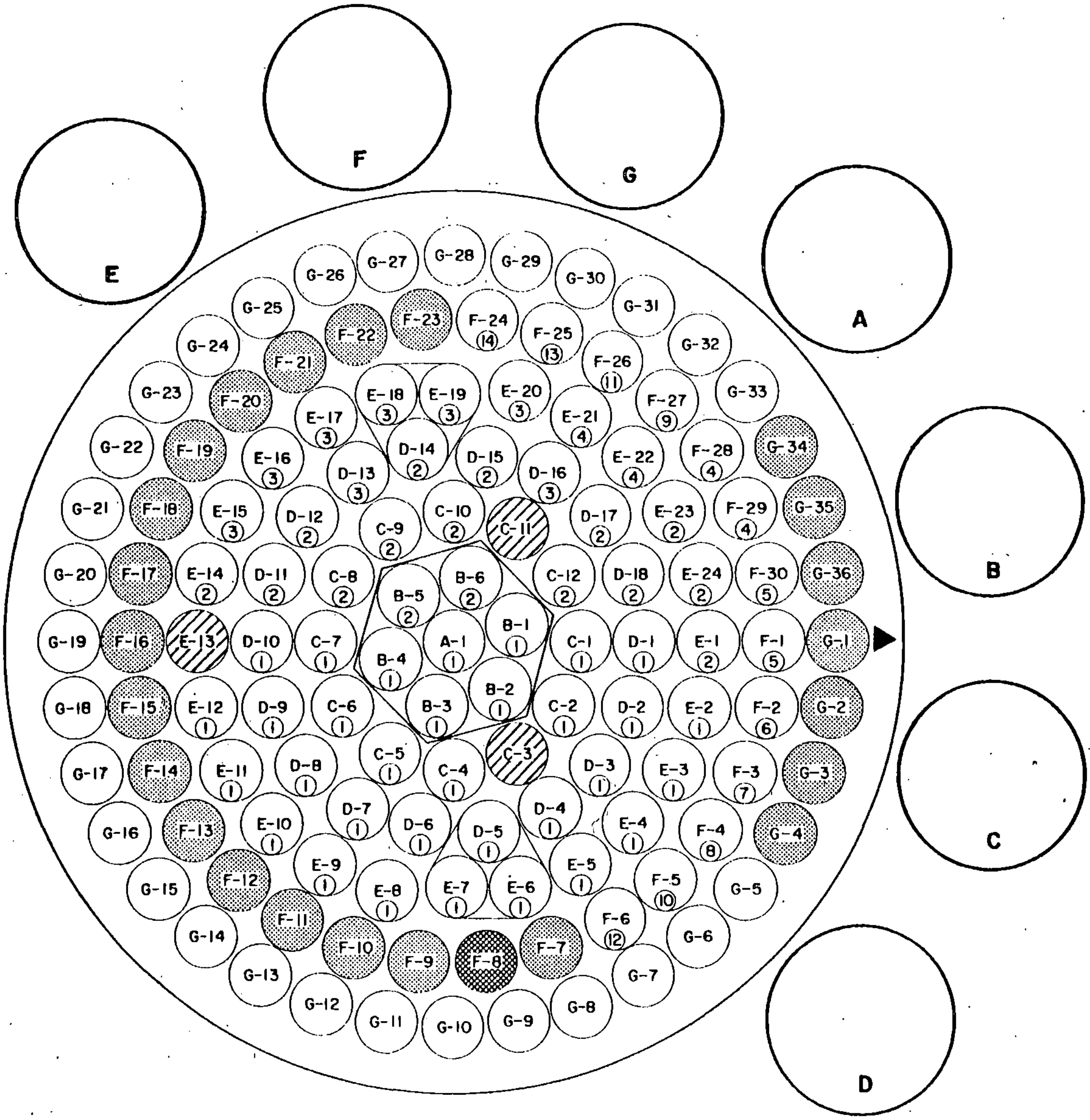
## ANNUNCIATED CONDITIONS

Area radiation

Water radioactivity

Crane bridge location

Water flow




LEGEND

GRAPHITE DUMMY ELEMENT

CONTROL ROD

SOURCE DUMMY ELEMENT

G-22 EMPTY POSITION

E-22 (7): RING NUMBER, RING POSITION } ELEMENT LOCATION; LOADING STEP NUMBER

CONTROL ROD IDENTIFICATION

E 13 REGULATING

C 11 SHIM

C 3 SAFETY

85.39-GA-2617

FIGURE 1. AGNIR FUEL LOADING SEQUENCE

At critical, the unused holes in Rings F and G will be filled with water, (7 in the F ring and 29 in the G ring). The loading sequence to be used in the initial critical experiment is shown in Table 3.

## D. APPROACH TO CRITICALITY

During the initial critical assembly the maximum number of fuel elements loaded into the reactor per step shall be that shown in Table 3, or one-half the experimentally-determined incremental loading required to achieve criticality, whichever is less. The loading sequence shown in Table 3 was chosen, as opposed to a nearly circular loading array, because 1) the source will not have to be moved during the course of the assembly, thereby eliminating possible errors due to renormalization of the data to more than one source position, 2) a high-worth safety rod is placed near the center of the loaded core providing a high degree of shutdown safety, and 3) the majority of the criticality monitoring instrumentation does not have a direct view of the source.

The negative temperature coefficients associated with the TRIGA fuel provide an emergency shutdown mechanism. However, the following precautions shall also be observed: Before loading fuel the shim rod and the regulating rod shall both be in the fully inserted position to suppress any false period indication caused by fuel insertion. The safety rod shall remain in the fully withdrawn position. The source element and the 23 graphite-filled dummy elements will be loaded as shown in Figure 1 prior to loading any fuel elements. Upon completion of a loading step, the safety rod shall be inserted to the lower limit and subcritical measurements shall be obtained on all nuclear instrument channels. The safety rod, shim rod and control rod shall then be withdrawn and a second subcritical measurement obtained on each nuclear channel.

## TABLE 3

## AGNIR FUEL LOADING SEQUENCE

| Loading Step | No. Elements Added | Total Elements | Loading Sequence |
|---|---|---|---|
| 1 | 32 | 32 | E6, E7, E5, E8, D4, D6, D5, C4, C5, D7, E9, C2, D3, B2, B3, E4, C6, D8, E10, B4, E3, D2, E2, D9, E11, E12, A1, C7, D10, C1, B1 and D1 |
| 2 | 16 | 48 | E1, B5, B6, C8, C12, D11, D18, E14, E24, C10, C9, D17, D12, E23, D14 and D15 |
| 3 | 8 | 56 | D16, D13, E15, E16, E17, E18, E19 and E20 |
| 4 | 4 | 60 | E21, E22, F28 and F29 |
| 5 | 2 | 62 | F30 and F1 |
| 6 | 1 | 63 | F2 |
| 7 | 1 | 64 | F3 |
| 8 | 1 | 65 | F4 |
| 9 | 1 | 66 | F27 |
| 10 | 1 | 67 | F5 |
| 11 | 1 | 68 | F26 |
| 12 | 1 | 69 | F6 |
| 13 | 1 | 70 | F25 |
| 14 | 1 | 71 | F24 |

The multiplication data above, when plotted as a function of fuel mass or of the number of fuel elements, determines the extrapolated criticality. The difference between the extrapolated criticality with all rods withdrawn and the extrapolated criticality with all rods fully inserted is the shutdown reactivity margin at critical expressed in terms of the fuel mass.

E. SUPERCRITICAL LOADING

The critical and excess reactivity loading shall be made in a manner that will result in maximum safety for all personnel.

Fuel loading will follow the procedure used in the critical experiment. The following procedures shall be used after the addition to the core of the fuel element expected to result in supercriticality with all rods out.

1. Insert the safety rod; measure and record the subcritical multiplication.
2. Withdraw the safety and shim rod fully from the core; again measure and record the subcritical multiplication.
3. Withdraw the regulating rod until a stable reactor period is established.
4. Insert the regulating rod, leveling out the reactor on an infinite period at some desired low power level. (Not to exceed 6 decades above source level.)
5. Insert the shim rod fully to shut down reactor in preparation for rod calibration experiments.

## IV. REACTOR CALIBRATIONS

A complete and thorough evaluation of the AGNIR reactor characteristics is essential for the over-all operation of the system. These reactor characteristics include: 1) control rod calibrations, 2) fuel element worth as a function of core position, 3) reactor core flux distribution, 4) reactor power calibration, 5) temperature and power coefficient of reactivity and 6) danger coefficient measurements as a function of reactor core position for selected materials.

The suggested methods of determining the reactor characteristics are detailed below and may be changed or expanded as necessary. Detailed reactor operating procedures are presented in a separate document.

## A. CRITICAL CONTROL ROD CALIBRATION

The control rods will be calibrated in terms of rod worth as a function of rod position using positive reactor period measurements. The procedures used during the rod calibration tests are described below, and are typical for the regulating rod and the shim rod.

1. Obtain and record an accurate critical position with shim rod, with the safety and regulating rods fully withdrawn to upper limits.
2. Insert shim rod to lower limit and allow reactor power to decay.
3. Withdraw shim rod to establish an approximate 100 second reactor period. Do not exceed a reactor power of 6 decades above source level during period measurement. (Channel 4 will be set to scram the reactor at this power level.) Use stop watches or other timing devices for measurement of reactor period. Decrease power level, Step 2.
4. Repeat Step 3, establishing a reactor period of approximately 50 seconds.
5. Repeat Step 3, establishing a reactor period of approximately 30 seconds.
6. Adjust the regulating rod to obtain a new critical position at approximately the same power level as in Step 1. The reactivity value corresponding to the observed reactor period, Step 3, is also the incremental worth of the regulating rod.

7. Repeat Steps 2 through 6, until the regulating rod has been completely inserted and the shim rod is maintaining the excess reactivity.

Figure 2 is a typical plot of the AGNIR Inhour Equation showing stable reactor period in seconds as a function of reactivity in cents. The total reactivity worth of each control rod is determined by performing individual rod drop tests from criticality. The procedures to be followed in the rod drop measurements are as follows:

1. Connect scaler start switch for Startup Channel F to the lower limit switch of the shim rod. Bring the reactor to a power level that will yield a count rate of about $10^6$ counts/minute on Startup Channel F by triggering the scaler manually.
2. Perform 3 one-minute counts on Channel F and compare these counts to assure that the reactor power level is not increasing or decreasing within statistical variations.
3. Record position of all control rods.
4. Depress shim rod scram button.
5. When shim rod reaches lower limit switch an electrical signal will trigger the scaler attached to the proportional counter on Channel F. The counter will accumulate counts for a period of one minute.
6. Using tabulated data obtained from the AGN DROP Code and the ratio of the initial accumulated counts (steady state) to the final accumulated counts (rod scrammed), the reactivity worth of the shim rod interval inserted into the reactor during the test can be evaluated.
7. Repeat Steps 1 through 6 for varying positions of the shim rod.
8. Repeat Steps 1 through 7 for the regulating rod.

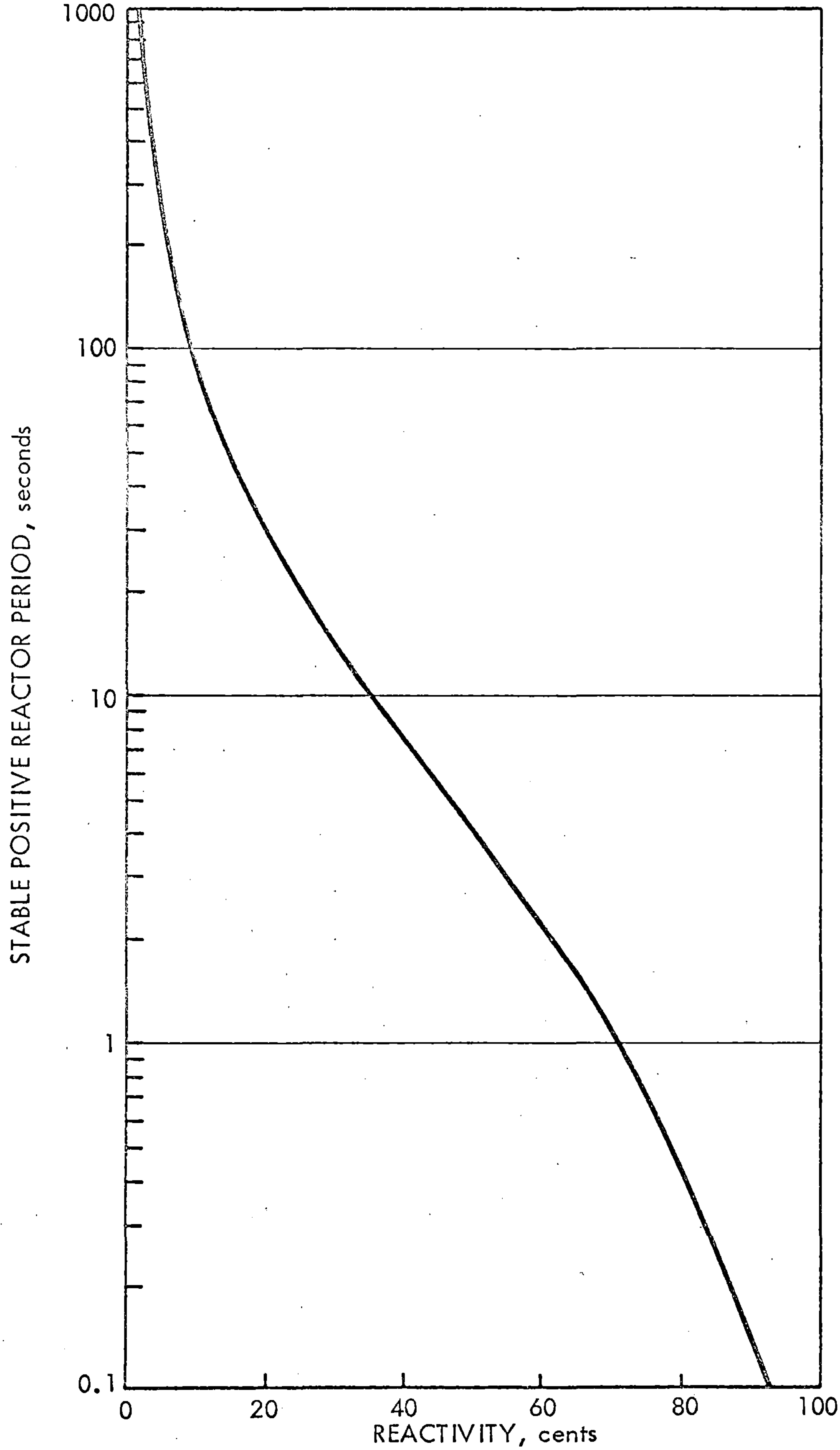



FIGURE 2. AGNIR INHOUR EQUATION

9. Repeat Steps 1 through 6 for the safety rod. Due to rod interlock procedures, only the full worth of the safety rod can be evaluated.
10. Repeat Steps 1 through 6 for full reactor scram of all rods. For this measurement, the lower limit switch start signals are ganged together so that the first rod to reach bottom triggers the scaler to start the counting.

## B. FUEL ELEMENT WORTH AS A FUNCTION OF CORE POSITION

To determine the reactivity worth of a fuel element as a function of core position, the reactor conditions listed below are to be fulfilled before initiating fuel handling procedures.

1. All reactor alarm and scram circuits shall be operative.
2. During the fuel handling operations, the safety rod shall remain at the fully withdrawn position, with the shim and regulating rods at the fully inserted position.
3. The procedures and measurements to be performed while determining the reactivity worth of a fuel element are presented for one typical measurement, i.e., the fuel element in position F-1.
    a. Initial criticality is determined prior to moving the fuel element, and control rod positions are recorded.
    b. With the safety rod withdrawn and the shim and regulating rods fully inserted, neutron count rates are determined on the pulse channels of instrumentation.
    c. The fuel element from reactor core position F-1 is removed from the reactor core and temporarily placed in the fuel storage rack on the wall of the reactor pool tank.
    d. The reactor is brought to critical at the power level used in Step a. Control rod positions are recorded.

e. The reactor is shut down and pulse count rate data is recorded.

f. The fuel element in the storage rack is replaced in core position F-1 and the critical position is again checked and recorded.

The above procedures are repeated for other fuel element positions.

The worth of the glory hole thimble is also to be determined as a function of core position. The worth of plastic rods 0.25 in. in diameter will be determined as a function of core position using the 0.315 in. diameter flux measuring holes in the grid plate. Concurrent fuel handling operations are recorded on the AGNIR Fuel Inventory Chart (Figure 1) during all fuel element transfer operations.

## C. REACTOR CORE FLUX DISTRIBUTION

The AGNIR core has special holes in the grid plates for performing in-core flux distribution measurements. These holes are nominally 0.315 in. in diameter and are provided in both the top and bottom grid plates. Plastic rods 0.25 in. in diameter will be used to position gold flux wires and foils in these holes. Provisions have been made to obtain flux measurements at 22 places in the core using wire holders. Normalization factors correlating the flux-wire data to actual flux in the reactor core will be determined by irradiating foils at selected locations in the AGNIR core and comparing these with foils irradiated in the AGN 201 reactor. The AGN 201 reactor has been calibrated at selected locations by National Bureau of Standards (NBS) using calibrated AGN standard foils. Therefore, the AGN 201 may be considered a secondary neutron standard for use in mapping the neutron flux in the AGNIR core.

Operational procedures to be used during the flux-wire and foil irradiations are listed below:

1. Obtain a critical point with the safety rod fully withdrawn, using the shim and regulating rod to control the reactor.
2. Fully insert shim and regulating rod.
3. Slowly insert flux-wire or foil holder into irradiation position observing change in shutdown multiplication. Repeat until all flux-wires are loaded into position.
4. Start up reactor, using normal startup procedures, and operate at steady state power level for the desired irradiation time.
5. Use accepted flux-wire and foil counting techniques to calculate the thermal flux distribution and absolute power calibrations.

## D. ABSOLUTE REACTOR POWER CALIBRATIONS AND APPROACH TO FULL POWER

Two basic techniques are available for establishing a reactor power calibration. The first consists of numerically integrating the thermal flux over the fuel volume and calculating the power level for a given reading on the power level meters. This calculation requires a knowledge of the relationship between the measured thermal neutron flux in the water and the fission rate in the fuel. This relationship can be estimated by supplementary neutronics calculations, but an error on the order of about 20% is inherent in the technique. Initial power calibration of the reactor will be estimated using this technique.

A second and more desirable method depends upon the calorimetric properties of the pool tank. Prior to loading the reactor core with fuel, resistance heaters are placed in the fuel positions of the reactor core. A desirable heater size is in the range of 10 to 30 kw total capacity distributed over several heaters. The current and voltage used by each heater are measured. Thermocouples are located at several positions in the water tank to measure the temperature rise of the water as a function of time. Several tests are performed for different power outputs of the heaters. The results are then compared with measurements of fission heating as described below.

Prior to any power operation, a measurement of the isothermal temperature coefficient (sometimes called the bath coefficient) is performed. With the water pump in the water purification system used to "stir" the water in the reactor pool, the immersion heaters are placed in the water tank and turned on. Thermocouples are placed at various points in the tank and connected to a multipoint recorder to keep a record of the pool water temperature. The reactor is maintained at critical and the control rod positions are recorded every 5 minutes for the duration of the test. Using the temperature information and the control rod calibrations, an isothermal temperature coefficient as a function of pool water temperature can be obtained.

After the reactor has achieved criticality and the low power tests and equipment checkout have been performed satisfactorily, an initial approach to power operation can be made using the following procedures:

1. Determine that the reactor pre-startup checklist is completed assuring proper reactor conditions.
2. Based upon the reactor shutdown source level and the estimated corresponding instrument readings, extrapolate the instrument readings to a power level of 10 kw based upon previously-performed foil irradiations, and record these estimates in the Experimental Log Book.
3. Using normal startup procedures bring the reactor to a calculated power level of 1 watt. Remove neutron source and place in fuel storage rack.
4. Increase the reactor power level by half decade steps to an indicated power level of 10 kw as calculated in 2, above. Maintain the reactor critical for 5 minutes at each power level step and record the following items in the Experimental Log Book:
   a. Position of all control rods
   b. Water temperatures of pool thermocouples
   c. Nuclear instrumentation readings of all channels

When a power level of 10 kw is reached, hold reactor power level constant for several hours, recording the pool water temperatures every 5 minutes for the duration of the run. Shut down reactor replacing source in reactor core, and compare temperature rise of water with the initial calorimetric measurements using resistance heaters. With this initial calibration data as a guide, a preliminary estimate of the actual power can be estimated by comparing the fission heating with the previously-obtained electrical heating. Using this information, the reactor can then be raised in power (again using half-decade steps), to a power range at which the electric heaters were operated removing neutron source at a power level of 1 watt prior to raising power to the kilowatt range. Repeat the reactor run until satisfactory calibration data is obtained.

LEGEND

See Note on Record Sheet

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