GREEK RESEARCH REACTOR PERFORMANCE CHARACTERISTICS AFTER ADDITION OF BERYLLIUM REFLECTOR AND LEU FUEL*

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ABSTRACT

The GRR-1 is a 5-MW pool-type, light-water-moderated and-cooled reactor fueled with MTR-type fuel elements. Recently received Be reflector blocks will soon be added to the core to add additional reactivity until fresh LEU fuel arrives. REBUS-3 xy fuel cycle analyses, using burnup dependent cross sections, were performed to assist in fuel management decisions for the water- and Be-reflected HEU nonequilibrium cores. Cross sections generated by EPRI-CELL have been benchmarked to identical VIM Monte Carlo models. The size of the Be-reflected LEU core has been reduced to 30 elements compared to 35 for the HEU water-reflected core, and an equilibrium cycle calculation has been performed.

INTRODUCTION

The Reduced Enrichment Research and Test Reactor (RERTR) Program and the National Center for Scientific Research "Demokritos" initiated a new joint study program in 1991 to investigate the conversion of the Greek Research Reactor (GRR-1) from HEU to LEU fuel. This study is a continuation of a previous joint study[1] completed in 1981. This paper presents the results of modeling the current HEU core operations and the core changes expected upon adding a new Be reflector on two core faces. Since LEU fuel is not expected before August 1993 and fresh HEU fuel supplies are very low, some attention is being devoted to fuel cycle strategies to increase the lifetime of the Be-reflected HEU core. One equilibrium Be-reflected LEU core design will be presented that has fuel cycle characteristics similar to the current HEU core. In addition to providing guidance on fuel management strategies, these preliminary calculations will provide fuel element loadings for use in analyzing the transition to an LEU core.

GRR-1 CORE AND FUEL CHARACTERISTICS

The GRR-1 is a 5-MW pool-type, light-water-moderated and -cooled reactor fueled with MTR-type HEU fuel elements. The core consists of 29 or 30 standard fuel elements and six control fuel elements. Each standard element consists of 18 flat fuel plates, and the control elements have ten fuel plates. A Ag-In-Cd control rod is inserted into the center of each control element. In the future the core will be used for various isotope production projects and Si-doping. The dimensions of the fuel plate and coolant volume of the proposed LEU fuel element are identical to those of the existing HEU design. A comparison of HEU and LEU fuel element characteristics is presented in Table 1.

TABLE 1
STANDARD AND CONTROL FUEL ELEMENT CHARACTERISTICS

DESIGN PARAMETER	STANDARD		CONTROL	
	HEU	LEU	HEU	LEU
Enrichment, wt. %	93	19.75	93	19.75
Fuel Meat Composition	UAl	U_3Si_2	UAl	U_3Si_2
^{235}U/Element, g	180.8	222.2	100.3	123.4
Number of Plates/Element	18	18	10	10
Plate Thickness, cm	0.152	0.152	0.152	0.152
Fuel Meat Thickness, cm	0.050	0.076	0.050	0.076
Clad Thickness, cm	0.051	0.038	0.051	0.038
Water Channel Thickness, cm	0.290	0.290	0.290	0.290

THE FUEL CYCLE ANALYSIS MODEL

The fuel cycle analyses were performed using REBUS-3 with five neutron groups in xy geometry.[2] The increased accuracy that would be gained by the use of three-dimensional analyses would be small for the GRR-1 because of its low discharge fuel burnup. The burnup-dependent microscopic cross sections were obtained from a slab geometry representation of important core materials using EPRI-CELL.[3] Based on previous studies, the side plate was separated from the fuel-clad-moderator zone to provide more accurate reactivity and power peaking predictions from the diffusion theory model. The fuel zone cross sections were found to be in excellent agreement with those obtained from a VIM[4] Monte Carlo calculation of the fuel cells using ENDF/B-IV data.

Modeling of ex-core materials consisted of representing the graphite thermal column and the Pb gamma shield located between the core face and the thermal column. Other ex-core features, including experiments, beam tubes, and irradiation rigs, were omitted from this model because of insufficient information. We believe this simplified model is sufficiently accurate for this stage of the study.

An estimate of the reactivity bias of the fuel cycle model was obtained from an xyz diffusion theory model of an all-fresh GRR-1 startup core configuration 4B-2. With control rods at their critical positions, k_{eff} was calculated to be 1.010. This overprediction in reactivity is probably caused by inaccuracies in radial and axial ex-core material descriptions as well as by the diffusion model itself. This reactivity bias has been adopted for all fuel cycle analyses. The extrapolation distances for the planar fuel cycle model were obtained from this fresh fuel startup core calculation.

ANALYSES OF THE HEU WATER-REFLECTED CORE

^{235}U loadings for each element in core and in the storage pools were provided by the GRR-1 staff and used to model the actual HEU core fuel cycle beginning on October 26, 1990. The core consisted of 29 HEU standard elements and six control elements arranged as shown in Fig. 1. The GRR-1 ^{235}U loadings were used in conjunction with an EPRI-CELL depletion model of the standard and control elements to obtain a complete set of fuel isotopics for each element in the core.

The operation of the October 26, 1990 core was followed for 6.66 fpd, after which a fresh fuel element was added and the highest burnup fuel element was discharged. This refueled core was depleted for an additional 22.61 fpd and shut down on May 31, 1991. At this point a spent fuel element was added to the core in position D-6 without discharging any fuel. This increased the core size to 30 standard elements and six control elements and the ^{235}U core loading by 126 g. This core configuration has remained unchanged to date. The current operation schedule has been significantly reduced due to the shortage of additional HEU fuel supplies.

The typical operation schedule for a week at the GRR-1 consists of full-power operation for five to six hours per week day; the reactor is shut down at all other times. From the exact shutdown and operation intervals, the core excess reactivity was calculated for June 3-7, 1991 using the REBUS fuel cycle model. The calculated core reactivities at the beginning and end of each irradiation day are compared to hypothetical equilibrium steady-state operation over the same period in Fig. 2. On Monday morning, with ^{135}Xe at its lowest level of the week, the core k_{eff} = 1.066. At the end of the day, the core reactivity has fallen to k = 1.060 due to the buildup of ^{135}Xe. For the remainder of the week, the core reactivity increases during the day due to the burnout of ^{135}Xe accumulated during the preceding night's shutdown period. During the week the startup excess reactivity decreases each day except Friday, when a slight increase in excess reactivity has been observed at the GRR-1 and predicted using this model. From these results, shown in Fig. 3, one can also note that the GRR-1 never reaches equilibrium ^{135}Xe. The ^{149}Sm concentration changes very little and remains between saturation and equilibrium values during the entire week, as shown in Fig. 4. This operation schedule, with short irradiation intervals and relatively long shutdown periods, maintains poison concentrations low enough to provide the excess reactivity required for continued operation.

HEU Water Reflected GRR-1 Reference Core 4B-13

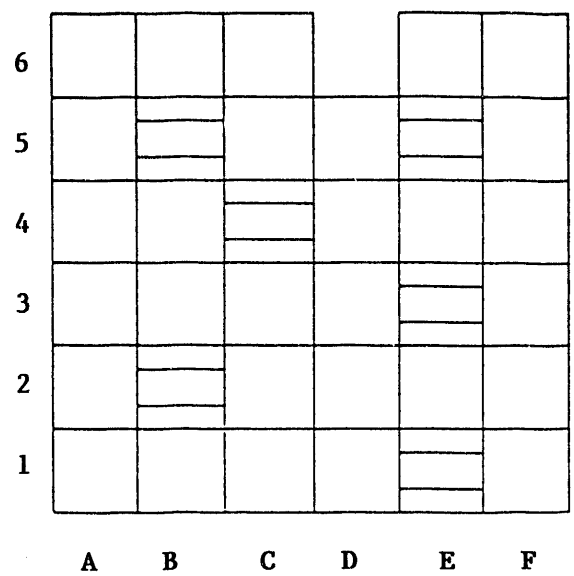

Figure 1

GRR−1 REBUS Reactivity During June 3−7,1991

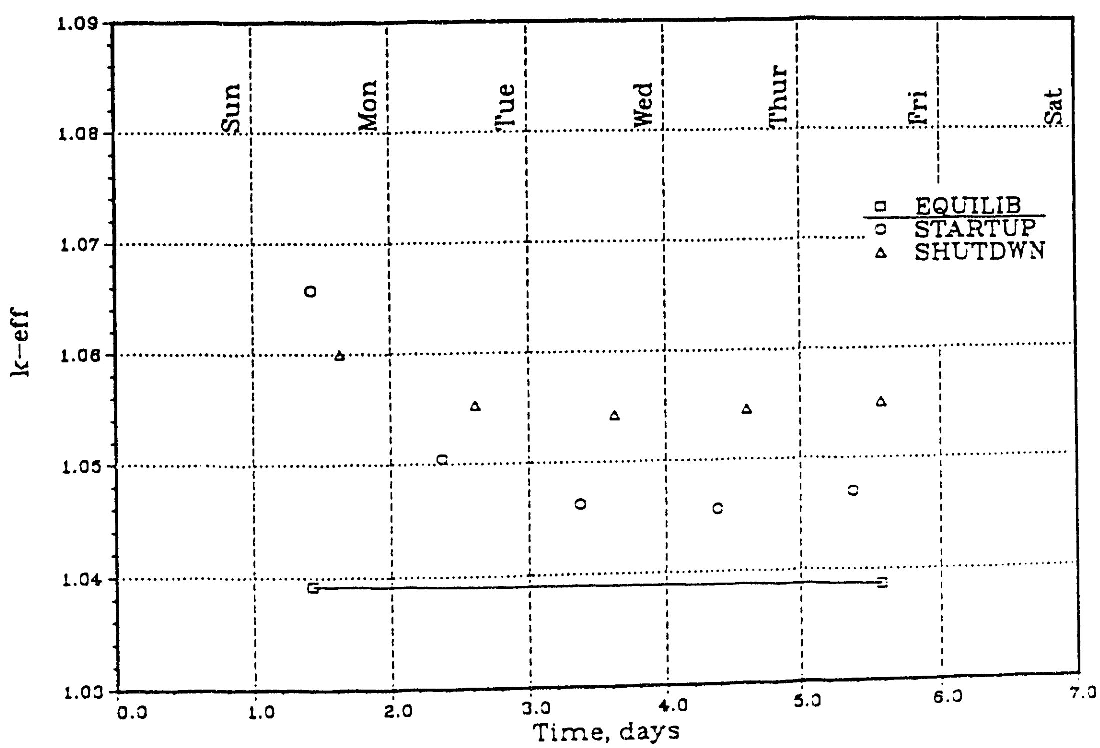

Figure 2

GRR-1 REBUS Xe-135 Inventory During June 3-7, 1991

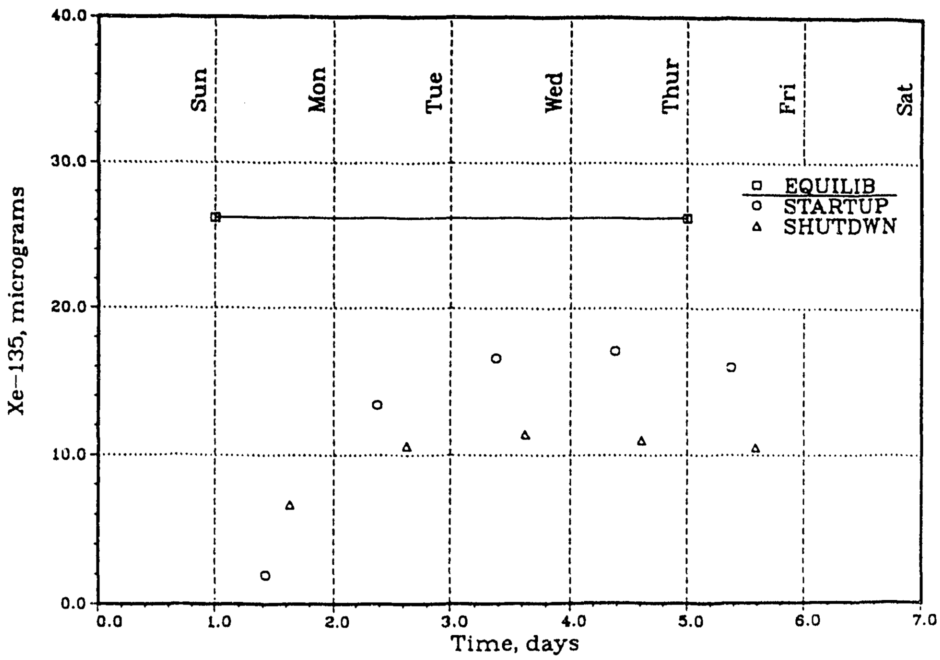

Figure 3

GRR-1 REBUS Sm-149 Inventory During June 3-7, 1991

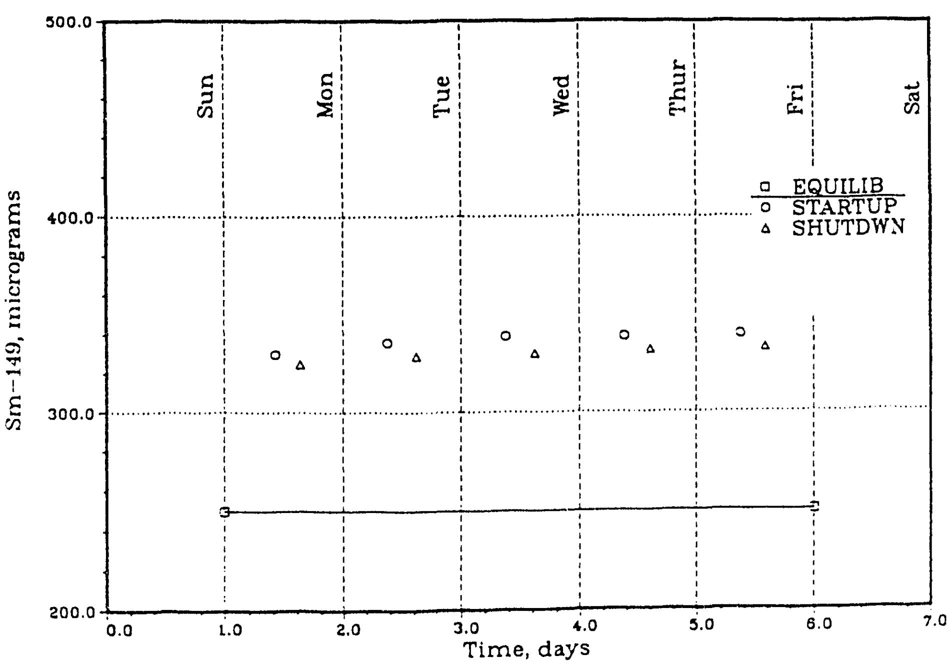

Figure 4

ANALYSES OF THE HEU Be-REFLECTED CORE

The actual depletion of the current water-reflected core has been modeled up to the current time and projected to January 1, 1993, assuming only 50 MWh of operation per week in order to conserve fuel. The Be blocks were received during this past summer and are expected to be positioned as shown in Fig. 5. The core size will be reduced from 30 standard and six control elements to 25 standard and five control elements by removing the highest-burnup elements. This Be-reflected core has an excess reactivity at startup of k_{eff} = 1.0382, which is very close to the beginning of cycle reactivity of an HEU water-reflected equilibrium core. This core loses about 85¢ in reactivity for each 10 fpd of operation. Therefore, the Be-reflected HEU core can be operated on the reduced operation schedule with the remaining fresh HEU fuel inventory until the summer of 1993 when the LEU fuel supplies arrive. If it should be deemed necessary to substitute an additional control element for a standard fuel element, approximately $2 in reactivity would be lost. Other fuel cycle options that might prove necessary would be an increase in core size using previously discharged fuel elements.

ANALYSES OF THE LEU Be-REFLECTED CORE

An equilibrium fuel cycle calculation of a preliminary LEU core configuration, shown in Fig. 6, has been made. One fresh standard element was loaded at the beginning of each cycle, and one control element was loaded at the beginning of each fourth cycle. The total residence time for all fuel was 24 cycles. The cycle length was chosen to be 10.3 days with a core consisting of 24 standard fuel elements and 6 control elements. The smaller LEU core has the same excess reactivity at the beginning and end of the cycle and the same cycle length as the reference water-reflected HEU equilibrium core. The power peaking in the LEU core has increased by 20%, which is inversely proportional to the core size decrease. The equilibrium discharge burnup in the LEU core was reduced to 24%. This core represents an initial attempt to design a replacement LEU core. If the LEU number of elements was reduced by removing one standard element in location C-6 in order to provide an in-core irradiation position, the core reactivity would be reduced by $2.5 for the same cycle length. Another option would be to remove one control element to provide an in-core irradiation position, in which case the reactivity penalty would be decreased.

HEU Be Reflected GRR-1 Core

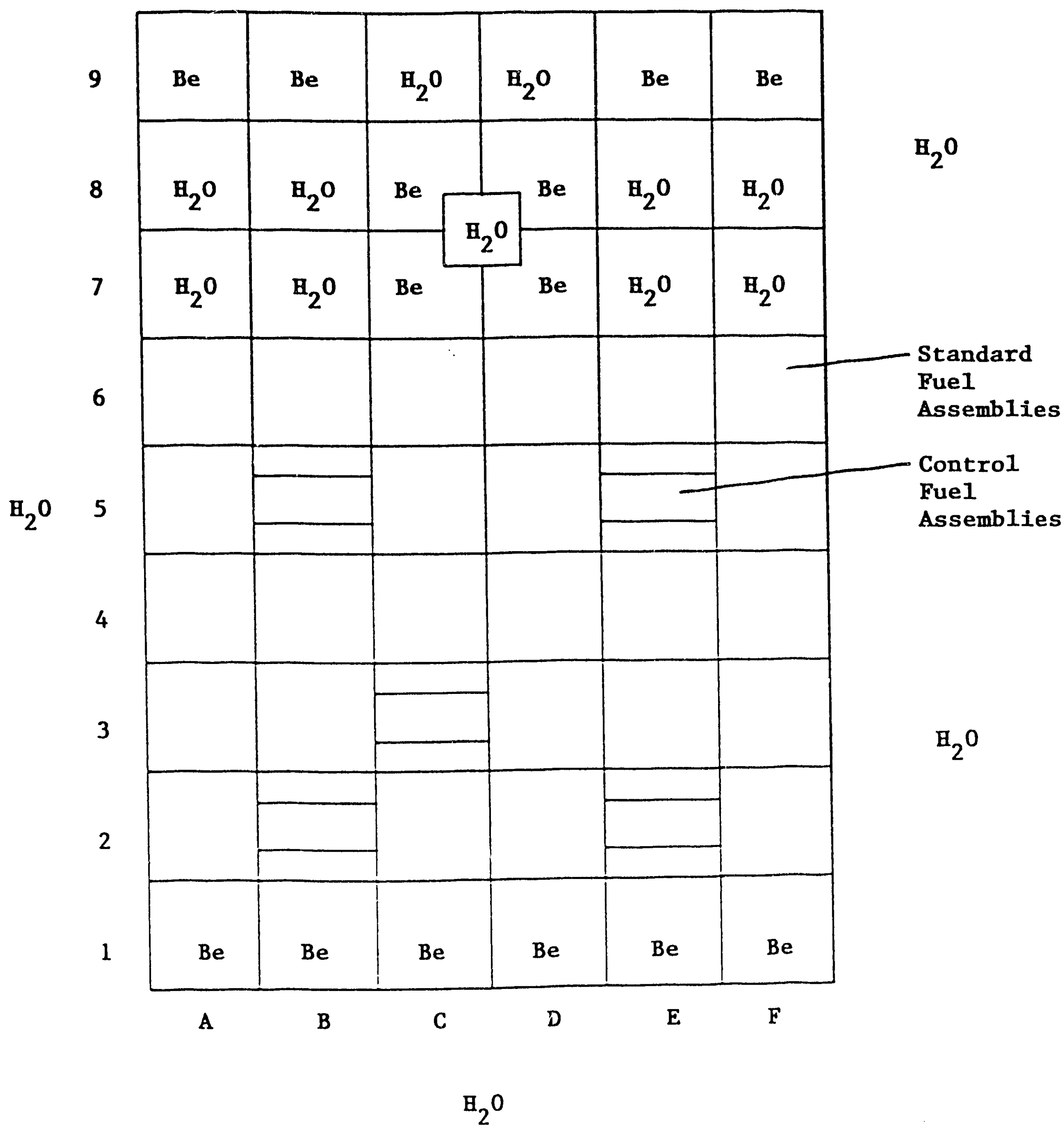

Figure 5 Be Core HEU Configuration with 25 + 5 Elements

LEU Be Reflected GRR-1 Core

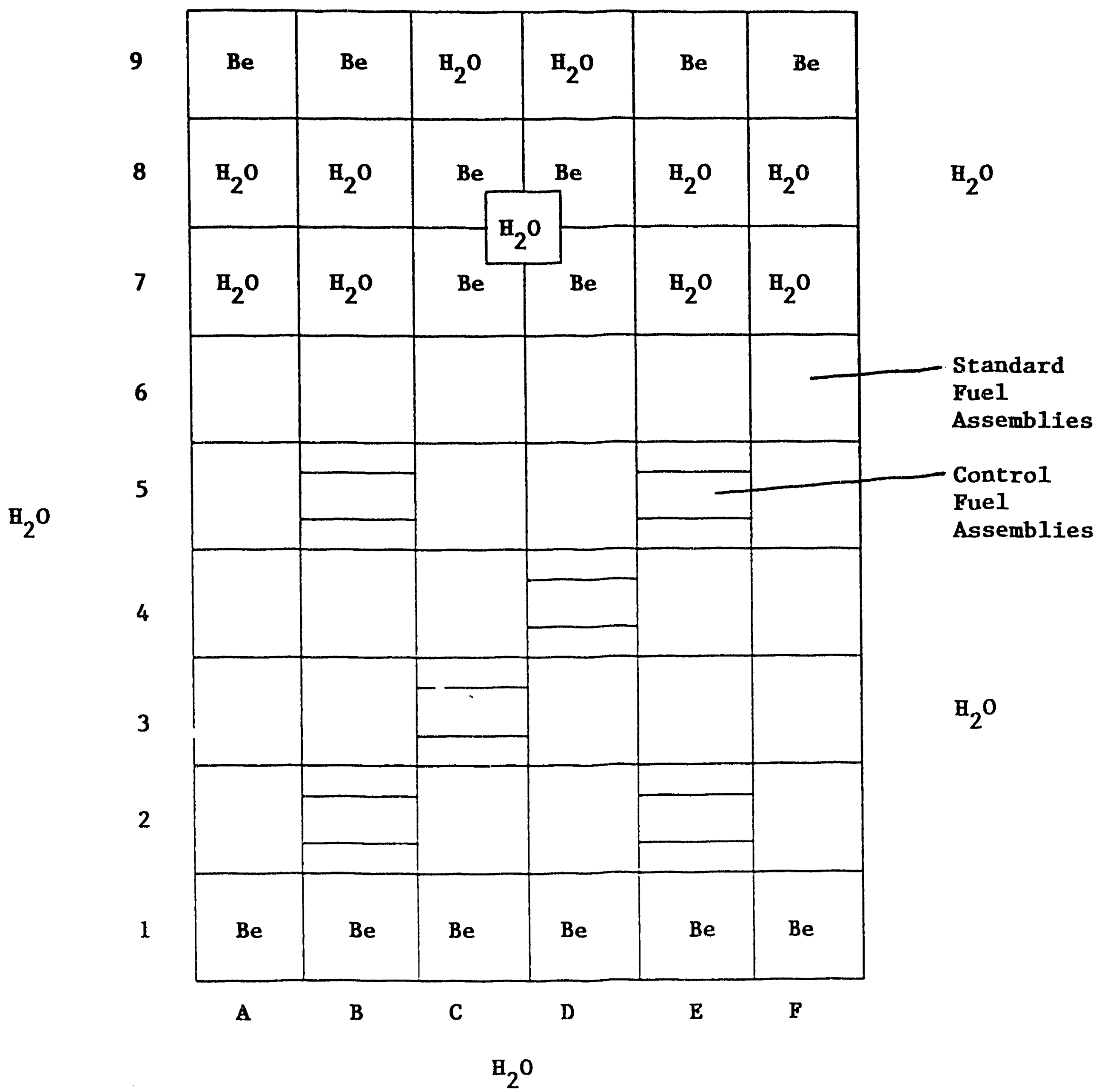

Figure 6. Be Core Configuration With LEU Fuel 24 + 6 Elements

Locations of experimental facilities will significantly affect the final core configuration. The reactivity performance could be increased without a change in core size by replacing one control element with a standard element if the core can be adequately controlled using five control elements.

CONCLUSIONS

The GRR-1 has had to significantly reduce its operation schedule caused by a shortage of fresh HEU fuel. Once all the necessary preparations for installation of the Be reflector for the HEU core have been completed, additional reactivity can be added to extend the core lifetime until LEU fuel arrives next summer. The use of the reactor for isotope production and Si-doping will significantly affect the final decision regarding the most suitable LEU core configuration. The issues of transition from HEU to equilibrium LEU cores by the addition of one element per cycle must also be addressed.

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