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An Overview of the Argonne National Laboratory Fast Critical Experiments 1963-1990

by L. G. LeSage



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AN OVERVIEW OF THE ARGONNE NATIONAL LABORATORY
FAST CRITICAL EXPERIMENTS
1963-1990

by

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ABSTRACT

The fast reactor critical experiments programs at Argonne National Laboratory (ANL), including the programs on Zero Power Reactor No. 6 (ZPR6), Zero Power Reactor No. 9 (ZPR9), and Zero Power Physics Reactor (ZPPR), are reviewed beginning with the start up of ZPR6 in 1963 and ending with the shut down of ZPPR in 1990. The programs on Zero Power Reactor No. 3 (ZPR3) are not included in this paper. Brief descriptions are given for each of the 9 ZPR6 assemblies, 35 ZPR9 assemblies, and 21 ZPPR assemblies, along with information on the experimental program on each assembly. Each major variant of each of these assemblies is described. Many figures are included showing the cross sectional and R-Z models of the assemblies along with the key assembly drawer loading patterns.

Brief descriptions of the ANL fast critical facilities are included in Appendix A. Lists of references for each of the fast critical assemblies as well as a few general references on the criticals programs and references on the experimental methods used in the criticals programs are included in Appendix C.

I. INTRODUCTION

The fast reactor critical experiments program at Argonne National Laboratory (ANL) began when Zero Power Reactor No. 3 (ZPR3) first went critical in October 1955 and terminated when Zero Power Physics Reactor (ZPPR) was shut down in September 1990. Experiments were performed at the Argonne National Laboratory-West (ANL-West) site in Idaho on ZPR3 and later on ZPPR. Experiments were performed at the Argonne National Laboratory-East (ANL-East) site on Zero Power Reactor No. 6 (ZPR6) and Zero Power Reactor No. 9 (ZPR9). The ZPR6 and ZPR9 facilities operated from 1963 to 1982. In total, there were 63 separate assemblies on ZPR3, 21 assemblies on ZPPR, 9 assemblies on ZPR6, and 35 assemblies on ZPR9. An assembly is a critical reactor configuration, usually a mock up of a particular reactor design. Some assemblies existed for only a month or two. They were loaded to critical, a short series of measurements were performed and the assembly was unloaded. Other assemblies were entire programs with several major phases, hundreds of experiments and lasting one to two years. The final engineering mockup core (EMC) on ZPPR for the Clinch River Breeder Reactor (CRBR) is an example of a major long-term program. The assembly lasted 22 months, and there were six major phases representing various stages in the life of the CRBR core (with different control rod patterns and fuel enrichments). The first four phases focused on performance and operational data and the final two phases on safety and licensing data.

It is the purpose of this report to provide an overview of the fast critical experiments program at ANL with an emphasis on providing enough information to decide which assemblies and experiments are the most important to preserve in the appropriate data files. The focus will be more on the later assemblies--the ZPPR assemblies and selected ZPR6 and ZPR9 assemblies--although all the ZPR6, ZPR9, and ZPPR assemblies are documented. It is unlikely that many of the ZPR3 assemblies will fall within the group of the most important ones. Therefore, only a few of the ZPR3 assemblies are mentioned in this report; however, it would be appropriate for a complete summary of the ZPR3 assemblies in the future. This report is the first total overview of the programs on ZPPR, ZPR6, and ZPR9.

Over the years, the experimental techniques and methodology and the analytical corrections improved greatly--resulting in more reliable and much more precise experimental results. For this reason and because the ZPPR assemblies represented the largest, most realistic fast reactor design mock ups, it is expected that the ZPPR results will prove to be the most useful. There were several assemblies on ZPR6 and ZPR9 that will also be useful, however. Some of these assemblies were designed to help evaluate nuclear data by emphasizing the importance of certain isotopes or specific region of the neutron energy spectrum. In another case, the small-sample heated Doppler reactivity measurements made in the central zones of the ZPR9 zoned assemblies were a key input to the understanding of the fast reactor Doppler effect.

II. ZPPR, ZPR6, AND ZPR9 PROGRAMS

The ZPPR Program began in March 1969. Its first assembly supported the Fast Test Reactor (FTR) at the Fast Flux Test Facility (FFTF). Most of the early assemblies (i.e., Assemblies 2 through 8 and Assemblies 11 and 12) supported the Demonstration Reactor Benchmark Criticals Program and the Clinch River Breeder Reactor (CRBR). Assembly 2 was a clean two-zoned design, and Assembly 3 was the first assembly to include mockup control rods (CRs) and control rod positions (CRPs). Assemblies 5 and 6 were the Engineering Mockup Cores (EMCs) for the CRBR conventional two-zone design and Assembly 11 was the EMC for the CRBR radial heterogeneous design. In these assemblies, the various stages in the reactor life cycle (e.g., Beginning of Life, End of Life) were mocked up by adjusting the mockup control rod positions and configurations, the fuel enrichment, and, sometimes, including plutonium build up in the blanket regions. Assemblies 9 and 10 were a cooperation with the Power Reactor Nuclear and Fuel Development Corporation (PNC) of Japan. This program was called JUPITER-I and was directed at 700-900 MWe-sized conventional cores. Assembly 13, a second cooperation with PNC called JUPITER-II, focused on 700 MWe radial heterogeneous designs. The final PNC cooperation, JUPITER-III, included Assemblies 17, 18, and 19. This program addressed an axial heterogeneous design of about 700 MWe size and very large conventional two-zone designs of about 1200 MWe size. Assembly 14 obtained information on the use of reflectors for reactor control. Assembly 15 was a clean benchmark supporting the Integral Fast Reactor (IFR) design effort, and Assembly 21 provided criticality information for the IFR fuel cycle operations. Assemblies 16 and 20 supported the design of the SP-100 Space Power Reactor.

The ZPR6 and ZPR9 facilities were built at the same time with a common fuel handling and loading room located between the two reactor cells serving both. ZPR6 began operation in July 1963 and ZPR9 followed in January 1964.

The first ZPR6 core was a simple U²³⁵/U²³⁸ assembly. It was identical to ZPR3-22. ZPR6 Assemblies 2 through 5 supported uranium carbide fast reactor designs. Assembly 3 was a pancake-shaped core designed to increase neutron leakage and reduce the sodium void reactivity. Assembly 4Z was the first zoned assembly with a central test zone, and Assembly 5 was a large, clean uranium carbide benchmark assembly. Assembly 6/6A was a clean single zone uranium oxide simulation, and Assembly 7 was its plutonium/uranium oxide counterpart. These assemblies were part of the Demonstration Reactor Benchmark Criticals Program as were several of the early ZPPR assemblies. ZPPR6-8 was planned to include a heated central zone containing rod-type fuel, but it was not constructed. ZPR6 was then shut down for several years and was restarted with Assemblies 9 and 10 which were part of the Diagnostic Core Program. ZPR6 was shut down in July 1982.

The first nine ZPR9 assemblies supported a nuclear rocket program. There was no Assembly 10. Assemblies 11 through 25 (except Assembly 17) were zoned assemblies with central test zones. Their programs were directed at primarily spectral dependent quantities (e.g., reaction rate ratios, small sample reactivity worths, and Doppler reactivity worth) and some effort was directed at using the zone measurements to predict the properties of full-sized cores. Assembly 24, along with ZPR3 Assembly 55, were null-zone assemblies ($k_{\infty} = 1.0$ in the test

zone) used in the measurement of the capture-to-fission ratio for U^{235} and Pu^{239} . Assemblies 26 and 27 supported the final design of the FTR. Assembly 27 was the FTR-EMC. Assemblies 28, 29, and 30 supported the evaluation and design of Gas Cooled Fast Reactors (GCFRs). Assembly 31 was a clean benchmark directed at evaluation of advanced carbide fast reactor fuel. Assembly 32 was a program for the Nuclear Regulatory Commission to obtain data to test core disassembly calculations associated with a hypothetical severe loss-of-flow accident. Assembly 33 was a single-zone core composed of enriched uranium and iron supporting the design of the Safety Test Facility (STF). Assemblies 34, 35, and 36 along with ZPR6 Assemblies 9 and 10 were all part of the Diagnostic Core Program. These assemblies were generally clean and were designed to isolate or emphasize certain isotopes and certain parts of the neutron energy spectrum in order to better identify data problems. ZPR9 was shut down in 1981.

III. ASSEMBLY DESCRIPTIONS

Appendix A contains brief descriptions of each of the ZPPR, ZPR9, and ZPR6 assemblies. A common format is used which includes, on a single page, the assembly number and name, an overview description of the assembly design and the focus of the associated experimental program, a list of related assemblies, some key details of the assembly design, and a list of the variants of this assembly program. Following this one page description, several figures, as available, are included--generally showing the interface diagram and an RZ model for the assembly and the key drawer loading patterns (see section on Facility Description). When appropriate, this information is included for each of the major variants of the assembly.

The purpose of this report is to provide a broad overview of the ANL fast critical experiments program, but it is not intended to provide precise details on the designs of the assemblies. Therefore, the following comments are appropriate.

- The overview of each assembly and the focus of the associated experimental program is brief. Generally, the experimental programs were lengthy and quite complex with possibly several objectives. Only the most important assembly parameters and the key program objectives are mentioned.
- Only the obvious cases are listed under the Related Assemblies heading. Intercomparisons among many assemblies not listed have been made in the past and will be useful in the future.
- The Assembly Details section was not meant to be exact. Both the critical mass and core volume values have been rounded off. For exact values to be useful, one would need to know a great deal more detailed information on the exact assembly loading and the conditions under which the measurement was made. In this section, "Sodium cooling" simply means that sodium enclosed in a stainless-steel cans has been loaded into a region in the assembly to simulate the sodium coolant in a sodium-cooled reactor.
- A single-page description, with accompanying figures, is devoted to each of the 21 ZPPR assemblies. For the ZPR6 and ZPR9 assemblies, this is not always the case. When several of these assemblies are closely related, they were grouped together on a single page. For example, ZPR9-28, -29, and -30 were GCFR-I, GCFR-II, and GCFR-III (GCFR means Gas Cooled Fast Reactor). These three assemblies were grouped together since they were similar in concept to one of the ZPPR assemblies with several variants.
- The set of figures following the single-page assembly descriptions are many times not complete. In particular, R-Z models for only a few variants and drawer loading patterns for only the most important drawers are usually included. Sometimes these other figures were not available but mostly they were omitted to avoid excessive redundancy and to keep the report a manageable length.

IV. EXPERIMENTAL PROGRAMS

Most of the ZPR6, ZPR9, and ZPPR assemblies fall into one of the following four types:

- Zoned Assembly with Central Test Zone
- Clean Benchmark Assemblies
- Engineering Benchmark Assemblies or Engineering Mockup Cores
- Special Purpose Assemblies

There exists, for each of these assembly types, a characteristic set of measurements that are generally performed on all assemblies of this type. Clearly there were many exceptions, and measurement techniques evolved considerably over the years of the ZPR/ZPPR Program. Nevertheless, there were certain measurements that were generally repeated on each of the, for example, clean benchmark assemblies. In the appendix describing each of the assemblies, only the special or unique measurements associated with an assembly are mentioned. An example is the ex-vessel neutron detector experiment in ZPPR-11. It can be assumed, however, that nearly all the characteristic measurements for engineering mockup assemblies were also performed on ZPPR-11 which was the EMC for the final CRBR heterogeneous design. The same is true for the other assemblies.

In addition, there were a number of operational measurements performed on each assembly (i.e., operational control rod worth and shut down margin, temperature coefficient, edge fuel worth, etc.). These will not be mentioned further.

In the following paragraphs, the measurements generally performed in each assembly type are listed.

Zoned Assemblies with Central Test Zone

- Spatial measurements to confirm spectral convergence in the test zone.
- Central reaction rate ratios (including fission and capture rates for U^{235} , U^{238} , Pu^{239} and possibly some other absorbing materials).
- Central material reactivity worths for the constituent materials and other interesting isotopes.
- Neutron spectrum.
- Kinetics parameters.
- Central small sample Doppler reactivity (in some assemblies only).
- The worth of a central control rod (some assemblies only).

Clean Benchmark Assemblies

- Most of the central measurements performed in zone assemblies with central test zone.
- Spatial distribution of fission and capture rates (using both fission counters and activation foils).
- Spatial distributions of small sample reactivity worths.
- Spatial distributions of γ heating using thermal luminescent dosimeters (TLDs).
- Worths of sodium voided zones at various locations in the assembly.
- Worths of individual control rod mockup at various points in the assembly.
- Expansion reactivity worth in some of the later cores.

Engineering Benchmark Assemblies or Engineering Mockup Cores

- Most of the measurements performed in clean benchmark assemblies.
- Generally more detailed fission and capture rate distributions performed in many configurations [i.e., for a variety of control rod (CR) patterns].
- Detailed fission and capture rate distributions at specific locations (e.g., near CRs, test loops, or region interfaces).
- Worths of individual CRs, CR banks, and various other CR patterns, both symmetrical and asymmetrical.
- Simulations of various stages in the core life cycle (BOL, EOL, etc.).

Special Purpose Assemblies

Only three assemblies are classified in this category.

ZPPR-20 (SP-100 Space Power Reactor--100 kWe)

In this program, the key was a detailed mockup of not only the core but also the whole structure, whether the ground test assembly or the flight system. Configurations such as the assembly immersed in water or buried in sand were unique. Still measurements such as fission and capture rate distributions and control assembly worths were still important.

ZPR-21 (IFR Fuel Cycle Studies)

This program focused on criticality considerations for a spectrum of metal fuel compositions that could exist in the IFR fuel cycle.

ZPR9-32 (Safety Related Critical Experiments)

This program was concerned with obtaining data to test codes used to predict reactivity changes during a core disassembly accident resulting from a severe loss-of-flow transient. The key data was reactivity changes between configurations and reaction rate distributions in the various configurations.

V. CRITICAL FACILITIES

The ZPPR, ZPR6, and ZPR9 critical facilities at ANL have been described in detail in many previous publications. Only a brief description is included here. The cores were made up on many platelets of various materials which were loaded into drawers. The drawers were then loaded into a matrix structure which was made up of many square matrix tubes clamped tightly together into a large square array. The array of matrix tubes was positioned horizontally so that the drawers were inserted horizontally into the matrix tubes, and the core simulations were generally cylindrical with axis of the cylinder positioned horizontally. In addition, the array of matrix tubes was separated into two halves at the cylindrical axial midplane. During operation, the two halves of the array of matrix tubes were positioned tightly together, but at shut down the two halves of the assembly were separated giving easy access to the midplane of the assembly and providing a huge shut down reactivity margin.

Appendix B contains drawings and photographs providing additional information on the fast critical facilities. Figure 135 is a line drawing of the ZPR6 and ZPR9 facilities before these facilities were expanded and modified for the use of plutonium fuel. It shows the essential features of the split table fast critical facility typical of all four of the ANL facilities. Figures 136 through 140 are photographs from the ZPPR facility. Figures 136 and 137 show the plates of various materials, loaded drawers and also a pin calandria. Figure 138 shows fuel drawers partially loaded into the matrix. Figures 139 and 140 show the matrix interfaces with the matrix halves separated. The matrix drawer loading machine is also shown in Figs. 139 and 140.

In almost all cases, both the matrix tubes and the drawers were stainless steel. This means that stainless steel was always a core constituent no matter what materials were loaded into the drawers. In Assemblies 1 through 9 of ZPR9, the rocket cores, both the matrix tubes and the drawers, were made of aluminum. In ZPR9-33, the STF all-converter core, aluminum trays were used in the core and axial blanket regions rather than stainless-steel drawers.

The general design of the ZPR6, ZPR9, and ZPPR critical facilities were similar; however, the array of matrix tubes in ZPPR was considerably larger allowing much larger cores to be simulated in ZPPR. The dimensions of the individual matrix tubes in ZPR6, ZPR9, and ZPPR-7F through ZPPR-21 were square and the same. In ZPPR-1 through ZPPR-7E, the matrix tubes were slightly larger in the vertical direction providing a larger gap between the top of the drawer and the underside of the matrix tube. Thus, in the early ZPPR assemblies, there was about 5% additional void in the assembly relative to the assemblies in ZPR6 and ZPR9 and the later ZPPR assemblies.

VI. REFERENCES AND RELATED DOCUMENTS

Appendix C contains a listing of the references for the ZPPR, ZPR9 and ZPR6 assemblies described in this report. These references contain information not only on a description of the assemblies and the experimental programs but also include the experimental results and in many cases the analysis results. The references are grouped by assembly so that some references that include information on more than one assembly will appear in the reference lists for more than one assembly.

In addition to the references for these individual critical assemblies, two other special lists of references have been included. The first includes general references applicable to all or most of the assemblies. Examples are the references that report the results of the assessment studies. In these cross-cutting studies, the experimental results for a particular parameter (e.g., control-rod-reactivity worth) for a large number of different critical assemblies were evaluated using consistent analysis methods so the results were comparable. The objectives of the assessment studies were several--to see how consistently experiments performed on different assemblies and facilities, at different times, and on greatly different reactor configurations, could be predicted; to look for trends in predictions; to observe the scatter in the predictions; and to recommend a preferred analysis methodology with experimentally-based uncertainties and bias factors. Assessment studies were performed for three parameters--critical eigenvalue, control-rod worth, and sodium-void worth. General references 1 through 7 report the results of the assessment studies.

The second special list includes many of the key references describing the experimental techniques, methodologies, and equipment used on the fast critical assembly experimental programs. There was, of course, an evolution and refinement of the measurements over the lifetime of the fast critical experiments program. Improved experimental methods and equipment and more powerful analytical techniques both contributed to a more accurate understanding of many of the required experimental corrections. Measurements made on the later assemblies generally had smaller experimental uncertainties. The references listed tend to focus more on the experimental methods near the end of the program although in some cases the most comprehensive descriptions were included in an earlier reference.

Experimental methods references 1 through 7 describe reactivity-related experimental methods, including small-sample reactivities, control-rod worths and Doppler reactivities. References 8 through 12 describe reaction-rate-related experimental methods including absolute fission and capture rate measurements and methods for determining cell-average reaction rates. References 13 through 15 describe methods for measuring the neutron energy spectrum and gamma-ray energy deposition.

In many cases, the reports on individual assemblies also describe the experimental methods used. In addition, there were many one-of-a-kind-type measurements made. These were usually described in the assembly reports.

It should be noted that the reference lists are almost certainly not complete. Considerable effort was expended in compiling these lists but, considering the number of publications over the period of this report, there are clearly other references that have been inadvertently omitted.

A large part of the information in this report was obtained from the ANL ZPR-TM reports. Several hundred of these reports provided relevant and extremely detailed data and information. The ANL ZPR-TM reports were initiated in 1969 and continued until the termination of the ZPPR program. Between 1964 and 1972, the Reactor/Applied Physics Division at ANL issued open literature annual reports that contained considerable detail on the critical assembly programs (including ZPR3 which is not discussed here). These annual reports were issued as ANL greenback reports with numbers ANL-7010, -7110, -7210, -7310, -7410, -7610, -7710, -7910, and -8010. There have also been many articles on the critical experiments programs published in the open literature either in journals or in conference proceedings. These articles tended to focus more on program results (e.g., comparisons of experiments and analysis) and were not as useful in describing the assemblies and programs as are the internal ANL reports.

There were two internal summary reports that were particularly useful in the preparation of this report. One, prepared by S. B. Brumbach, summarized the ZPPR-2 through ZPPR-10 programs. The other, prepared by R. D. McKnight and W. R. Robinson, summarized the ZPR9-28 through ZPR9-36 and the ZPR6-6A, -7, and -10 programs. The lists of references compiled in these two reports have been essentially reproduced in Appendix C for the relevant assemblies. These reports, unfortunately, have had very limited distribution even within ANL.

Much of the material in this report has come from the direct personal knowledge of the author. From 1966 to 1973, he was a staff engineer working on the ZPR6 and ZPR9 programs, and from 1973 to 1990, when the last fast critical experiment on ZPPR was terminated, he had either direct or indirect responsibility for the management of these programs.

APPENDIX A

ANL FAST CRITICAL ASSEMBLY DESCRIPTIONS

A2

ZPPR-1

FTR-2, the second of four assemblies supporting the design of the Fast Test Reactor (FTR).

Overview:

This assembly was a simplified version of the FTR core at an intermediate stage of the design process. The objective of this criticals program was to provide design support.

Assembly Dates:

March 1969-November 1969

Related Assemblies:

ZPR3-56 (FTR1), ZPR9-26 (FTR3), and ZPR9-27 (FTR-EMC)

Assembly Details:

Type:	Cylindrical, two-zone, clean ¹ critical with a 2-in.-thick boron control ring surrounding the core
Fuel:	Mixed Pu/U oxide with sodium cooling ²
Critical Mass:	540 kg (Pu^{239} + Pu^{241})
Core Volume:	1000 liters
Blanket:	None
Reflection:	Stainless steel with sodium cooling

Assembly Variants:

The boron control ring was removed and a shield sector was added. A fuel storage zone was added to the shield sector.

¹By clean, we mean as simple geometry as possible and uniform material loading in each region. Clean assemblies were constructed to minimize analysis difficulties.

²The reactor fuel rods were simulated with plates of various materials (e.g., Pu/U alloy plates canned in stainless steel, depleted uranium metal and U_3O_8). Sodium cooling was simulated by sodium enclosed in stainless-steel cans.

ZPPR-2

Part of the Demonstration Reactor Benchmark Criticals Program. Physics benchmark assembly.

Overview:

This assembly was a clean, two-zone, cylindrical core of the approximate size, geometry, neutron spectrum, and composition as the proposed Demonstration Reactor. Its purpose was to support the design of the Demonstration Reactor by testing nuclear data, design and analysis codes, and design methodology on realistic experimental data.

Assembly Dates:

February 1970-January 1972

Related Assemblies:

ZPR6-6A, ZPR6-7, and ZPPR-3 are all part of the Demonstration Reactor Benchmark Criticals Program.

Assembly Details:

Type:	Cylindrical, two-zone clean critical
Fuel:	Typical Pu/U oxide with sodium cooling
Critical Mass:	1020 kg ($^{239}\text{Pu} + ^{241}\text{Pu}$)
Core Volume:	2500 liters
Blanket:	Depleted uranium (DU) oxide with Na cooling

Assembly Variants:

Four different critical configurations, all very similar.

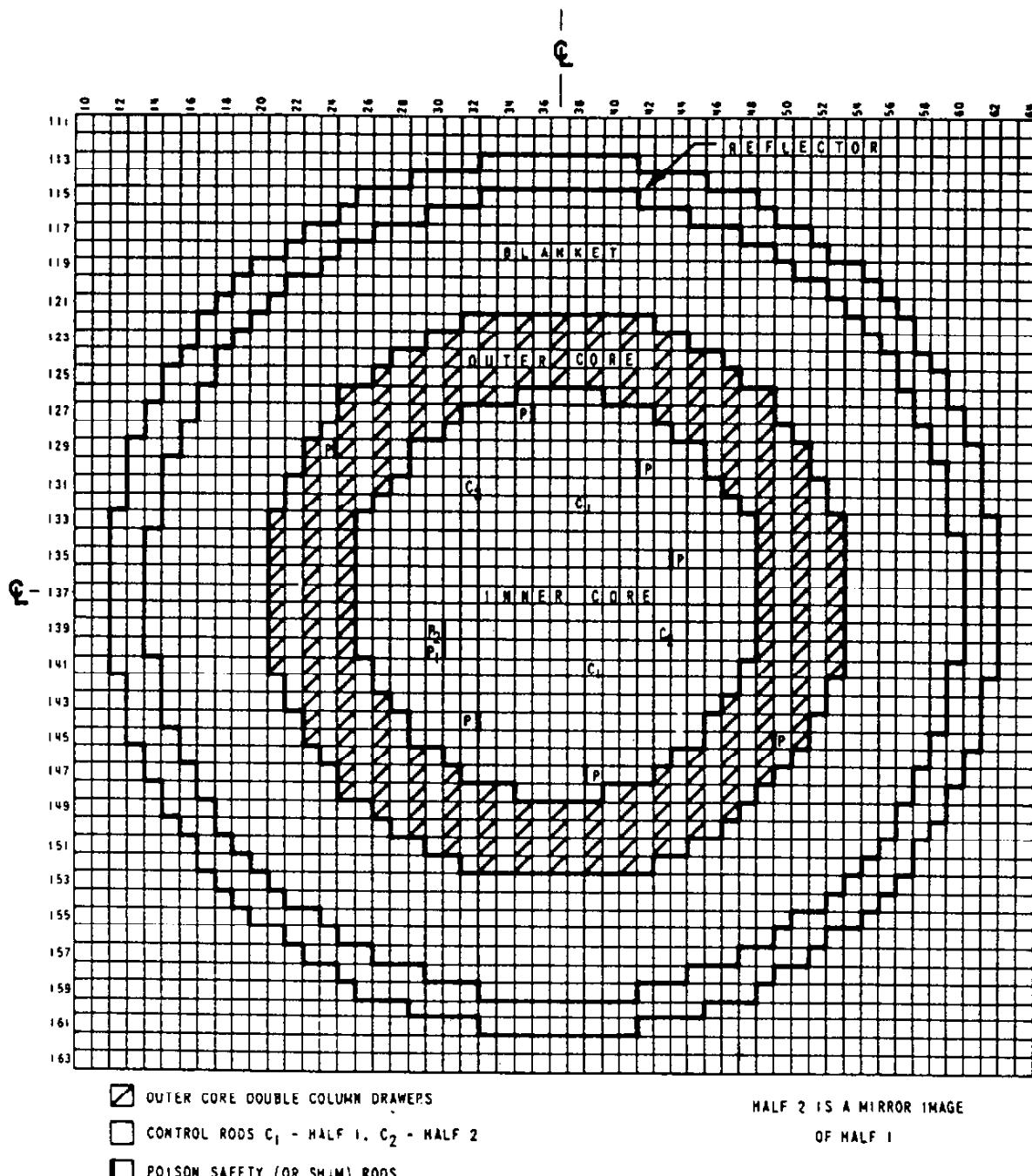


Fig. 1. Interface Diagram of ZPPR-2

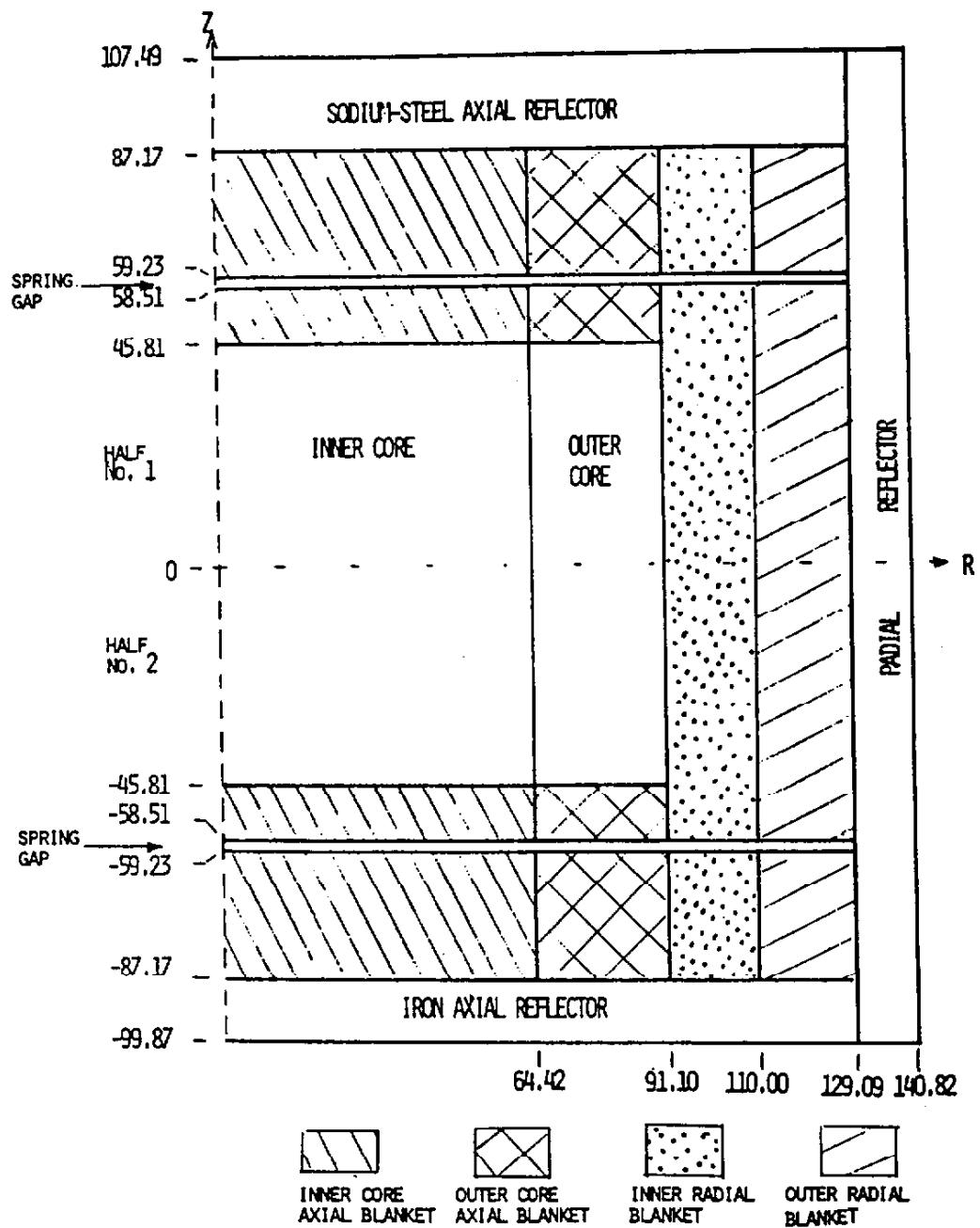


Fig. 2. R-Z Model for ZPPR-2

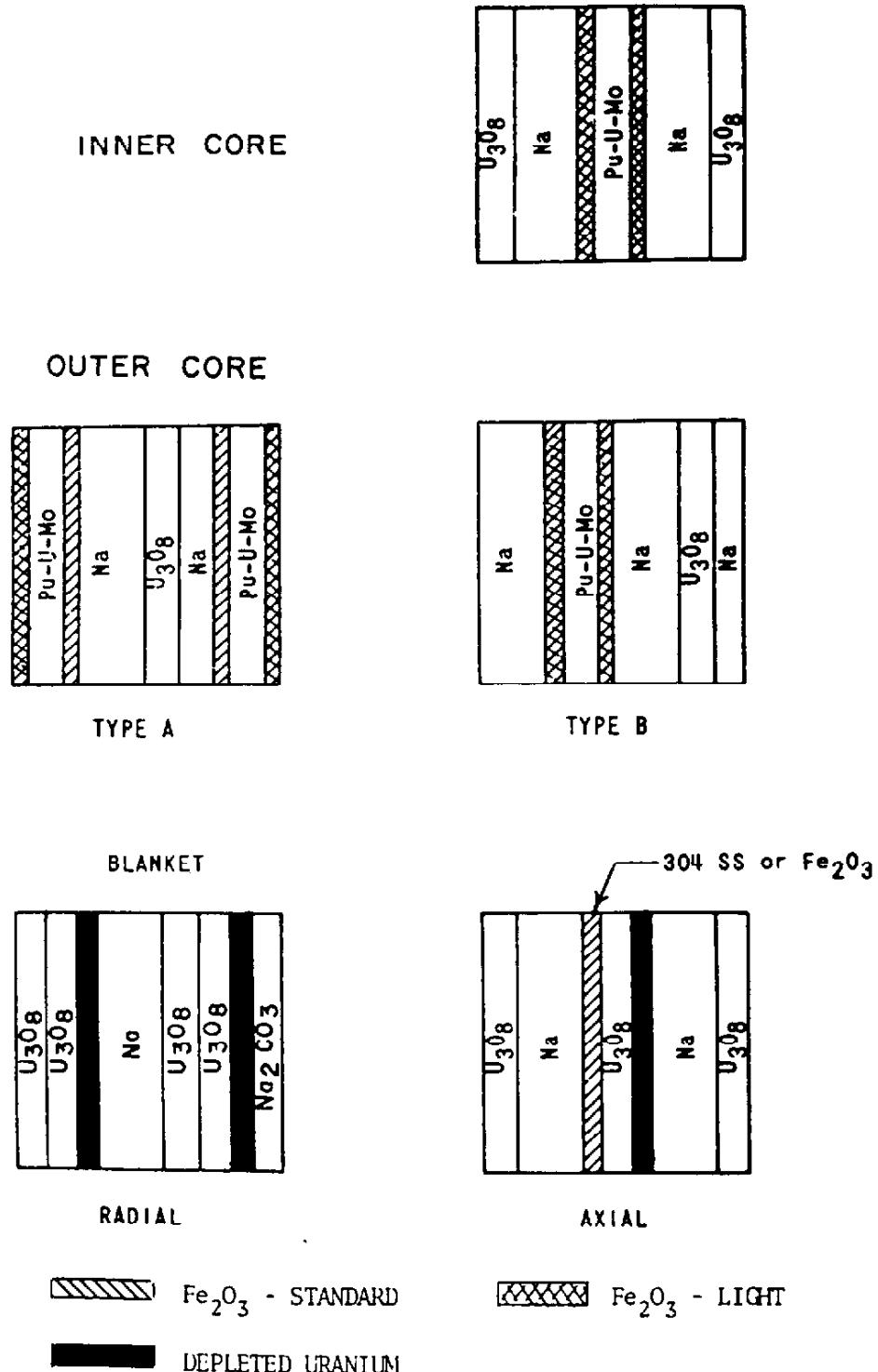


Fig. 3. Drawer Loading Patterns for ZPPR-2

ZPPR-3

Part of the Demonstration Reactor Benchmark Criticals Program. Engineering benchmark assembly.

Overview:

This assembly was a two-zone, cylindrical core with control rods (CRs) and control rod positions (CRPs)¹ with the approximate size, geometry, neutron spectrum, and composition of the proposed demonstration. It was ZPPR-2 with CRs and CRPs. Its purpose was to test codes, data, and methodology on a more realistic reactor layout, control elements included.

Assembly Dates:

March 1972-October 1972

Related Assemblies:

ZPPR-2, ZPPR-4, ZPR6-6A, and ZPR6-7 are all part of the Demonstration Reactor Benchmark Criticals Program.

Assembly Details (Phase 1A):

Type:	Cylindrical, two-zone critical with CRs and CRPs
Fuel:	Typical Pu/U oxide with sodium cooling
Critical Mass:	1340 kg (Pu^{239} + Pu^{241})
Core Volume:	3350 liters
Blanket:	Depleted uranium (DU) oxide with sodium cooling
Reactivity Adjustment:	Pu spike ²

Assembly Variants:

- Phase 1A: CRPs, no CRs.
- Phase 1B: Core Pu composition increased and core size reduced to about 2400 liters.
CRPs, no CRs.
- Phase 2: Similar to Phase 1B but six CRs fully inserted.
- Phase 3: Similar to Phases 1B and 2 but nine CRs, fully inserted.

¹Control rod positions were sodium-filled channels over the full height of the core.

²"Spike" refers to an extra plate of plutonium-bearing fuel added to the assembly drawers, with these drawers then scattered more or less uniformly throughout the core.

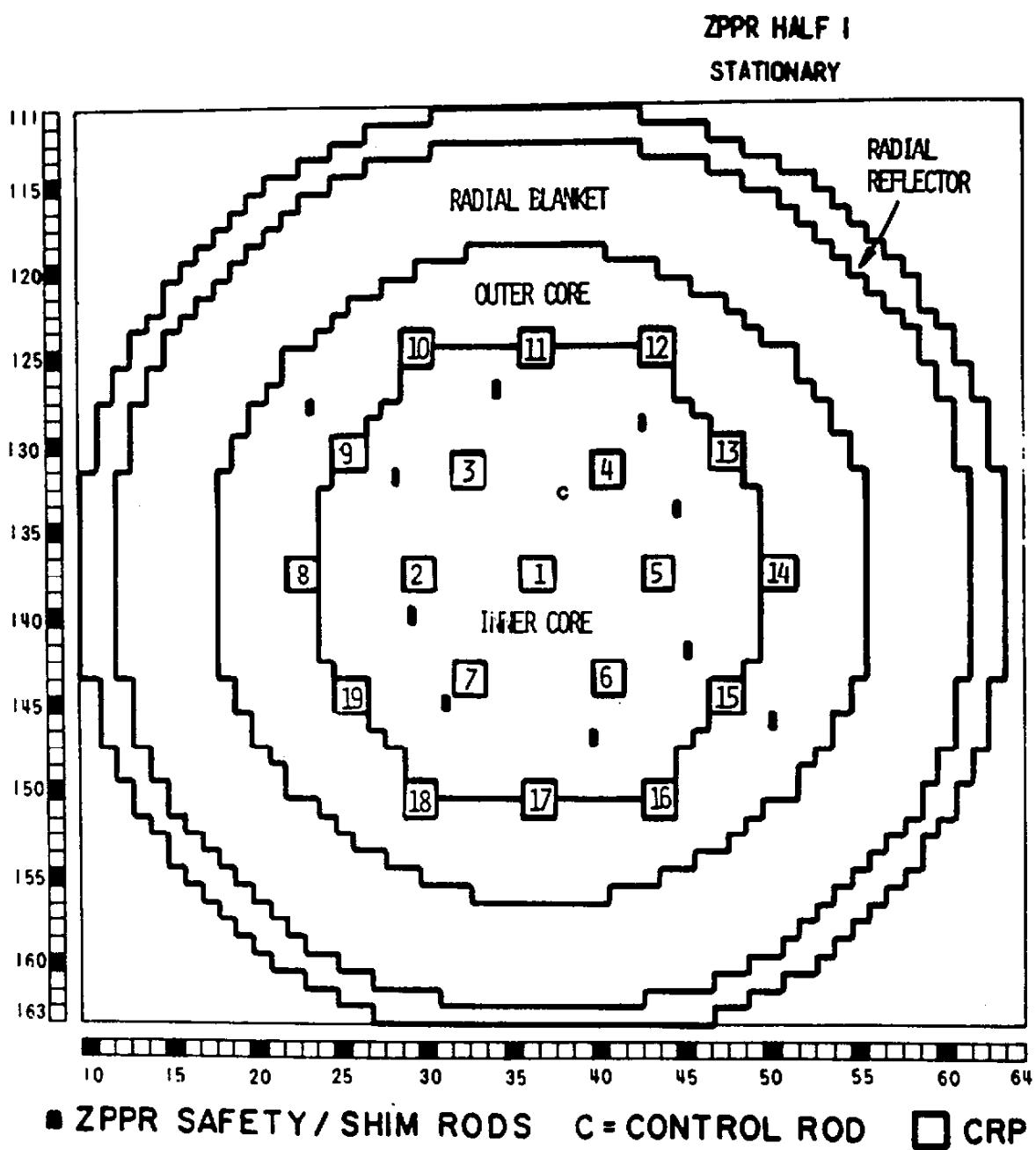


Fig. 4. Interface Diagram for ZPPR-3, Phase 1A

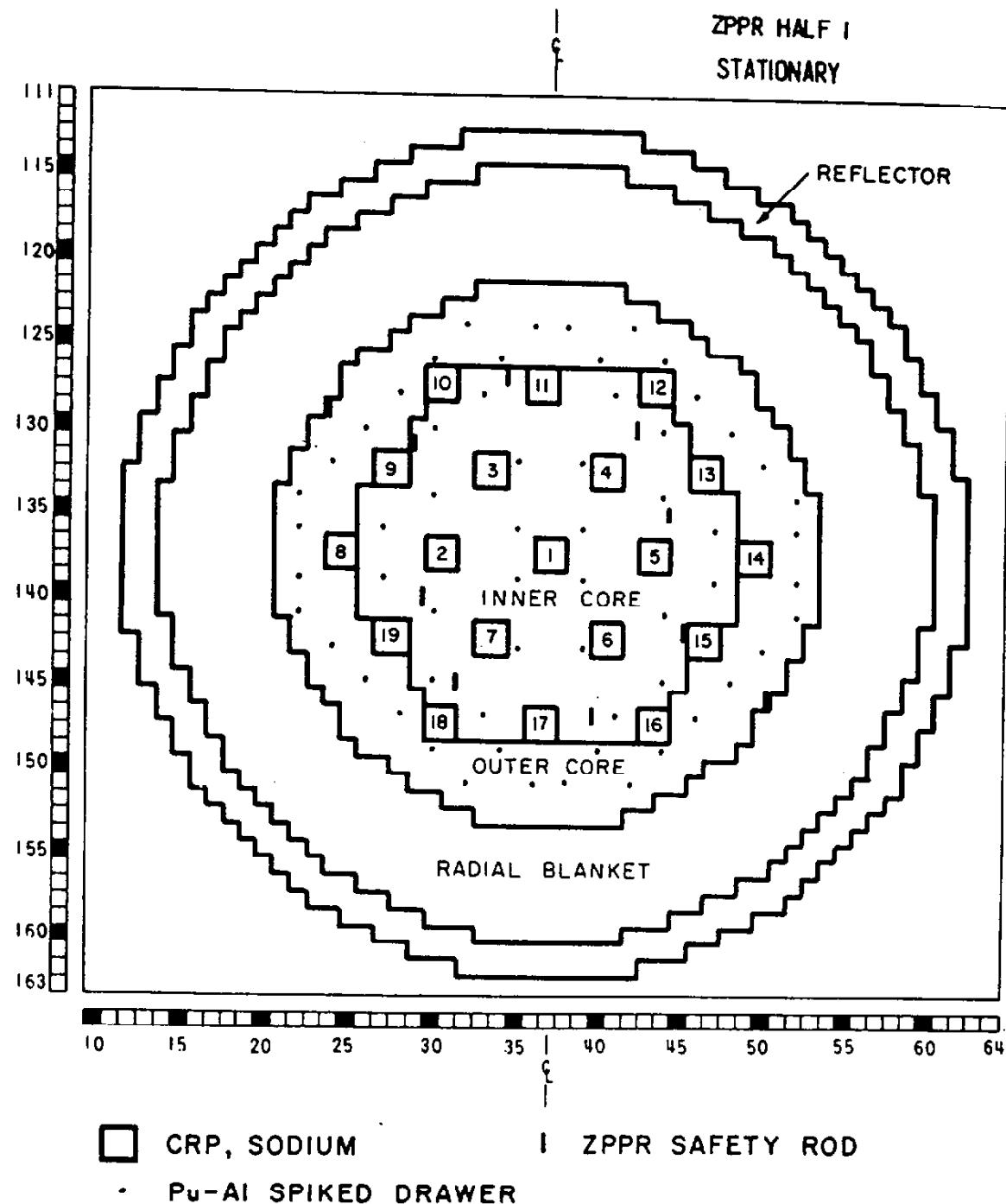


Fig. 5. Interface Diagram for ZPPR-3, Phase 1B

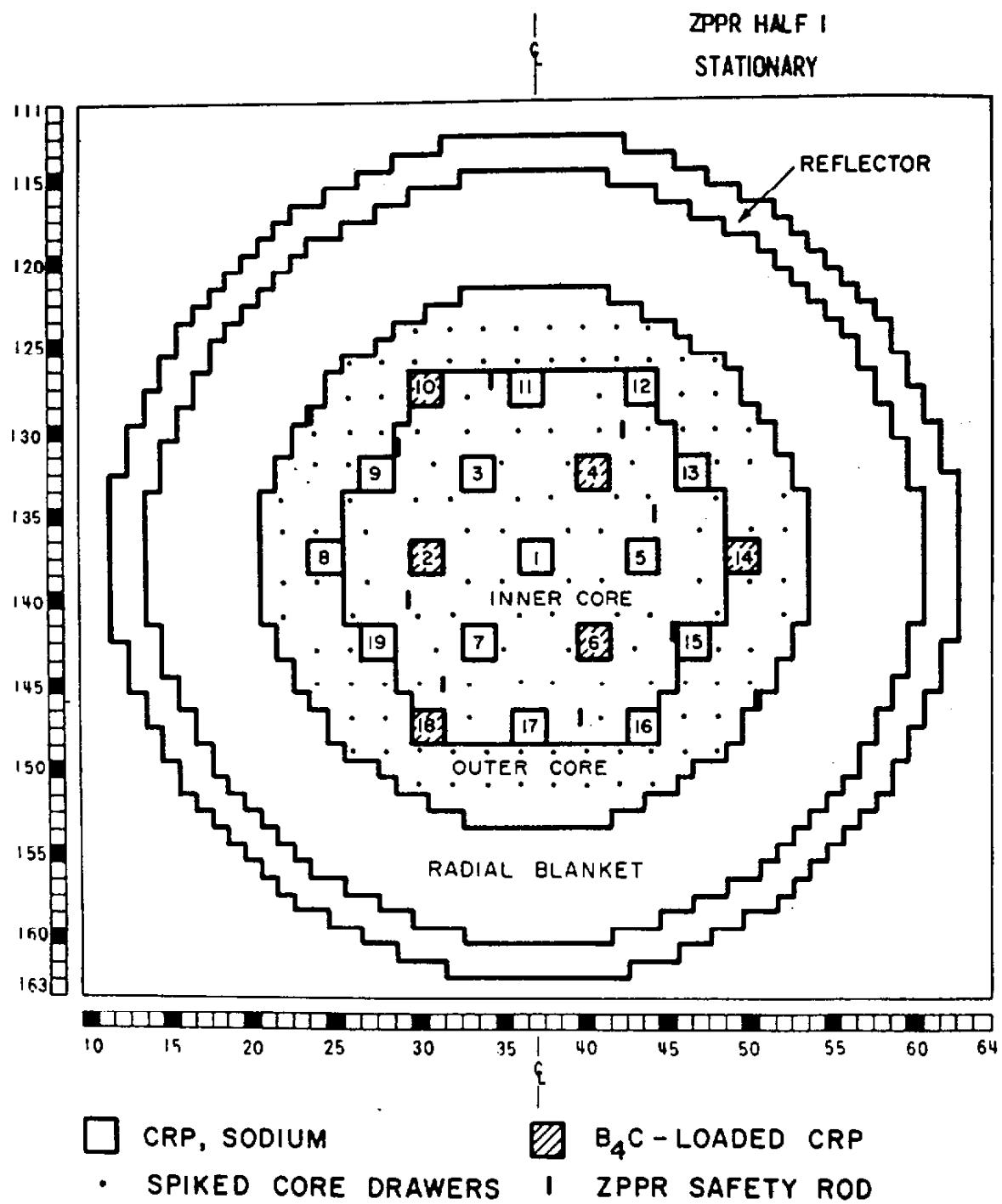


Fig. 6. Interface Diagram for ZPPR-3, Phase 2

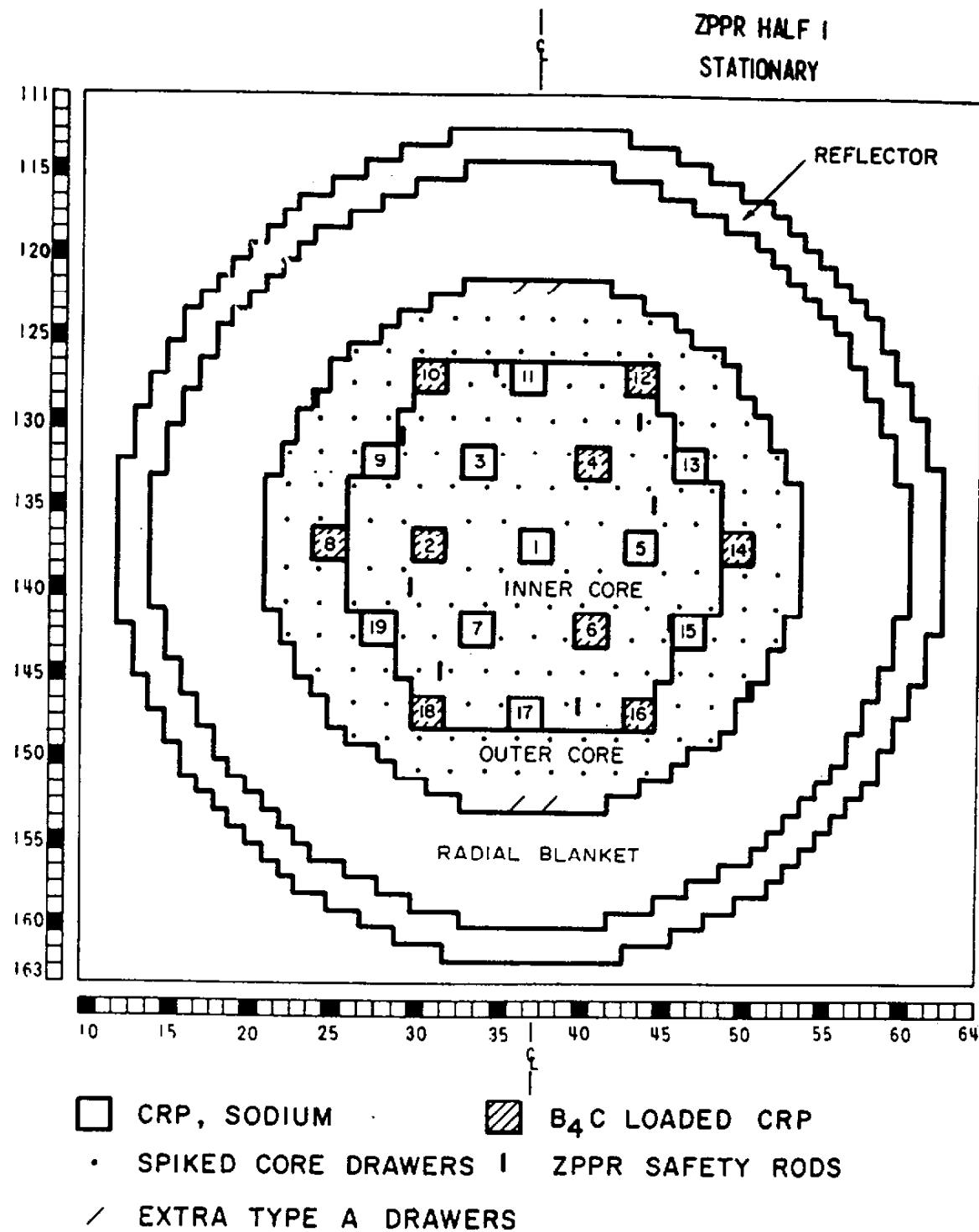


Fig. 7. Interface Diagram for ZPPR-3, Phase 3

ZPPR-4

Part of the Demonstration Reactor Benchmark Criticals Program. Engineering benchmark assembly.

Overview:

This assembly was a two-zone, hexagonal core with control rods (CRs) and control rod positions (CRPs). It was similar to ZPPR-3 with the adjustment from cylindrical to hexagonal. In some variants, plutonium buildup in the radial blanket¹ was introduced and a special assembly breeding ratio measurement was performed.

Assembly Dates:

November 73-January 1975

Related Assemblies:

ZPPR-2, ZPPR-3, ZPR6-6A, and ZPR6-7

Assembly Details (Phase 1):

Type:	Hexagonal, two-zone critical with CRs and CRPs
Fuel:	Typical Pu/U oxide with sodium cooling
Critical Mass:	1080 kg (Pu^{239} + Pu^{241})
Core Volume:	2540 liters (all phases)
Blanket:	Depleted uranium (DU) oxide with sodium cooling. Plutonium buildup in the radial blanket simulated in some phases.
Reactivity Adjustment:	Pu spikes

Assembly Variants:

- Phase 1: End-of-cycle (EOC) configurations, CRPs and CRs.
- Phase 2: Beginning-of-cycle (BOC) configurations, seven fully inserted CRs
- Phase 2: BOC with high Pu^{240} sector.
- Phase 2: Middle-of-cycle (MOC), seven half inserted CRs².
- Phase 3: BOC configuration, seven fully inserted CRs and Pu buildup in the radial blanket.
- Phase 3: MOC configuration, seven half inserted CRs and Pu buildup in the radial blanket.
- Phase 4: EOC configuration, CRPs only, Pu buildup in the radial blankets.

¹Plutonium buildup was simulated by adding a column of plutonium-bearing fuel to some of the blanket drawers, with these drawers then scattered more or less uniformly throughout the blanket.

²Half inserted CRs: A CR mockup is loaded in one half of the ZPPR assembly and a CRP mockup (sodium-filled channel) is loaded in the other half.

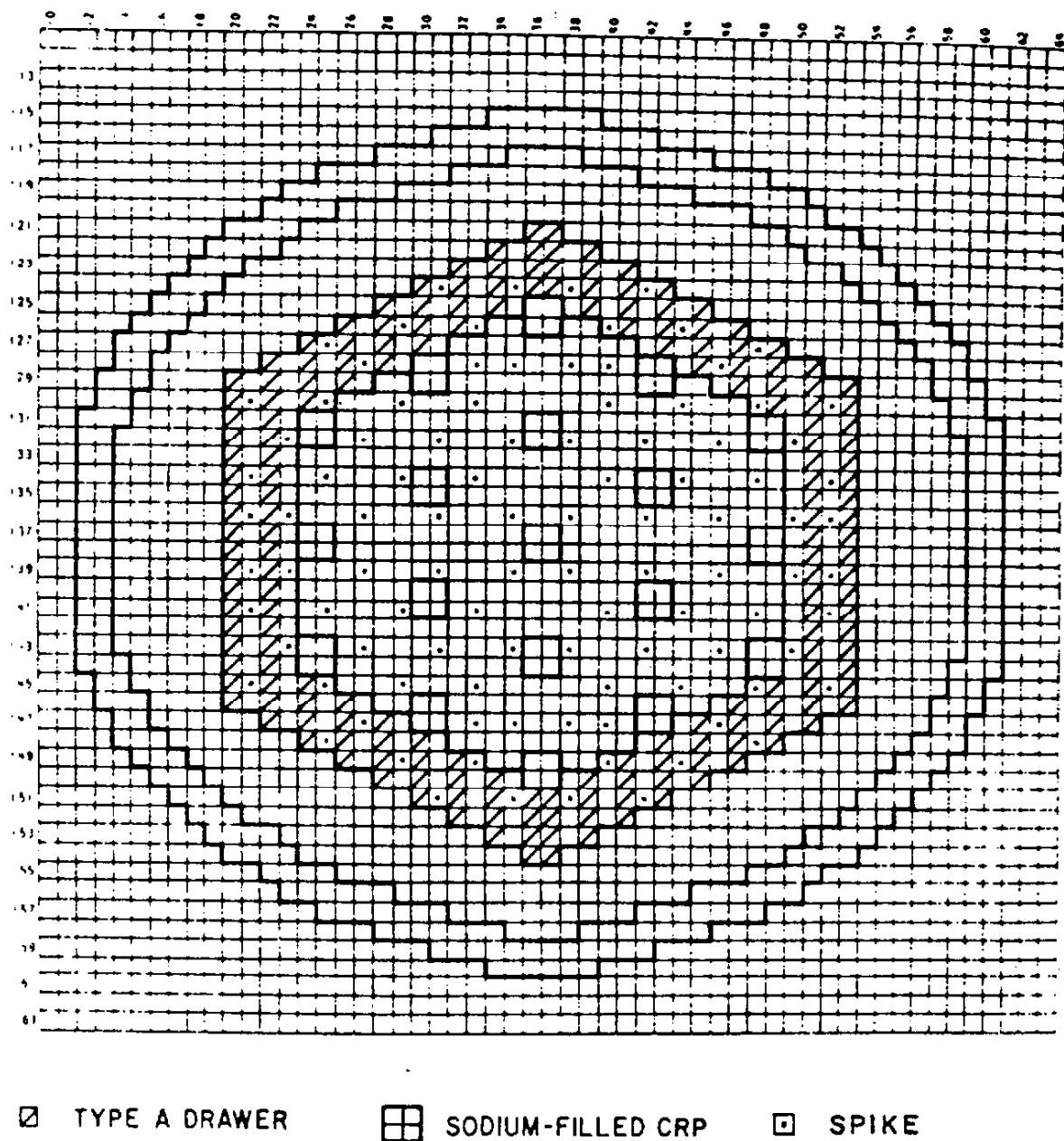


Fig. 8. Interface Diagram of ZPPR-4, Phase 1, End of Cycle (EOC)

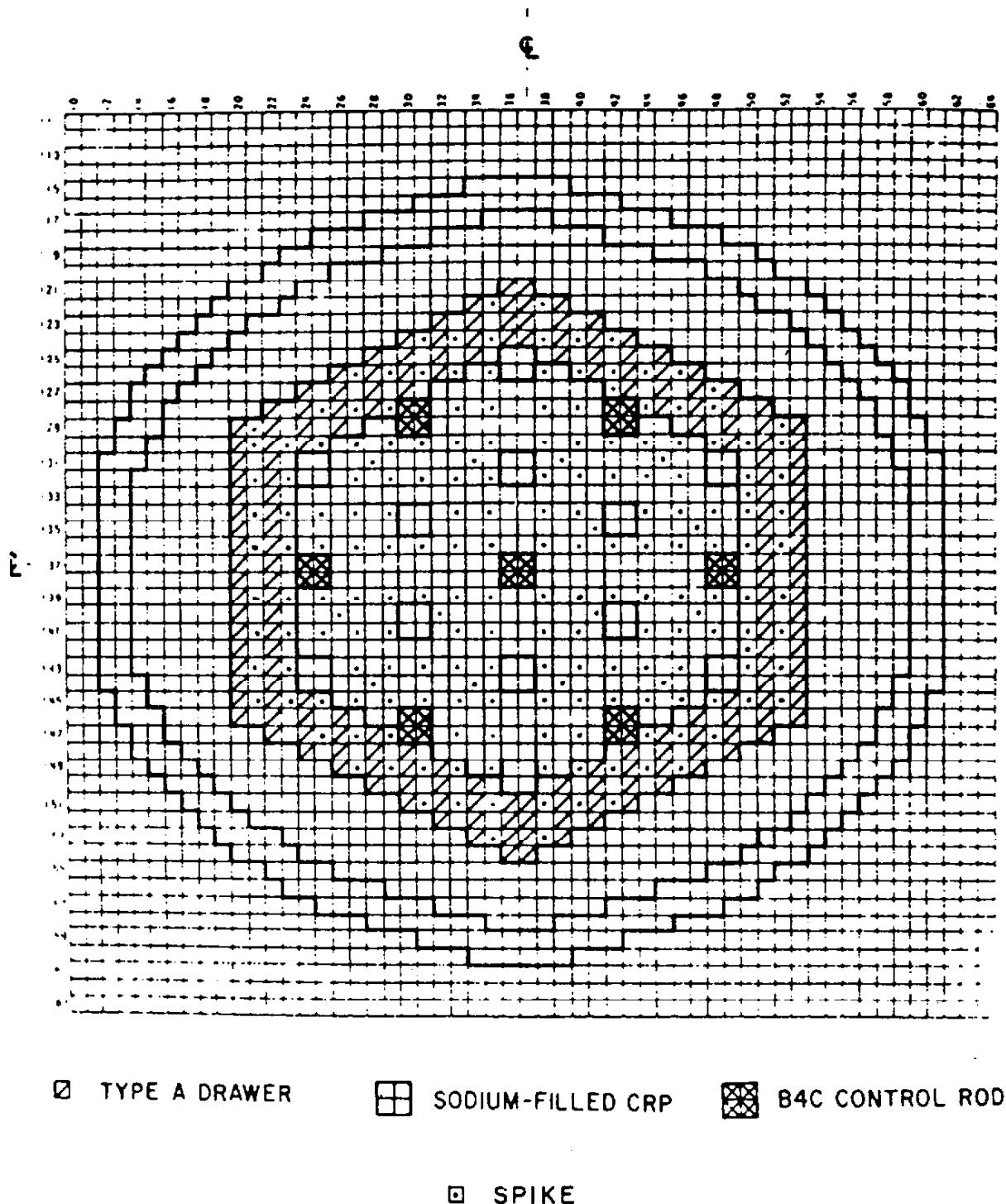


Fig. 9. Interface Diagram of ZPPR-4, Phase 2, Beginning of Cycle (BOC)

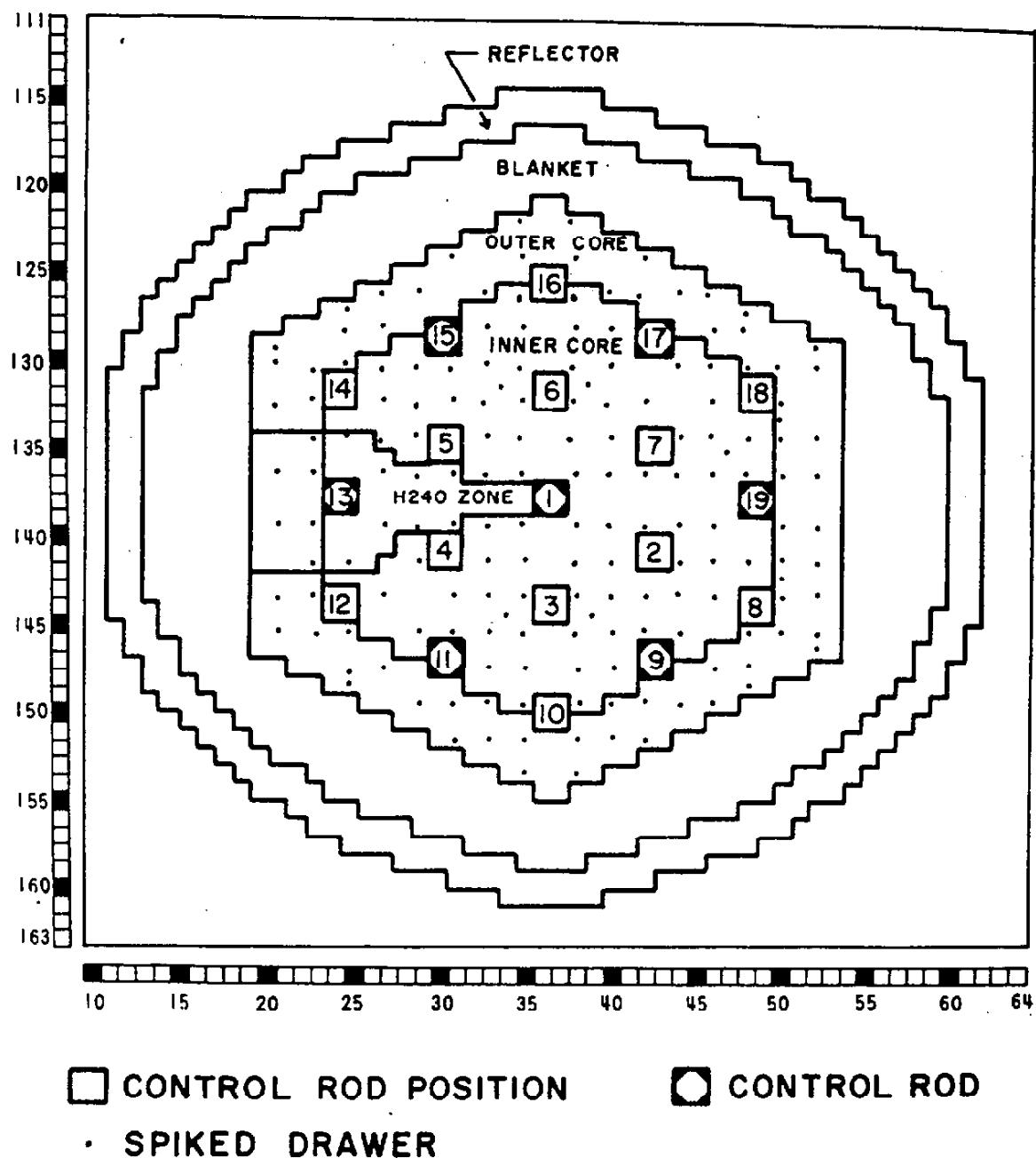


Fig. 10. Interface Diagram of ZPPR-4, Phase 2, High Pu²⁴⁰ Configuration

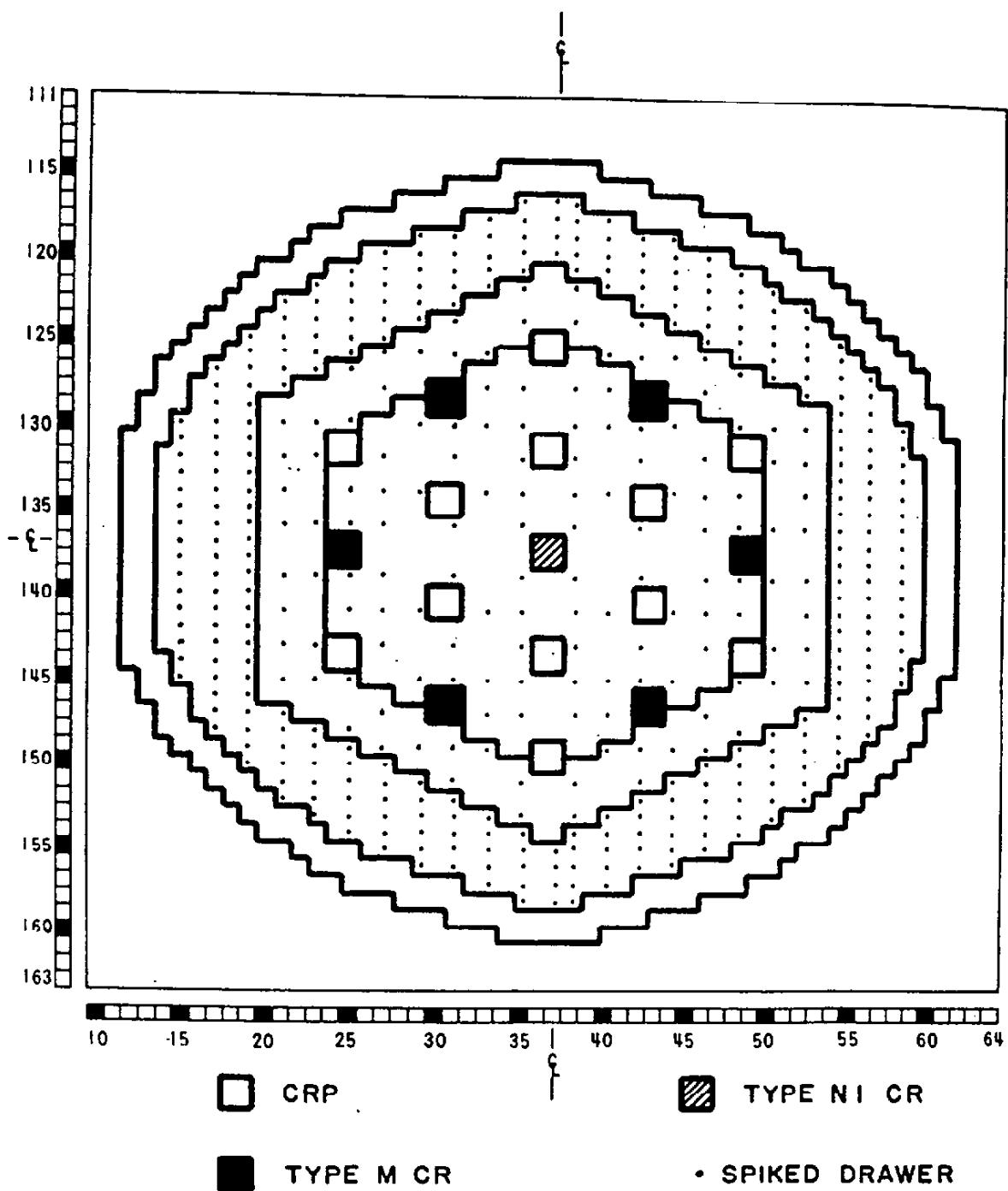


Fig. 11. Interface Diagram of ZPPR-4, Phase 2, Middle of Cycle (MOC)

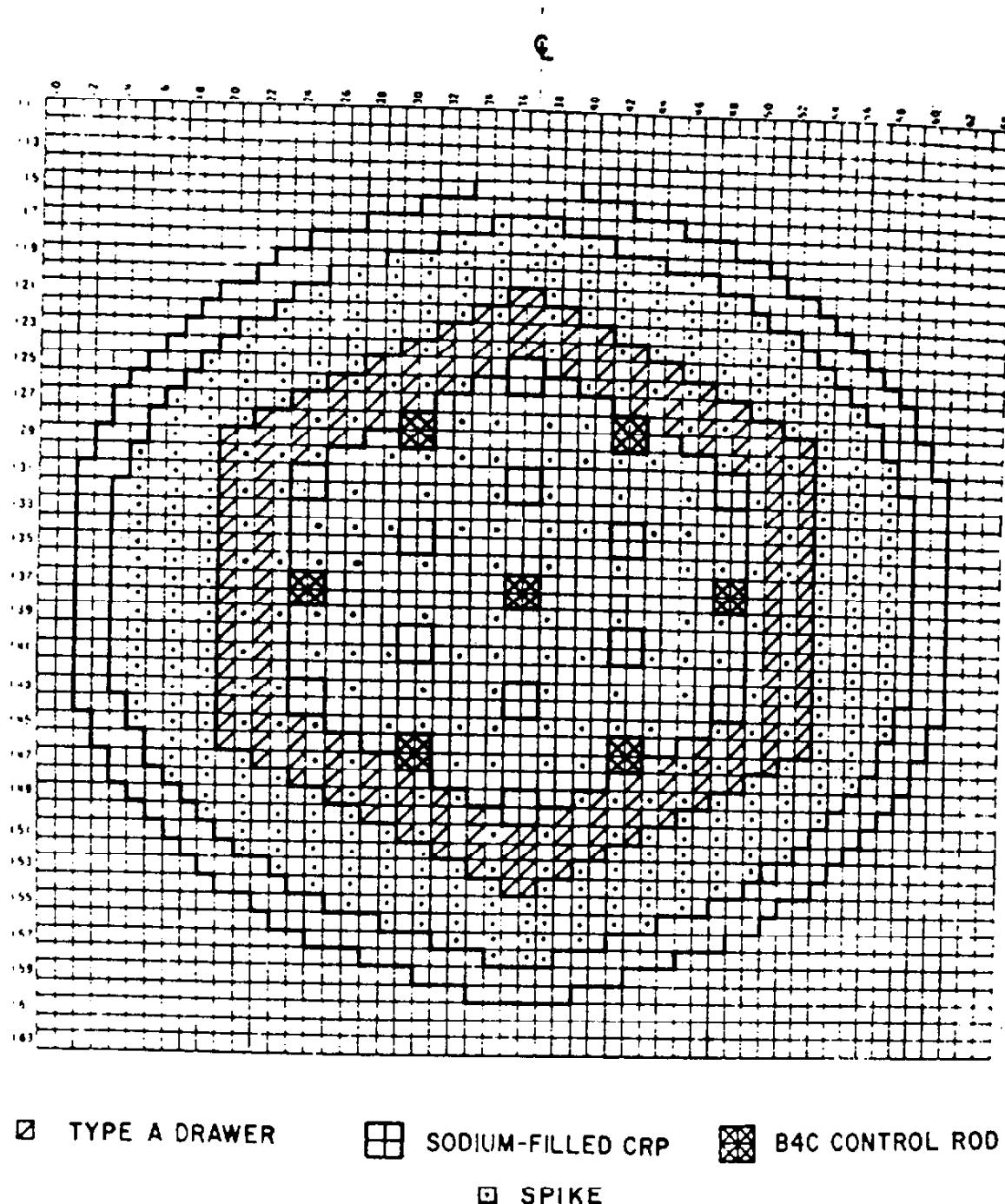


Fig. 12. Interface Diagram of ZPPR-4, Phase 3, Middle of Cycle (MOC)

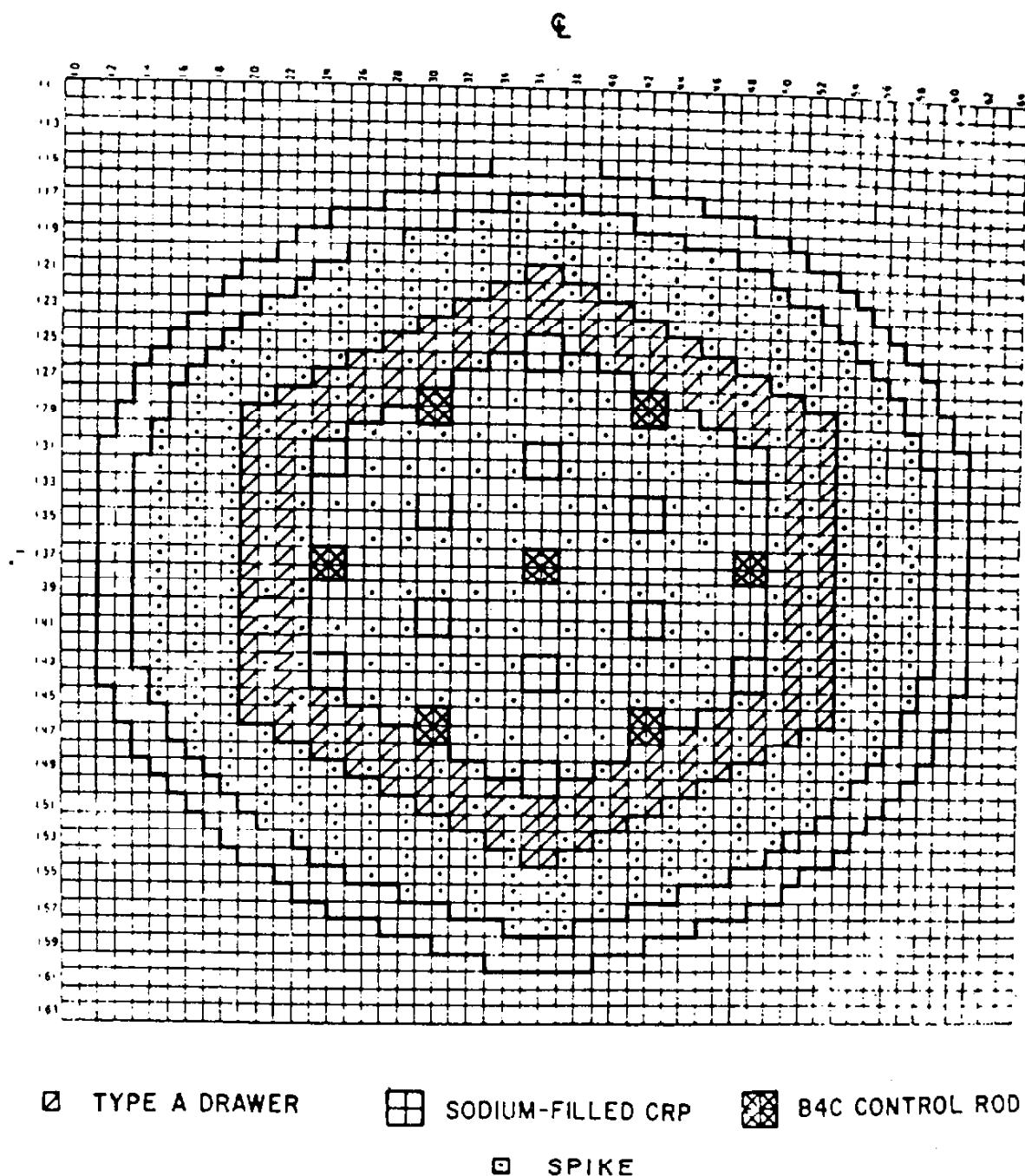


Fig. 13. Interface Diagram of ZPPR-4, Phase 3, Beginning of Cycle (BOC)

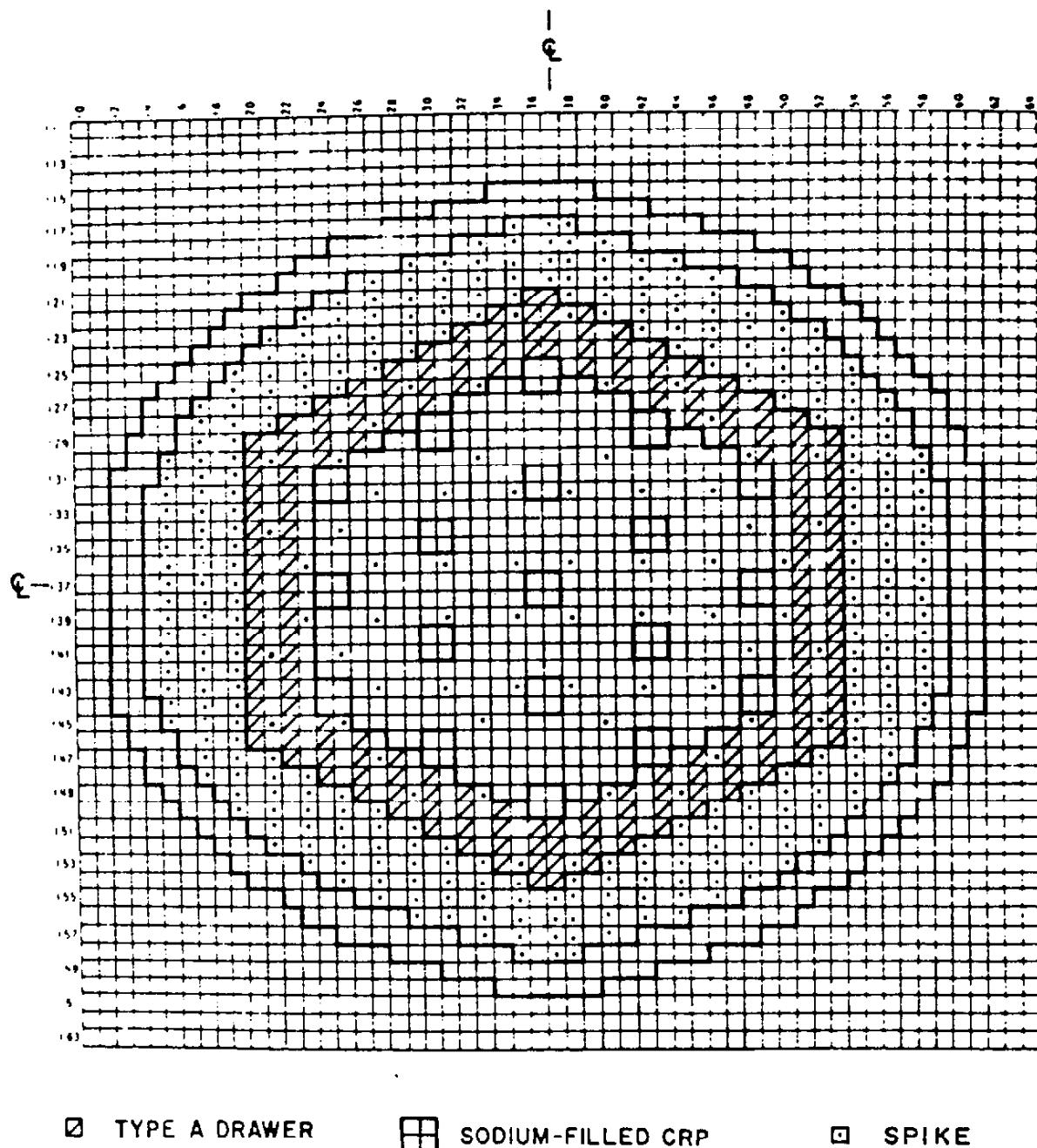


Fig. 14. Interface Diagram of ZPPR-4, End of Cycle (EOC)

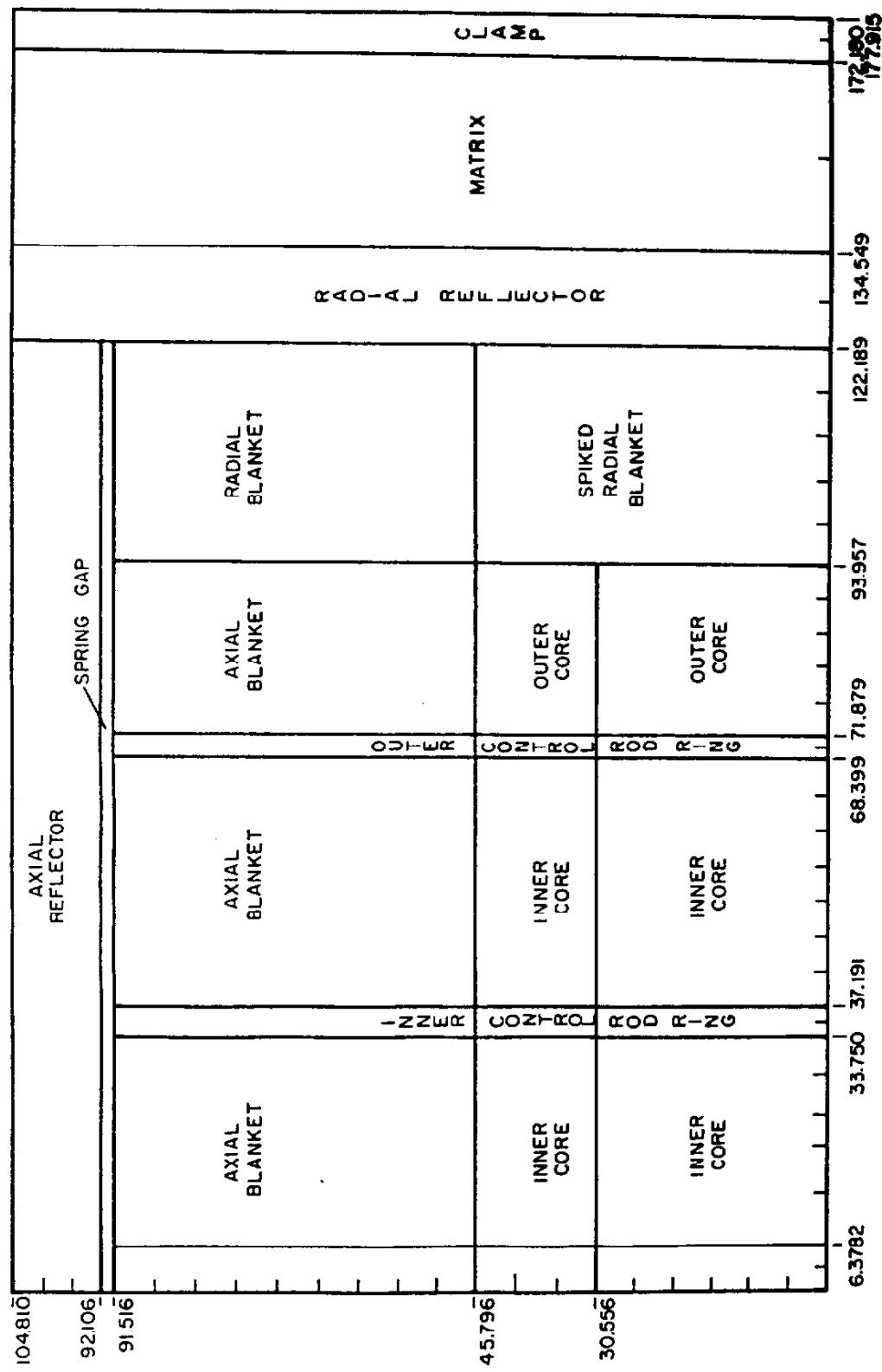
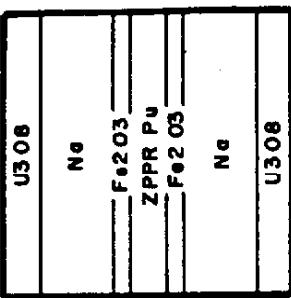
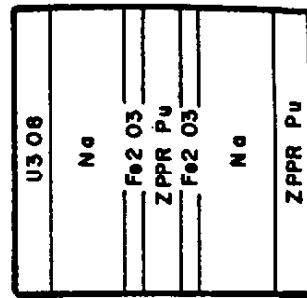


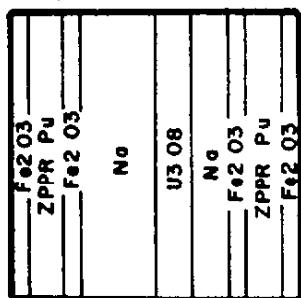
Fig. 15. R-Z Model for ZPPR-4



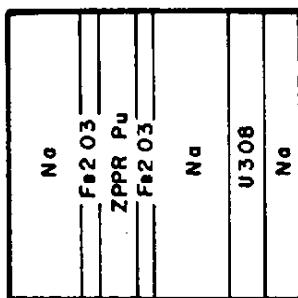
INNER CORE NORMAL
0.49779 Kg. FISSILE Pu.



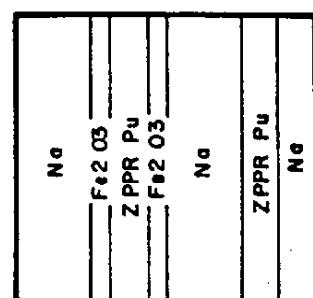
INNER CORE SPIKE
0.99648 Kg. FISSILE Pu.



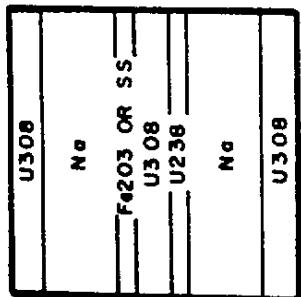
OUTER CORE TYPE A
0.99642 Kg. FISSILE Pu.



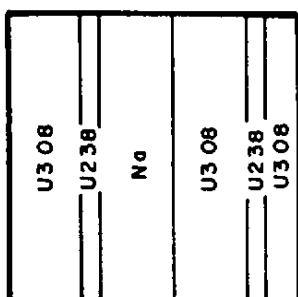
OUTER CORE TYPE B
0.49848 Kg. FISSILE Pu.



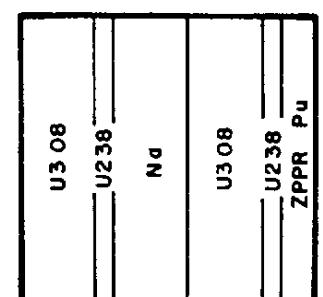
OUTER CORE SPIKE
0.99696 Kg. FISSILE Pu.



AXIAL BLANKET



RADIAL BLANKET



RADIAL BLANKET SPIKE
~0.498 Kg. FISSILE Pu.

Fig. 16. Drawer Loading Patterns for ZPPR-4

ZPPR-5

First engineering mockup core (EMC) for the Clinch River Breeder Reactor (CRBR).

Overview:

This assembly was similar to ZPPR-4 but a more accurate detailed mockup of the CRBR. Its purpose was to provide design support for the CRBR in safety-related areas such as sodium voiding and fuel slumping. A Source Level Flux Monitor (SLFM) experiment was performed in this assembly.

Assembly Dates:

January 1975-January 1976

Related Assemblies:

ZPPR-6 which was the second EMC for the final CRBR, two-zone conventional design. Fairly similar in design to ZPPR-4.

Assembly Details (Phase A):

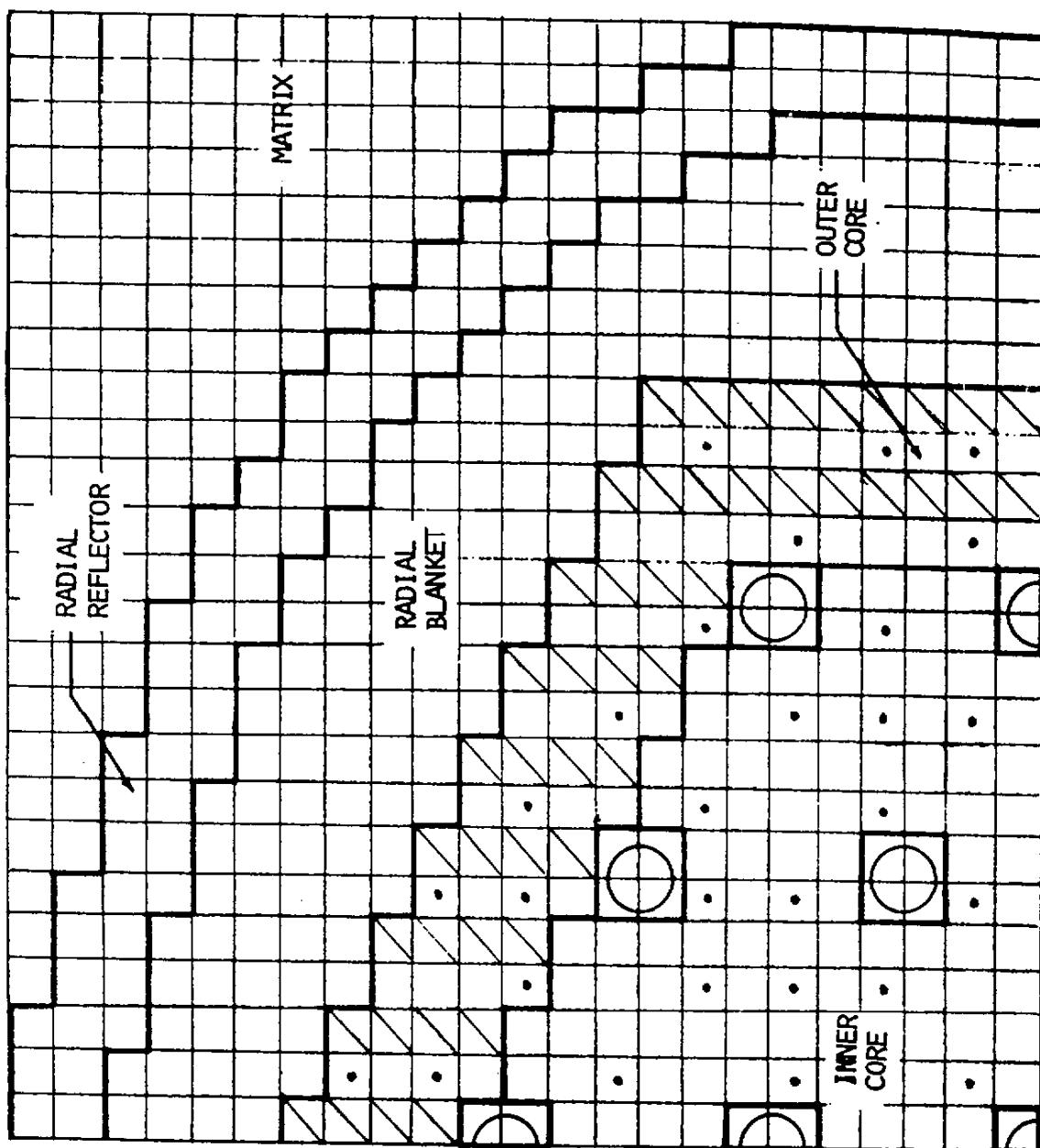
Type:	Hexagonal, two-zone critical with control rods (CRs) and control rod positions (CRPs)
Fuel:	Typical Pu/U oxide with Na cooling
Critical Mass:	1087 kg (Pu^{241} + Pu^{239})
Core Volume:	2500 liters
Blanket:	Depleted uranium (DU) oxide with sodium cooling
Reactivity Adjustment:	Pu spikes

Assembly Variants:

Phase A:	Initial core, end-of-cycle (EOC), similar to ZPPR-4 Phase 1 except it included mockups of the core support region and fission gas plenum. There were two variants of Phase A: (1) sodium filled CRPs and (2) all CRPs contained a CR parked at the core axial blanket interface.
Phase B:	Beginning-of-cycle (BOC) configuration. Seven fully inserted CRs and 12 CRs parked at core/axial blanket interface.

SLFM Experiment: Following Phase B, an ex-vessel SLFM was mocked up in the corner of the ZPPR matrix. The purpose was to correlate ex-vessel measurements with in-core measurements and evaluate the effect of a stored fuel element on this correlation.

Note: Sodium voided and fuel slumping configurations were introduced in both Phases A and B.



PARKED
CR



SPIKED
DRAWER



TYPE-A
DRAWER

Fig. 17. Quarter Core Interface Diagram for ZPPR-5, Phase A

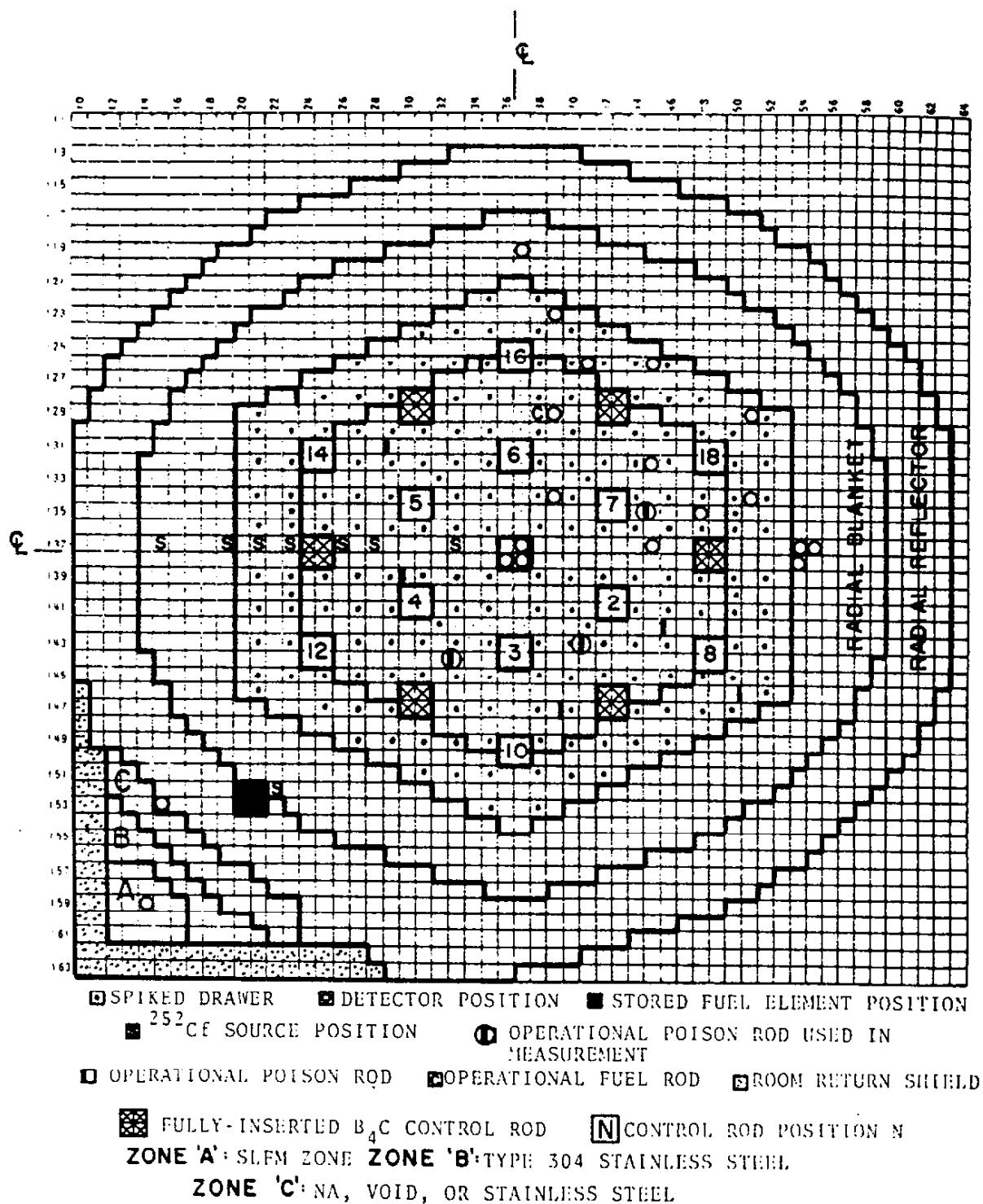


Fig. 18. Interface Diagram for ZPPR-5 Showing the Source Level Flux Monitor (SLFM)

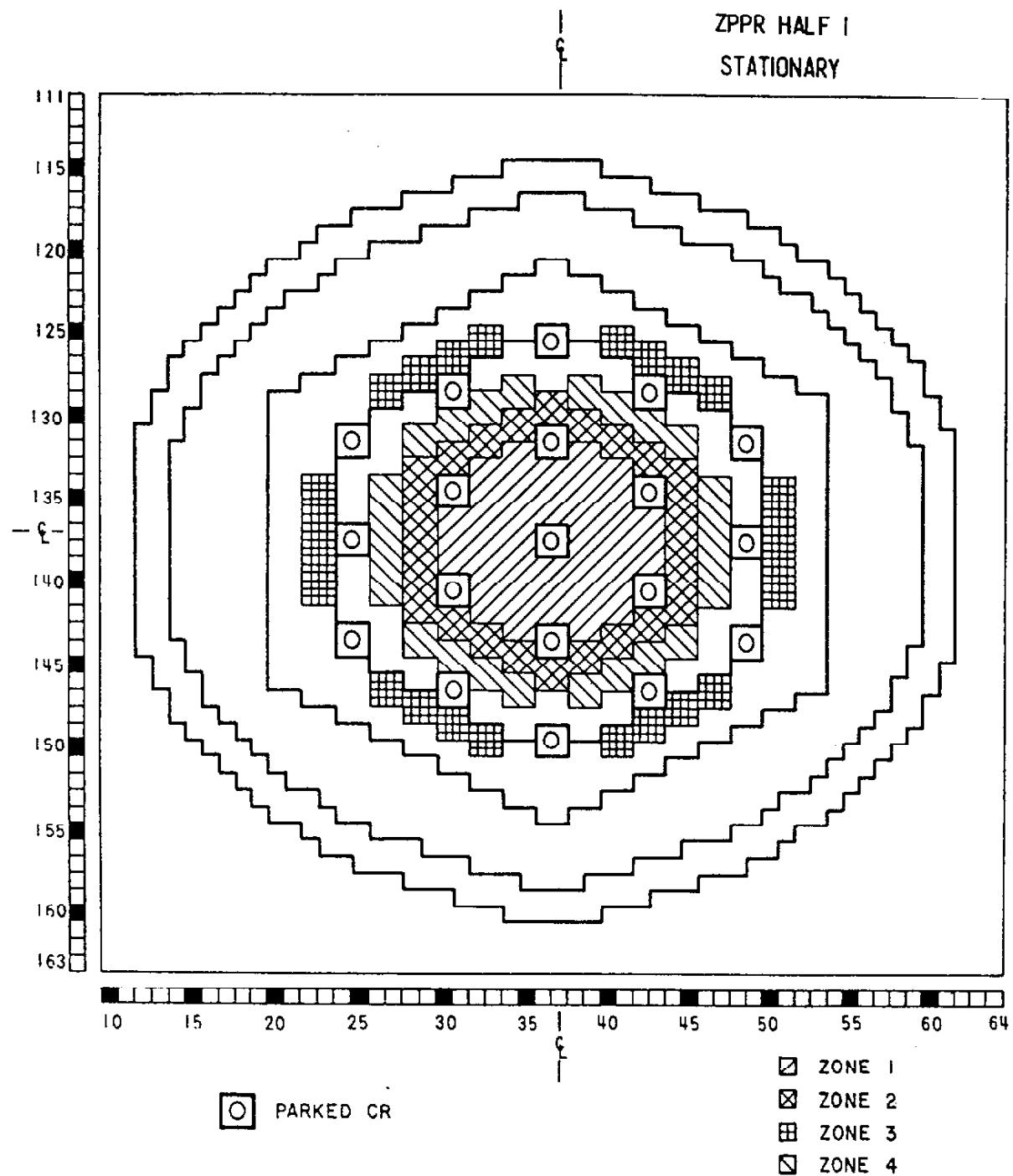


Fig. 19. Radial Sodium Voiding Zones in ZPPR-5, Phase A

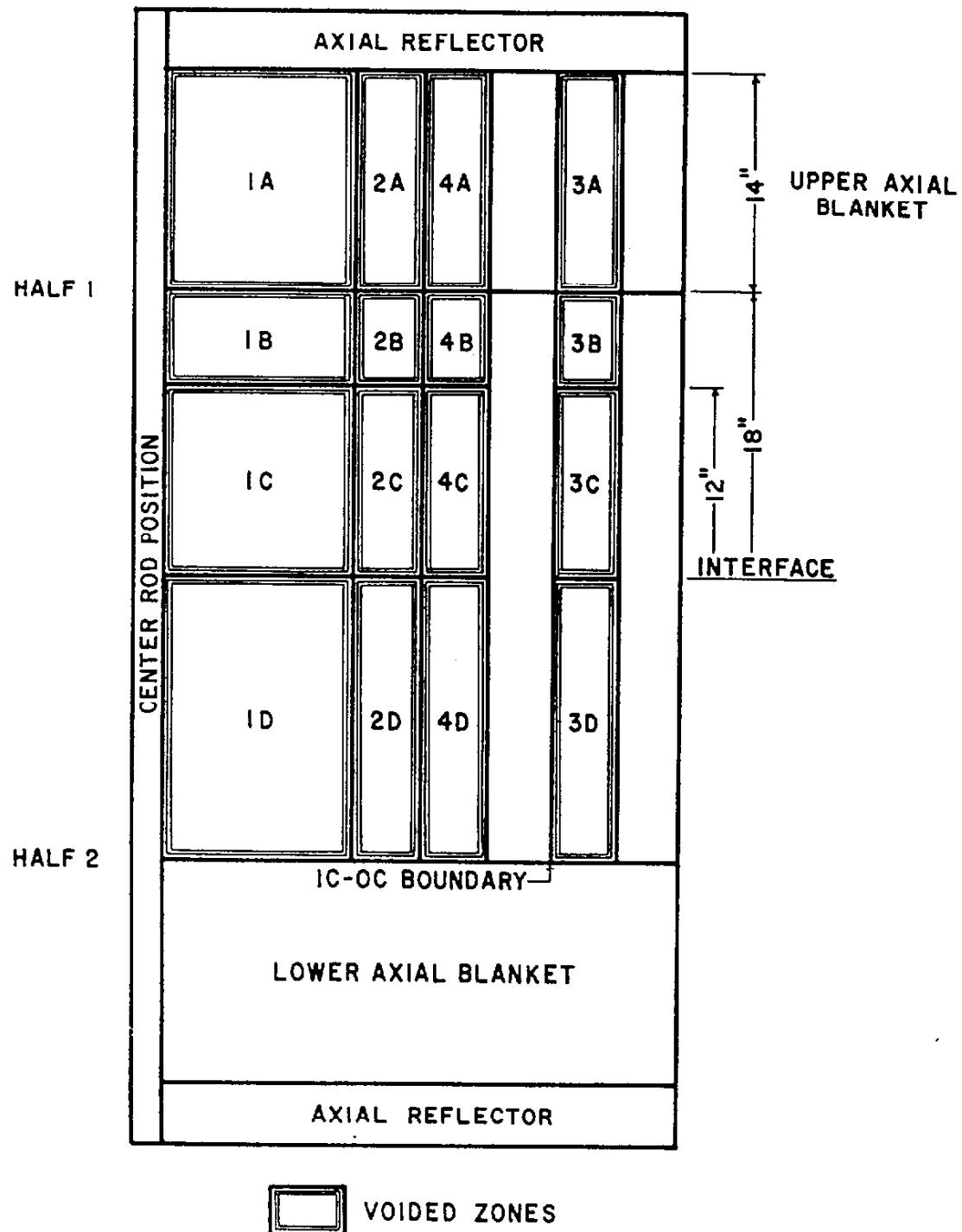


Fig. 20. Axial Sodium Voiding Zones in ZPPR-5, Phase A

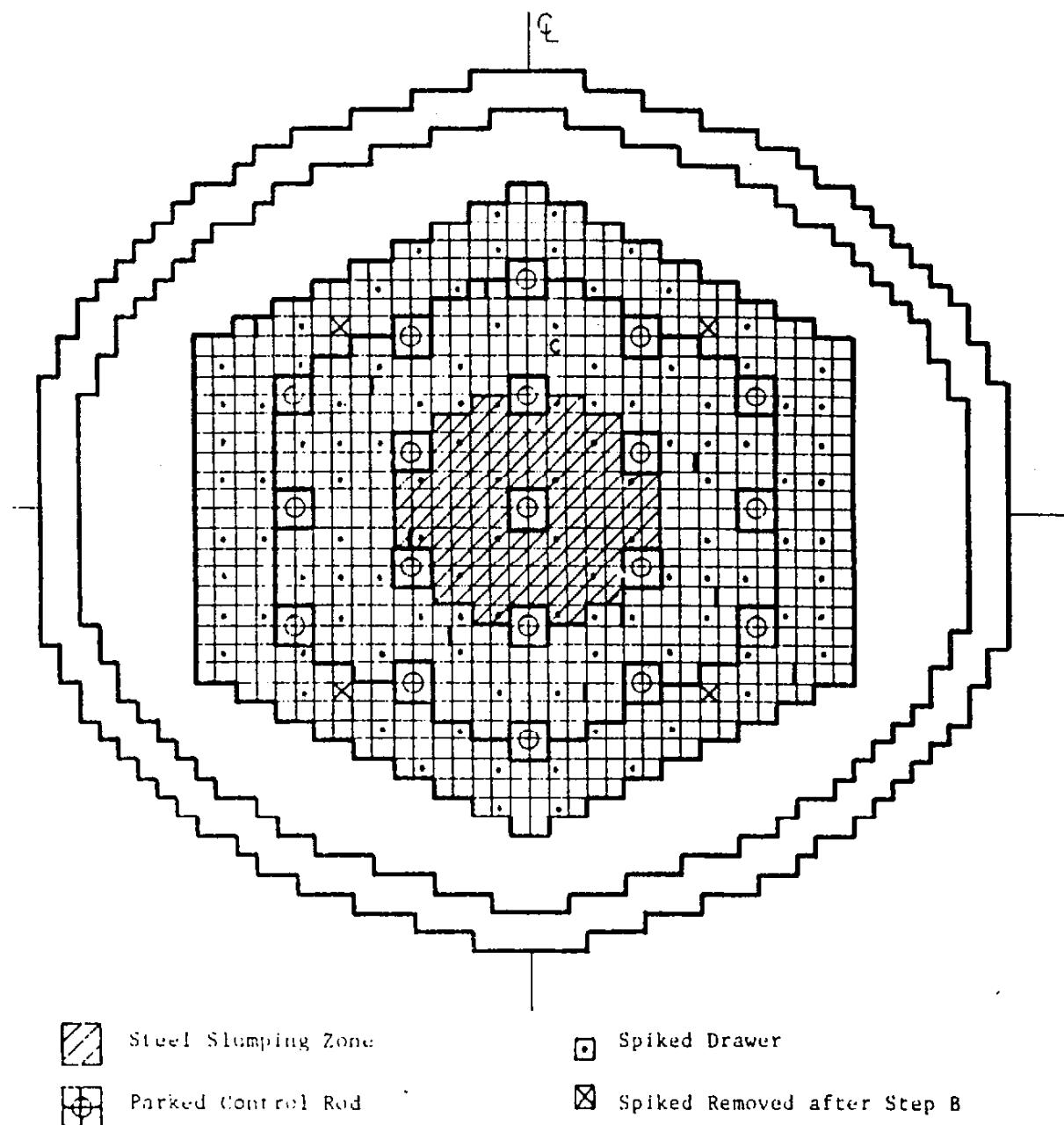


Fig. 21. Radial Steel Slumped Zones in ZPPR-5, Phase A

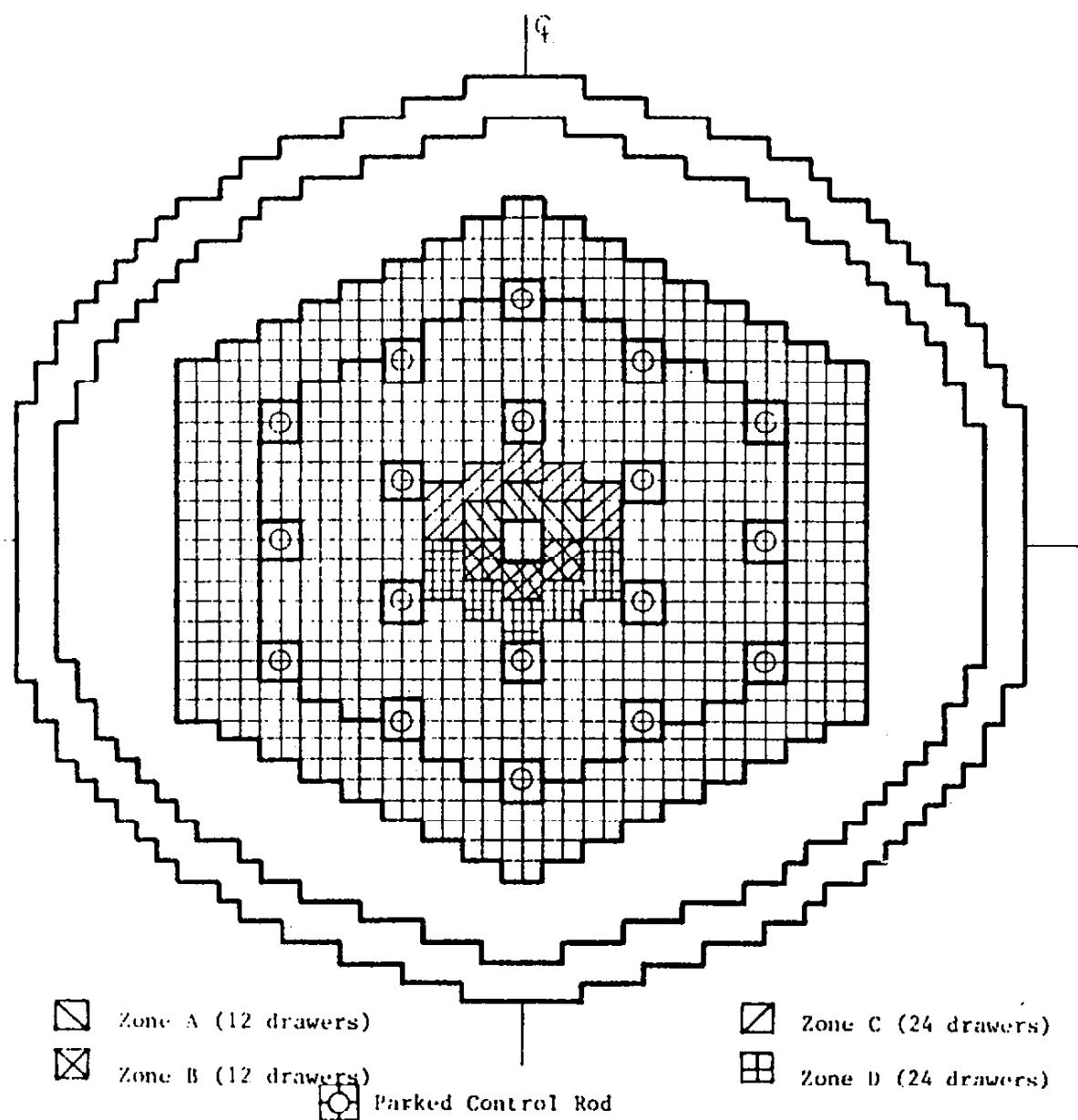


Fig. 22. Radial Fuel Slumped Zones in ZPPR-5, Phase A

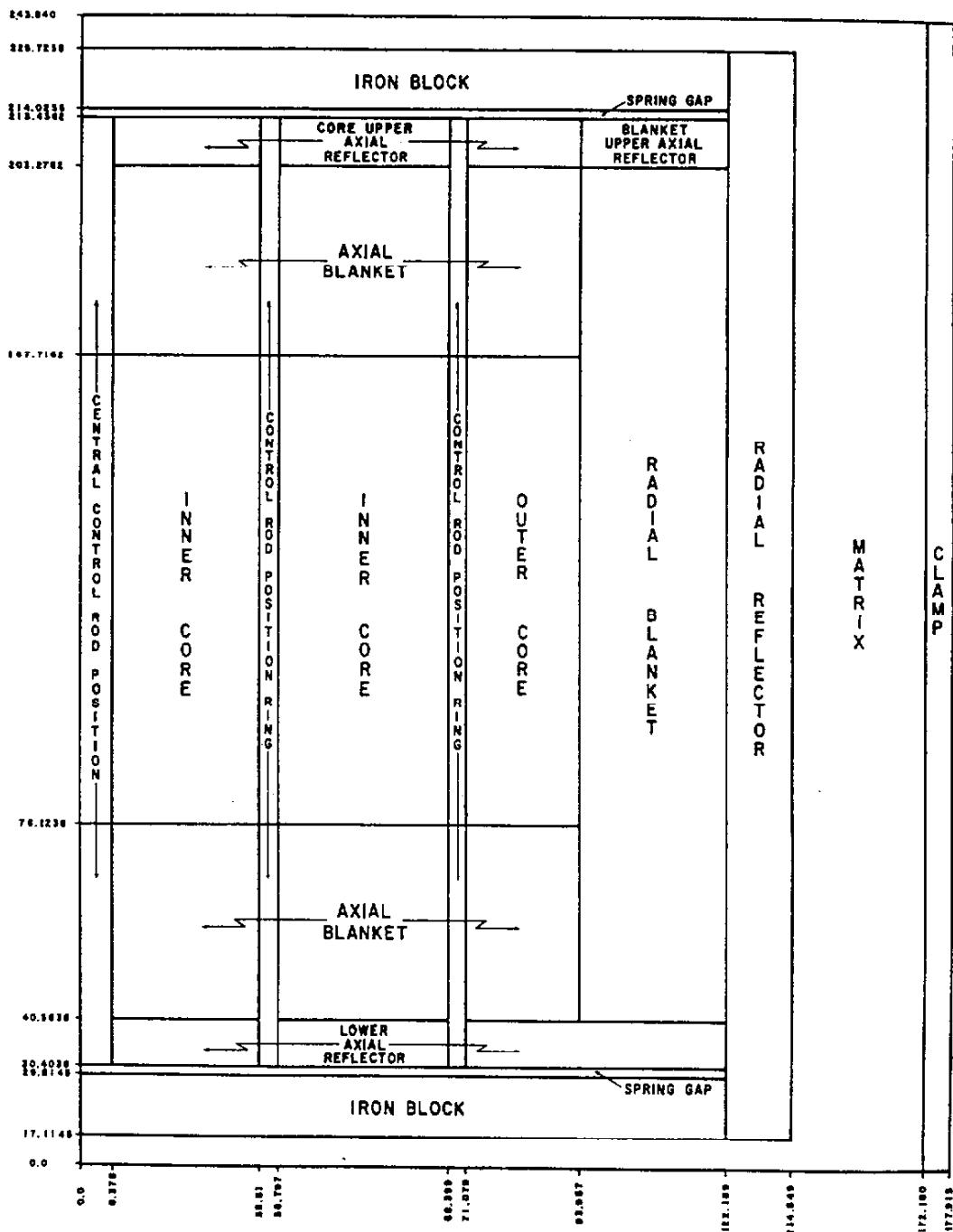


Fig. 23. R-Z Model for ZPPR-5

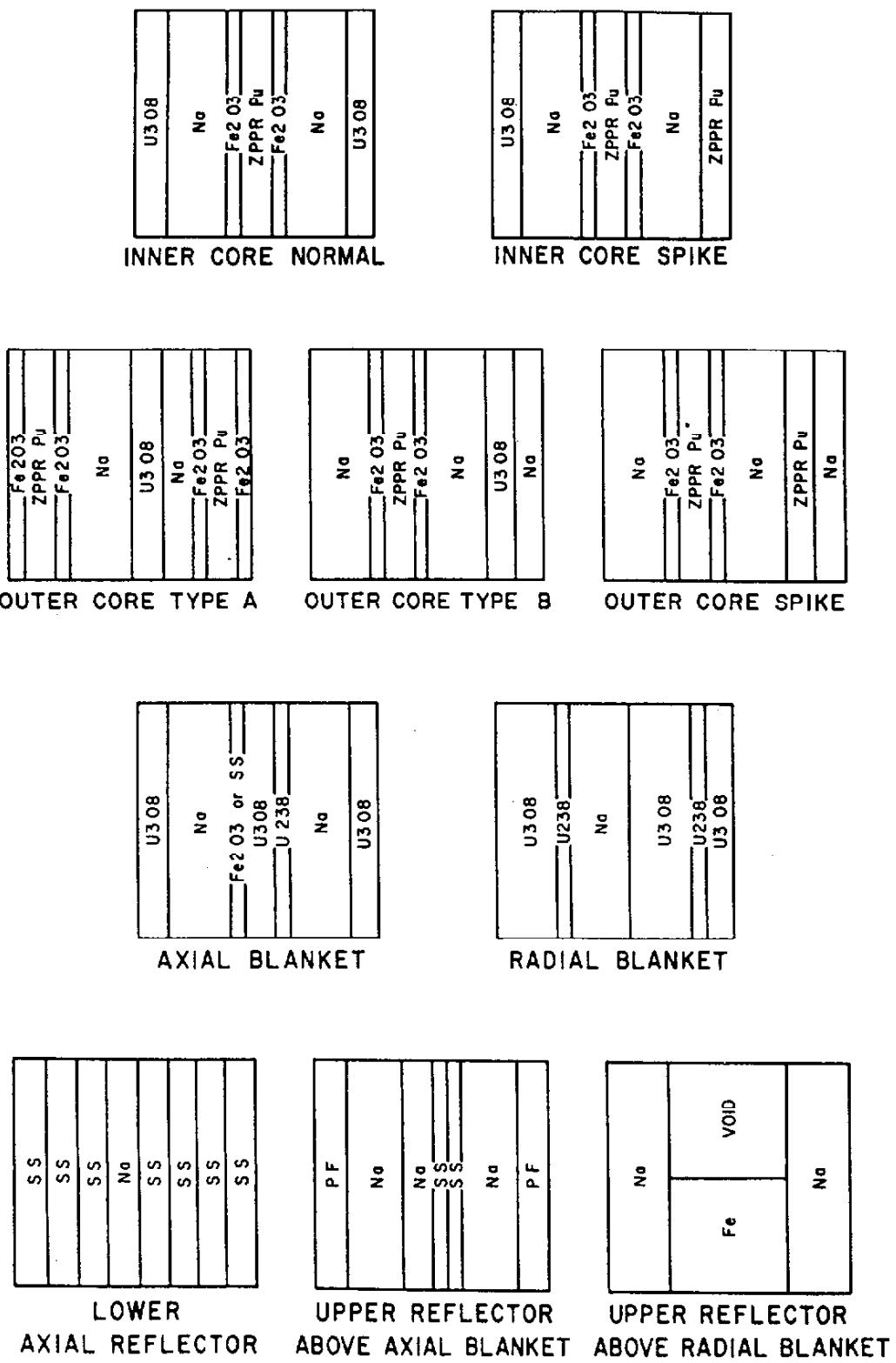


Fig. 24. Drawer Loading Patterns for ZPPR-5

A34

ZPPR-6

Second engineering mockup core (EMC) for the Clinch River Breeder Reactor (CRBR).

Overview:

This assembly was similar to ZPPR-5 except for an increase in radial reflector thickness, some changes in the radial reflector/blanket interface, and an increase in the core oxygen content by substituting Na_2CO_3 for some Na. The focus of the measurement was data for setting the initial core fuel and control enrichments.

Assembly Dates:

January 1976-June 1976

Related Assemblies:

ZPPR-5 which was the first CRBR-EMC.

Assembly Details [Beginning of cycle (BOC) rods fully inserted]:

Type:	Hexagonal, two-zone critical with control rods (CRs) and control rod positions (CRPs)
Fuel:	Typical Pu/U oxide with Na cooling
Critical Mass:	1195 kg (Pu^{239} + Pu^{241})
Volume:	2500 liters
Blanket:	Depleted uranium (DU) oxide with sodium cooling
Reactivity Adjustment:	Pu spikes

Assembly Variants:

Compared to ZPPR-5, there were some changes to radial reflector and more oxygen was added to the core by substituting Na_2CO_3 for Na. The variants were:

Beginning-of-cycle (BOC):	Rods fully inserted.
BOC:	CRBR expected. Seven CRs inserted 24 in.
End-of-cycle (EOC):	CRBR expected. Seven CRs inserted 12 in.
EOC:	All CRs parked at the core/axial blanket interface.

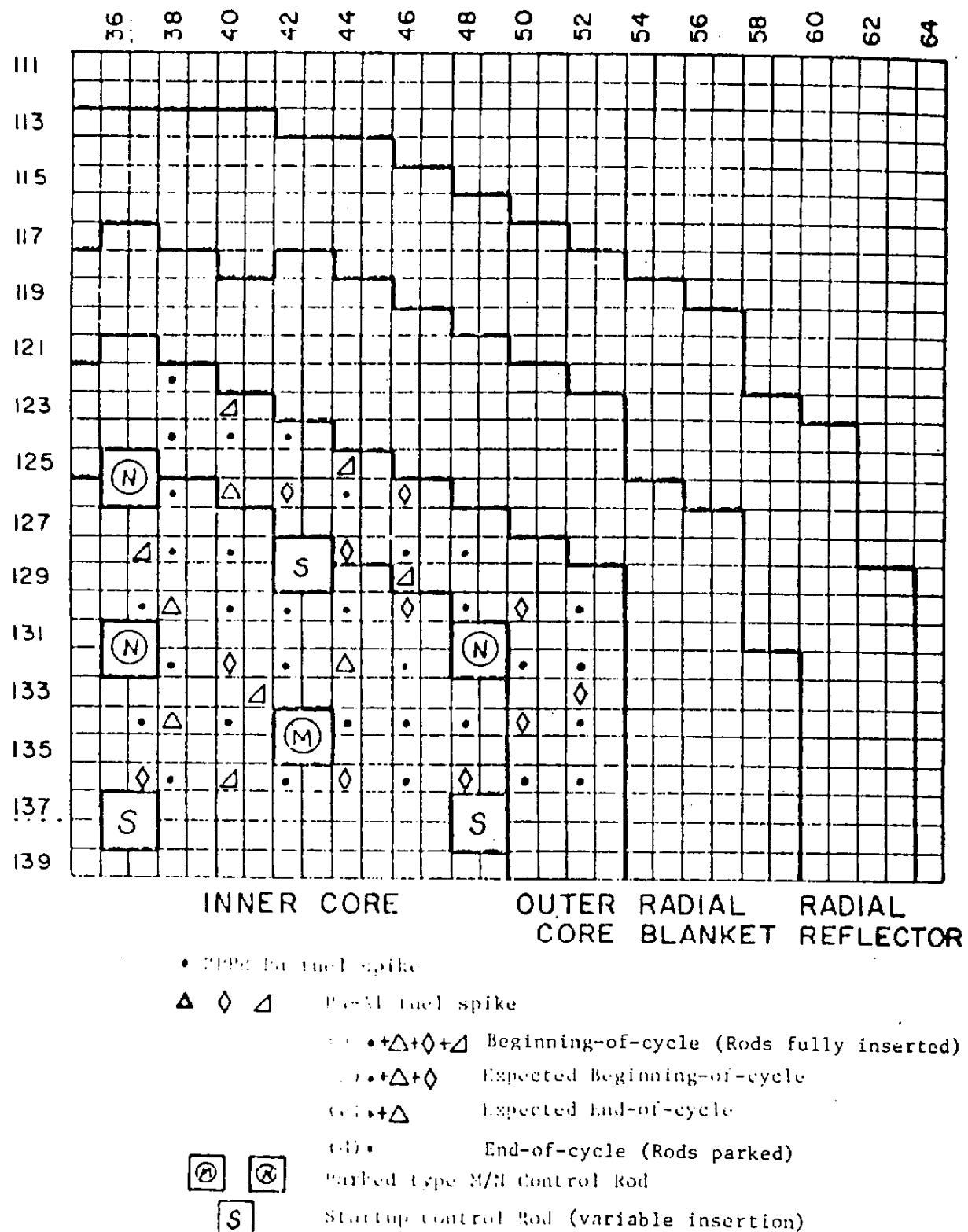


Fig. 25. Quarter Core Interface Diagram for ZPPR-6

ZPPR-7

The first of the radial heterogeneous Clinch River Breeder Reactor (CRBR) designs.

Overview:

This assembly was a series of eight radially heterogeneous designs of the appropriate size and average composition of CRBR. The assemblies began with a clean, cylindrical physics benchmark and ended with a hexagonal engineering benchmark with control rods (CRs) and control rod positions (CRPs). It had a single enrichment core with alternating radial rings of fuel regions and internal blanket regions. The purpose was to provide the experimental data required to evaluate the radial heterogeneous concept for CRBR.

Assembly Dates:

July 1976 and October 1977

Related Assemblies:

ZPPR-9 was the engineering mockup core (EMC) for the CRBR radial heterogeneous design.

Assembly Details (Phase A):

Type:	Cylindrical, clean radial heterogenous design
Fuel:	Typical Pu/U oxide with sodium cooling. Fuel enrichment was 25 %, higher than previous ZPPR cores.
Critical Mass:	1350 kg (Pu^{239} + Pu^{241})
Volume:	
Blanket:	Depleted uranium (DU) oxide with sodium cooling
Reactivity Adjustment:	Adjusting ratio of single- and double-column fuel drawers

Assembly Variants:

- Phase A: Clean, cylindrical physics benchmark.
- Phase B: Similar to Phase A except gaps were introduced in the internal blanket rings and 12 CRPs were added.
- Phase C: Similar to Phase B except plutonium buildup was simulated in the internal blankets and the core enrichment was reduced to simulate burnup.
- Phase D: Similar to Phase C except the number of CRPs was increased to 15 and the core and reflector outer boundaries were extended radially.
- Phase E: Similar to Phase D except six CRPs were converted to CRs.
- Phase F: Similar to Phase E. The ZPPR matrix was expanded between these two phases.
- Phase G: The CRPs were rearranged relative to Phase F and the inner two of the blanket rings were made continuous. All CRPs in this phase.
- Phase H: Similar to Phase G except six half inserted CRs. The critical mass is now 1542 kg (Pu^{239} + Pu^{241}) relative to 1350 kg in Phase A.

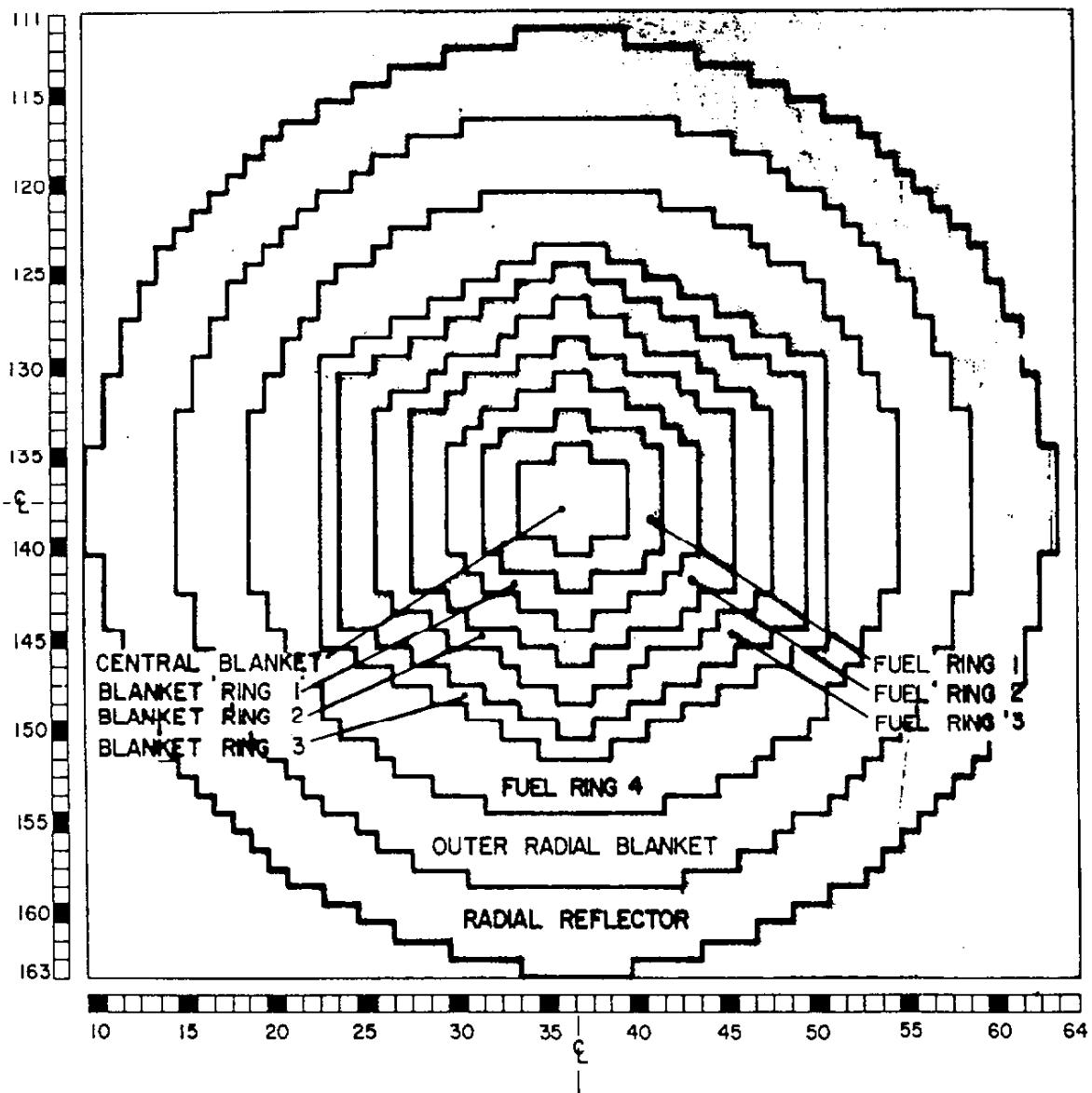


Fig. 26. Interface Diagram for ZPPR-7, Phase A

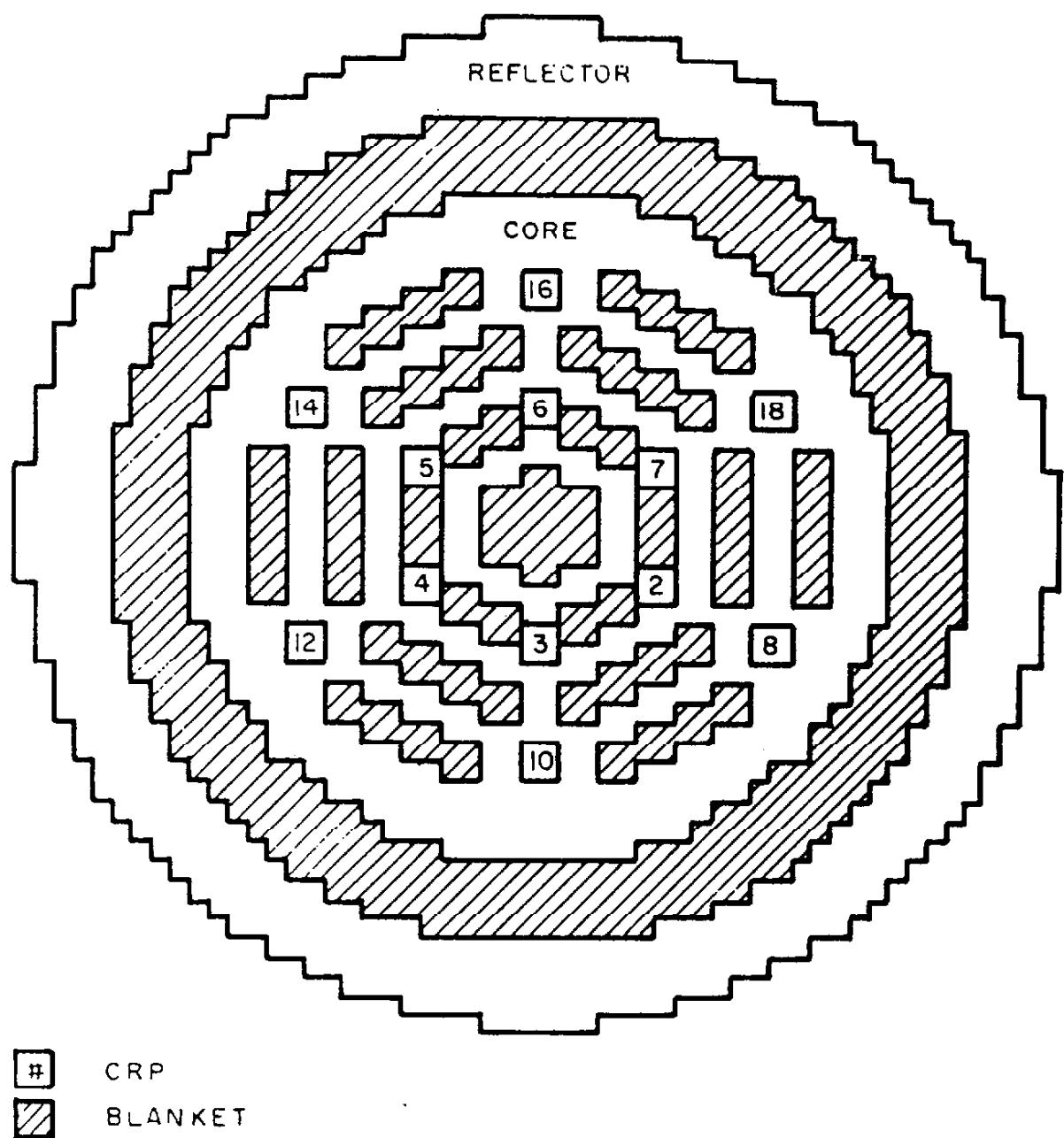


Fig. 27. Interface Diagram for ZPPR-7, Phase B

A40

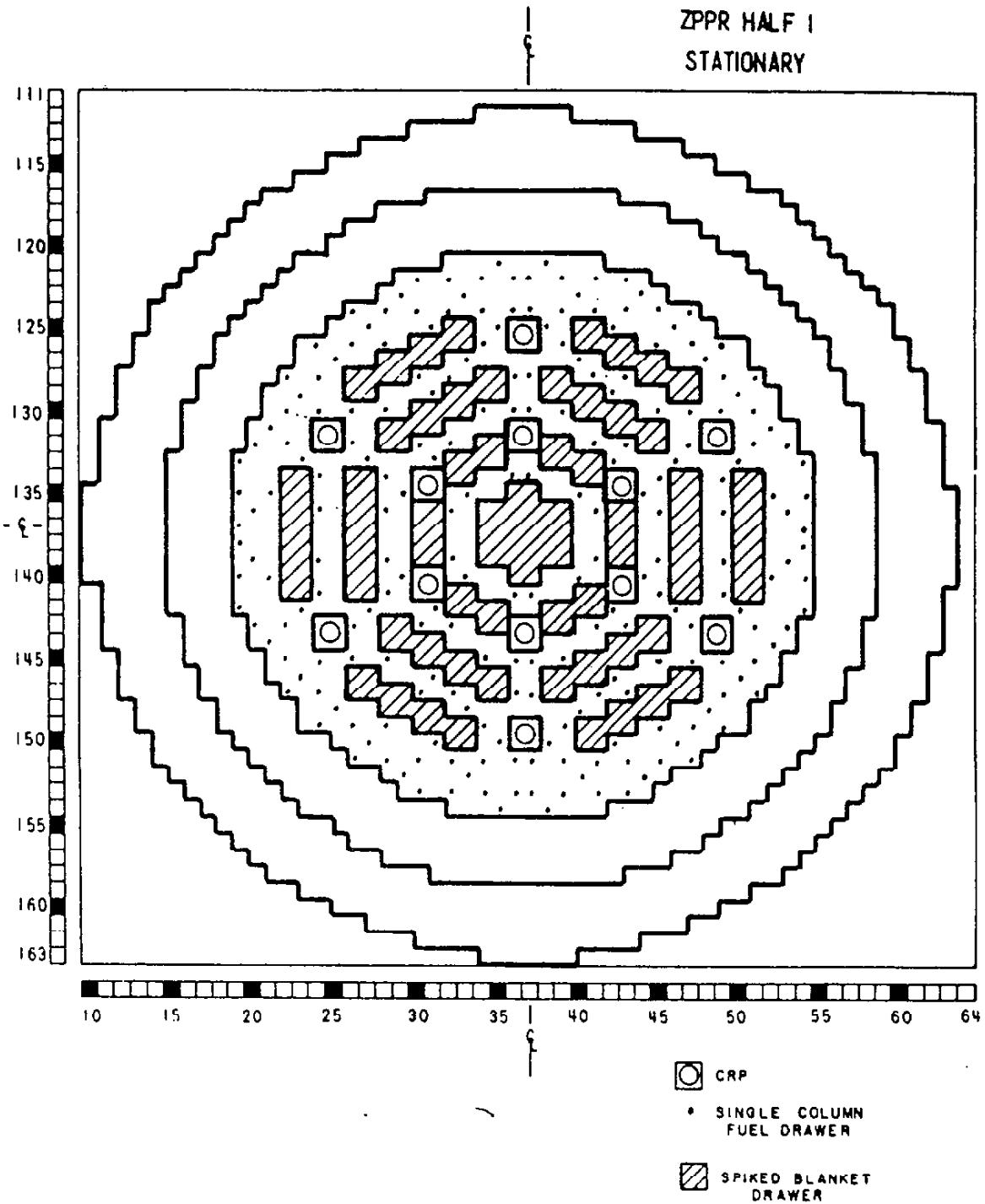


Fig. 28. Interface Diagram for ZPPR-7, Phase C

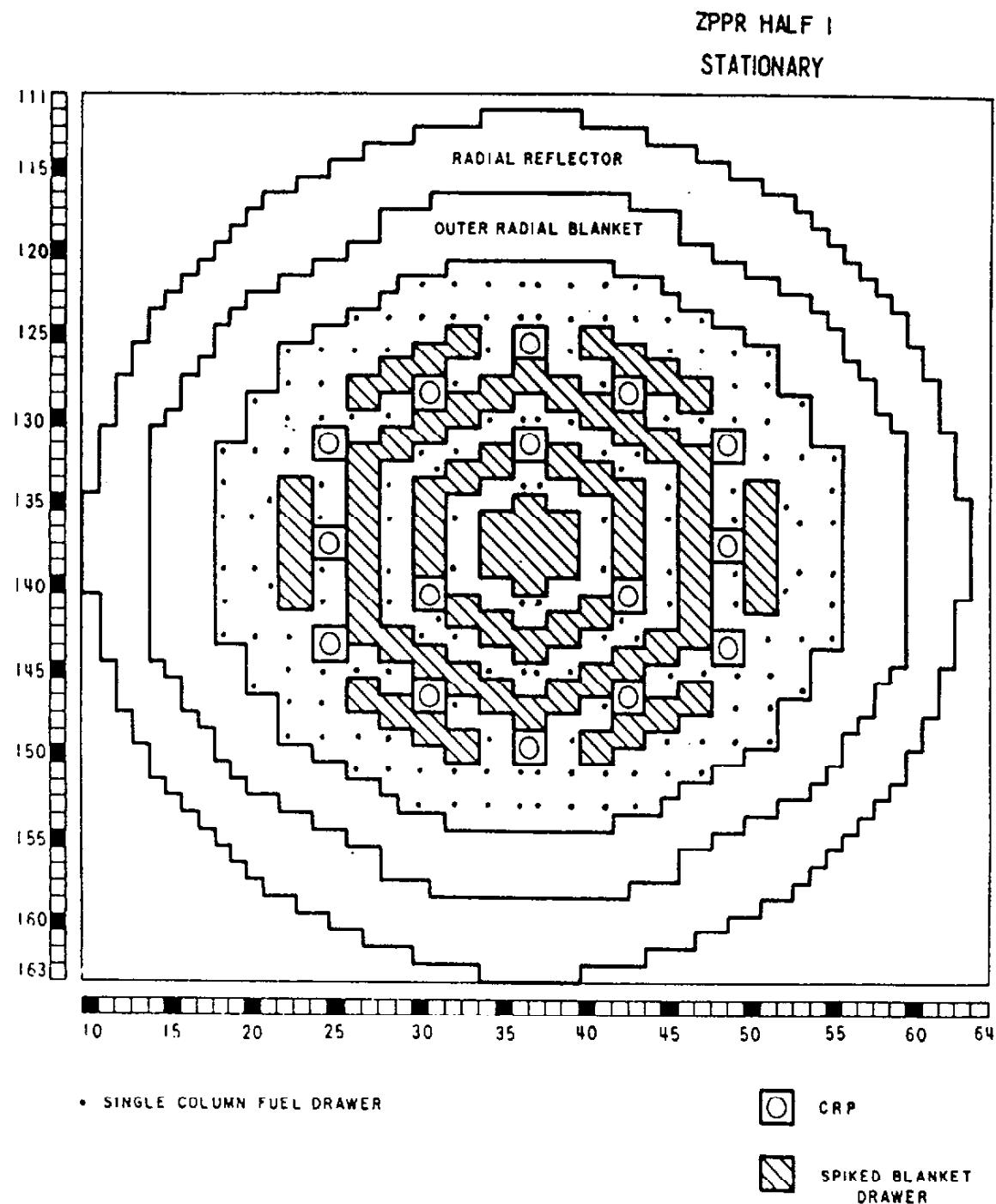


Fig. 29. Interface Diagram for ZPPR-7, Phase D

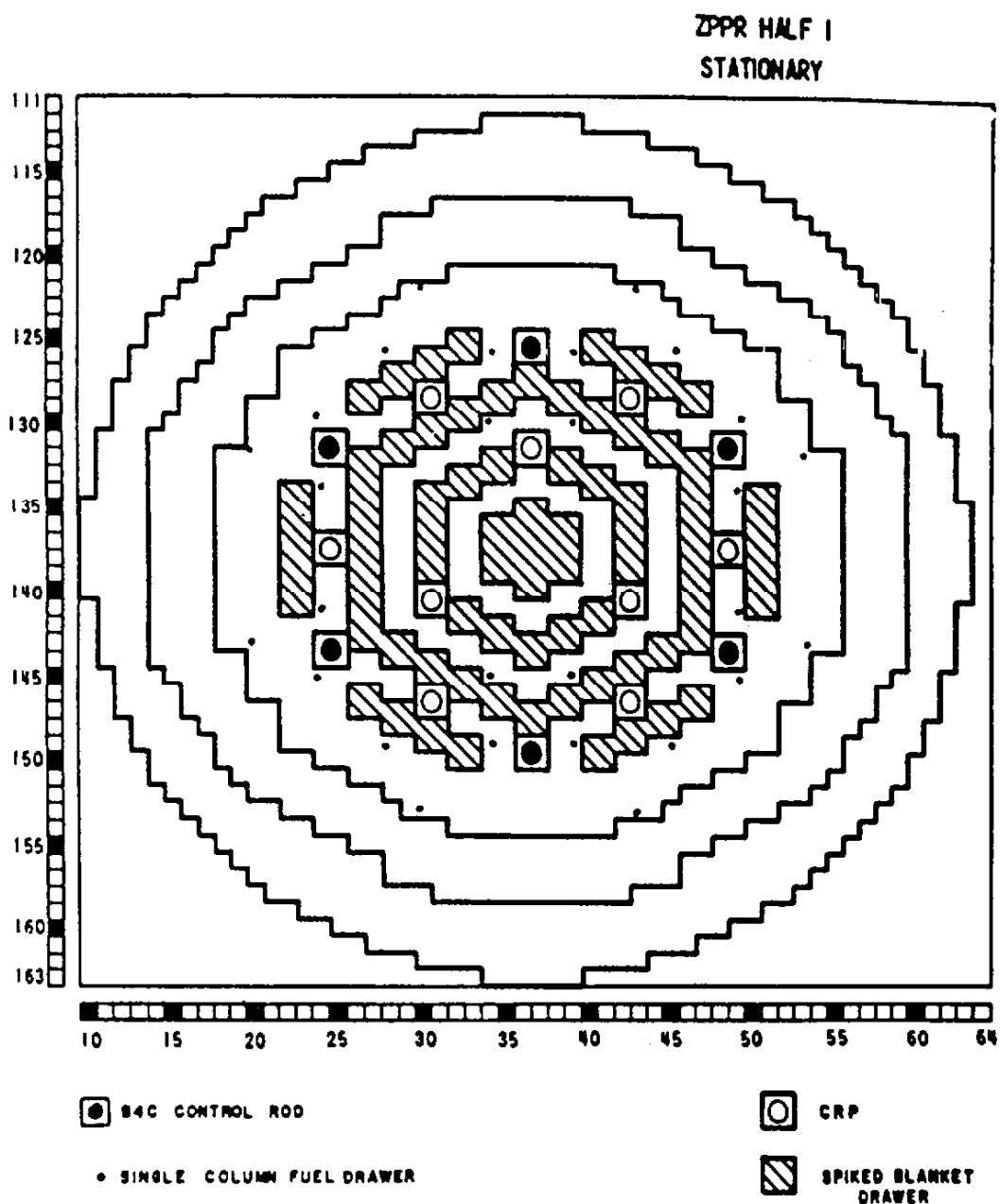


Fig. 30. Interface Diagram for ZPPR-7, Phase E

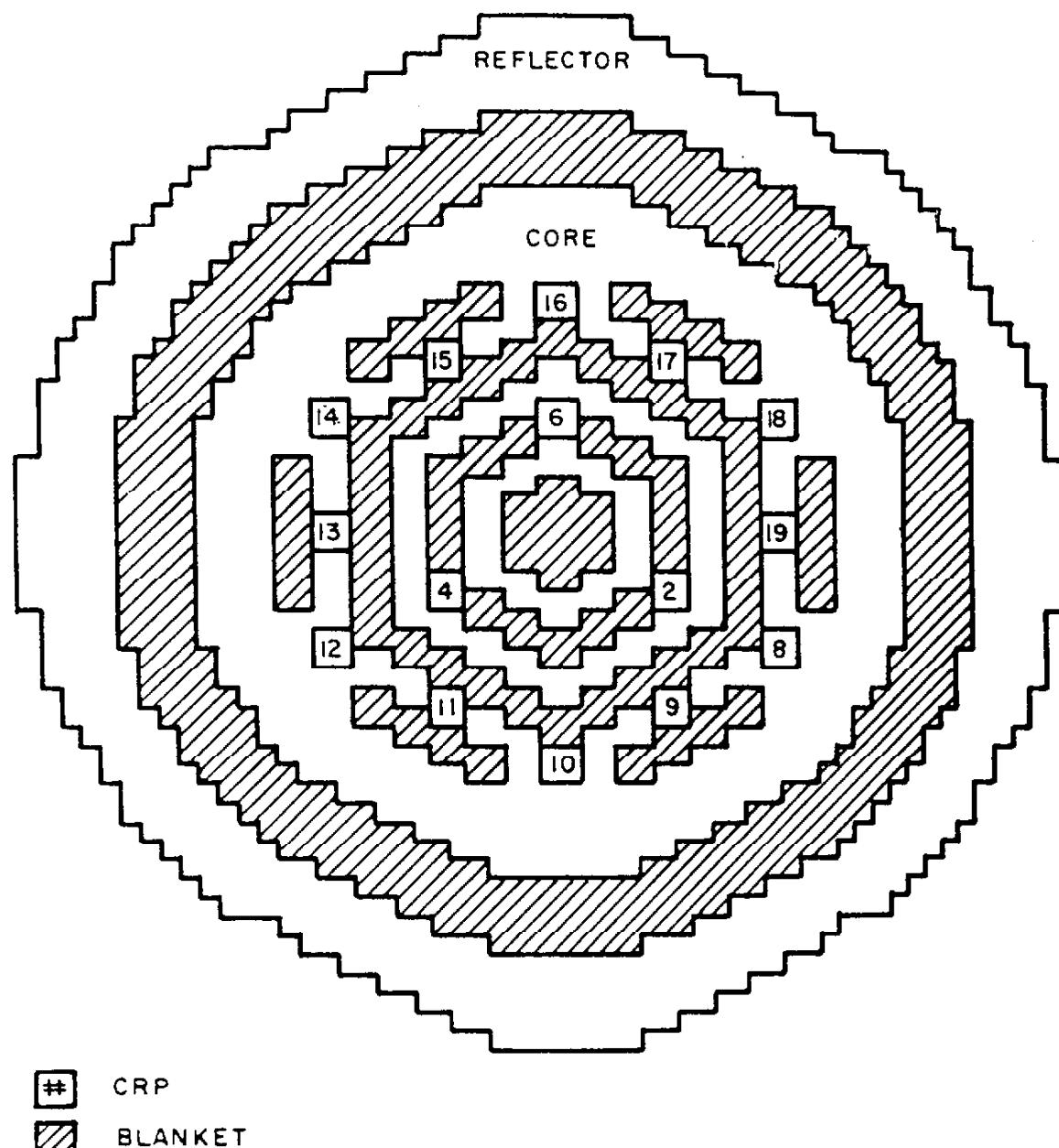


Fig. 31. Interface Diagram for ZPPR-7, Phase G

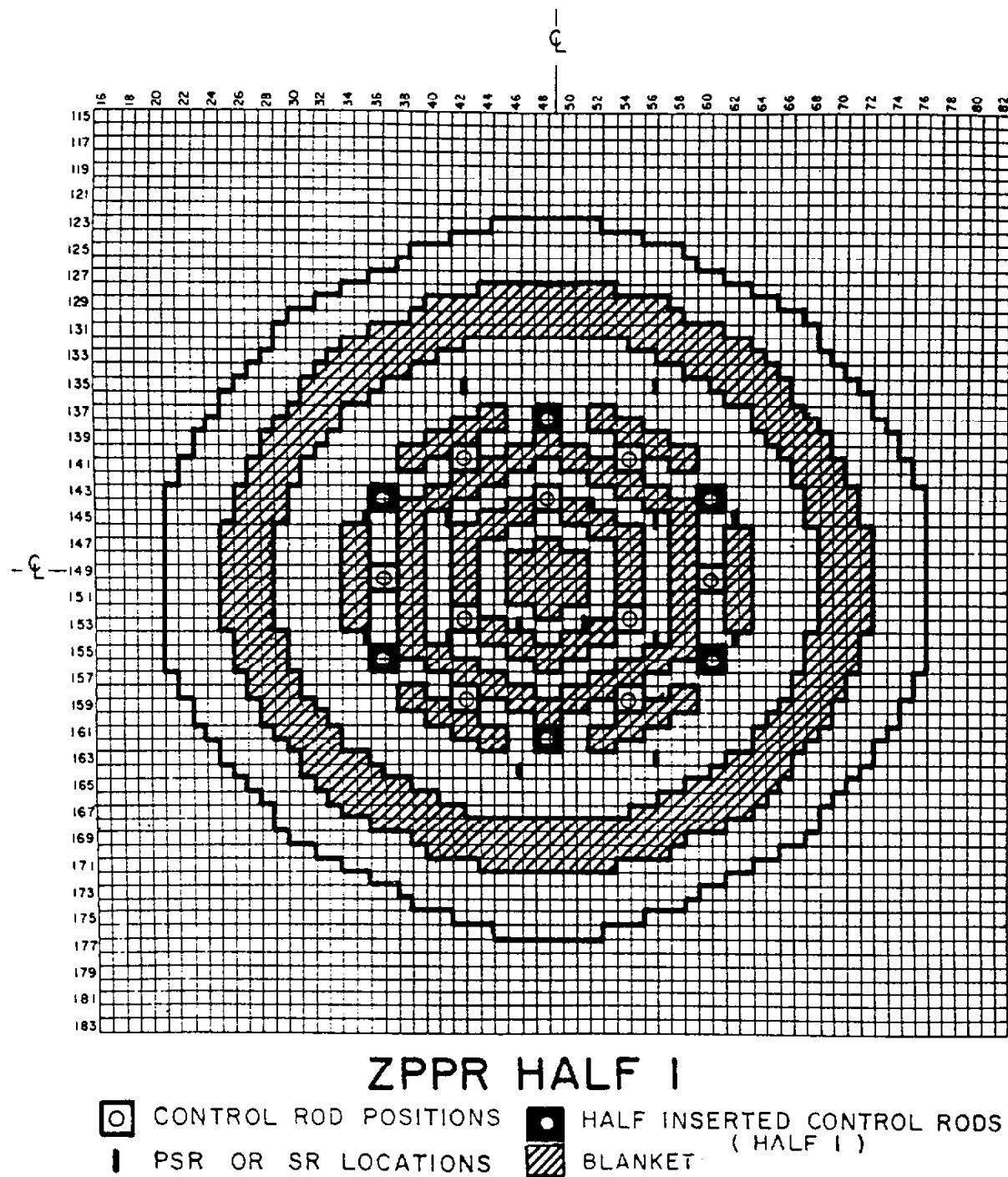


Fig. 32. Interface Diagram for ZPPR-7, Phase H

121.925

104.810

92.106
91.516

81.356

MATRIX

AXIAL REFLECTOR

SPRING GAP

81.356

ARC
ARB
ARC
ARB
ARC
ARB
ARC
ARBUPPER
BLANKET
REFLECTOR
(ARB)AXB
AXB
AXB
AXB

-

AXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXB

-

AXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBCENTRAL
BLANKETAXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBUPPER
CORE
REFLECTOR
(ARC)AXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBAXIAL
BLANKET
(AXB)AXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBOUTER
RADIAL
BLANKETAXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBRADIAL
REFLECTORAXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXB

CLAMP

AXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXBAXB
AXB
AXB

16.8752	38.2694	59.8351	79.1517	100.0386	122.5217	147.2528
28.5243	50.2222	71.8790				150.0 CM

Fig. 33. R-Z Model for ZPPR-7, Phases A through E

121.925

104.810

MATRIX

IRON BLOCK AXIAL REFLECTOR

92.106
91.516

81.356

CENTRAL
BLANKET

1

81.796

UPPER
BLANKET
REFLECTOR
(ARB)
AXB
B
L
A
N
K
E
TOUTER
RADIAL
BLANKETF
U
E
L
R
I
N
G
1
R
I
N
G
2
R
I
N
G
3
R
I
N
G
4UPPER
CORE
REFLECTOR
(ARC)
AXB
B
L
A
N
K
E
TAXIAL
BLANKET
(AXB)

F

U

E

L

3

R

I

N

G

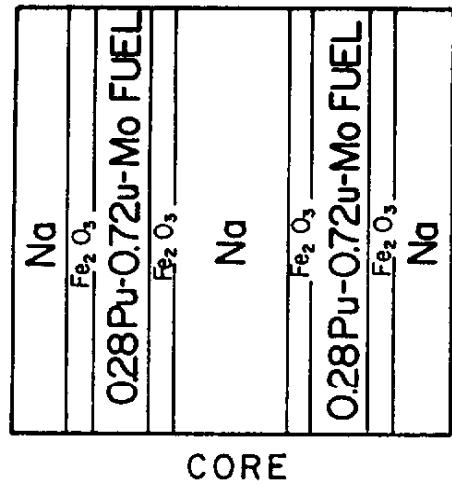
4

16.4929 37.9182 57.4721 76.6014 102.0506 123.7360 147.517 , 164.095
27.1722 48.6870 68.5710

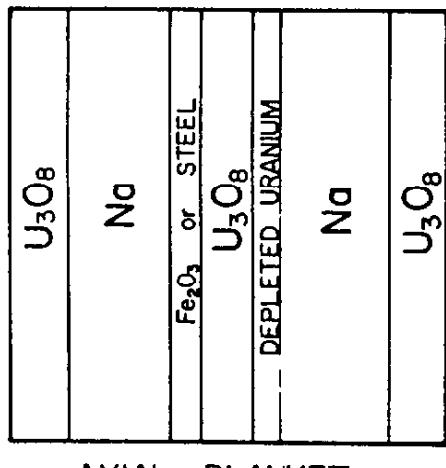
r (cm)

Fig. 34. R-Z Model for ZPPR-7, Phase F

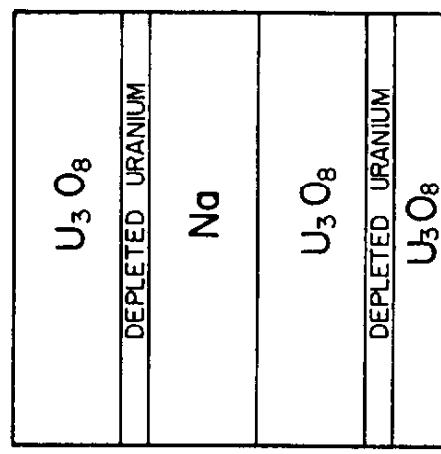
A46



CORE



AXIAL BLANKET



RADIAL BLANKET

Fig. 35. Drawer Loading Patterns for ZPPR-7

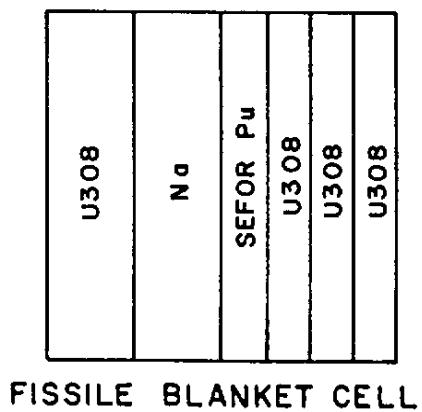
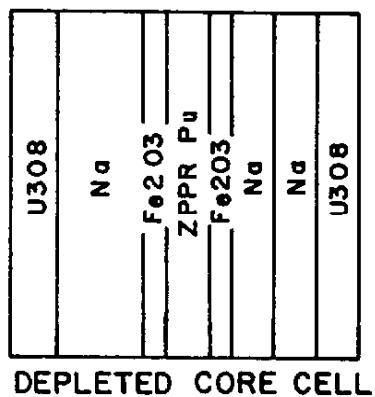
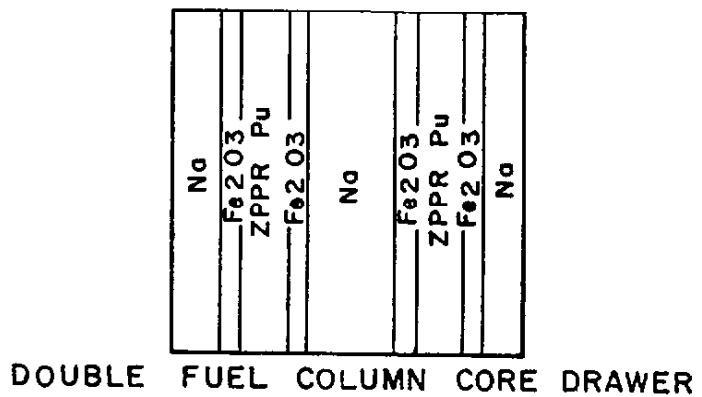


Fig. 36. Modified Drawer Loading Patterns for ZPPR-7, Phase C

ZPPR-8

Thorium cycle studies in the Clinch River Breeder Reactor (CRBR) radial heterogeneous configuration.

Overview:

Using Phase F of ZPPR-7 as the reference, experiments were performed to evaluate the effect of replacing uranium with thorium at various locations in inner and radial blankets.

Assembly Dates:

October 1977-March 1978

Related Assemblies:

ZPPR-7F

Assembly Details (Phase A):

Type:	Radial heterogeneous engineering benchmark
Fuel:	Typical Pu/U oxide with sodium cooling similar to ZPPR-7
Critical Mass:	1250 kg (Pu^{239} + Pu^{241})
Blanket:	Depleted uranium (DU) oxide with sodium cooling
Reactivity Adjustment:	Adjusting ratio of single- and double-column fuel drawers

Assembly Variants:

- Phase A: Similar to ZPPR-7 Phase F except 12 control rod positions (CRPs).
- Phase B: Similar to Phase A except thorium replaced the uranium in the axial blankets above and below fuel ring 1.
- Phase C: Similar to Phase A except the central blanket region was loaded with thorium, replacing uranium.
- Phase D: Similar to Phase A except thorium replaced part of the uranium in blanket ring 1.
- Phase E: Similar to Phase A except that thorium replaced part of the uranium in the radial blanket. Only about 300 kg of thorium was available for these experiments.
- Phase F: No thorium in this phase. Similar to Phase A except now 15 CRPs, blanket rings 1 and 2 were made continuous, and fuel was added around the CRPs to enhance CR worth. CRs were added later to Phase F.

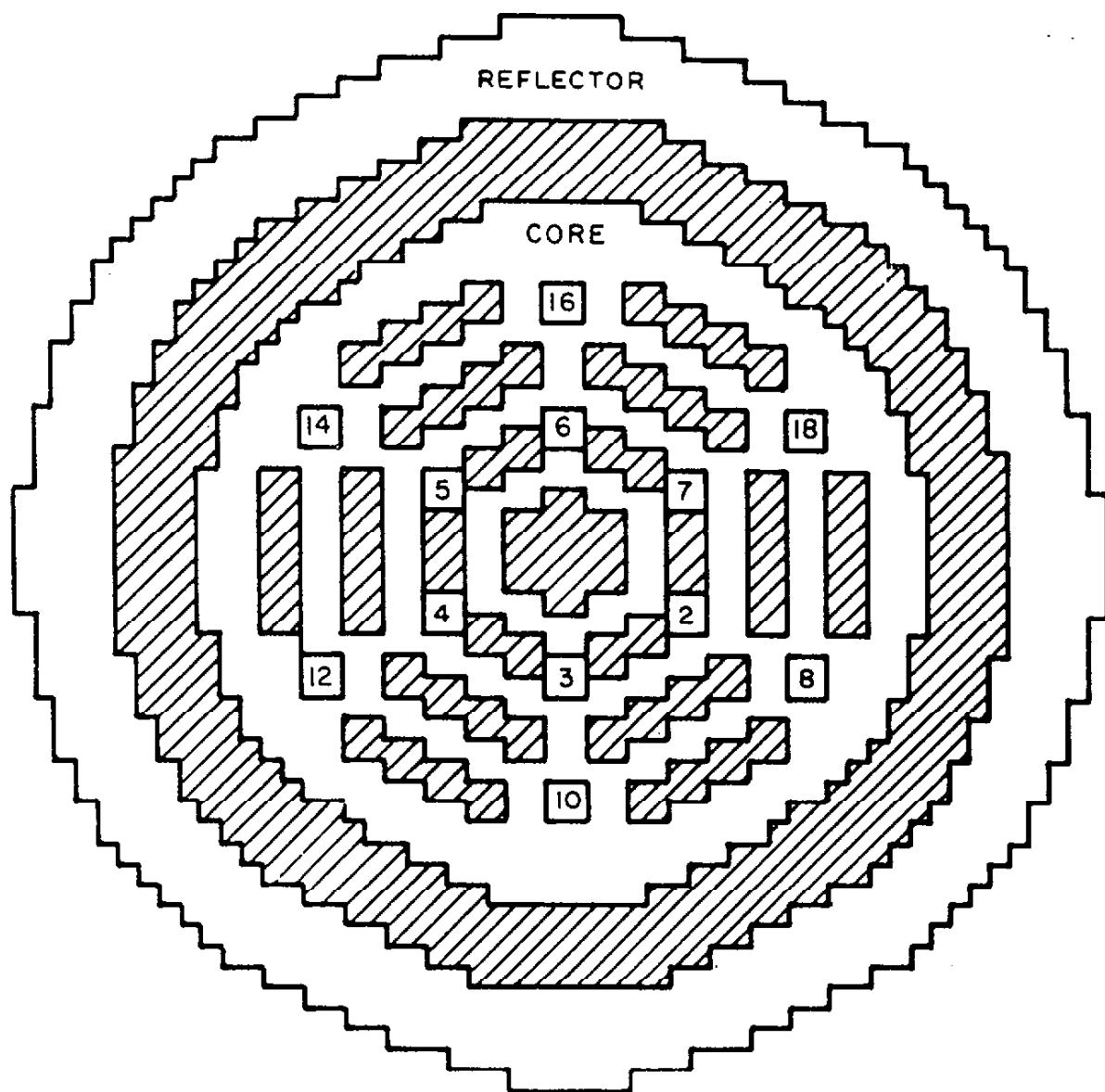


Fig. 37. Interface Diagram for ZPPR-8, Phase A

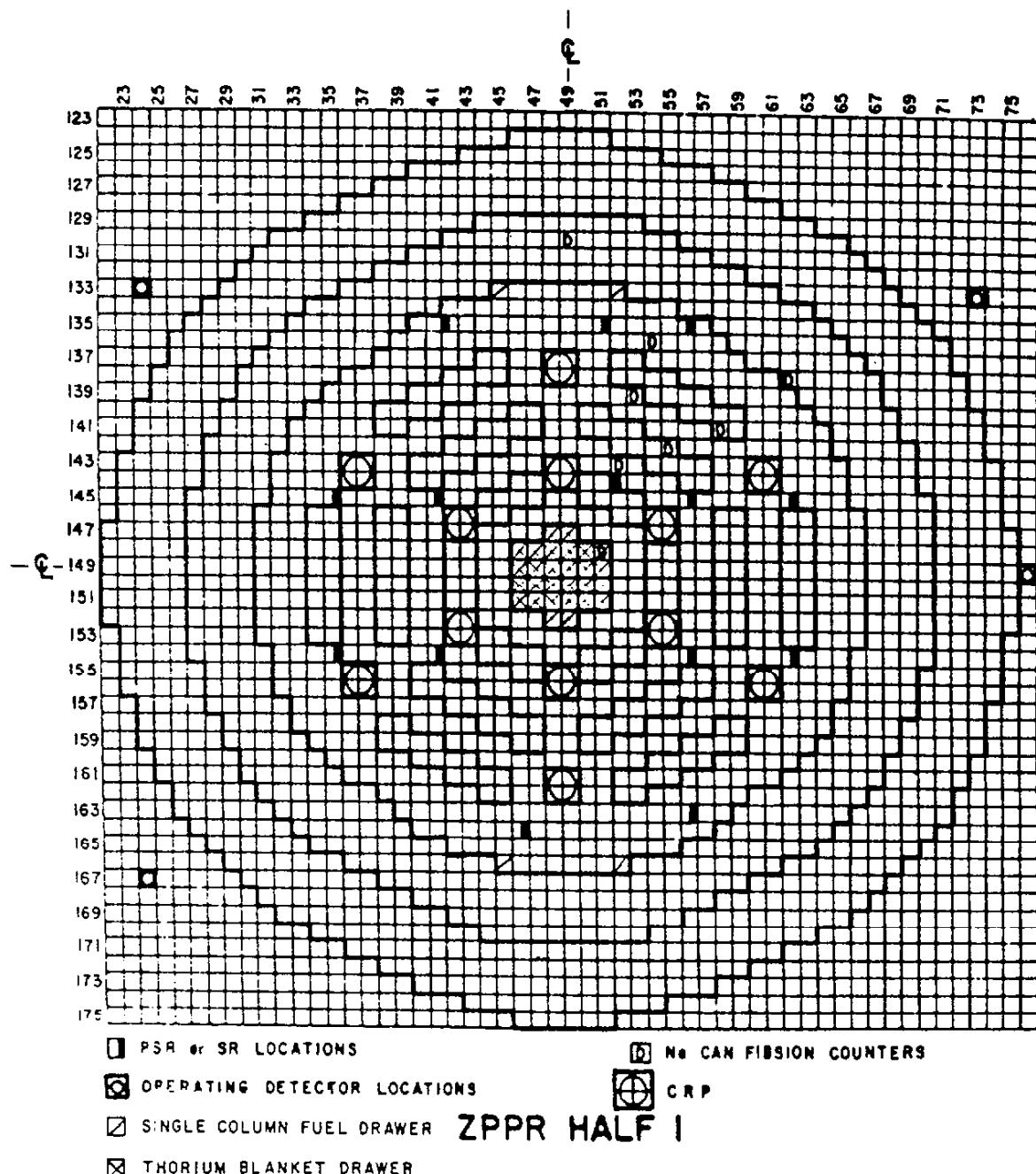


Fig. 38. Interface Diagram for ZPPR-8, Phase C

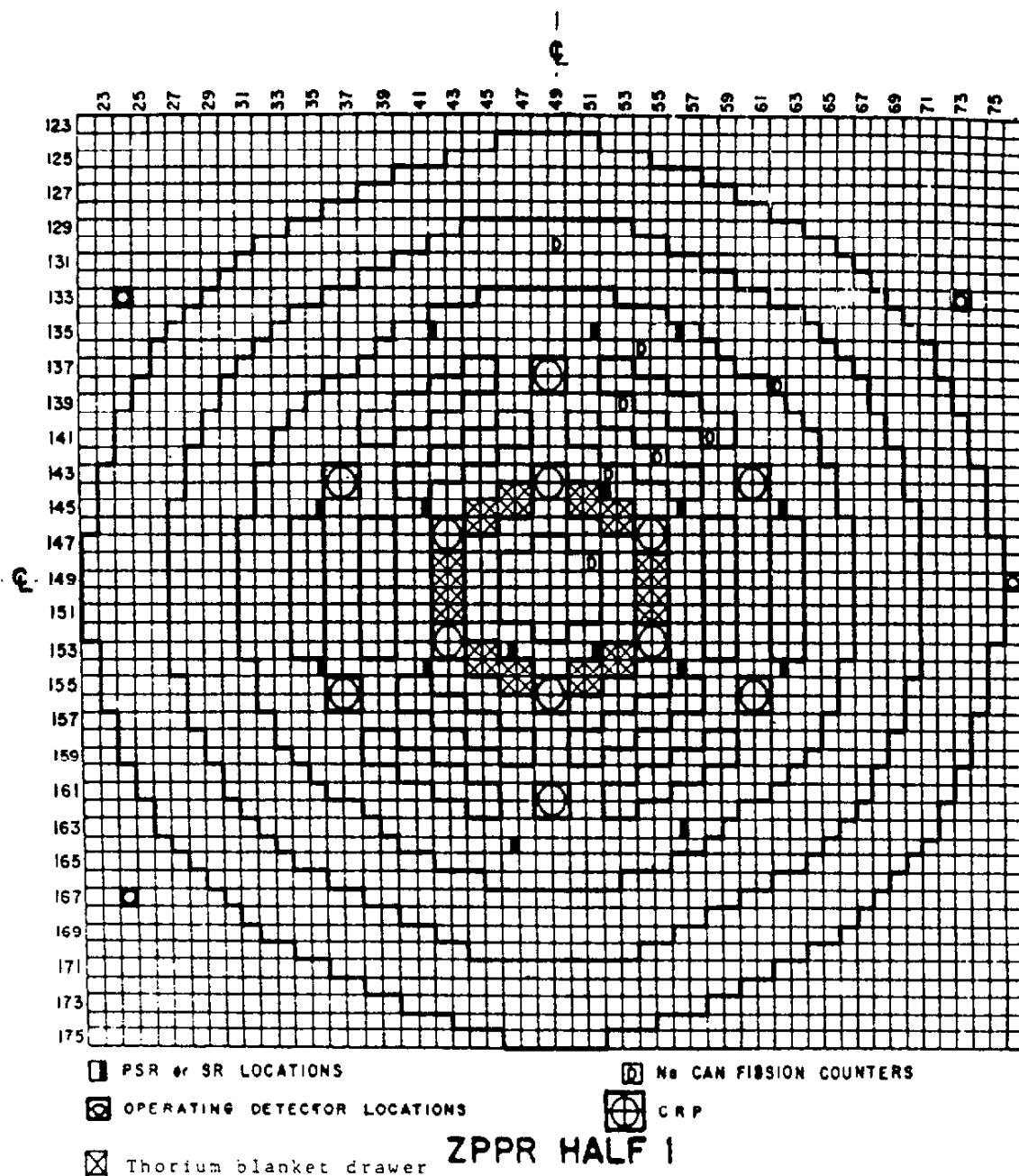


Fig. 39. Interface Diagram for ZPPR-8, Phase D

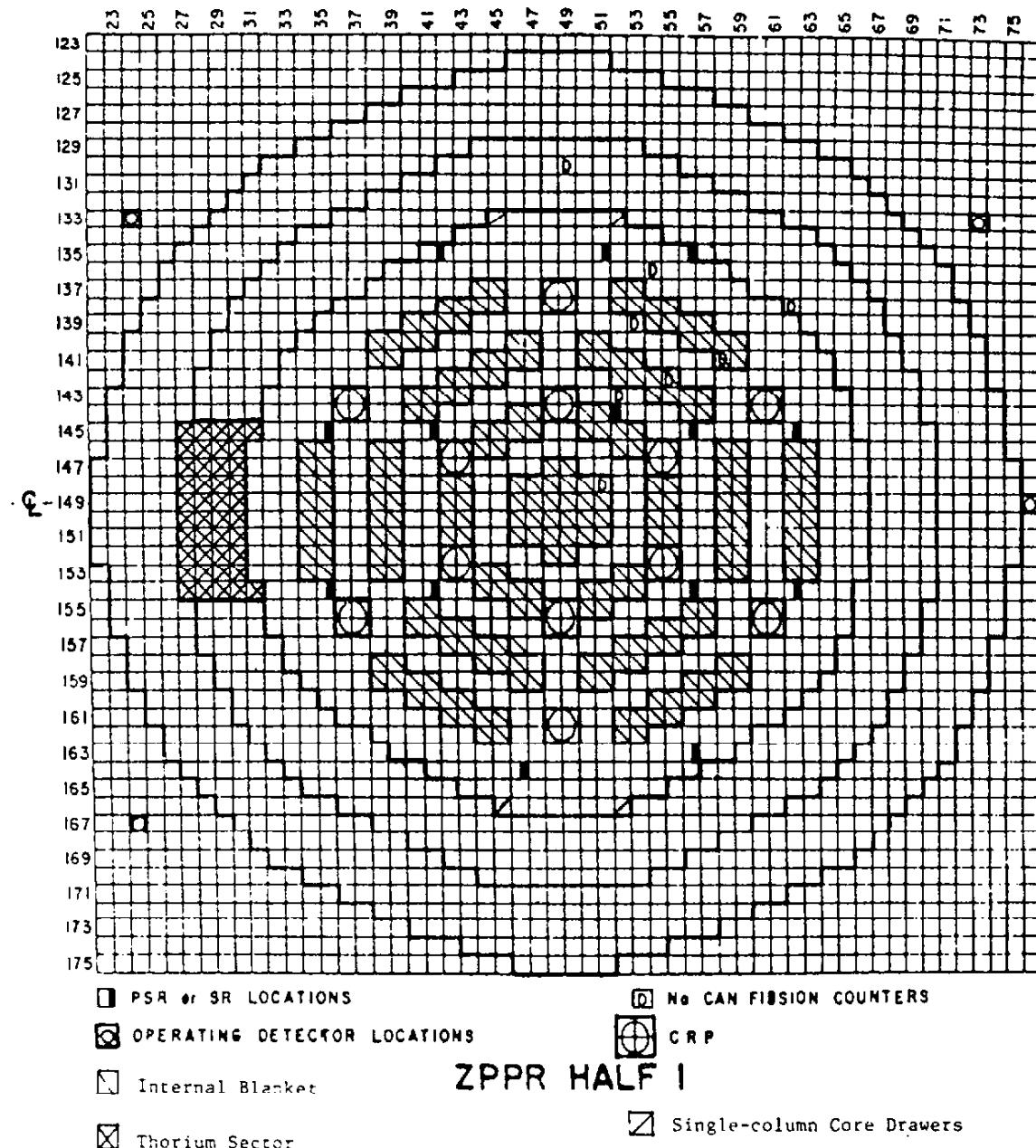
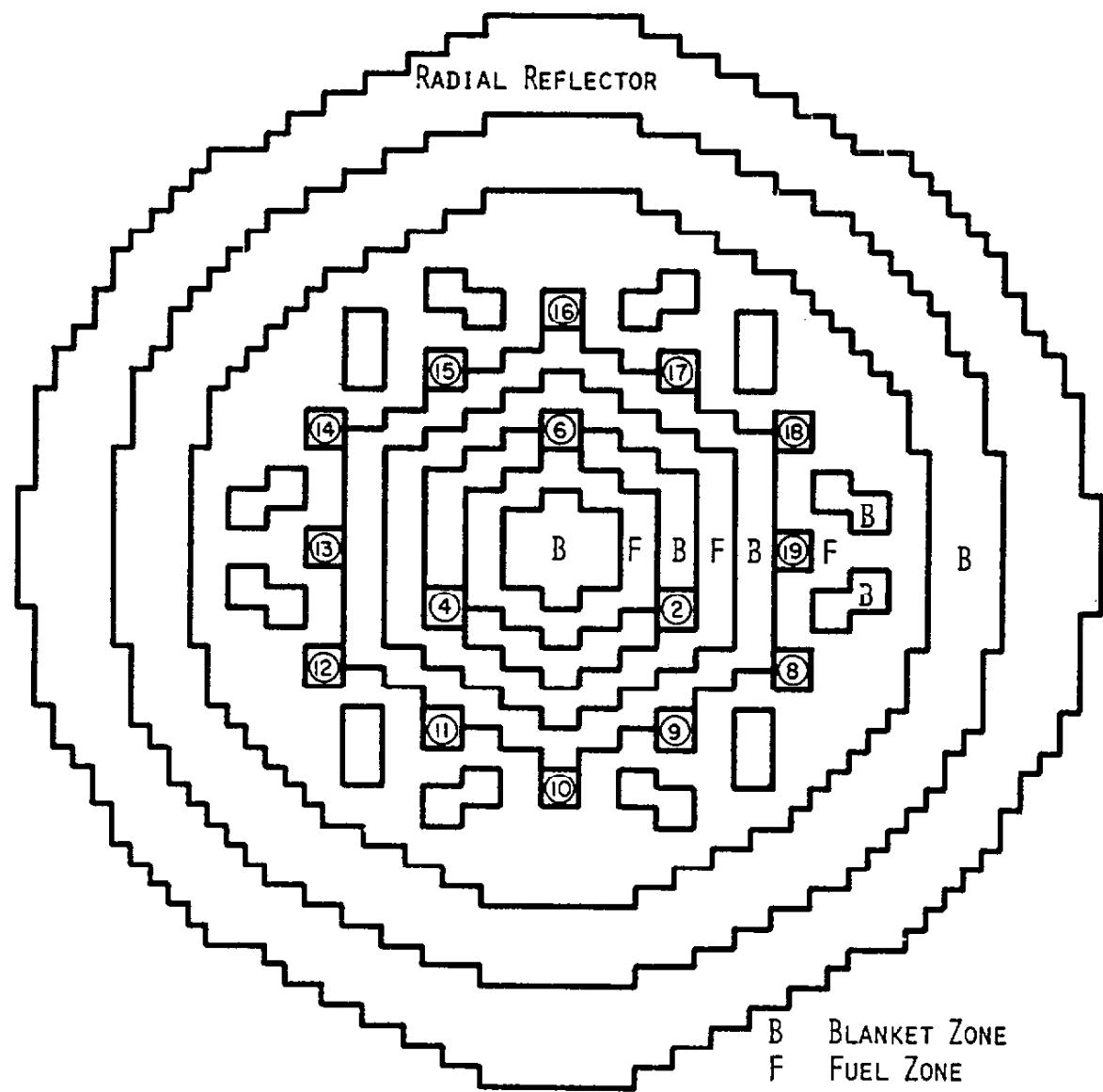


Fig. 40. Interface Diagram for ZPPR-8, Phase E



CONTROL ROD POSITION

Fig. 41. Interface Diagram for ZPPR-8, Phase F

ZPPR-9

Physics benchmark for 700 MWe conventional design.

Overview:

This assembly was a clean, cylindrical two-zone physic benchmark for a reactor of approximately 700 MWe. It is a larger version of ZPPR-2. The measurements were directed at evaluating the effect of the larger core size on all of the important physics parameters. The assembly was part of the JUPITER-I Program, a cooperation between Power Reactor and Nuclear Fuel Development Corporation (PNC) and Argonne National Laboratory/Department of Energy (ANL/DOE).

Assembly Dates:

May 1978-October 1978

Related Assemblies:

ZPPR-2 and ZPPR-10

Assembly Details:

Type:	Cylindrical, two-zone, clean critical
Fuel:	Typical Pu/U oxide with sodium cooling
Critical Mass:	1956 kg (Pu^{239} + Pu^{241})
Volume:	4600 liters
Blanket:	Depleted uranium (DU) oxide with sodium cooling

Assembly Variants:

None

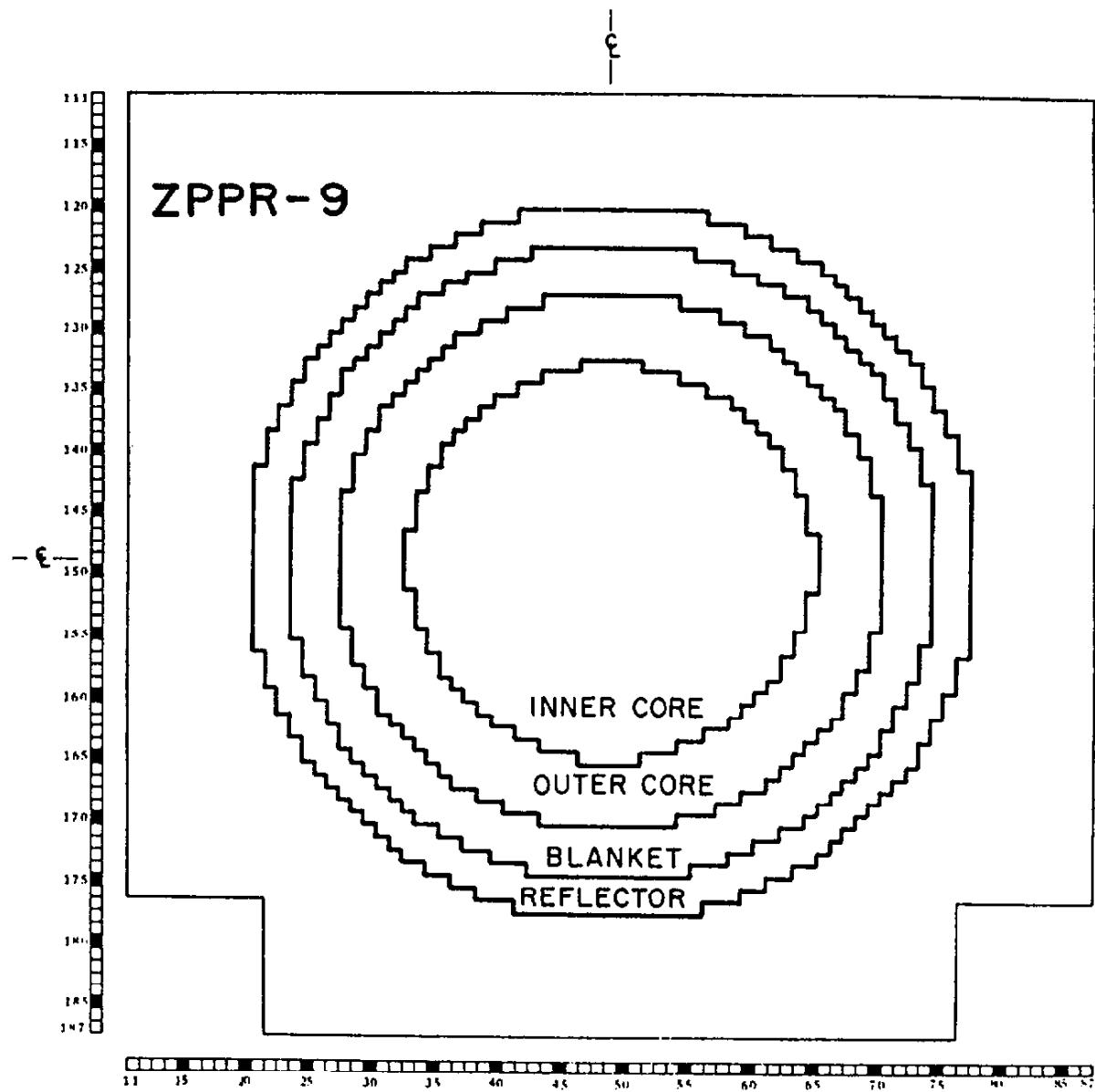
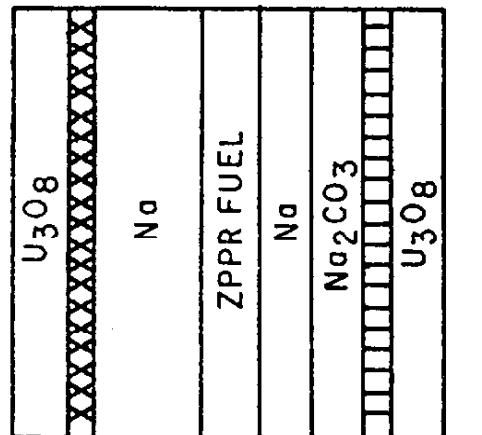
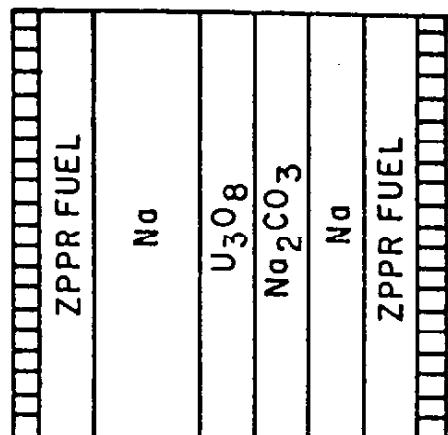


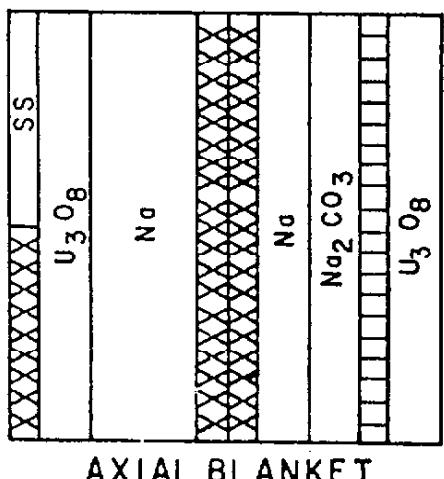
Fig. 42. Interface Diagram for ZPPR-9



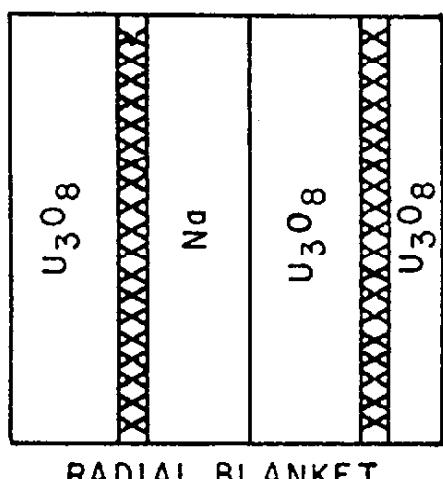
INNER CORE / OUTER CORE
SINGLE FUEL COLUMN



OUTER CORE
DOUBLE FUEL COLUMN



AXIAL BLANKET



RADIAL BLANKET

Fe_2O_3

U^{238}

Fig. 43. Drawer Loading Patterns for ZPPR-9

ZPPR-10

Engineering benchmark for 700-900 MWe conventional designs.

Overview:

Evolving from ZPPR-9, this assembly contained control rods (CRs) and control rod positions (CRPs) and the shape was made hexagonal. In later variants, the size was increased from 4600 liters to 6000 liters. The assembly was the second core in the JUPITER-I Program, a cooperation between the Japan Nuclear Cycle Development Institute (PNC) and Argonne National Laboratory/Department of Energy (ANL/DOE).

Assembly Dates:

November 1978-August 1979

Related Assemblies:

ZPPR-9

Assembly Details (Phase A):

Type:	Hexagonal, two-zone critical with CRs and CRPs
Fuel:	Typical Pu/U oxide with sodium cooling
Critical Mass:	2070 kg (Pu^{239} + Pu^{241})
Volume:	4600 liters
Blanket:	Depleted uranium (DU) oxide with sodium cooling
Reactivity Adjustment:	Adjusting the ratio of single- to double-column fuel drawers

Assembly Variants:

- Phase A: Contained 19 CRPs and no CRs
- Phase B: Similar to Phase A except it contained seven CRs and 12 CRPs
- Phase C: Core volume expanded to 6160 liters with a critical mass of about 2600 kg (Pu^{239} + Pu^{241})
- Phase D: Similar to Phase C except it contained 31 CRPs and no CRs. Size of CRPs reduced by 1/3 except the central CRP which remained the same size as in the earlier phases.

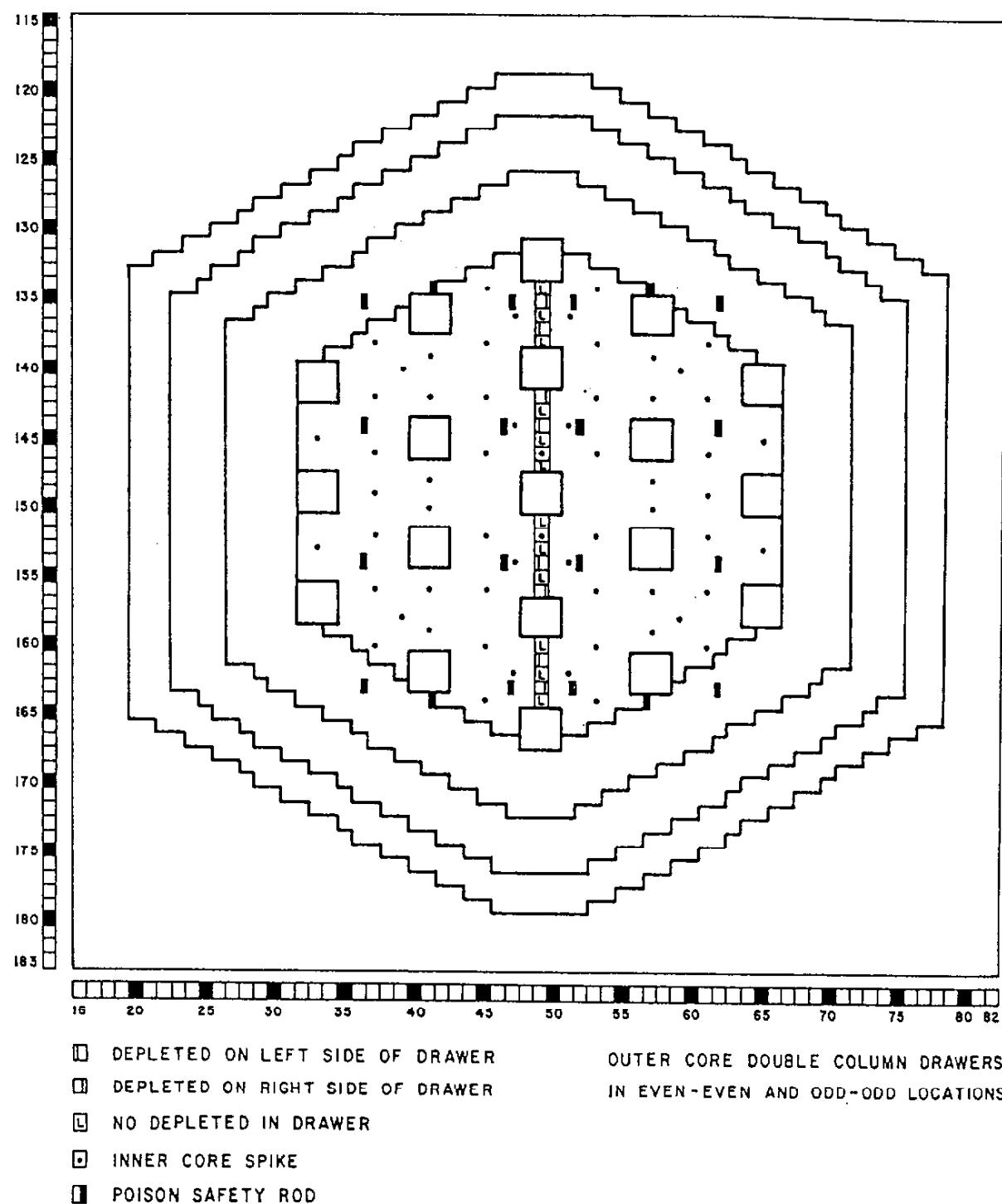


Fig. 44. Interface Diagram for ZPPR-10, Phase A

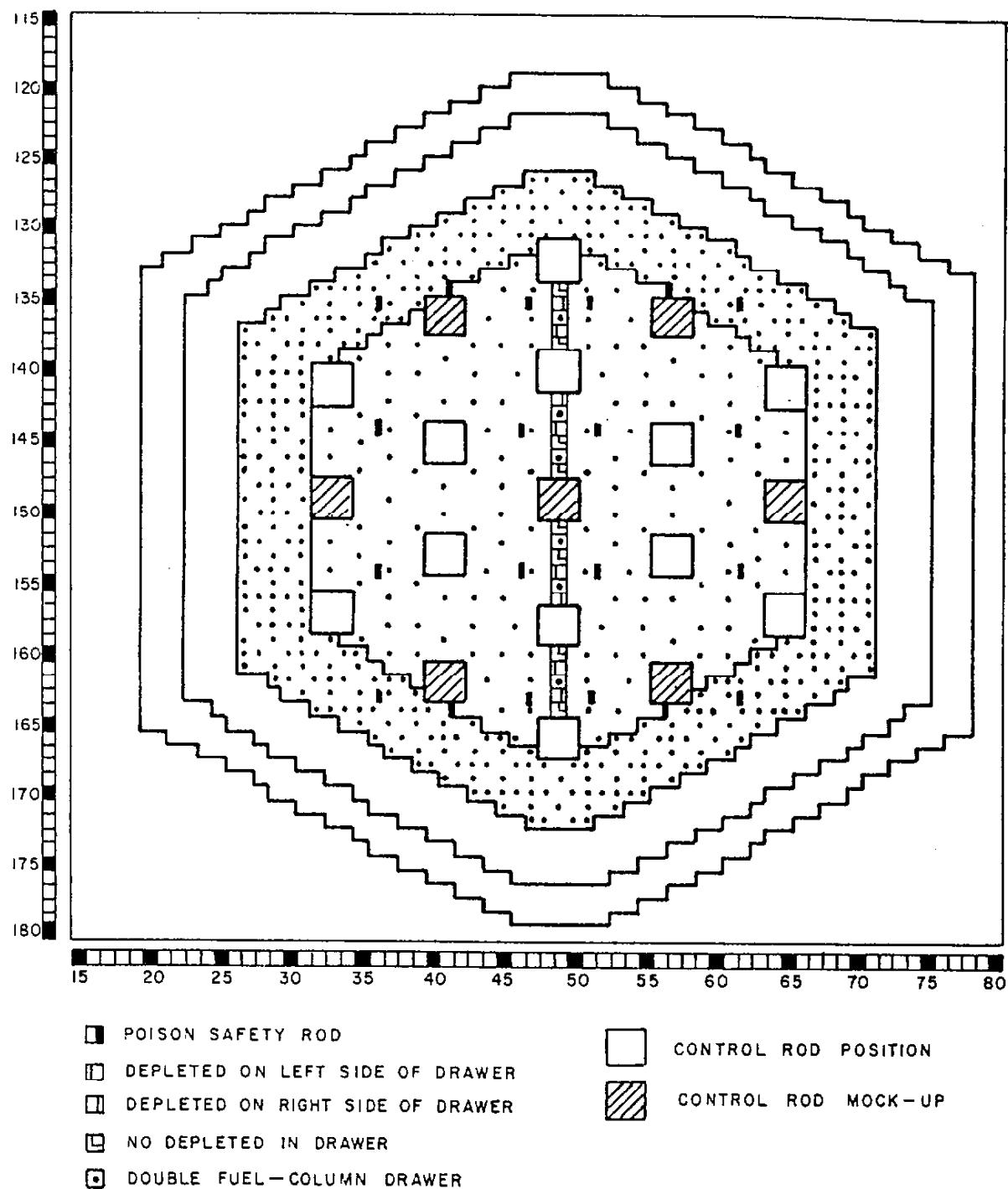


Fig. 45. Interface Diagram for ZPPR-10, Phase B

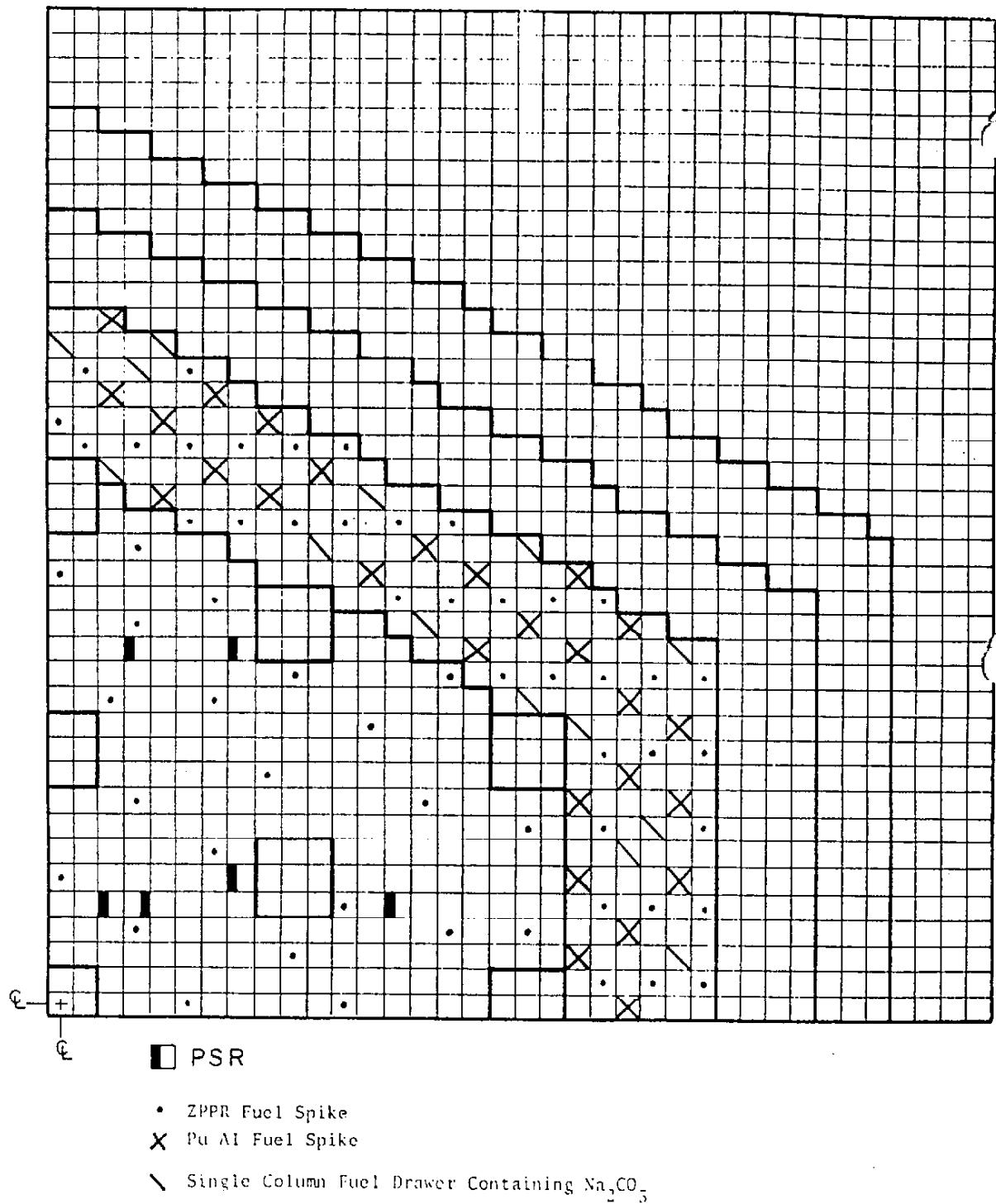


Fig. 46. Quarter Core Interface Diagram for ZPPR-10, Phase C

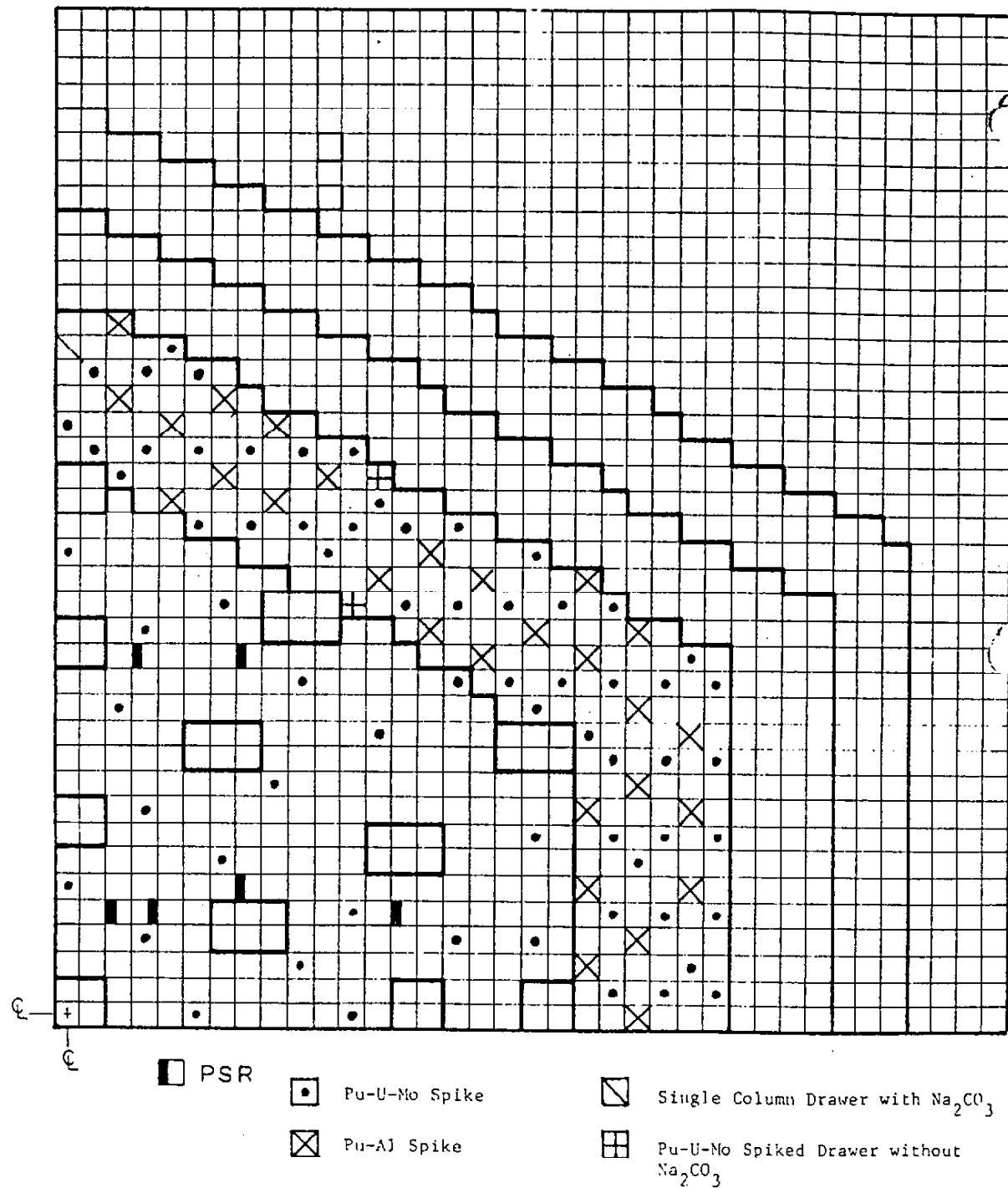


Fig. 47. Quarter Core Interface Diagram for ZPPR-10, Phase D

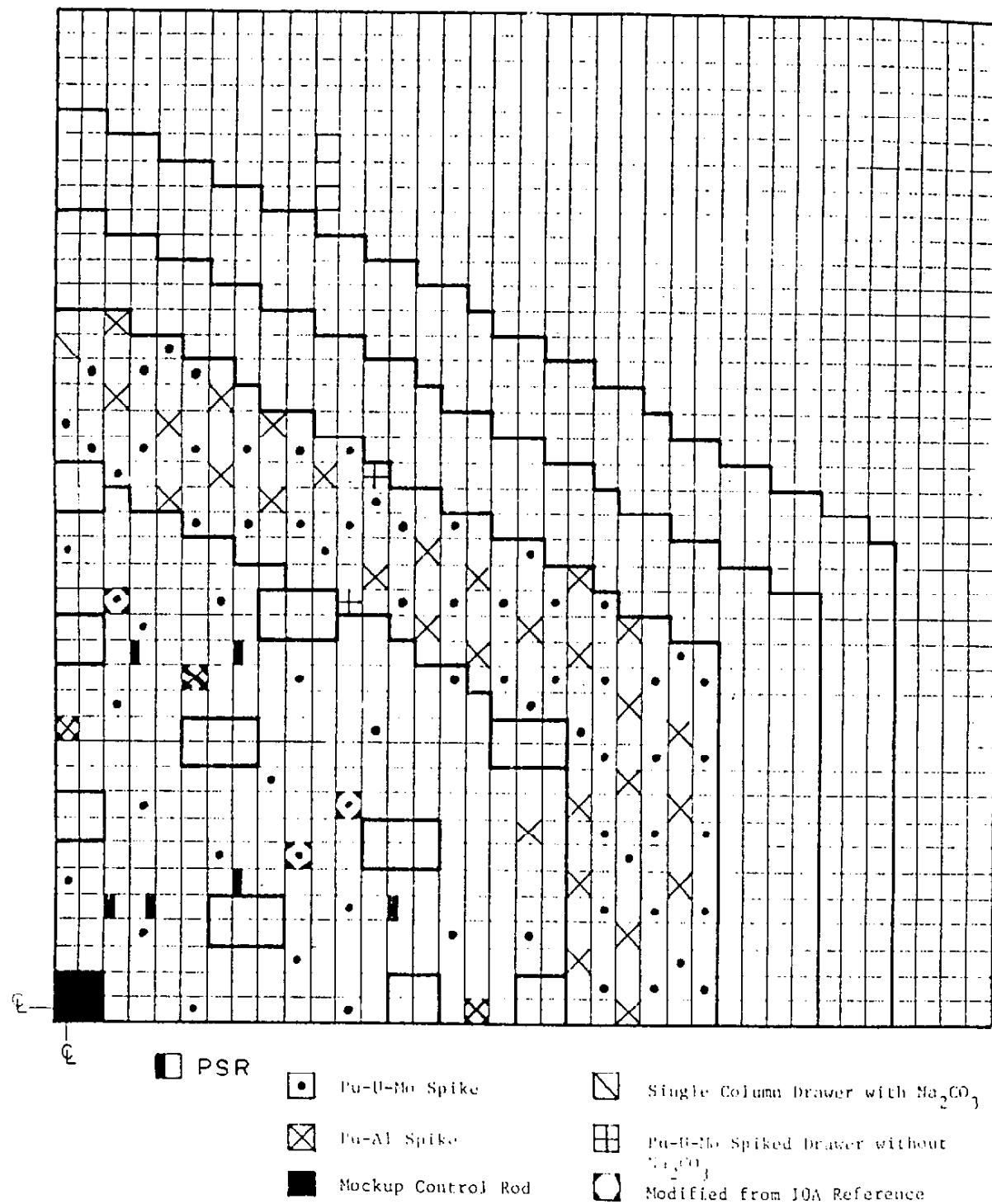


Fig. 48. Quarter Core Interface Diagram for ZPPR-10, Phase D/1

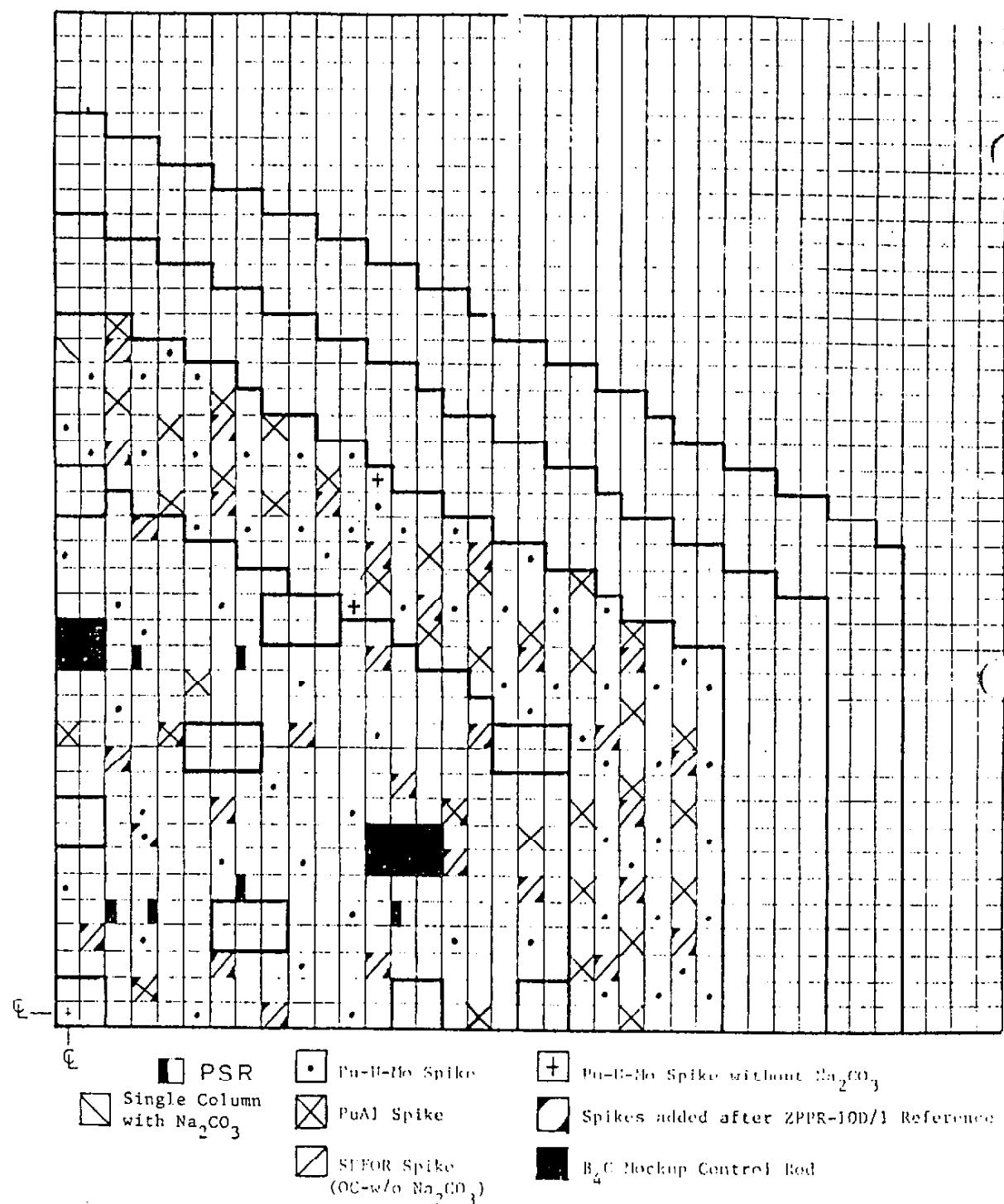


Fig. 49. Quarter Core Interface Diagram for ZPPR-10, Phase D/2

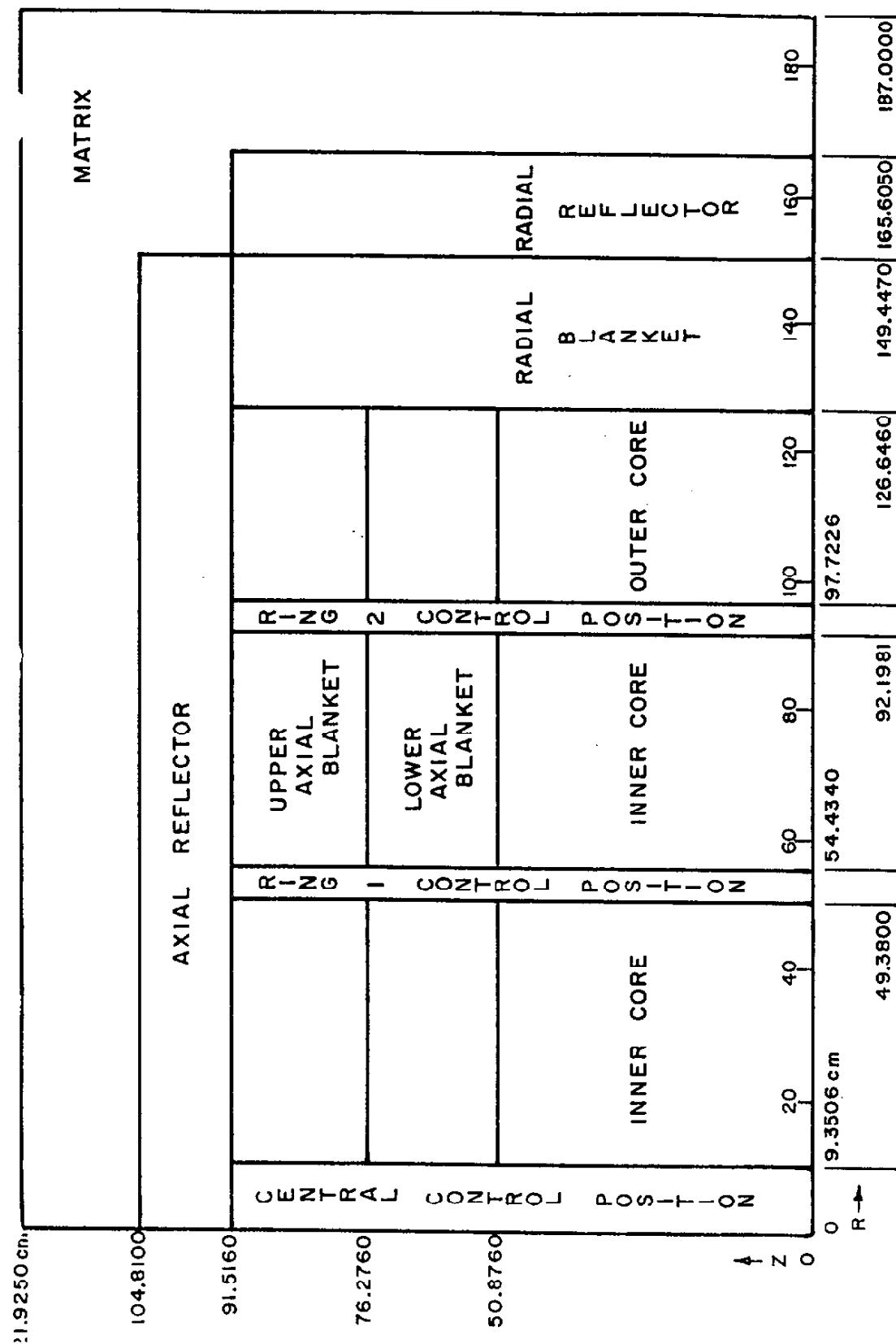


Fig. 50. R-Z Model for ZPPR-10

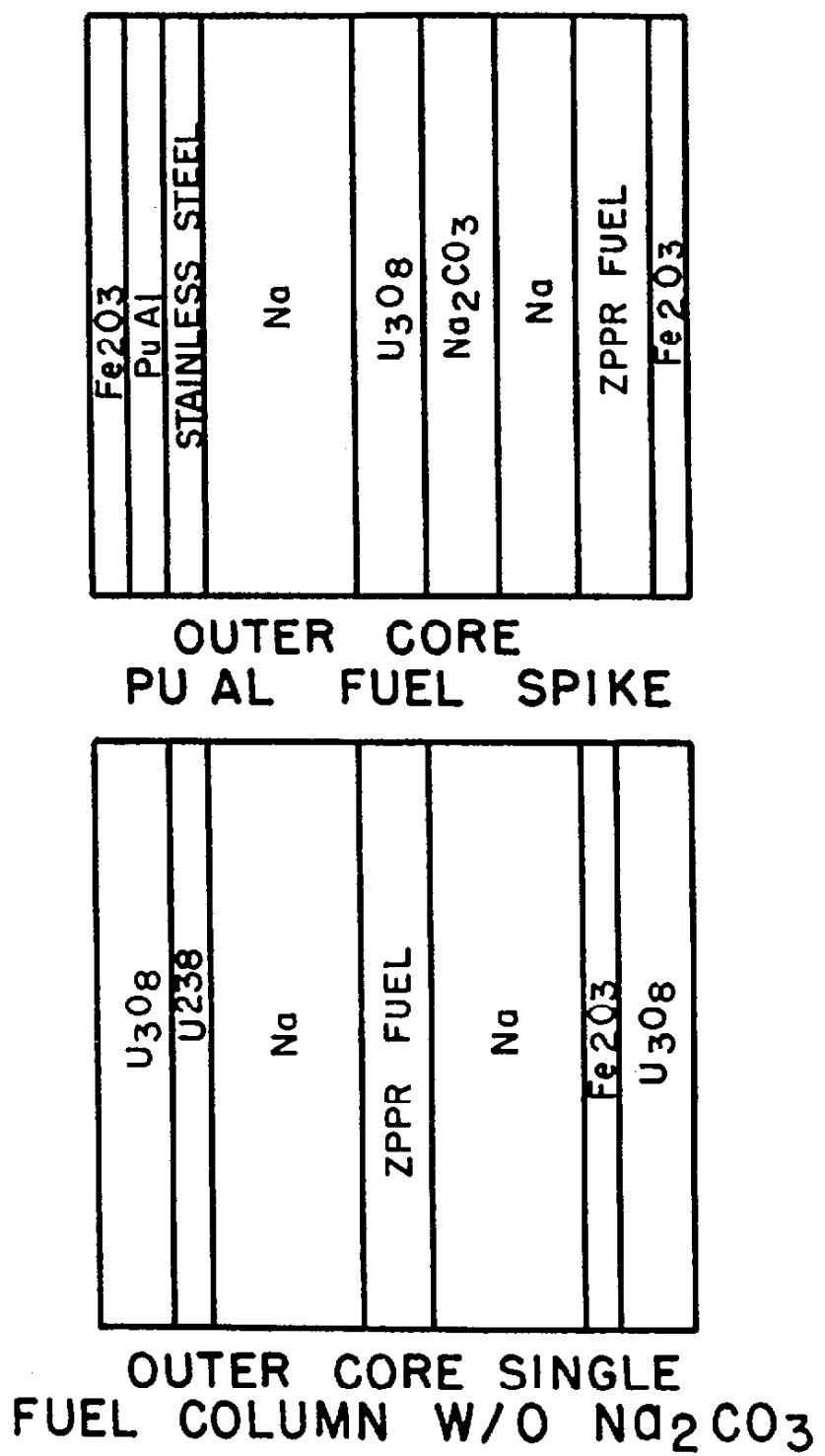


Fig. 51. Drawer Loading Patterns for Additional Drawers Used in ZPPR-10, Phase C

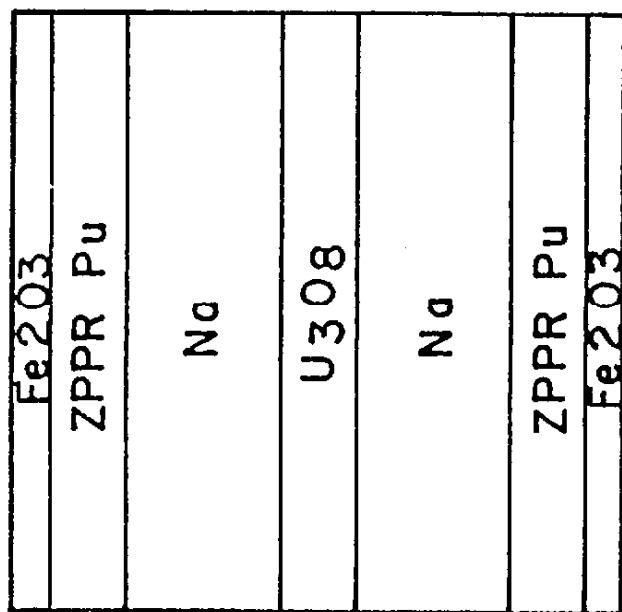


Fig. 52. Drawer Loading Pattern for Additional Drawer Used in ZPPR-10, Phase D

ZPPR-11

Engineering mockup core (EMC) for the Clinch River Breeder Reactor (CRBR) Final Heterogeneous Design.

Overview:

A decision had been made to convert CRBR to a radial heterogeneous configuration. This assembly was the EMC for the final CRBR heterogeneous configuration. The first four phases provided design support and the final two phases provided licensing support. The phases simulated different times in the CRBR fuel cycle and plutonium buildup in the blanket regions was simulated. Core was loaded into the bottom of the ZPPR matrix to allow inclusion of a sector mockup of the reflector, sodium pool, vessel wall and an external neutron detector in an upper corner of the ZPPR matrix.

Assembly Dates:

January 1980-November 1981

Related Assemblies:

ZPPR-7. This assembly was very similar to ZPPR-7, Phase F.

Assembly Details:

Type: Hexagonal, radial heterogeneous assembly with control rods (CRs) and control rod positions (CRPs)
Fuel: Typical Pu/U oxide with sodium cooling, similar to ZPPR-7
Critical Mass: 1500 kg (Pu^{239} + Pu^{241})
Reactivity Adjustment: Adjusting the ratio of single- and double-column fuel drawers

Assembly Variants:

Phase A: Expected beginning-of-life (BOL) core with six half inserted CRs and nine parked CRs. Mockup of ex-core detector included to follow initial start up, one of the few deep-penetration measurements ever done in the criticals program.
Phase B: Clean BOL core. 15 CRPs.
Phase C1: Clean end-of-life (EOL) core. 15 CRPs. Plutonium buildup in the internal blankets and radial blanket. Critical mass about 1575 kg.
Phase C: Clean EOL core. 15 CRPs. Plutonium buildup in the internal blankets and radial blanket. Critical mass about 1575 kg.
Phase D: Expected EOL core. Nine CRs inserted 1/3 into core, six CRs parked at axial blanket/core interface.
Phase E: Clean EOL core similar to Phase C.
Phase F: Expected BOL core similar to Phase A except only CRPs. No parked or partially inserted CRs. Extensive sodium void and Doppler measurements.

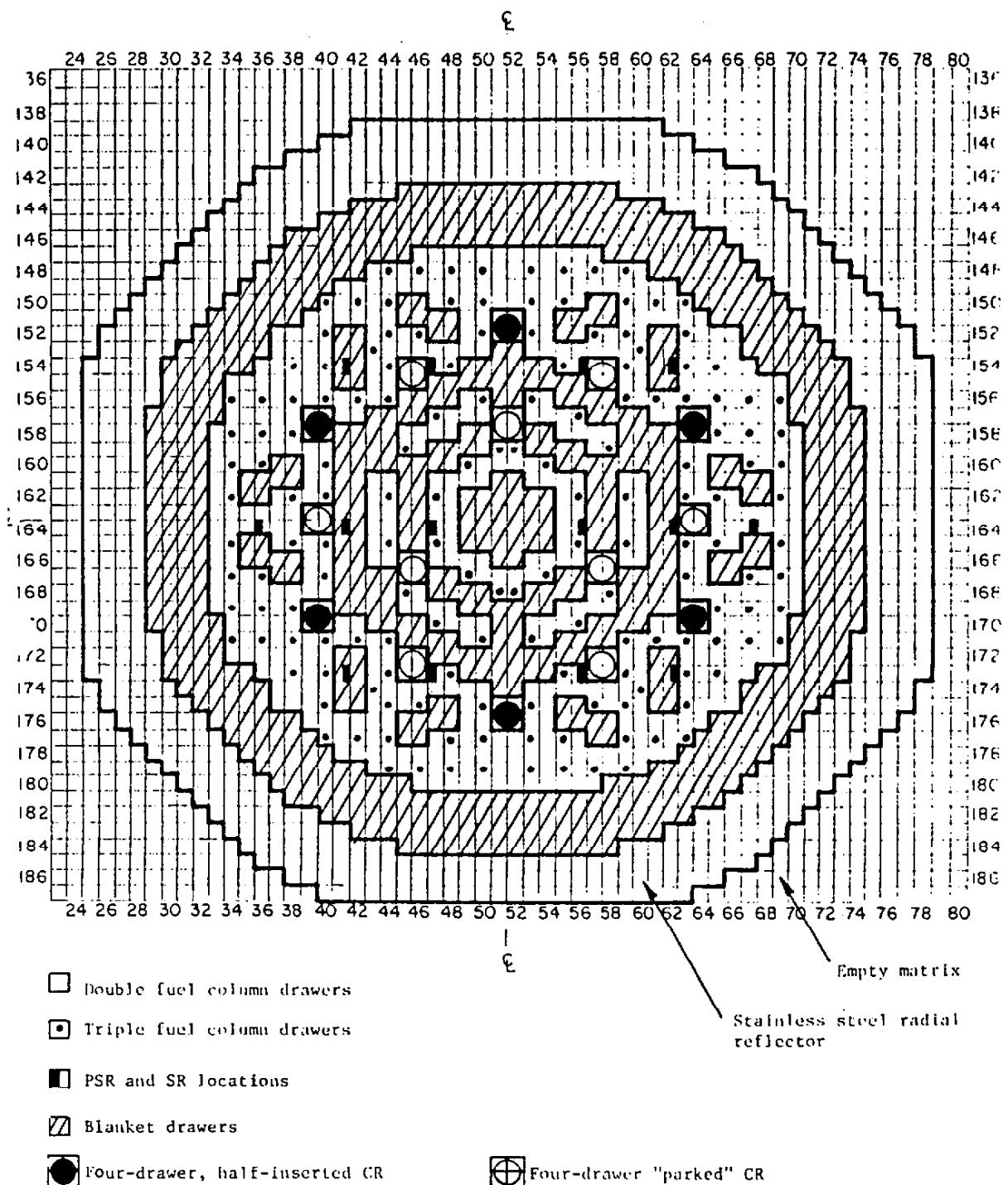


Fig. 53. Interface Diagram for ZPPR-11, Phase A

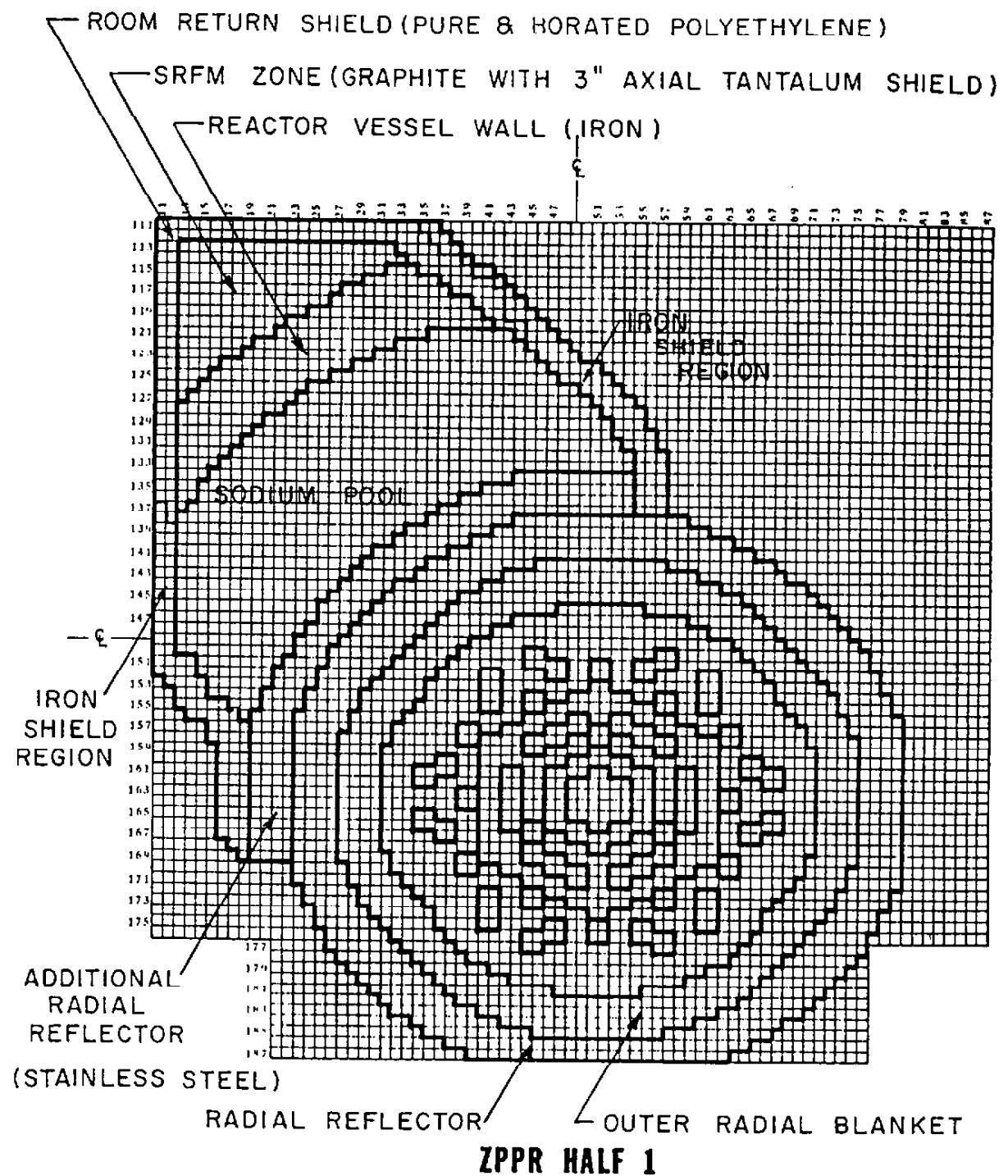


Fig. 54. Interface Diagram of ZPPR-11 Showing the Mockup of the Ex-Vessel Neutron Detector

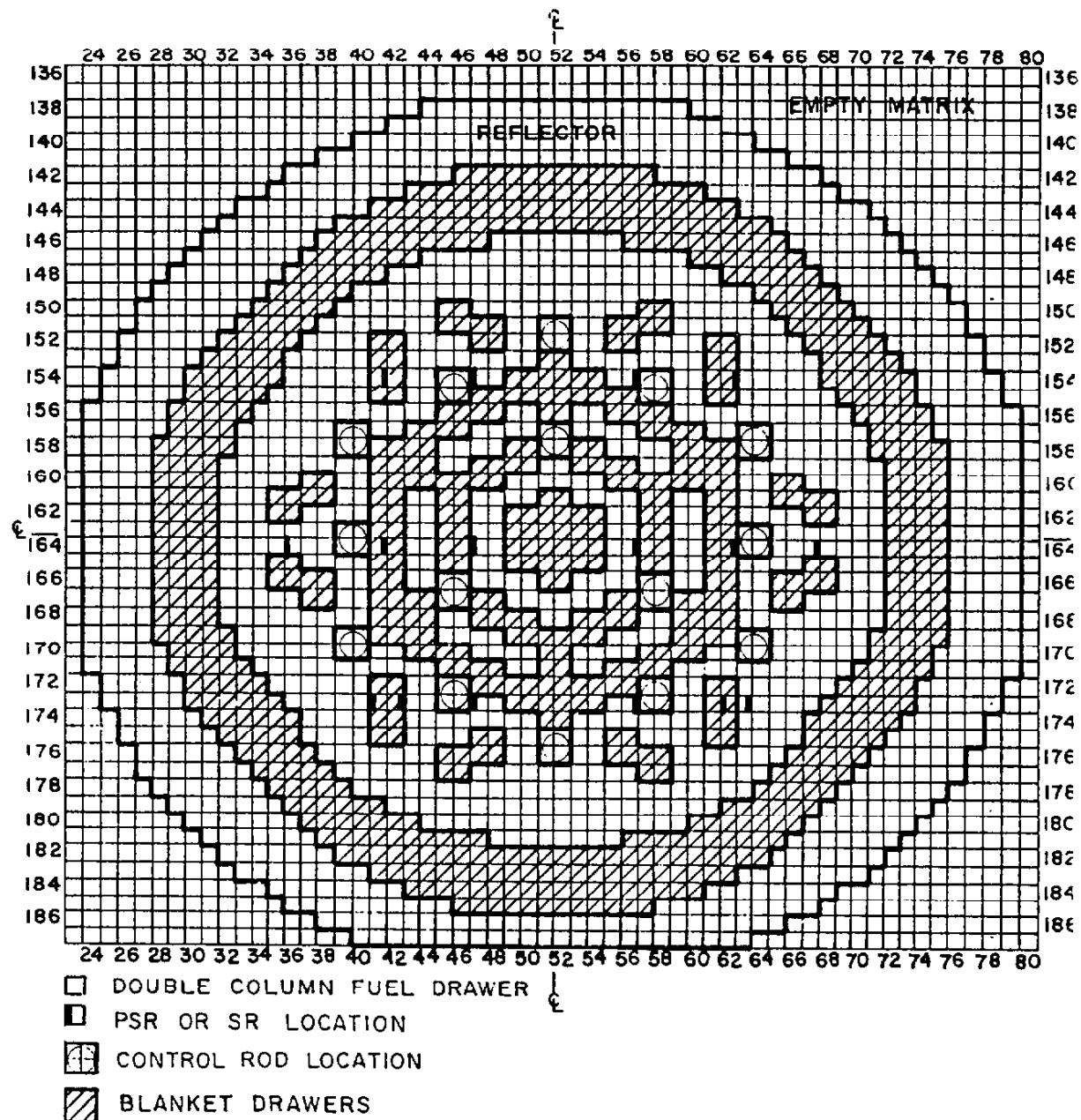


Fig. 55. Interface Diagram for ZPPR-11, Phase B

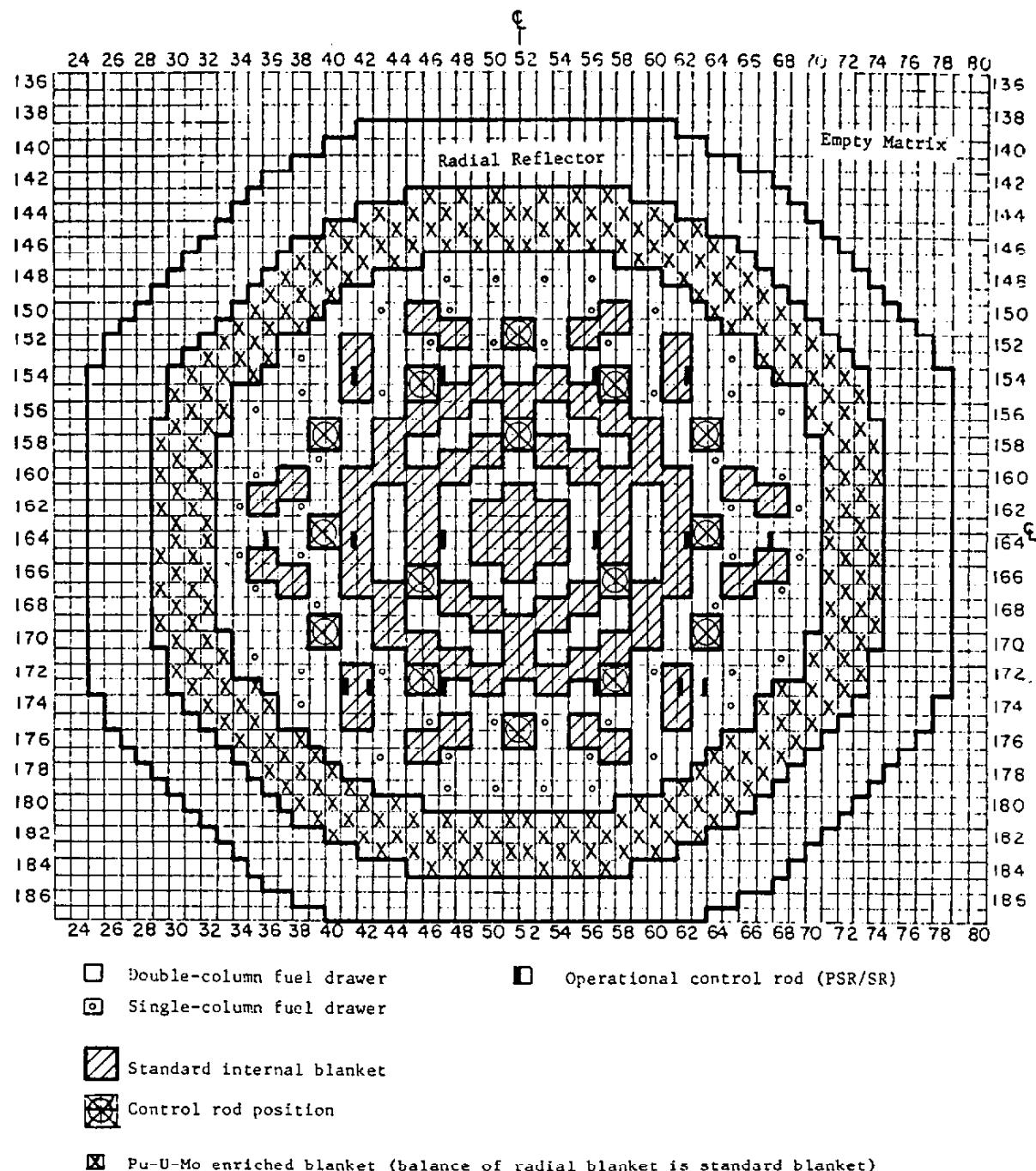


Fig. 56. Interface Diagram for ZPPR-11, Phase C/1

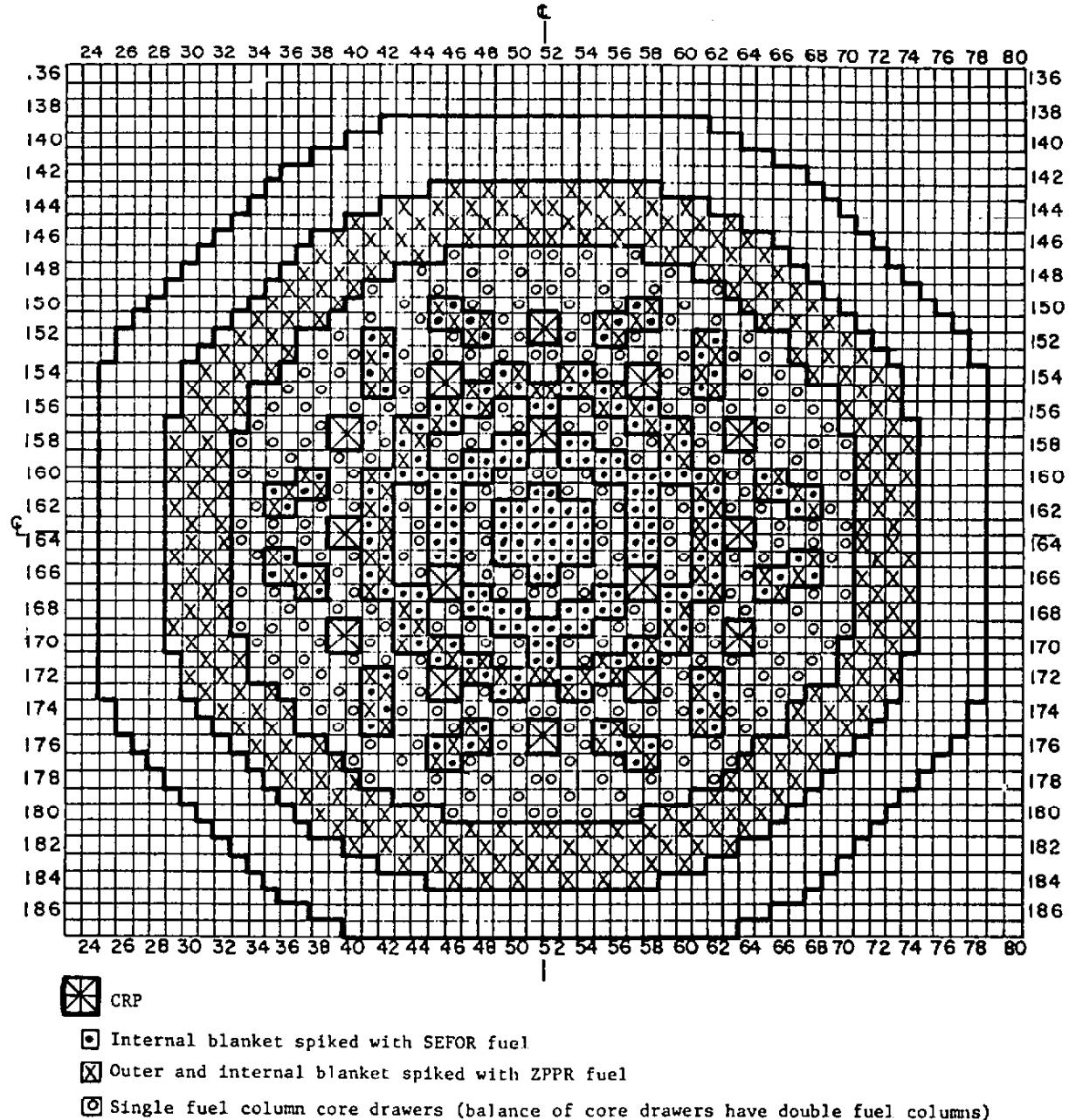


Fig. 57. Interface Diagram for ZPPR-11, Phase C

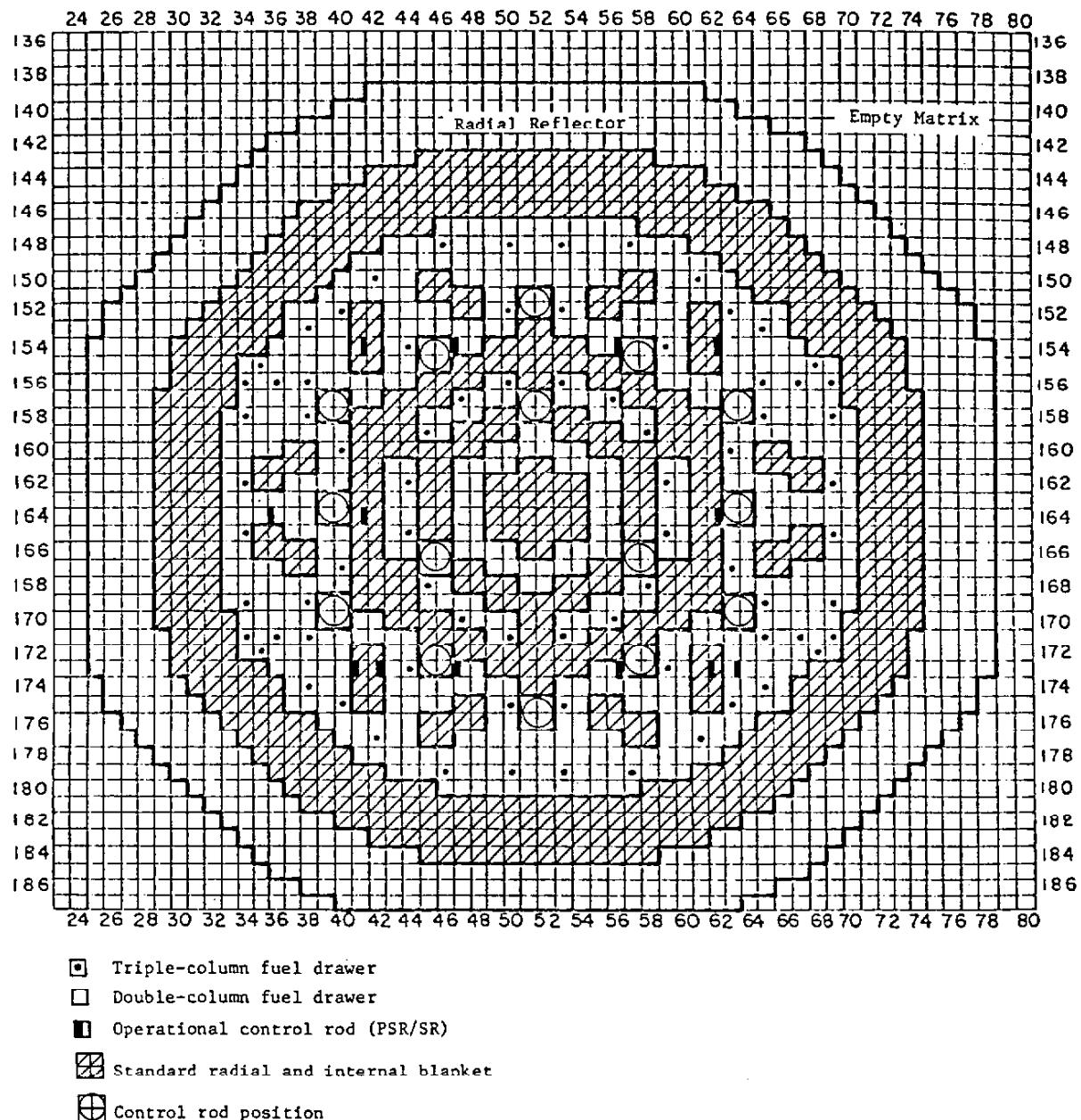


Fig. 58. Interface Diagram for ZPPR-11, Phase F

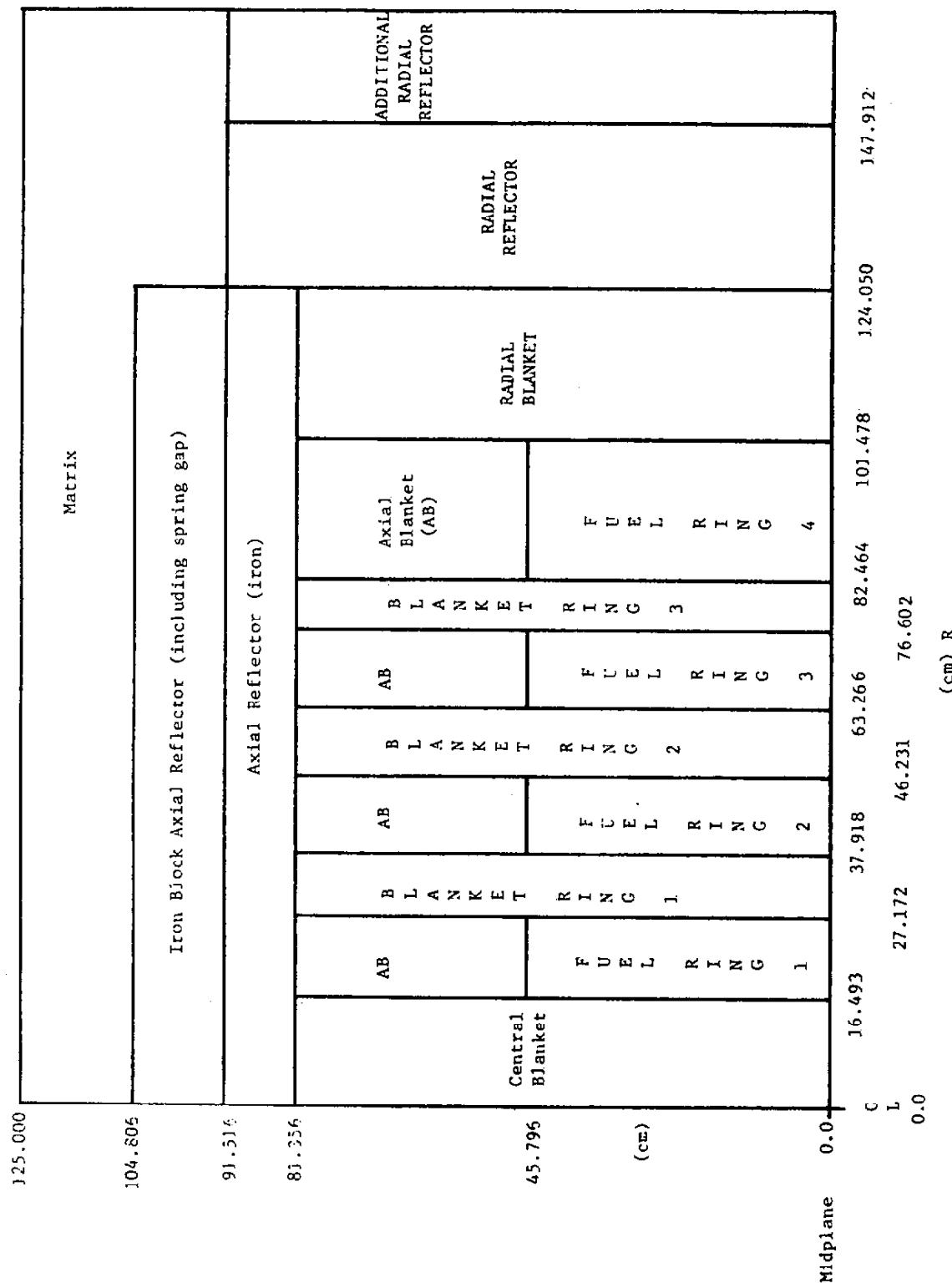


Fig. 59. R-Z Model for ZPPR-11, Phases A through F

ZPPR-12

Clean physics core to study Clinch River Breeder Reactor (CRBR) fuel properties.

Overview:

Clean, cylindrical, single-zone physics core with the same core composition as ZPPR-11, the CRBR radial heterogeneous engineering mockup core. Measurements focused on cell heterogeneity, neutron streaming, and the control worth discrepancy.

Assembly Dates:

December 1981-April 1982 for ZPPR-12; October 1984-November 1984 for ZPPR-12MB

Related Assembly:

ZPPR-11

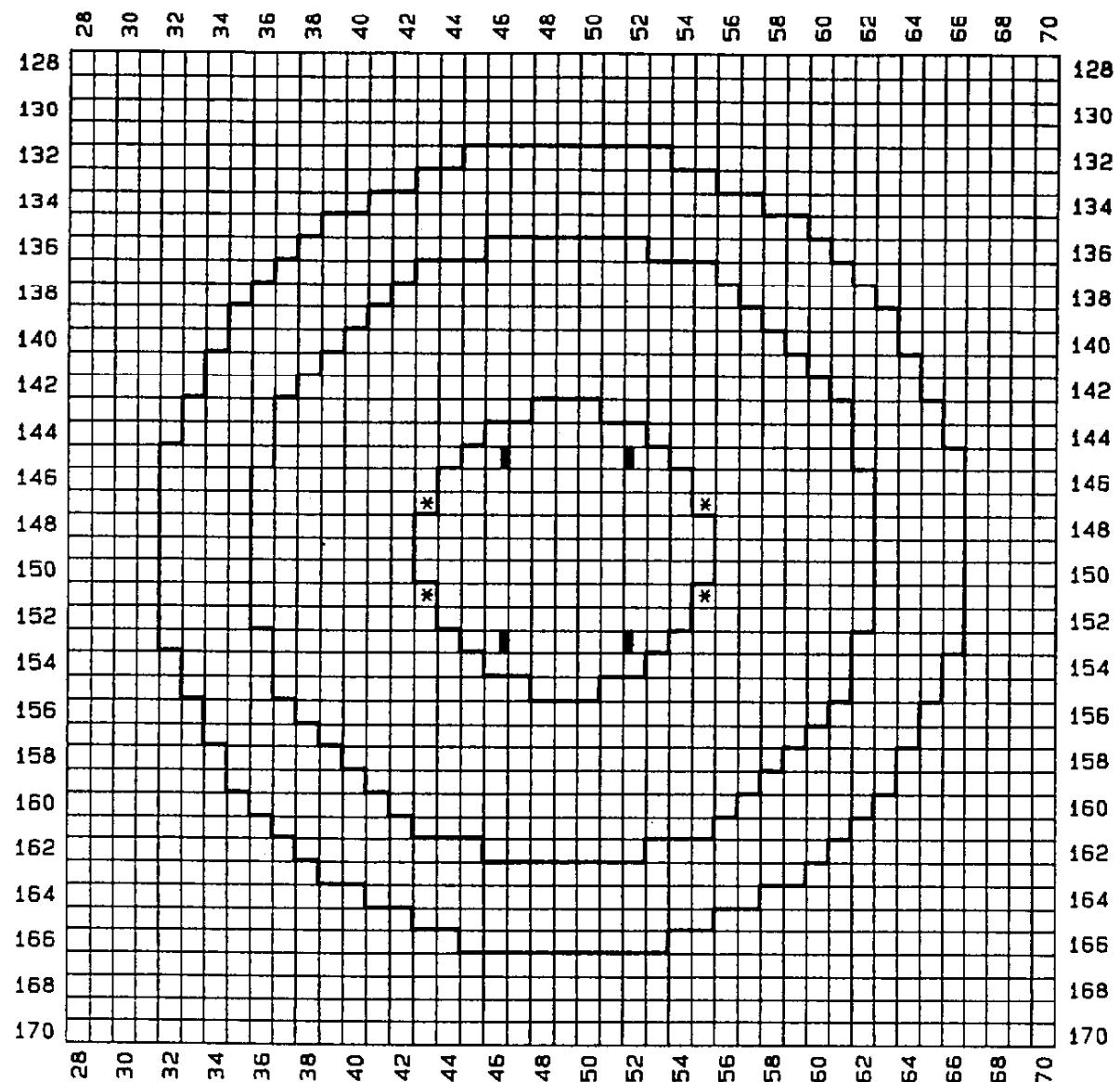
Assembly Details:

Type:	Clean, cylindrical, single-zone core
Fuel:	Pu/U oxide with sodium cooling, identical to ZPPR-11
Critical Mass:	250 kg (Pu^{239} + Pu^{241})
Volume:	340 liters
Blanket:	Solid U_3O_8
Reactivity Adjustment:	None

Assembly Variants:

There were no phases to ZPPR-12; however, there were several significant configurations. These included:

- total sodium voiding of the core
- plate arrangement to give enhanced neutron streaming
- plate arrangement to give reduced neutron streaming
- pin zone on core periphery
- pin zone at core center
- ZPPR-12 MB. The U_3O_8 blanket was removed and a depleted uranium (DU) blanket added to determine the effect on criticality.



* PARTIAL LENGTH FUEL DRAWER

±10 INCHES IN SUBCRITICAL REFERENCE

±13 INCHES IN CRITICAL REFERENCE

Fig. 60. Interface Diagram for ZPPR-12

ZPPR-13

Large radial heterogeneous core. JUPITER-II Program.

Overview:

Assembly 13 was focused on studying the properties of radial heterogeneous cores of about 700 MWe size. It consisted of six variants ranging from a clean, cylindrical physics benchmark to a hexagonal engineering benchmark. Sensitivity of the power shapes to decoupling of the core's zone was a key issue. Some flux asymmetries observed in this assembly due to small asymmetries in the assembly structure.

Assembly Dates:

June 1982-July 1984

Related Assemblies:

ZPPR-7 which was the series of radial heterogeneous cores of Clinch River Breeder Reactor (CRBR) size. ZPPR-9 and ZPPR-10 which comprised the JUPITER-I Program, a cooperation between the Power Reactor and Nuclear Fuel Development Corporation (PNC) and Argonne National Laboratory/Department of Energy (ANL/DOE).

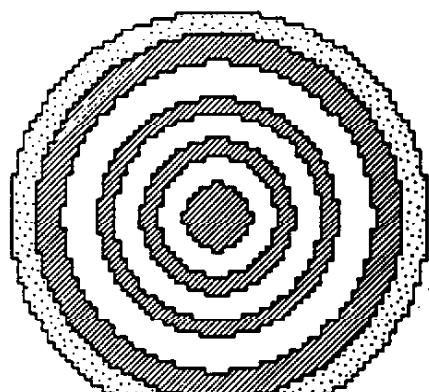
Assembly Details (All Phases):

Type: Large, radial heterogeneous, both physics and engineering benchmark configurations
Fuel: Typical Pu/U oxide with sodium cooling
Critical Mass: About 2500 kg (Pu^{239} + Pu^{241})
Volume: About 4000 liters

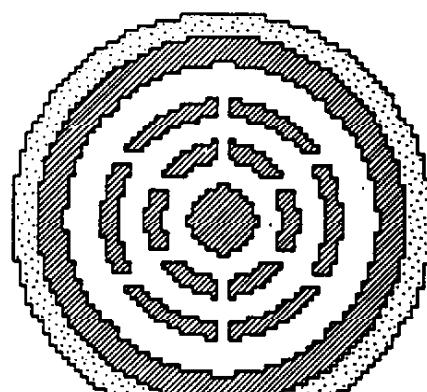
Assembly Variants:

Phase A: Clean, cylindrical, radial heterogeneous physics core with continuous internal blanket rings.
Phase B/1: Gaps introduced into the internal blanket rings (broken circular).
Phase B/2: Configuration made more hexagonal (broken hexagonal).
Phase B/3: Some isolated blanket subassemblies added to core regions in Phase B/2.
Phase B/4: Control rods positions (CRPs) added to Phase B/3.
Phase C: Load back to continuous internal blanket rings in a snowflake configuration.
Phase D: Not part of the JUPITER program. Configuration same as Phase C. Specialty control rod measurements, some plutonium buildup in blankets, radial expansion effects and helium production in CR.

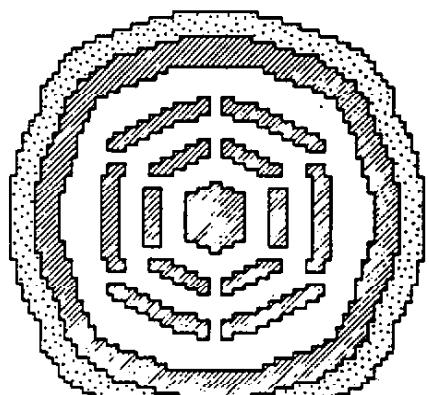
A80



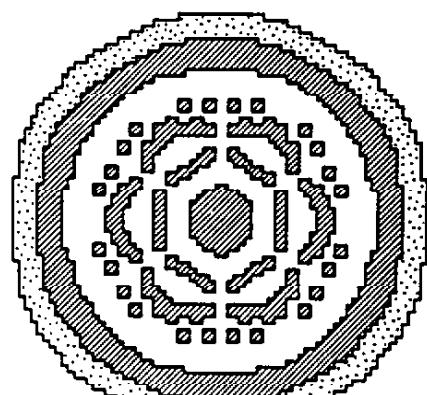
■ BLANKET ■ REFLECTOR
ZPPR - 13 A



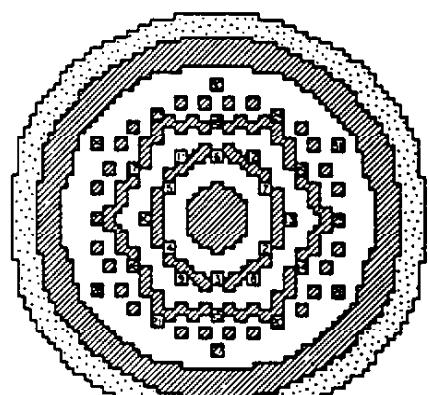
■ BLANKET ■ REFLECTOR
ZPPR - 13 B/1



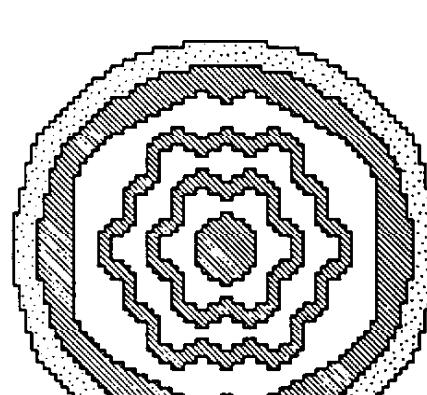
■ BLANKET ■ REFLECTOR
ZPPR - 13 B/2



■ BLANKET ■ REFLECTOR
ZPPR - 13 B/3



■ BLANKET ■ REFLECTOR
■ CONTROL ROD POSITION
ZPPR - 13 B / 4



■ BLANKET ■ REFLECTOR
ZPPR - 13 C

Fig. 61. Interface Diagram for ZPPR-13, Phases A through C

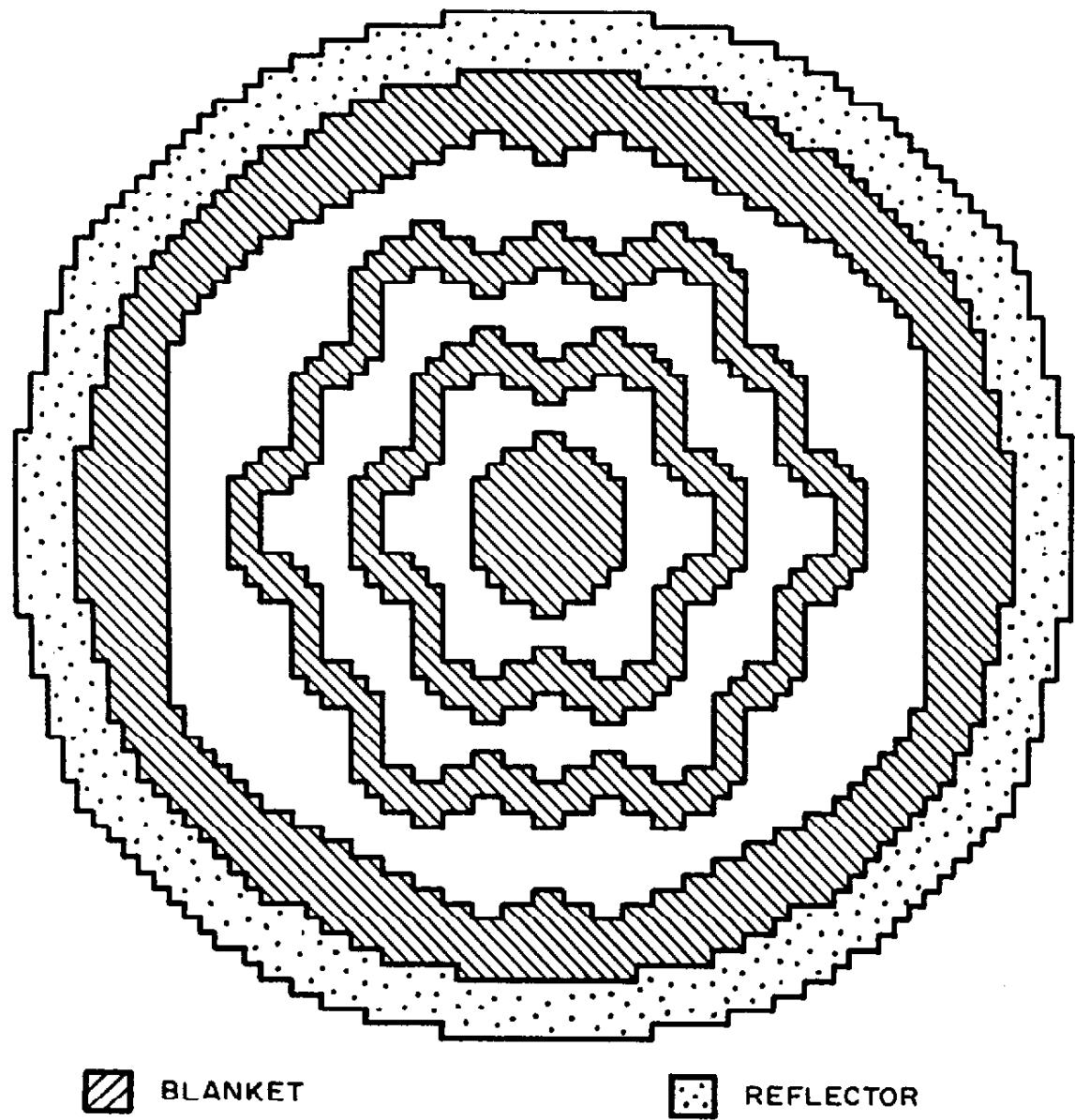


Fig. 62. Interface Diagram for ZPPR-13, Phase C

A82

ZPPR-14

Small beryllium oxide reflector controlled assembly.

Overview:

Small assembly (about 10 MWe size) to evaluate the use of beryllium oxide (BeO) radial reflector to control the reactor. The radial reflector segments moved axially.

Assembly Dates:

January 1985-February 1985

Related Assembly:

None

Assembly Details:

Type:	Clean, cylindrical, two-zone core
Fuel:	Typical uranium oxide with sodium cooling; fairly high enrichment. Some plutonium added to core to provide a neutron source for control purposes.
Critical Mass:	500 kg U ²³⁵ + 30 kg Pu ²³⁹
Volume:	600 liters
Reactivity Adjustment:	None
Control Reflector:	Be metal + graphite used to simulate BeO

Assembly Variants:

Phase A: End of cycle (EOC) core. Fully inserted control reflector.

Phase B: Middle of cycle (MOC) core. Reflectors half inserted axially.

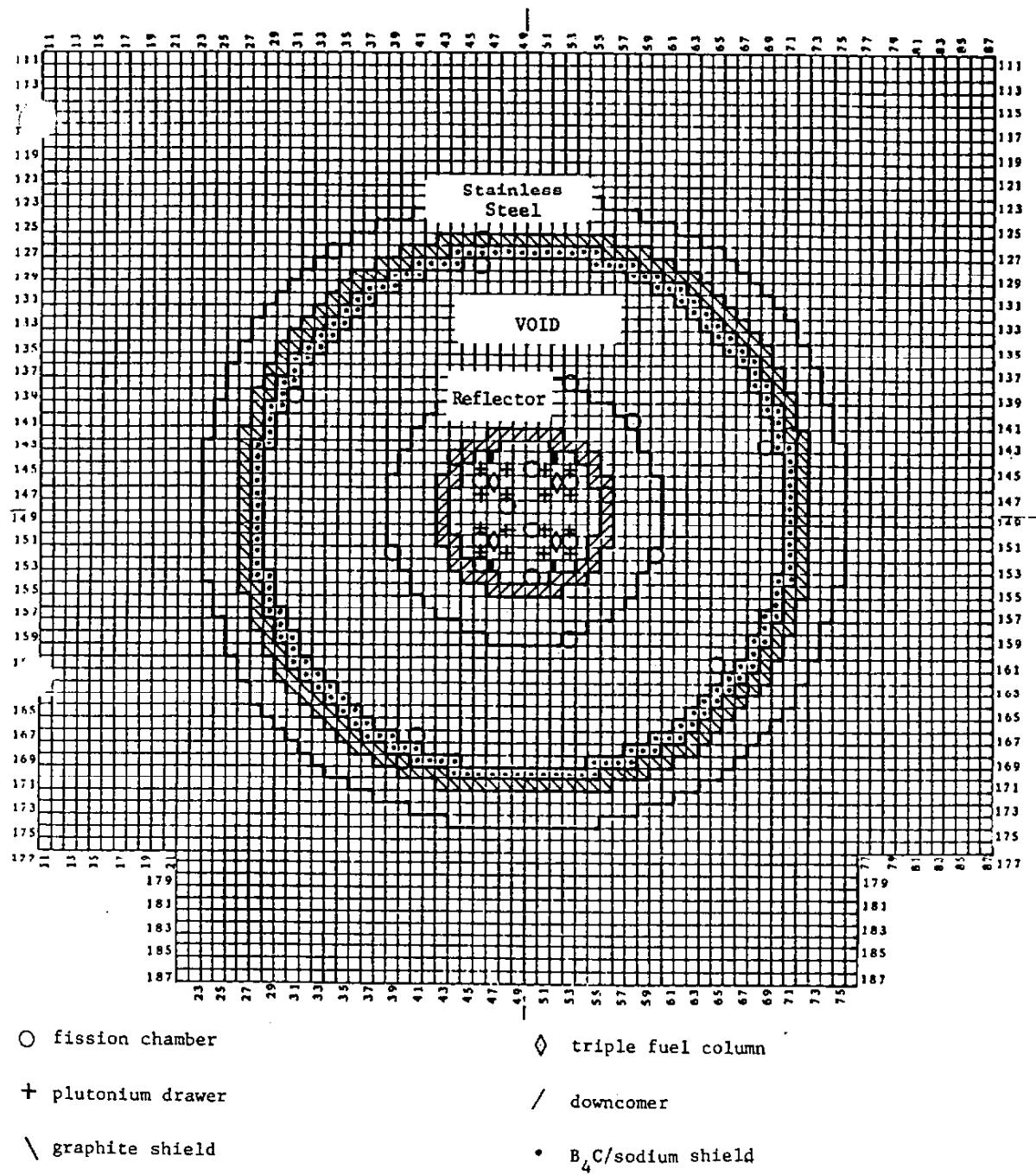


Fig. 63. Interface Diagram for ZPPR-14, Phase A

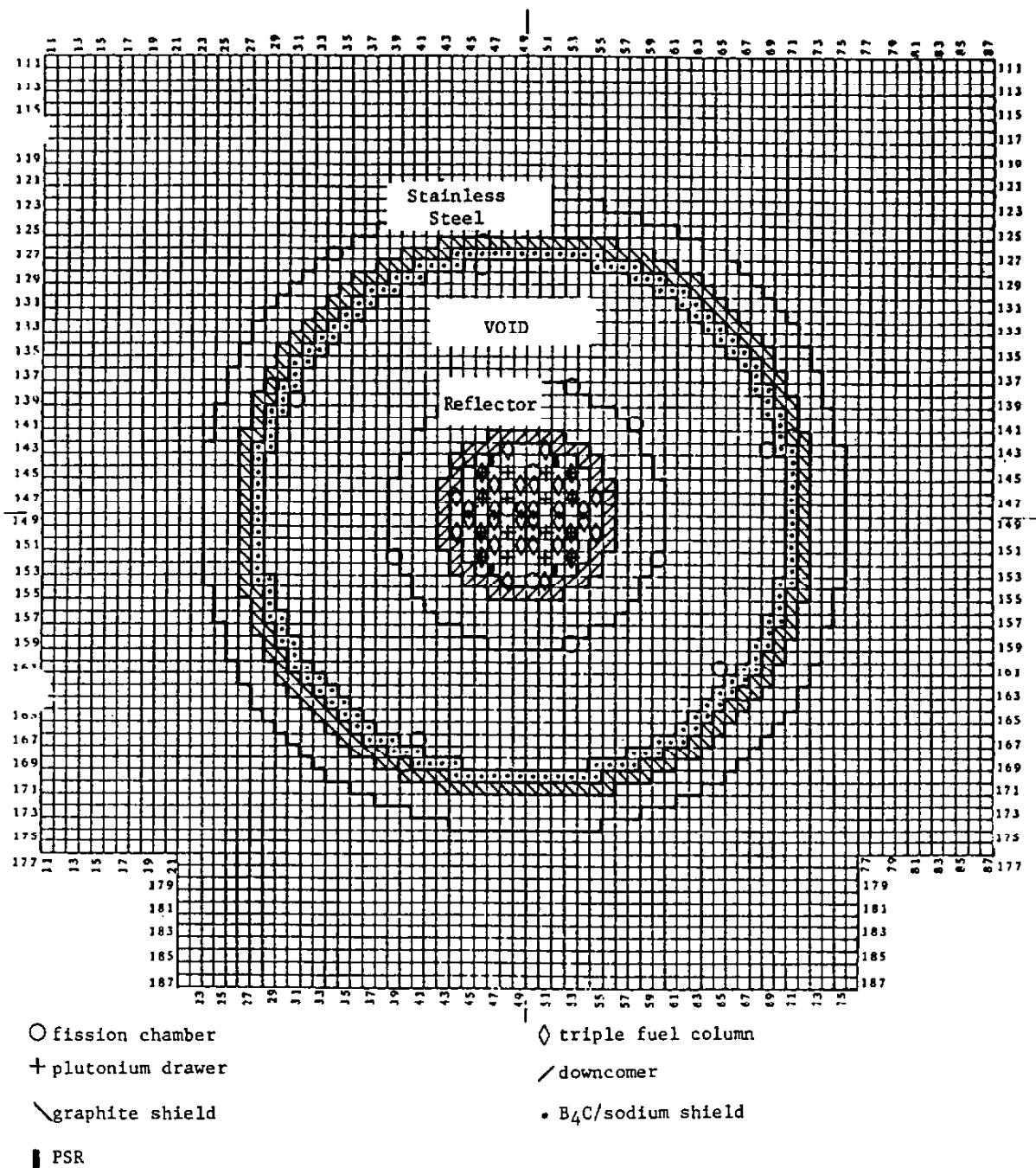
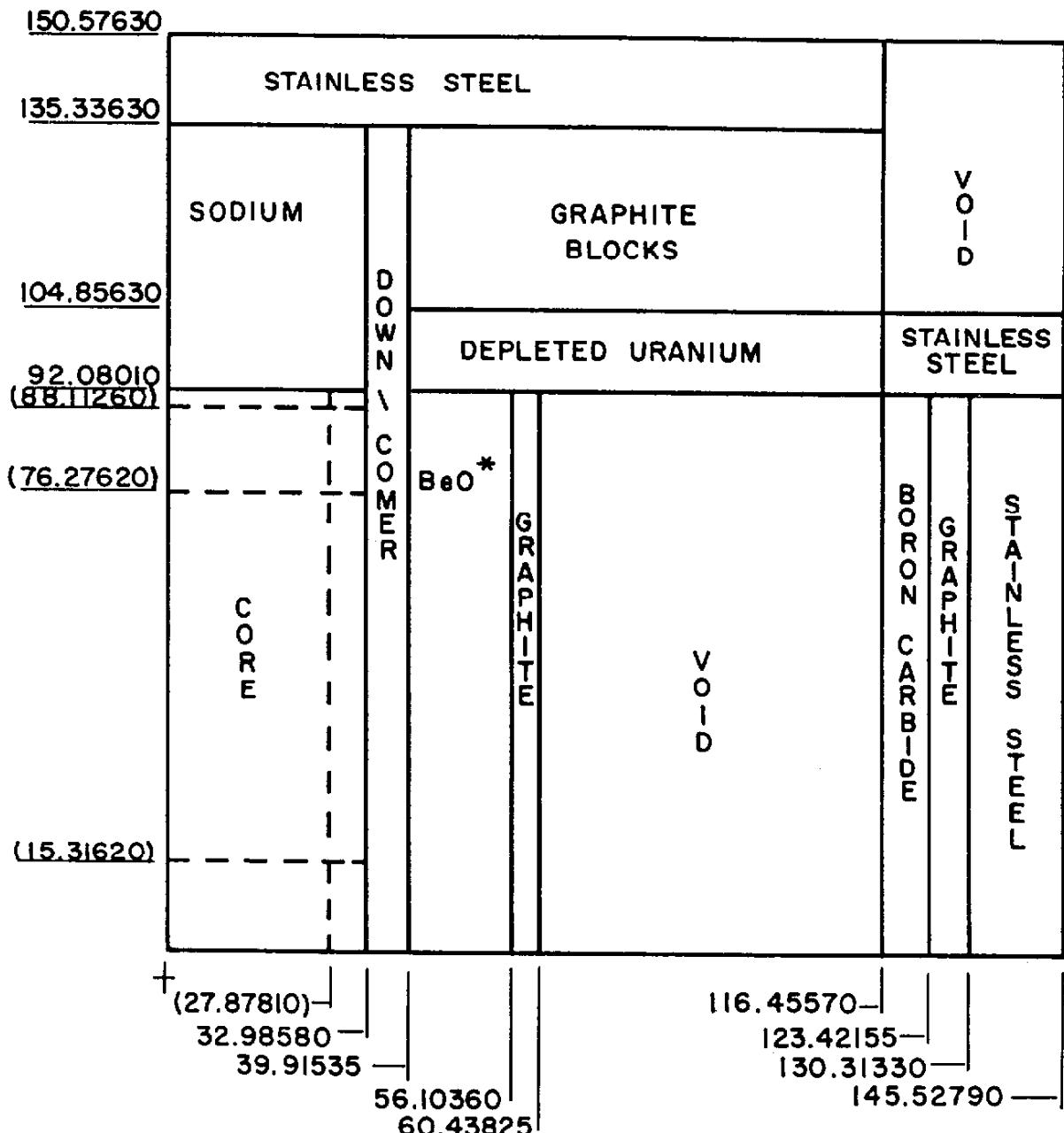


Fig. 64. Interface Diagram for ZPPR-14, Phase B



* 0.20 Volume fraction Be metal drawers.

Fig. 65. R-Z Model for ZPPR-14, Phase A

ZPPR-15

Metal fuel physics benchmark related to the Integral Fast Reactor (IFR) Program.

Overview:

Clean, two zone, circular physics core of about 330 MWe size with IFR type metallic fuel composition. This is the first ZPPR that did not simulate oxide fuel. The focus of the program was to provide experimental support for metal fuel designs. Test included radial and axial expansion effects and the use of a B_4C radial shield.

Assembly Dates:

April 1985-July 1986

Related Assemblies:

None

Assembly Details:

Type:	Clean, circular, two-zone configuration
Fuel:	IFR type Pu/U/Zr metal fuel with sodium cooling. No Zr in Phase A.
Critical Mass:	1170 kg (Pu^{239} + Pu^{241})
Volume:	2500 liters
Blanket:	Depleted uranium (DU) with sodium cooling

Assembly Variants:

Phase A:	A clean physics assembly containing only plutonium, depleted uranium, stainless steel and sodium.
Phase B:	Zirconium (Zr) added to the core composition. Representative of mature equilibrium cycle core.
Phase C:	Transition core. About half the core fueled with enriched uranium and half fueled with plutonium.
Phase D:	Near beginning-of-life (BOL) core, with 90% of core fueled with enriched uranium. Critical mass is now about 1520 kg U^{235} and 140 kg (Pu^{239} + Pu^{241}).

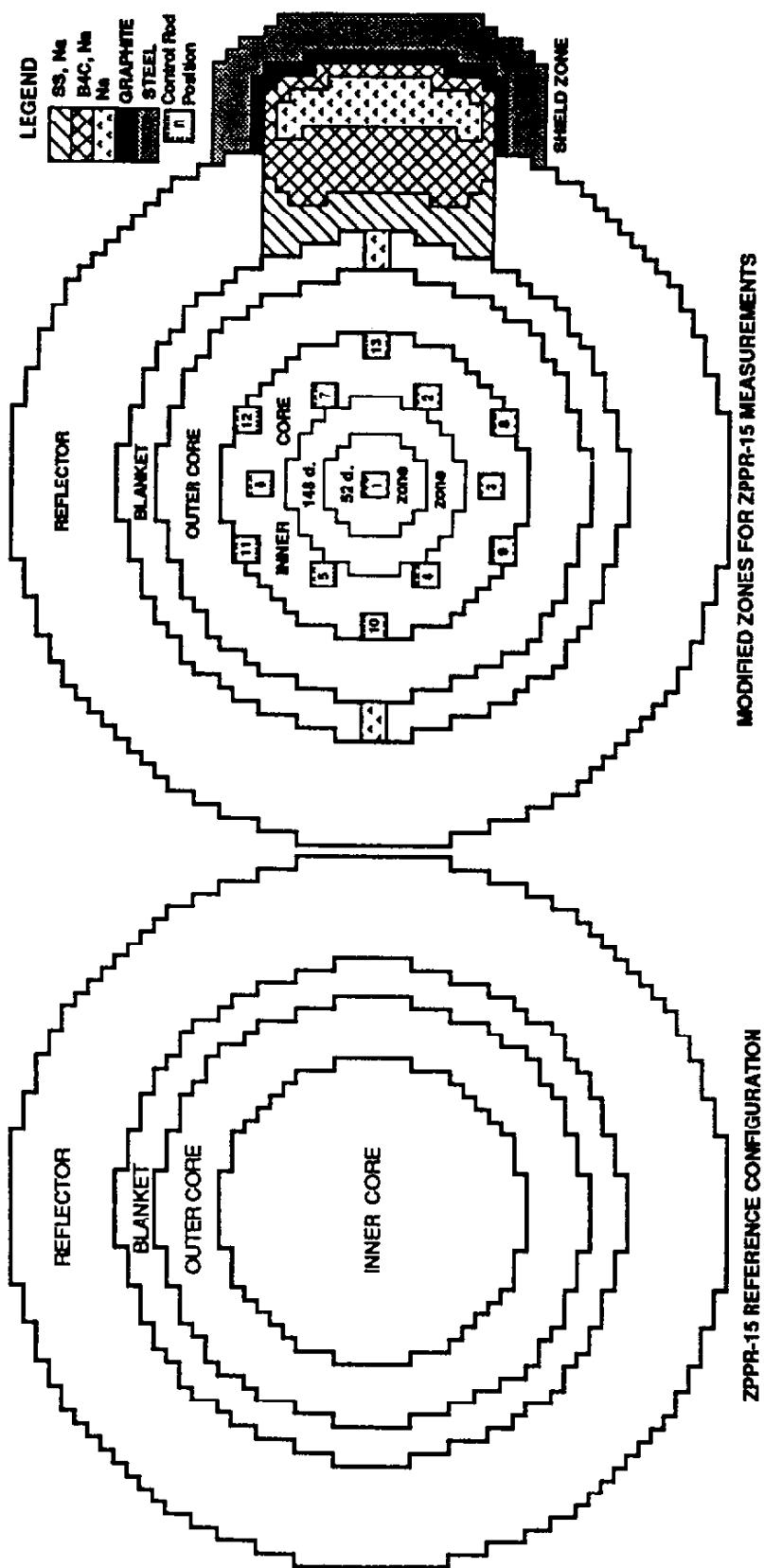
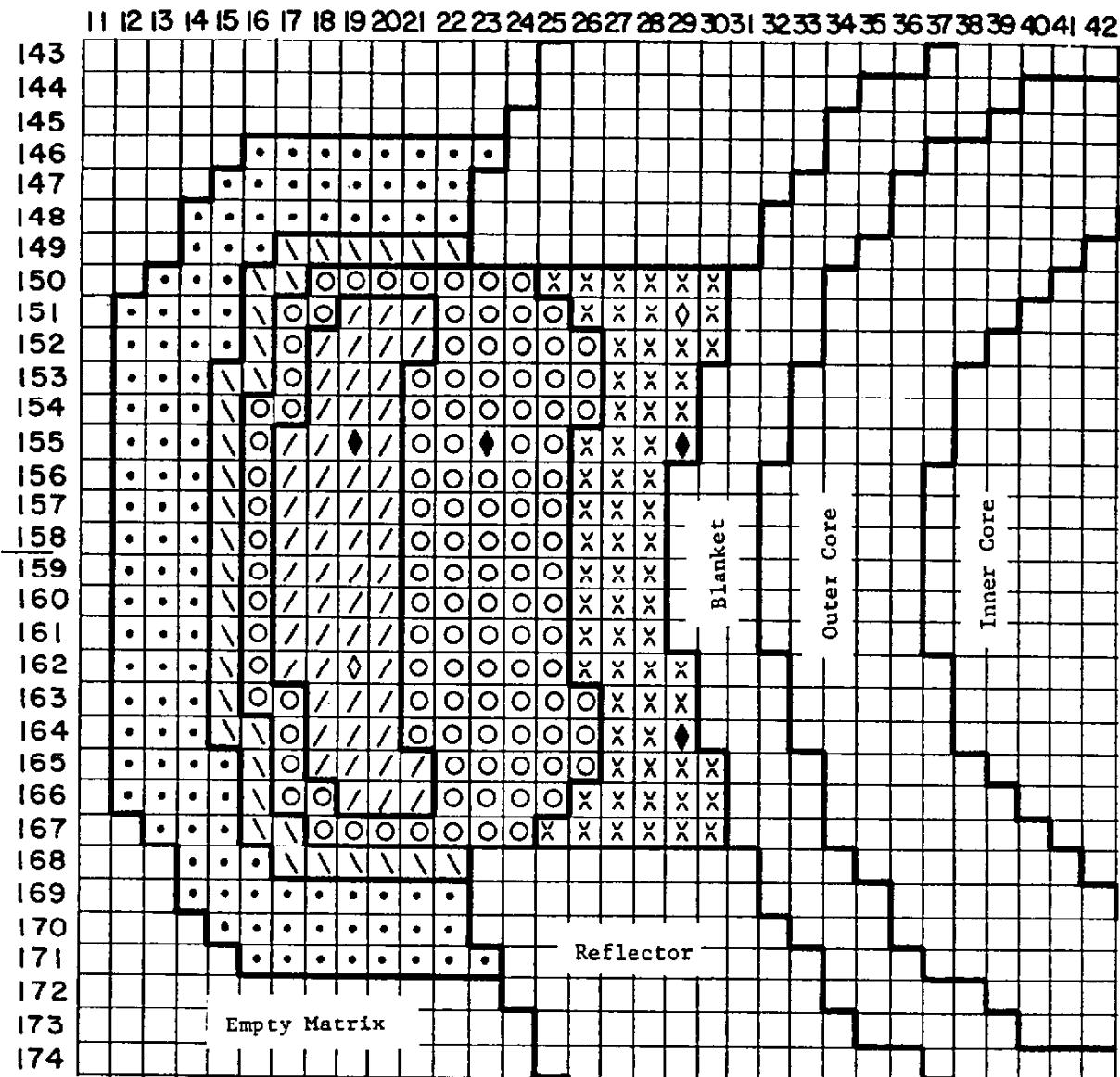


Fig. 66. Interface Diagrams for ZPPR-15 Reference and Modified Configurations



- | | | | |
|-------------------------------------|----------------------------|-------------------------------------|------------------------|
| <input checked="" type="checkbox"/> | Stainless Steel and Sodium | <input type="checkbox"/> | Mild Steel |
| <input type="circle"/> | Natural B_4C and Sodium | <input checked="" type="checkbox"/> | Half 1 Fission Chamber |
| <input checked="" type="checkbox"/> | Sodium | <input checked="" type="checkbox"/> | Half 2 Fission Chamber |
| <input checked="" type="checkbox"/> | Graphite | | |

Fig. 67. Interface Diagram for ZPPR-15, Phase B Shielding Experiment

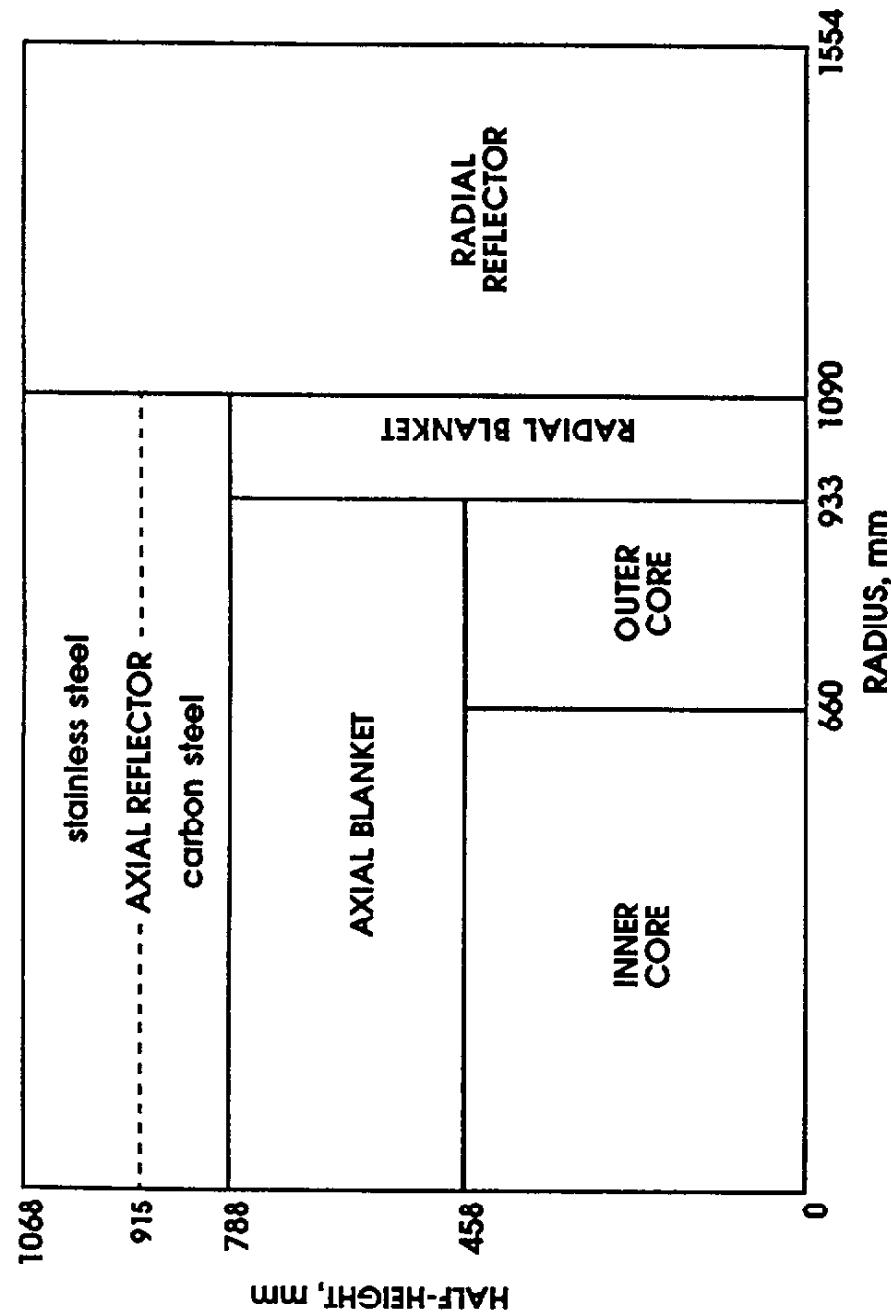


Fig. 68. R-Z Model for ZPPR-15

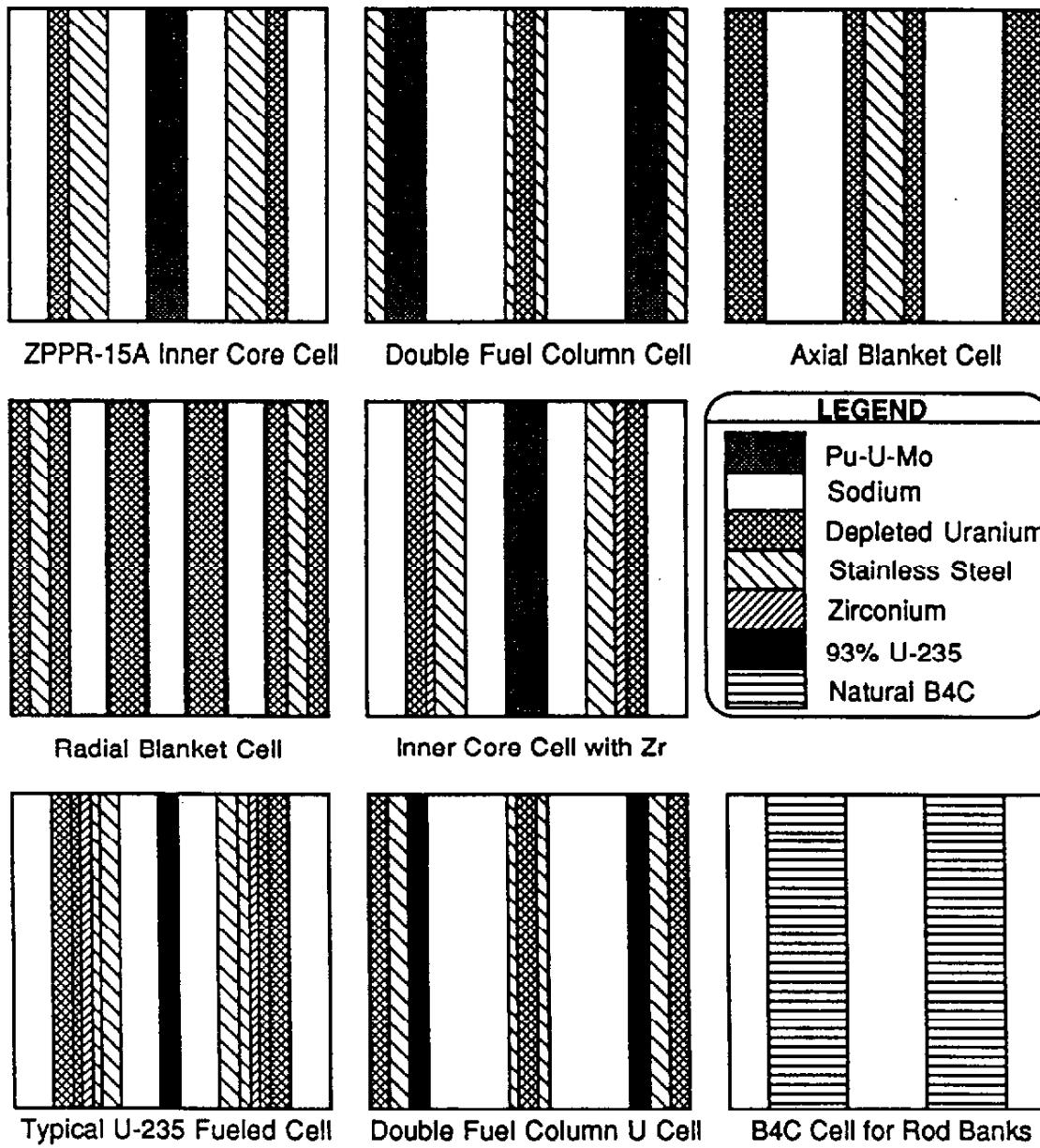


Fig. 69. Drawer Loading Patterns for ZPPR-15

A92

SP-100 Space Power Reactor--300 kWe.

Overview:

Simplified mockup of the 300 kWe SP-100 Space Power Reactor design, with three radial and two axial enrichment zones and in-core control rods (CRs).

Assembly Dates:

September 1986-December 1986

Related Assemblies:

ZPPR-20 was a study of the 100 MWe SP-100 design.

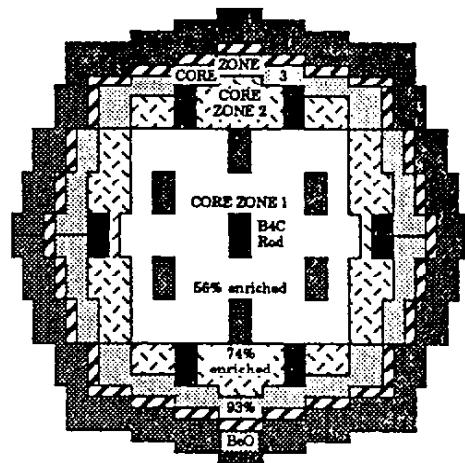
Assembly Details (Phase A):

Type: Space reactor mockup with six enrichment zones, internal B_4C CRs and a BeO external reflector.
Fuel: Enriched uranium (EU), C, Nb, SS with sodium cooling (enrichments 56%-93% in Phase A, 37%-74% in other phases)
Critical Mass: 332 kg U^{235}
Volume: 165 liters
Reflector: Radial BeO

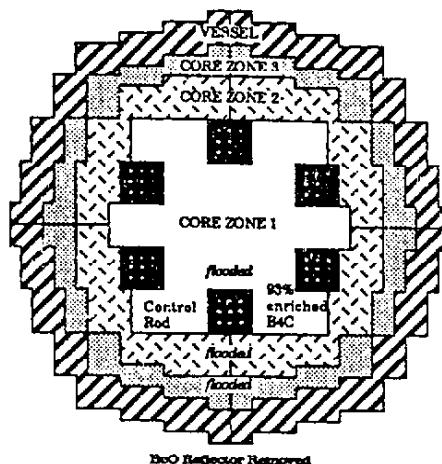
Assembly Variants:

Phase A: Seven B_4C CRs in core and six BeO CR followers in core. Thin vessel.
Phase B: Six BeO CR followers in core. No CRs in core. Thick vessel.
Phase C: Configuration like Phase B but six B_4C CRs inserted, CH_2 replaces Na in core and fills the plenum 6 in. above the core. This is the flooded configuration.

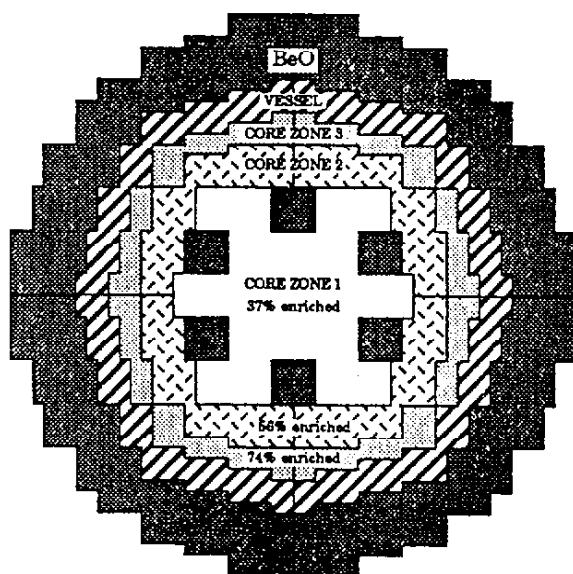
Note: Phase C was critical with no radial reflector. Also worth measurements of many constituent and refractor materials included in program.



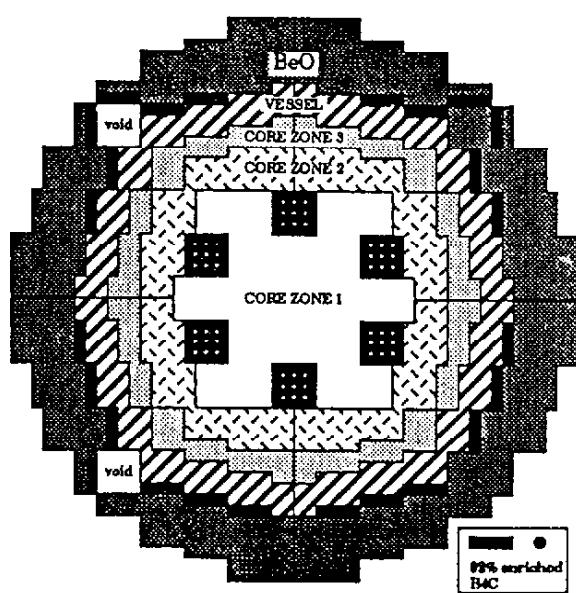
ZPPR-16A REFERENCE CONFIGURATION



ZPPR-16C REFERENCE CONFIGURATION



ZPPR-16B REFERENCE CONFIGURATION



ZPPR-16B CONTROL WORTH MEASUREMENTS

Fig. 70. Interface Diagrams for ZPPR-16 Configurations

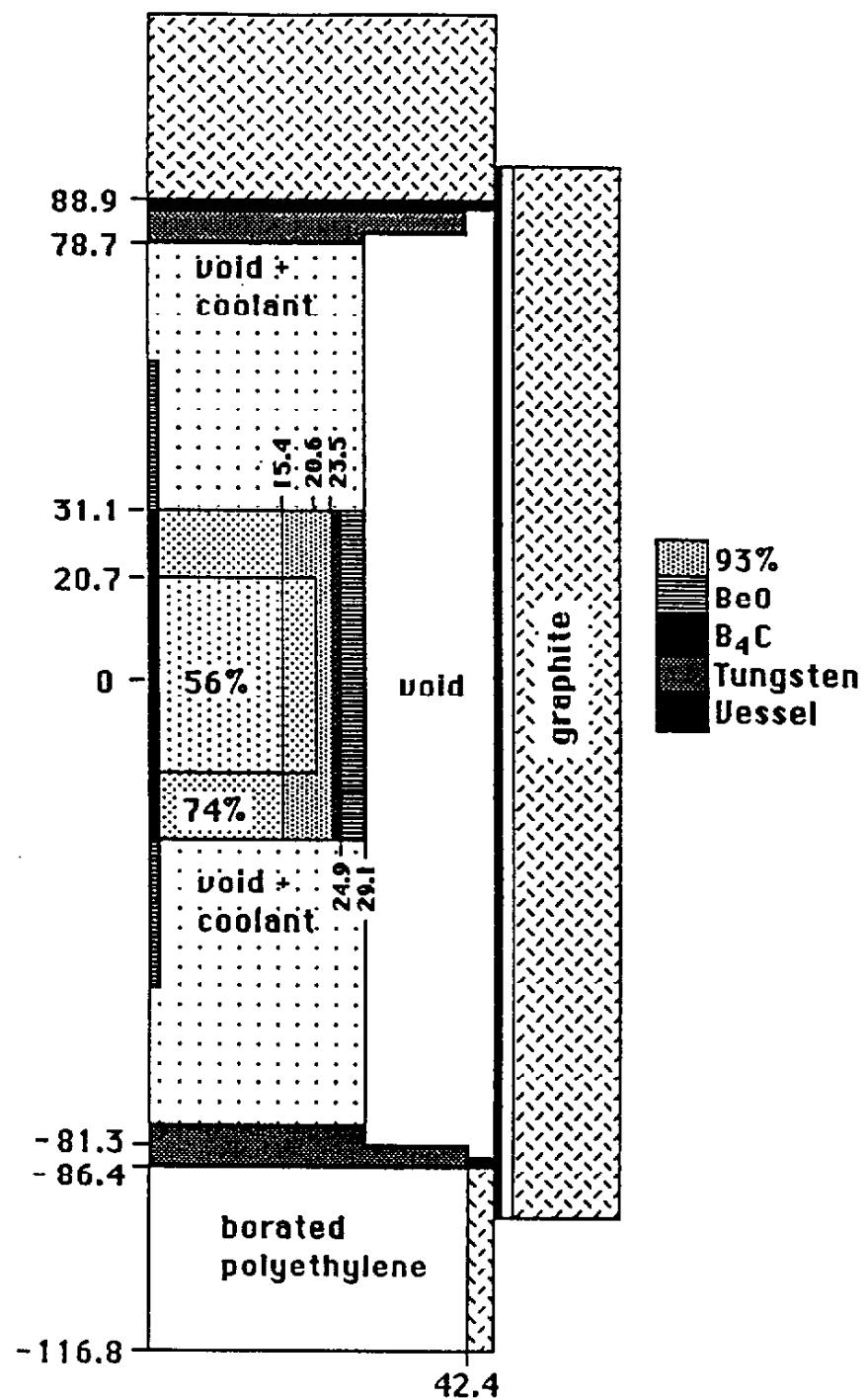


Fig. 71. R-Z Diagram for ZPPR-16, Phase A

ZPPR-17

Large, axial heterogeneous benchmark. Part of the JUPITER-III Program.

Overview:

This assembly was a large (700 MWe), cylindrical two-zone core with a single, axial heterogeneous internal blanket. The core was relatively flat ($H/D = 0.39$) and the internal blanket was a flat disk with $H/D = 0.17$. The measurements focused on evaluation of axial heterogeneous designs.

Assembly Dates:

January 1987-July 1987

Related Assemblies:

ZPPR-18 and ZPPR-19 were also part of JUPITER-III.

Assembly Details (Phase A):

Type:	Large, axial heterogeneous design
Fuel:	Typical Pu/U oxide with sodium cooling
Critical Mass:	$2270 (\text{Pu}^{239} + \text{Pu}^{241})$
Volume:	4700 liters
Blankets:	Depleted uranium (DU) with sodium cooling
Reactivity Adjustment:	Adjusting the ratio of single- and double-column fuel drawers

Assembly Variants:

- Phase A: Cylindrical physics benchmark with no control rods (CRs) or control rod positions (CRPs).
- Phase B: 25 CRPs added.
- Phase C: 13 half inserted CRs and 12 CRPs. Bowing reactivity measurements using new bowing simulation oscillator.

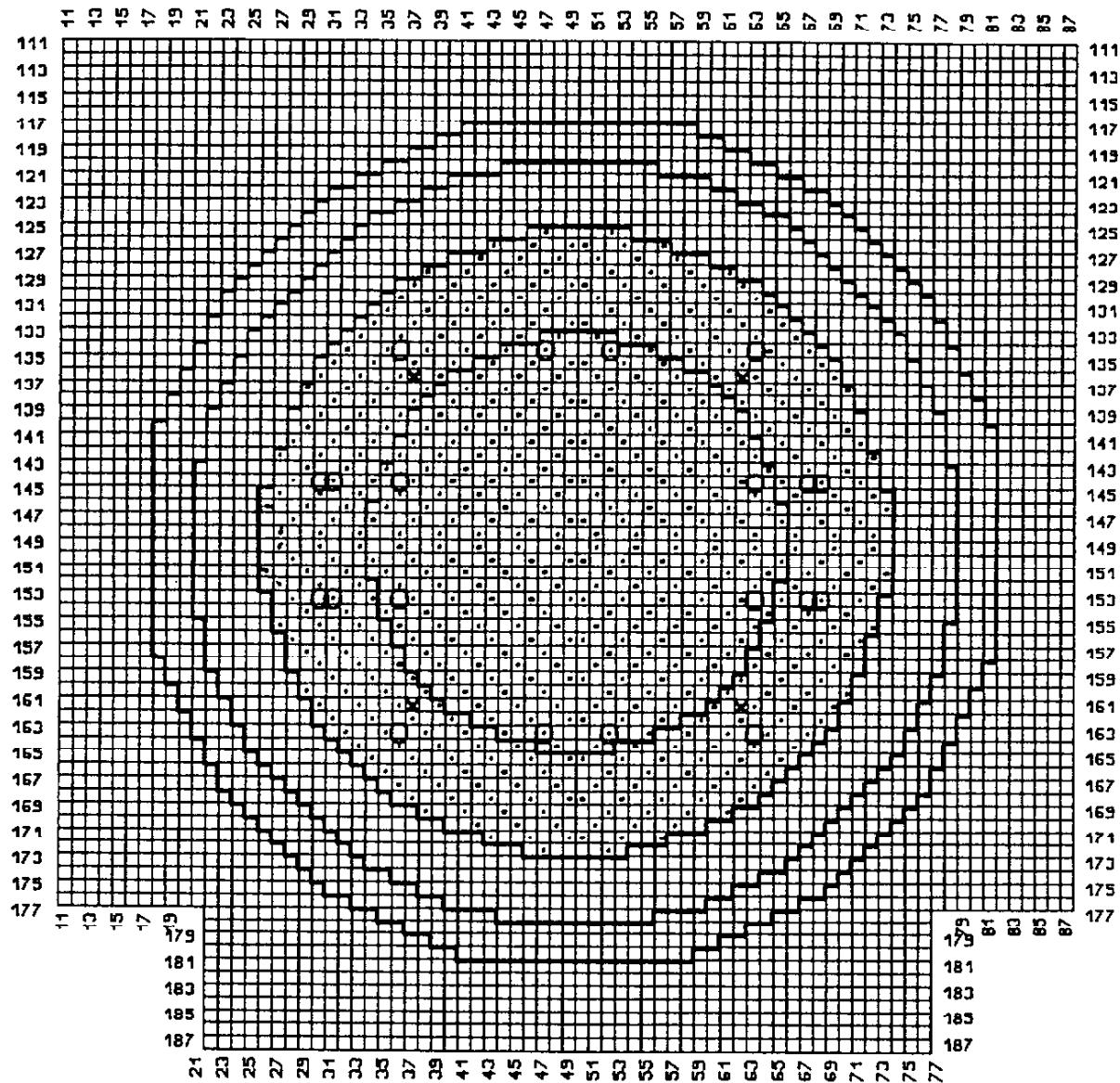


Fig. 72. Interface Diagram for ZPPR-17, Phase A

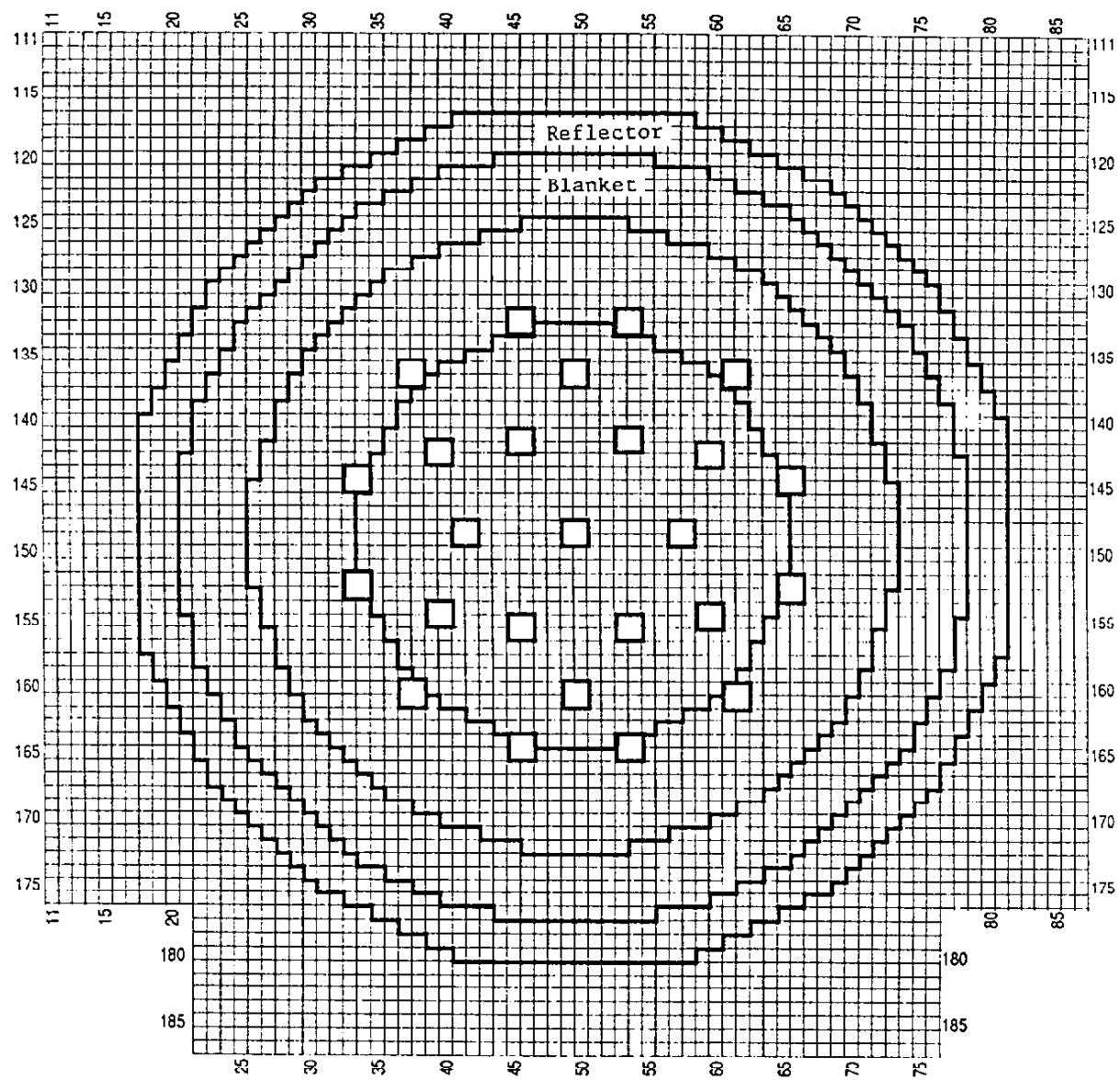


Fig. 73. Interface Diagram for ZPPR-17, Phase B

A100

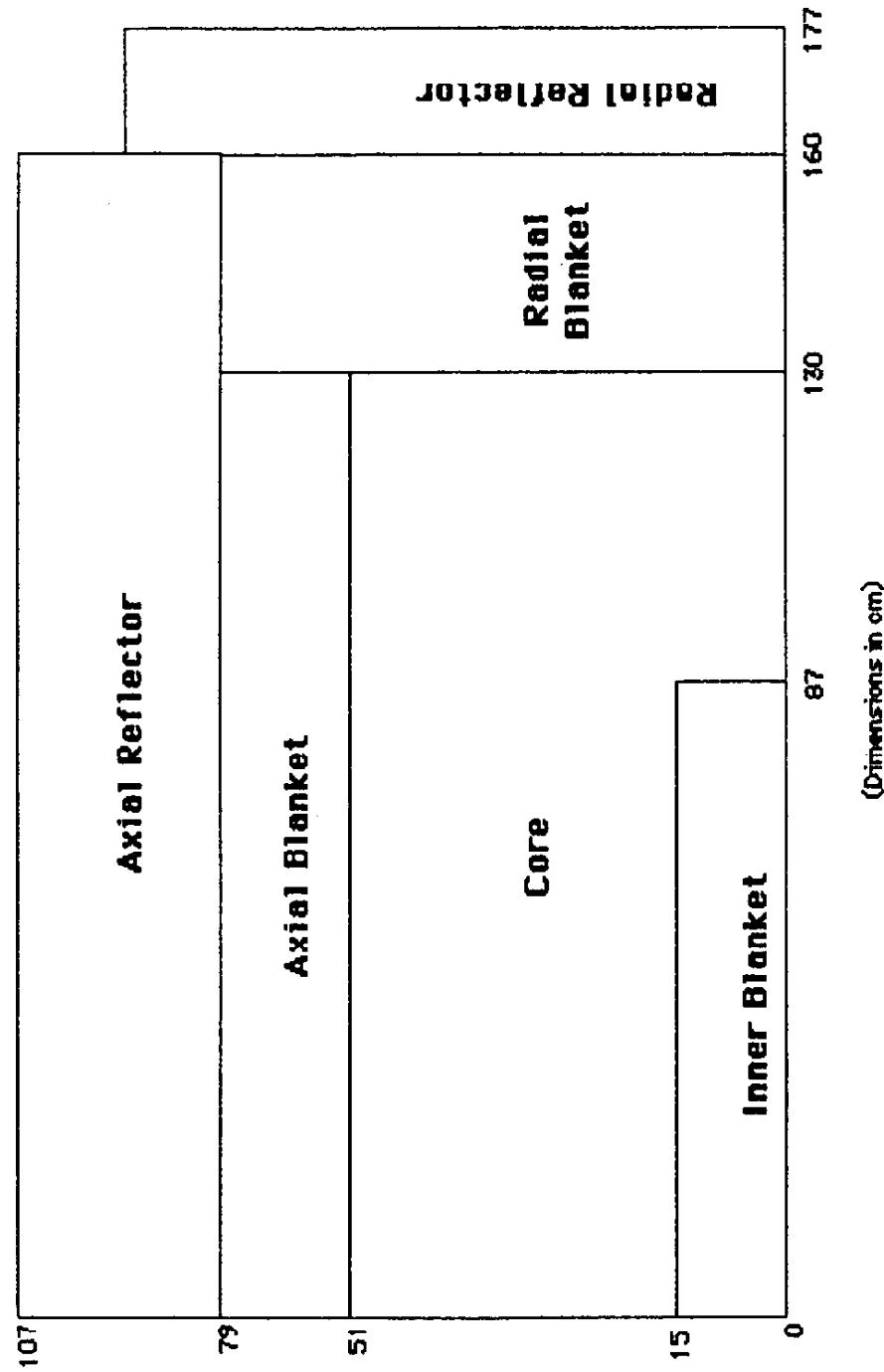


Fig. 74. R-Z Model for ZPPR-17

ZPPR-18

Engineering benchmark for very large (1200 MWe) conventional design. Part of the JUPITER-III Program.

Overview:

Very large, hexagonal, two-zone design assembly with control rods (CRs) and control rod positions (CRPs). Objective was to evaluate large conventional designs with emphasis on spatial distributions and CR patterns. This was the largest assembly ever built on ZPPR. It used both plutonium and enriched uranium fuel because the critical mass exceeded the ZPPR plutonium inventory.

Assembly Dates:

September 1987-December 1987

Related Assemblies:

ZPPR-17 and ZPPR-19 are the other JUPITER-III cores. ZPPR-10 is a similar design of about the 700-900 MWe size.

Assembly Details:

Type:	Large, hexagonal engineering benchmark with CRs and CRPs.
Fuel:	Typical Pu/U oxide with sodium cooling. About 60% of the outer core was loaded with an uranium oxide designed to match the reactivity of the Pu/U oxide fuel in the remainder of the outer core. The ZPPR plutonium inventory was exceeded with this assembly.
Critical Mass:	About 3500 kg (Pu^{239} + Pu^{241})
Volume:	8500 liters
Blanket:	Depleted uranium (DU) oxide with sodium cooling
Reactivity Adjustment:	Adjusting the ratio of single- and double-column fuel drawers

Assembly Variants:

- Phase A: 24 CRPs. Over 50 CR patterns measured in this phase.
- Phase B: 18 half inserted CRs, six CRPs.
- Phase C: One outer ring CR is removed to provide an asymmetrical pattern.

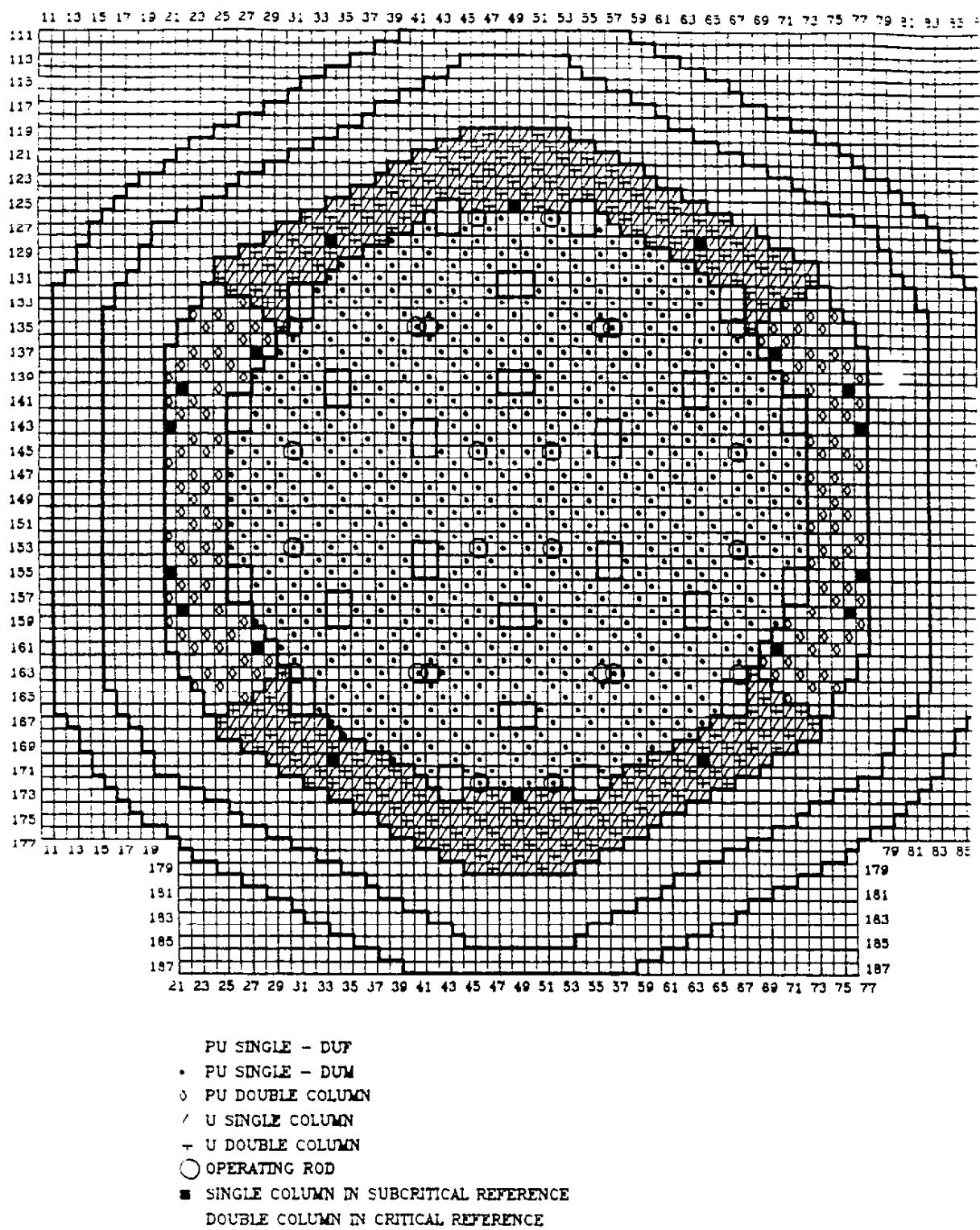


Fig. 75. Interface Diagram for ZPPR-18, Phase A

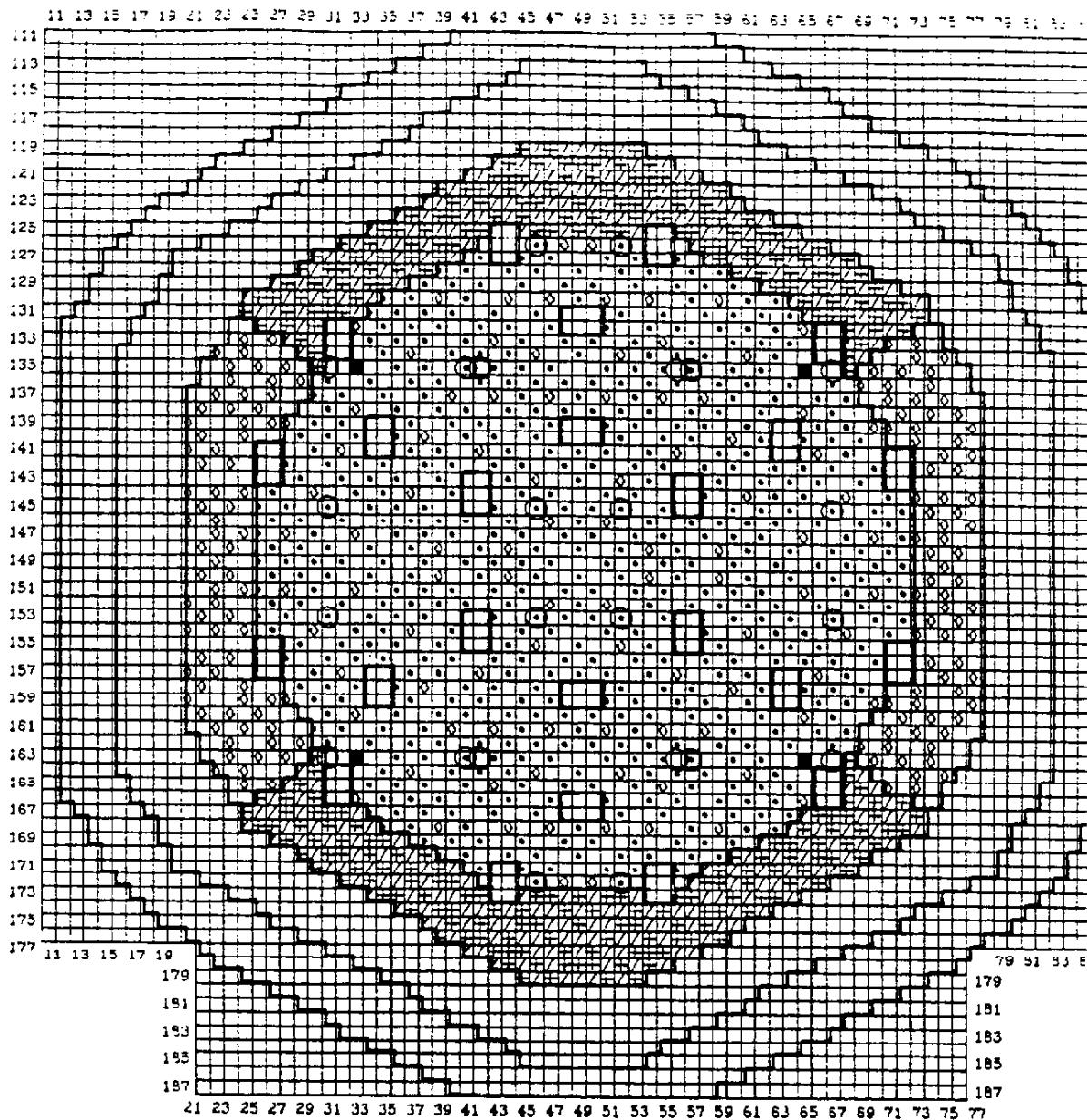


Fig. 76. Interface Diagram for ZPPR-18, Phase B

A104

ZPPR-19

Large conventional core similar to ZPPR-18. Part of JUPITER-III.

Overview:

This assembly was the same as ZPPR-18 but the measurement program focused on eigenvalue (ev) separation and spatial flux sensitivity effects.

Assembly Dates:

January 1988-February 1988

Related Assemblies:

ZPPR-17 and ZPPR-18 are also part of the JUPITER-III Program.

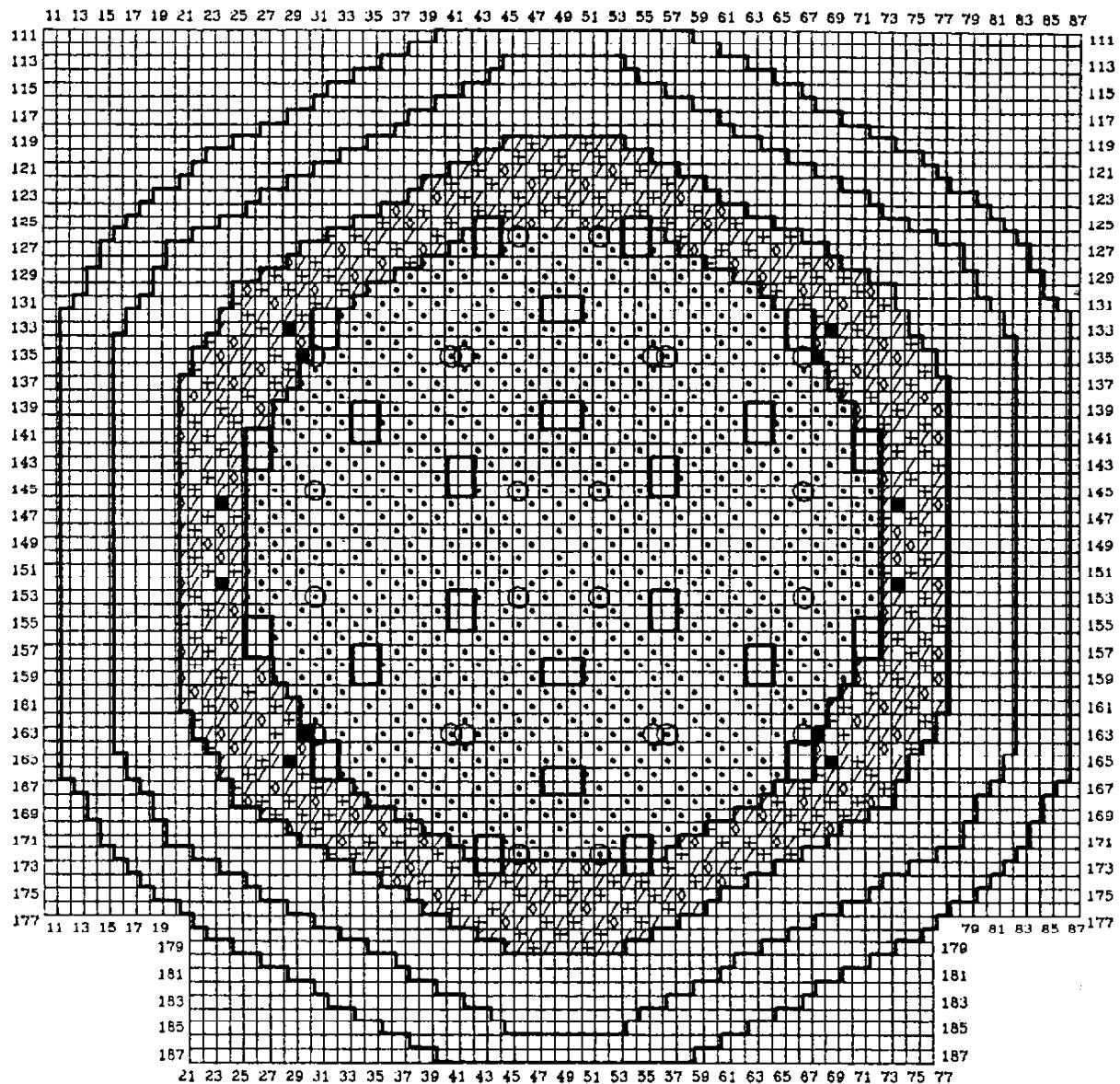
Assembly Details:

Same as ZPPR-18

Assembly Variants:

Phase A: Same as Phase A of ZPPR-18 except six inner core ring CRs. This reduced the ev separation by a factor of 2.

Phase B: Same as Phase A of ZPPR-18 except the Pu/U oxide and the U oxide fuel was mixed uniformly in the outer core rather than in sectors. No CRs in this phase.



- PU SINGLE - DUF
- PU SINGLE - DUM
- ♦ PU DOUBLE COLUMN
- / U SINGLE COLUMN
- + U DOUBLE COLUMN
- (O) OPERATING ROD
- SINGLE COLUMN IN SUBCRITICAL REFERENCE
- DOUBLE COLUMN IN CRITICAL REFERENCE

Fig. 77. Interface Diagram for ZPPR-19, Phase B

ZPPR-20

SP-100 Space Power Reactor--100 kWe.

Overview:

This assembly was a detailed, complex mockup of the SP-100 Space Power Reactor 100 kWe design. It included several materials not included in other ZPPR programs; rhenium, zirconium alloy, high purity Li⁷, lithium hydride and hafnium. Detailed reports on this assembly were not published.

Assembly Dates:

April 1988-January 1989

Related Assemblies:

ZPPR-16, the SP-100 Space Power Reactor 300 kWe design

Assembly Details:

Type:	Space reactor mockup
Fuel:	Uranium nitride. Poor simulation.
Critical Mass:	176 kg U ²³⁵
Volume:	36 liters

Assembly Variants:

Phase A: Reflector fully open.

Phase B: Reflector fully closed.

Phases A and B supported the ground engineering system--nuclear test assembly mockup.

Phase C: Near shield and vacuum vessel mockup removed. Room return shield moved inward. Measurements include flooding and water emersion.

Phase C supported the flight system. It is the reference configuration.

Phase D: Worth of CRs measured.

Phase E: Earth burial simulation. Surrounded by silica.

Phase F: Similar to Phases A and B. Measurements on operational instruments.

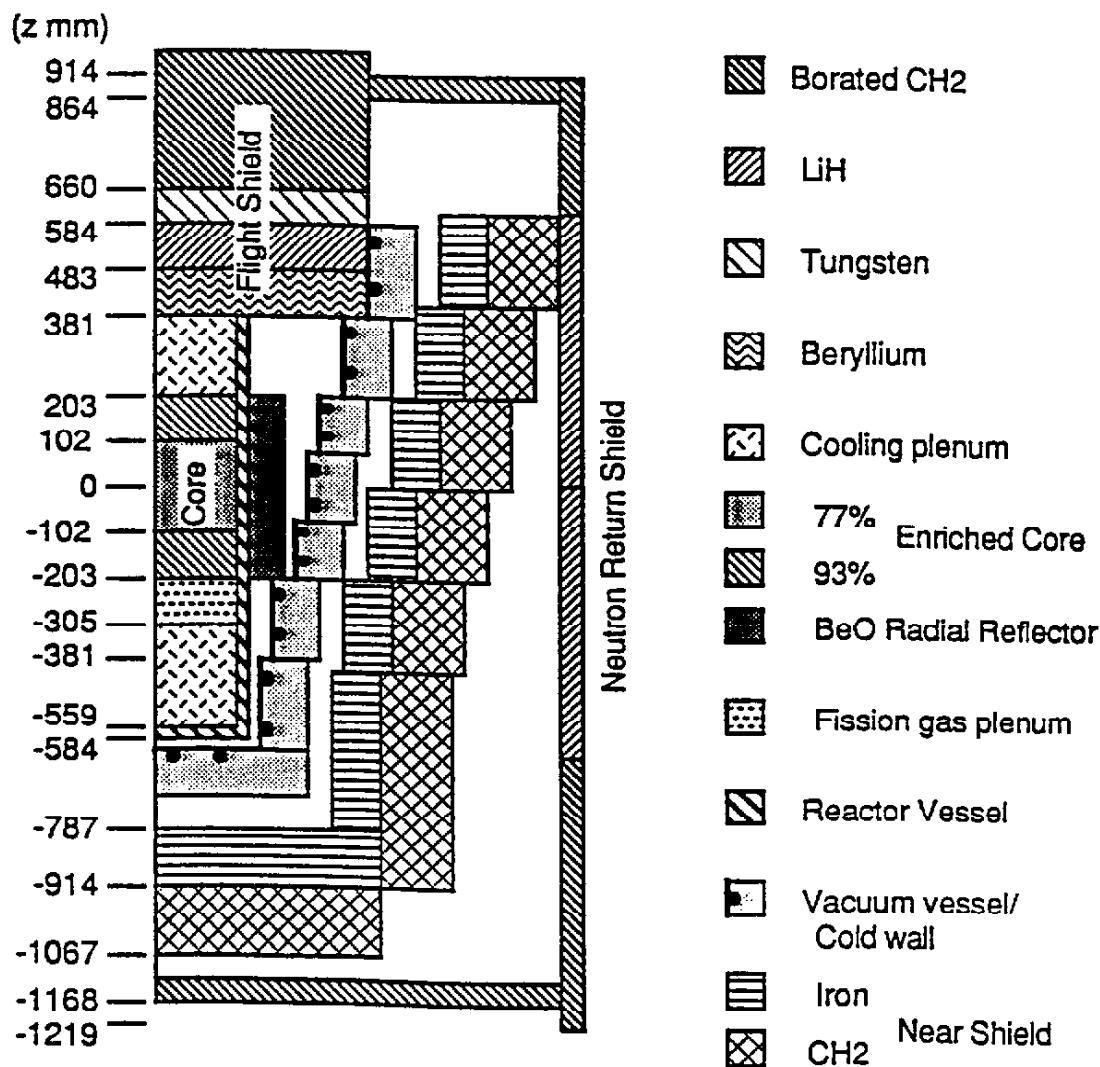


Fig. 78. Longitudinal Section of ZPPR-20, Phase B

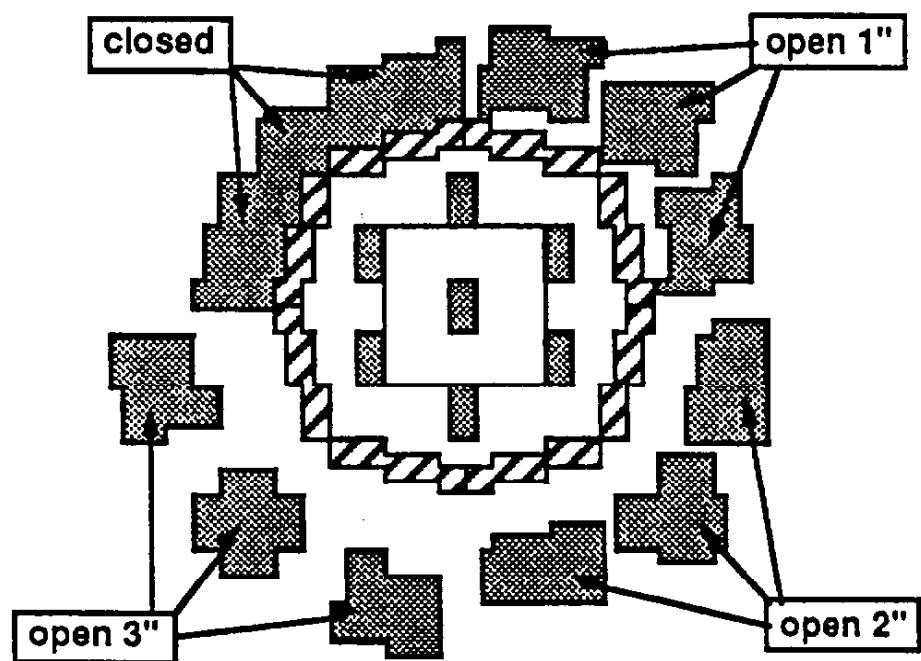
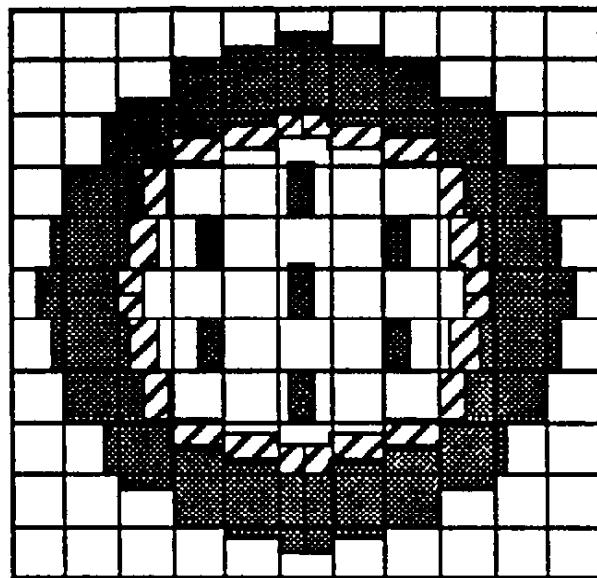


Fig. 79. Interface Diagrams for ZPPR-20, Phase C, with the BeO Radial Reflector Fully Closed and Partially Opened

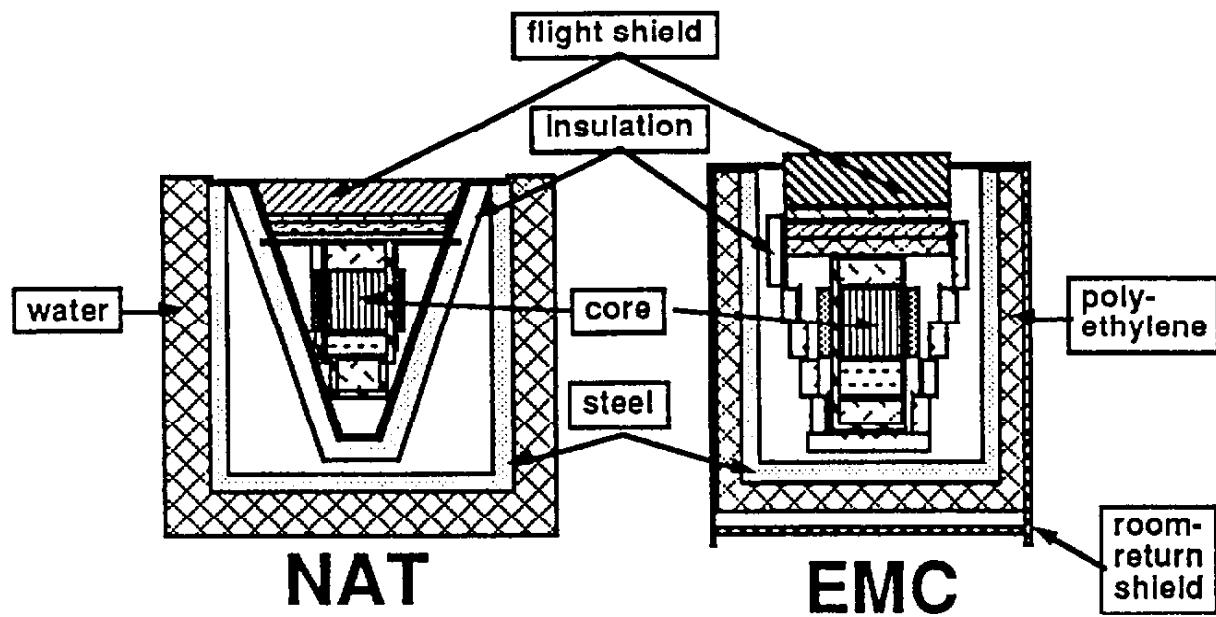


Fig. 80. Comparison of the Nuclear Test Assembly (NAT) for the Space Power-100 (SP-100) Reactor and ZPPR-20, Phase B, the Ground Test Engineering Mockup Core (EMC)

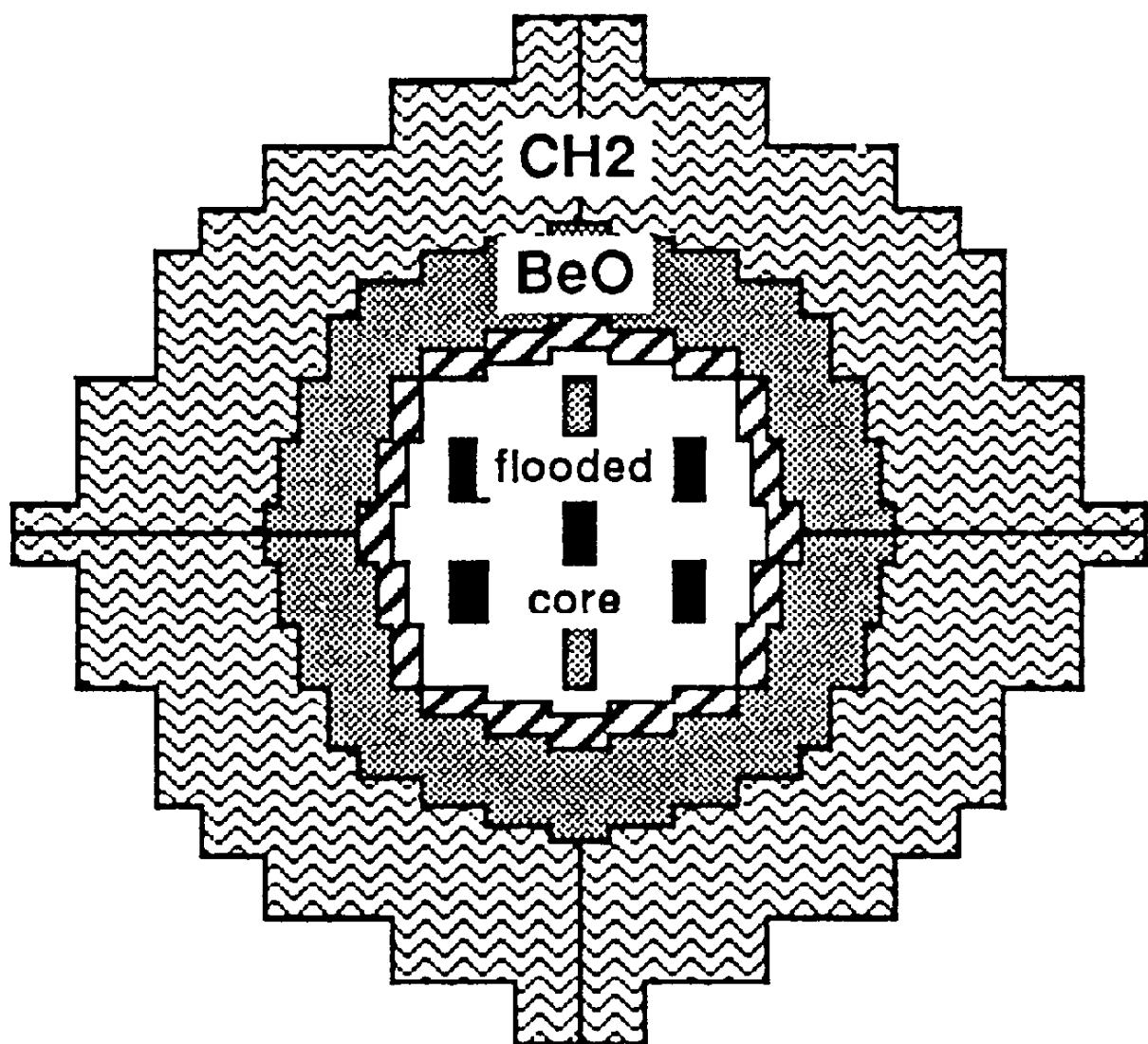


Fig. 81. Interface Diagram for ZPPR-20, Phase C, Water Immersion

A112

Criticality studies for Integral Fast Reactor (IFR) fuel types during the IFR fuel cycle.

Overview:

Six near critical assembly variants were investigated to support parts of the IFR fuel cycle.

Assembly Dates:

January 1990-September 1990

Related Assemblies:

None

Assembly Details:

Type: Simple, clean assemblies surrounded by a graphite reflector. The reflector thickness was varied to adjust each assembly to near critical. The core size was held constant.

Fuel: IFR fuel. In Phase A, the fissile was all Pu²³⁹ and Pu²⁴¹. In Phase F, the fissile was all U²³⁵ and the mixture varied in the intermediate phases.

Critical Mass: 95 kg Pu²³⁹ + Pu²⁴¹ in Phase A and 162 kg U²³⁵ in Phase F

Volume:

Reactivity Adjustment: Reflector thickness variation

Assembly Variants:

Phases A through F varied only in the exchange of U²³⁵ for fissile plutonium and in some adjustments in the reflector thickness.

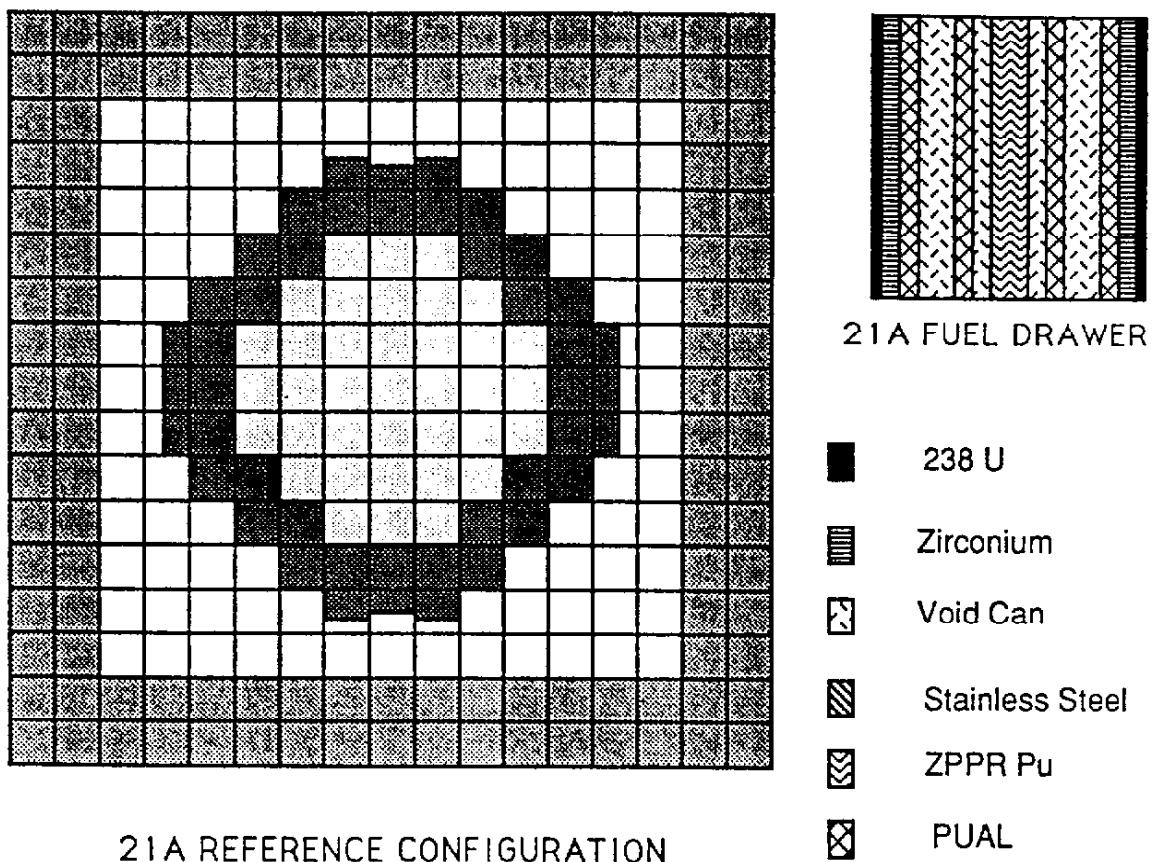


Fig. 82. Interface Diagram and Drawer Loading Pattern for ZPPR-21, Phase A

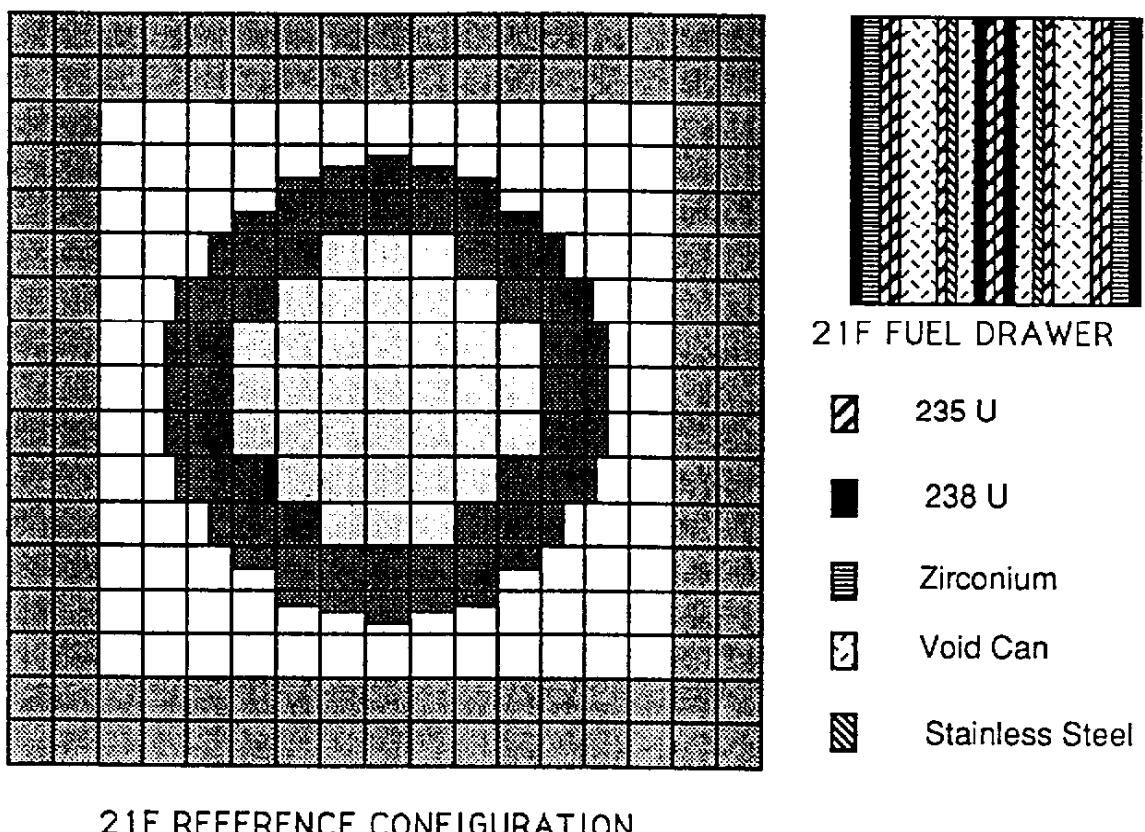


Fig. 83. Interface Diagram and Drawer Loading Pattern for ZPPR-21, Phase F

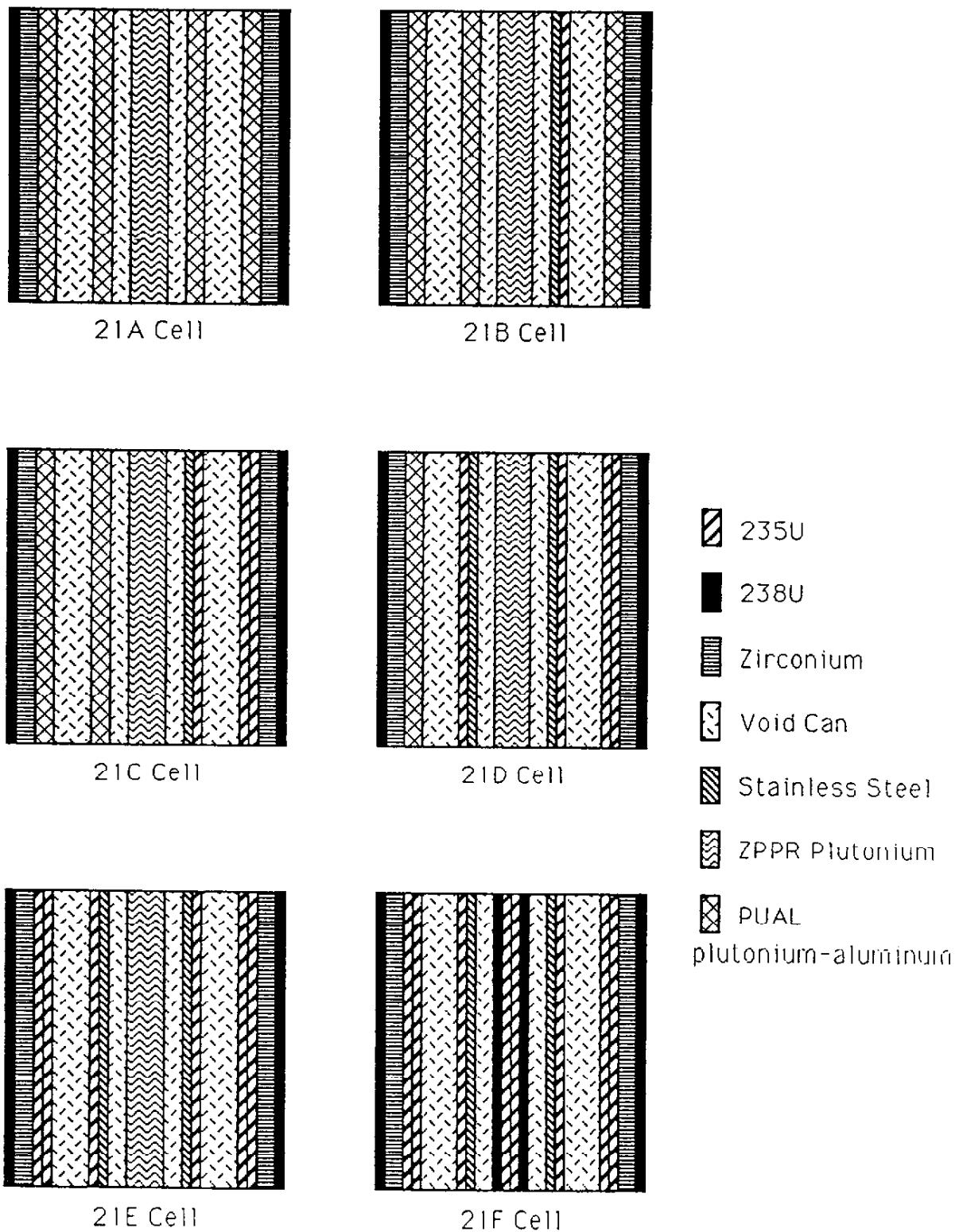


Fig. 84. Drawer Loading Patterns for ZPPR-21, Phases A through F

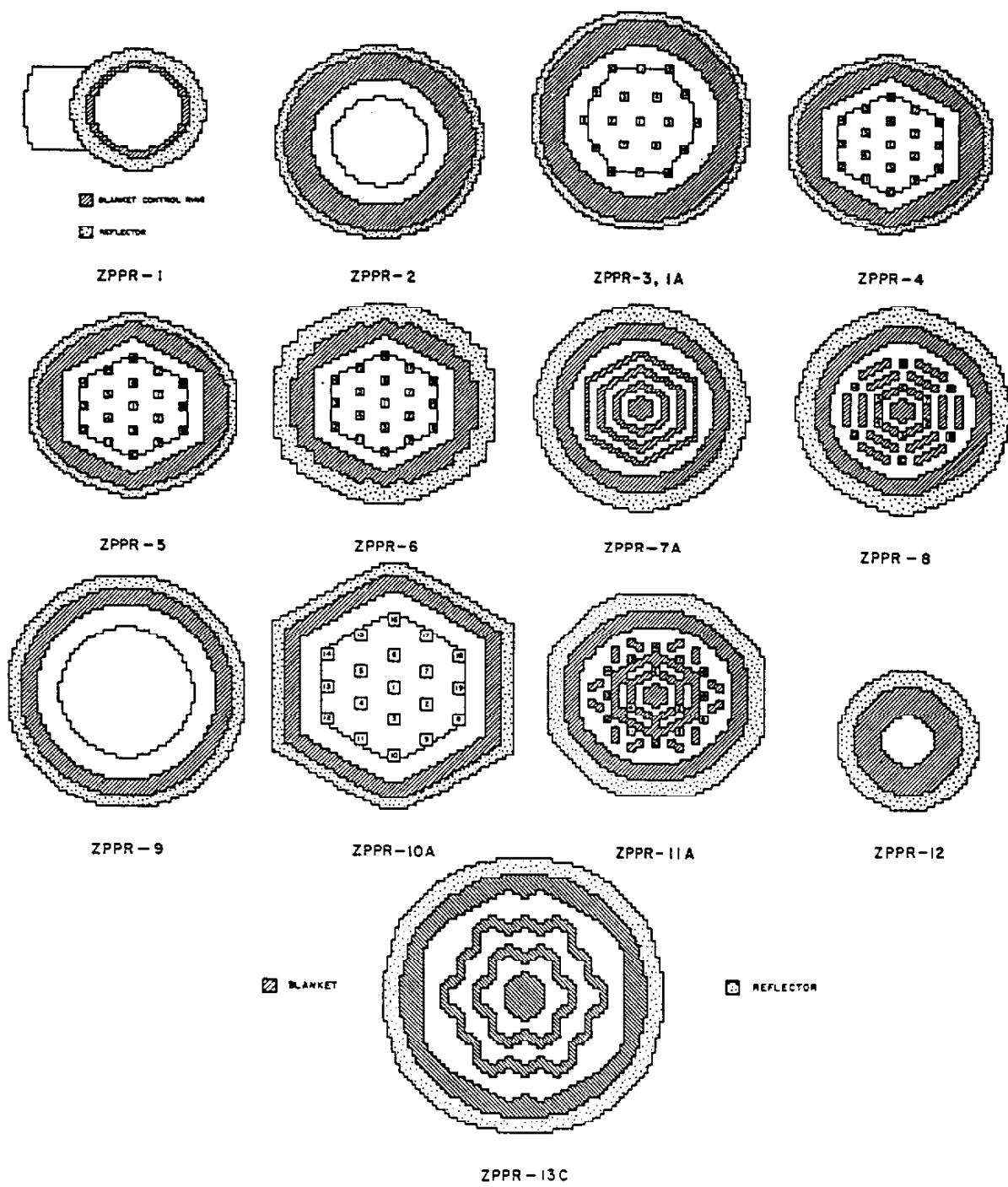
ZPPR PROGRAMS - 1969-1984

Fig. 85. Interface Diagram for ZPPR-1 through ZPPR-13

A118

ZPR9-1 through ZPR9-9

Nuclear Rocket Assemblies.

Overview:

A series of nine small, clean, single-zone, cylindrical fast critical assemblies were constructed to evaluate the physics properties of possible nuclear rocket cores using tungsten-based fuels. The primary focus of these assemblies was a test of available analytical methods and data.

Assembly Dates:

January 1964-

Related Assemblies:

None

Assembly Details:

Assembly	Core Materials	Radial Reflector	Fuel Enrichment (%)	U ²³⁵ Mass (kg)	Volume (liters)
1	U, Al	A1	11	278	158
2	U, Al, W	A1	16	393	224
3	U, Al, W	A1	21	494	283
4	U, Al, W	A1	93	286	109
5	U, Al, W, C	A1	93	355	203
6	U, Al, W	Al	93	455	258
7	U, Al, W	Al, O	93	214	127
8	U, Al, W, O	Al, Be, O	93	283	161
9	U, Al, W, O	Al	93	193	110

The H/D was between 0.80 and 1.0 for all assemblies. The axial reflectors were aluminum except Assemblies 7 and 9 which were aluminum oxide. A second variant of the Assembly 4 core was diluted with rhenium. All assemblies, except Assembly 1, contained at least 36.4% tungsten. An outer radial reflector of aluminum was included on Assemblies 7, 8, and 9. The fuel material number densities were consistent with a partial void fraction appropriate for a nuclear rocket core.

There was no ZPR9 Assembly 10.

A120

Small, cylindrical, zoned assemblies with uranium carbide fuel in the core (central test zone).

Overview:

A series of nine small, cylindrical, zoned assemblies were constructed to test the use of zoned assemblies to measure spectrum sensitive physics parameters and then to perform such measurements. The test zones contained uranium carbide fuel, with both the addition of a small amount of polyethylene and a variation in the ratio of depleted uranium to graphite employed to soften the neutron spectrum in Assemblies 13 through 17. Measurements focused on Doppler, reaction rate ratios and material reactivity worths.

Assembly Dates:

March 1966-June 1967

Related Assemblies:

The test zones in Assemblies 11, 12, and 18, matched the core composition of ZPR6 Assembly 5.

Assembly Details:

Type: Each of the assemblies (except Assembly 17) were cylindrical zoned assemblies consisting of a central test zone, a buffer region to adjust the neutron spectrum to be characteristic of the test zone, and a more highly-enriched driver region. Assemblies 12 and 18 were identical. The buffer and driver regions were the same for each of the zoned assemblies.

Fuel: Uranium carbide with sodium cooling in the test zone. Assemblies 11, 12, and 18 matched the large (2600 liter), single zone uranium carbide assembly, ZPR6-5. Assembly 13 was created from Assembly 12 by the removal of a small amount of depleted uranium and graphite and the addition of 8.7 v/o polyethylene to the test zone. The polyethylene remained in the test zone through Assembly 17. In Assemblies 14 through 17, the depleted uranium concentration was decreased and the carbon concentration increased in the test zones to produce an increasingly soft neutron spectrum. Assembly 17 was a single-zone core (not zoned) because the test zone could be made critical without a driver.

Test Zone Radius:	Assembly 11:	20.9 cm
	Assemblies 12 through 16 and Assembly 18:	25.9 cm
	Assembly 17:	15.6 cm
	Core sodium of Assembly 17:	27.6 cm

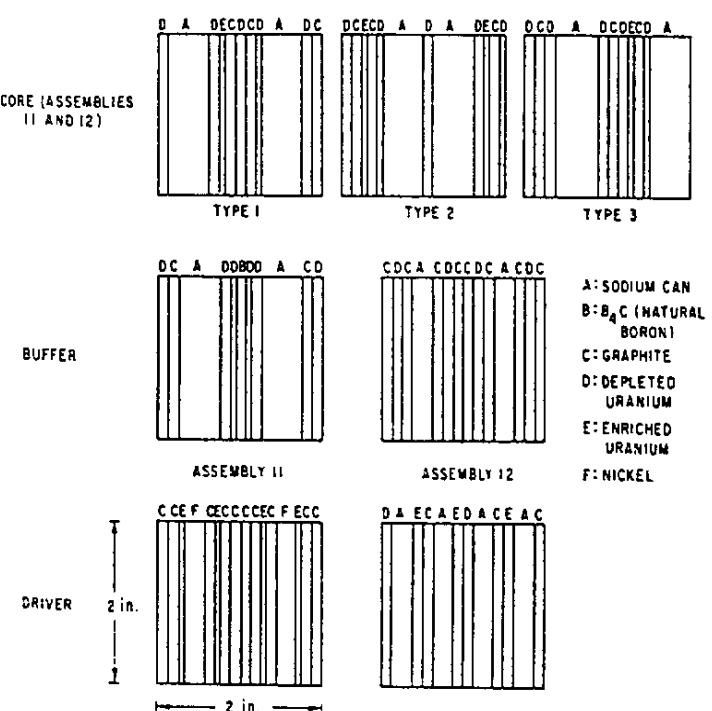
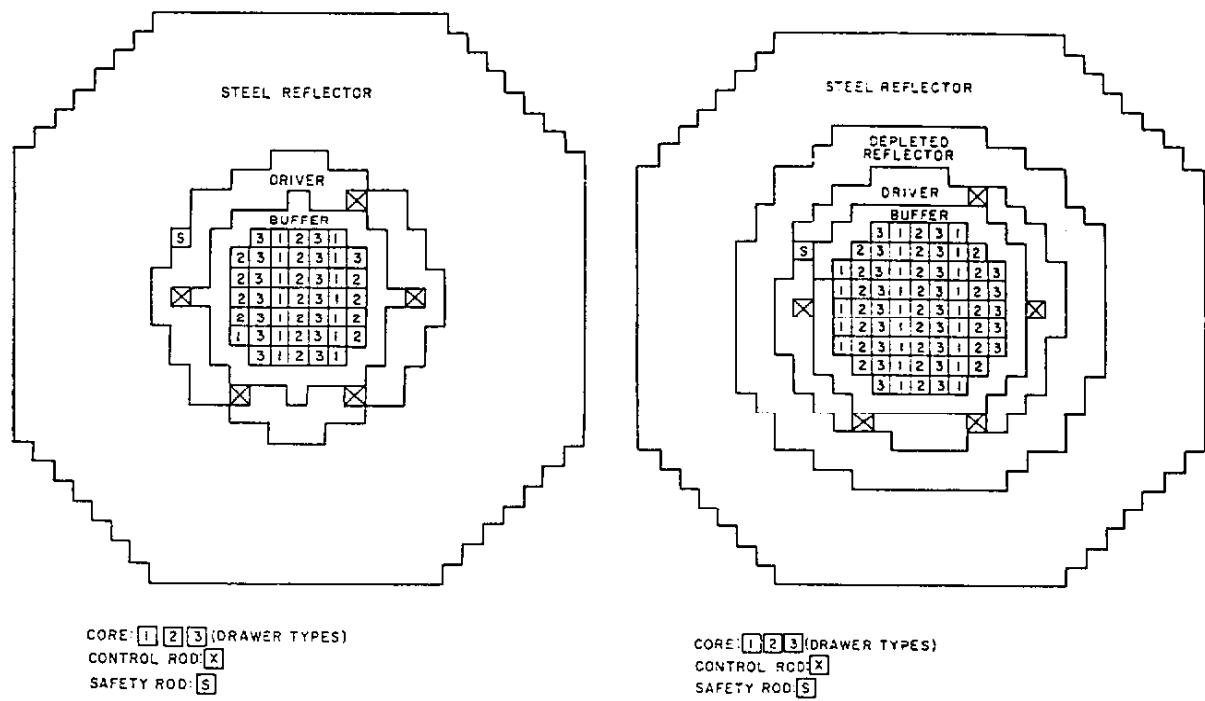


Fig. 86. Interface Diagrams and Drawer Loading Patterns for ZPR9-11 and -12

ZPR9-19, -21, -22, and -23

Small, cylindrical zoned assemblies with uranium oxide fuel in the core (central test zone).

Overview:

A series of small, cylindrical, zoned assemblies were constructed to perform neutron spectrum physics measurements. The test zone contained uranium oxide fuel and was the same in all four assemblies. Experiments focused on the measurement of the central, small heated sample U²³⁸, U²³⁵, and Pu²³⁹ Doppler although other spectrum sensitive measurements were also performed.

Assembly Dates:

July 1967-Early 1968

Related Assemblies:

The test zones in each of these assemblies matched the core compositions of ZPR6 Assemblies 6 and 6A.

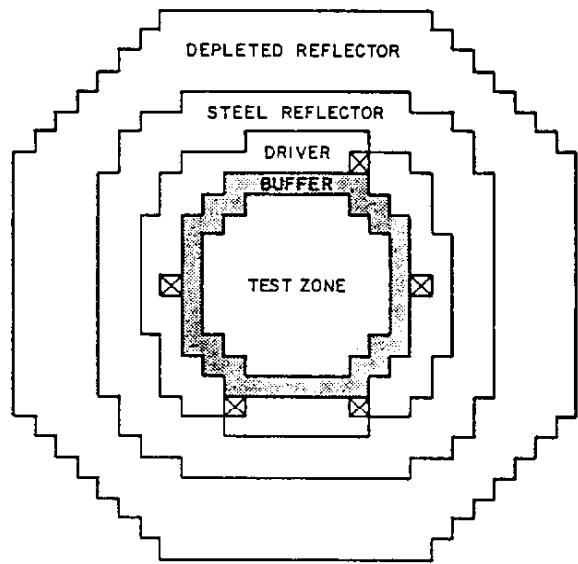
Assembly Details:

Type: Each of the assemblies were cylindrical, zoned assemblies consisting of a central test zone, a buffer region for spectral adjustment, and a more highly-enriched driver region. All of the test zones were the same size except for Assembly 21 which had a smaller test zone. Assembly 22 was similar to Assembly 19 except that the buffer region was solid aluminum rather than a mixture of uranium oxide and aluminum.

Fuel: Uranium oxide fuel with sodium cooling in the test zone. This fuel matched the core composition in the large (4000 liter) single-zone uranium oxide assemblies ZPR6-6 and 6A.

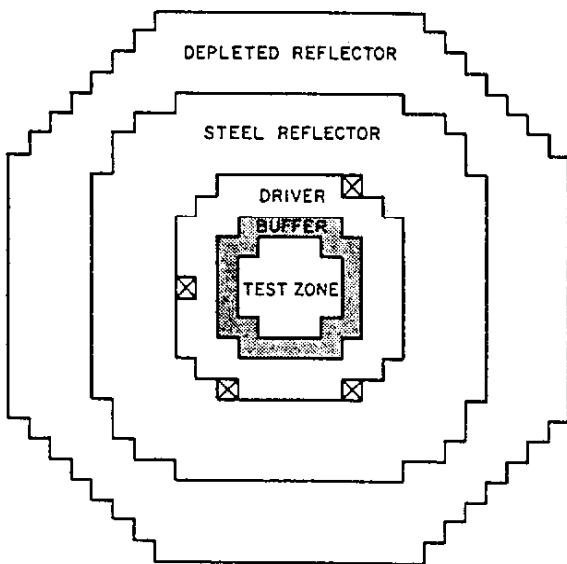
Critical Mass
and Volume: Not relevant.

Test Zone Radius: Assemblies 19, 22, 23: 25.9 cm
Assembly 21: 14.27 cm



CONTROL ROD

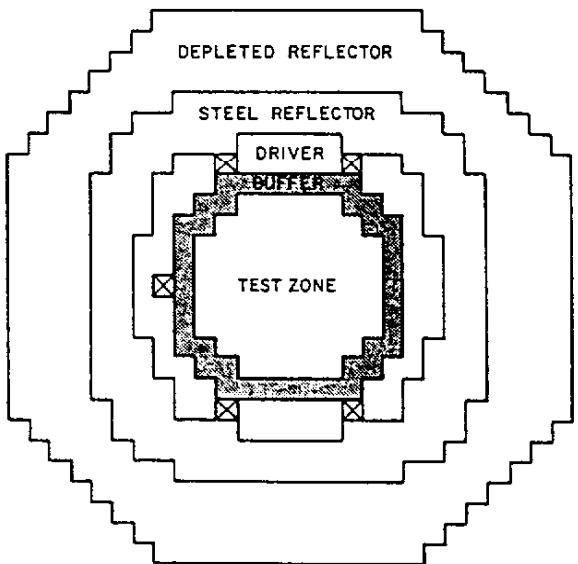
Assembly 19



CONTROL ROD

NOTE: STATIONARY HALF SHOWN ABOVE, MOVABLE HALF HAS FIVE CONTROL RODS.

Assembly 21



CONTROL ROD

Assembly 22

Test Zone Assemblies 19, 21 and 22	$\frac{1}{4}$ U ₃ O ₈ , $\frac{1}{2}$ Na, $\frac{1}{8}$ Fe ₂ O ₃ , $\frac{1}{16}$ SS, ^(a) $\frac{1}{16}$ E, ^(a) $\frac{1}{8}$ D, ^(a) $\frac{1}{8}$ Fe ₂ O ₃ , $\frac{1}{8}$ Na, $\frac{1}{4}$ U ₃ O ₈ .
Buffer Assemblies 19 and 21	$\frac{1}{4}$ U ₃ O ₈ , $\frac{1}{4}$ Al, $\frac{1}{4}$ U ₃ O ₈ , $\frac{1}{4}$ Al, $\frac{1}{4}$ U ₃ O ₈ , $\frac{1}{8}$ Al, $\frac{1}{4}$ U ₃ O ₈ , $\frac{1}{4}$ Al, $\frac{1}{4}$ U ₃ O ₈ .
Buffer Assembly 22	2 Al (full drawer of aluminum)
Driver Assemblies 19, 21 and 22	$\frac{1}{8}$ C, ^(a) $\frac{1}{8}$ SS, $\frac{1}{8}$ C, ^(a) $\frac{1}{8}$ E, $\frac{1}{8}$ SS, $\frac{1}{8}$ C, $\frac{1}{8}$ SS, $\frac{1}{8}$ C, $\frac{1}{8}$ C, $\frac{1}{8}$ SS, $\frac{1}{8}$ E, $\frac{1}{8}$ C, $\frac{1}{8}$ SS, $\frac{1}{8}$ C.

Fig. 87. Interface Diagrams and Drawer Loading Patterns for ZPR9-19, -21, and -22

ZPR9-24 and -25, ZPR3-55

Small, cylindrical zoned assemblies with null-reactivity compositions (i.e., $k_{\infty} = 1.0$) in the test zone.

Overview:

ZRP9 Assemblies 24 and 25 were small null-zoned assemblies with uranium fuel in the test zone. ZPR3-55 was similar except it contained plutonium fuel in the test zone. Assemblies 24 and 55 were used to develop the null-zone technique and in the measurement of the capture-to-fission ratio for U²³⁵ and Pu²³⁹. Assemblies 24 and 25 had graphite in the test zones and has relative soft neutron energy spectra. Assembly 25 had only enriched and depleted uranium in the test zone and a hard neutron energy spectra. Assemblies 24 and 25 emphasized different parts of the neutron spectra and were used in data testing. ZPR3-55 is included in this section because of its close tie with Assembly 24.

Assembly Dates:

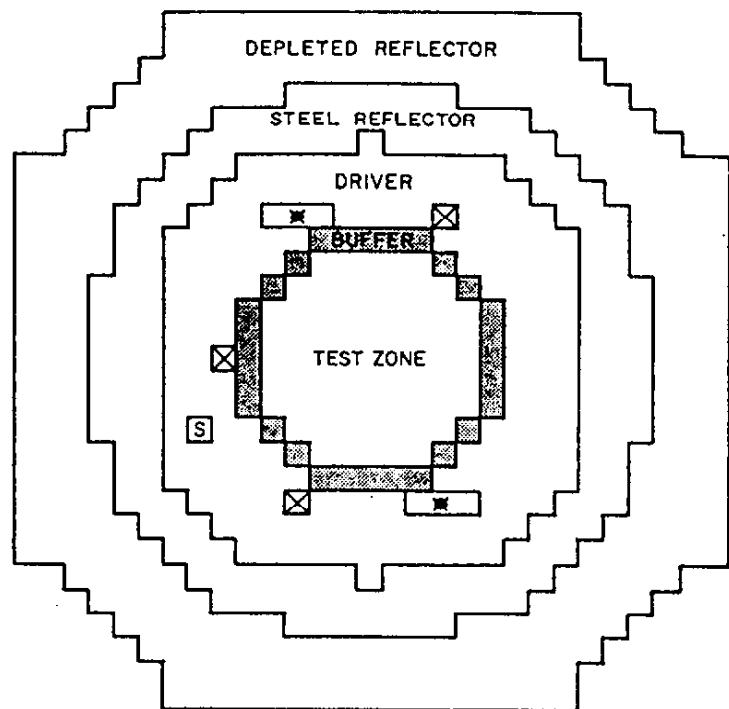
Spring 1968 for Assembly 24; September 1968-November 1968 for Assembly 55

Related Assemblies:

None in any of the ZPR programs, although there were a series of null-zone assemblies performed at the ZEBRA Facility in the UK.

Assembly Details:

Type:	Small, cylindrical null-zoned assemblies.	
Fuel:	The test zone compositions were enriched uranium, depleted uranium and graphite for Assembly 24, enriched and depleted uranium for Assembly 25, and plutonium, depleted uranium, and graphite for Assembly 55. There was a small region at the center of Assembly 55 null zone that was reloaded with high (22%) Pu ²⁴⁰ plutonium. This was designated Assembly 55A.	
Critical Mass and Volume:	Not relevant.	
Test Zone Radius:	Assemblies 24 and 25: Assembly 25: Assembly 55A high Pu ²⁴⁶ zone:	25.9 cm 18.9 cm 14.0 cm

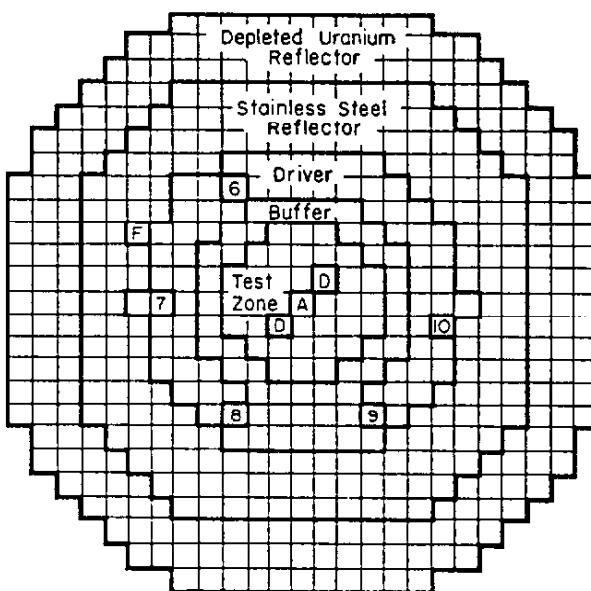


- CONTROL ROD AND ADJACENT DRAWERS
(THREE COLUMNS OF FUEL IN ROD, NO FUEL IN
ADJACENT DRAWERS)
- CONTROL ROD (ONE COLUMN OF FUEL)
- S BORON SAFETY ROD

Test Zone (Null Composition) Assembly 24	$\frac{3}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{4}$ C, $\frac{3}{8}$ D, $\frac{1}{16}$ Row: $\frac{3}{8}$ C & $\frac{1}{8}$ D, $\frac{1}{4}$ C, $\frac{1}{16}$ E, $\frac{1}{4}$ C, $\frac{1}{4}$ D, $\frac{1}{4}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C.
Buffer Assembly 24	$\frac{1}{8}$ D, $\frac{1}{4}$ C, $\frac{1}{8}$ D, $\frac{1}{4}$ C, $\frac{1}{8}$ D, $\frac{1}{4}$ C, $\frac{1}{8}$ D, $\frac{1}{4}$ C, $\frac{1}{8}$ D, $\frac{1}{4}$ C, $\frac{1}{8}$ D.
Driver Assembly 24	$\frac{1}{8}$ C, $\frac{1}{8}$ SS, $\frac{1}{4}$ C, $\frac{1}{8}$ SS, $\frac{1}{4}$ C, $\frac{1}{16}$ SS, $\frac{1}{8}$ E, $\frac{1}{16}$ SS, $\frac{1}{4}$ C, $\frac{1}{8}$ SS, $\frac{1}{4}$ C, $\frac{1}{8}$ SS, $\frac{1}{8}$ C.

* The symbols E and D designate respectively, enriched and depleted uranium, C refers to graphite (carbon) and SS to stainless steel.

Fig. 88. Interface Diagram and Drawer Loading Patterns for ZPR9-24



Fuel Bearing Control Rod: [6] Numbers 6 through 10

Fine Auto Rod: [F]

Axial Oscillator: [A]

Fission Detector: [D]

E: Enriched uranium

D: Depleted uranium

A: Aluminum (100% dense)

AA: Aluminum (45% dense)

S: Stainless Steel

B: $B_4^{not C}$

W: Extra wall thickness on fuel bearing control rods

X: 1/2 column AA, 1/2 column D

Y: 54% col. D, 46% col. AA

Z: 3/4 column D, 1/4 column AA

Test Zone:

1/16 X	1/32 E	1/8 D	1/8 C	1/8 C
1/16 D	1/8 D	1/8 D	1/8 C	1/8 C
1/16 Y	1/8 D	1/8 D	1/8 E	1/8 E
1/16 Z	1/8 D	1/8 A	1/8 C	1/8 C
	1/8 D	1/8 D	1/8 C	1/8 C

Buffer:

1/8 D	1/8 D	1/8 S	1/8 S	1/8 S
1/8 D	1/8 D	1/8 C	1/8 C	1/8 C
1/8 D	1/8 D	1/8 C	1/8 C	1/8 C
1/8 D	1/8 D	1/8 C	1/8 C	1/8 C
1/8 D	1/8 D	1/8 C	1/8 C	1/8 C

Driver:

1/8 C	1/8 C	1/8 S	1/8 S	1/8 S
1/8 C				
1/8 C				
1/8 C				
1/8 C				

Fuel Bearing Control Rod:
(Movable half has identical pattern)

1/8 C	1/8 C	1/8 B	1/8 B	Tapered Polyethylene Spear
1/8 C	1/8 C	1/8 B	1/8 B	
1/8 C	1/8 C	1/8 B	1/8 B	

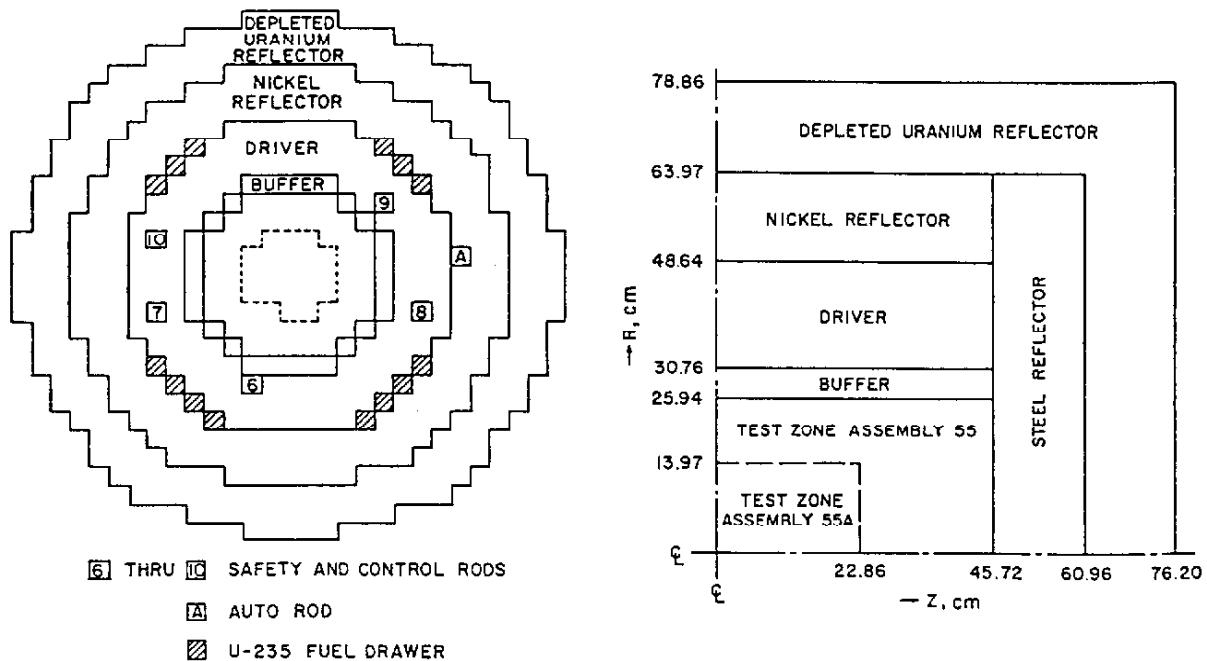
Fine Auto Rod:
(Continuous through both halves)

1/8 C	1/8 S	1/8 S	1/8 S	Tapered Polyethylene Spear
1/8 C	1/8 S	1/8 S	1/8 S	
1/8 C	1/8 S	1/8 S	1/8 S	

Boron Control Rod:
(Moveable half only)

Stainless Steel		Boron Blade
2 in.		

Fig. 89. Interface Diagram and Drawer Loading Patterns for ZPR9-25



Assembly 55

Test Zone Assembly 55	$\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ ZPR-3 Pu, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ C, ($\frac{1}{16}$ Row: $\frac{3}{8}$ D and $\frac{1}{8}$ C), $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C.
Test Zone Assembly 55A	$\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ ZPR-3 Pu (22% 240), $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ C, $\frac{1}{8}$ C, $\frac{1}{4}$ SS frame.
Buffer Assemblies 55 & 55A	$\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C, $\frac{1}{8}$ D, $\frac{1}{8}$ C.
Driver—Type A† Assemblies 55 & 55A	$\frac{1}{8}$ C, $\frac{1}{4}$ SEFOR Pu, $\frac{1}{2}$ C, $\frac{1}{4}$ ZPPR Pu, $\frac{1}{2}$ C, $\frac{1}{4}$ SEFOR Pu, $\frac{1}{8}$ C.
Driver—Type B Assemblies 55 & 55A	$\frac{1}{4}$ C, $\frac{1}{4}$ ZPPR Pu, $\frac{5}{8}$ C, $\frac{1}{8}$ ZPR-3 Pu, $\frac{1}{2}$ C.
U-235 Fuel Drawer Assemblies 55 & 55A	$\frac{1}{8}$ C, $\frac{1}{8}$ SS, $\frac{1}{4}$ C, $\frac{1}{8}$ SS, $\frac{1}{4}$ C, $\frac{1}{8}$ SS, $\frac{1}{8}$ E, $\frac{1}{16}$ SS, $\frac{1}{4}$ C, $\frac{1}{8}$ SS, $\frac{1}{4}$ C, $\frac{1}{8}$ SS, $\frac{1}{8}$ C.

Fig. 90. Interface Diagram, R-Z Model and Drawer Loading Patterns for ZPR3-55 and -55A

ZPR9-26 and -27

FTR-3 and FTR-EMC.

Overview:

Assembly 26 was the third assembly supporting the design and safety evaluation of the Fast Test Reactor (FTR). Assembly 27 was the engineering mockup core (FTR-EMC) for the FTR. It provided final design support and design validation. The FTR reactor is rated at 400 MW.

Assembly Dates:

Late 1969-1974

Related Assemblies:

ZPR3-56 (FTR-1) and ZPPR-1 (FTR-2)

Assembly Details (Assembly 26):

Type: Cylindrical, two-zone, with peripheral control assemblies at the inner edge of the radial reflector
Fuel: Typical Pu/U oxide with plutonium cooling
Critical Mass: 540 kg (Pu^{239} + Pu^{241})
Volume: 1050 liters
Reflector: Nickel with sodium cooling

Assembly Details (Assembly 27):

Type: This assembly was a detailed mockup of the final FTR design and was a much more complicated and detailed core than Assembly 26. It was a cylindrical, two-zone core with both peripheral and internal control assemblies. It also included at various locations: general purpose, special purpose, and material test loops.
Fuel: Typical Pu/U oxide with sodium cooling
Critical Mass: 530 kg (Pu^{239} + Pu^{241} + U^{235}) beginning of life (BOL) configuration
Volume: 870 liters (excluding loops and control assemblies)
1060 liters (including all in-core regions)
Reflector: Nickel with sodium cooling

Assembly Variants:

Many core variations were evaluated. Two significant configurations included beginning-of-equilibrium cycles (designated BOL) and end-of-equilibrium cycles (designated EOC). The fuel concentrations and control assembly positions were adjusted to achieve these configurations.

A130

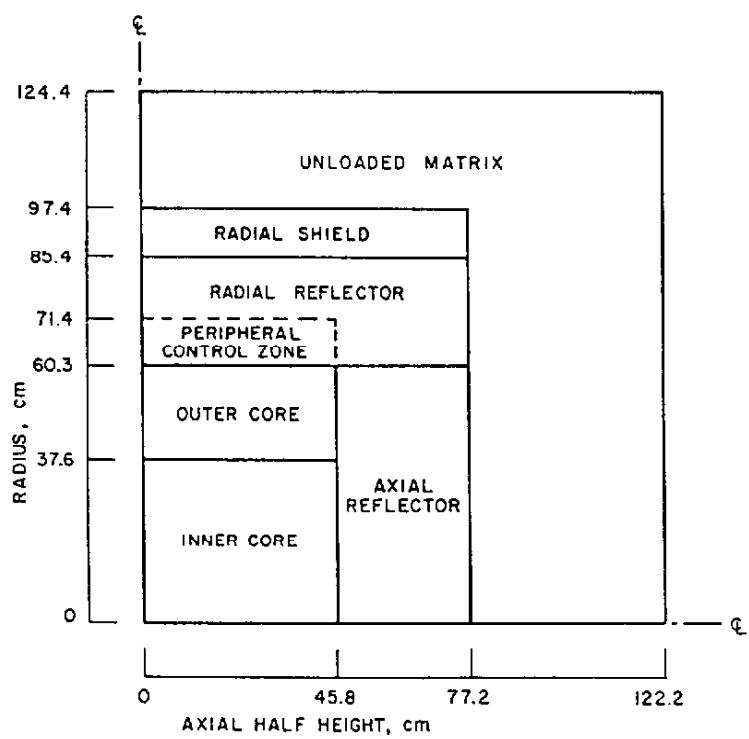
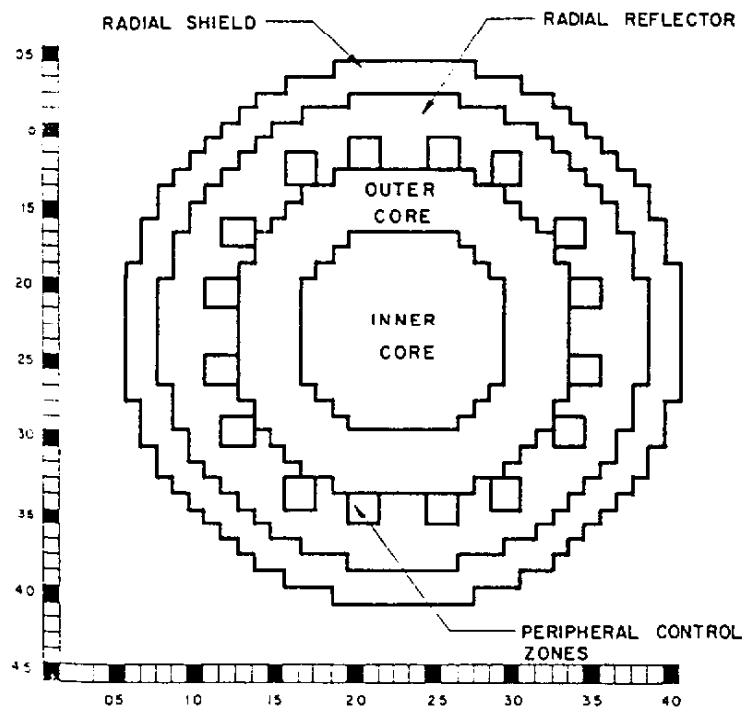
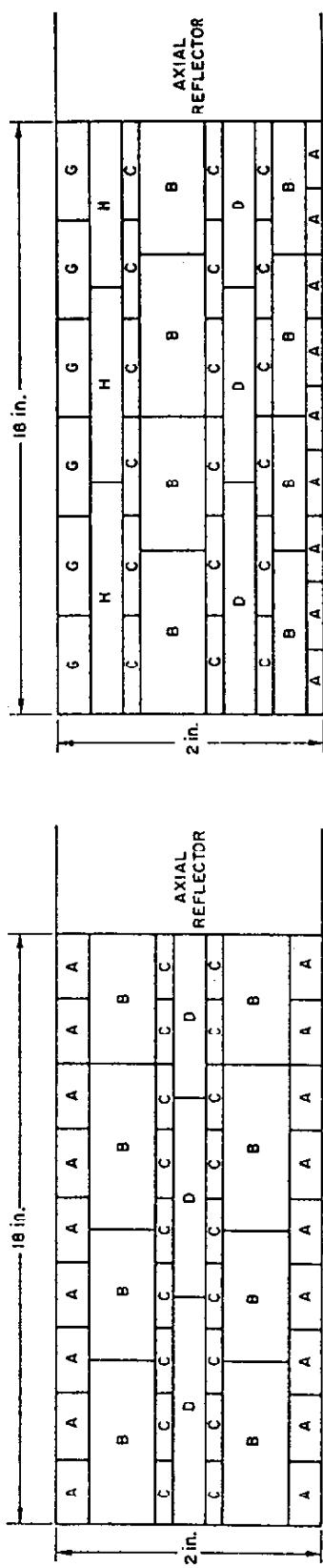
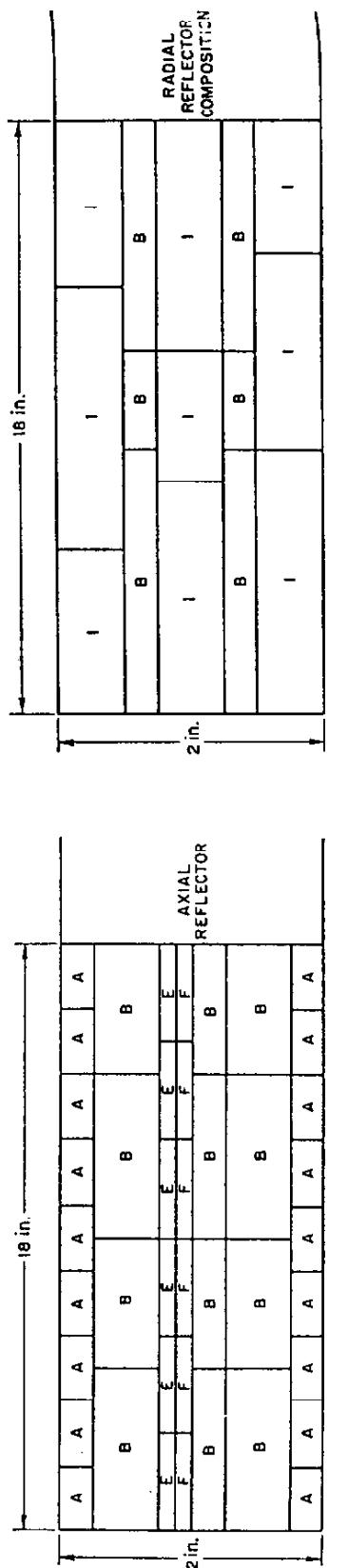


Fig. 91. Interface Diagram and R-Z Model for ZPR9-26 (FTR-3)



Inner Core Drawer Type A Loading Pattern
 $A = U_3O_8$ $B = Na$ $C = Fe_2O_3$ $D = Pu-U-Mo$

Outer Core Drawer Loading Pattern



Outer Core Drawer Loading Pattern
 $A = U_3O_8$ $B = Na$ $C = Fe_2O_3$ $D = Pu-U-Mo$ $G = Na_2CO_3$ $H = SF_6/PU$
 $I = BaC$

Peripheral Control Zone Drawer Loading Pattern

Fig. 92. Drawer Loading Patterns for ZPR9-26 (FTR-3)

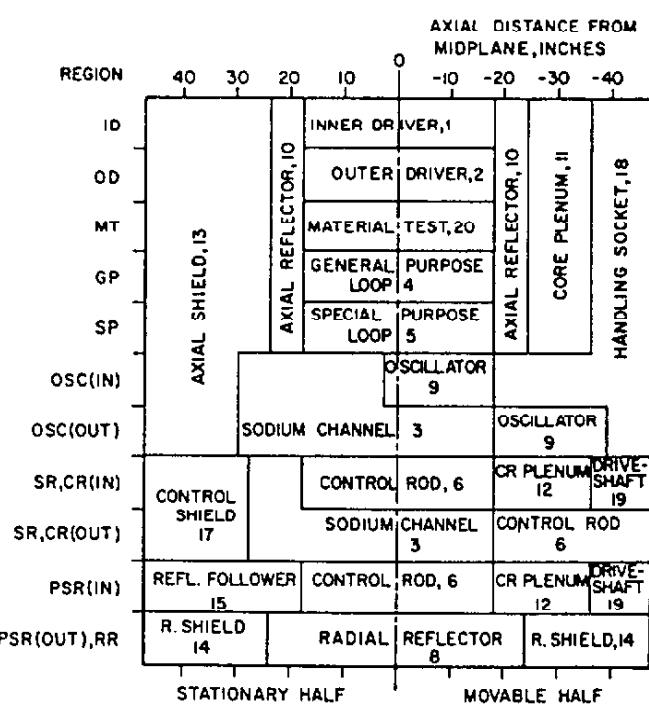
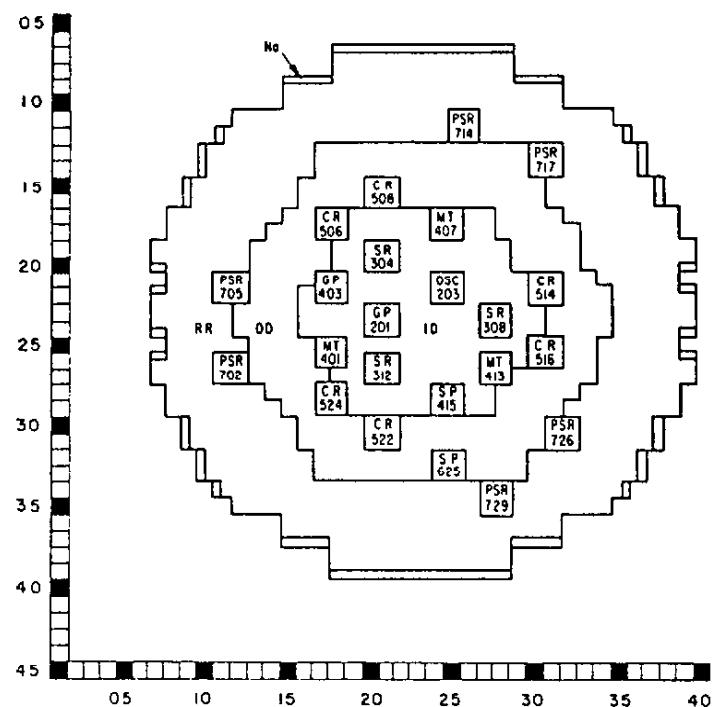


Fig. 93. Interface Diagram and Axial Subregions of ZPR9-27 (FTR-EMC)

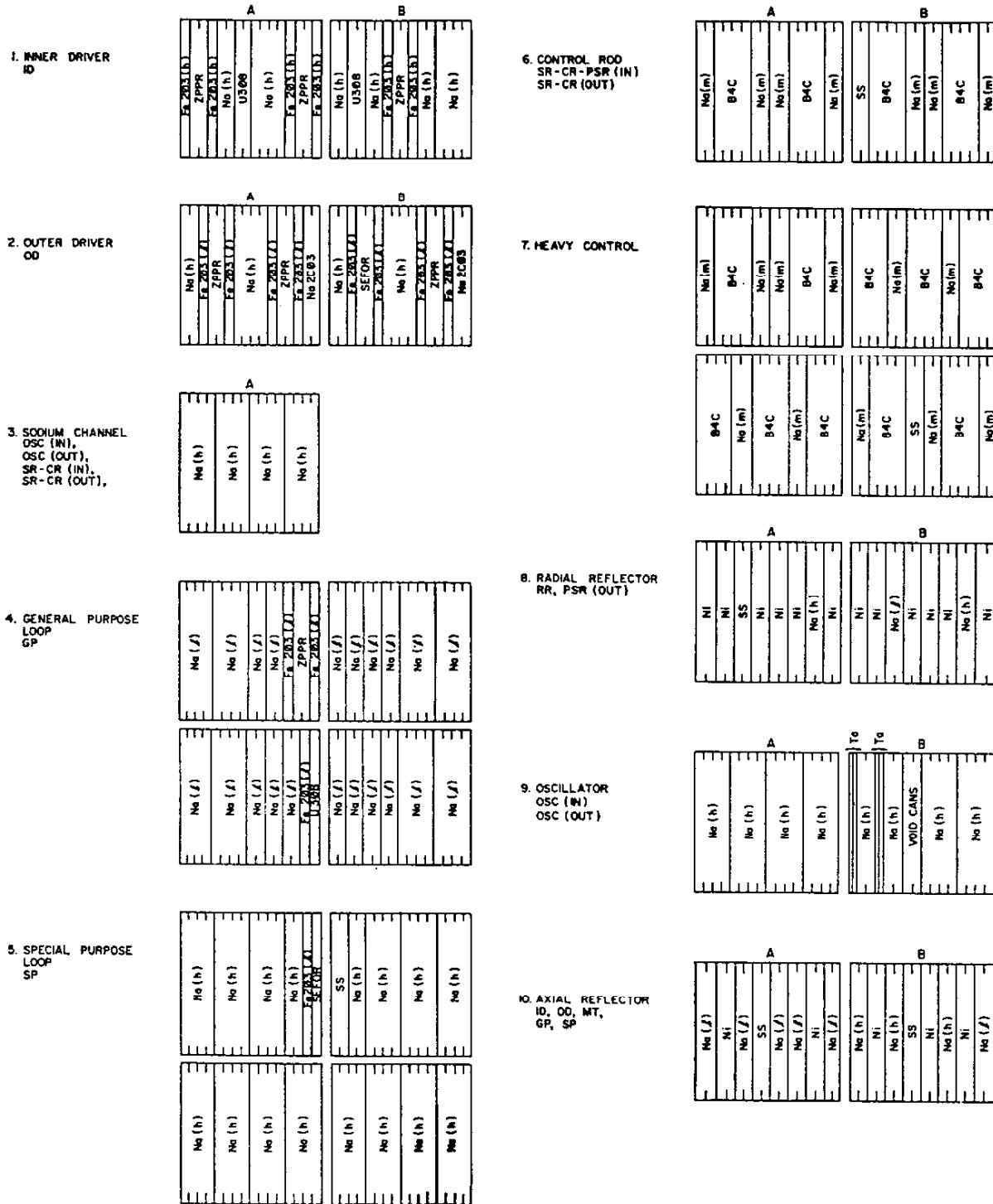


Fig. 94. Drawer Loading Patterns for ZPR9-27 (FTR-EMC)

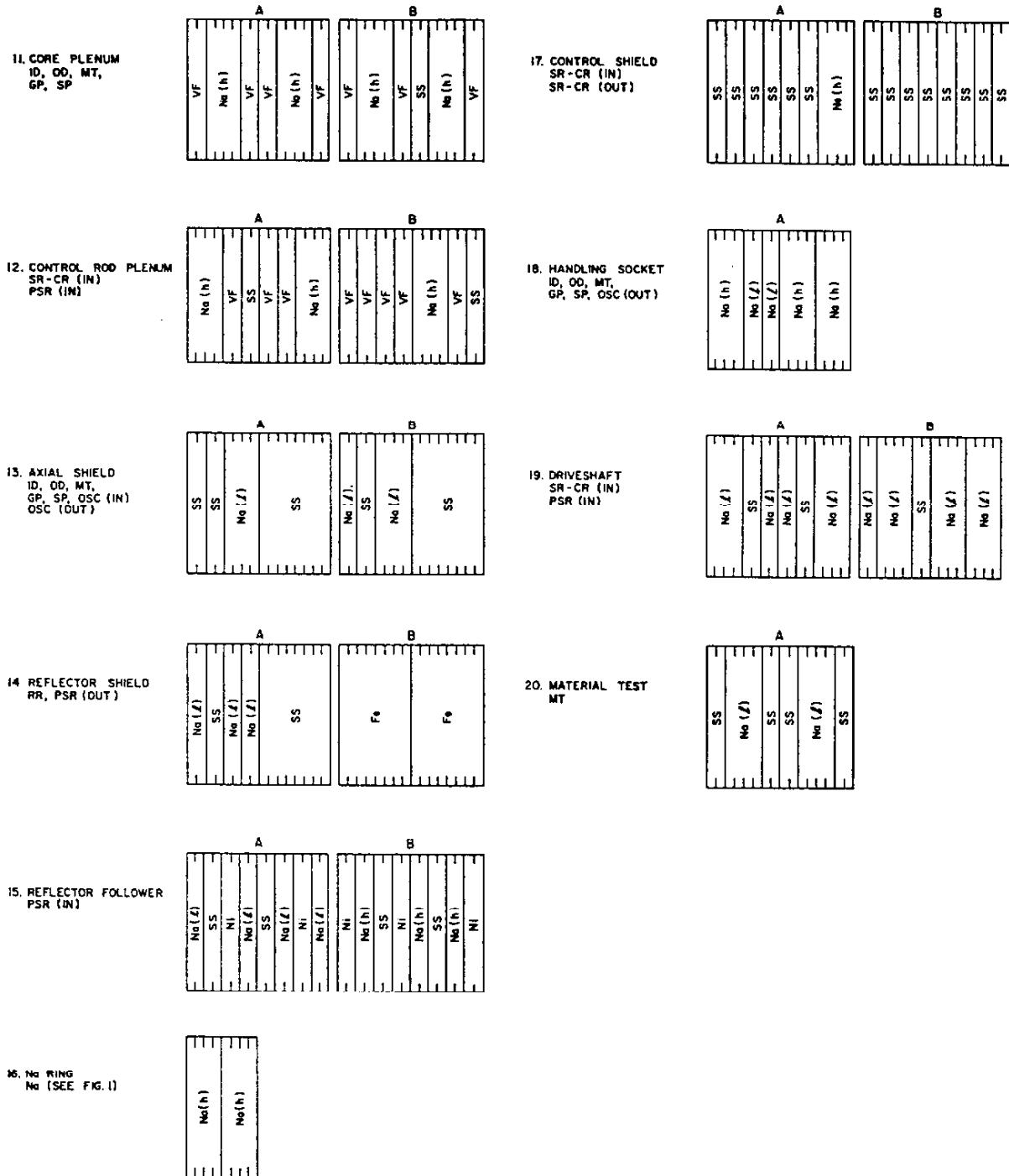


Fig. 94. Drawer Loading Patterns for ZPR9-27 (FTR-EMC)
(Contd.)

ZPR9-28, -29, and -30

GCFR-I, GCFR-II, and GCFR-III; assemblies to support the design and safety evaluation of the Gas Cooled Fast Reactor (GCFR).

Overview:

These three assemblies were focused on design and safety support for the GCFR. They addressed safety problems such as steam entry and analytical problems such as neutron streaming in the gas-filled channels.

Assembly Dates:

March 1975-July 1975 for GCFR-I; August 1975-May 1976 for GCFR-II; June 1975-September 1976 for GCFR-III

Related Assemblies:

None

Assembly Details:

	GCFR-I	GCFR-II	GCFR-III
Configuration	Cylindrical	Cylindrical	Cylindrical
Number of Core Zones	3	1	3
Fuel	Pu/U oxide	Pu/U oxide	Pu/U oxide
Void Fraction*	53 %	43 %	43 %
Blanket	U oxide	U oxide	U oxide
Reflector	None	SS	SS
Critical Mass ($\text{Pu}^{239} + \text{Pu}^{241}$) (kg)	1125	590	890
Volume (liters)	3150	1240	1910

*To simulate the gas cooling channels in the GCFR.

Assembly Variants:

There was an unreflected version of GCFR-II with a critical mass of 620 kg ($\text{Pu}^{239} + \text{Pu}^{241}$). Steam flooding of the gas cooling channels was simulated using low density polyethylene foam in a zone in GCFR-I and full core in GCFR-II. There was an octant in GCFR-I where every other drawer (in a checker board pattern) was turned 90° to break up streaming paths. There was a central pin zone in GCFR-III.

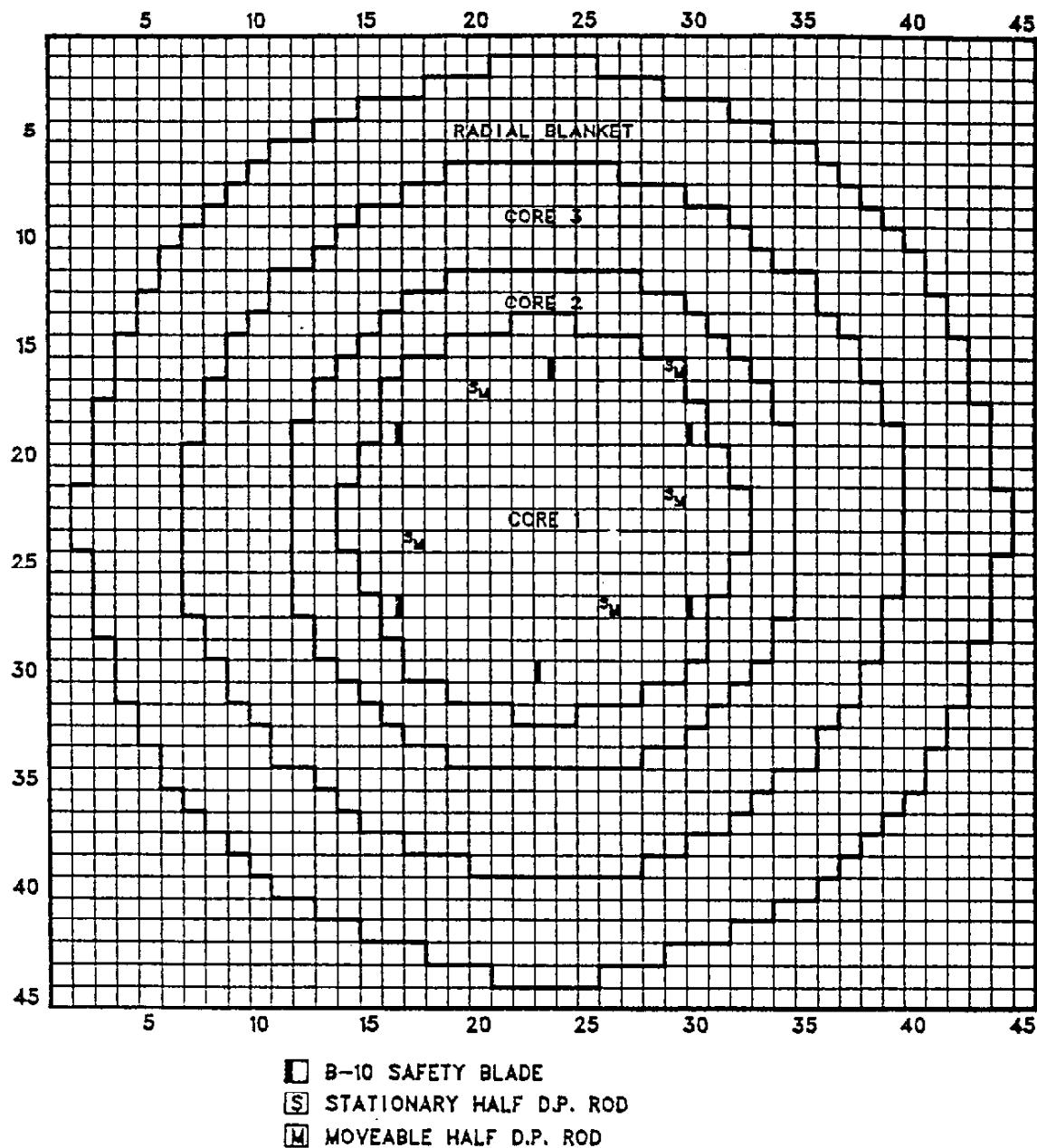


Fig. 95. Interface Diagram for ZPPR-28 (GCFR-I)

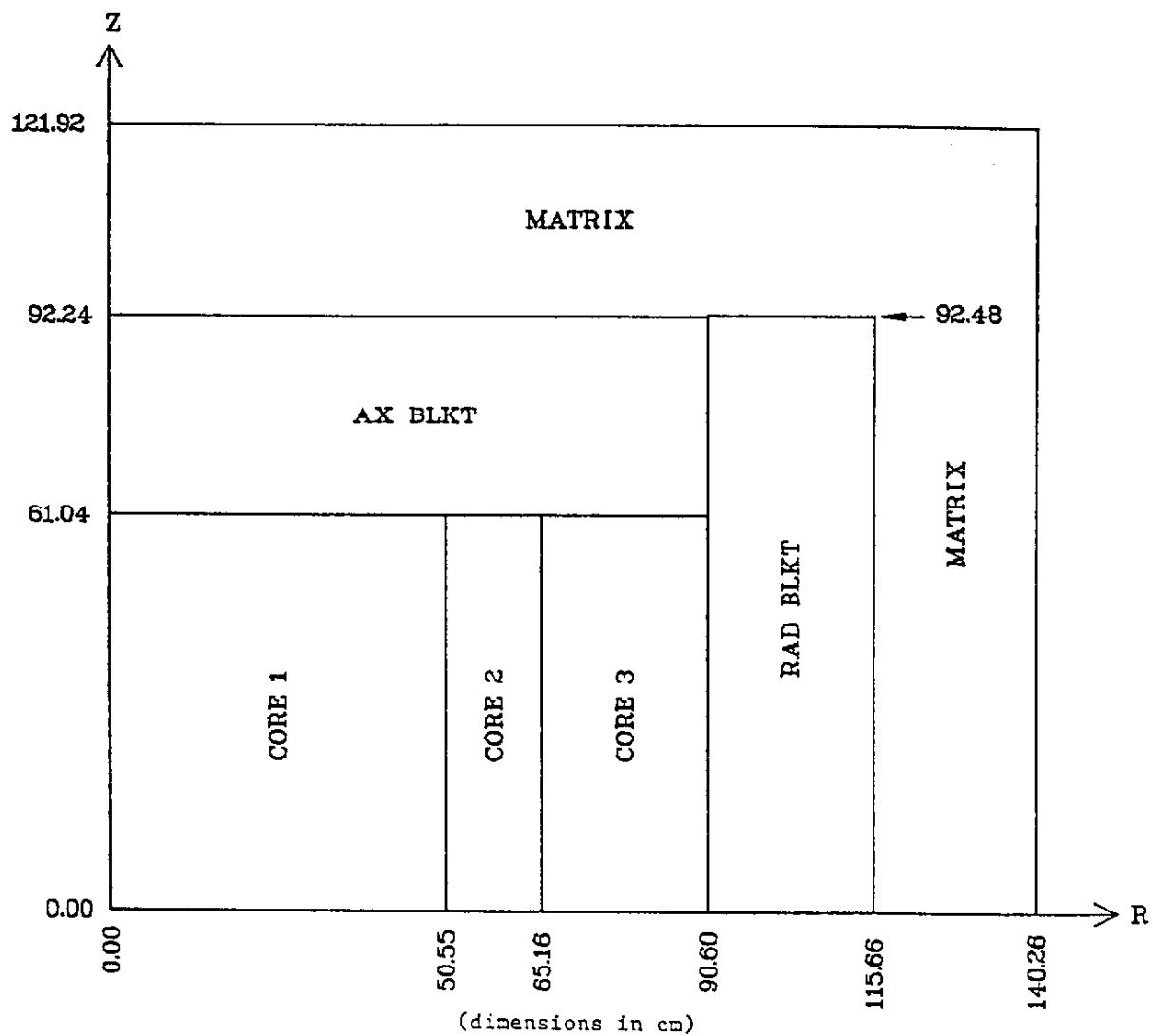


Fig. 96. R-Z Model for ZPR9-28 (GCFR-I)

A138

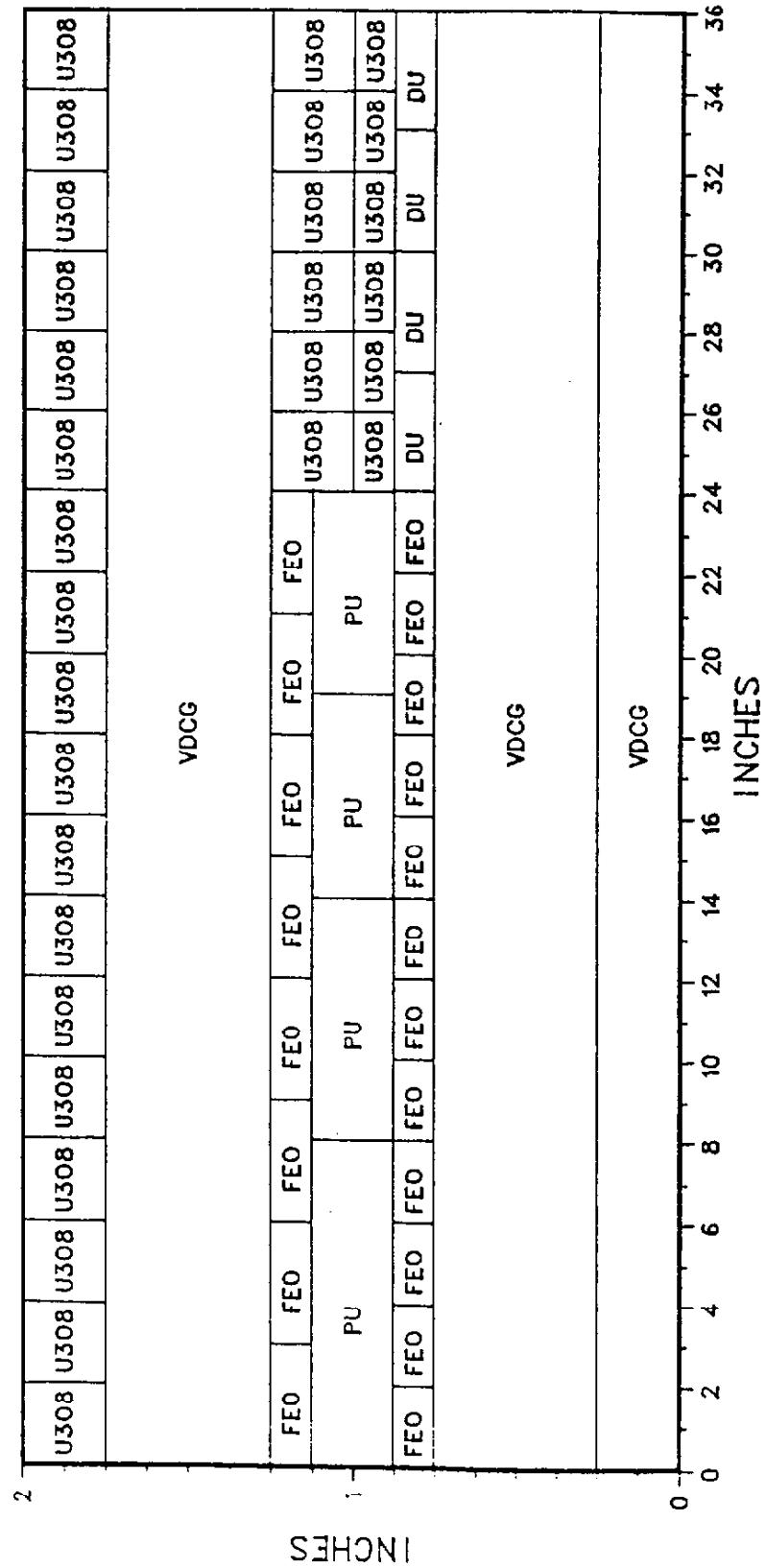


Fig. 97. Drawer Loading Pattern for ZPR9-28 (GCFR-I)

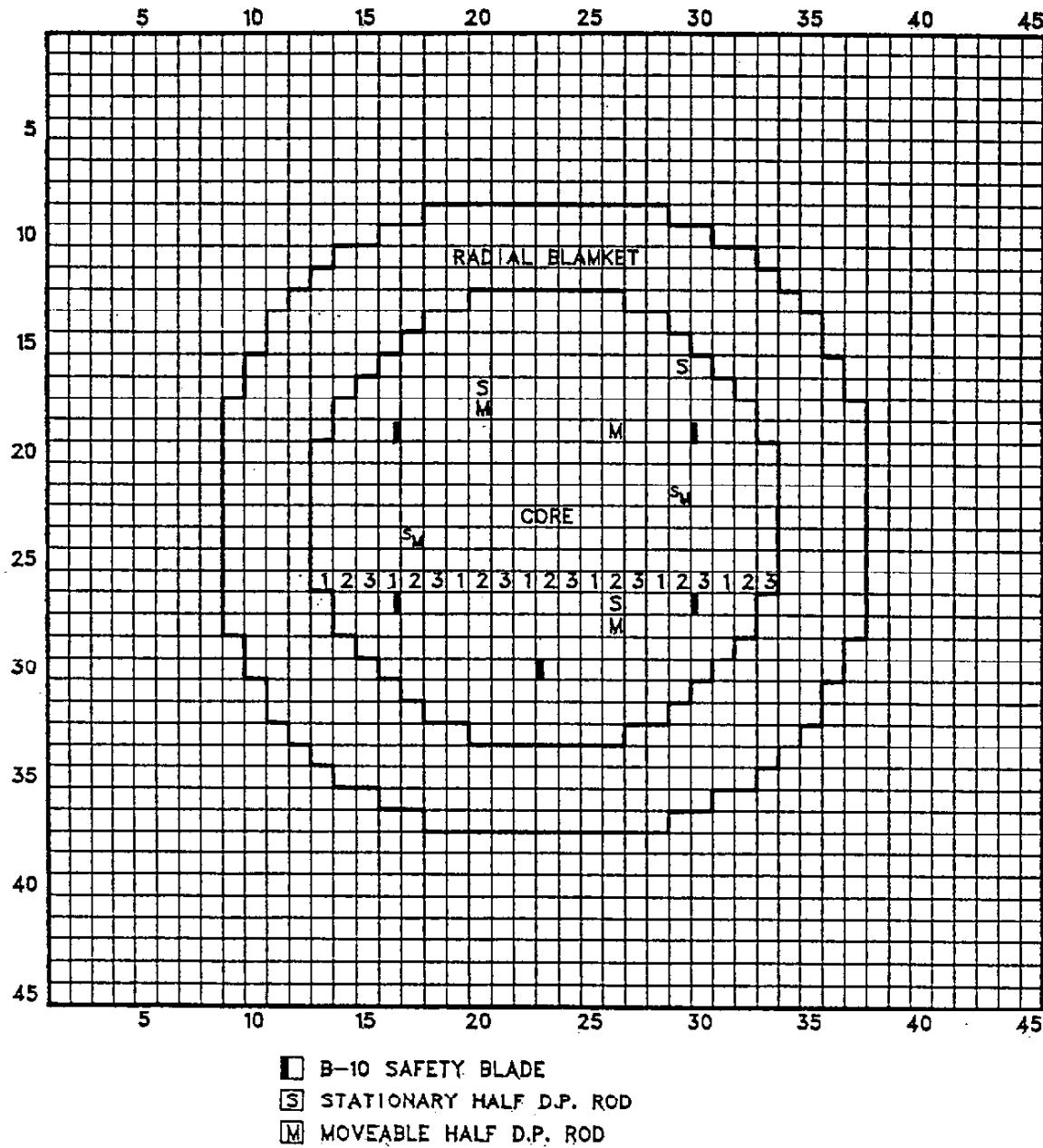


Fig. 98. Interface Diagram for ZPR9-29 (GCFR-II)

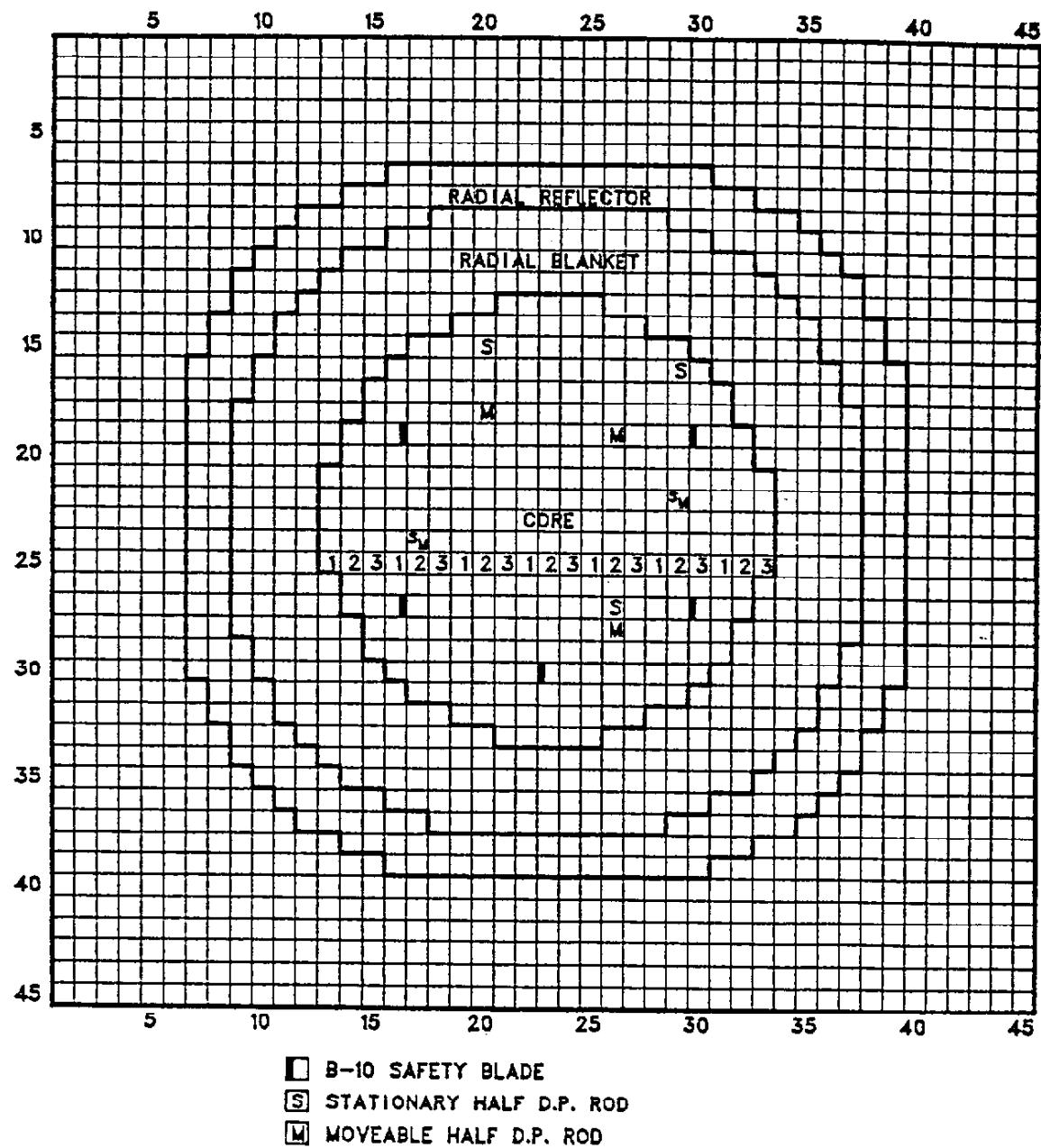


Fig. 99. Interface Diagram for ZPR9-29 (GCFR-II) with Radial Reflector

A141

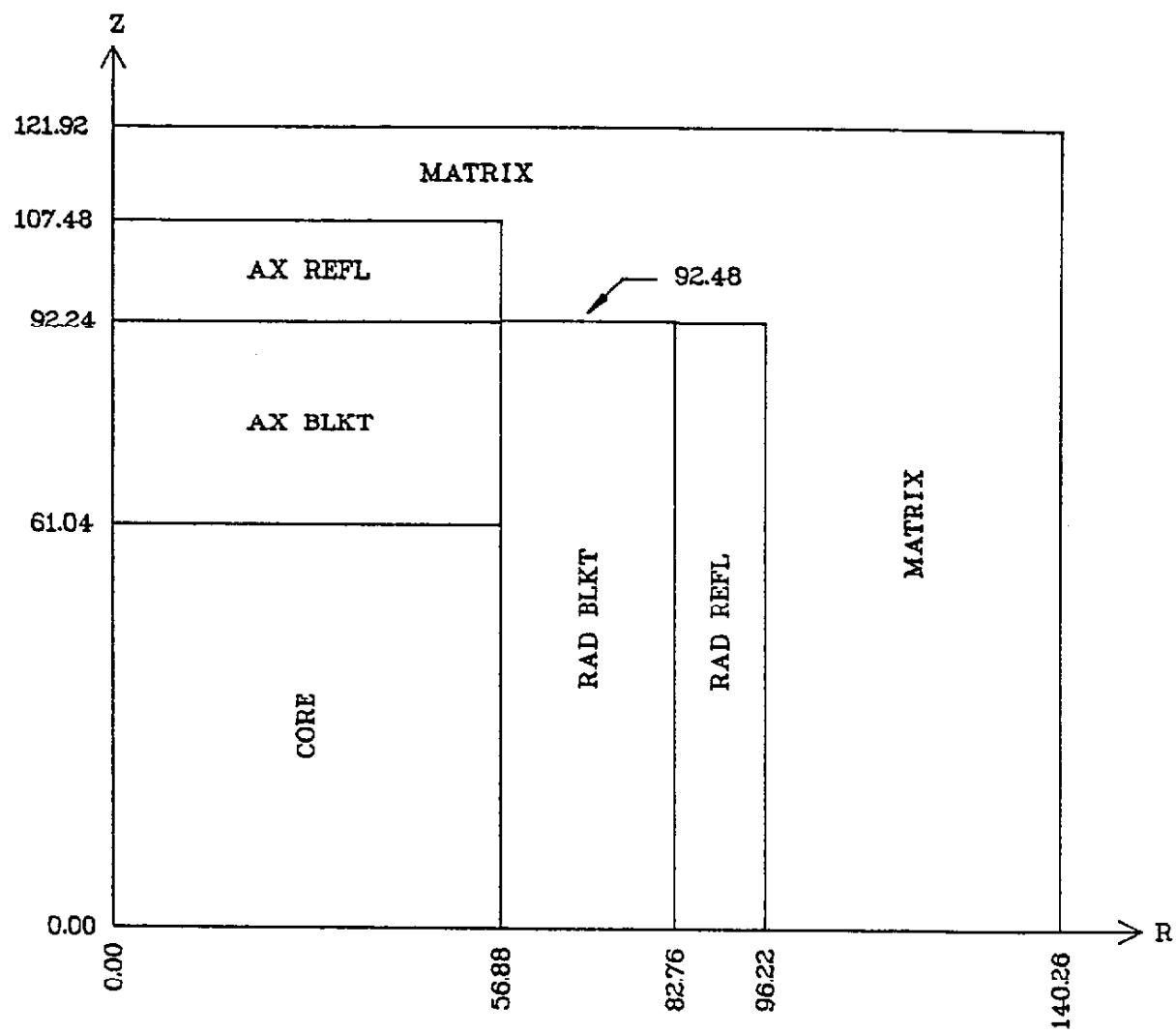


Fig. 100. R-Z Model for ZPR9-29 (GCFR-II) with Radial Reflector

A142

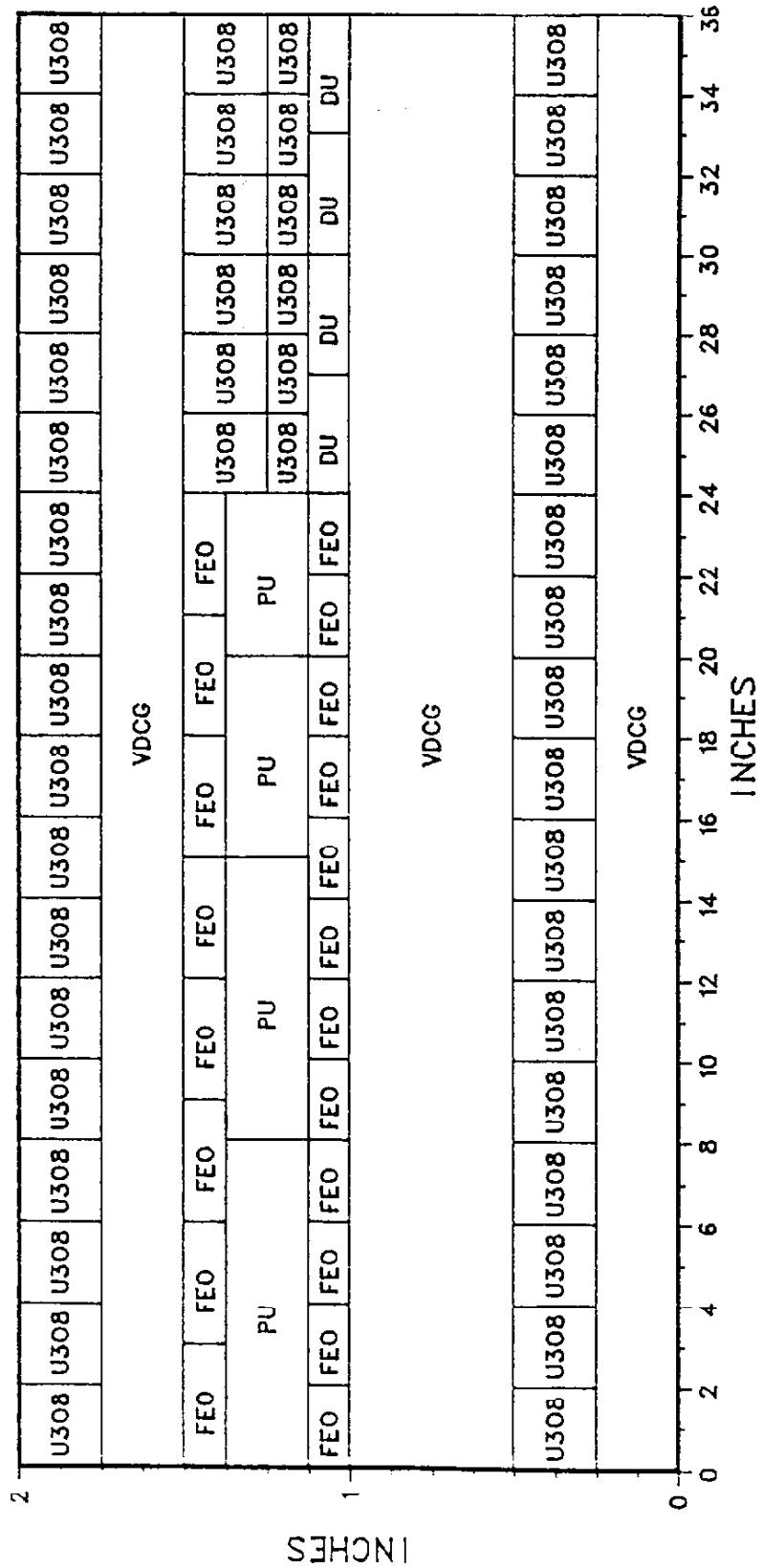


Fig. 101. Drawer Loading Pattern for ZPR9-29 (GCFR-II)

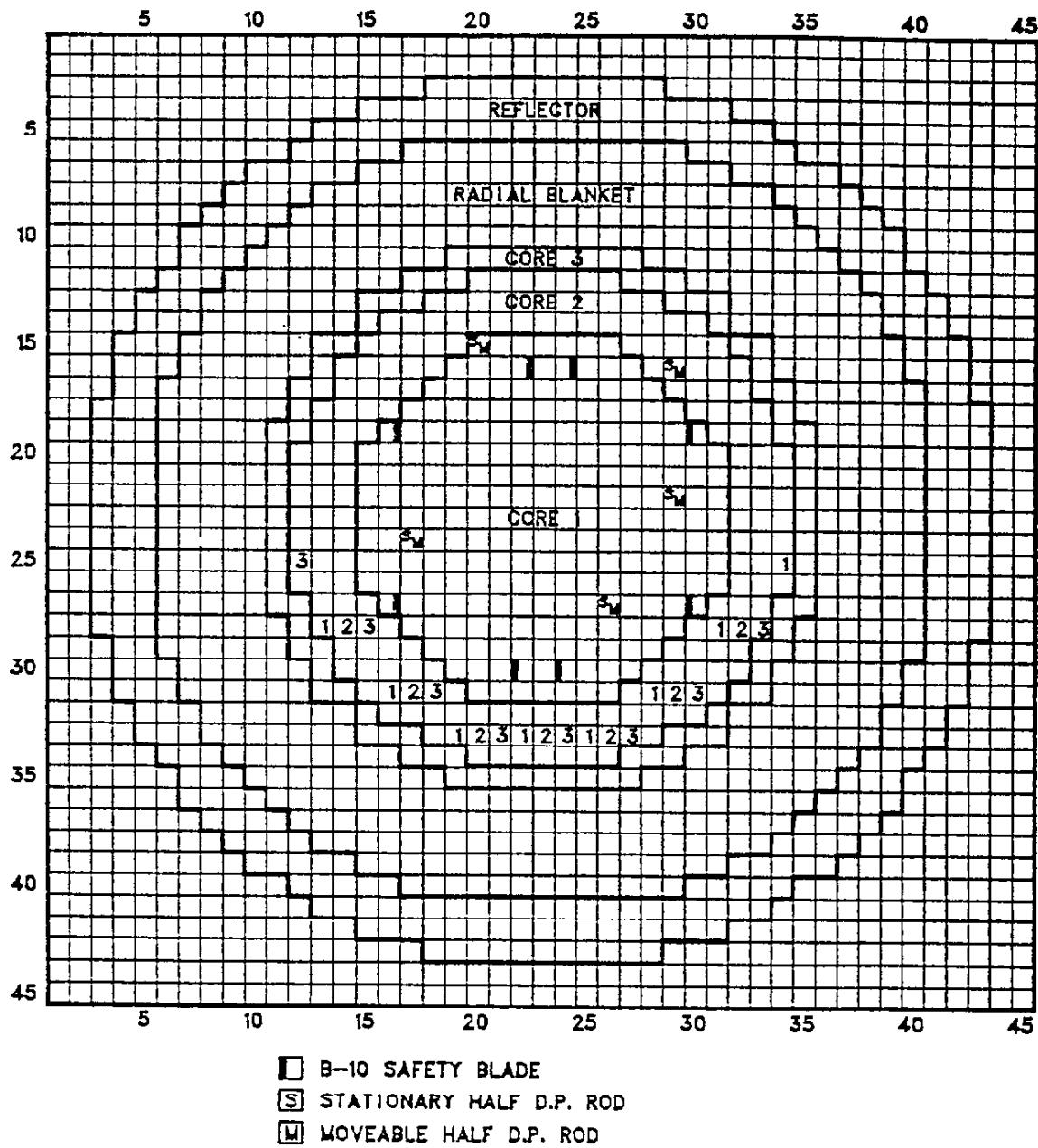


Fig. 102. Interface Diagram for ZPR9-30 (GCFR-III)

A144

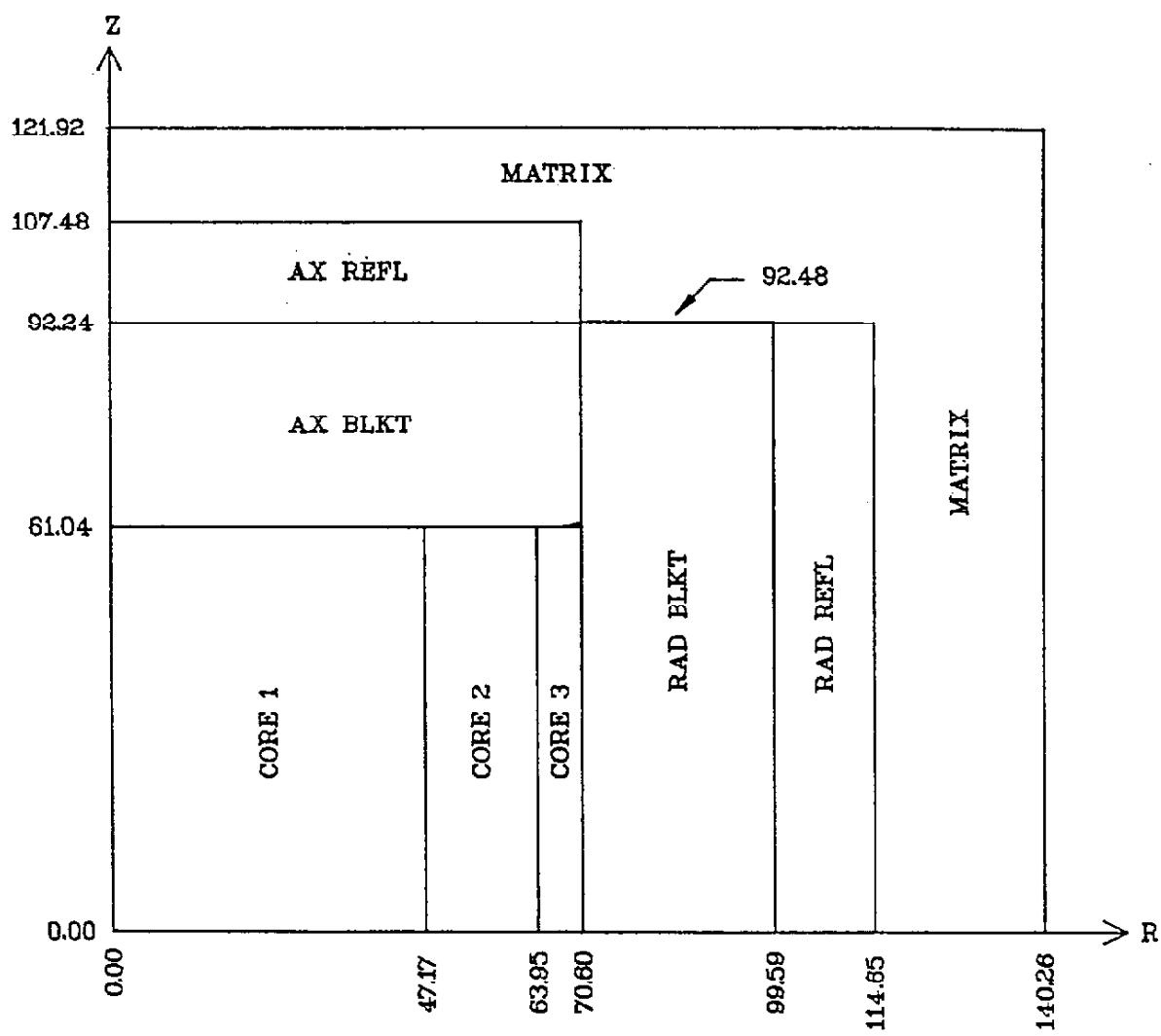


Fig. 103. R-Z Model for ZPR9-30 (GCFR-III)

A145

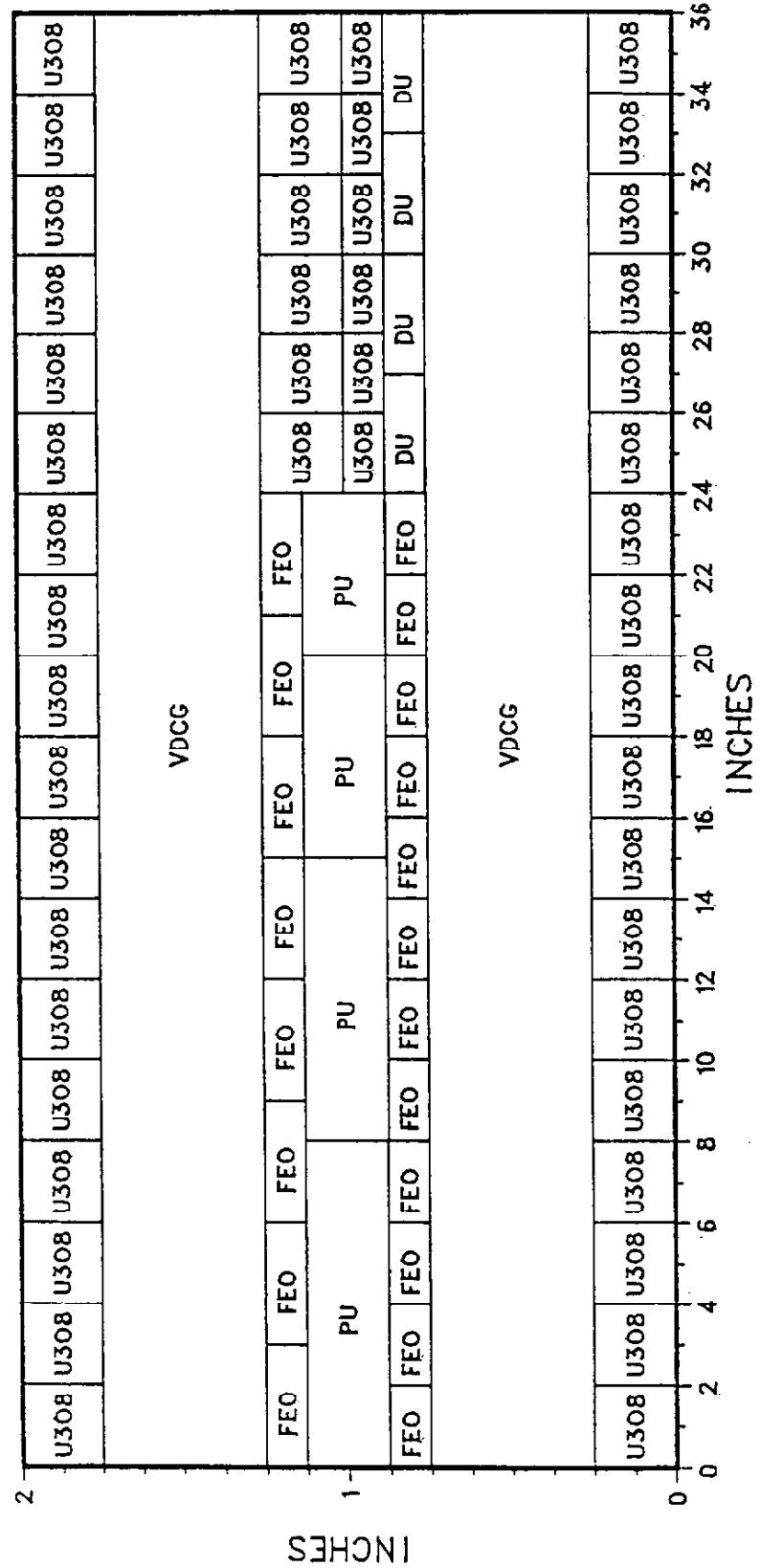


Fig. 104. Drawer Loading Pattern for ZPR9-30 (GCFR-III)

A146

Advanced Fuels Program, consisting of a plutonium carbide benchmark assembly and two different zones inside the benchmark assembly.

Overview:

The purpose of this program was to study the physics properties of some proposed alternate fuels. The clean, single zone benchmark assembly was plutonium carbide and the two zones constructed at the center of the benchmark assembly after measurements on the benchmark assembly were completed were plutonium carbide (with a lower plutonium concentration) and plutonium oxide.

Assembly Dates:

November 1976-June 1977

Related Assemblies:

Assembly Details (Benchmark Assembly):

Type:	Clean, cylindrical, single-zone physics assembly
Fuel:	Pu/U carbide with Na cooling
Critical Mass:	890 kg (Pu^{239} + Pu^{241})
Volume:	1900 liters
Blanket:	Depleted uranium (DU) carbide with Na cooling
Reflector:	Stainless steel

Assembly Variants:

Pu/U carbide zone at the center of the benchmark assembly. A reduced plutonium concentration from that of the benchmark.

Pu/U oxide zone at the center of the benchmark assembly. The oxide zone contained the same plutonium concentration as the standard ZPR6-7 composition but a higher oxygen concentration.

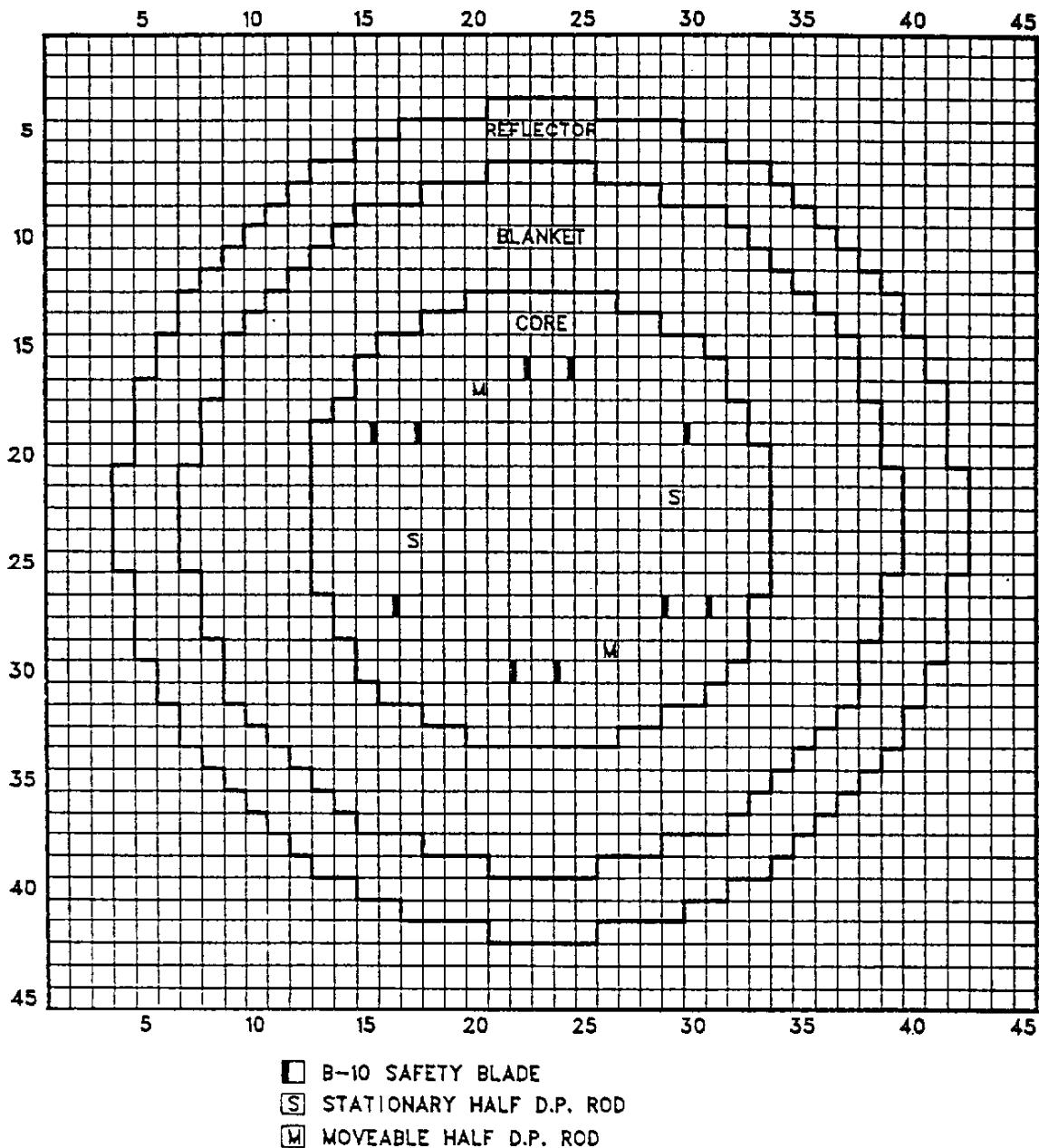


Fig. 105. Interface Diagram for ZPR9-31

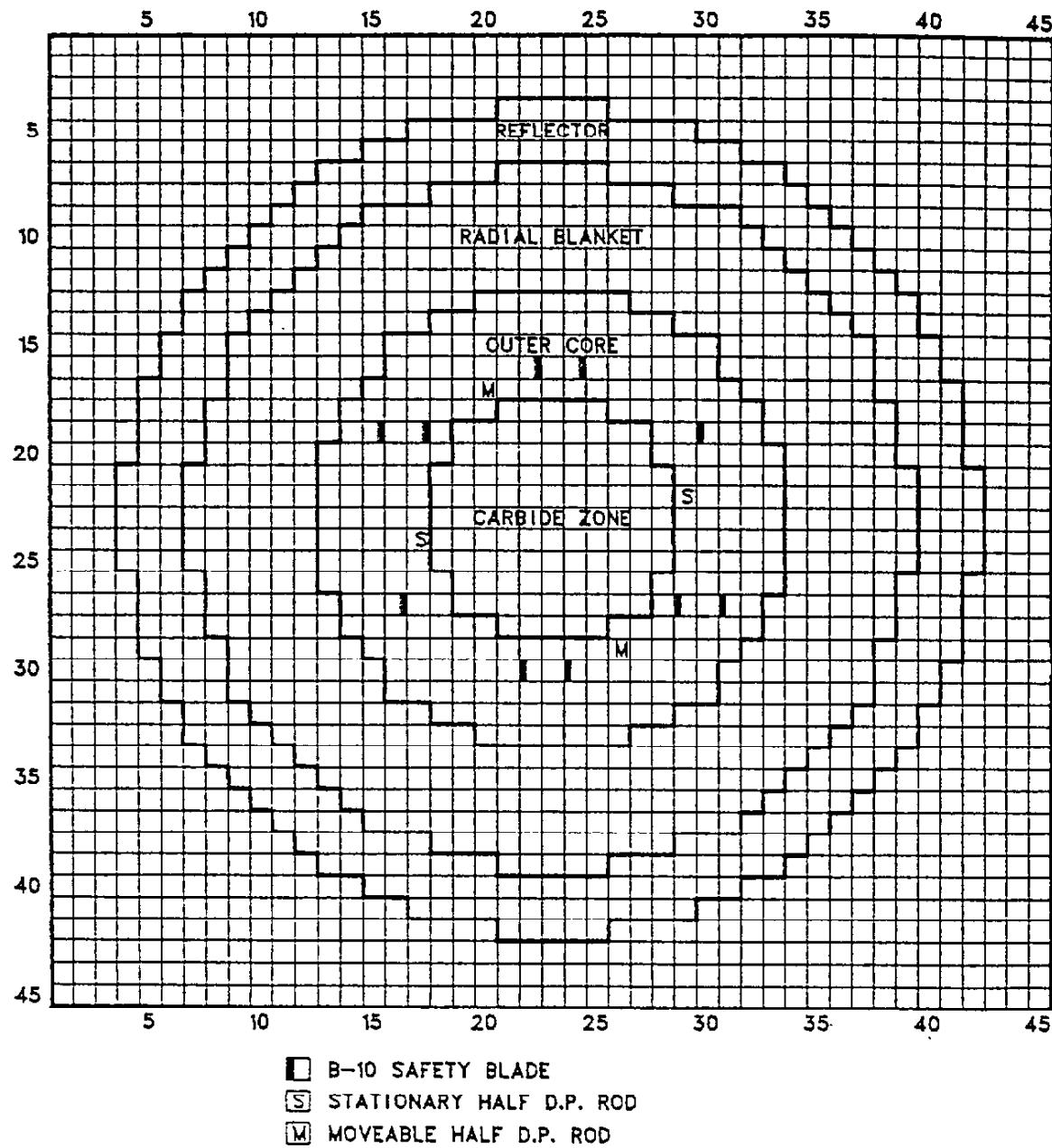


Fig. 106. Interface Diagram for ZPR9-31 with Carbide Zone

A150

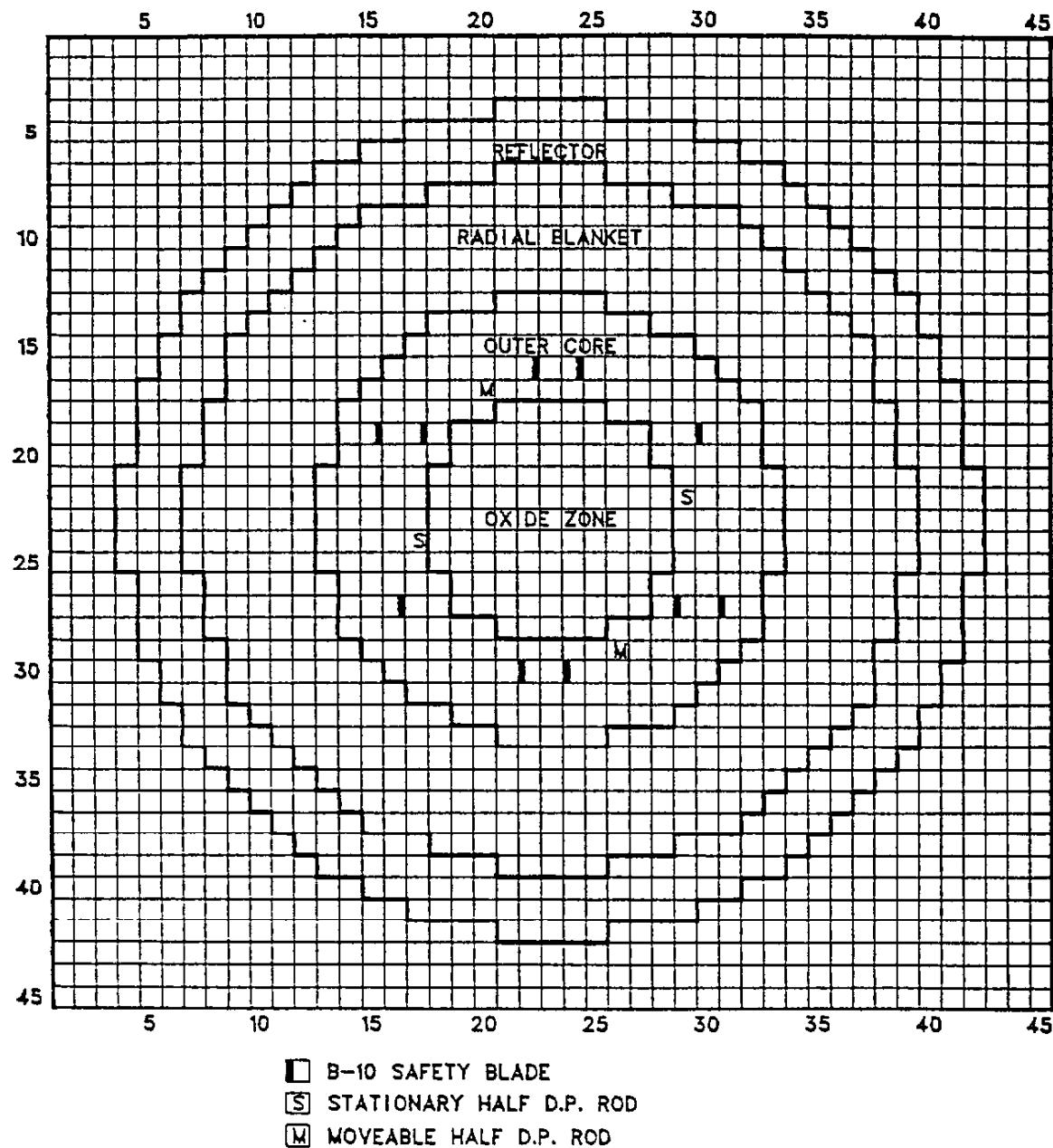


Fig. 107. Interface Diagram for ZPR9-31 with Oxide Zone

A151

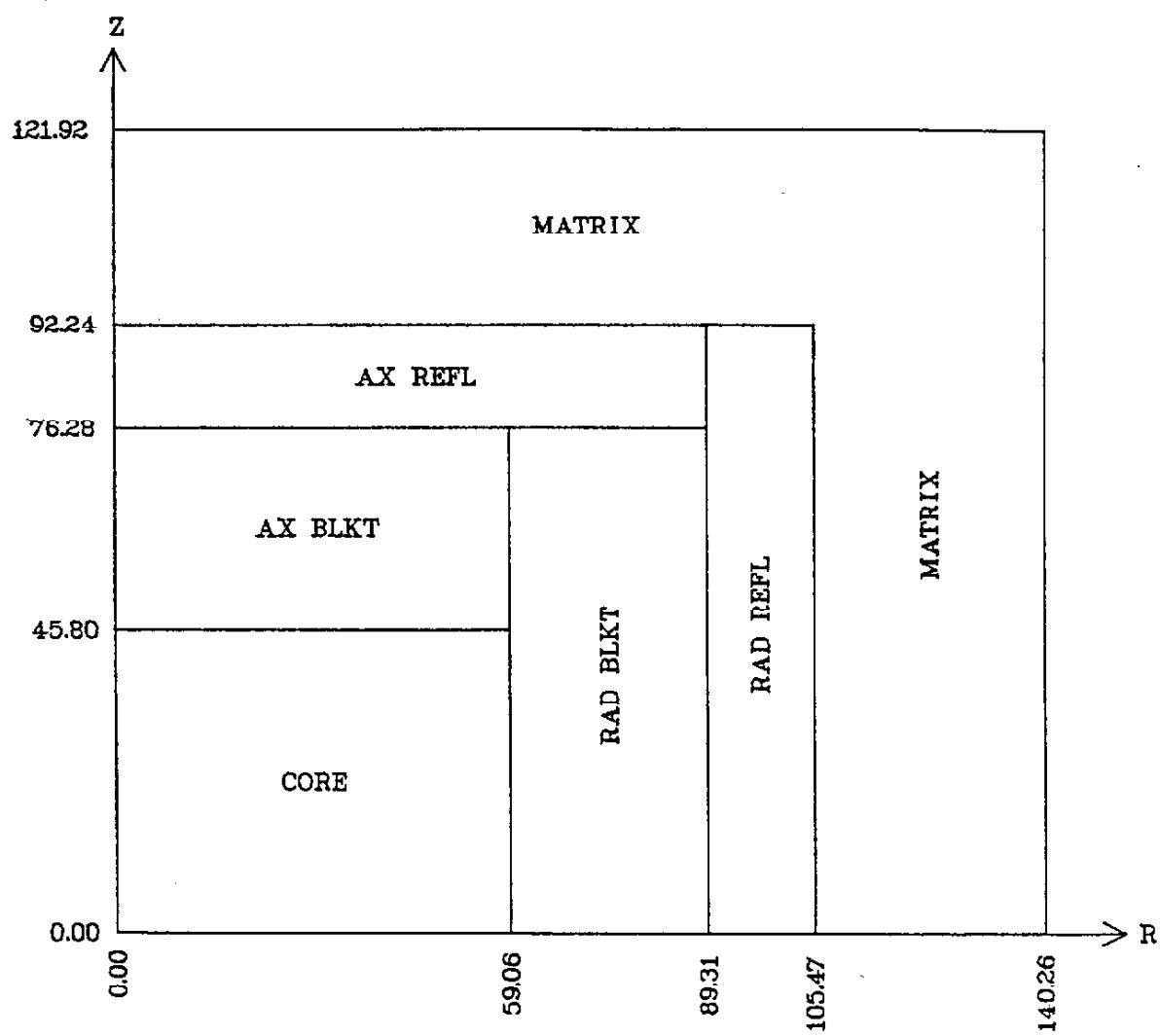
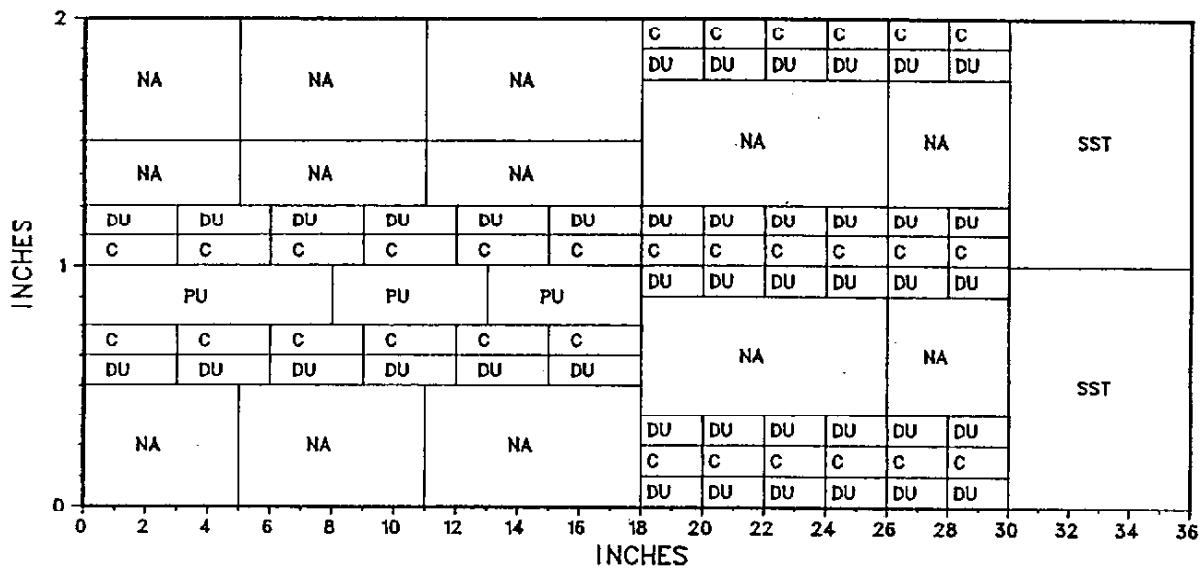
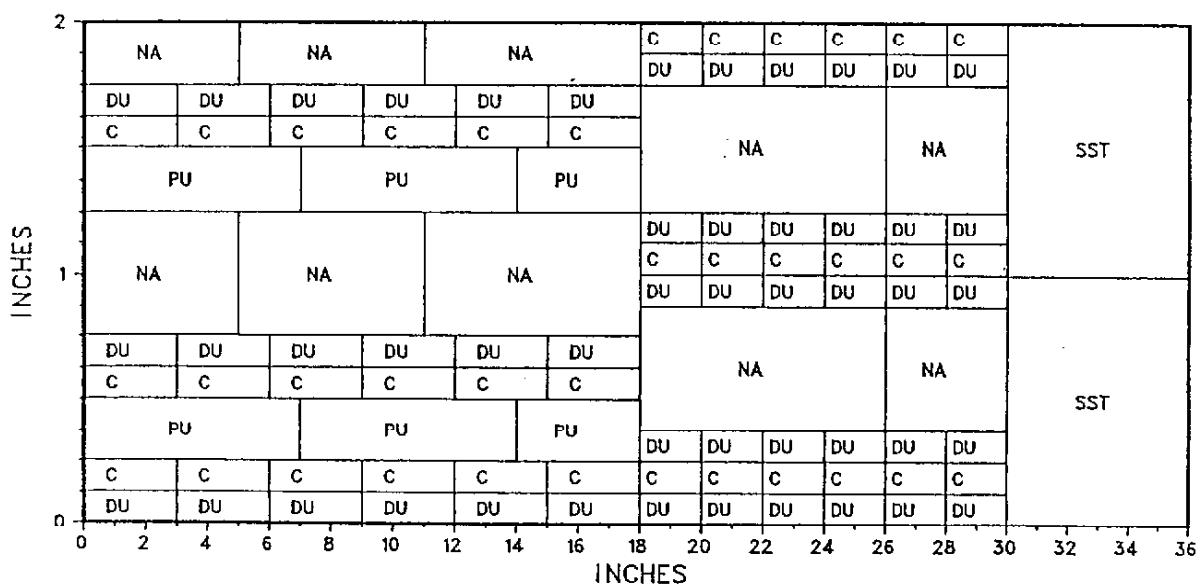


Fig. 108. R-Z Model for ZPR9-31



Type 1 Core Drawer



Type 2 Core Drawer

Fig. 109. Drawer Loading Patterns for ZPR9-31 Two-Drawer Unit Cell.
The Type-1 drawer was also used in the carbide zone.

A153

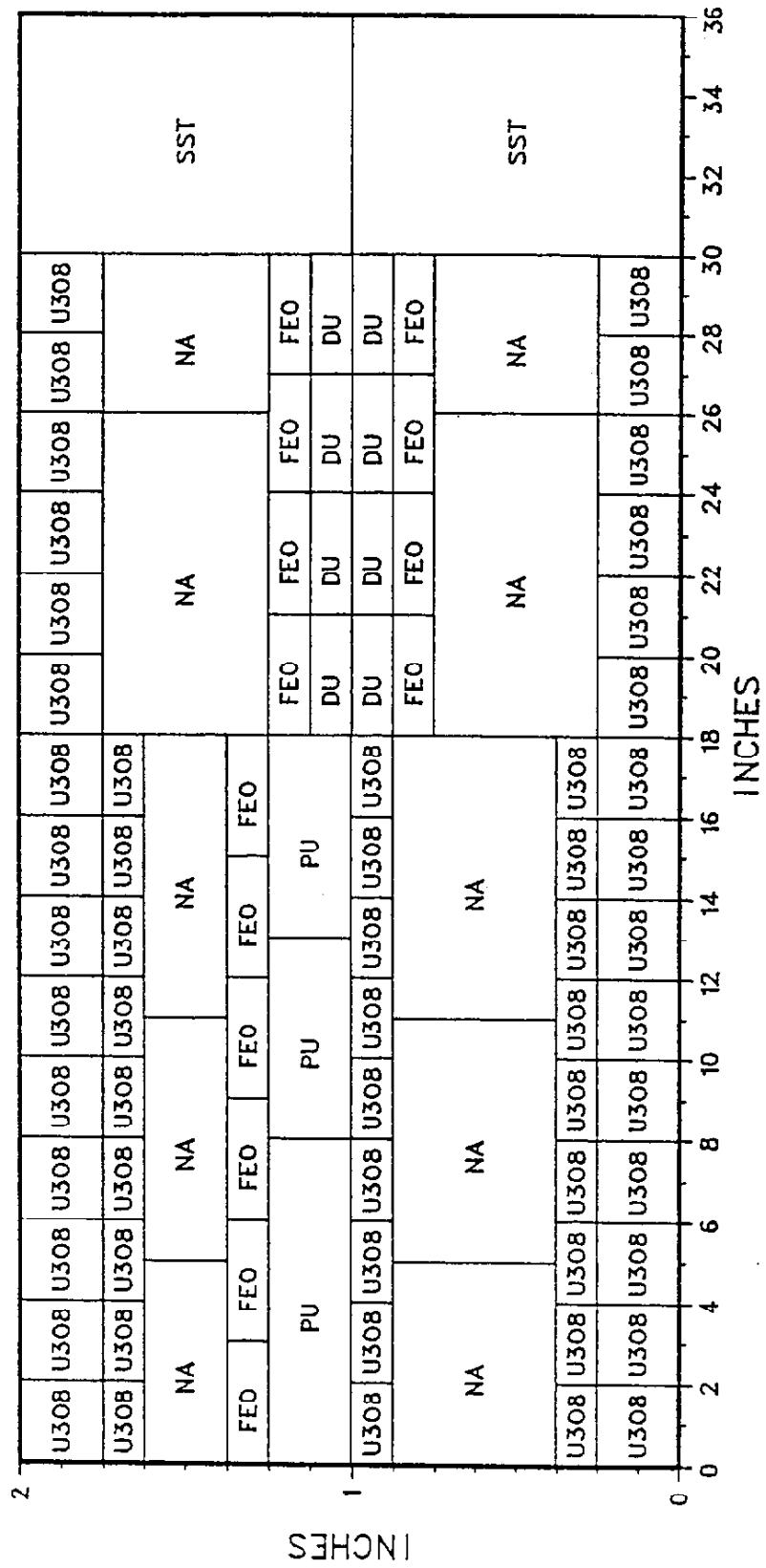


Fig. 110. Drawer Loading Pattern for ZPR9-31 Oxide Zone

A154

Safety related critical experiments (meltdown simulations).

Overview:

This program consisted of a clean, cylindrical, single-zone reference core followed by a sequence of idealized configurations designed to simulate various steps in a hypothetical severe core meltdown accident resulting from a loss-of-flow transient. Sodium voiding, fuel slumping, and axial blanket collapse were all simulated. Measurements focused on the reactivity worths of the various configurations and spatial distributions of key indices.

Assembly Dates:

July 1977-January 1978

Related Assemblies:

Fuel slumping experiments were also conducted in ZPPR-5 and ZPR3-27 and -28.

Assembly Details (Reference Configuration):

Type:	Cylindrical, single-zone physics benchmark-type core
Fuel:	Typical Pu/U oxide with sodium cooling. Plutonium concentration slightly higher than outer core composition of a typical CRBR size core.
Critical Mass:	330 kg (Pu^{239} + Pu^{241})
Volume:	560 liters
Blanket:	Depleted uranium (DU) with sodium cooling
Reflector:	Depleted uranium

Assembly Variants:

Reference Core

Sodium Voided Test Zone

Fuel Slump Out

Fuel Slump In

Axial Asymmetric Fuel Slump In

Axial Asymmetric Fuel Slump In with Blanket Collapse

Axial Asymmetric Fuel Slump Out

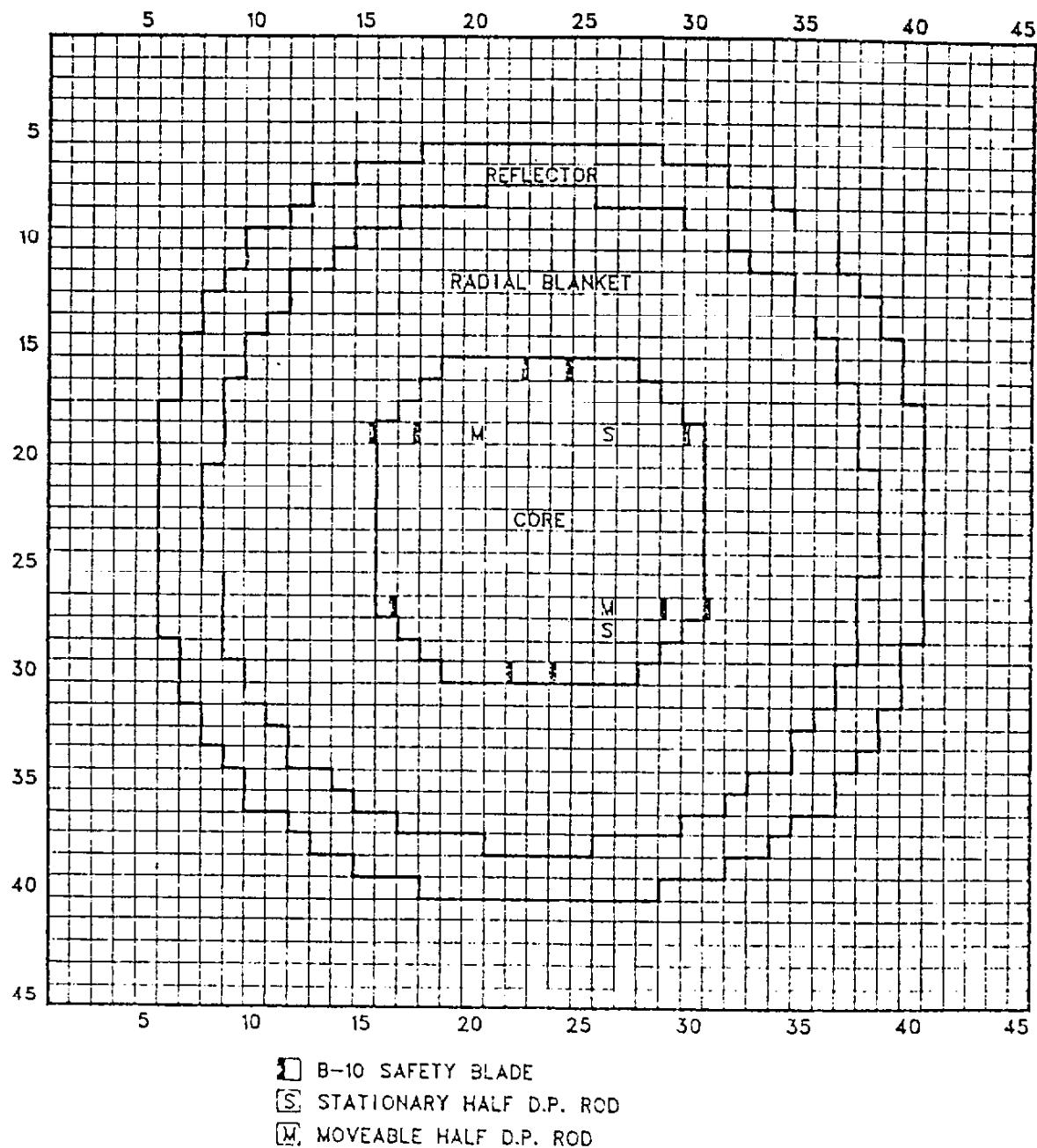


Fig. 111. Interface Diagram for ZPR9-32 Reference Core

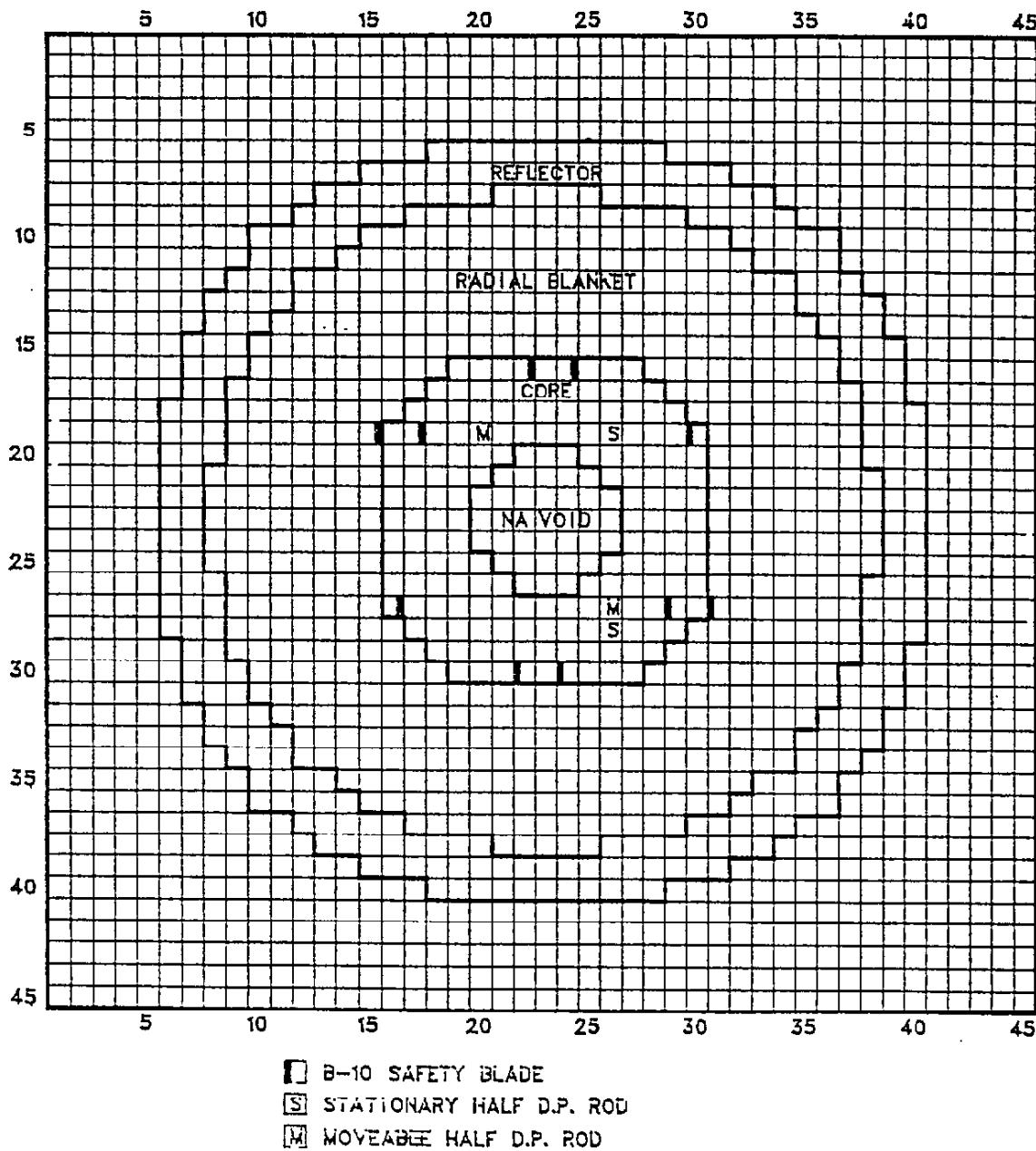


Fig. 112. Sodium Voided Region and Test Zone (the same) in ZPR9-32

A158

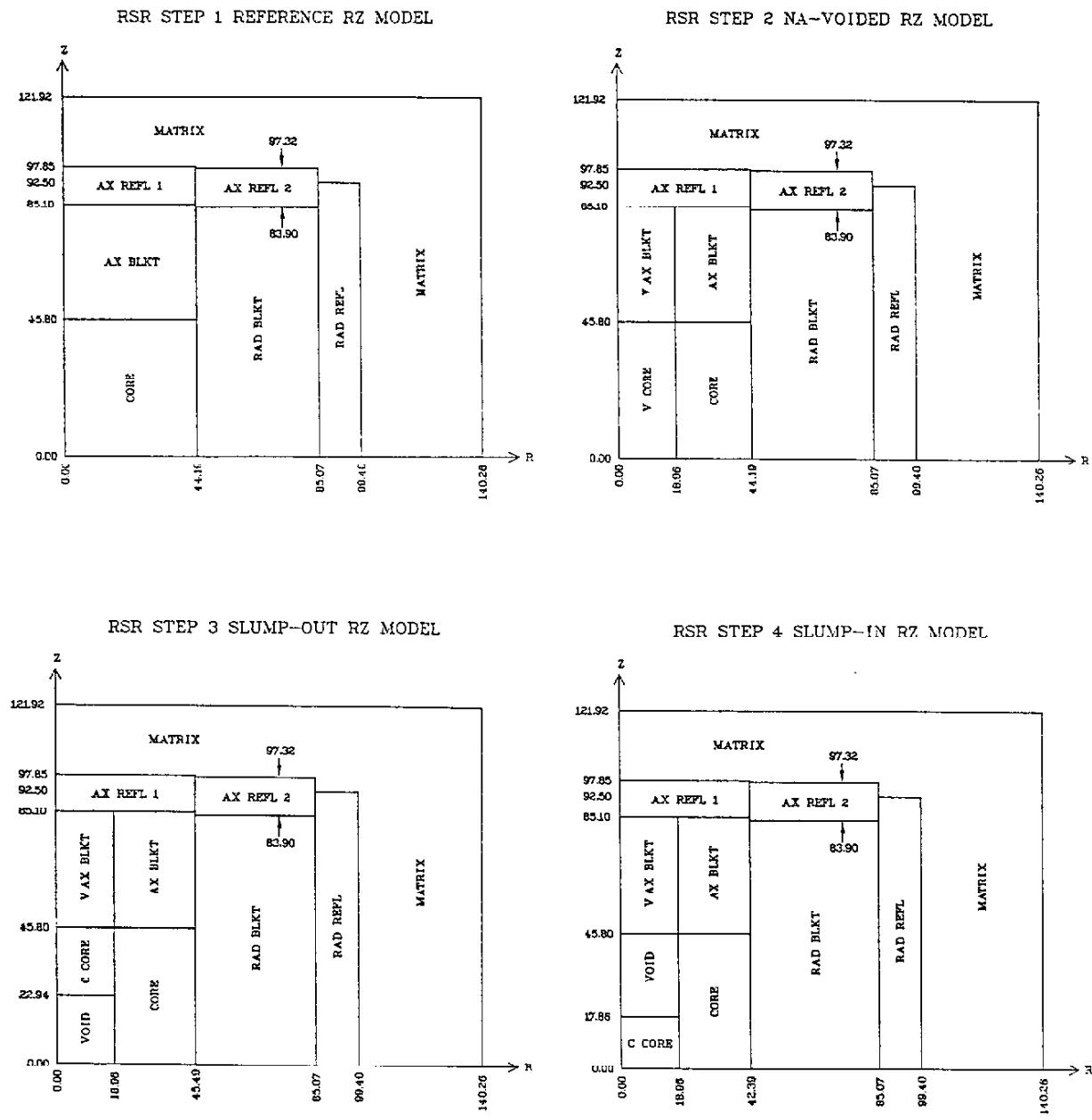
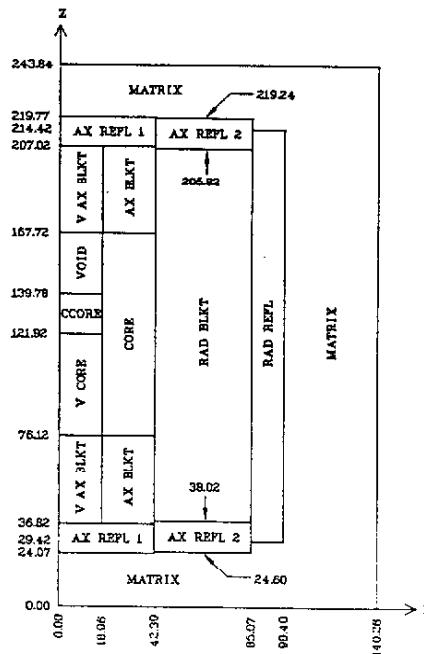
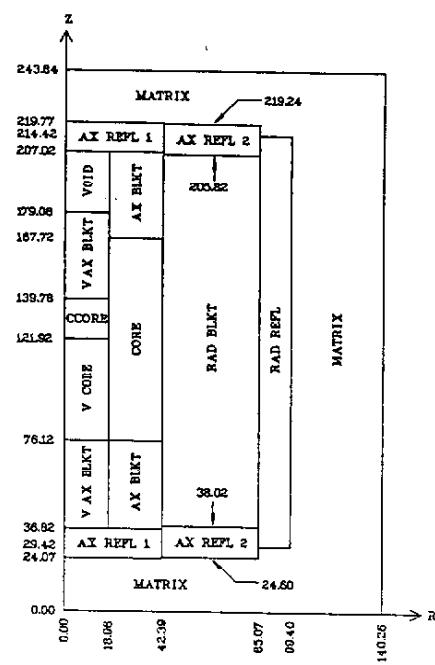


Fig. 113. R-Z Model for ZPR9-32 Reference, Sodium Void, Fuel Slump-Out, and Fuel Slump-In Configurations

RSR STEP 5 ASYMMETRIC SLUMP-IN RZ MODEL



RSR STEP 6 ASYM SLUMP-IN W/ BLKT COLLAPSE RZ MODE



RSR STEP 7 ASYMMETRIC SLUMP-OUT RZ MODEL

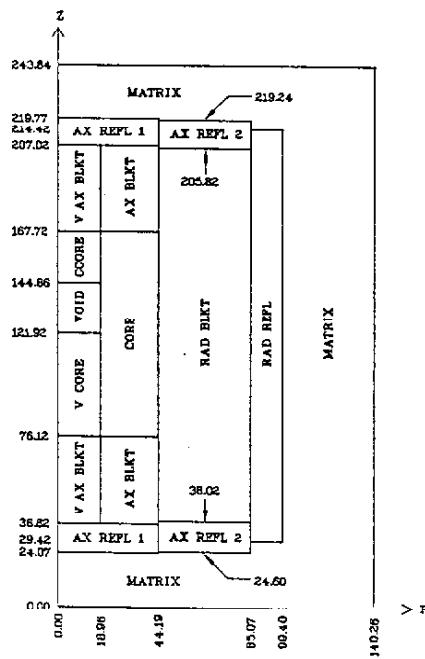


Fig. 114. R-Z Models for ZPR9-32 Asymmetric Slump-In, Asymmetric Slump-In with Axial Blanket Collapse, and Asymmetric Slump-Out Configurations

A160

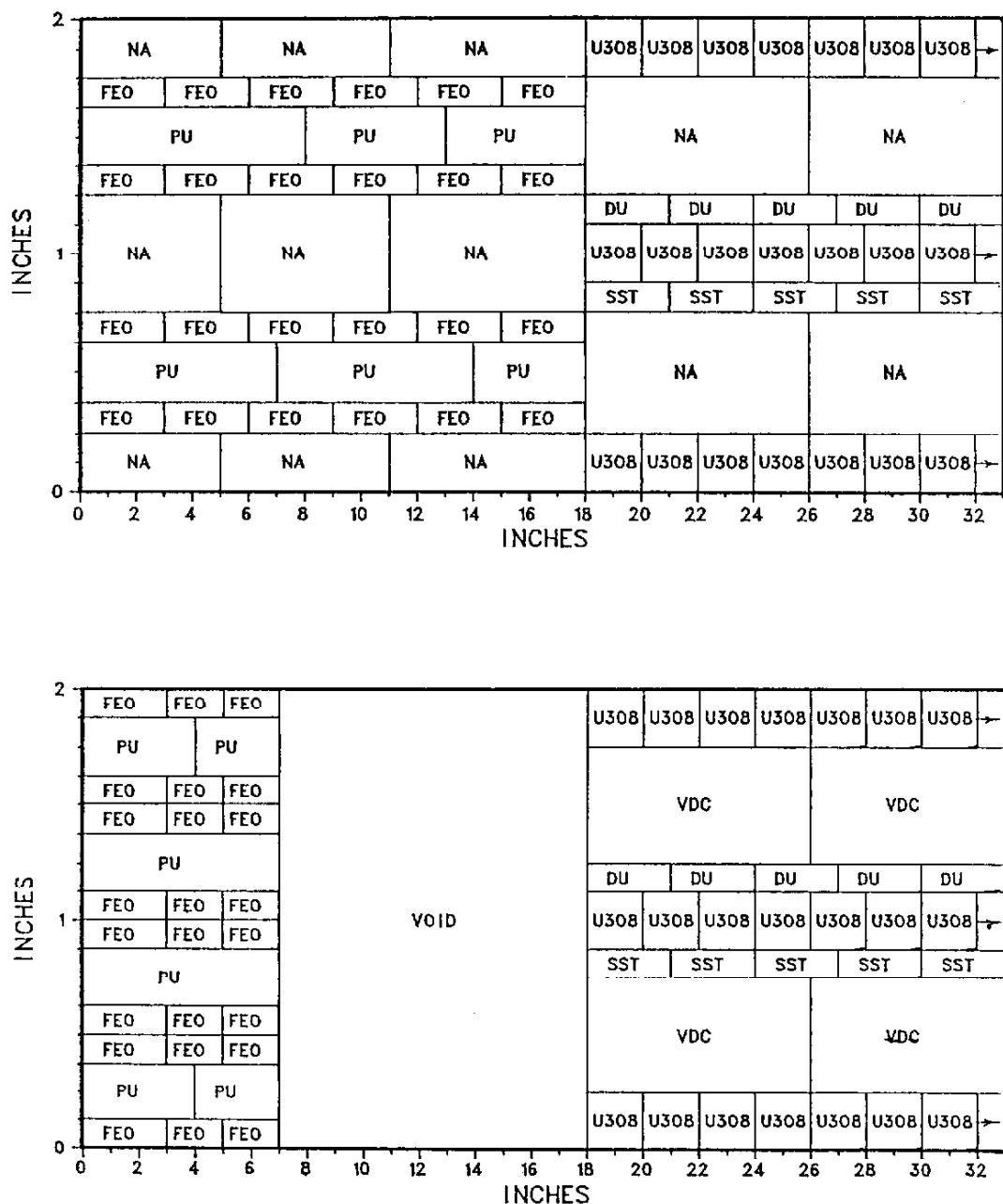


Fig. 115. Drawer Loading Patterns for ZPR9-32 Reference and Fuel Slump-In Configurations

Safety Test Facility (STF) All-Converter Assembly.

Overview:

The STF was a test reactor designed to perform overpower transient tests on groups of fast reactor subassemblies. The STF was not built; however, this experiment was performed to support the design. The STF design consisted of a central test region, surrounded by a large converter region, and this was surrounded by a large epithermal spectrum driver region. The converter region was designed to convert the driver neutron spectrum to the desired fast spectrum of the test region. Assembly 33 was a single-zone core made up entirely of the converter region composition.

Assembly Dates:

March 1978-May 1979

Related Assemblies:

None

Assembly Details:

Type: Large, clean, cylindrical physics benchmark-type core
Fuel: Enriched uranium (low concentration) and iron
Critical Mass: 1420 kg U²³⁵
Volume: 4300 liters
Reflector: Stainless steel

Assembly Variants:

Reference Assembly with 3/4 fuel loading (three columns of enriched uranium fuel in every four core drawers)

Assembly with 4/5 fuel loading--slightly small size.

Note: Assembly 33 used aluminum trays rather than the normal stainless-steel drawers for both the core and axial blanket loadings.

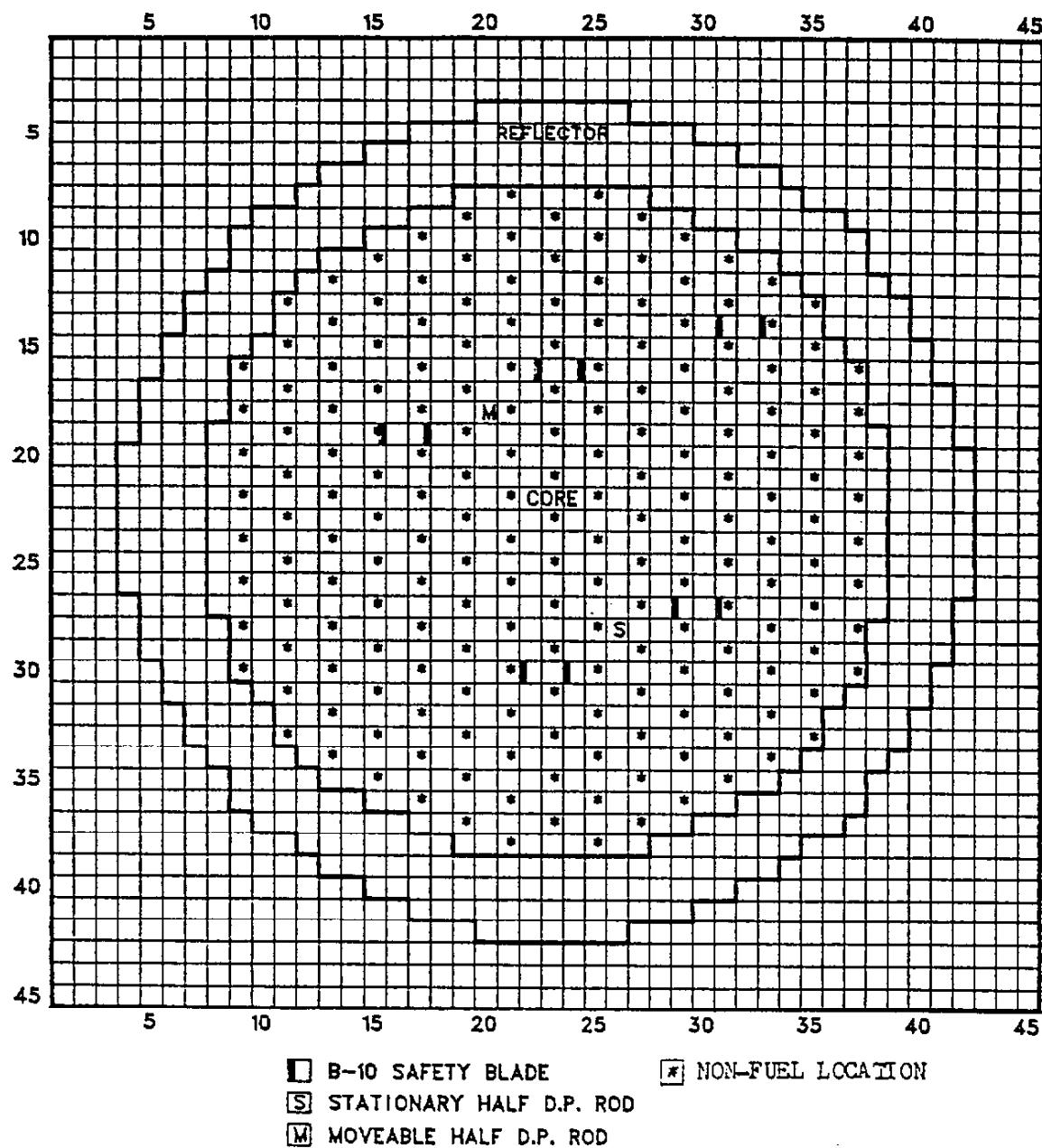


Fig. 116. Interface Diagram for ZPR9-33 (Safety Test Facility 3/4 Loading)

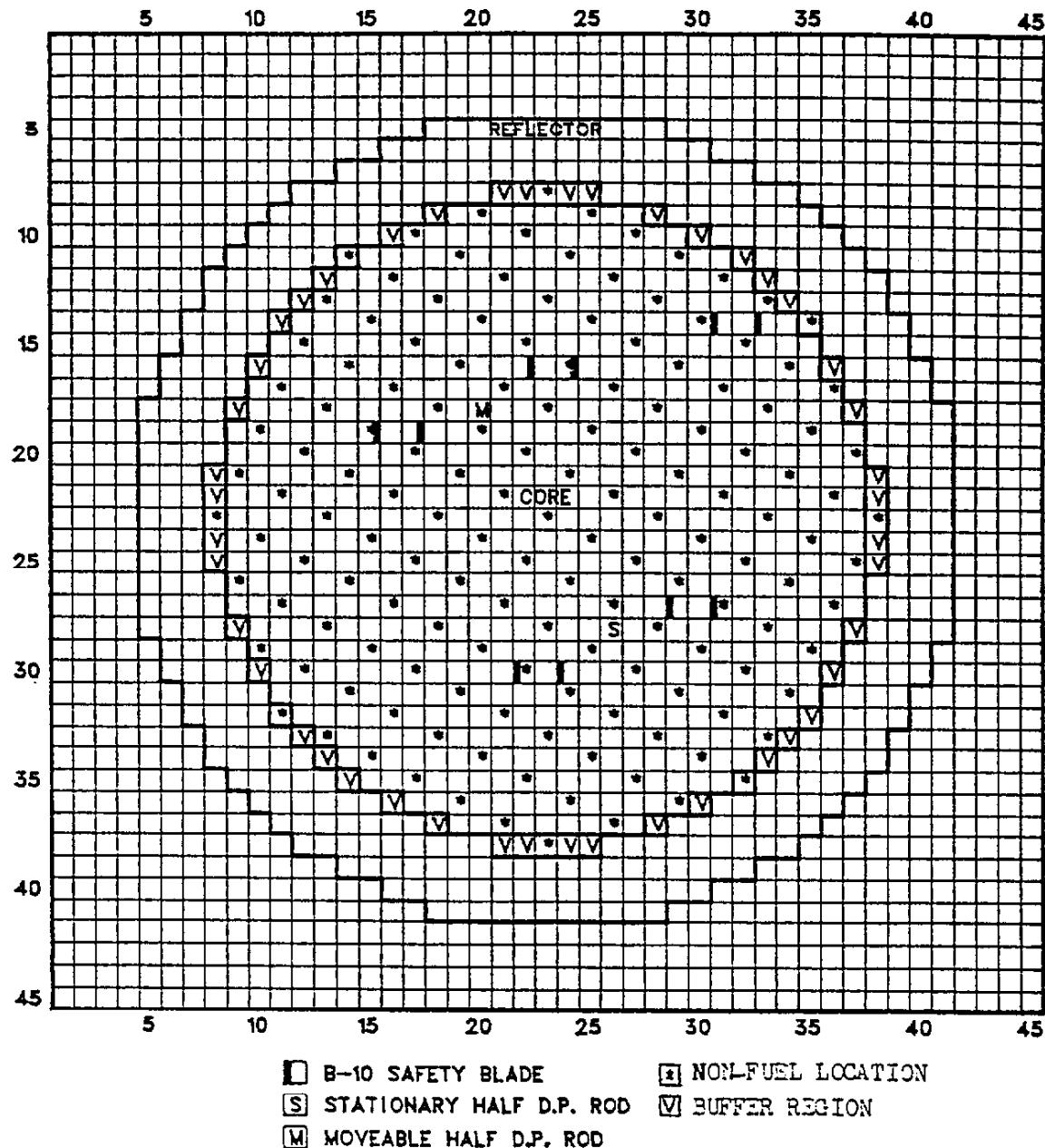
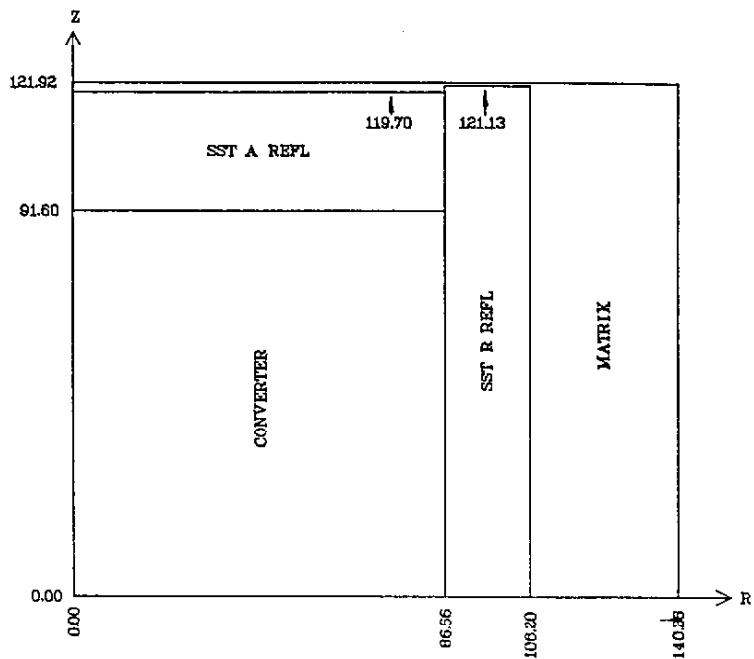


Fig. 117. Interface Diagram for ZPR9-33 (Safety Test Facility 4/5 Loading)

A164



EU

SPR

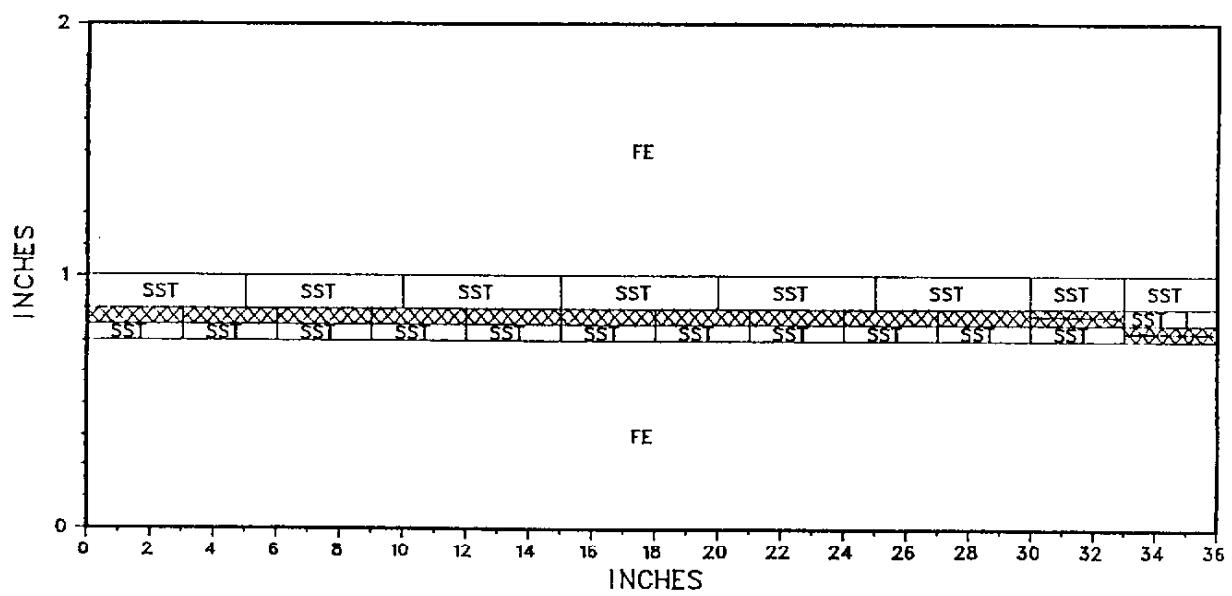


Fig. 118. R-Z Model and Drawer Loading Pattern for ZPR9-33 (Safety Test Facility 3/4 Loading)

ZPR9-34 and -35

Uranium/iron benchmark assembly. Part of the Diagnostic Cores Program.

Overview:

The Diagnostic Cores Program consisted of a series of critical assemblies designed to evaluate longstanding discrepancies between calculated and experimental fast reactor integral physics parameters. The diagnostic cores assemblies were designed to isolate the effects of specific isotopes and regions of the neutron spectrum. Assembly 34 was a very clean design consisting of only enriched uranium and iron. Assembly 35 was a Pu/U oxide zone plate (similar to ZPR6-6A) loaded in the center of Assembly 34. It was surrounded by a compositionally-matched pin zone.

Assembly Dates:

May 1979-June 1980

Related Assemblies:

The other assemblies in the Diagnostic Cores Program were ZPR9-36, ZPR6-9 (same as ZPR9-36), and ZPR6-10.

Assembly Details (Assembly 34):

Type:	Clean, cylindrical, single-zone benchmark core
Fuel:	Enriched uranium and iron
Critical Mass:	990 kg U ²³⁵
Volume:	2265 liters
Reflector:	Stainless steel with depleted uranium (DU) outer reflector

Assembly Variants:

Reference Configuration

Leaky U/Fe Assembly--the outer DU reflector was removed

ZPR9-35: This assembly was really a variation of Assembly 34. It consisted of a symmetrical ZPR6-6A plate zone, surrounded by a compositionally matched pin zone both loaded into the center of Assembly 34. The measurements focused on the central worth discrepancy.

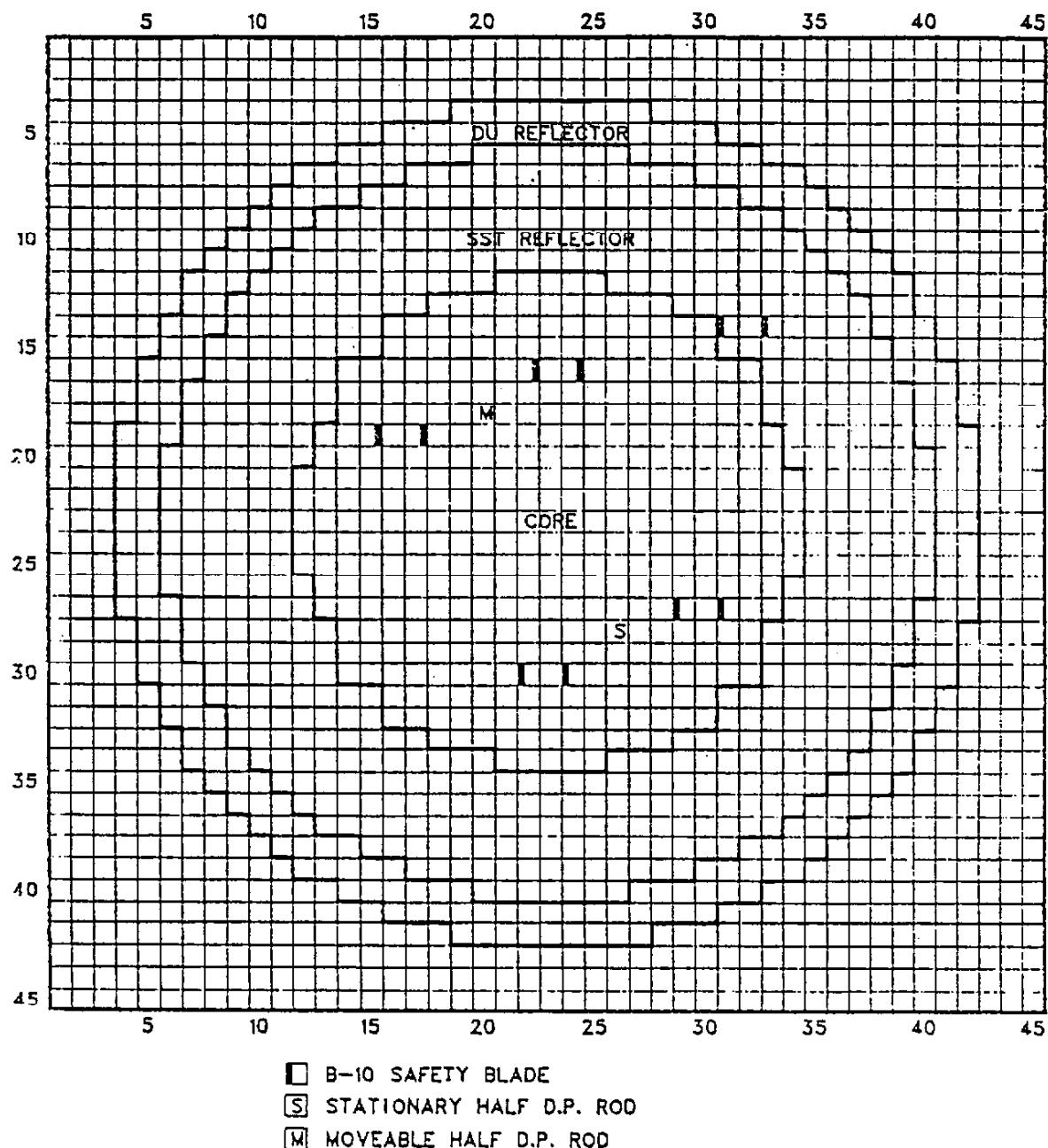


Fig. 119. Interface Diagram for ZPR9-34 (U/Fe Benchmark)

A167

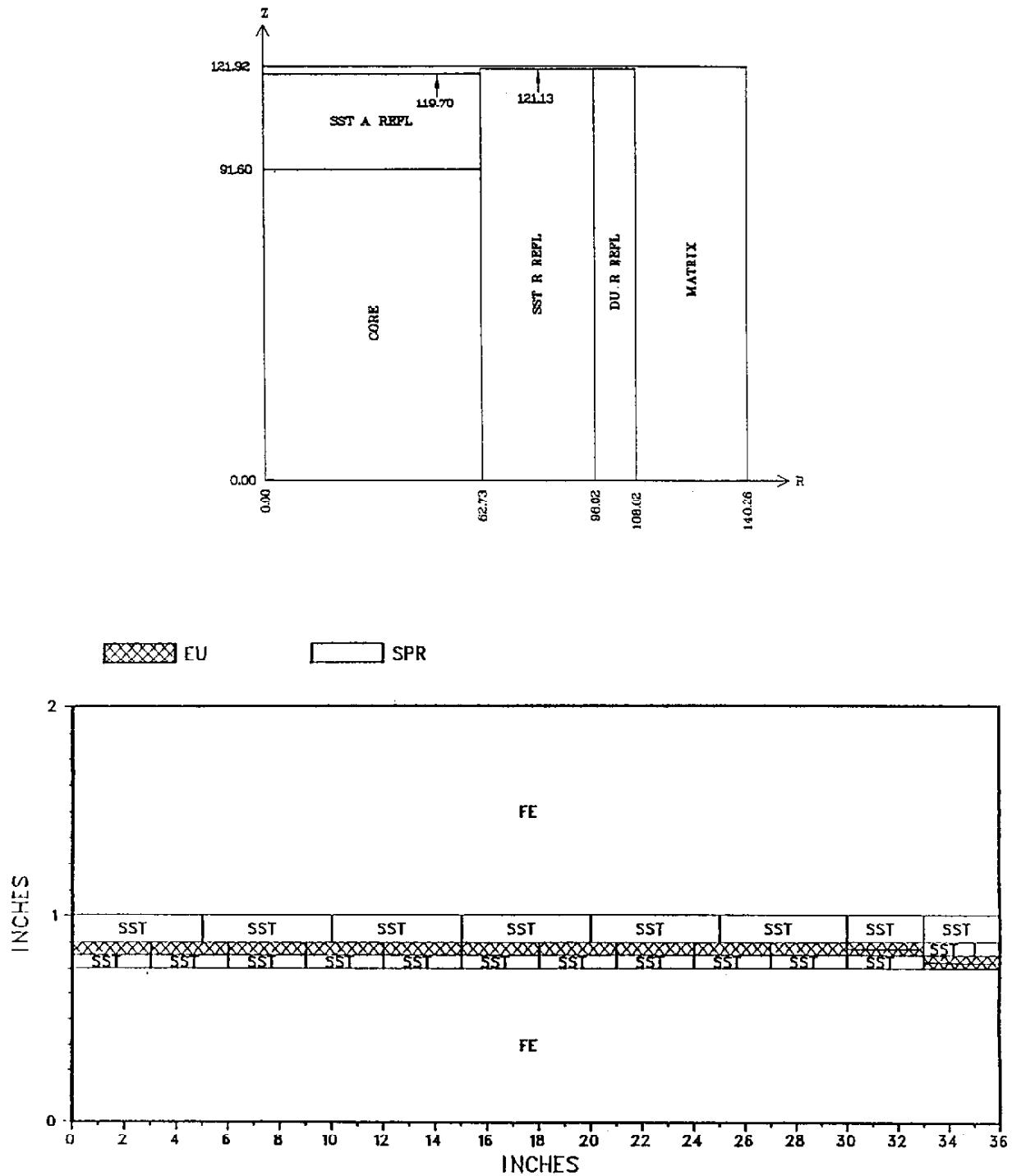


Fig. 120. R-Z Model and Drawer Loading Pattern for ZPR9-34

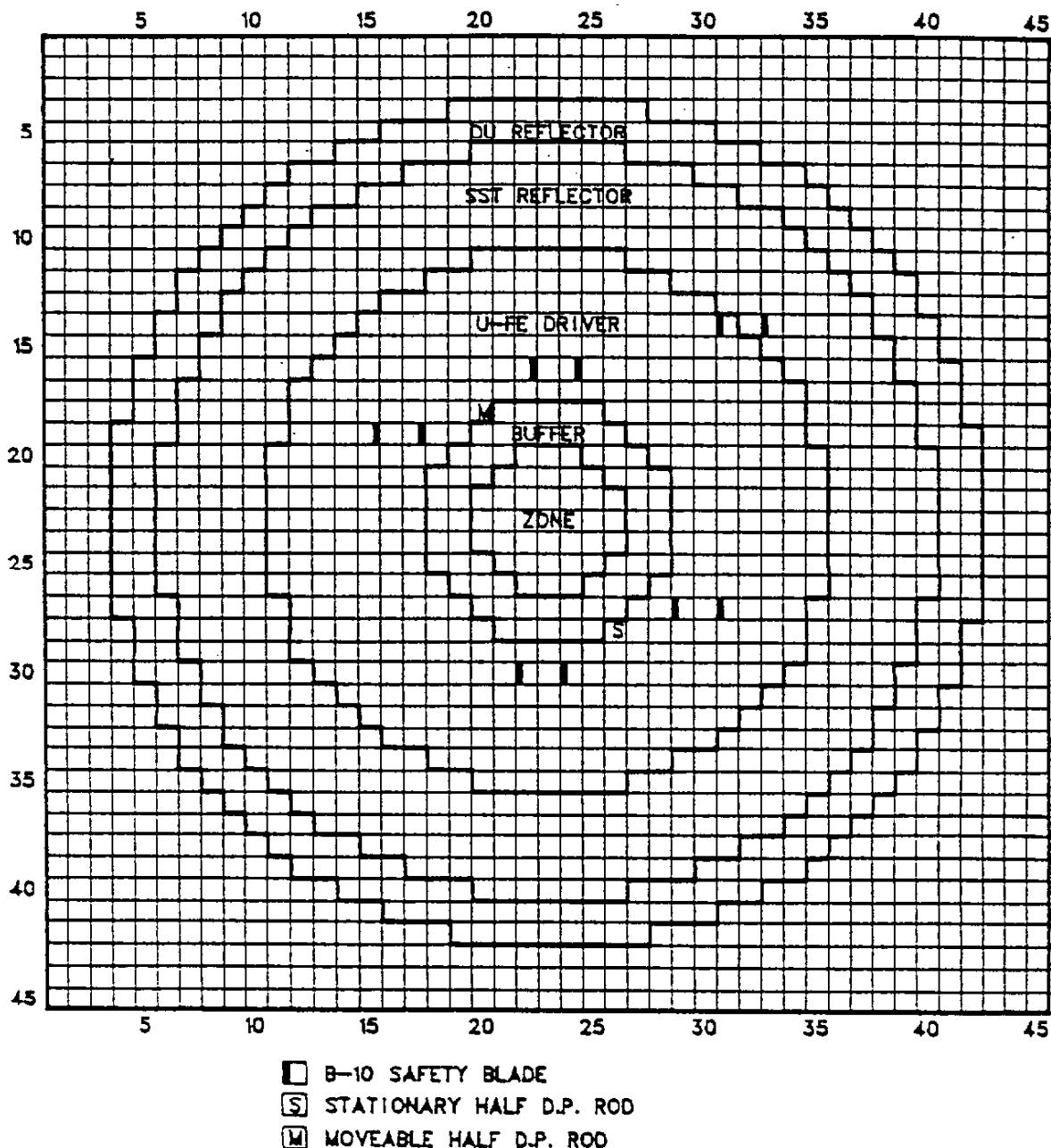


Fig. 121. Interface Diagram for ZPR9-35

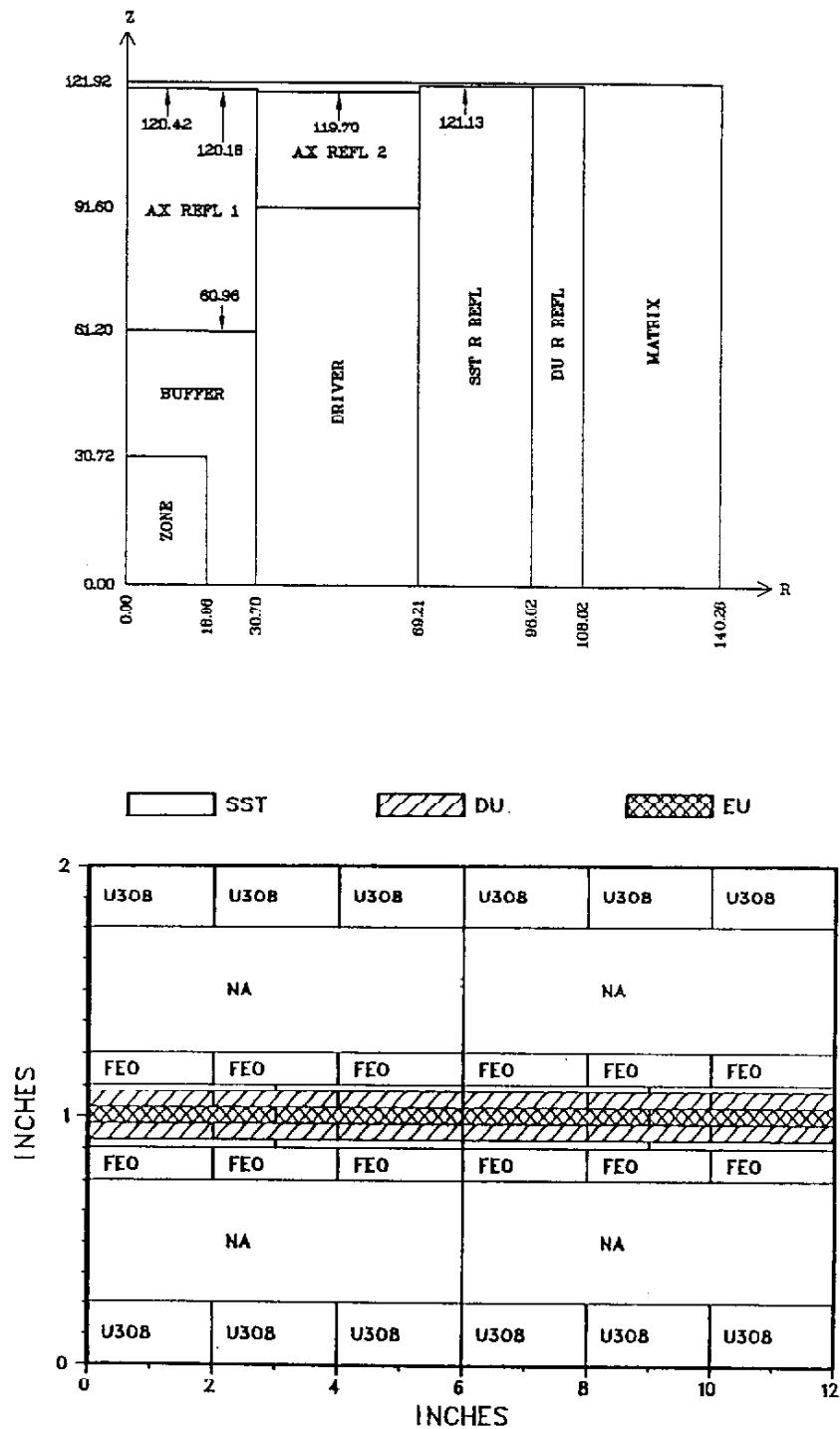


Fig. 122. R-Z Model for ZPR9-35 with Central Zone and Drawer Loading Pattern for the Zone

A170

ZPR9-36

All-uranium core with 9% enrichment (i.e., the U9 core). Part of the Diagnostics Cores Program.

Overview:

This assembly consisted of only enriched and depleted uranium (plus the stainless steel in the matrix) at 9% enrichment. It was a clean, cylindrical benchmark assembly.

Assembly Dates:

August 1980-August 1981

Related Assemblies:

The other assemblies in the Diagnostic Cores Program were: ZPR9-34, ZPR9-35, ZPR6-9 (the same as this core), and ZPR6-10. It was also somewhat similar to the LANL Big-10 assembly.

Assembly Details:

Type: Clean, cylindrical, single-zone benchmark
Fuel: Enriched uranium and depleted uranium
Critical Mass: 550 kg U²³⁵
Volume: 400 liters
Blanket: Depleted uranium

Assembly Variants:

Reference Assembly

Clumped Fuel Zone: The three enriched uranium (EU) columns per drawer were clumped together in a central zone to maximize the heterogeneity effect.

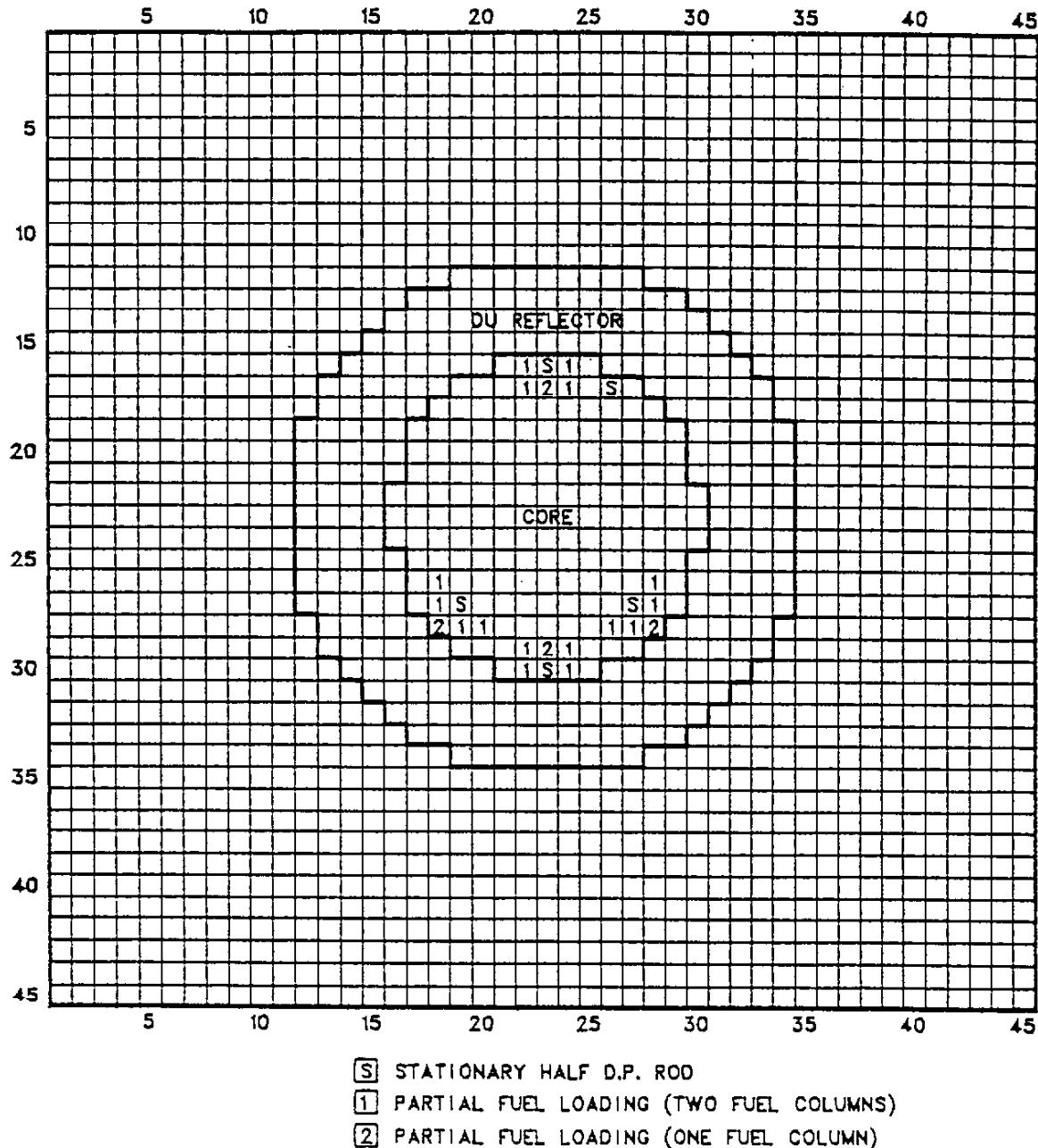


Fig. 123. Interface Diagram for ZPR9-36

A173

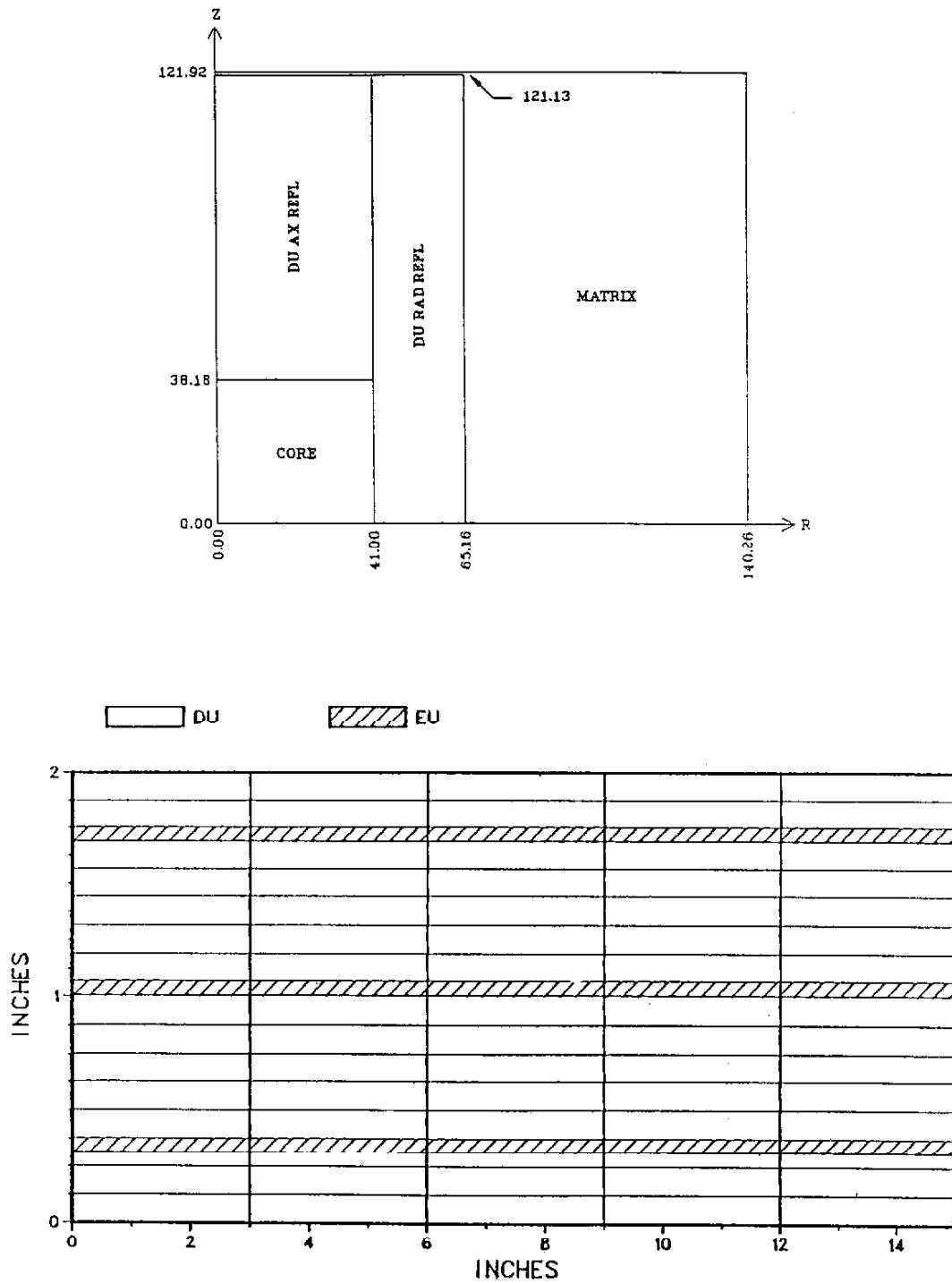


Fig. 124. R-Z Model and Drawer Loading Pattern for ZPR9-36

A174

ZPR6-1

All uranium assembly (14% enriched).

Overview:

ZPR6 became operational in July 1963. The purpose of ZPR6-1 was to provide a test of the ZPR6 facility and the experimental equipment and techniques that had been developed for the facility. The core was similar to ZPR3-22.

Assembly Dates:

July 23, 1963-December 1963

Related Assemblies:

Similar in composition and geometry to ZPR3-22. Also similar to ZPR3-11.

Assembly Details:

Type:	Clean, cylindrical core with H/D* = 0.88
Fuel:	Enriched and depleted uranium (12.5% enriched)
Critical Mass:	235 kg U ²³⁵
Volume:	140 liters

*H/D is the core height divided by the core diameter.

A176

ZPR6-2

Uranium carbide core (600 liters).

Overview:

This was a clean, cylindrical, medium-sized physics benchmark assembly. The primary focus of the measurements was sodium void reactivity.

Assembly Dates:

December 1963-July 1964

Related Assemblies:

ZPR6-3, ZPR6-4Z, and ZPR6-5 were also uranium carbide assemblies.

Assembly Details:

Type:	Clean, cylindrical physics benchmark with H/D* \approx 1
Fuel:	Uranium carbide with sodium cooling
Critical Mass:	550 kg U ²³⁵
Volume:	600 liters
Blanket:	Depleted uranium

Assembly Variants:

None

*H/D is the core height divided by the core diameter.

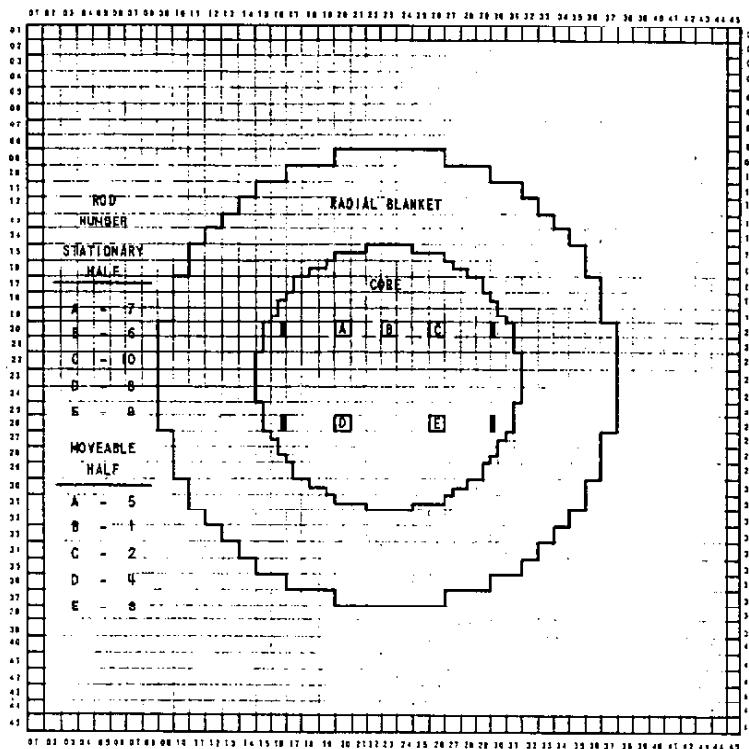


Fig. 125. Interface Diagram and Drawer Loading Pattern for ZPR6-2

ZPR6-3

Uranium carbide pancake core (950 liters).

Overview:

This assembly had an H/D of 1/3. It had the same core composition as ZPR6-2. It was built to determine if the pancake configuration would result in a significant reduction in the positive sodium void reactivity (relative to ZPR6-2) due to the relatively larger importance of neutron leakage in this core. The focus of the measurements was sodium void reactivity in zones of various shapes and sizes.

Assembly Dates:

August 1964-

Related Assemblies:

ZPR6-2, ZPR6-4Z, and ZPR6-5 were also uranium carbide assemblies.

Assembly Details:

Type: Clean, cylindrical, physics benchmark with H/D of 1/3
Fuel: Uranium carbide with sodium cooling
Critical Mass: 850 kg U²³⁵
Volume: 950 liters
Blanket: Depleted uranium

Comment: There was only a modest decrease in positive sodium void between ZPR6-2 and ZPR6-3.

A180

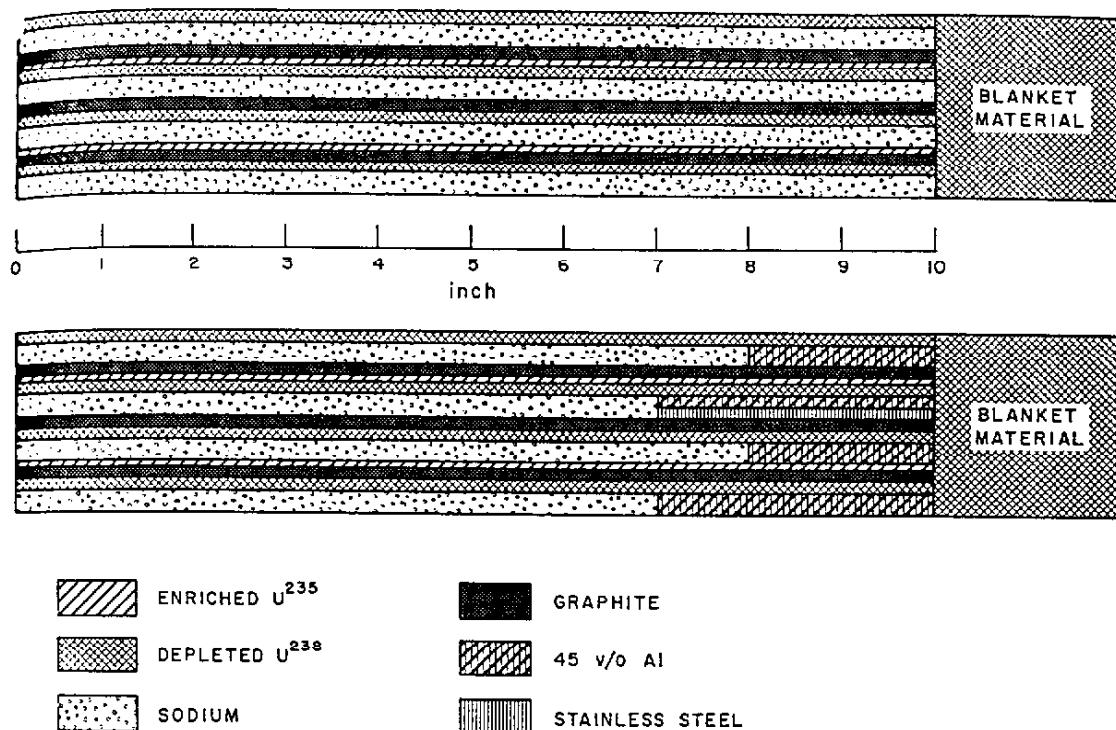
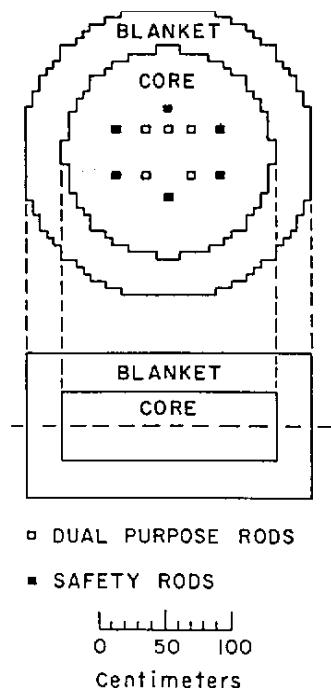


Fig. 126. Interface Diagram and Drawer Loading Patterns for ZPR6-3

ZPR6-4Z

Uranium carbide zoned assembly.

Overview:

Assembly 4Z contained a large central zone with a uranium carbide composition representative of a large single-zone uranium carbide assembly of about 2600 liter volume. Buffer and driver regions surrounded the zone. A key element of this program was to test how well parameters in the full-size assembly could be predicted based on measurements in the zone.

Assembly Dates:

Mid 1965-

Related Assemblies:

ZPR6-5 is the reference full-size uranium carbide assembly matched to the central zone of Assembly 4Z.

Assembly Details:

Type:	Cylindrical, zoned assembly. Zone radius 41.4 cm.
Fuel:	Uranium carbide with sodium cooling
Critical Mass:	1100 kg U ²³⁵ (not relevant)
Volume (zone):	1100 liters
Buffer:	Depleted uranium and carbide
Driver:	Uranium carbide with sodium cooling (with higher fuel enrichment)
Blanket:	Depleted uranium

Comment: There was no ZPR6-4.

A182

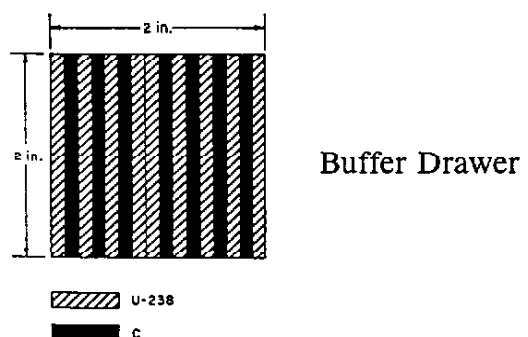
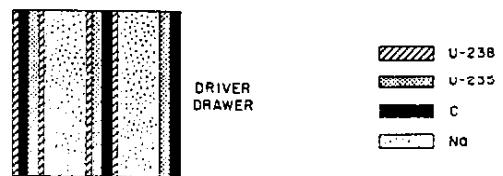
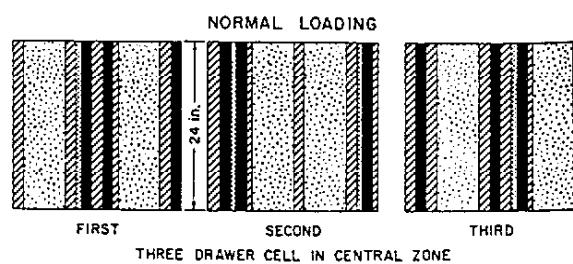
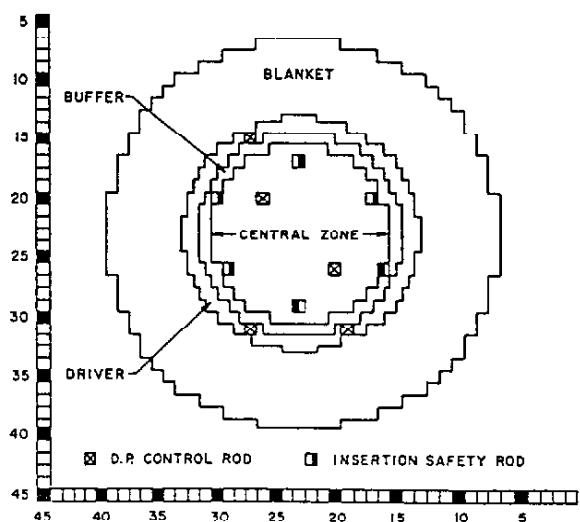


Fig. 127. Interface Diagram and Drawer Loading Patterns for ZPR4-4Z

ZPR6-5

Large uranium carbide benchmark core (2600 liters).

Overview:

This was a large, clean, cylindrical uranium carbide benchmark assembly. Its composition matched the central zone composition of Assembly 4Z. The measurements focused on parameter studies of a large uranium carbide core and, in conjunction with Assembly 4Z, confirmation of the use of zoned assemblies to predict parameters in the full-size core.

Assembly Dates:

June 1966-Fall 1967

Related Assemblies:

ZPR6-4Z was the matched zoned assembly. The test zones in ZPR9 Assemblies 11, 12, and 18 also matched the Assembly 5 composition.

Assembly Details:

Type:	Large, clean, cylindrical physics benchmark with H/D = 1.1
Fuel:	Uranium carbide with sodium cooling
Critical Mass:	1580 kg U ²³⁵
Volume:	2600 liters
Blanket:	Depleted uranium

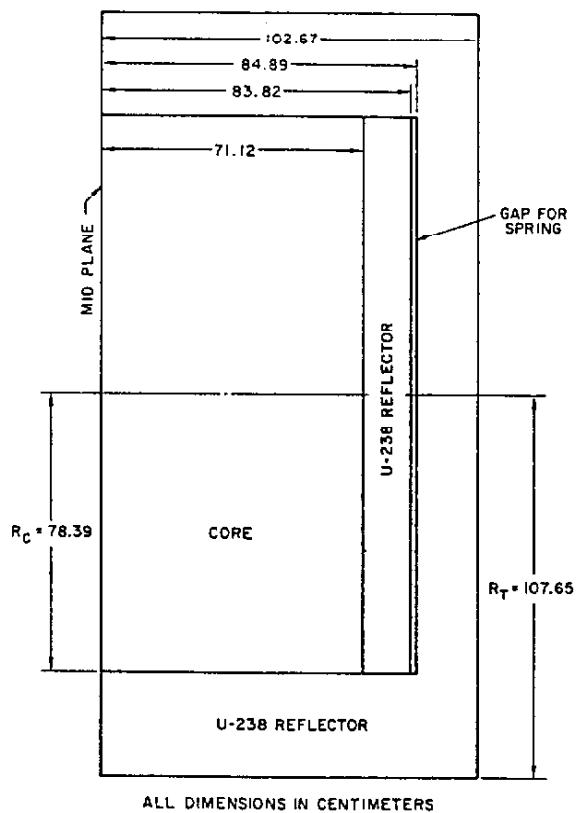
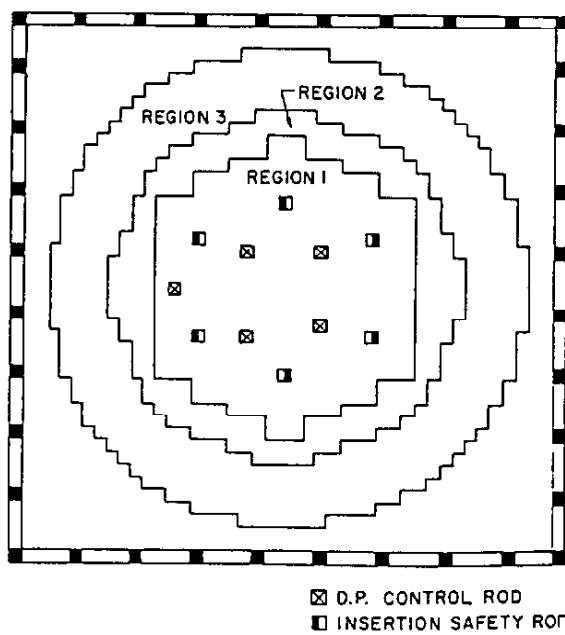


Fig. 128. Interface Diagram and R-Z Model for ZPR6-5

ZPR6-6 and 6A

Large uranium oxide physics assembly. Part of the Demonstration Reactor Benchmark Criticals Program.

Overview:

This was a large, clean, cylindrical, single-zone uranium oxide benchmark assembly. Assemblies 6 and 6A were essentially identical. The program was interrupted by facility modification. The reloaded assembly after the interruption was designated 6A. This was a major program including a wide spectrum of measurements. This program is usually referred to as ZPR6-6A.

Assembly Dates:

December 1967- for ZPR6-6

November 1969-February 1970 for ZPR6-6A

Related Assemblies:

The Assembly 6/6A unit cell was used widely in the ANL fast criticals program. The ZPR6-7 unit cell was similar except plutonium was substituted for enriched uranium. The Assembly 6/6A unit cell was used in the test zones of ZPR9-19, -21, -22, and -23 and in the central zone of ZPR9-35. The Assembly 7 unit cell was used in the inner cores of ZPPR-2, -3, -4, -5, and -6.

Assembly Details:

Type:	Cylindrical, single-zone clean critical
Fuel:	Typical uranium oxide with sodium cooling
Critical Mass:	1780 kg U ²³⁵
Volume:	4000 liters
Blanket:	Depleted uranium

Assembly Variants:

There was a small region at the center of the assembly, called the exact zone, where the weights of constituent materials were carefully controlled. A later comparison to a matched pin zone was planned.

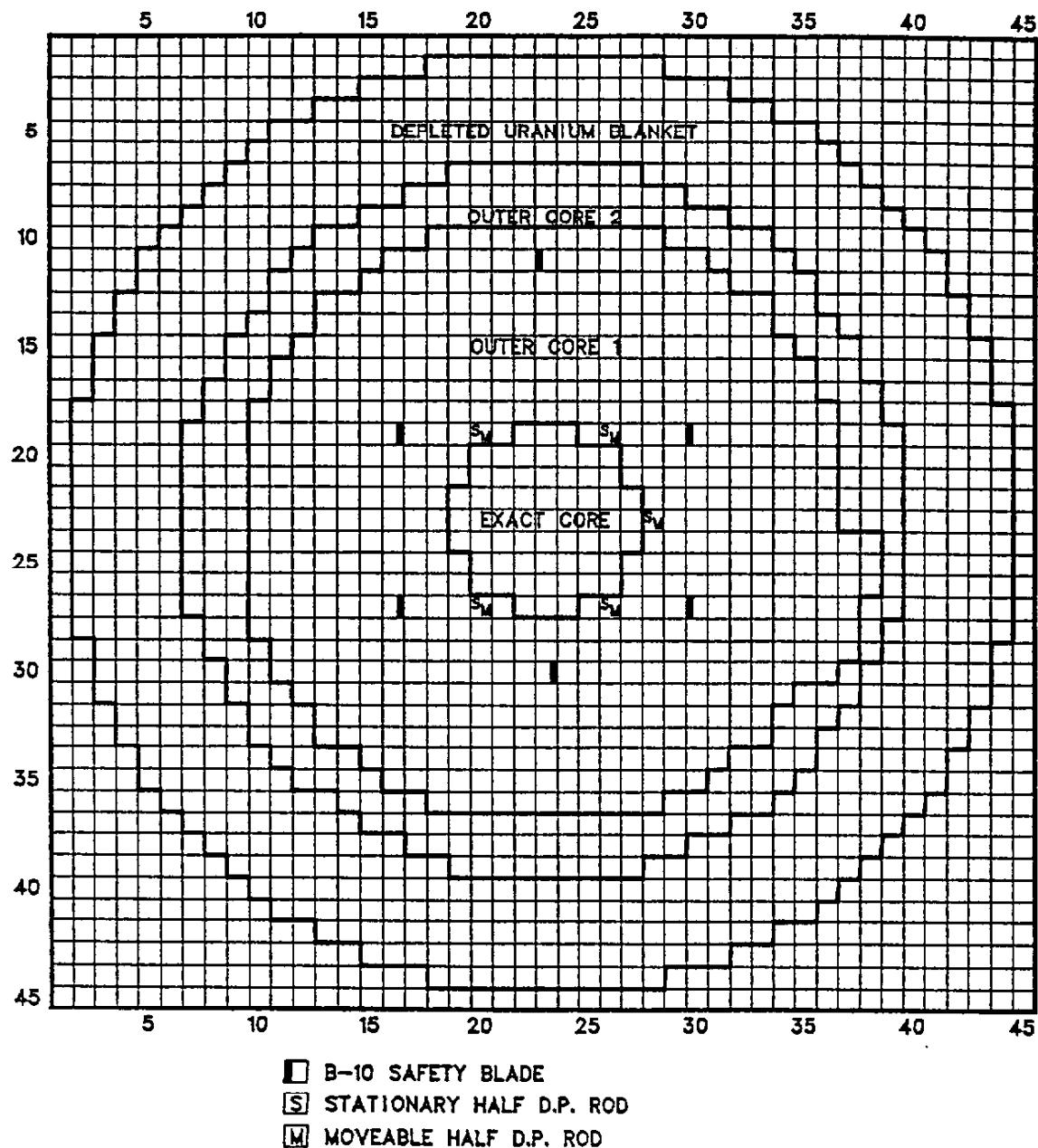


Fig. 129. Interface Diagram for ZPR6-6A

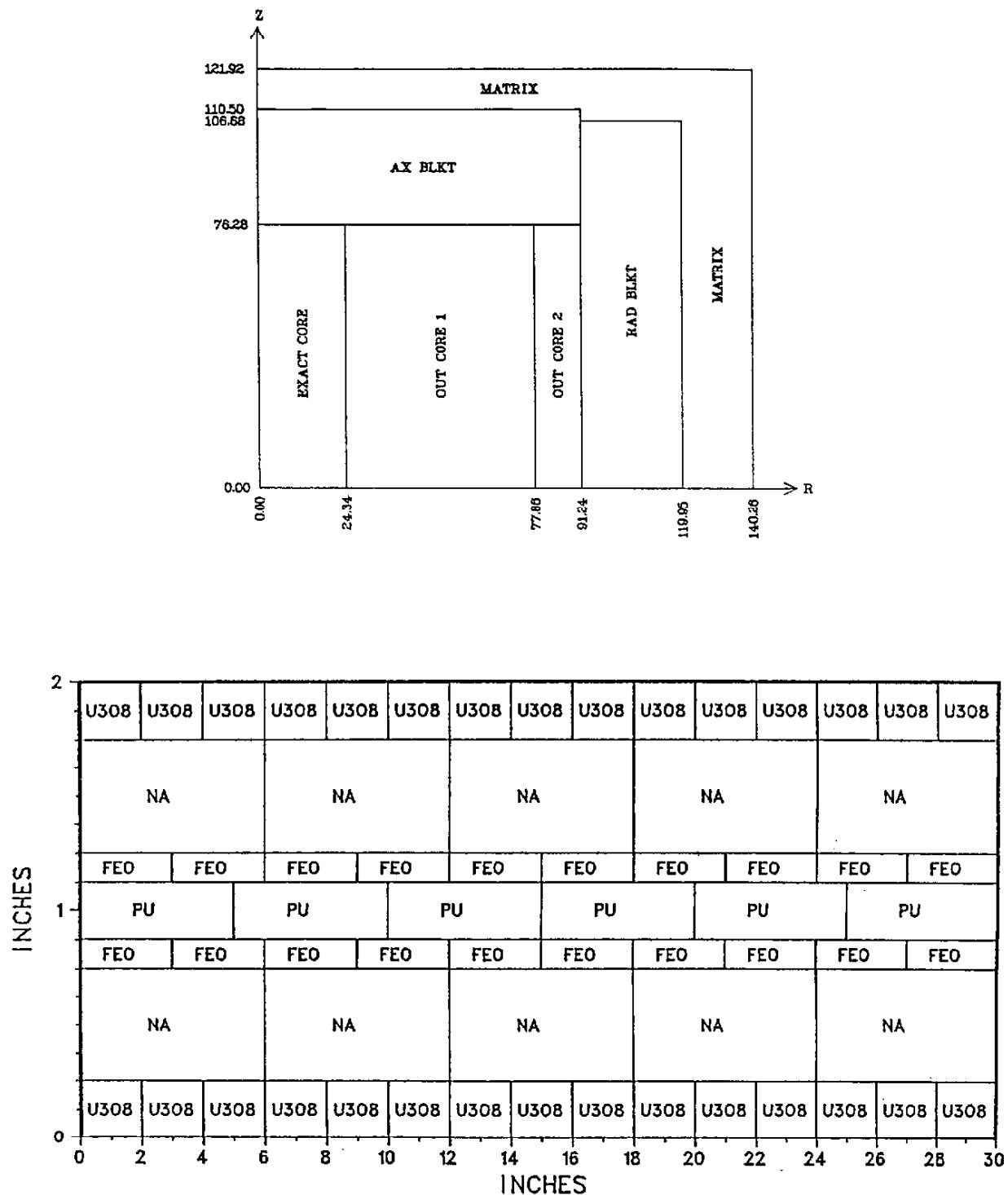


Fig. 130. R-Z Model and Drawer Loading Pattern for ZPR6-6A

A188

ZPR6-7

Large plutonium uranium oxide physics assembly. Part of the Demonstration Reactor Benchmark Program.

Overview:

This was a large, cylindrical, single-zone, plutonium/uranium oxide benchmark assembly. It was the plutonium equivalent of ZPR6-6A. There were many measurements made in Assembly 7. It had a material composition and neutron spectrum typical of the proposed demonstration reactor and a simple, readily calculable configuration.

Assembly Dates:

July 1970-October 1971

Related Assemblies:

ZPR6-6A. It also had a similar composition to the inner cores of ZPPR-2, -3, -4, -5, and -6. The other assemblies in the Demonstration Reactor Benchmark Program were ZPR6-6A and ZPPR-2, -3, and -4.

Assembly Details:

Type:	Cylindrical, single zone, clean critical
Fuel:	Typical plutonium uranium oxide with sodium cooling
Critical Mass:	1118 kg (Pu^{239} + Pu^{241})
Volume:	3100 liters
Blanket:	Depleted uranium

Assembly Variants:

There was an exact core region as in ZPR6-6A.

Sodium Voided Zone

Central Pin Zone

Central High Pu^{240} Zone

Central Sodium Voided High Pu^{240} Zone

Note: ZPR6-8 was planned to include a heated central zone containing rod-type fuel. This was called the variable temperature rodded zone (VTRZ). Program priorities changed and ZPR8-6 was not constructed. ZPR6-9 was identical to ZPR9-36.

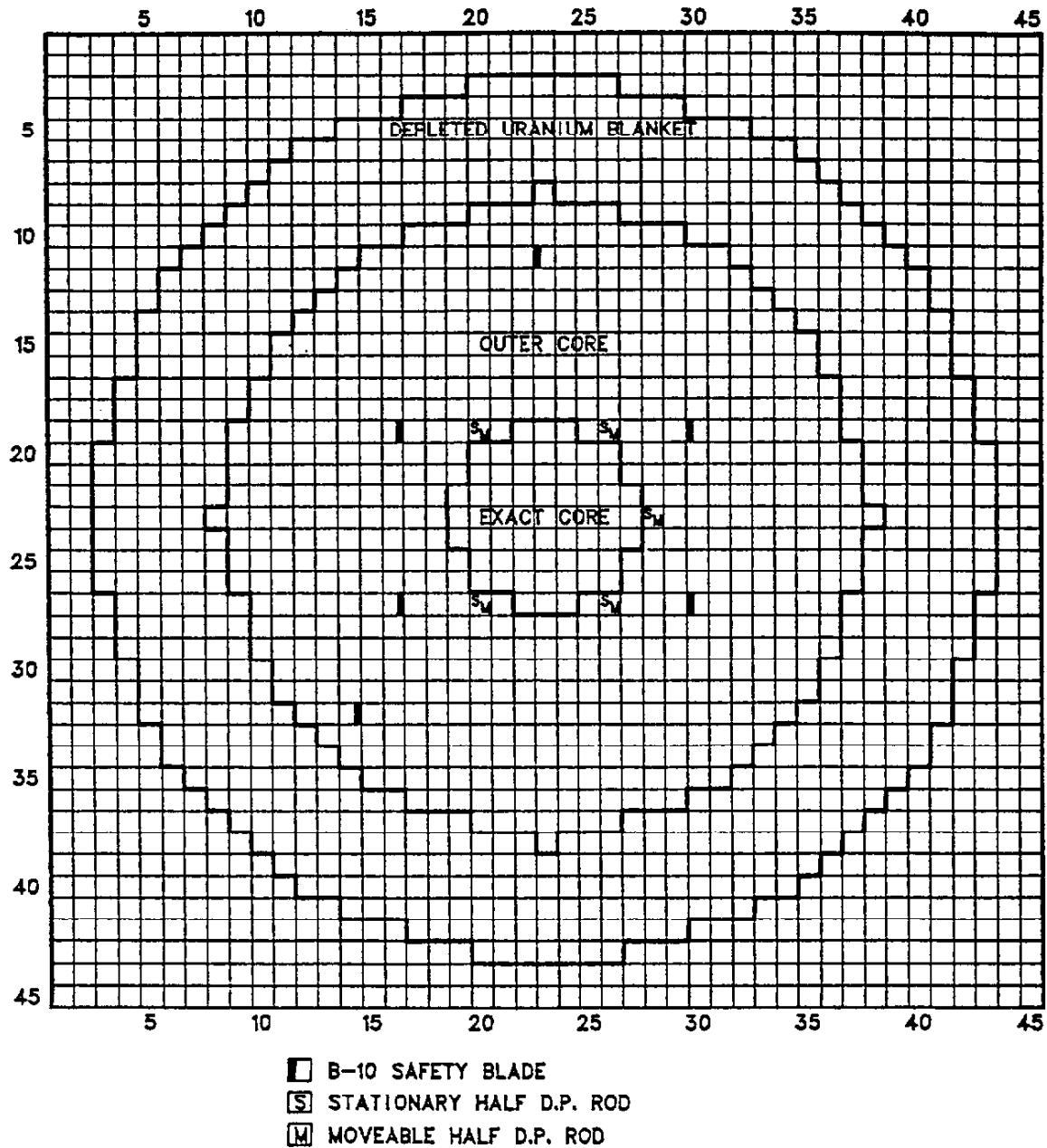


Fig. 131. Interface Diagram for ZPR6-7

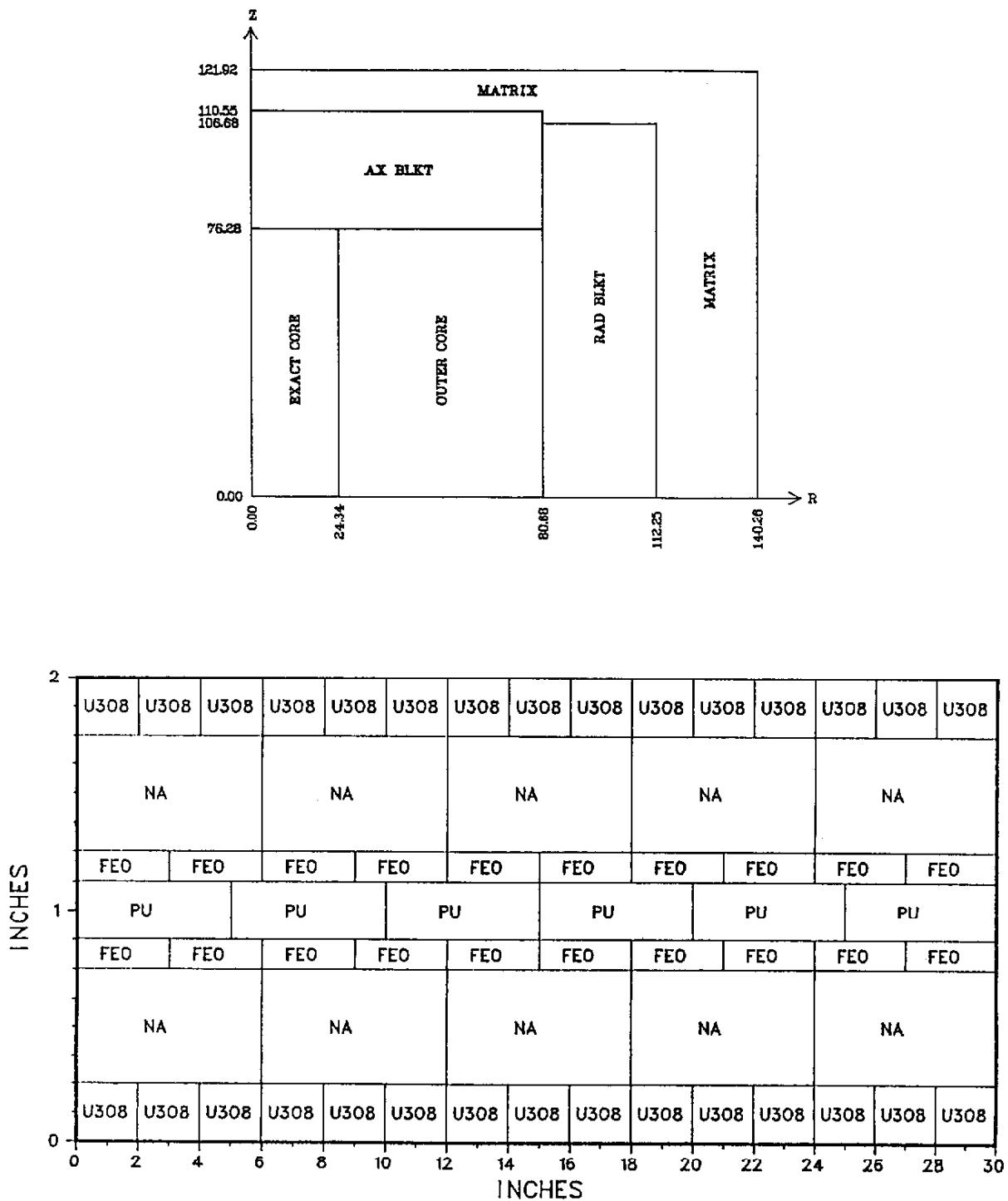


Fig. 132. R-Z Model and Drawer Loading Pattern for ZPR6-7

A192

ZPR6-10

Plutonium/carbon/stainless steel core. Part of the Diagnostic Cores Program.

Overview:

This was a small, clean, cylindrical assembly consisting of plutonium, carbon, and stainless steel (i.e., no uranium).

Assembly Dates:

September 1981-July 1982

Related Assemblies:

The other assemblies in the Diagnostic Cores Program were: ZPR9-34, ZPR9-35, ZPR9-36, and ZPR6-9.

Assembly Details:

Type: Simple, clean, cylindrical benchmark
Fuel: Plutonium, carbon, and stainless steel
Critical Mass: 178.5 kg ($Pu^{239} + Pu^{241}$); 178.2 kg Pu^{239}
Volume: 420 liters
Reflector: Stainless steel

Assembly Variants:

Reference Assembly

Assembly 10Z: A plutonium, depleted uranium, carbon zone in Assembly 10. (Few details available on this zone.)

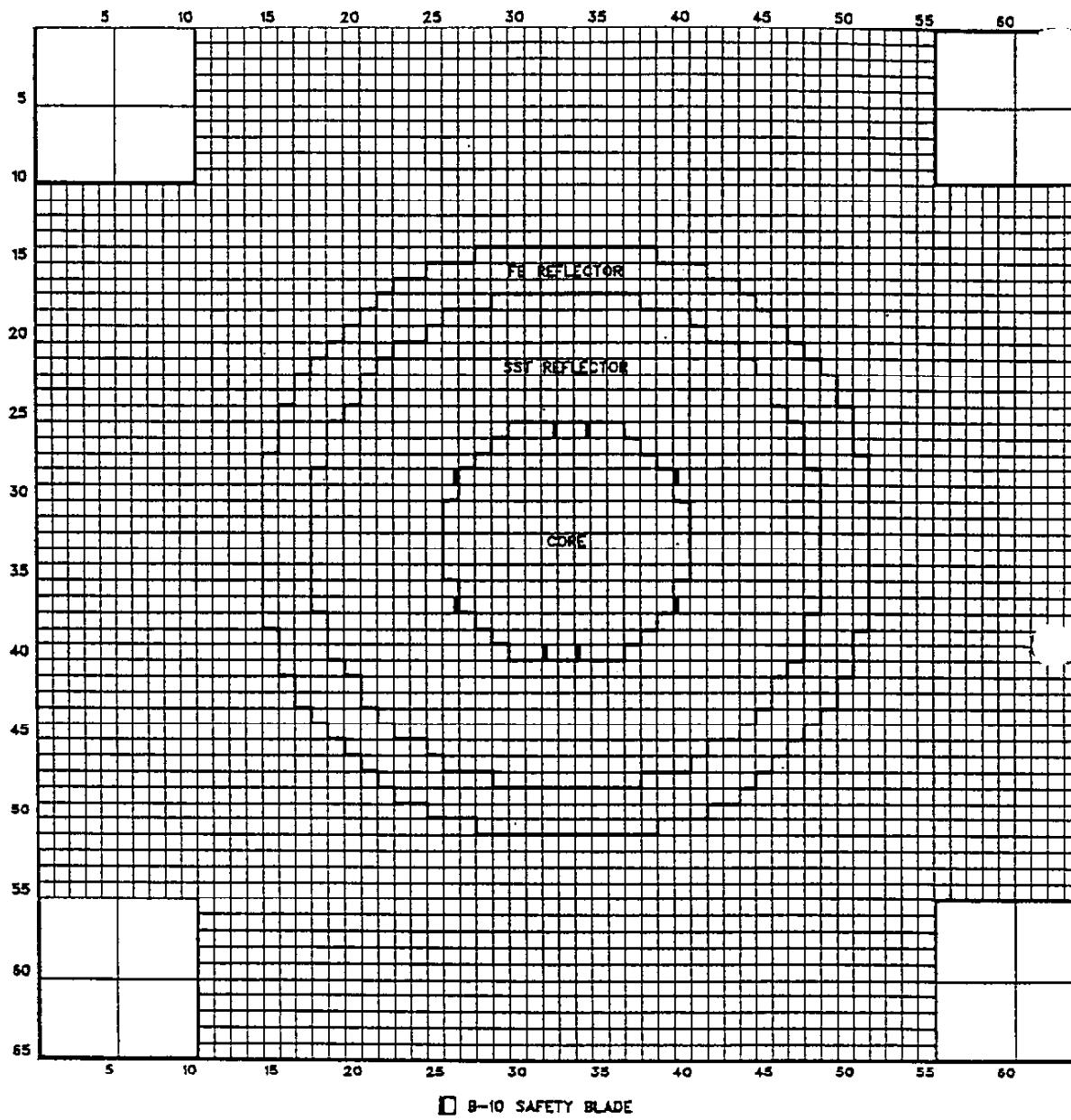


Fig. 133. Interface Diagram for ZPR6-10

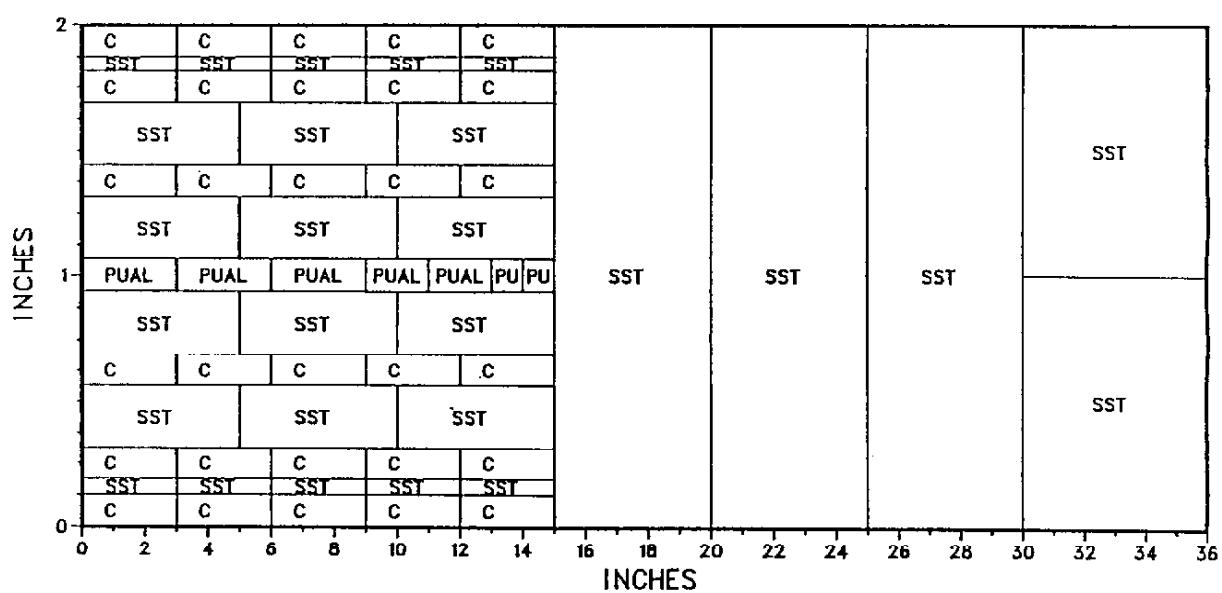
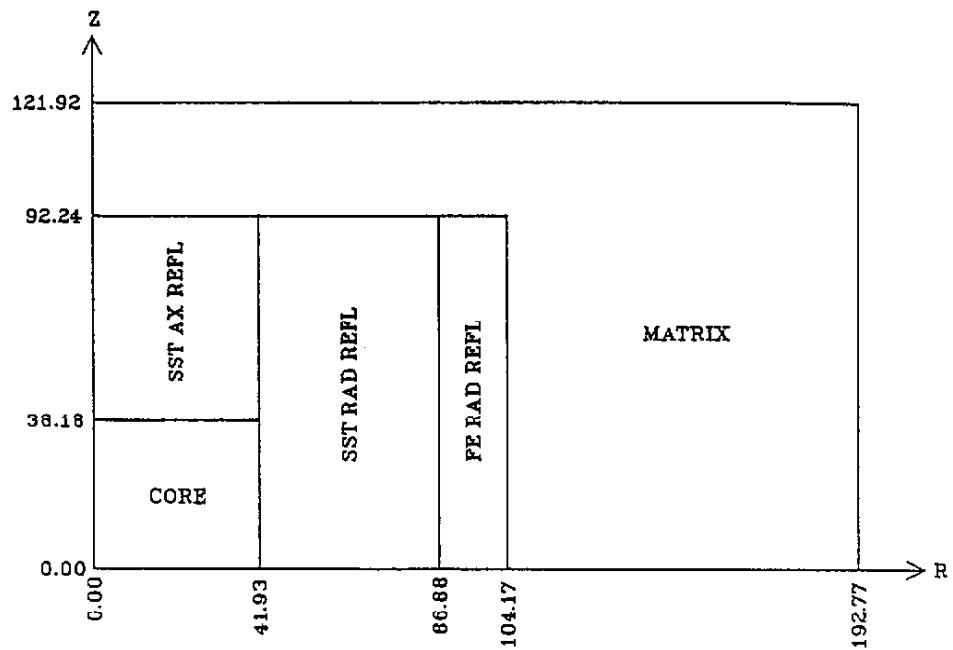


Fig. 134. R-Z Model and Drawer Loading Pattern for ZPR6-10

A196

APPENDIX B

ANL FAST CRITICAL FACILITY DRAWINGS AND PHOTOGRAPHS

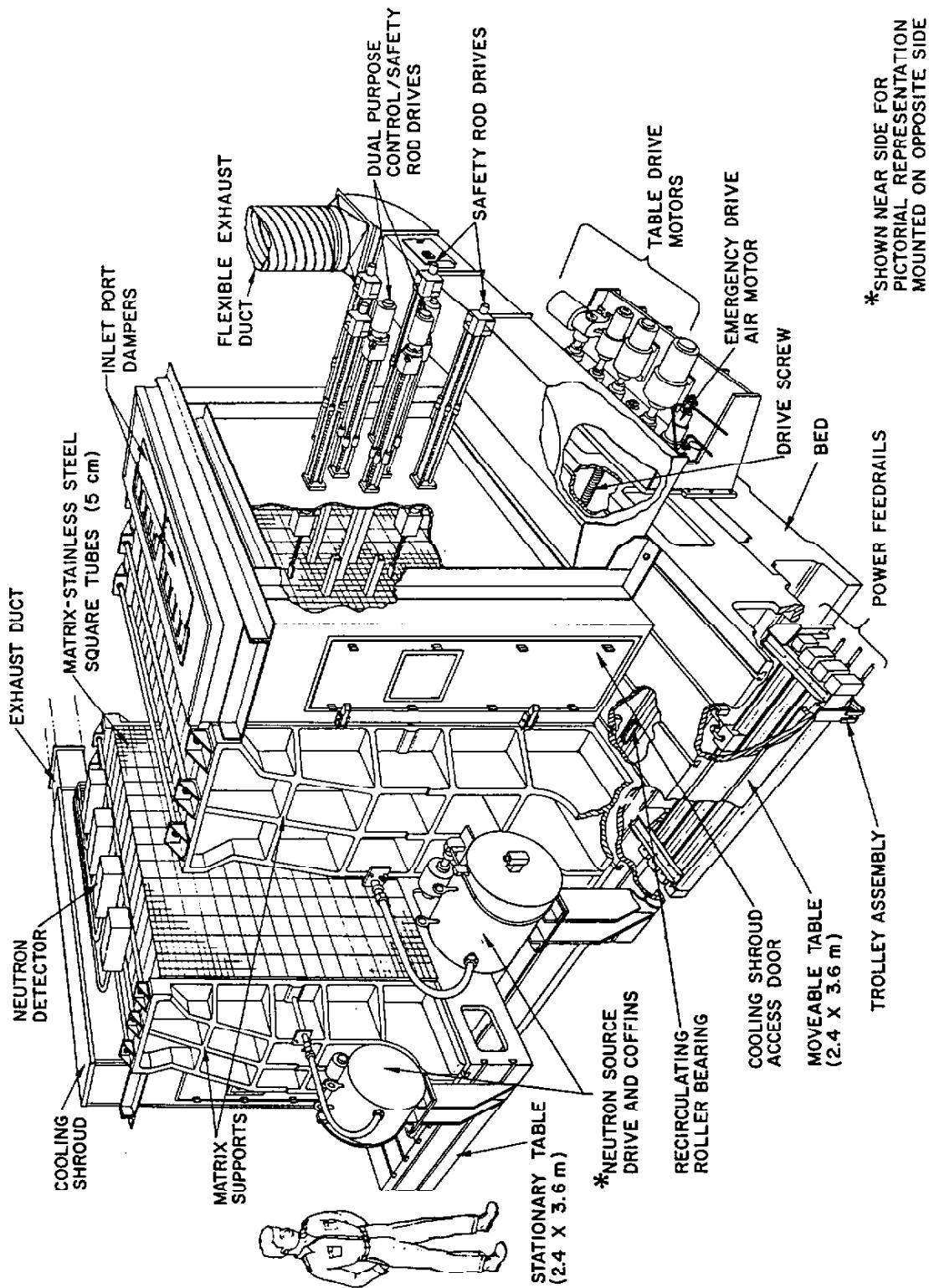


Fig. 135. Outline Drawing of the ZPR6 and ZPR9 Critical Facilities
(Before Modifications to Allow the Use of Plutonium Fuel).

The general features are typical of all the ZPRs.

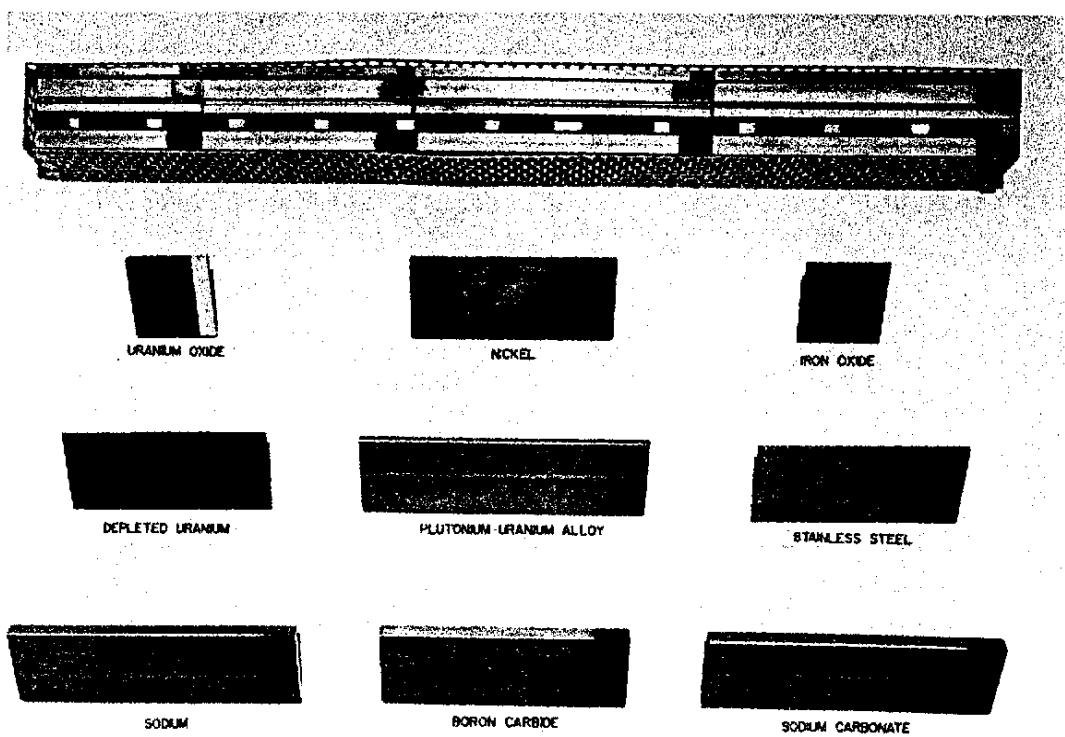


Fig. 136. Plates of Materials and a Loaded Fuel Drawer (ZPPR)

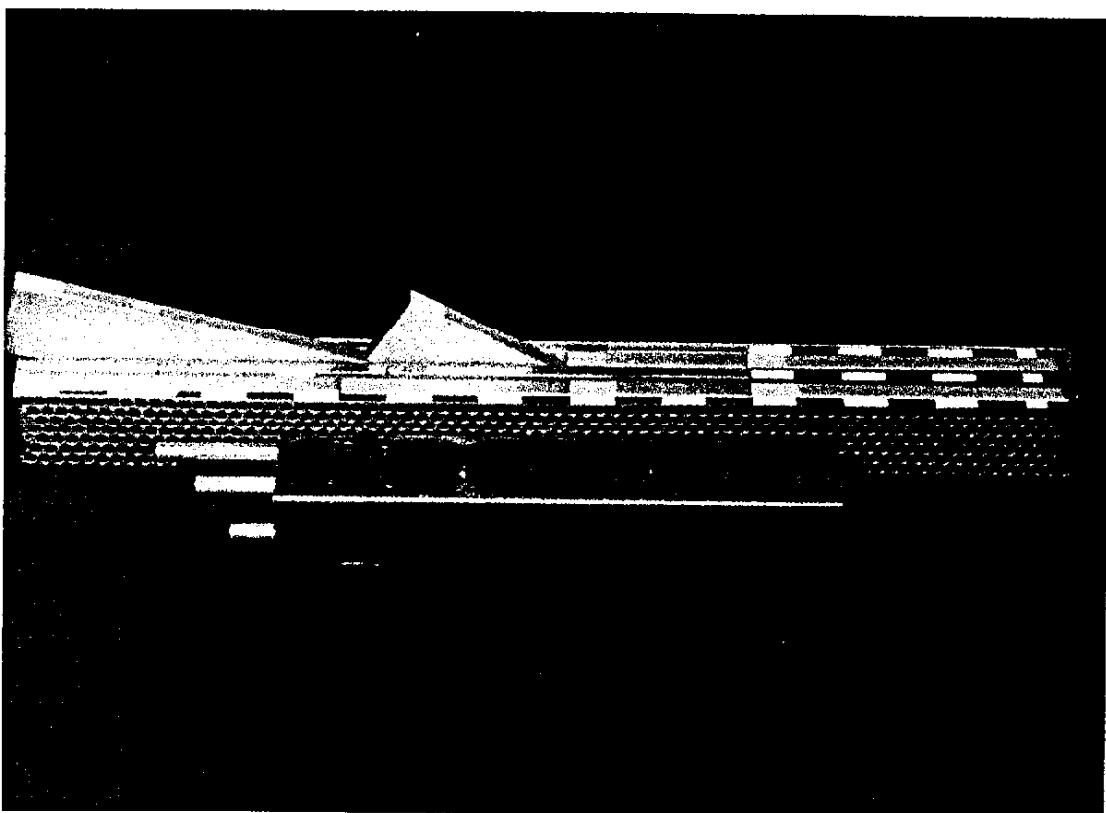


Fig. 137. Loaded Fuel Drawer with Plates Partially Inserted.
Pin Calandria (ZPPR)

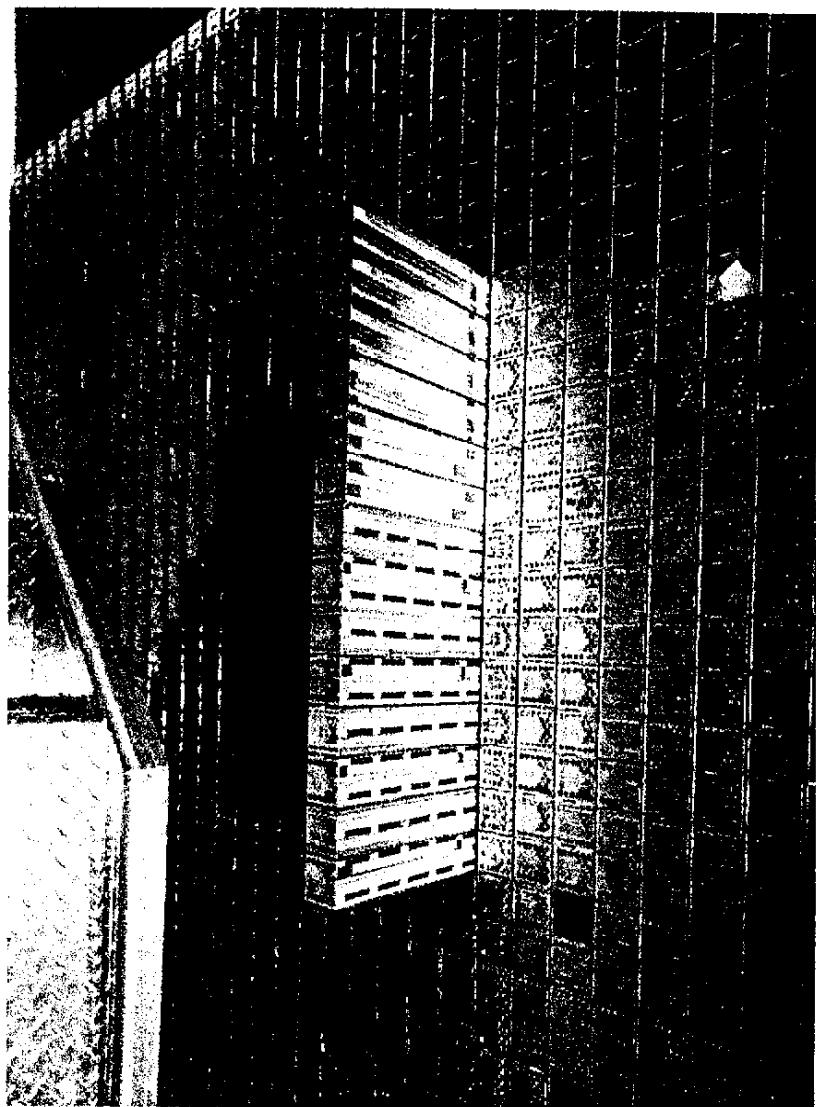


Fig. 138. Matrix Interface with Several Fuel Drawers Partially Inserted (ZPPR)

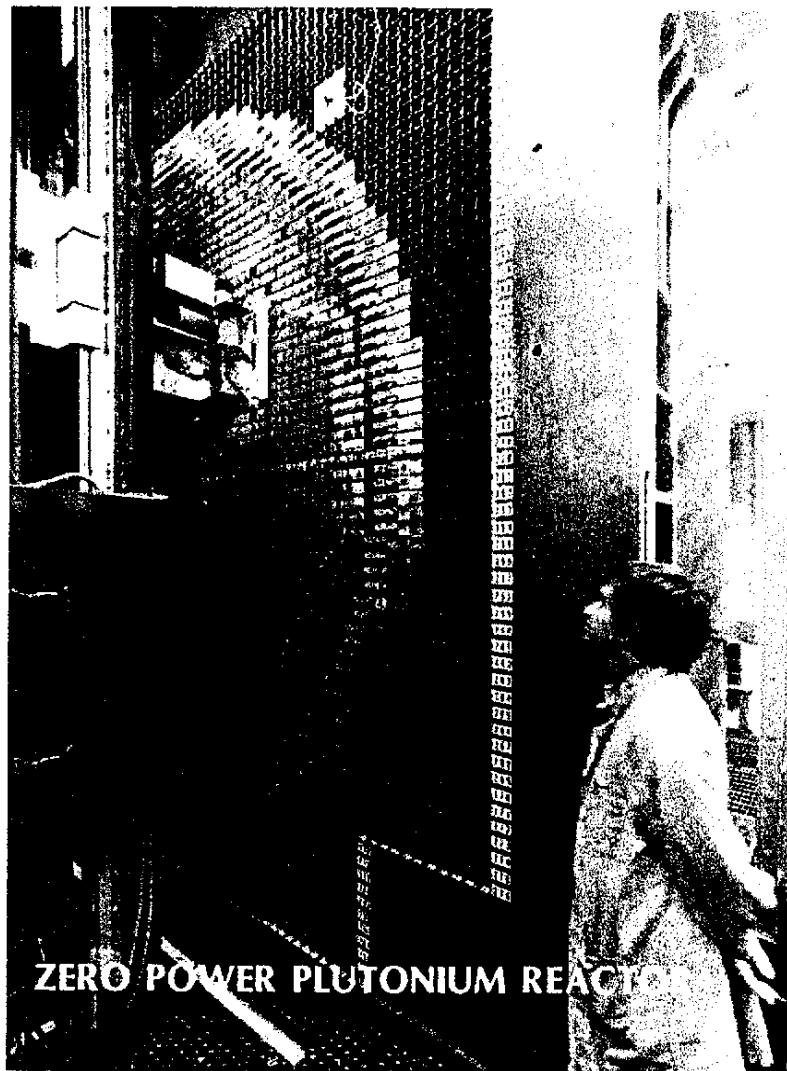


Fig. 139. Matrix Interface with Drawer Loading Machine (ZPPR)

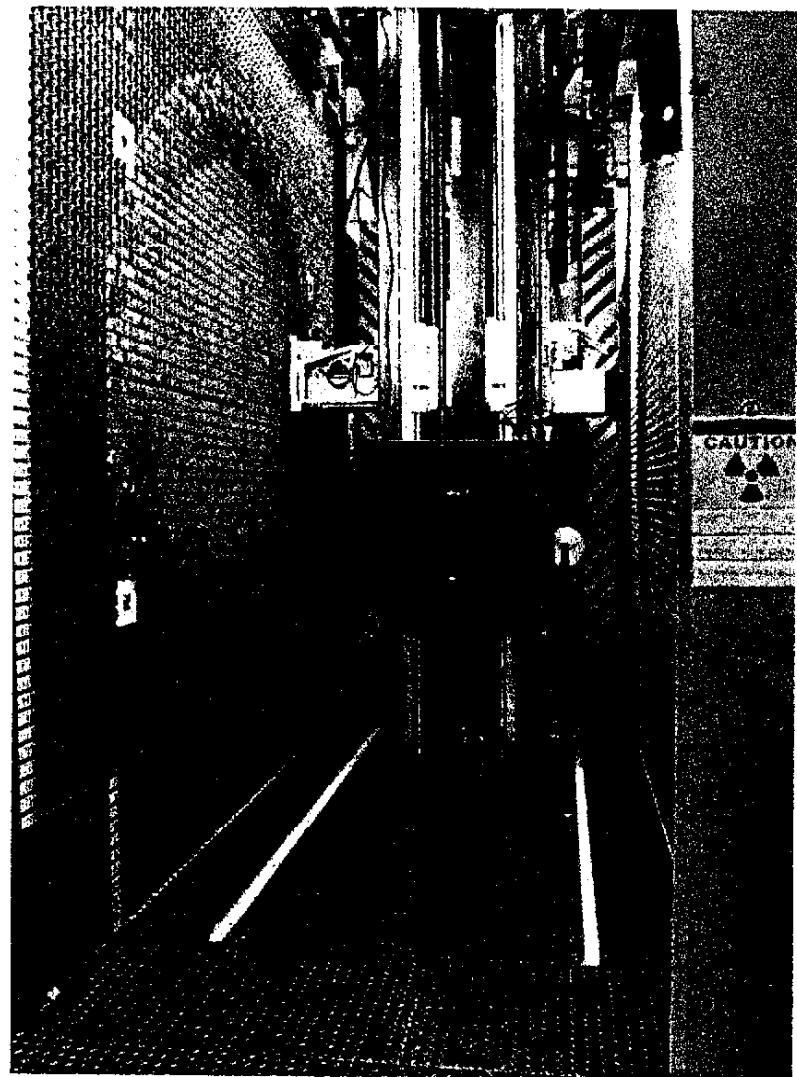


Fig. 140. Matrix Interface with Drawer Loading Machine (ZPPR)

APPENDIX C

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C2

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C4

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