**GENERAL ATOMIC**

DIVISION OF **GENERAL DYNAMICS**

AEC RESEARCH AND
DEVELOPMENT REPORT

GA-5924

# 40-MW(E) PROTOTYPE HIGH-TEMPERATURE GAS-COOLED REACTOR POSTCONSTRUCTION RESEARCH AND DEVELOPMENT PROGRAM

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## SUMMARY PROGRESS REPORT FOR THE PERIOD ENDING OCTOBER 31, 1964

Prepared under
Contract AT(04-3)-314
for the
San Francisco Operations Office
U.S. Atomic Energy Commission

December 15, 1964

# DISCLAIMER

**GENERAL ATOMIC**
DIVISION OF
**GENERAL DYNAMICS**

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# I. INTRODUCTION

This report is the second in the series of quarterly progress reports describing the work performed by General Atomic Division of General Dynamics Corporation on the Postconstruction Research and Development Program for the 40-Mw(e) HTGR power plant. The over-all objective of the program is to develop further information concerning the performance features of this reactor plant. The general scope of the program is more fully outlined in the first report in the series, GA-5700. In the present report, emphasis has been placed on describing in detail the initial phases of the zero-power program.

The zero-power measurement program will start with the initial loading of fuel into the reactor. Before the fuel loading sequence begins, the reactor will be loaded with dummy graphite elements, which will be replaced with fuel elements, one at a time, until criticality is reached. Of the dummy elements, 126 will contain neutron poison, and it is expected that initial criticality will be reached with about 100 of these remaining in the core, i.e., about 704 fuel elements in the remaining positions. At this point, the core will be just critical with all control rods withdrawn.

The poisoned dummy elements have been designed to duplicate approximately the neutron-absorption cross section of a fuel element. Through the use of the poison, this initial critical core will approximate the nuclear characteristics of the actual end-of-life condition of the core, when all the rods have been withdrawn. A series of detailed measurements of control rod worths, power distributions, and reactivity worths will be started during this initial stage. As additional fuel elements are added and poison elements removed, the series of measurements will be continued. The loading sequence has been so planned that measurements will be obtained with control-rod configurations and core conditions approximating those that will occur over the entire life of the core. The final core will consist entirely of the 804 fuel elements that will remain through the power operation.

The materials and equipment described herein have been limited to those specifically obtained for the Postconstruction Research and Development Program. The standard plant equipment will be utilized wherever possible, and no attempt to describe it is made here.

# II. ZERO-POWER TESTS

## SEQUENCE OF TESTS

The sequence in which the physics tests are to be performed has been established up to and including the initial rise to 1 Mw(t). These tests fall into three general categories in their normal sequence. An asterisk (*) follows the titles of tests of primary importance; the test procedures are described in GA-5700.

### Physics Tests During Core Loading

This series of measurements is performed while the 804 fuel elements are being loaded. It is planned to have clean, dry air in the primary system during these tests for convenience in manipulation of the in-core instrumentation. It should be noted that tests BP-10, BP-15, and BP-12 are performed concurrently with BP-11.

1. Initial Loading to Criticality (BP-1)*
2. Power Distribution Measurement - Unrodded (BP-8)*
3. Bank Control Rod Worth Measurement - Pulsed Source (BP-9)*
4. Excess Reactivity Measurement - Distributed Poison (BP-7)*
5. Differential Control Rod Worth Measurements (BP-11)*
6. Power Distribution Measurement with Control Rods (BP-10)*
7. Reactivity Worth Measurements (BP-15)
8. Flux Tilt Measurements (BP-12)*

### Physics Tests Following Loading (helium not required)

This series of tests is performed after the 804 fuel elements have been loaded. As in the preceeding tests, it is planned to have air in the primary system.

1. Outer Bank Control Rod Worth Measurements - Pulsed Source (BP-13)*
2. Shutdown Margin Measurement - Pulsed Source (BP-4)*
3. Loading Adjustment (BP-5)*
4. Complete Rod Calibration (BP-14)
5. Rod Scram Transient Test (BP-16)

## Physics Tests Requiring Helium in Primary Coolant System

The tests in this series by their nature require helium at pressures up to full design conditions in the primary coolant system.

1. Helium Pressure Coefficient (BP-17)*
2. Helium Flow Coefficient (BP-18)*
3. Noise Analysis (BP-19)
4. Isothermal Temperature Coefficient (CP-1)*
5. Control Rod Calibration (CP-2)
6. Initial Rise to 1 Mw(t) (DP-O)*

## INITIAL LOADING TO CRITICALITY (BP-1)*

The fuel element loading sequence has been established. In order to retain the same relative reactivity worths between control rods in the various control rod rings during fuel loading, the center-out sequence described in GA-5700 has been changed to a uniform-loading sequence. With loading from the center out, the reactivity worths of the outer rods remained very small until a large number of elements were loaded. The new loading sequence permits three control rods in each of the four control rod rings to be withdrawn and available for automatic or manual scram during fuel loading. This is in contrast with three control rods in the central two rings as reported for the earlier loading sequence. In addition to the 12 withdrawn control rods, the 19 emergency shutdown rods are withdrawn and available for manual scram.

The major criteria that were employed in developing the fuel element loading sequence were:

1. The sequence would approximate a uniformly loaded full-size core at all times during fuel loading.

2. The first fuel elements would be loaded around control rod or emergency shutdown rod locations.
3. All fuel elements containing lumped burnable poisons would be loaded before the poisoned dummy elements were removed.

The core configuration at six typical stages during the initial loading is seen in Fig. 1. All six segments of the core are loaded identically to the segment shown in this figure for each stage, with the exception of the centermost element. Thus, the core loading is as symmetric and uniform as possible throughout the entire sequence. A 60-curie Po-Be source is placed at the location of one of these centermost elements during loading.

The location of this central source relative to the proposed locations of three in-core detectors and the permanent source range detectors is shown in Fig. 2. This central source should be sufficient to produce a count rate well above background on the in-core detectors. However, four additional Po-Be sources can be placed in the radial reflector to increase the count rate if required. In addition to the Po-Be sources, a steady-state accelerator neutron source will be available.

A series of one-dimensional, multigroup, GAZE diffusion theory and GAPLSN transport theory calculations have been performed to predict the unrodded core reactivity and the in-core detector response during loading. In addition, some two-dimensional, multigroup, calculations were performed in XY geometry with the EXTERMINATOR code. These calculations accounted for azimuthal effects on the core reactivity during loading. The calculated effective multiplication constant of the core as a function of the number of elements loaded is presented in Fig. 3. With 677 fuel elements loaded, the calculated effective multiplication constant is 0.974. Beginning at this point, poisoned dummy elements are removed, and the effective multiplication has an abrupt change in shape.

The response of the in-core detectors during loading was calculated using the GAPLSN code in a series of calculations in which the presence of the 60-curie Po-Be source at the core center was accounted for. The predicted inverse multiplication (the ratio of the count rate with no fuel to the count rate with fuel) as calculated for the in-core neutron detectors is presented in Fig. 4. The initial shape of the predicted inverse multiplication curve is significantly influenced by the following effects:

1. The hardening of the neutron spectrum as fuel is loaded results in a significant reduction in the sensitivity of the in-core neutron detectors. Therefore, even though the

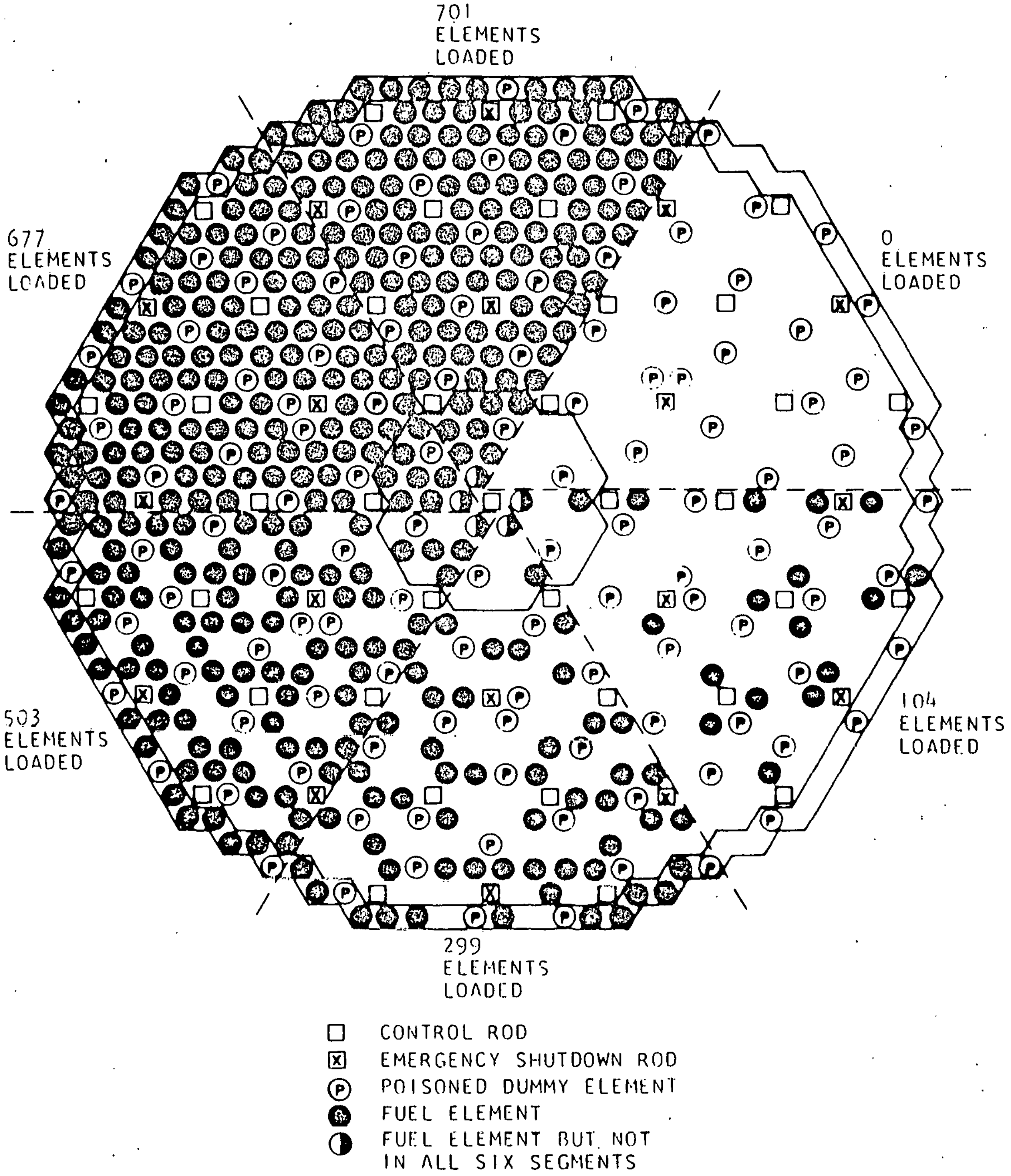


Fig. 1--Core configuration at six typical stages during initial loading

● AND ◉ 804 FUEL ELEMENTS
☐ 36 CONTROL RODS
☒ 19 EMERGENCY CONTROL RODS

| REGION 1 | REGION 2 | REGION 3 |
|---|---|---|
| ● 54 HEAVY RHODIUM ELEMENTS | ● 588 LIGHT RHODIUM ELEMENTS<br>◉ 60 LIGHT RHODIUM ELEMENTS WITH POISONED SPINES | ● 102 LIGHT URANIUM HEAVY THORIUM ELEMENTS |

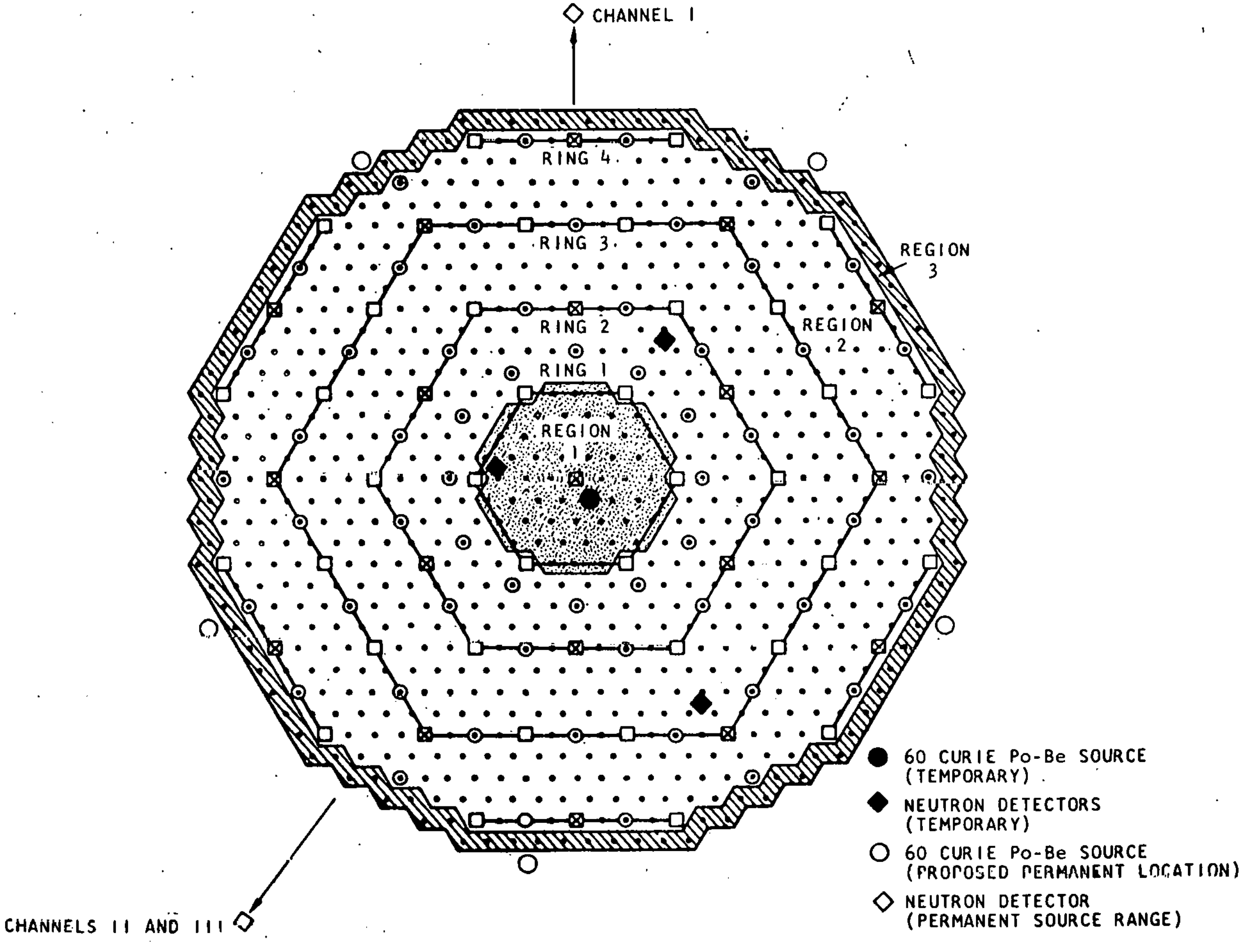


Fig. 2--Cross section of Peach Bottom core showing location of permanent and temporary sources and detectors

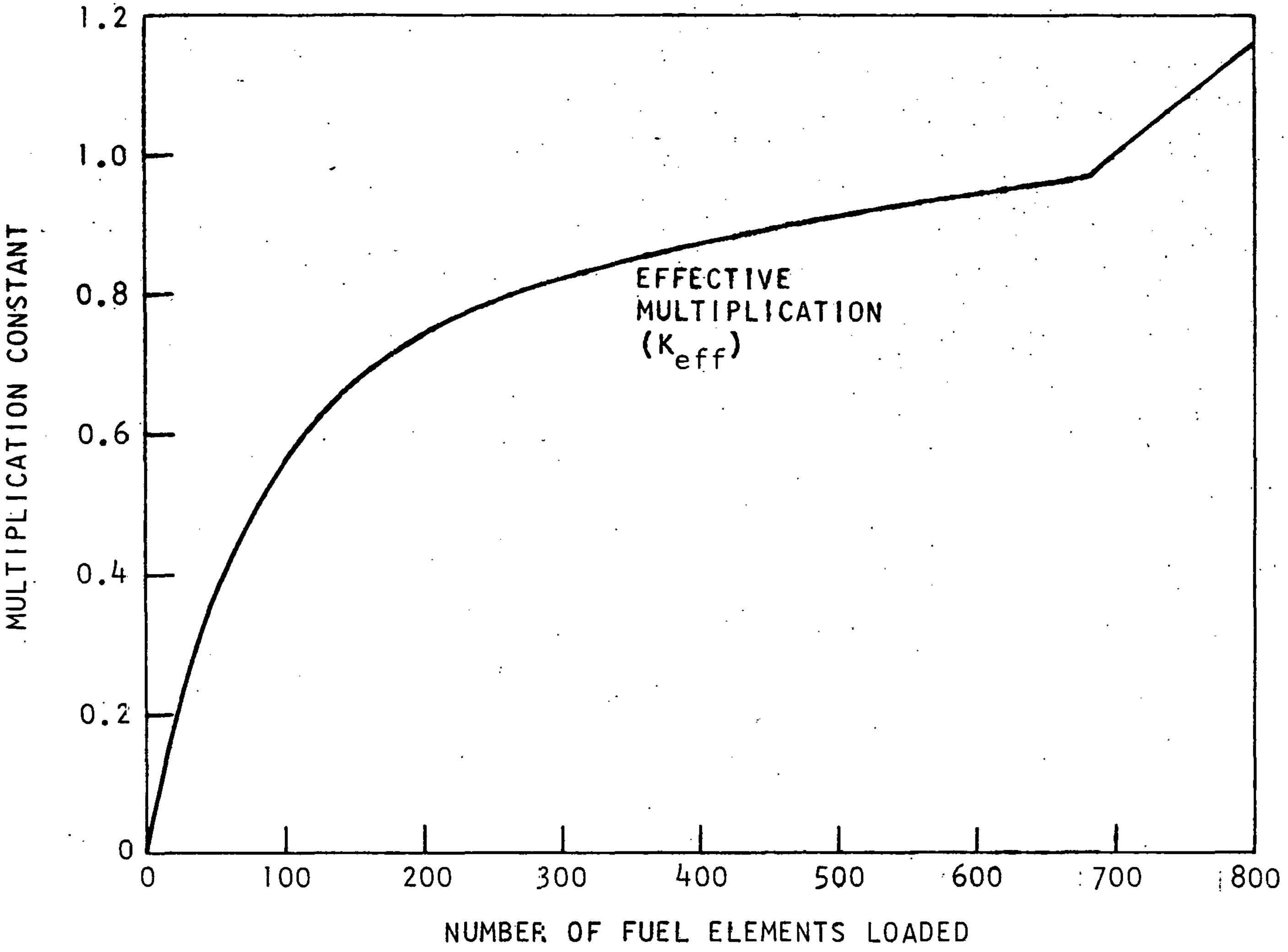


Fig. 3--Multiplication during initial loading (unrodded)

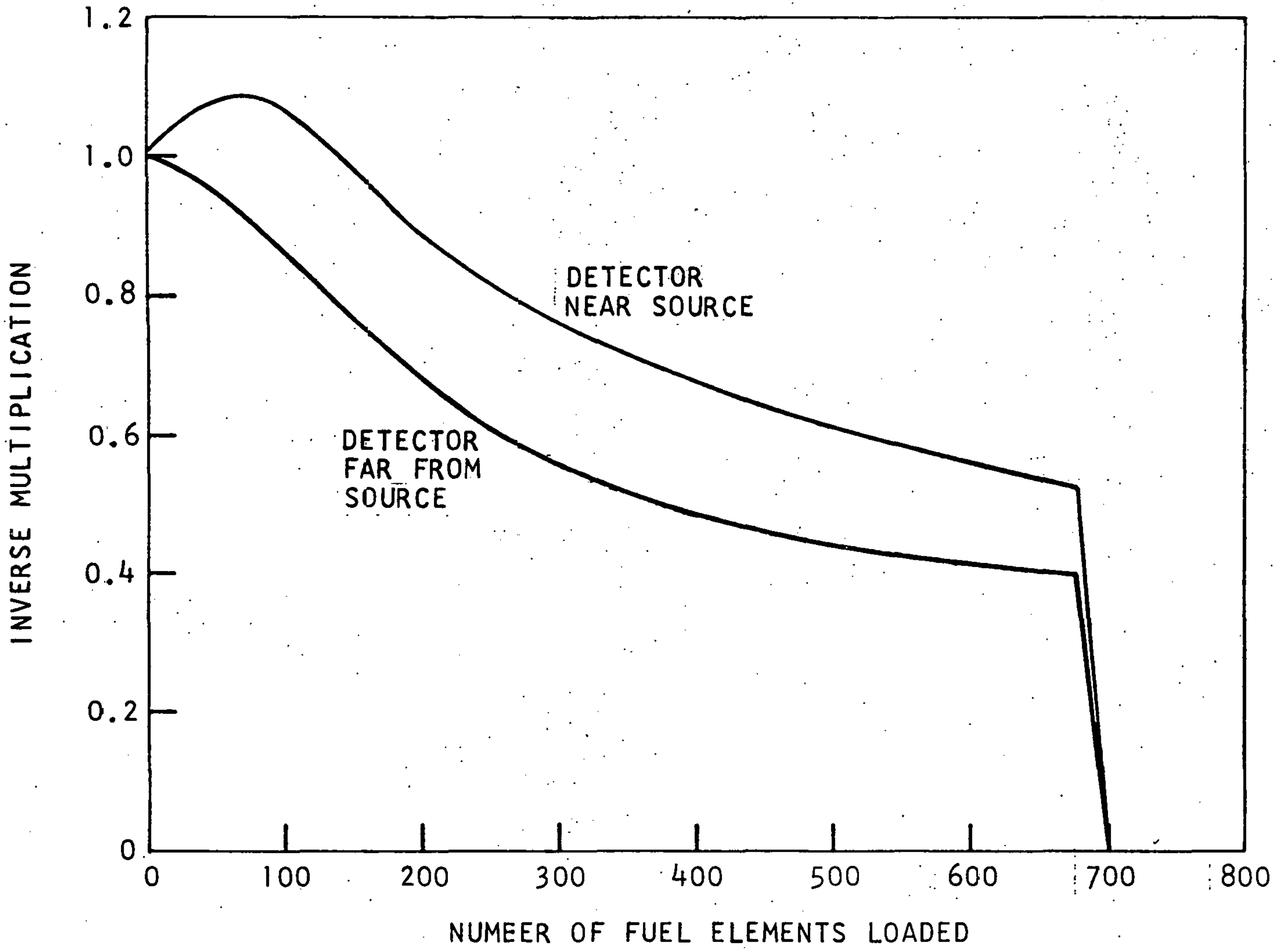


Fig. 4--Multiplication during loading (unrodded)

neutron population increases as fuel elements are loaded, the reduction in the detector sensitivity can cause the measured count rate to decrease.

2. The long diffusion length of the dummy graphite core results in a large number of direct source neutrons reaching the in-core detectors. As fuel is loaded, the diffusion length is decreased and fewer direct source neutrons reach the in-core detector locations. This phenomenon tends to decrease the count rate as fuel is loaded, even though the fission neutron population is increasing.

Even though these effects may result in a measured inverse multiplication curve which deviates significantly from the ideal curve during the initial stages of loading, the curve is nearly linear during the final stages of loading as poisoned dummy elements are removed. Criticality should not be achieved before poisoned dummy removal, and the inverse multiplication curve up to this point in loading serves as a guide to verify that criticality is not being achieved during this initial stage of loading. After each of the first three poisoned dummy elements are removed, inverse multiplication measurements will be performed with all control rods withdrawn. Since the curve is nearly linear over this portion, extrapolation to critical can be performed with a great deal of accuracy.

## REACTIVITY WORTH MEASUREMENTS (BP-15)

The reactivity worth of fully enriched uranium, thorium, rhodium, and the lumped burnable poison will be measured using six spare Type-2 (light rhodium) fuel elements, six Type-4 (heavy-thorium, uranium) elements, and six special fuel elements. The six special elements have been fabricated and are identical with the standard Type-2 elements, with the exception of the carbon and the thorium loading. The carbon and thorium loadings in these elements are identical to the loading in the standard Type-4 elements. The six special elements are described below in more detail in Section III, "Materials and Equipment."

This test is performed immediately after the power distribution measurement with three control rods in the central ring inserted one-third of their full travel (part 1 of BP-10). With the reactor shut down by approximately 4% $\Delta\rho$, the following changes are successively made in the loading:

1. The central six Type-1 (heavy rhodium) elements are replaced by six Type-2 elements, which results in a reduction of 74.09 g of rhodium at the center of the

core. The reduction in rhodium is calculated to increase the core reactivity by $9.5 \times 10^{-4}$ $\Delta\rho$, or ≈ 6 in. of rod insertion.

2. The central six Type-2 elements are replaced by the six special fuel elements, which results in an 11,387 g increase in thorium and a 2,160 g decrease in carbon at the core center. This is calculated to reduce the core reactivity by $1.82 \times 10^{-3}$ $\Delta\rho$, or ≈ 12 in. of rod withdrawal.

3. These central six special elements are replaced by six Type-4 elements, which results in a 36.94 g reduction in rhodium and an 820.8 g reduction in fully enriched uranium. This is calculated to reduce the core reactivity by $6.9 \times 10^{-4}$ $\Delta\rho$, or 8 in. of rod withdrawal.

4. After replacing the six central Type-4 elements with the original six Type-1 elements, a Type-3 lumped burnable poison element at four different radial positions is replaced by a standard Type-2 element. The calculated increase in core reactivity as a result of these exchanges varies with position from $1.1 \times 10^{-3}$ $\Delta\rho$ to $6 \times 10^{-4}$ $\Delta\rho$, and corresponds to control rod insertions of from 7 to 4 in.

With each of the above configurations the control rod calibration is checked by period measurement.

The results of the measurements will be compared with calculations made for the same core configurations. This will provide a direct over-all check on the calculational methods, particularly with respect to the effective integral cross sections of the lumped boron, thorium, rhodium, and uranium.

# III. MATERIALS AND EQUIPMENT

## NUCLEAR INSTRUMENTATION

Fission counters and boron trifluoride proportional counters will be used for flux mapping and in-core neutron detection during fuel loading.

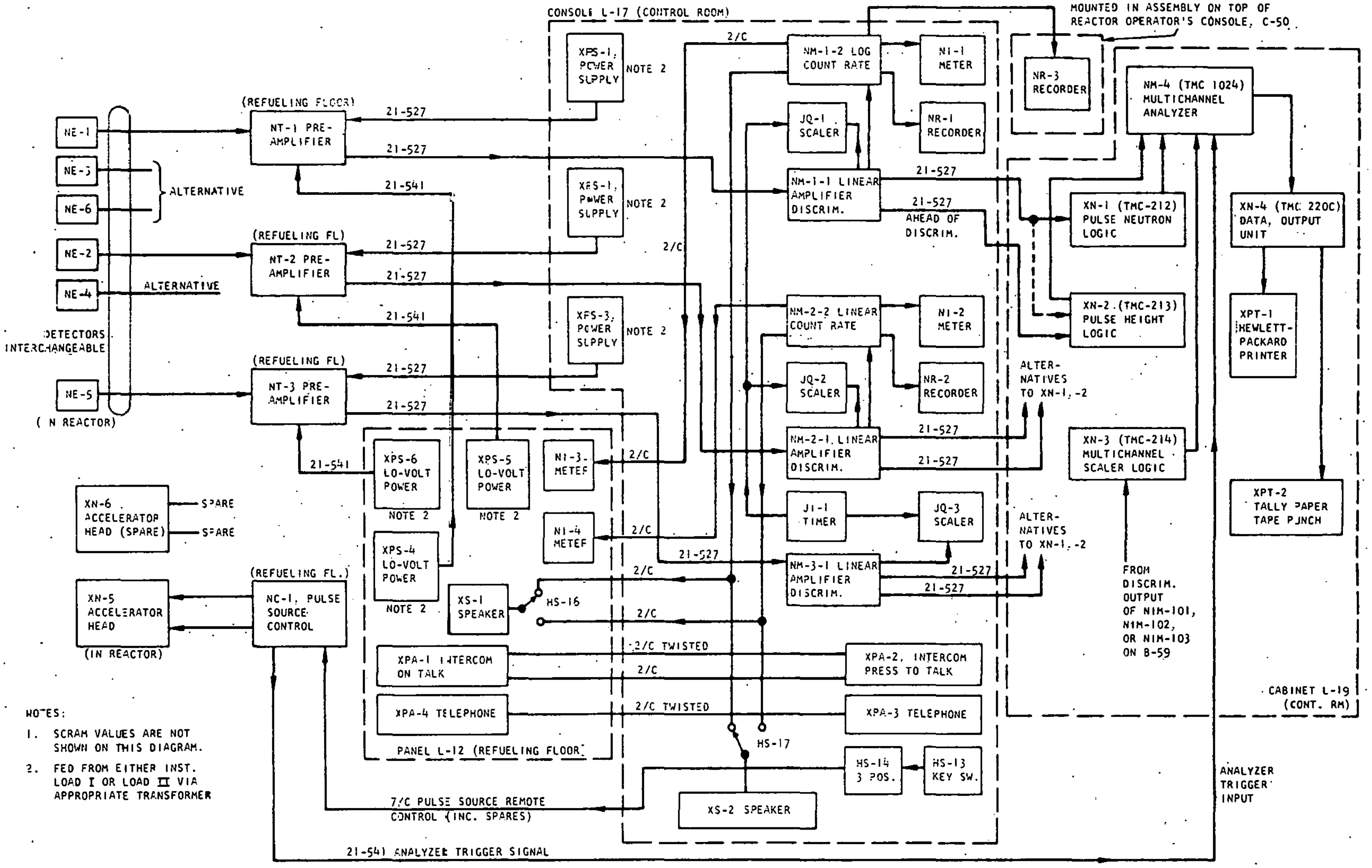
Three instrumentation channels (see Fig. 5) are to be used to obtain count rate information in the control room from the in-core detectors. Each of these channels is basically the same as the others and includes the following units which are common to all three:

1. A transistorized preamplifier located in the reflector area at the top of the core.
2. A high-voltage power supply located in the control room.
3. A pulse amplifier and discriminator located in the control room.
4. A scaler and timer located in the control room.

One of these channels has a log-count-rate circuit with output to a meter and a recorder; another channel has a linear count rate circuit with output to a meter and a recorder. The output of either count rate circuit can be used to give an audible signal proportional to count rate at both the refueling floor and the control room console.

The following instrumentation is to be used for the experimental measurements:

1. A 1024 channel analyzer, with the following plug-in units for various modes of operation: (1) pulse height mode, (2) pulsed neutron mode, and (3) multiscalar mode.
2. A pulsed neutron generator and control unit for performing subcritical pulsed neutron measurements on the core. The pulsed neutron unit will be placed on top of the core for these experiments.
3. A steady-state neutron generator to permit turning off the source of neutrons at critical (thus avoiding pulling and inserting the fixed sources) to permit source-free measurements of reactor periods and pulsed neutron measurements.



NOTES:

1. SCRAM VALUES ARE NOT SHOWN ON THIS DIAGRAM.
2. FED FROM EITHER INST. LOAD I OR LOAD II VIA APPROPRIATE TRANSFORMER

Fig. 5--Instrumentation channels to be used to obtain count rate information in the control room from the in-core detectors

4. A remote recorder available to the reactor operator giving the count rate from the log count rate circuit of one of the in-core detectors. This will be more sensitive during loading than the plant source range instruments.

In addition, an intercom and telephone system is provided for communication between the control room and the refueling floor.

## DUMMY FUEL ELEMENTS

Before fuel loading is begun, 126 poisoned dummy fuel elements will be inserted into the core in a uniform distribution. The remainder of the core will consist of the standard graphite dummy fuel elements. The poisoned dummy elements are fabricated by boring out a standard dummy element and inserting boron stainless steel rods. Thus, all dummy elements will have external dimensions identical to a standard fuel element. A typical dummy fuel element modified to include the poison sections is shown in Fig. 6.

## SPECIAL FUEL ELEMENTS FOR REACTIVITY WORTH MEASUREMENTS

The six special fuel elements required to perform test BP-15 have been fabricated. These six elements have the uranium and rhodium loading of normal Type-2 elements and the thorium and carbon content of normal Type-4 elements, as follows:

| | Loading/3-in. Compact (g) | |
|---|---|---|
| Isotope | Type E | Type F |
| $Th^{232}$ | 115.36 | 115.36 |
| $U^{234}$ (max) | 0.156 | 0.156 |
| $U^{235}$ | 9.70 | 9.70 |
| $U^{236}$ (max) | 0.052 | 0.052 |
| $U^{238}$ | 0.505 | 0.505 |
| $Rh^{103}$ | 0.0 | 0.342 |
| Carbon | 275.0 | 275.0 |

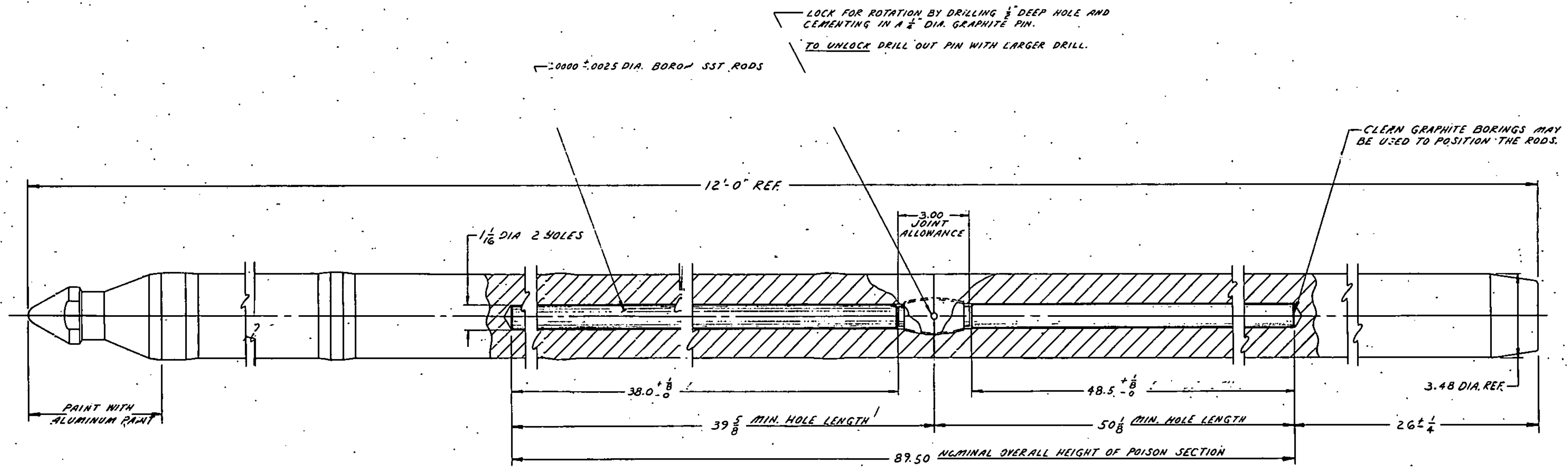


Fig. 6--Poisoned dummy fuel element

The stacking of these compacts is as follows:

| Position | Type |
|---|---|
| Upper 9 in. . . . . . . . . . | E |
| Middle 54 in. . . . . . . . . | F |
| Lower 27 in. . . . . . . . . | E |

The six special elements will not be exposed to a significant amount of irradiation. The specifications for the graphite members of these elements have been relaxed relative to the normal elements.