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Data for Modeling the Irradiation of Mixed Oxide Fuel in the SAXTON Reactor

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Fissile Materials Disposition Program

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Department of Nuclear Engineering
Texas A&M University

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CONTENTS

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LIST OF FIGURES

Page Intentionally Blank

LIST OF TABLES

Page Intentionally Blank

1. Introduction

1.1. Goal

With the end of the cold war, thousands of nuclear warheads have been deemed excess to national security needs by both the United States and Russia [1]. The inter-governmental U.S./Russia Joint Study on Plutonium Disposition has determined that one of the means by which weapons-plutonium could reach the secure spent fuel standard is that it be processed as fuel in a light water reactor. Historically, the United States has not been involved in the use of Plutonium in reactors since 1976 while Russia has had very little experience with plutonium in light water reactors. In order to fulfill this new disposition mission however, there is a need to use past data to benchmark neutronics codes utilized nowadays in nuclear power plants operations. The object of this report is to analyze the data from the Saxton Plutonium Program performed by Westinghouse under sponsorship of the U.S. Government in the 60's and early 70's. This report will present these data and compare them with results obtained with a two-dimensional neutronics collision probability code called HELIOS [40].

Historically, the Saxton critical experiments [15] have been regarded as one of the only U.S. data available involving lattice moderated MOX rods. Hence these experiments have been the starting point, worldwide, for the evaluation and benchmarking of MOX lattices in foreign reactors (see for instance [2]). These critical experiments were a small set of a much larger program called the Saxton Plutonium Program which lasted ten years (1964-1974) and saw the first use of mixed oxide fuel in a power generating reactor. This small set of critical experiments were performed at Waltz Mill, PA in mid-1965 while the Saxton Plutonium Program was undertaken at the Saxton reactor in Pennsylvania. During this undertaking, most critical experiment configurations did not have more than 250 fuel rods and hence had very large bucklings and leakages. These small critical experiments were studied in a previous publication [3]. Our report aims at describing operations of the much larger Saxton cores I, II and III described in the different Westinghouse quarterly progress reports to AEC/DOE and NRC [5-39]. We have attempted to implement these core configurations with the HELIOS computer code system (version 1.4). HELIOS is a collision probability neutron and gamma transport code system for lattice burn-up calculations in general two-dimensional geometry. Unfortunately, due to lack of funding, computational studies could not be completed.

The primary goal of reviewing data from an old project such as the Saxton Plutonium Program is to try to find a good reference on the performance of plutonium-loaded cores. The information presented in this report is expected to provide a benchmark for recently available nuclear data libraries and computer code systems. An aspect of our computations includes a comparison with similar computer generated data used during the project. Since our approach would use a two dimensional code, and, since the current state-of-the-art in transport computation does not allow for rapid, three-dimensional transport solvers, it is expected that the output of HELIOS will provide, at least, cross sections valuable for three-dimensional analyses using diffusion codes.

1.2. History

The purpose of the Saxton Plutonium Program was to develop information concerning the utilization of plutonium enriched fuel in pressurized water reactor systems, through design, fabrication and operation of a partial core of PuO_2-UO_2 fuel in the Saxton reactor. In-pile performance of this fuel was evaluated and post irradiation examination of fuel samples was made. The plutonium core configuration used as a basis for the analysis consisted of nine plutonium fuel assemblies installed in the center of the core with twelve uranium fuel assemblies installed on the periphery. Seven of the nine plutonium fuel assemblies contained pelletized fuel while two contained vibratory compacted (VIPAC) fuel. In order to provide a reference to uranium based cores, the designers made Core I a uranium-only core. Cores II and III were uranium-plutonium loaded cores. The three cores operated at or near full power during most of the program period. Detailed information about this experimental program is open and available in the form of quarterly reports which cover almost the whole program. [5-39].

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2. System description

2.1. Reactor core overview

The Saxton reactor was originally designed to hold 32 fuel assemblies. However, only 21 fuel assemblies were used. Some details about Saxton reactor Core I and Core II are summarized below:

	Core I **UO_2**		**Core II** **UO_2** **PuO_2 - UO_2**	
Number of fuel assemblies	UO_2 – 21		UO_2 – 12 PuO_2 – 9	
Total number of assemblies	21		21	
Number of rods per assembly	UO_2 – 71		UO_2 – 71	
Equivalent core diameter	71.2978cm	28.07 in	71.2978cm	28.07 inches
Core length	92.964 cm	36.6 in	92.964 cm	36.6 inches
Measured weight of UO_2 in the core	1023.3043 kg	2256 lbs	-	

Number of rod positions available :

21 assemblies of 72 rods each	1512
6 followers of 18 rods each	108
9 inserts of 9 rods each	81
Total	1701
23 instrumentation thimbles	23
2 secondary source tubes	2
Net number of rods for potential use	1676

Please note that the number of rod positions available reveals a potential for utilization. While there are 72 rod positions available in every assemblies, only 71 were used in either core I, II and III. A typical fuel assembly is presented in Figure 1. Core I was a uranium-only core. The numbering scheme for the location of every assembly is given in Figure 2.

Generic reactor core characteristics:

Thermal power, MW thermal:	20 (Core I) and 23.5 (Core II)
Moderator temperature, K:	549.8167 (Core I) and 551.4830 (Core II)
Operating pressure, MPa (psi):	13.7895 (2000)

Special characteristics of the Saxton Core II configuration:

Core II occurred shortly after Core I. The configuration of Core II is similar to that of Core I except for the fact that the nine central UO_2 assemblies were replaced with mixed oxide (PuO_2 - UO_2) assemblies.

Ten of the eleven peripheral UO_2 assemblies were replaced with fresh ones (all assemblies except for location E-1 - see Fig. 2). Out of the nine mixed oxide assemblies, seven assemblies contained pelletized fuel and the remaining two assemblies (D-2 and D-4) contained VIPAC fuel. The basic difference between pelletized and VIPAC fuel resides in the theoretical density: the density of VIPAC fuel is less than that of the pelletized fuel. Most of the mixed oxide fuel rods were clad in zircalloy-4 and a few (around 30) were clad in type 304-SS. The stainless steel clad rods were distributed throughout the core, for comparative purposes.

Special characteristics of Saxton Core III configuration:

The general objectives of the investigations, which were carried out with the Saxton Core III configuration, were the following:

- Demonstration of the performance capability of MOX fuel elements with Zircaloy-4 cladding over a broad spectrum of fuel burnups and reactor power levels, achievable in power reactors;
- Validate predictions of fuel element performance, including determination of power/burnup failure limitations;
- Obtain depletion characteristics for high burnup MOX fuel.

The construction of the nine center assemblies and of the unirradiated peripheral UO_2 assemblies remains essentially the same as that of Cores I and II, except that these assemblies have been reinforced. Two locations in each of the twenty-one main fuel assemblies in the core (A-5 and E-1) were used for either flux thimbles, removable fuel rods, removable cladding test specimen assemblies, removable water-filled tubes containing spot-weld test specimens or removable solid zircaloy bars. The nine central assemblies differ from previous assemblies in that the top nozzle is removable.

Each top nozzle is fastened on to the assembly by three stainless steel tie-rods and held captive by nuts with integral locking cup washers. The tie-rods consisted of type 304-SS tubing of 0.99314cm (0.391”) diameter with a 0.0381cm (0.015”) wall thickness, and type 304-SS special end plugs. The bottom end plug of each tie rod is welded into the bottom nozzle and the rod passes through the grids in the same manner as a fuel rod. The top end plug consists of two square sections with a threaded section at the top end.

2.2. Fuel assembly

Each fuel assembly was a 9x9 configuration (see Fig. 1). Out of the eighty-one positions available, seventy-one were occupied by fuel rods and one location was earmarked for the instrumentation thimble.

In the case of the nine central assemblies, the remaining nine rod locations located along an edge were slotted to form an L-shaped profile to accommodate the control rods (see Fig. 4). In the case of the peripheral assemblies, these L-shaped sections contained uranium fuel at these locations. The L-shaped section inserts were made of type 348-SS with a thickness of 0.07112cm (0.028”). Five assemblies out of the twenty-one were annular in configuration in the sense that they had provisions for insertion of experimental 3x3 or 2x2 subassemblies. Their locations were D-3, E-1, B-3, F-4 and C-5 in Figure 2. The naming convention for these locations became increasingly sophisticated during the course of the program. In Figure 3, the same locations were named N-1, N-4, N-2, N-5 and N-3 respectively and were named as such in the references.

The basic components of a fuel assembly consisted of four grids, two enclosure halves and one each top and bottom nozzles. The grid assemblies were of brazed “egg-crate” construction and were spaced axially at 25.4 cm spans (ten-inch spans) to provide lateral support for the fuel rods. The enclosure halves were welded to the peripheral straps of the grid assemblies to support the grids and to tie the fuel assemblies together. The nozzles were welded to the top and bottom ends of the enclosure halves.

Special characteristics of the Saxton Core II configuration:

The peripheral uranium oxide fueled assemblies had a U-235 enrichment of 5.7 wt. %. The central mixed oxide fueled assemblies had natural uranium oxide and 6.6 wt % plutonium oxide fuel, with an isotopic enrichment of 90.49 % Pu-239, 8.57 % Pu-240, 0.89 %Pu-241 and 0.04 % Pu-242.

The removable subassembly in the central location D-3 was previously irradiated in Core I to burnup levels of 1400 MWD/t. In contrast to the rest of the fuel assembly in D-3, the inter-element pitch in this sub-assembly was 1.36652cm (0.538”). Assembly in location E-1 contained a special, hollow, 51 UO_2 rod configuration, designed to accommodate a supercritical steam test loop. This assembly had already accumulated 2100 MWD/t burnup during Core I operation. Out of the 12 UO_2 assemblies, five were original of Core I design (with SS grids) and seven were new, Core II design (Inconel grids). All UO_2 assemblies, except for E-1, were fresh fuel at the start of Core II. All the mixed oxide (PuO_2 - UO_2) assemblies contained inconel grids.

The special L-shaped insert assemblies that occupied the slotted regions of the fuel elements were also used in Core II. In addition, the original, fuel-bearing control rod followers were also used in Core II. However, the control rods 1 & 2 and 5 & 6 were interchanged, placing the fuel followers with the lowest burnups at the center of the core.

The central, PuO_2-UO_2-fuelled assembly (D-3) and three peripheral (B-3, F-4, C-5) UO_2-fueled assemblies had provisions for the insertion of 3x3 subassemblies.

Special characteristics of the Saxton Core III configuration:

The 21 main fuel assemblies (9x9 rod array) in Core III were made up of seven loose lattice assemblies, two special fuel test (load-follow) assemblies, one peripheral non-irradiated UO_2 assembly and eleven UO_2 assemblies from Core I (see Fig. 2).

The seven loose lattice assemblies consisted of four 36-rod assemblies, one 35-rod assembly, one 34-rod assembly and one 32-rod assembly. This last assembly accommodated, in addition to 32 fuel rods, a four rod removable subassembly. The rods in these loose lattice assemblies were composed of irradiated rods removed from Core II assemblies. They were loaded into the original 9x9 assemblies with zircaloy tubes filled with coolant at every other rod position. As in Core II, in each of the main fuel assemblies, two rod positions were used for either in-core instrumentation, source rods or removable fuel rods, depending on the location of the fuel assembly in the core. In addition, the L-shaped assemblies in the corner of the peripheral assemblies were reused with fuel assemblies in Core III.

Each of the two special fuel test (load-follow) assemblies C-3 and E-3 contained sixty fuel rods with design variations in fuel pellet diameter, density, and internal gas pressure. The unirradiated peripheral UO_2 assembly contained pelletized, enriched UO_2 and zircaloy-4 clad fuel rods.

The remaining fuel loading consisted of six control rod followers already in the reactor, four removable 3x3 type fuel assemblies in the peripheral UO_2 assemblies and the L-shaped assemblies in the peripheral slot positions already in place in Core II.

Summary of fuel assemblies in the Saxton reactor Core III:

Description:	**Number of Assemblies**			
	72-Rod	**63-Rod**	**36 /35 /34-Rod**	**32-Rod**
Loose lattice assemblies, MOX	-	-	6	1
Special test assemblies, UO_2	2	-	-	-
Cores I & II , UO2 assemblies	8	4	-	-

Construction and loading plan for the loose-lattice assemblies

The loose-lattice assemblies were loaded with a loose lattice pitch of 2.0828cm (0.82”). A water tube occupied each alternate rod position on the normal lattice pitch of 1.3732cm (0.58”). The water tubes, as well as the tie rods, had two holes, 0.15875cm (1/16”) diameter, near the bottom, and two holes, 0.3175cm (1/8 ”) diameter, at the top of the cladding, to permit the flow of primary coolant through the rods. To maintain uniform fuel rod pitch across the core, two types of fuel assemblies were necessary and were called Type A and Type B assemblies. The 32-rod Type A assembly contained, in addition to the 32 rods, a removable subassembly with four fuel rods arranged with a

1.92532cm (0.758”) pitch. These four fuel rods in this 3x3 subassembly consisted of the mixed oxide rods with the highest burnups from previous operation in Core II. This assembly was designed as a removable assembly so that the rods could be removed to monitor core performance.

The fuel rods in the 9x9 loose lattice assemblies were selected from previously irradiated Core II assemblies. The loose lattice plutonium region is made up of seven reconstituted assemblies that were subdivided into zones distinguished by the amount of rod burnup in Core II. At intermediate locations between the loose lattice fuel rods, open zircalloy tubes were installed to provide additional moderator while maintaining the desired flow characteristics. Three of these intermediate positions contained open SS tubes that were used to attach the fuel assembly nozzle.

The fuel assemblies were strengthened by replacing the six zircaloy-4 tubes with six SS tubes and by spot welding 0.07112cm (0.028”) thick SS angles between the can and the six SS water-filled tubes. The 2.54cm (one inch) long clips, which previously fastened the two halves of the enclosure were replaced by full-length clips in the spans between the grids. The loose-lattice region of the core contained one L-shaped assembly at core location E-2. This L-shaped assembly contained nine pelletized UO_2 fuel rods clad with type 348-SS.

Construction and loading plan for the load-follow assemblies

At the beginning of Core III life, core locations E-3 and C-3 were occupied by load-follow assemblies 503-18-3 and 503-18-1 respectively. However, at mid-life, these locations were reversed. These two assemblies contain 60 fuel rods arranged with a nominal pitch of 1.4732cm (0.58”). They have the same dimensions as Core II type fuel rods and contain pelletized UO_2 fuel with two enrichments (9.5 or 12.5% weight percent (w/o) U-235). The pellet densities range between 89.5 and 94.5% of theoretical density and have nominal pellet-to-clad gaps of 0.01397cm to 0.02413cm (5.5 to 9.5 mils).

Each of the assemblies also contained four water-filled zircaloy-4 tubes and one water-filled SS tube. The tie-rods in each load follow assembly contained filler material. Two contained inconel and one contained SS fillers. The purpose of the filler material was to control local power perturbations in the assemblies. The load follow assemblies were also structurally strengthened.

The removable rod position at location A-5 was occupied by a solid zircaloy bar. The removable rod position at location E-1 was occupied by a flux thimble tube. Assembly 503-18-1 was located in C-3. The cladding test specimen was located in assembly 503-18-3 at core location E-3. Locations A-5 and E-1 were blank (not much information on location A-5 is given in the series of reports).

Other assemblies

Eleven previously irradiated assemblies from Core I were loaded into eleven of twelve Core III peripheral locations. The other peripheral location, B-2, was occupied by a non-irradiated enriched UO_2 assembly designated 503-10-7. This assembly contained 68 zircaloy-4 clad fuel rods containing pelletized UO_2 fuel arranged on a 1.4732cm (0.58”) pitch. This assembly was also strengthened similar to the load-follow assemblies. However, this assembly contained solid zircaloy-4 bars at both the E-1 and A-5 removable rod locations; whereas the load follow assemblies contained only one solid zircaloy-4 bar.

Subassembly design

The removable subassemblies could be placed at several positions in the core as shown in Fig.3. They were similar in construction to the main fuel assemblies except that the can was made of 0.04826 cm (0.019”) thick perforated SS and the rods were arranged on a 1.36144cm (0.536”) pitch (see Fig. 4).

Subassembly 503-4-31 was initially in the N-1[a] location. This subassembly contained four previously irradiated mixed oxide fuel rods clad in zircaloy-4, a flux thimble in the center rod location and four water filled zircaloy-4 tubes in the four corner locations.

Subassembly 503-4-33 was initially in the N-2 [a] location. This subassembly contained two hydriding effects test fuel rods which contained fuel having average D_2O concentration of 120 ppm and two high-pressure creep rods at 13.203 MPa (1915 Psi) initial pressure. This subassembly also contained a flux thimble in the center location and four water-filled zircaloy-4 tubes at the four corner locations.

Subassembly 503-4-25 was initially in the N-3[a] location. This subassembly contained five non-removable fuel rods clad with type 304-SS and enriched to 5.7 % w/o U-235. In addition, this subassembly contained four removable fuel rods clad with zircaloy-4, enriched to 5.7 % w/o U-235, with various internal pressures.

Subassembly 503-4-32 was initially in the N-4 [a] location. This subassembly contained four non-removable fuel rods clad with zircaloy-4, enriched to 12.5 % w/o U-235; two low-pressure creep test rods; a flux thimble, and two irradiated zircaloy-4 clad, PuO2-UO2 rods.

Subassembly 503-4-34 was initially in the N-5[a] location. This subassembly contained two hydriding effects test fuel rods and two materials compatibility test rod.

a- See Fig.3

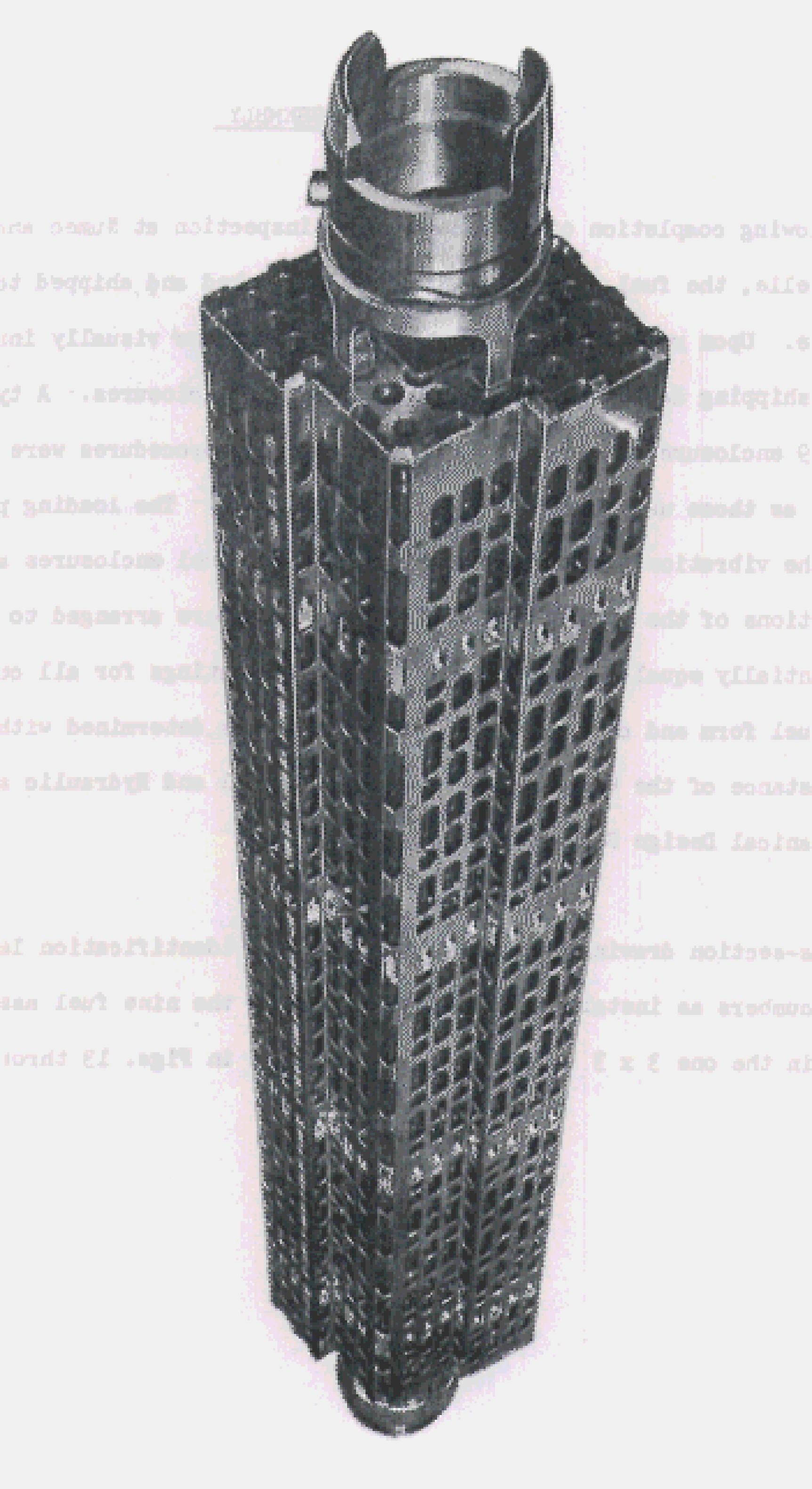


Figure 1: Saxton fuel assembly

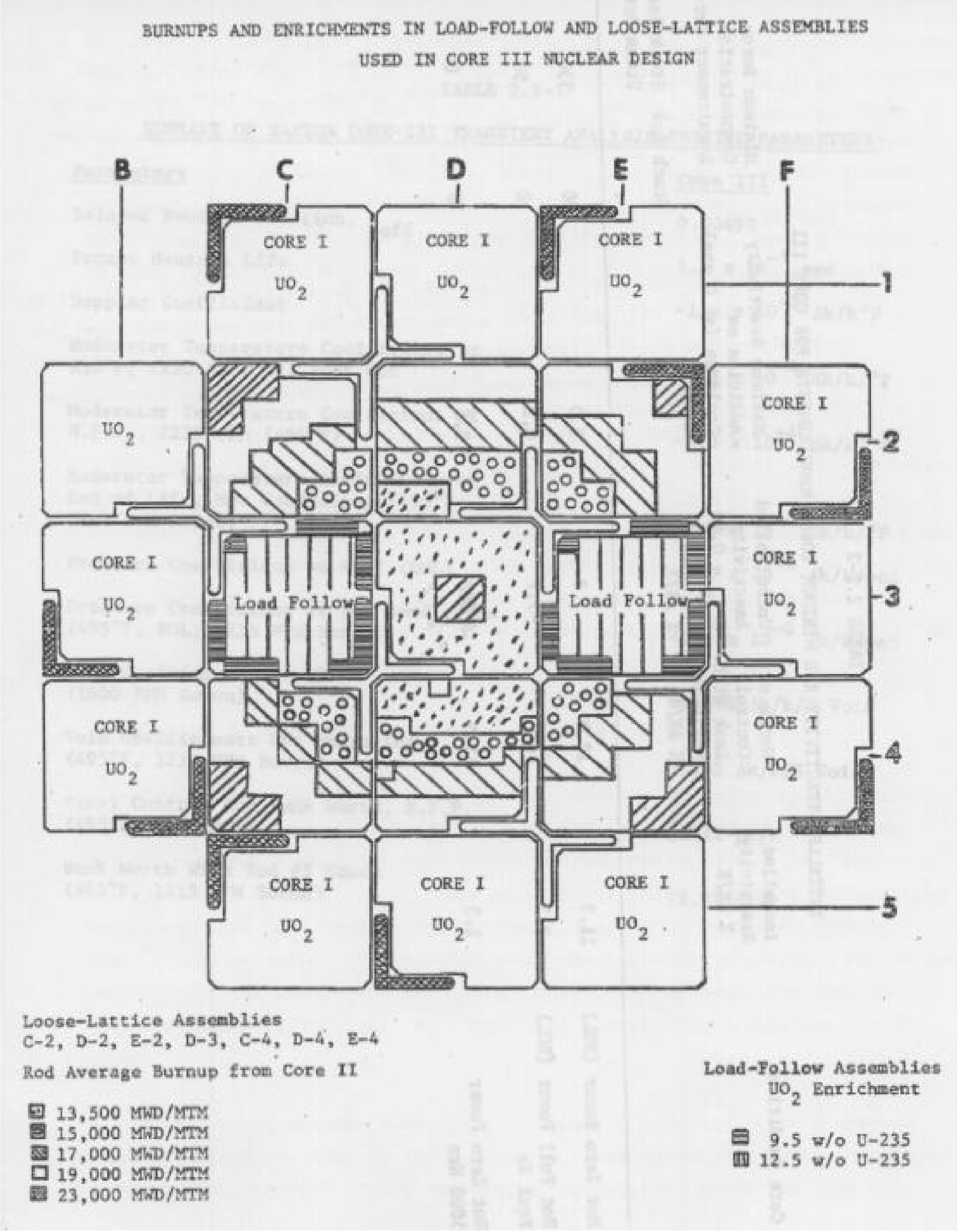


Figure 2: Core III map

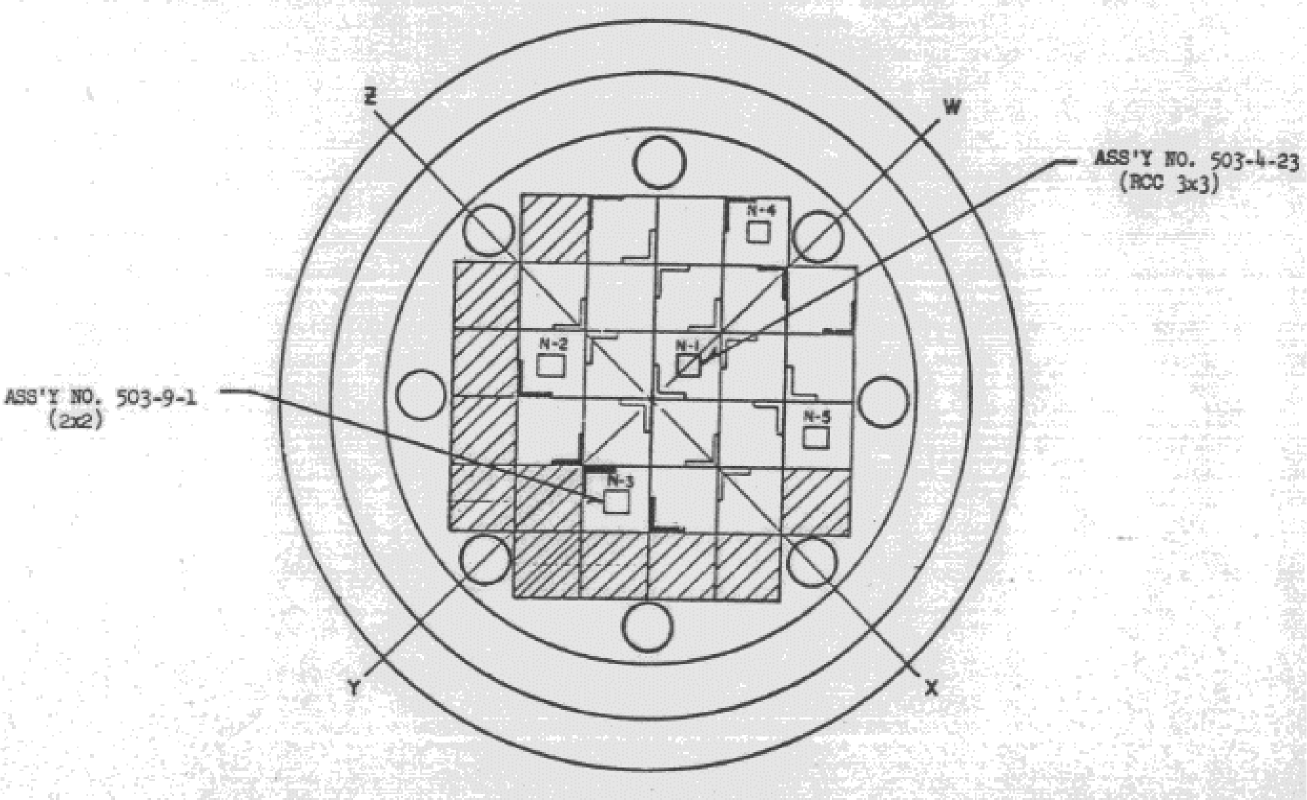


Figure 3: Global map of the Saxton core and location of the special removable 3x3 (RCC) and 2x2 assembly

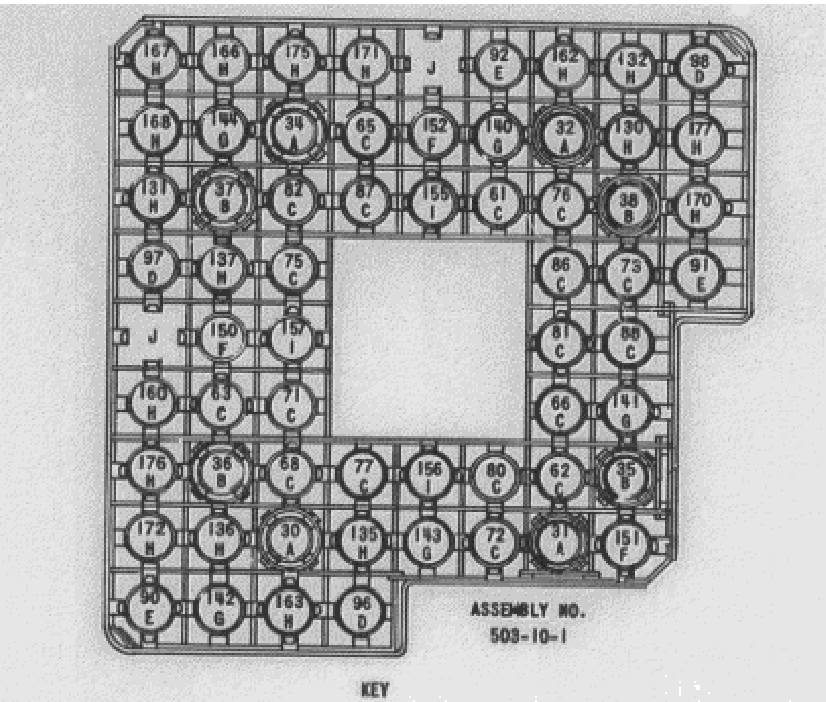


Figure 4: Generic fuel assembly detailed description

2.3. Fuel elements

The fuel elements were assembled into the fuel assemblies by brazing or welding. Thin metal spacers arranged in a grid pattern were placed between fuel elements at appropriate intervals. Fuel-rod details are given in Tables 1A and 1B below, and the plutonium fuel rods are shown in Fig. 5. The alternative, water-tube rod is shown in Fig. 6.

Table 1A Fuel Rod details in the Uranium Assemblies.

Fuel tube outer diameter	0.99314 cm	0.391 in.
Fuel tube inner diameter	0.91694 cm	0.361 in.
Fuel rod pitch	1.4732 cm	0.58 in.
UO_2 enrichment, wt. % (^{235}U)	5.74	
Clad:	Zircaloy-4 unless noted otherwise in text	
Material		
Thickness		
	0.0381 cm	0.015 in.
Pellet dimensions:		
Pellet Diameter	0.90678 cm	0.357 in.
Pellet Length	1.85928 cm	0.732 in.
UO_2 density, g/cm^3:		
Theoretical	10.96	
Average in the uranium fueled rods	10.18 (~93 % theoretical density))	

Table 1B Fuel Rod details in the Plutonium Assemblies.

UO_2	Natural
PuO_2-UO_2 enrichment, wt. % (PuO_2)	6.60
Theoretical density (TD), g/cm^3:	
UO_2	10.96
PuO_2	11.46

Fuel Configuration	**Pelletized**	**VIPAC**		
Clad type	**SS304**	**Zircalloy**	**SS304**	**Zircalloy**
Clad:				
ID, mm	9.1694	8.7503	9.1948	8.7503
(in)	(0.3610)	(0.3445)	(0.362)	(0.3445)
Wall thickness, mm	0.381	0.5664	0.3810	0.5664
(in)	(0.0150)	(0.0233)	(0.015)	(0.0223)
OD,mm	9.9314	9.9314	9.9314	9.9314
(in)	(0.3910)	(0.3910)	(0.391)	(0.3910)
Pellet dimensions:				
Pellet diameter, mm	9.0373	8.7503	9.0373	8.7503
(in)	(0.3558)	(0.3445)	(0.3558)	(0.3445)
Pellet length, mm	9.2964	9.2964	9.2964	9.2694
(in)	(0.3660)	(0.3660)	(0.3660)	(0.3660)
Diametral gap, mm	0.1321	0.1803	0.1321	0.1803
(in)	(0.0052)	(0.0071)	(0.0052	(0.0071)
Fuel column height, mm	929.64	929.64	929.64	929.64
(in)	(36.600)	(36.600)	(36.600)	(36.600)
End gap, mm	20.244	20.244	21.717	21.717
(in)	(0.7970)	(0.7970)	(0.8550)	(0.8550)
Fuel density, % TD	94		87	

2.4. Control rods and chemical shim

The reactor used six offset cruciform-shaped control rods made of an alloy of silver, indium and cadmium (Fig. 7). The control rods had fueled following sections. Reactor control was also achieved by using boric acid dissolved in the primary coolant as chemical shim. Control rod details are shown below. Little information was available on the control rods in the series of reports. We assumed similar shape and information traditionally used by Westinghouse in this time frame. In particular, it was difficult to locate information on the fuel followers.

Number of moveable control rods	6
Control Rod material	80%Ag, 15%In, 5%Cd
Control Rod Shape	Offset cruciform
Control Rod span	14.2367 cm (5.605 in.)
Control Rod Thickness	0.99695 cm (0.3925 in.)
Estimated control rod worth (average per rod, in %)	3.8
Boron concentration (natural boron), ppm: • **To shutdown the reactor down to K = 0.97 with no rods inserted (all requirements in ppm):** **Cold/Hot** • **To control at power with no rods inserted:** **Unpoisoned** **Poisoned (Xe & Sr)** • **Approximate concentration for one percent worth:** **Cold/Hot**	2200/2330 1835 1495 80/110

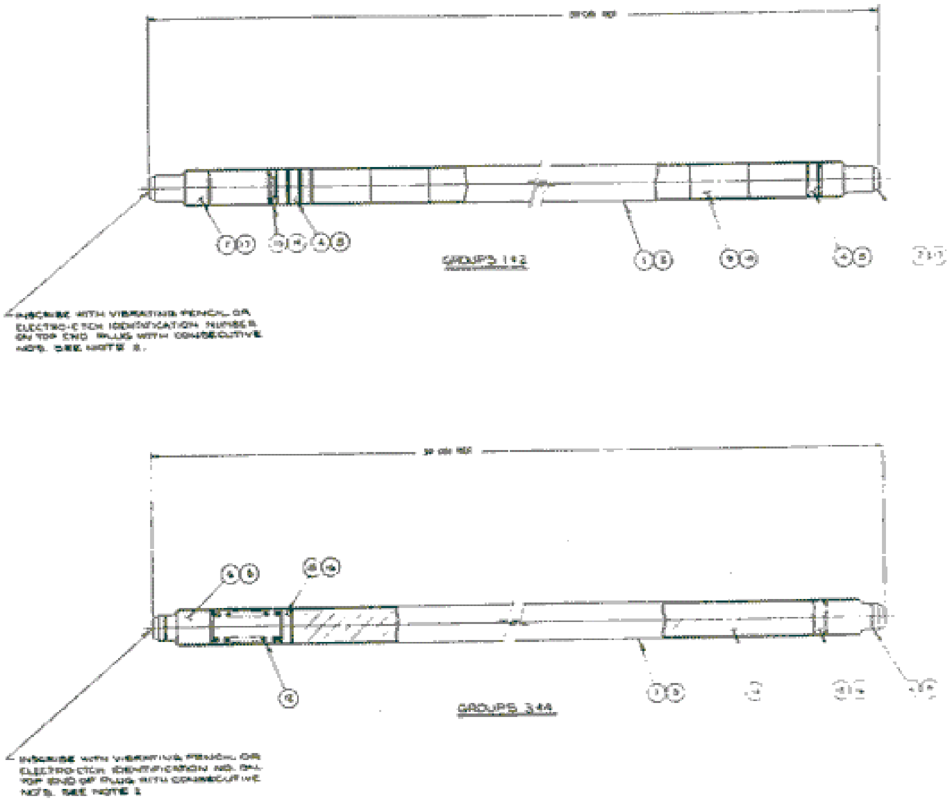


Figure 5: Plutonium rods

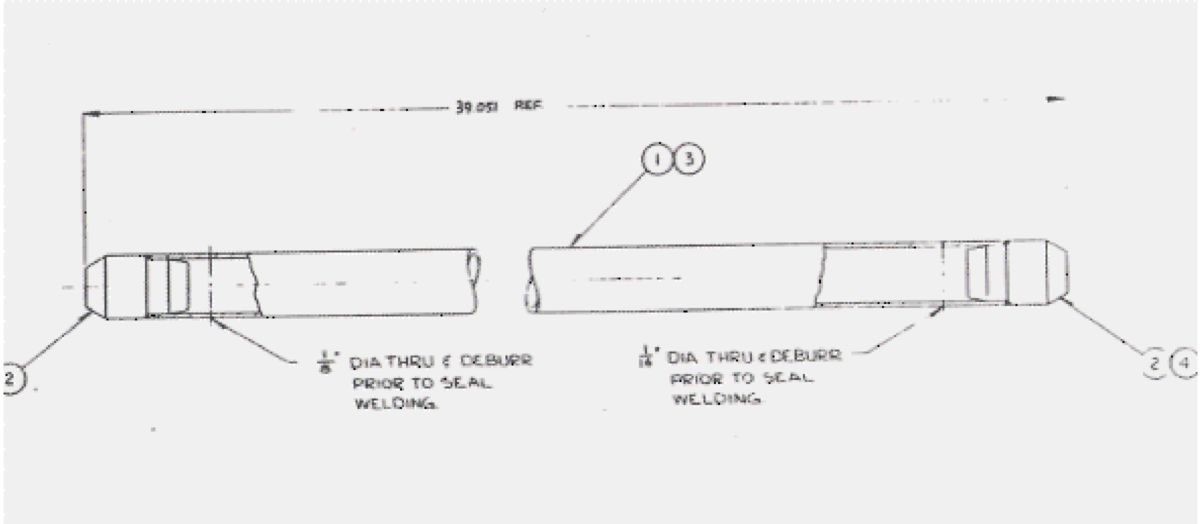


Figure 6: Water tube rod

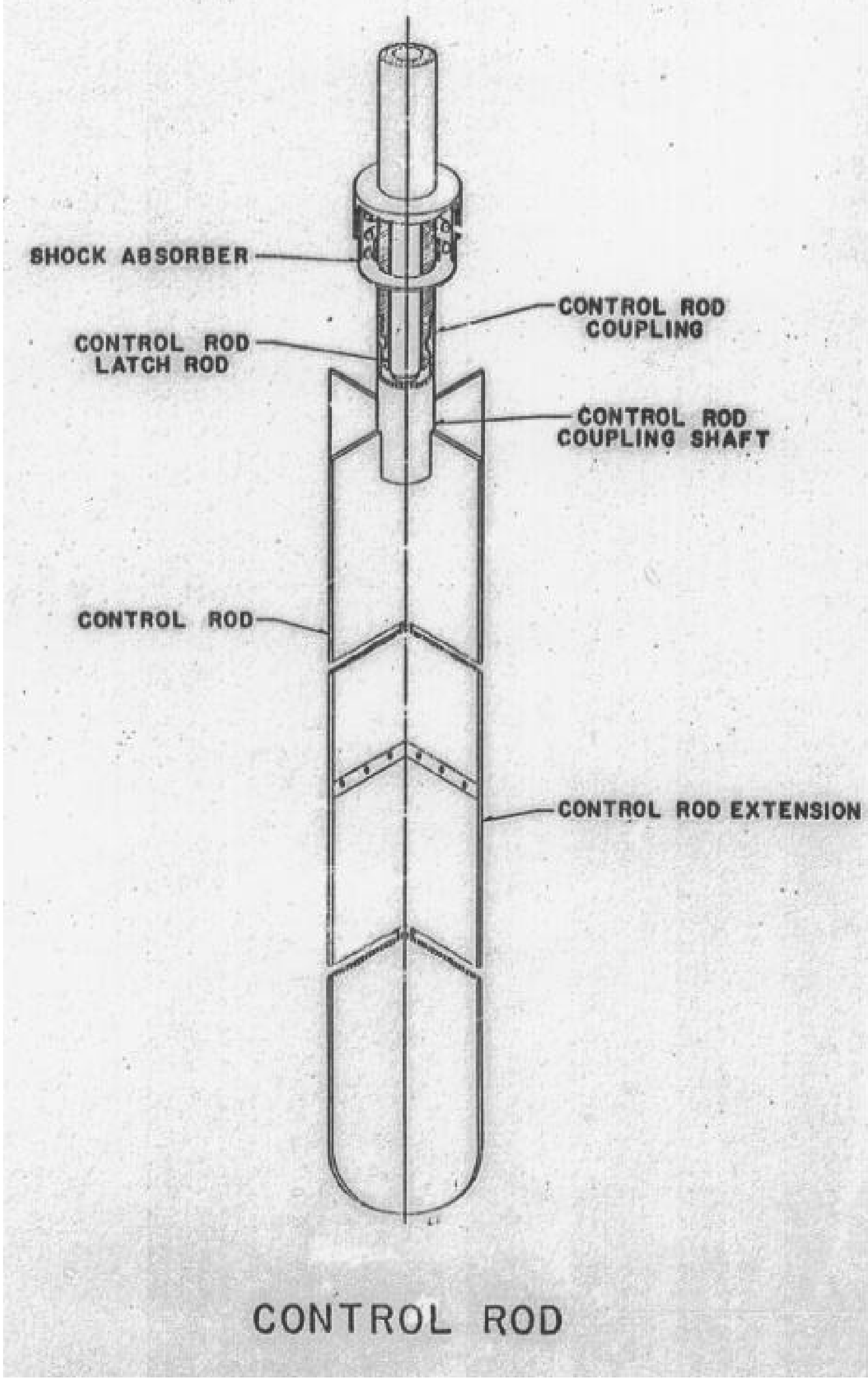
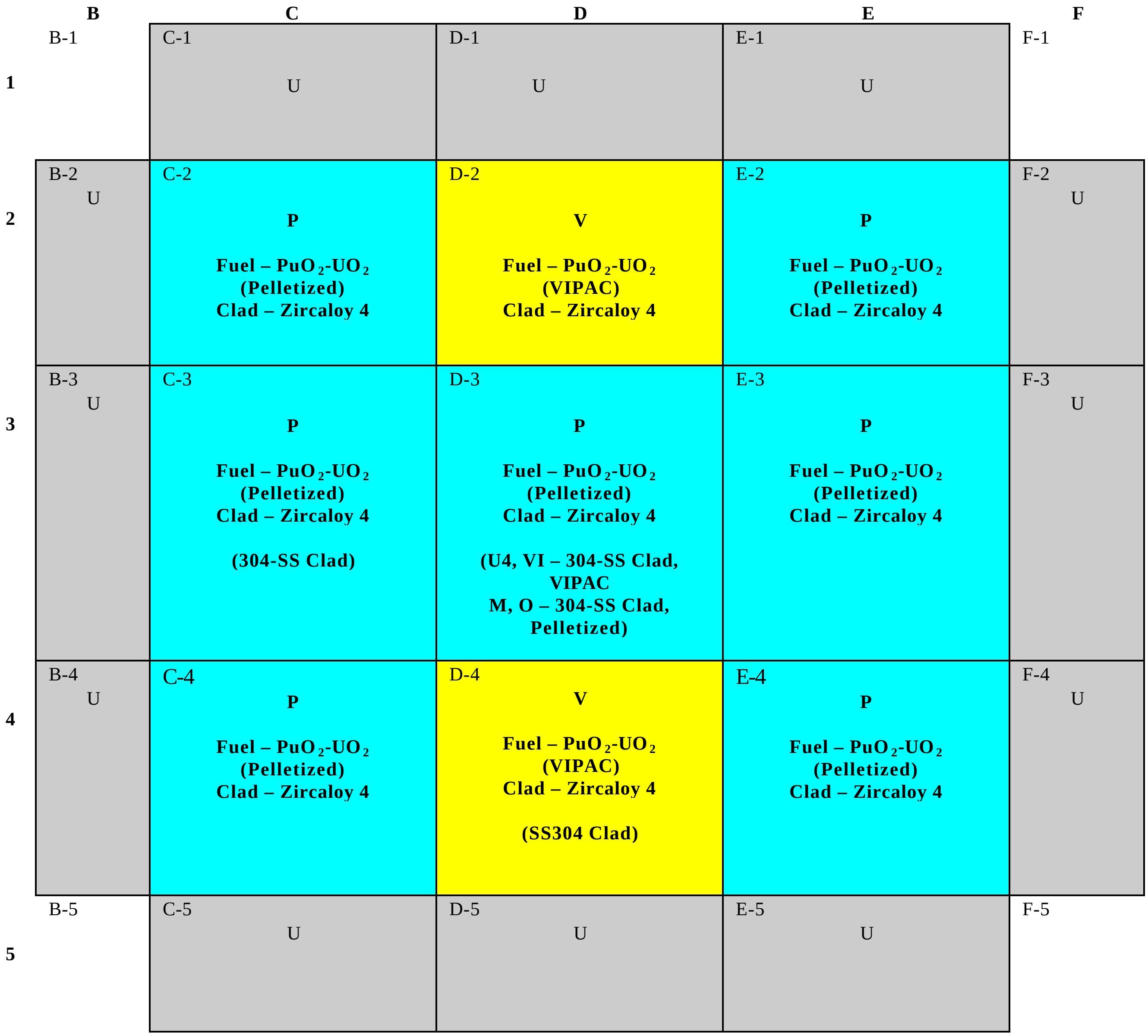


Figure 7: Control rod description. The fueled portion is in the control rod extension.

2.5. Saxton reactor core map

A generic plane view of Saxton Core II is shown in Fig. 8. A similar plan was used for Core I. Fig. 9 shows the generic assembly configuration of Core III.



	B	C	D	E	F
1	B-1	C-1 U	D-1 U	E-1 U	F-1
2	B-2 U	C-2 **P** **Fuel – PuO_2-UO_2** **(Pelletized)** **Clad – Zircaloy 4**	D-2 **V** **Fuel – PuO_2-UO_2** **(VIPAC)** **Clad – Zircaloy 4**	E-2 **P** **Fuel – PuO_2-UO_2** **(Pelletized)** **Clad – Zircaloy 4**	F-2 U
3	B-3 U	C-3 **P** **Fuel – PuO_2-UO_2** **(Pelletized)** **Clad – Zircaloy 4** **(304-SS Clad)**	D-3 **P** **Fuel – PuO_2-UO_2** **(Pelletized)** **Clad – Zircaloy 4** **(U4, VI – 304-SS Clad, VIPAC** **M, O – 304-SS Clad, Pelletized)**	E-3 **P** **Fuel – PuO_2-UO_2** **(Pelletized)** **Clad – Zircaloy 4**	F-3 U
4	B-4 U	C-4 **P** **Fuel – PuO_2-UO_2** **(Pelletized)** **Clad – Zircaloy 4**	D-4 **V** **Fuel – PuO_2-UO_2** **(VIPAC)** **Clad – Zircaloy 4** **(SS304 Clad)**	E-4 **P** **Fuel – PuO_2-UO_2** **(Pelletized)** **Clad – Zircaloy 4**	F-4 U
5	B-5	C-5 U	D-5 U	E-5 U	F-5

Figure 8. Generic floor map of Saxton Core II and assembly specifications. Letters U, P and V represent Uranium, pelletized MOX and VIPAC MOX assemblies respectively.

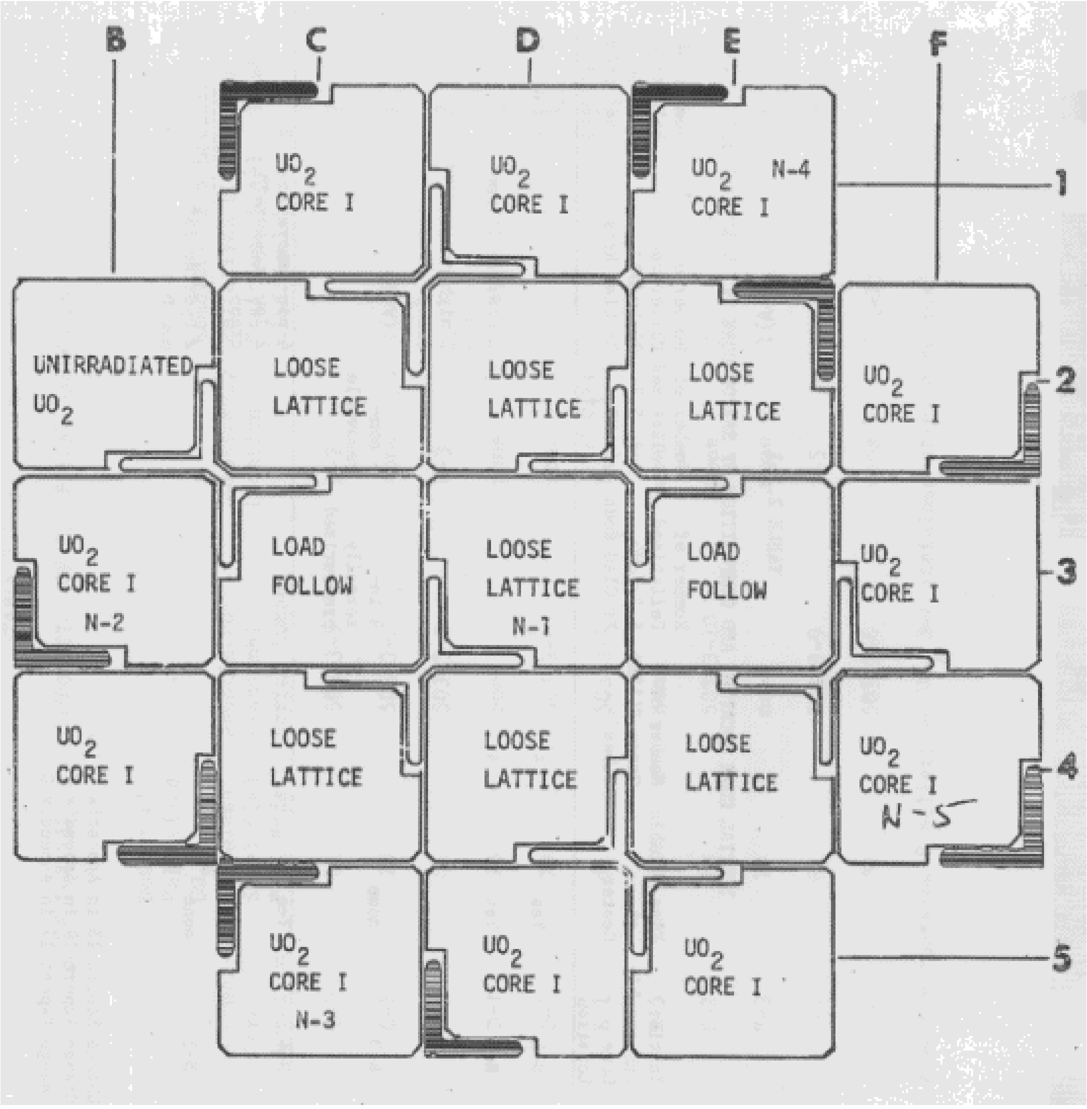


Figure 9. Core III assembly configuration

3. Model description

3.1. Assumptions and simplifications

A generalized model has been created for the Saxton reactor core description. This model describes Saxton Core I, II, and III configurations and enables us to perform consistent analyses of the reactor core characteristics throughout the configurations studied within the frame of the Saxton Plutonium Program. The Saxton Core III configuration is shown in Fig. 9.

Because of the extreme complexity of the Saxton reactor core, several simplifications and assumptions were made in the model. Our main assumptions and simplifications are listed below:

- All UO_2-loaded fuel elements are the same and contain fresh pelletized fuel;
- All cells centered on one fuel element have the same fuel element cell pitch;
- The design of fuel assemblies is assumed to be the same for all Saxton reactor core configurations (Core I – III), only the grid material is changed:

MOX fuel assemblies	– Inconel grid;
UO_2 assemblies	– Stainless Steel and Inconel grids;

- All control rods are assumed to have the same characteristics as described in section 3.4;
- A constant thermal power level has been assumed for the fuel lifetime of the Saxton reactor core (detailed power history description can be found in the Saxton project reports but this information was not used within the framework of the present study. The use of this information is discussed further in this report);
- A simplified uniform temperature distribution has been assumed for the Saxton reactor core as described in the sections that follow. (The detailed temperature distribution within the Saxton reactor core can be found in the Saxton project reports but this information was not applied within the framework of the present study);
- All specific characteristics of the Saxton reactor core are implemented into the model as described in sections 3.2 to 3.5.

3.2. Fuel elements

Overall, five different types of fuel element may be found in the Saxton Cores I, II, and III:

Type 001	(UOX, S):	UO_2-loaded fuel elements, fresh fuel;
Type 002	(MOX, P, Z4):	PuO_2-UO_2-loaded fuel elements, pelletized fuel;
Type 003	(MOX, V, Z4):	PuO_2-UO_2-loaded fuel elements, VIPAC fuel;
Type 004	(MOX, V, S):	PuO_2-UO_2-loaded fuel elements, VIPAC fuel;
Type 005	(MOX, P, S):	PuO_2-UO_2-loaded fuel elements, pelletized fuel.

All these types are taken into account in the applied model of the Saxton Core. It is presumed, that Saxton Core I contains only fuel elements of the first type 001, and Saxton Cores II and III contain fuel elements of all five types. Detailed descriptions of all fuel element types are provided in the following pages.

Type 001 (UOX, S): UO_2-loaded fuel elements, fresh fuel

Fuel: UO_2, 10.18 g/cm^3, 5.74 wt. % ^{235}U; fuel region diameter, cm (PD1) - 0.90678
Clad: SS304, 7.94 g/cm^3; clad ID, cm (CID1) - 0.91694, clad OD, cm (COD) - 0.99314
Pitch: pitch, cm (p) – 1.47320

Characteristics of the cell centered on one fuel element:

Fuel element cell pitch, cm (p): 1.47320

Clad OD, cm (COD): 0.99314
Clad ID, cm (CID1): 0.91694
Clad wall thickness, cm (CWT1): 0.03810
Pellet diameter, cm (PD1): 0.90678

UOX fuel characteristics:

UO_2 theoretical density (TD), g/cm^3: 10.9600

% Theoretical density (TD): 92.8832, pelletized

UO_2 enrichment, wt. % (^{235}U): 5.74000

Average UO_2 density, g/cm^3: 10.1800

Clad material: SS304
Clad material density, g/cm^3: 7.94000

Clad region composition (type 304-SS , 7.94 g/cm^3):

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %		Atomic mass, amu	Atomic density(b^{-1}cm^{-1})
Iron	68.375	**Fe**	26000	26054	5.6990	53.93961480	3.413080E-3
				26056	91.870	55.93494210	5.502012E-2
				26057	2.1410	56.93539870	1.282226E-3
				26058	0.2900	57.93328050	1.736784E-4
Chromium	19.000	**Cr**	24000	24050	4.1740	49.94604960	6.946348E-4
				24052	83.700	51.94051190	1.392931E-2
				24053	9.6730	52.94065380	1.609775E-3
				24054	2.4530	53.93888490	4.082269E-4
Nickel	9.5000	**Ni**	28000	28058	67.395	57.93534790	5.607920E-3
				28060	26.653	59.93079060	2.217789E-3
				28061	1.1730	60.93106040	9.760501E-5
				28062	3.7880	61.92834880	3.151984E-4
				28064	0.9910	63.92796960	8.246084E-5
Manganese	2.0000	**Mn**	25000	25055	100.00	54.93804960	1.751784E-3
Silicon	1.0000	**Si**	14000	14028	91.873	27.97692650	8.047081E-4
				14029	4.8180	28.97649470	4.220047E-5
				14030	3.3080	29.97377020	2.897450E-5
Carbon	0.0800	**C**	6000	6012	98.809	12.00000000	6.923680E-5
				6013	1.1910	13.00335480	8.345498E-7
Phosphorus	0.0450	**P**	15000	15031	100.00	30.97376150	3.941513E-5

Fuel region composition (UO_2 fresh fuel composition):

Component	**Symbol**	**ID**	**Isotopic distribution, wt. %**	**Atomic mass, amu**	**Atomic density ($b^{-1}cm^{-1}$)**
Uranium	**^{235}U** **^{235}U**	92235 92238	5.7400 94.260	235.0439231 238.0507826	1.303954E-3 2.141301E-2
Oxygen	**O**	8016	100.00	15.99491460	4.543393E-2

Type 002 (MOX, P, Z4): PuO_2-UO_2-loaded fuel elements, pelletized fuel

Fuel: 6.6 wt. % PuO_2-UO_2 (natural), pelletized, 9.5692 g/cm^3, fuel region diameter, cm (PD2) - 0.87503
Clad: Zircaloy-4, 6.58 g/cm^3; clad ID, cm (CID2) - 0.87503, clad OD, cm (COD) - 0.99314
Pitch: pitch, cm (p) – 1.47320

Characteristics of the cell centered on one fuel element:

Fuel element cell pitch, cm (p):	1.473200
Clad OD, cm (COD):	0.993140
Clad ID, cm (CID2):	0.875030
Clad wall thickness, cm (CWT2):	0.059055
Pellet diameter, cm (PD2):	0.875030

MOX fuel characteristics:

UO_2 theoretical density (TD), g/cm^3:	10.96000	
PuO_2 theoretical density (TD), g/cm^3:	11.46000	
% Theoretical density (TD):	94, pelletized	
PuO_2-UO_2 enrichment, wt. % (PuO_2):	6.600000	
PuO_2 isotopic distribution, wt. %:	^{239}Pu	90.49000
	^{240}Pu	8.570000
	^{241}Pu	0.890000
	^{242}Pu	0.040000
Average PuO_2-UO_2 density, g/cm^3:	10.33342	

Clad material:	Zircaloy-4
Clad material density, g/cm^3:	6.580000

Clad region composition (Zircaloy-4, 6.58 g/cm^3):

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %		Atomic mass, amu	Atomic density (b^{-1}cm^{-1})
Zirconium	98.200	**Zr**	40000	40090	50.707	89.90470370	2.19483E-02
				40091	11.181	90.90564500	4.78636E-03
				40092	17.278	91.90504010	7.31593E-03
				40094	17.891	93.90631580	7.41405E-03
				40096	2.9440	95.90827570	1.19453E-03
Tin	1.5000	**Sn**	50000	50112	0.9140	111.9048208	4.85504E-04
				50114	0.6240	113.9027818	3.25646E-04
				50115	0.3480	114.9033460	1.80029E-04
				50116	14.186	115.9017441	7.27554E-03
				50117	7.5630	116.9029538	3.84560E-03
				50118	24.055	117.9016063	1.21278E-02
				50119	8.5940	118.9033089	4.29632E-03
				50120	32.917	119.9021966	1.63188E-02
				50122	4.7550	121.9034401	2.31862E-03
				50124	6.0430	123.9052746	2.89907E-03
Iron	0.2000	**Fe**	26000	26054	5.6990	53.93961480	8.37385E-04
				26056	91.870	55.93494210	1.30174E-02
				26057	2.1410	56.93539870	2.98036E-04
				26058	0.2900	57.93328050	3.96738E-05
Chromium	0.1000	**Cr**	24000	24050	4.1740	49.94604960	3.31173E-04
				24052	83.700	51.94051190	6.38592E-03
				24053	9.6730	52.94065380	7.24062E-04
				24054	2.4530	53.93888490	1.80219E-04

Fuel region composition (PuO_2-UO_2 fuel composition, pelletized):

Component	Symbol	ID	Isotopic distribution, wt. %	Atomic mass, amu	Atomic density (b^{-1}cm^{-1})

Plutonium	**^{239}Pu**	94239	90.490	239.0521565	1.376016E-03
	^{240}Pu	94240	8.5700	240.0538075	1.303178E-04
	^{241}Pu	94241	0.8900	241.0568453	1.353359E-05
	^{242}Pu	94242	0.0400	242.0587368	6.082511E-07
Uranium	**^{235}U**	92235	0.7160	235.0439231	1.540774E-04
	^{235}U	92238	99.284	238.0507826	2.136511E-02
Oxygen	**O**	8016	100.00	15.99491460	4.607963E-02

Type 003 (MOX, V, Z4): PuO_2-UO_2-loaded fuel elements, VIPAC fuel

Fuel: 6.6 wt. % PuO_2-UO_2 (natural), VIPAC, 8.8566 g/cm^3, fuel region diameter, cm (PD2) - 0.87503
Clad: Zircaloy-4, 6.58 g/cm^3; clad ID, cm (CID2) - 0.87503, clad OD, cm (COD) - 0.99314
Pitch: pitch, cm (p) – 1.47320

Characteristics of the cell centered on one fuel element:

Fuel element cell pitch, cm (p): 1.473200
Clad OD, cm (COD): 0.993140
Clad ID, cm (CID2): 0.875030
Clad wall thickness, cm (CWT3): 0.056642
Pellet diameter, cm (PD2): 0.875030

MOX fuel characteristics:

UO_2 theoretical density (TD), g/cm^3: 10.96000
PuO_2 theoretical density (TD), g/cm^3: 11.46000

% Theoretical density (TD): 87 , VIPAC

PuO_2-UO_2 enrichment, wt. % (PuO_2): 6.600000

PuO_2 isotopic distribution, wt. %:	^{239}Pu	90.49000
	^{240}Pu	8.570000
	^{241}Pu	0.890000
	^{242}Pu	0.040000

Average PuO_2-UO_2 density, g/cm^3: 9.563910

Clad material: Zircaloy-4
Clad material density, g/cm^3: 6.580000

Clad region composition (Zircaloy-4, 6.58 g/cm^3):

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %		Atomic mass, amu	Atomic density ($b^{-1}cm^{-1}$)
Zirconium	98.200	**Zr**	40000	40090	50.707	89.90470370	2.19483E-02
				40091	11.181	90.90564500	4.78636E-03
				40092	17.278	91.90504010	7.31593E-03
				40094	17.891	93.90631580	7.41405E-03
				40096	2.9440	95.90827570	1.19453E-03
Tin	1.5000	**Sn**	50000	50112	0.9140	111.9048208	4.85504E-04
				50114	0.6240	113.9027818	3.25646E-04
				50115	0.3480	114.9033460	1.80029E-04
				50116	14.186	115.9017441	7.27554E-03
				50117	7.5630	116.9029538	3.84560E-03
				50118	24.055	117.9016063	1.21278E-02
				50119	8.5940	118.9033089	4.29632E-03
				50120	32.917	119.9021966	1.63188E-02
				50122	4.7550	121.9034401	2.31862E-03
				50124	6.0430	123.9052746	2.89907E-03
Iron	0.2000	**Fe**	26000	26054	5.6990	53.93961480	8.37385E-04
				26056	91.870	55.93494210	1.30174E-02
				26057	2.1410	56.93539870	2.98036E-04
				26058	0.2900	57.93328050	3.96738E-05
Chromium	0.1000	**Cr**	24000	24050	4.1740	49.94604960	**3**.31173E-04
				24052	83.700	51.94051190	6.38592E-03
				24053	9.6730	52.94065380	7.24062E-04
				24054	2.4530	53.93888490	1.80219E-04

Fuel region composition (PuO_2-UO_2 fuel composition, VIPAC):

Component	Symbol	ID	Isotopic distribution, wt. %	Atomic mass, amu	Atomic density ($b^{-1}cm^{-1}$)

Plutonium	**^{239}Pu**	94239	90.490	239.0521565	1.273547E-03
	^{240}Pu	94240	8.5700	240.0538075	1.206133E-04
	^{241}Pu	94241	0.8900	241.0568453	1.252577E-05
	^{242}Pu	94242	0.0400	242.0587368	5.629558E-07
Uranium	**^{235}U**	92235	0.7160	235.0439231	1.426035E-04
	^{235}U	92238	99.284	238.0507826	1.977409E-02
Oxygen	**O**	8016	100.00	15.99491460	4.264817E-02

Type 004 (MOX, V, S): PuO_2-UO_2-loaded fuel elements, VIPAC fuel

Fuel: 6.6 wt. % PuO_2-UO_2 (natural), VIPAC, 8.8566 g/cm^3, fuel region diameter, cm (PD3) - 0.903732
Clad: SS304, 7.94 g/cm^3; clad ID, cm (CID3) - 0.91948, clad OD, cm (COD) - 0.99314
Pitch: pitch, cm (p) – 1.47320

Characteristics of the cell centered on one fuel element:

Fuel element cell pitch, cm (p): 1.473200
Clad OD, cm (COD): 0.993140
Clad ID, cm (CID3): 0.919480
Clad wall thickness, cm (CWT1): 0.038100
Pellet diameter, cm (PD3): 0.903732

MOX fuel characteristics:

UO_2 theoretical density (TD), g/cm^3: 10.96000
PuO_2 theoretical density (TD), g/cm^3: 11.46000

% Theoretical density (TD): 87, VIPAC

PuO_2-UO_2 enrichment, wt. % (PuO_2): 6.600000
PuO_2 isotopic distribution, wt. %: ^{239}Pu 90.49000
^{240}Pu 8.570000
^{241}Pu 0.890000
^{242}Pu 0.040000

Average PuO_2-UO_2 density, g/cm^3: 9.563910

Clad material: SS304
Clad material density, g/cm^3: 7.94000

Clad region composition (SS304 (Stainless Steel – 304, 7.94 g/cm^3) Composition):

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %		Atomic mass, amu	Atomic density ($b^{-1}cm^{-1}$)
Iron	68.375	**Fe**	26000	26054	5.6990	53.93961480	3.413080E-3
				26056	91.870	55.93494210	5.502012E-2
				26057	2.1410	56.93539870	1.282226E-3
				26058	0.2900	57.93328050	1.736784E-4
Chromium	19.000	**Cr**	24000	24050	4.1740	49.94604960	6.946348E-4
				24052	83.700	51.94051190	1.392931E-2
				24053	9.6730	52.94065380	1.609775E-3
				24054	2.4530	53.93888490	4.082269E-4
Nickel	9.5000	**Ni**	28000	28058	67.395	57.93534790	5.607920E-3
				28060	26.653	59.93079060	2.217789E-3
				28061	1.1730	60.93106040	9.760501E-5
				28062	3.7880	61.92834880	3.151984E-4
				28064	0.9910	63.92796960	8.246084E-5
Manganese	2.0000	**Mn**	25000	25055	100.00	54.93804960	1.751784E-3
Silicon	1.0000	**Si**	14000	14028	91.873	27.97692650	8.047081E-4
				14029	4.8180	28.97649470	4.220047E-5
				14030	3.3080	29.97377020	2.897450E-5
Carbon	0.0800	**C**	6000	6012	98.809	12.00000000	6.923680E-5
				6013	1.1910	13.00335480	8.345498E-7
Phosphorus	0.0450	**P**	15000	15031	100.00	30.97376150	3.941513E-5

Fuel region composition (PuO_2-UO_2 fuel composition, VIPAC):

Component	Symbol	ID	Isotopic distribution, wt. %	Atomic mass, amu	Atomic density ($b^{-1}cm^{-1}$)

Plutonium	**^{239}Pu** **^{240}Pu** **^{241}Pu** **^{242}Pu**	94239 94240 94241 94242	90.490 8.5700 0.8900 0.0400	239.0521565 240.0538075 241.0568453 242.0587368	1.273547E-03 1.206133E-04 1.252577E-05 5.629558E-07
Uranium	**^{235}U** **^{235}U**	92235 92238	0.7160 99.284	235.0439231 238.0507826	1.426035E-04 1.977409E-02
Oxygen	**O**	8016	100.00	15.99491460	4.264817E-02

Type 005 (MOX, P, S): PuO_2-UO_2-loaded fuel elements, pelletized fuel
Fuel: 6.6 wt. % PuO_2-UO_2 (natural), pelletized, 9.5692 g/cm^3, fuel region diameter, cm (PD3) - 0.903732
Clad: SS304, 7.94 g/cm^3; clad ID, cm (CID1) - 0.91694, clad OD, cm (COD) - 0.99314
Pitch: pitch, cm (p) – 1.47320

Characteristics of the cell centered on one fuel element:

Fuel element cell pitch, cm (p):	1.473200
Clad OD, cm (COD):	0.993140
Clad ID, cm (CID1):	0.916940
Clad wall thickness, cm (CWT1):	0.038100
Pellet diameter, cm (PD3):	0.903732

MOX fuel characteristics:

UO_2 theoretical density (TD), g/cm^3:	10.96000	
PuO_2 theoretical density (TD), g/cm^3:	11.46000	
% Theoretical density (TD):	94 , pelletized	
PuO_2-UO_2 enrichment, wt. % (PuO_2):	6.600000	
PuO_2 isotopic distribution, wt. %:	^{239}Pu	90.49000
	^{240}Pu	8.570000
	^{241}Pu	0.890000
	^{242}Pu	0.040000
Average PuO_2-UO_2 density, g/cm^3:	10.33342	

Clad material:	304-SS
Clad material density, g/cm^3:	7.94000

Clad region composition (304-SS– 304, 7.94 g/cm^3):

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %		Atomic mass, amu	Atomic density (b^{-1}cm^{-1})
Iron	68.375	**Fe**	26000	26054	5.6990	53.93961480	3.413080E-3
				26056	91.870	55.93494210	5.502012E-2
				26057	2.1410	56.93539870	1.282226E-3
				26058	0.2900	57.93328050	1.736784E-4
Chromium	19.000	**Cr**	24000	24050	4.1740	49.94604960	6.946348E-4
				24052	83.700	51.94051190	1.392931E-2
				24053	9.6730	52.94065380	1.609775E-3
				24054	2.4530	53.93888490	4.082269E-4
Nickel	9.5000	**Ni**	28000	28058	67.395	57.93534790	5.607920E-3
				28060	26.653	59.93079060	2.217789E-3
				28061	1.1730	60.93106040	9.760501E-5
				28062	3.7880	61.92834880	3.151984E-4
				28064	0.9910	63.92796960	8.246084E-5
Manganese	2.0000	**Mn**	25000	25055	100.00	54.93804960	1.751784E-3
Silicon	1.0000	**Si**	14000	14028	91.873	27.97692650	8.047081E-4
				14029	4.8180	28.97649470	4.220047E-5
				14030	3.3080	29.97377020	2.897450E-5
Carbon	0.0800	**C**	6000	6012	98.809	12.00000000	6.923680E-5
				6013	1.1910	13.00335480	8.345498E-7
Phosphorus	0.0450	**P**	15000	15031	100.00	30.97376150	3.941513E-5

Fuel region composition (PuO_2-UO_2 fuel composition, pelletized):

Component	Symbol	ID	Isotopic distribution, wt. %	Atomic mass, amu	Atomic density (b^{-1}cm^{-1})

Plutonium	**^{239}Pu** **^{240}Pu** **^{241}Pu** **^{242}Pu**	94239 94240 94241 94242	90.490 8.5700 0.8900 0.0400	239.0521565 240.0538075 241.0568453 242.0587368	1.376016E-03 1.303178E-04 1.353359E-05 6.082511E-07
Uranium	**^{235}U** **^{235}U**	92235 92238	0.7160 99.284	235.0439231 238.0507826	1.540774E-04 2.136511E-02
Oxygen	**O**	8016	100.00	15.99491460	4.607963E-02

Technical summary from the above complete description of the fuel elements is given in Table 2 and shown in Figure 9. Special notation was established in order to define characteristics of the fuel elements and distinguish between different types of the fuel elements.

Table 2 Types of Fuel Elements

a) Notation

Fuel element	**UOX, S**	**MOX, P, Z4**	**MOX, V, Z4**	**MOX, P, S**	**MOX, V, S**
Fuel element cell pitch, in	P=0.58				
Fuel region diameter, in	PD1=0.357	PD2=0.3445		PD3=0.3558	
Clad:					
Outside diameter, in	COD=0.391	COD=0.391	COD=0.391	COD=0.391	COD=0.391
Inside diameter, in	CID1=0.361	CID2=0.3445	CID2=0.3445	CID1=0.361	CID3=0.362
Thickness, in	CWT1=0.015	CWT2=0.0233	CWT3=0.0223	CWT1=0.015	CWT1=0.015

b) Summarized characteristics

Type of Fuel Element	**FE001**	**FE002**	**FE003**	**FE005**	**FE004**
Description	UOX, S	MOX, P, Z4	MOX, V, Z4	MOX, P, S	MOX, V, S
Fuel element cell pitch, cm	p=1.47320				
Fuel region:					
Diameter, cm	PD1=0.9067800	PD2=0.87503	PD2=0.87503	PD3=0.903732	PD3=0.903732
Fuel,	UO$_2$,	PuO$_2$ - UO$_2$,	PuO$_2$ - UO$_2$,	PuO$_2$ - UO$_2$,	PuO$_2$ - UO$_2$,
Enrichment, wt %	5.74 (^{235}U)	6.6 (PuO$_2$)	6.6 (PuO$_2$)	6.6 (PuO$_2$)	6.6 (PuO$_2$)
Density, g/cm^3	10.18	10.33342	9.563910	10.33342	9.563910
Composition (Nuclei/(b*cm)):					
94239	-	1.376016E-03	1.273547E-03	1.376016E-03	1.273547E-03
94240	-	1.303178E-04	1.206133E-04	1.303178E-04	1.206133E-04
94241	-	1.353359E-05	1.252577E-05	1.353359E-05	1.252577E-05
94242	-	6.082511E-07	5.629558E-07	6.082511E-07	5.629558E-07
92235	1.303954E-3	1.540774E-04	1.426035E-04	1.540774E-04	1.426035E-04
92238	2.141301E-2	2.136511E-02	1.977409E-02	2.136511E-02	1.977409E-02
8016	4.543393E-2	4.607963E-02	4.264817E-02	4.607963E-02	4.264817E-02
Clad:					
OD, cm	COD=0.993140	COD=0.993140	COD=0.993140	COD=0.993140	COD=0.993140
ID, cm	CID1=0.9169400	CID2=0.8750300	CID2=0.8750300	CID1=0.9169400	CID3=0.9194800
Thickness, cm	CWT1=0.038100	CWT2=0.059055	CWT3=0.056642	CWT1=0.038100	CWT1=0.038100
Material	SS304,	Zircaloy-4,	Zircaloy-4,	SS304,	SS304,
Density, g/cm^3	7.94	6.58	6.58	7.94	7.94
Composition (Nuclei/(b*cm)):					
Zirconium 40090	-	2.159841E-02	2.159841E-02	-	-
40091	-	4.762495E-03	4.762495E-03	-	-
40092	-	7.359484E-03	7.359484E-03	-	-
40094	-	7.620589E-03	7.620589E-03	-	-
40096	-	1.253983E-03	1.253983E-03	-	-
Tin 50112	-	5.946753E-06	5.946753E-06	-	-
50114	-	4.059928E-06	4.059928E-06	-	-
50115	-	2.264190E-06	2.264190E-06	-	-
50116	-	9.229829E-05	9.229829E-05	-	-
50117	-	4.920710E-05	4.920710E-05	-	-
50118	-	1.565089E-04	1.565089E-04	-	-
50119	-	5.591509E-05	5.591509E-05	-	-
50120	-	2.141677E-04	2.141677E-04	-	-
50122	-	3.093743E-05	3.093743E-05	-	-
50124	-	3.931754E-05	3.931754E-05	-	-

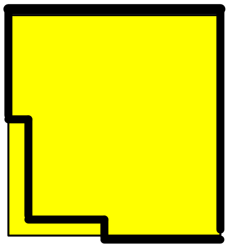
Iron	26054	3.413080E-3	4.943916E-06	4.943916E-06	3.413080E-3	3.413080E-3
	26056	5.502012E-2	7.969777E-05	7.969777E-05	5.502012E-2	5.502012E-2
	26057	1.282226E-3	1.857330E-06	1.857330E-06	1.282226E-3	1.282226E-3
	26058	1.736784E-4	2.515767E-07	2.515767E-07	1.736784E-4	1.736784E-4
Chromium	**24050**	6.946348E-4	1.810485E-06	1.810485E-06	6.946348E-4	6.946348E-4
	24052	1.392931E-2	3.630512E-05	3.630512E-05	1.392931E-2	1.392931E-2
	24053	1.609775E-3	4.195692E-06	4.195692E-06	1.609775E-3	1.609775E-3
	24054	4.082269E-4	1.063996E-06	1.063996E-06	4.082269E-4	4.082269E-4
Nickel	28058	5.607920E-3	-	-	5.607920E-3	5.607920E-3
	28060	2.217789E-3	-	-	2.217789E-3	2.217789E-3
	28061	9.760501E-5	-	-	9.760501E-5	9.760501E-5
	28062	3.151984E-4	-	-	3.151984E-4	3.151984E-4
	28064	8.246084E-5	-		8.246084E-5	8.246084E-5
Manganese	**25055**	1.751784E-3	-	-	1.751784E-3	1.751784E-3
Silicon	14028	8.047081E-4	-	-	8.047081E-4	8.047081E-4
	14029	4.220047E-5	-	-	4.220047E-5	4.220047E-5
	14030	2.897450E-5	-	-	2.897450E-5	2.897450E-5
Carbon	**6012**	6.923680E-5	-	-	6.923680E-5	6.923680E-5
	6013	8.345498E-7	-	-	8.345498E-7	8.345498E-7
Phosphorus	15031	3.941513E-5	-	-	3.941513E-5	3.941513E-5

P – Pelletized fuel; V – VIPAC fuel; S – SS304 clad; Z4 – Zircaloy-4

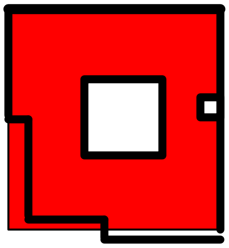
3.3. Fuel assemblies

Eight different types of fuel assembly geometry have been found in the Saxton Core I and Saxton Core II:

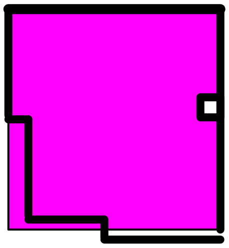
- **Type 100:**



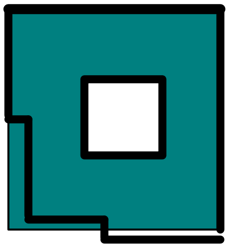
- **Type 200:**



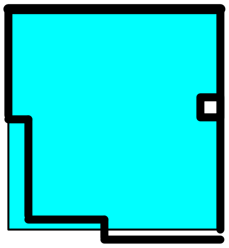
- **Type 300:**



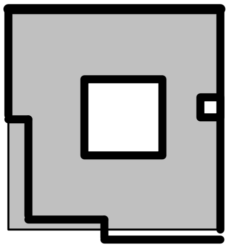
- **Type 400:**



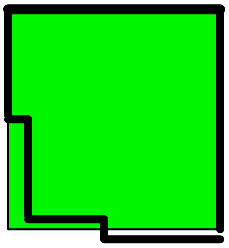
- **Type 500:**



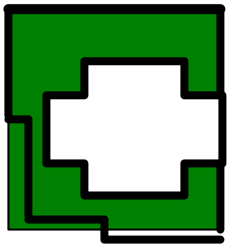
- **Type 600:**



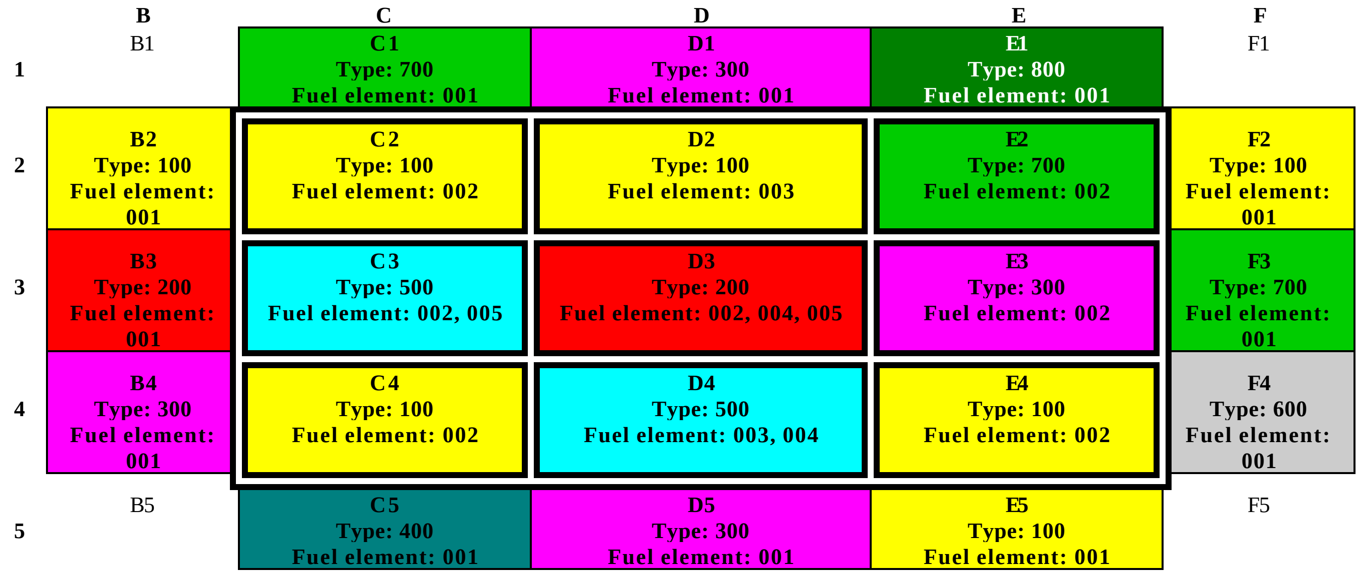
- **Type 700:**



- **Type 800:**



Locations of the fuel assemblies of each type are shown in Figure 10 below. All these types of geometry are taken into account explicitly in the Saxton Core Model.



	B	C	D	E	F
1	B1	C1 Type: 700 Fuel element: 001	D1 Type: 300 Fuel element: 001	E1 Type: 800 Fuel element: 001	F1
2	B2 Type: 100 Fuel element: 001	C2 Type: 100 Fuel element: 002	D2 Type: 100 Fuel element: 003	E2 Type: 700 Fuel element: 002	F2 Type: 100 Fuel element: 001
3	B3 Type: 200 Fuel element: 001	C3 Type: 500 Fuel element: 002, 005	D3 Type: 200 Fuel element: 002, 004, 005	E3 Type: 300 Fuel element: 002	F3 Type: 700 Fuel element: 001
4	B4 Type: 300 Fuel element: 001	C4 Type: 100 Fuel element: 002	D4 Type: 500 Fuel element: 003, 004	E4 Type: 100 Fuel element: 002	F4 Type: 600 Fuel element: 001
5	B5	C5 Type: 400 Fuel element: 001	D5 Type: 300 Fuel element: 001	E5 Type: 100 Fuel element: 001	F5

Figure 10. Types of the fuel assembly geometry in the Model of Saxton Core II

Out of the 12 UO_2 assemblies, five were original Core I design (SS grids) and seven were new, Core II design (Inconel grids). All the mixed oxide (PuO_2-UO_2) assemblies contained inconel grids.

Within the framework of the present study the following materials were used for the assembly:

- Stainless Steel (304-SS)
- INCONEL
- Aluminum

Material compositions are listed below:

Stainless Steel grid:

Type 304-SS, 7.94 g/cm^3:

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %		Atomic mass, amu	Atomic density (b^{-1}cm^{-1})
Iron	68.375	**Fe**	26000	26054	5.6990	53.93961480	3.45429E-03
				26056	91.870	55.93494210	5.36981E-02
				26057	2.1410	56.93539870	1.22943E-03
				26058	0.2900	57.93328050	1.63659E-04
Chromium	19.000	**Cr**	24000	24050	4.1740	49.94604960	7.59235E-04
				24052	83.700	51.94051190	1.46401E-02
				24053	9.6730	52.94065380	1.65996E-03
				24054	2.4530	53.93888490	4.13162E-04
Nickel	9.5000	**Ni**	28000	28058	67.395	57.93534790	5.28420E-03
				28060	26.653	59.93079060	2.02018E-03
				28061	1.1730	60.93106040	8.74489E-05
				28062	3.7880	61.92834880	2.77853E-04
				28064	0.9910	63.92796960	7.04171E-05
Manganese	2.0000	**Mn**	25000	25055	100.00	54.93804960	1.74072E-03
Silicon	1.0000	**Si**	14000	14028	91.873	27.97692650	1.57021E-03
				14029	4.8180	28.97649470	7.95046E-05
				14030	3.3080	29.97377020	5.27710E-05
Carbon	0.0800	**C**	6000	6012	98.809	12.00000000	3.14975E-04
				6013	1.1910	13.00335480	3.50363E-06
Phosphorus	0.0450	**P**	15000	15031	100.00	30.97376150	6.94688E-05

Inconel grid:

INCONEL (8.30 g/cm^3) Composition:

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %	Atomic mass, amu	Atomic density (b^{-1}cm^{-1})

Iron	7.0000	**Fe**	26000	26054 26056 26057 26058	5.6990 91.870 2.1410 0.2900	53.93961480 55.93494210 56.93539870 57.93328050	3.69673E-04 5.74669E-03 1.31571E-04 1.75145E-05
Chromium	15.000	**Cr**	24000	24050 24052 24053 24054	4.1740 83.700 9.6730 2.4530	49.94604960 51.94051190 52.94065380 53.93888490	6.26573E-04 1.20820E-02 1.36991E-03 3.40970E-04
Nickel	73.000	**Ni**	28000	28058 28060 28061 28062 28064	67.395 26.653 1.1730 3.7880 0.9910	57.93534790 59.93079060 60.93106040 61.92834880 63.92796960	4.24459E-02 1.62274E-02 7.02443E-04 2.23189E-03 5.65633E-04
Silicon	2.5000	**Si**	14000	14028 14029 14030	91.873 4.8180 3.3080	27.97692650 28.97649470 29.97377020	4.10352E-03 2.07773E-04 1.37909E-04
Titanium	2.5000	**Ti**	22000	22046 22047 22048 22049 22050	7.6780 7.1580 73.903 5.6220 5.6390	45.95262950 46.95176380 47.94794710 48.94787080 49.94479210	2.08789E-04 1.90506E-04 1.92602E-03 1.43524E-04 1.41085E-04

Aluminum:

Aluminum (2.702 g/cm^3) Composition:

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %		Atomic mass, amu	Atomic density ($b^{-1}cm^{-1}$)
Iron	100.00	**Al**	13000	13027	100.00	26.98180000	6.03067E-2

3.4. Control rods

Description:

The reactor used six offset cruciform shaped control rods made of an alloy of silver, indium and cadmium. The control rods had fueled follow-on sections. Details of the control rods are given below.

Number:	6
Type:	Offset cruciform shaped control rod
Material:	An alloy of silver, indium, and cadmium

Characteristics of the control rod:

Shape:	Offset cruciform
Span, cm (CRS):	14.23670
Half-span, cm (half-CRS):	7.118350
Thickness, cm (CRT):	0.996950
Half-thickness, cm (half-CRT):	0.498475

Alloy components distribution, wt. %:

Ag (silver)	80.00000, theoretical density – 10.50 g/cm^3
In (indium)	15.00000, theoretical density – 7.300 g/cm^3
Cd (cadmium)	5.000000, theoretical density – 8.642 g/cm^3

Control rod average material density, g/cm^3: 9.927100

Control rod composition:

Component	Wt. %	Symbol	ID	Isotopic distribution, wt. %	Atomic mass, amu	Atomic density ($b^{-1}cm^{-1}$)

Silver	80.000	**Ag**	47000	47107 47109	51.377 48.623	106.9050930 108.9047555	2.29844E-02 2.13530E-02
Indium	15.000	**In**	49000	49113 49115	4.2280 95.772	112.9040612 114.9038783	3.35807E-04 7.47426E-03
Cadmium	5.0000	**Cd**	48000	48106 48108 48110 48111 48112 48113 48114 48116	1.1780 0.8540 12.211 12.628 24.021 12.273 29.111 7.7230	105.9064580 107.9041834 109.9030056 110.9041816 111.9027572 112.9044009 113.9033581 115.9047554	3.32480E-05 2.36572E-05 3.32112E-04 3.40353E-04 6.41643E-04 3.24925E-04 7.63948E-04 1.99172E-04

3.5. Coolant

Type of coolant: H_2O

Characteristics of the coolant:

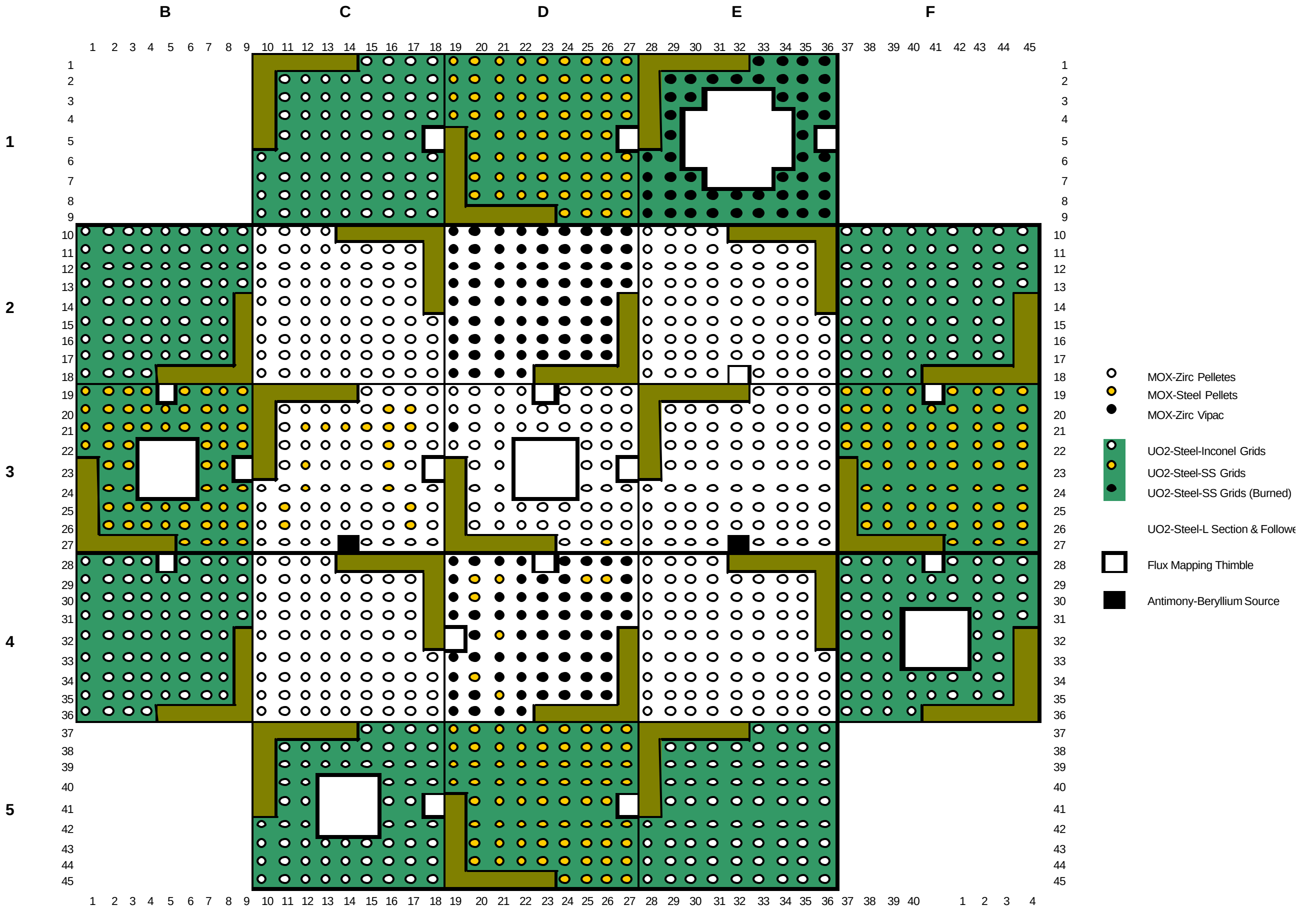
System pressure (nominal), MPa:	13.789514586
Average coolant temperature, K:	551.483
Coolant average density, g/cm^3:	0.7656

Coolant composition:

Component	Symbol	ID	Natural Element, amu	Isotopic distribution, wt. %	Atomic mass, amu	Atomic density ($b^{-1}cm^{-1}$)
Hydrogen	**H**	1001	1.00794	100.000	1.007825000	5.11983E-02
Oxygen	**O**	8016	15.9994	100.000	15.99491460	2.559914E-02

3.6. Reactor core

The layout of Saxton Core II is given below:



Characteristics of the SAXTON partial plutonium core:

Thermal power, MWt: 23.5

Fuel lifetime, hours 7300 - 8400

Temperature, K:

Fuel temperature: 810.928

Clad temperature: Zircaloy – 591.483/SS304 – 588.706

Average coolant temperature: 551.483

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4. HELIOS Input data specification

4.1. General sequence of calculations with the HELIOS computer codes system

The HELIOS computer code system (version 1.4) provides the capability to perform neutron and gamma transport calculations for lattice burn-up in general two-dimensional geometry. This code system consists of four functional components:

- AURORA – input processor;
- HELIOS – general 2D geometry coupled neutron-gamma transport code for lattice burn-up;
- ZENITH – output processor;
- HERMES – database and subroutine package.

The HELIOS system execution starts with an AURORA run. AURORA prepares technical HELIOS input information on the basis of the user's input file. This technical information is then stored in the HERMES database in the form applicable for utilization by HELIOS and ZENITH. HELIOS then takes the input data from HERMES and performs the set of requested calculations. All results of HELIOS calculations are also stored in the HERMES database for further processing by ZENITH, which converts output information to the form requested by user.

4.2. Nuclear data library

The nuclear data library for HELIOS has the following characteristics (note that NO stands for "Number Of" in the following listing):

- TECHNICAL IDENTIFICATION: "HEBE", Version: 1.4, July 29 1996
- LIBRARY IDENTIFICATION: *HELIOS LIBRARY: 11 APR 1996*
- NO OF DATA IN LIBRARY (I0): 5750412
- SIZE OF RSTAB1 (I1): 535
- SIZE OF RESDAT (I2): 676
- SIZE OF RSTAB2 (I3): 2248
- SIZE OF XSTEMP AND ISTART (I4): 601
- SIZE OF XSBAFR (I5): 0
- MAX SIZE OF XSDATA IN ANY GROUP (I7): 21041
- SIZE OF P1TEMP (I8): 45
- MAX SIZE OF P1DATA IN ANY GROUP (I10): 12330
- START INDEX OF RESONANCE DATA (INDRES): 3962
- START INDEX OF XS-DATA (INDXSD): 377688
- START INDEX OF BURNUP DATA (INDBUR): 2498988
- START INDEX OF P1-MATRICES (INDP1M): 25046160
- NO OF GROUPS (NOG): 190
- NO OF FAST GROUPS (NOFG): 63
- NO OF RESONANCE GROUPS (NORG): 69
- NO OF THERMAL GROUPS (NOTG): 62
- NO OF FISSION SOURCE GROUPS (NCHI): 72
- NO OF ISOTOPES INCLUDING BA (NELT): 271
- NO OF ISOTOPES WITH COMPLETE XS SETS (NELR): 169
- NO OF RESONANCE ISOTOPES (NRES): 31
- NO OF BURNUP ISOTOPES (NBUR): 158
- NO OF BURNABLE ABSORBER ISOTOPES (NBA): 0
- NO OF ISOTOPES WITH FISSION XS (NFIS): 32
- NO OF ISOTOPES WITH P1-DATA (NP1): 19
- NO OF ISOTOPES WITH FISS SPECTRA (NCHIX): 13
- NO OF ISOTOPES WITH N2N-DATA (N2N): 4
- NO OF ISOTOPES WITH N3N-DATA (N3N): 4

- NO OF GAMMA DATA (IG0, INCLUDED IN I0): 2850512
- SIZE OF TEMPNG AND NGSTAR (IG1): 460
- MAX NO OF GAMMA XS IN ANY GROUP (IG2): 2982
- MAX NO OF G-PROD XS IN ANY GROUP (IG3): 71984
- START INDEX OF GAMMA DATA, SAVED AT I0: 2899899
- NO OF GAMMA GROUPS (NOGG): 48
- NO OF GAMMA ISOTOPES (NGISO): 270

4.3. Materials

In the generalized model of the Saxton reactor core, a limited number of different material compositions were defined in order to simulate the real system. These material compositions have been checked for consistency with information available in the applied nuclear data library. A complete list of different compositions used and their characteristics are listed below together with corresponded nomenclature:

- Fuel compositions:

  UOX
  MOXP
  MOXV

- Non-fuel compositions:

  SS304
  ZR40
  INCONEL
  AL
  MCR
  H2O

Fuel compositions:

Composition name: UOX
Application: fuel element (type: 001; fuel region)
Description:

Component	Symbol	HELIOS Library ID	Atomic density, $b^{-1}cm^{-1}$
Uranium	^{235}U ^{238}U	92235 92238	1.303954E-3 2.141301E-2
Oxygen	O	8016	4.543393E-2

Composition name: MOXP
Application: fuel element (type: 002, 005; fuel region)
Description:

Component	Symbol	HELIOS Library ID	Atomic density, $b^{-1}cm^{-1}$
Plutonium	^{239}Pu ^{240}Pu ^{241}Pu ^{242}Pu	94239 94240 94241 94242	1.376016E-03 1.303178E-04 1.353359E-05 6.082511E-07
Uranium	^{235}U ^{238}U	92235 92238	1.540774E-04 2.136511E-02
Oxygen	O	8016	4.607963E-02

Composition name: MOXV
Application: fuel element (type: 003, 004; fuel region)
Description:

Component	Symbol	HELIOS Library ID	Atomic density, $b^{-1}cm^{-1}$
Plutonium	^{239}Pu	94239	1.273547E-03
	^{240}Pu	94240	1.206133E-04
	^{241}Pu	94241	1.252577E-05
	^{242}Pu	94242	5.629558E-07
Uranium	^{235}U	92235	1.426035E-04
	^{238}U	92238	1.977409E-02
Oxygen	O	8016	4.264817E-02

Non-fuel compositions:

Composition name: SS304
Application: fuel element (type: 001, 004, 005; clad region); grid material
Description:

Component	Symbol	HELIOS Library ID	Atom Density [#/(bn*cm)]
Iron	Fe	26054	3.45429E-03
		26056	5.36981E-02
		26057	1.22943E-03
		26058	1.63659E-04
Chromium	Cr	24050	7.59235E-04
		24052	1.46401E-02
		24053	1.65996E-03
		24054	4.13162E-04
Nickel	Ni	28058	5.28420E-03
		28060	2.02018E-03
		28061	8.74489E-05
		28062	2.77853E-04
		28064	7.04171E-05
Manganese	Mn	25055	1.74072E-03
Silicon	Si	14000	1.57021E-03
			7.95046E-05
			5.27710E-05
Carbon	C	6000	3.14975E-04
			3.50363E-06
Phosphorus	P	15031	6.94688E-05

Composition name: ZR40
Application: fuel element (type: 002, 003; clad region)
Description:

Component	Symbol	HELIOS Library ID	Atomic density, $b^{-1}cm^{-1}$
Zirconium	Zr	40000	4.259454E-02
Tin	Sn	50112 50114 50115 50116 50117 50118 50119 50120 50122 50124	See Table 2b
Iron	Fe	26054 26056 26057 26058	See Table 2b

Chromium	Cr	24050 24052 24053 24054	See Table 2b

Composition name: INCONEL
Application: grid material
Description:

Component	Symbol	HELIOS Library ID	Atomic density, $b^{-1}cm^{-1}$
Iron	Fe	26054 26056 26057 26058	See Sec. 3.3
Chromium	Cr	24050 24052 24053 24054	See Sec. 3.3
Nickel	Ni	28058 28060 28061 28062 28064	See Sec. 3.3
Silicon	Si	14000	See Sec. 3.3
Titanium	Ti	22000	See Sec. 3.3

Composition name: AL
Application: grid material
Description:

Component	Symbol	HELIOS Library ID	Atomic density, $b^{-1}cm^{-1}$
Aluminum	Al	13027	See Sec. 3.3

Composition name: MCR
Application: control rod material
Description:

Component	Symbol	HELIOS Library ID	Atomic density, $b^{-1}cm^{-1}$
Silver	Ag	47107 47109	See Sec. 3.4
Indium	In	49113 49115	See Sec. 3.4
Cadmium	Cd	48000	See Sec. 3.4

Composition name: H2O
Application: coolant material
Description:

Component	Symbol	ID	Atomic density, $b^{-1}cm^{-1}$
Hydrogen	H	1006	See Sec. 3.5
Oxygen	O	8001	See Sec. 3.5

4.4. Circular cylindrical system

The structure of an elementary unit cell is shown in Figure 11 below. This unit cell is centered on one fuel element. The fuel region has been subdivided in six concentric internal regions. The influence of the number of concentric regions on computations was investigated.

Fractions of the concentric regions:
[cross sectional area fractions (volume per unit length)]

Region 6: 0.09
Region 5: 0.09
Region 4: 0.10
Region 3: 0.12
Region 2: 0.15
Region 1: 0.45

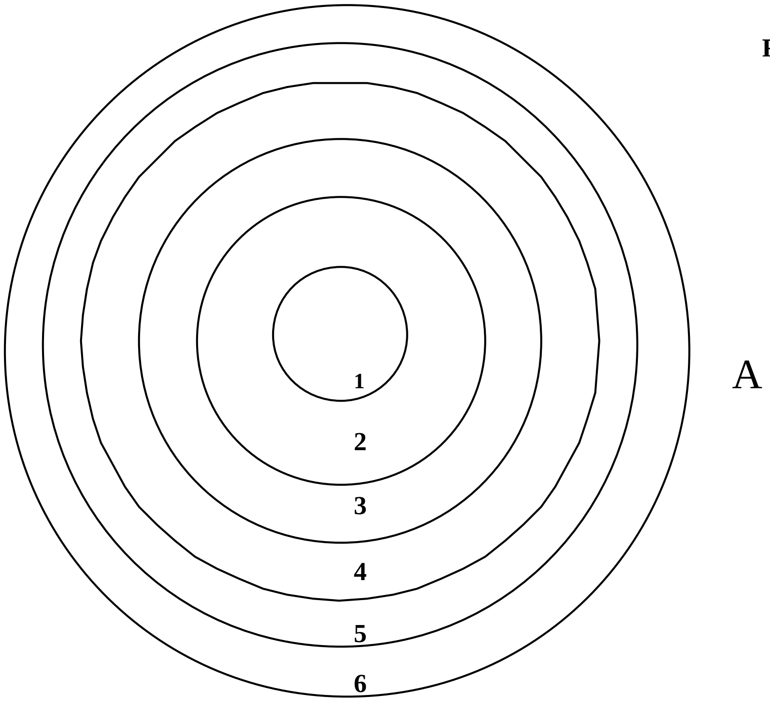
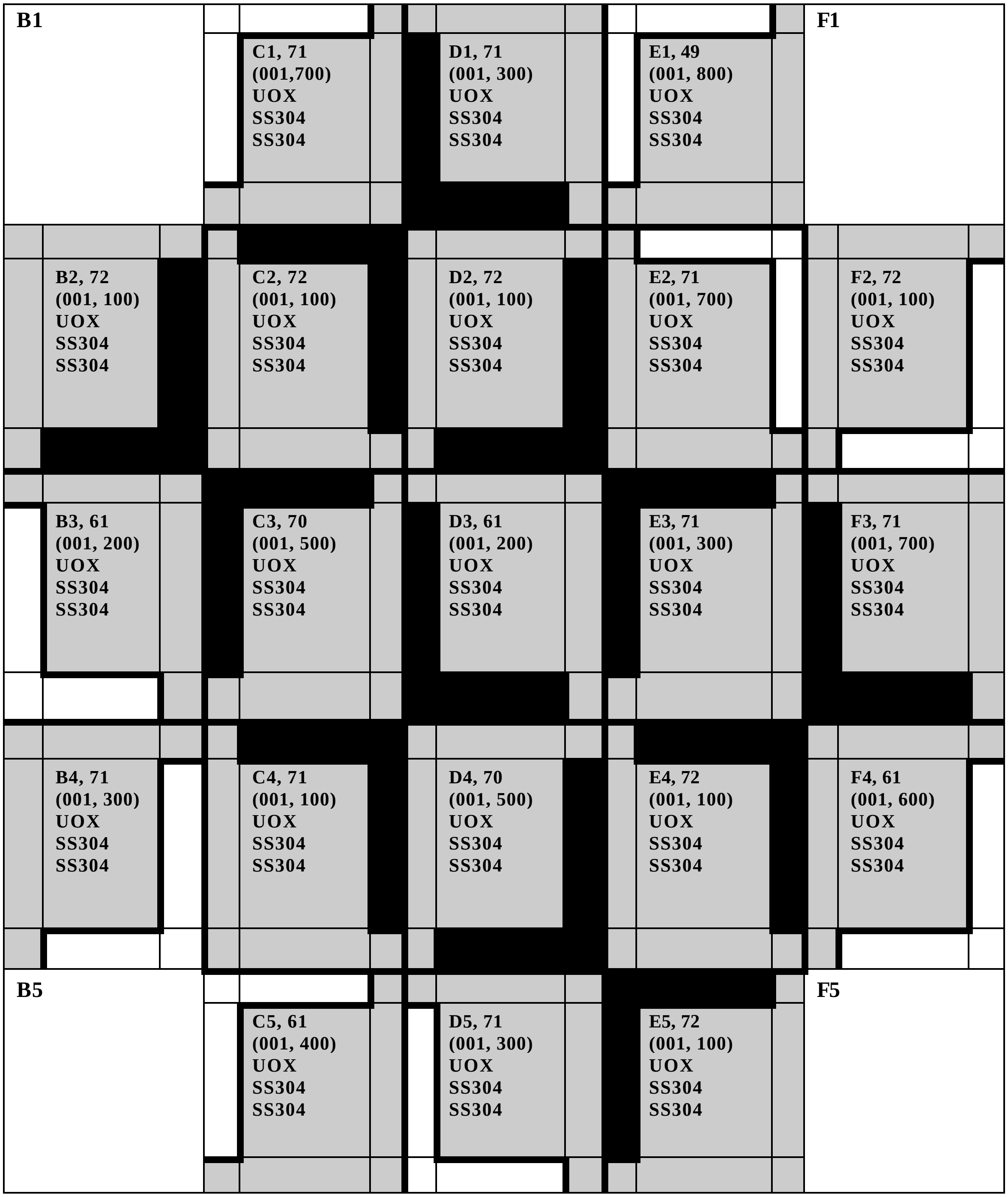


Figure 11. Elementary unit cell centered on one fuel element:
A – moderator (coolant)
6 – clad (zirconium or stainless steel)
1-5 – fuel regions; initially all same material

4.5. Structure description

The fuel loadings for Saxton Cores I, II and III are shown in Fig. 12 A, 12 B and 12C. The control rod locations are shown in Fig. 13. Models of the twenty-one fuel assemblies and one sub-assembly follow these figures.

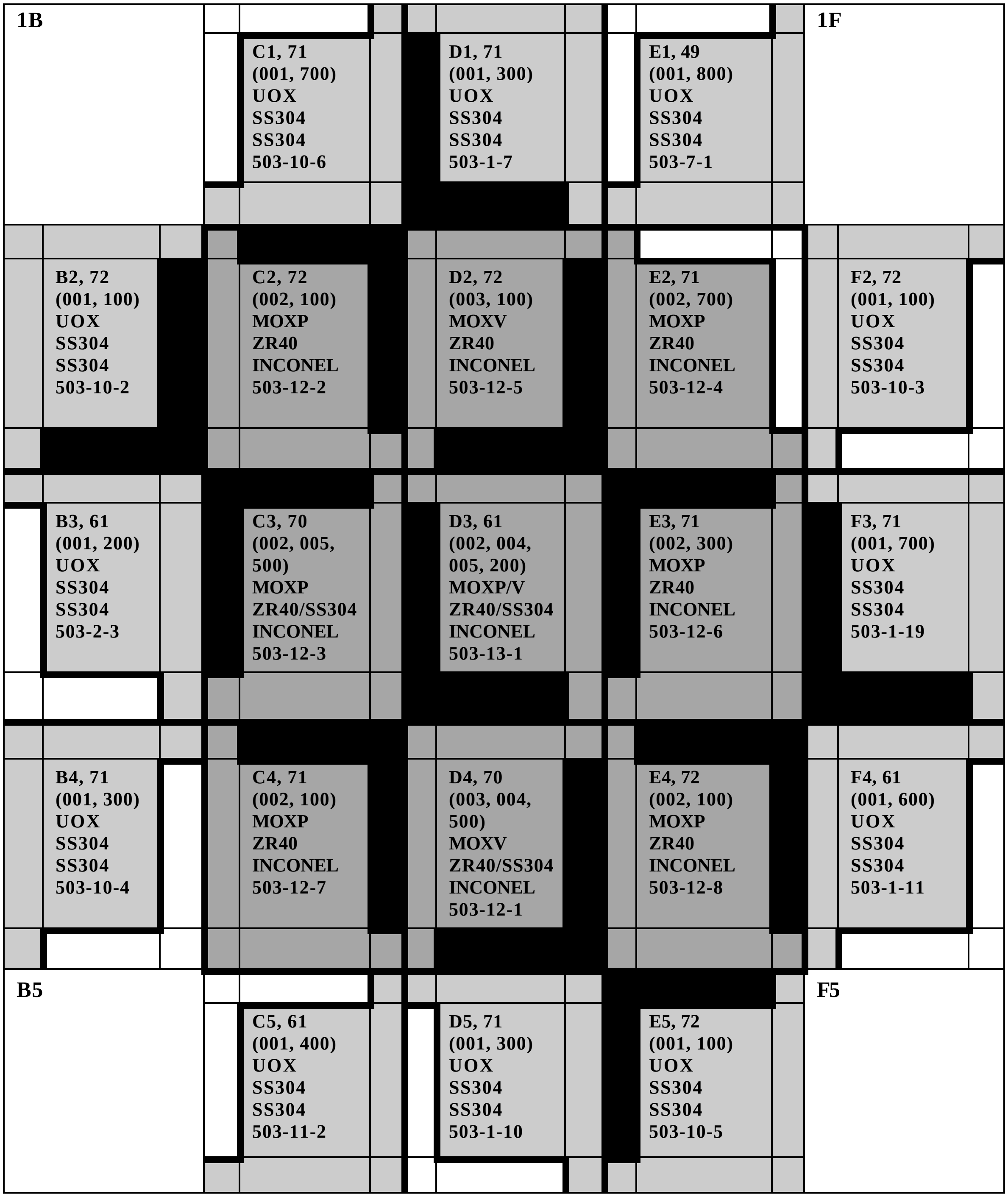


B1	**C1, 71** **(001,700)** **UOX** **SS304** **SS304**	**D1, 71** **(001, 300)** **UOX** **SS304** **SS304**	**E1, 49** **(001, 800)** **UOX** **SS304** **SS304**	**F1**
B2, 72 **(001, 100)** **UOX** **SS304** **SS304**	**C2, 72** **(001, 100)** **UOX** **SS304** **SS304**	**D2, 72** **(001, 100)** **UOX** **SS304** **SS304**	**E2, 71** **(001, 700)** **UOX** **SS304** **SS304**	**F2, 72** **(001, 100)** **UOX** **SS304** **SS304**
B3, 61 **(001, 200)** **UOX** **SS304** **SS304**	**C3, 70** **(001, 500)** **UOX** **SS304** **SS304**	**D3, 61** **(001, 200)** **UOX** **SS304** **SS304**	**E3, 71** **(001, 300)** **UOX** **SS304** **SS304**	**F3, 71** **(001, 700)** **UOX** **SS304** **SS304**
B4, 71 **(001, 300)** **UOX** **SS304** **SS304**	**C4, 71** **(001, 100)** **UOX** **SS304** **SS304**	**D4, 70** **(001, 500)** **UOX** **SS304** **SS304**	**E4, 72** **(001, 100)** **UOX** **SS304** **SS304**	**F4, 61** **(001, 600)** **UOX** **SS304** **SS304**
B5	**C5, 61** **(001, 400)** **UOX** **SS304** **SS304**	**D5, 71** **(001, 300)** **UOX** **SS304** **SS304**	**E5, 72** **(001, 100)** **UOX** **SS304** **SS304**	**F5**

Simplified image of each fuel assembly contains the following information:

- Assembly location (1C, 1D, etc.)
- Number of fuel rods per assembly (72, etc.)
- Fuel element type (001, 002, etc.) according to description made above.
- Clad material (SS304, ZR40, etc.)
- Model type of fuel assembly geometry (100, 200, etc.) according to description made above.
- Assembly grid type (SS304, INCONEL, etc.)

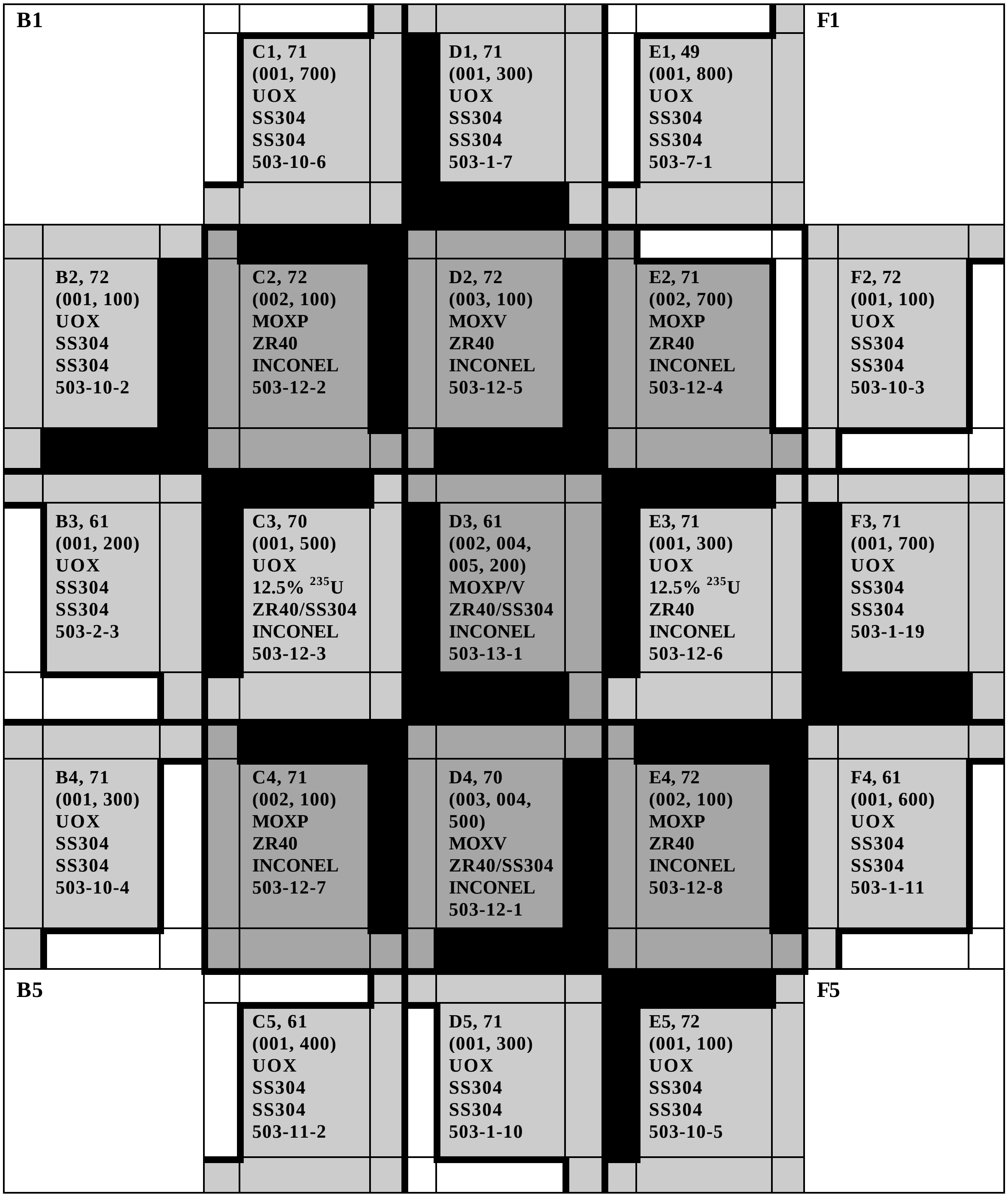
Figure 12A: Saxton reactor core model (Saxton uranium core, Saxton Core I configuration)



Simplified image of each fuel assembly contains the following information:

- Assembly location (1C, 1D, etc.)
- Number of fuel rods per assembly (72, etc.)
- Fuel element type (001, 002, etc.) according to description made above
- Model type of fuel assembly geometry (100, 200, etc.) according to description made above
- Type of fuel (UOX, MOXP, MOXV etc)
- Clad material (SS304, ZR40, etc.)
- Assembly grid type (SS304, INCONEL, etc.)
- Assembly serial number (prototype assembly ID (Saxton project reports), 503-13-1, etc.)

Figure 12B: Saxton reactor core model (Saxton partial plutonium core, Saxton core II configuration)



B1	C1, 71 (001, 700) UOX SS304 SS304 503-10-6	D1, 71 (001, 300) UOX SS304 SS304 503-1-7	E1, 49 (001, 800) UOX SS304 SS304 503-7-1	F1
B2, 72 (001, 100) UOX SS304 SS304 503-10-2	C2, 72 (002, 100) MOXP ZR40 INCONEL 503-12-2	D2, 72 (003, 100) MOXV ZR40 INCONEL 503-12-5	E2, 71 (002, 700) MOXP ZR40 INCONEL 503-12-4	F2, 72 (001, 100) UOX SS304 SS304 503-10-3
B3, 61 (001, 200) UOX SS304 SS304 503-2-3	C3, 70 (001, 500) UOX 12.5% ^{235}U ZR40/SS304 INCONEL 503-12-3	D3, 61 (002, 004, 005, 200) MOXP/V ZR40/SS304 INCONEL 503-13-1	E3, 71 (001, 300) UOX 12.5% ^{235}U ZR40 INCONEL 503-12-6	F3, 71 (001, 700) UOX SS304 SS304 503-1-19
B4, 71 (001, 300) UOX SS304 SS304 503-10-4	C4, 71 (002, 100) MOXP ZR40 INCONEL 503-12-7	D4, 70 (003, 004, 500) MOXV ZR40/SS304 INCONEL 503-12-1	E4, 72 (002, 100) MOXP ZR40 INCONEL 503-12-8	F4, 61 (001, 600) UOX SS304 SS304 503-1-11
B5	C5, 61 (001, 400) UOX SS304 SS304 503-11-2	D5, 71 (001, 300) UOX SS304 SS304 503-1-10	E5, 72 (001, 100) UOX SS304 SS304 503-10-5	F5

Simplified image of each fuel assembly contains the following information:

- Assembly location (C1, D1, etc.)
- Number of fuel rods per assembly (72, etc.)
- Assembly serial number (prototype assembly ID (Saxton project reports), 503-13-1, etc.)
- Fuel element type (001, 002, etc.) according to description made above (see Fig. 2 for summary)
- Clad material (304-SS, ZR40, etc.)
- Model type of fuel assembly geometry (100, 200, etc.) according to description made above (see Fig. 3 for summary)
- Assembly grid type (304-SS, INCONEL, etc.

Figure 12C: Saxton reactor core model (Saxton partial plutonium core, Saxton core III configuration) Saxton Core III Fuel Loading at BOL

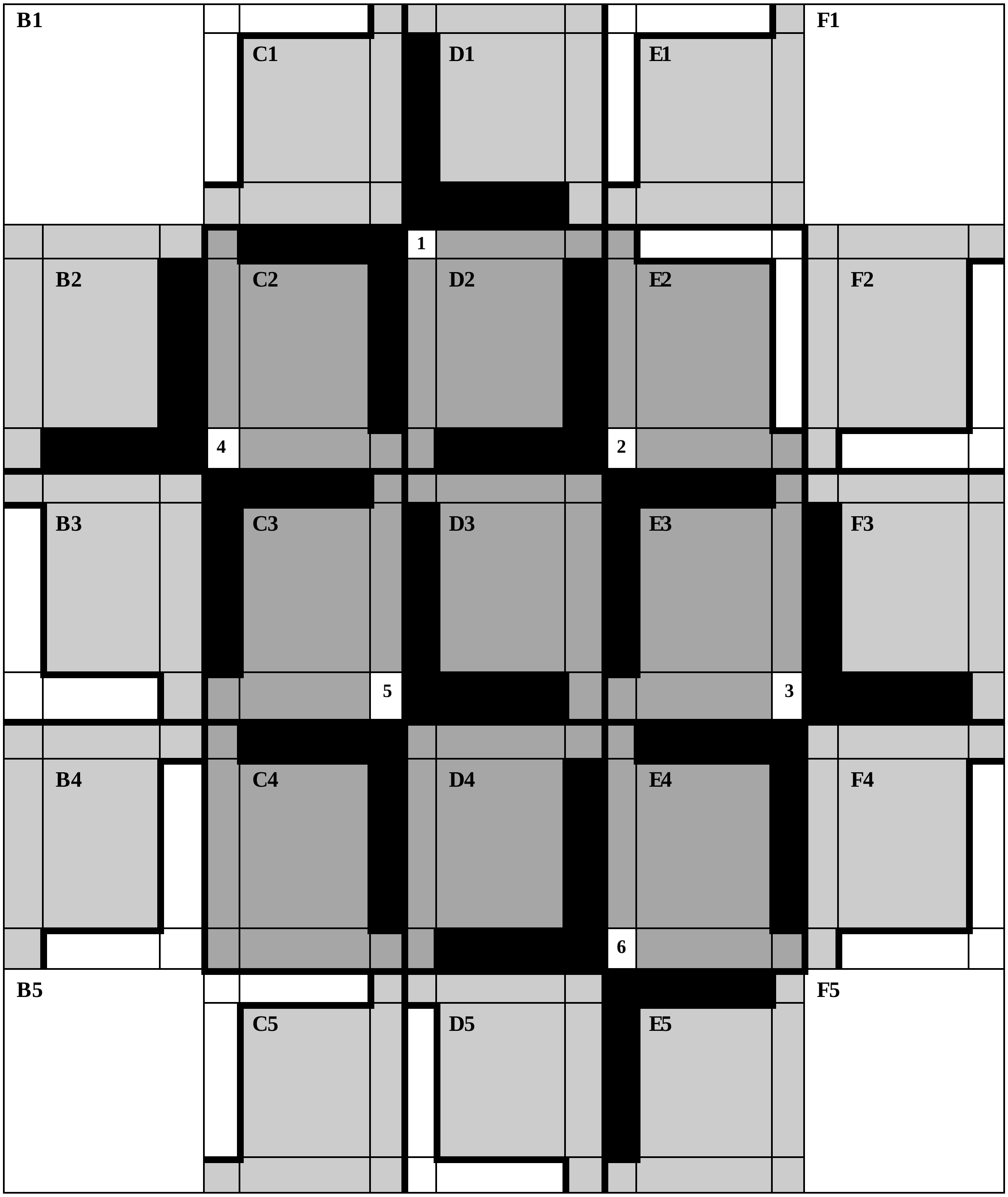
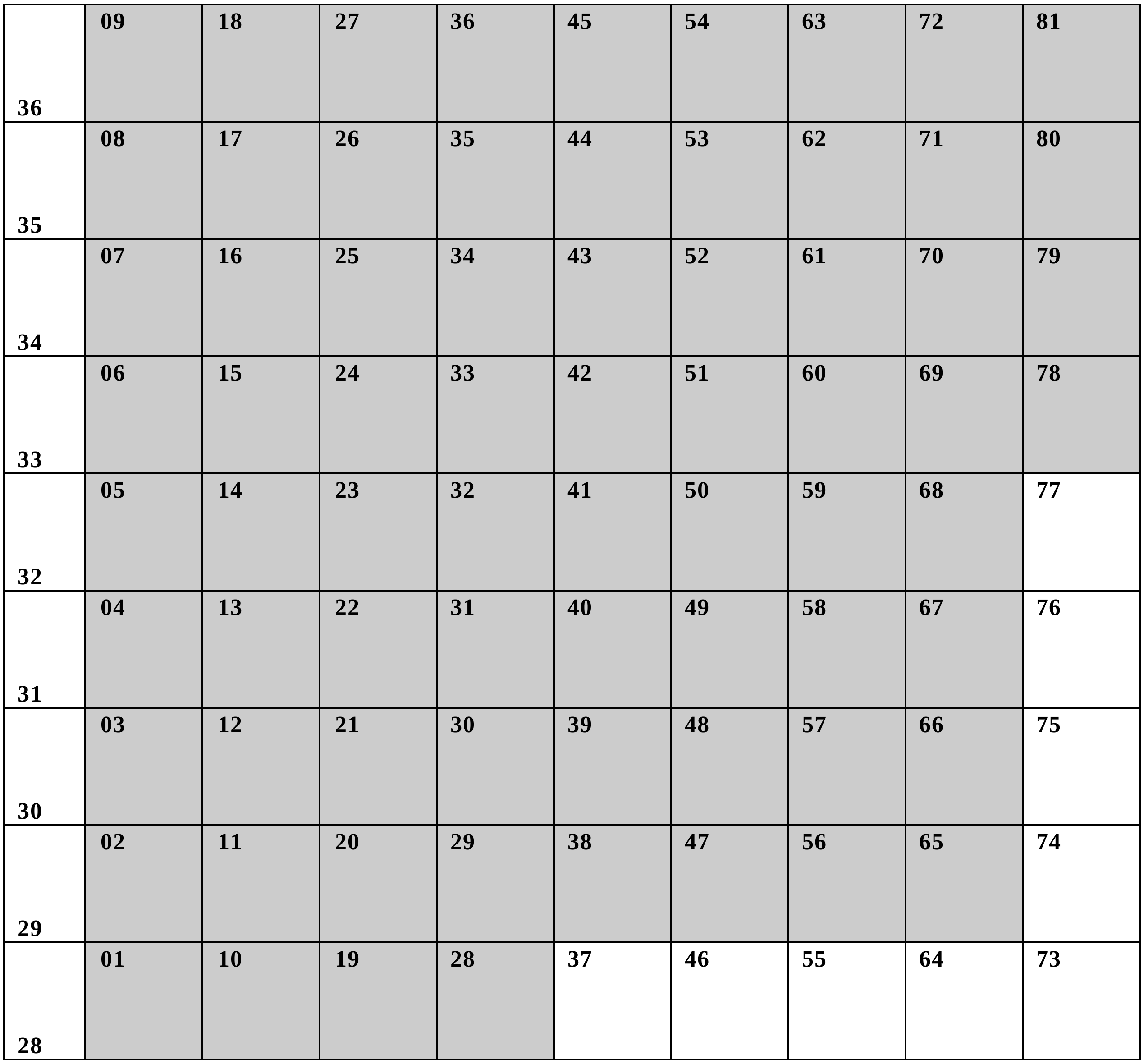


Figure 13: Location and numbering of the control rods in the Saxton reactor core model

The following assembly maps are the detailed assemblies of Core II.

Assembly:	**Uranium assembly**
Assembly location:	B2
Assembly type:	100
Prototype assembly ID (Saxton project reports):	503-10-2



36	**09**	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
35	**08**	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
34	**07**	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
33	**06**	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
32	**05**	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
31	**04**	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
30	**03**	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
29	**02**	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
28	**01**	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 72
- Rods:

304-SS UO_2 Pelletized Fuel (type 001)

Assembly:	**Uranium assembly**
Assembly location:	B3
Assembly type:	200
Prototype assembly ID (Saxton project reports):	503-2-3

27	**09** ▨	**18** ▨	**27** ▨	**36** ▨	**45**	**54** ▨	**63** ▨	**72** ▨	**81** ▨
26	**08** ▨	**17** ▨	**26** ▨	**35** ▨	**44** ▨	**53** ▨	**62** ▨	**71** ▨	**80** ▨
25	**07** ▨	**16** ▨	**25** ▨	**34** ▨	**43** ▨	**52** ▨	**61** ▨	**70** ▨	**79** ▨
24	**06** ▨	**15** ▨	**24** ▨	**33**	**42**	**51**	**60** ▨	**69** ▨	**78** ▨
23	**05**	**14** ▨	**23** ▨	**32**	**41**	**50**	**59** ▨	**68** ▨	**77**
22	**04**	**13** ▨	**22** ▨	**31**	**40**	**49**	**58** ▨	**67** ▨	**76** ▨
21	**03**	**12** ▨	**21** ▨	**30** ▨	**39** ▨	**48** ▨	**57** ▨	**66** ▨	**75** ▨
20	**02**	**11** ▨	**20** ▨	**29** ▨	**38** ▨	**47** ▨	**56** ▨	**65** ▨	**74** ▨
19	**01**	**10**	**19**	**28**	**37**	**46** ▨	**55** ▨	**64** ▨	**73** ▨

Description:

- Total number of fuel rods: 61
- Rods:

304-SS UO_2 Pelletized Fuel (type 001)
45, 77 – flux thimble

Assembly: **Uranium assembly**
Assembly location: B4
Assembly type: 300
Prototype assembly ID (Saxton project reports): 503-10-4

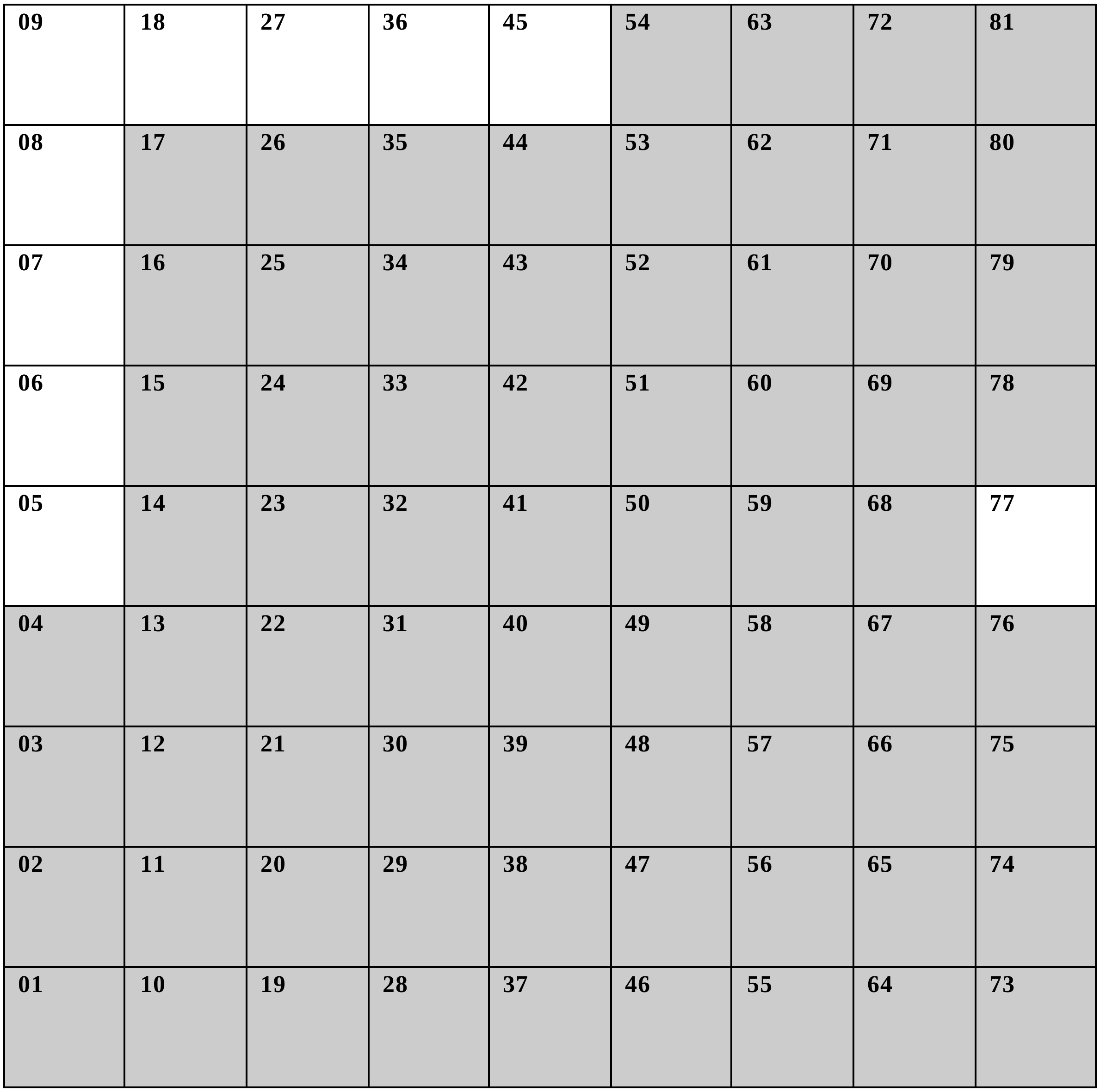
18	**09**	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
17	**08**	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
16	**07**	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
15	**06**	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
14	**05**	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
13	**04**	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
12	**03**	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
11	**02**	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
10	**01**	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 71
- Rods:

304-SS UO_2 Pelletized Fuel (type 001)
45 – flux thimble

Assembly:	**Uranium assembly**
Assembly location:	C1
Assembly type:	700
Prototype assembly ID (Saxton project reports):	503-10-6



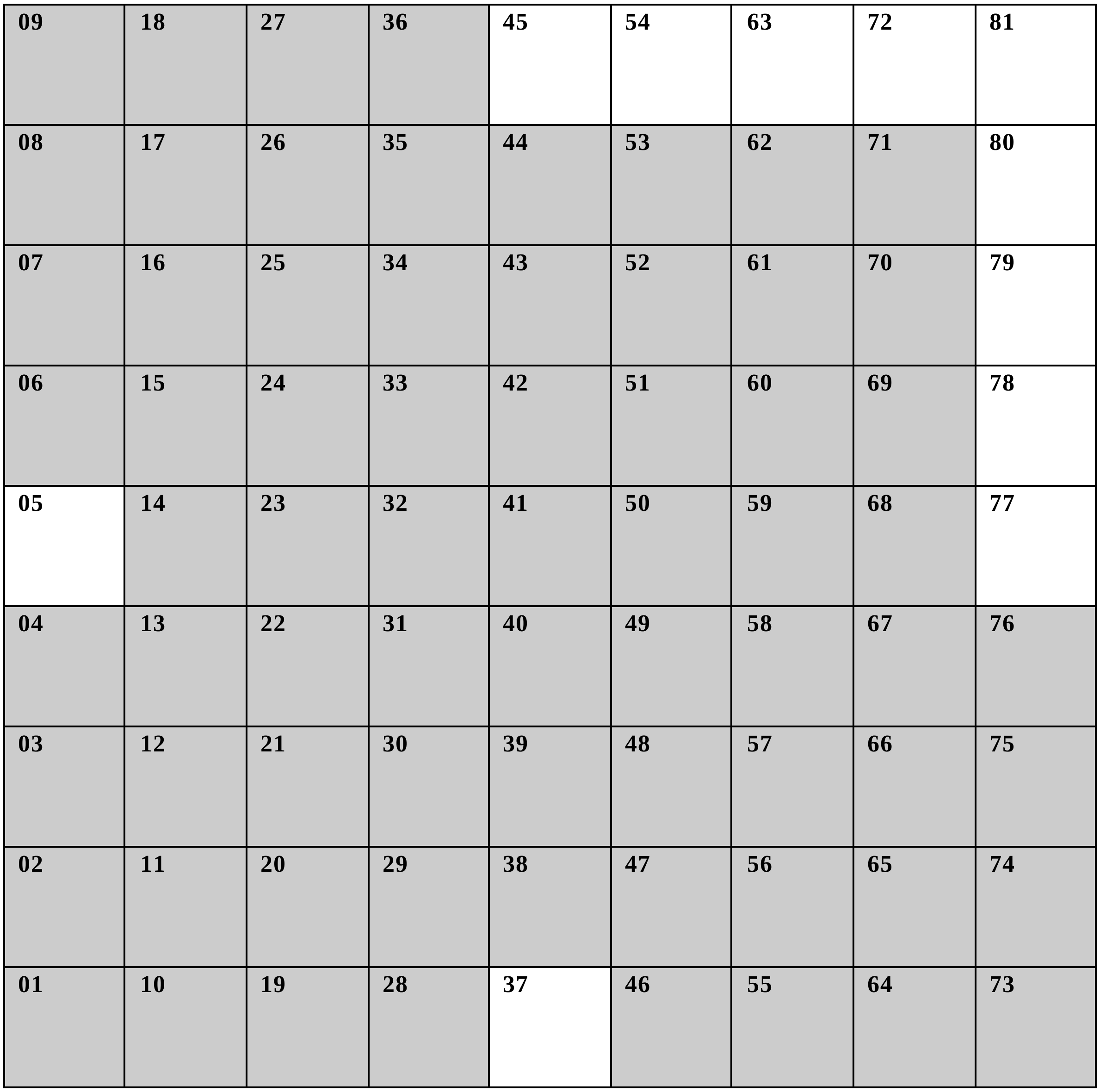
09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 71
- Rods:

304-SS UO_2 Pelletized Fuel (type 001)
77 – flux thimble

Assembly: **Plutonium assembly**
Assembly location: C2
Assembly type: 100
Prototype assembly ID (Saxton project reports): 503-12-2



09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

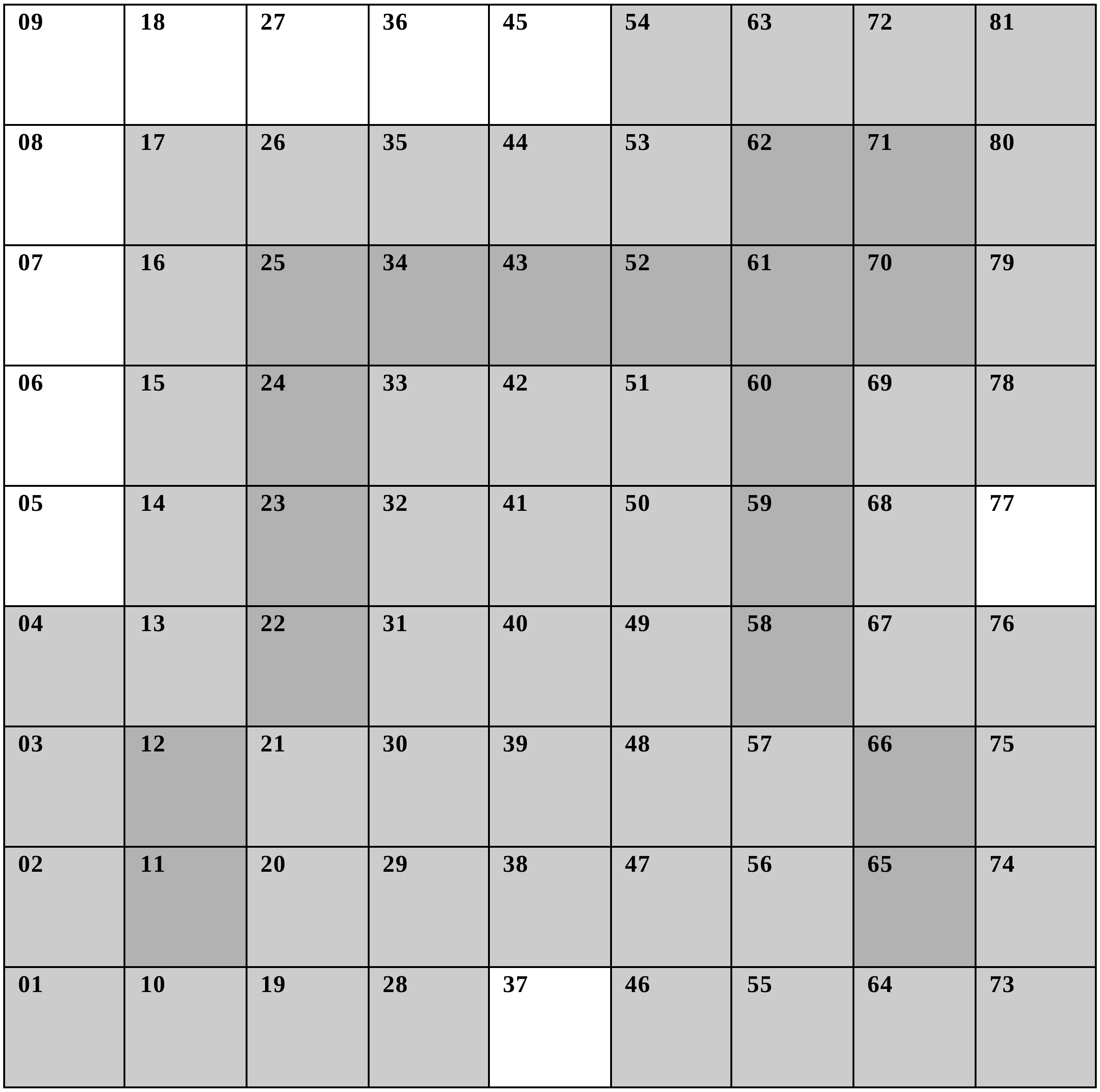
Description:

- Total number of fuel rods: 72
- Rods:

Zircaloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type 002)
05, 37 – removable rods

Assembly: **Plutonium assembly**

Assembly:	**Plutonium assembly**
Assembly location:	C3
Assembly type:	500
Prototype assembly ID (Saxton project reports):	503-12-3



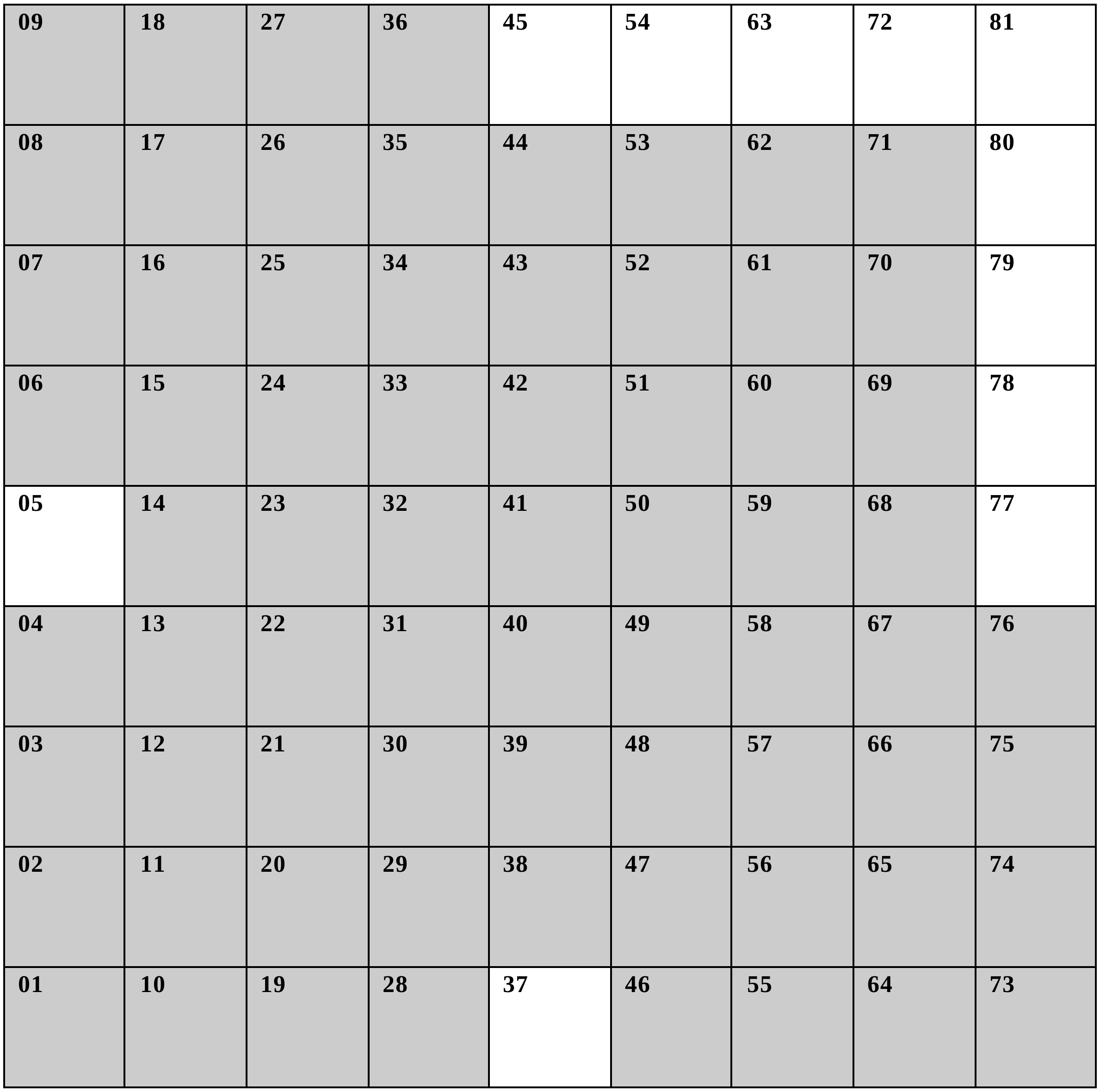
09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 70
- Rods:

11, 12, 22, 23, 24, 25, 34, 43, 52, 58, 59, 60, 61, 62, 65, 66, 70, 71 – 304-SS Clad PuO_2-UO_2 Pelletized Fuel (type: 005)
Zircaloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type 002)
77 – flux thimble
37 – secondary source rod

Assembly: **Plutonium assembly**
Assembly location: C4
Assembly type: 100
Prototype assembly ID (Saxton project reports): 503-12-7



09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 71
- Rods:

Zircaloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type: 002)
37 – flux thimble
05 – removable rod

Assembly: **Uranium assembly**
Assembly location: C5
Assembly type: 400
Prototype assembly ID (Saxton project reports): 503-11-2

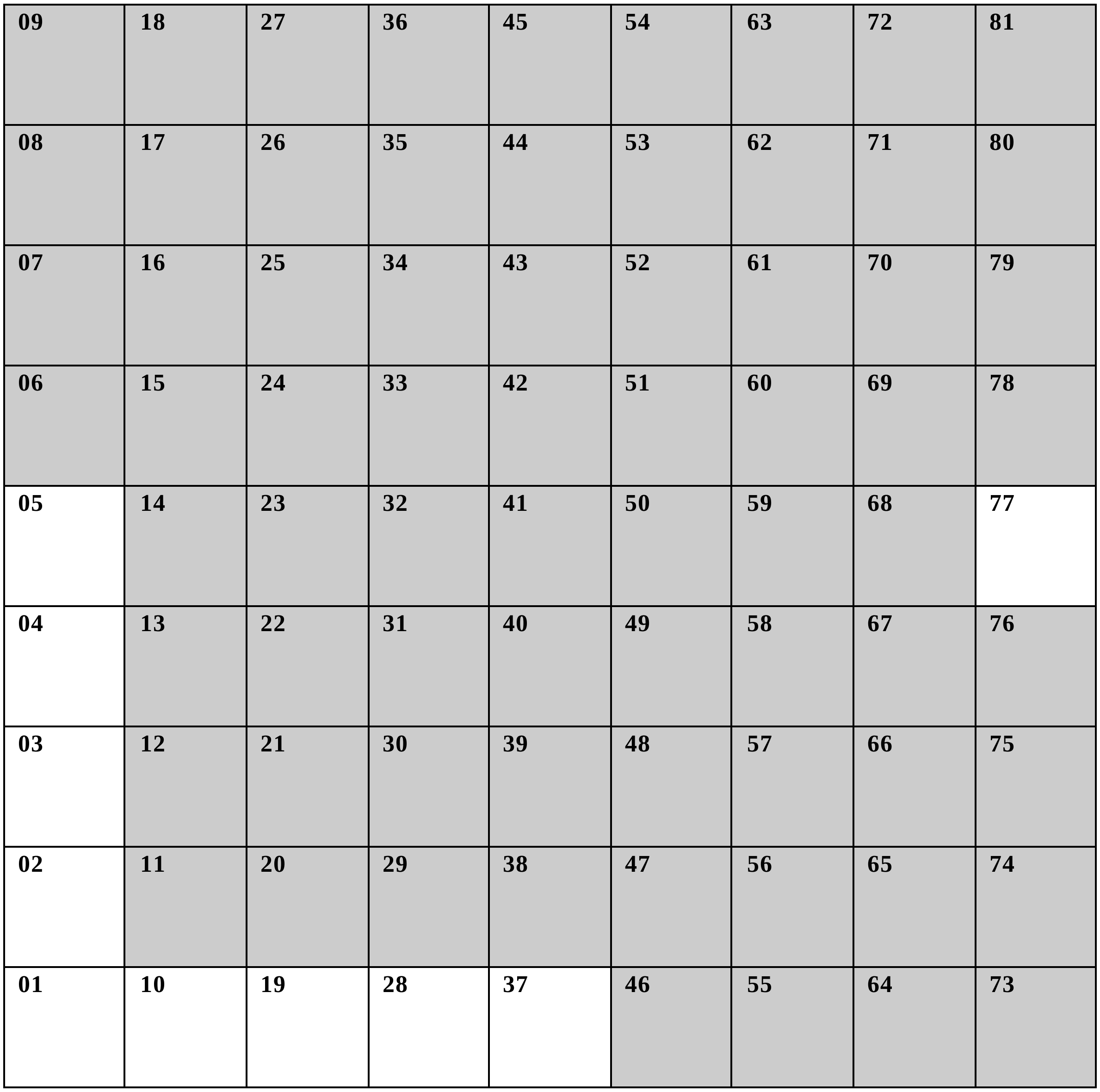
09	**18**	**27**	**36**	**45**	**54** ▨	**63** ▨	**72** ▨	**81** ▨
08	**17** ▨	**26** ▨	**35** ▨	**44** ▨	**53** ▨	**62** ▨	**71** ▨	**80** ▨
07	**16** ▨	**25** ▨	**34** ▨	**43** ▨	**52** ▨	**61** ▨	**70** ▨	**79** ▨
06	**15** ▨	**24** ▨	**33**	**42**	**51**	**60** ▨	**69** ▨	**78** ▨
05	**14** ▨	**23** ▨	**32**	**41**	**50**	**59** ▨	**68** ▨	**77**
04 ▨	**13** ▨	**22** ▨	**31**	**40**	**49**	**58** ▨	**67** ▨	**76** ▨
03 ▨	**12** ▨	**21** ▨	**30** ▨	**39** ▨	**48** ▨	**57** ▨	**66** ▨	**75** ▨
02 ▨	**11** ▨	**20** ▨	**29** ▨	**38** ▨	**47** ▨	**56** ▨	**65** ▨	**74** ▨
01 ▨	**10** ▨	**19** ▨	**28** ▨	**37** ▨	**46** ▨	**55** ▨	**64** ▨	**73** ▨

Description:

- Total number of fuel rods: 61
- Rods:

304-SS Clad UO_2 Pelletized Fuel (type: 001)
77 – flux thimble

Assembly:	**Uranium assembly**
Assembly location:	D1
Assembly type:	300
Prototype assembly ID (Saxton project reports):	503-1-7



09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 71
- Rods:

304-SS Clad UO_2 Pelletized Fuel (type: 001)
77 – flux thimble

Assembly:	**Plutonium assembly**
Assembly location:	D2
Assembly type:	100
Prototype assembly ID (Saxton project reports):	503-12-5

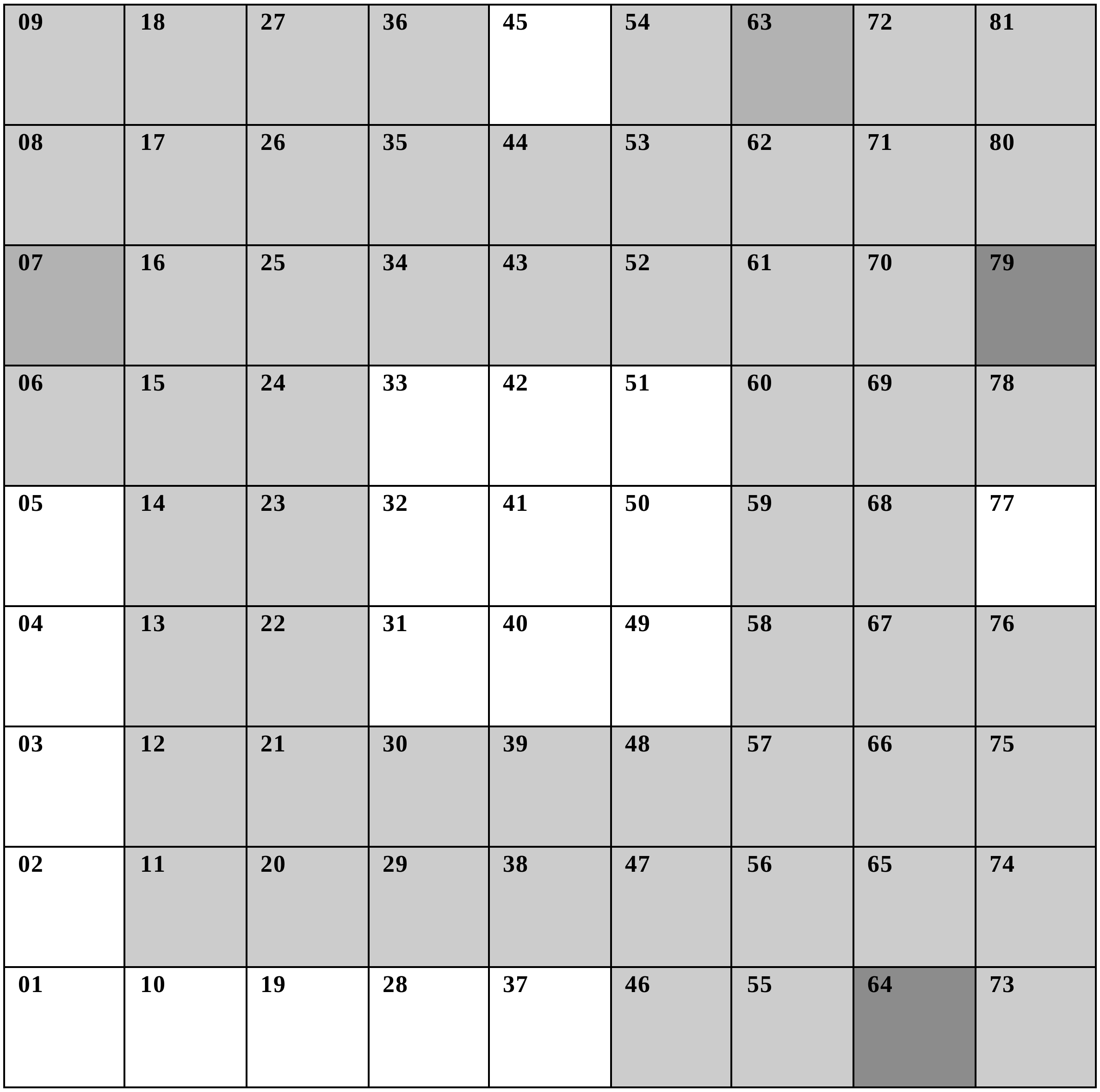
09 ▨	**18** ▨	**27** ▨	**36** ▨	**45**	**54** ▨	**63** ▨	**72** ▨	**81** ▨
08 ▨	**17** ▨	**26** ▨	**35** ▨	**44** ▨	**53** ▨	**62** ▨	**71** ▨	**80** ▨
07 ▨	**16** ▨	**25** ▨	**34** ▨	**43** ▨	**52** ▨	**61** ▨	**70** ▨	**79** ▨
06 ▨	**15** ▨	**24** ▨	**33** ▨	**42** ▨	**51** ▨	**60** ▨	**69** ▨	**78** ▨
05	**14** ▨	**23** ▨	**32** ▨	**41** ▨	**50** ▨	**59** ▨	**68** ▨	**77**
04 ▨	**13** ▨	**22** ▨	**31** ▨	**40** ▨	**49** ▨	**58** ▨	**67** ▨	**76**
03 ▨	**12** ▨	**21** ▨	**30** ▨	**39** ▨	**48** ▨	**57** ▨	**66** ▨	**75**
02 ▨	**11** ▨	**20** ▨	**29** ▨	**38** ▨	**47** ▨	**56** ▨	**65** ▨	**74**
01 ▨	**10** ▨	**19** ▨	**28** ▨	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 72
- Rods:

Zircaloy-4 Clad PuO_2-UO_2 VIPAC Fuel (type: 003)
05, 45 – removable rods

Assembly:	**Plutonium assembly**
Assembly location:	D3
Assembly type:	200
Prototype assembly ID (Saxton project reports):	503-13-1



09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 61
- Rods:

  Zircaloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type: 002)
  07, 63 – 304-SS Clad PuO_2-UO_2 VIPAC Fuel (type: 004)
  64, 79 – 304-SS Clad PuO_2-UO_2 Pelletized Fuel (type: 005)
  45, 77 – flux thimble

Sub-Assembly: **Plutonium sub-assembly**
Sub-Assembly location: D3
Prototype assembly ID (Saxton project reports): 503-4-26

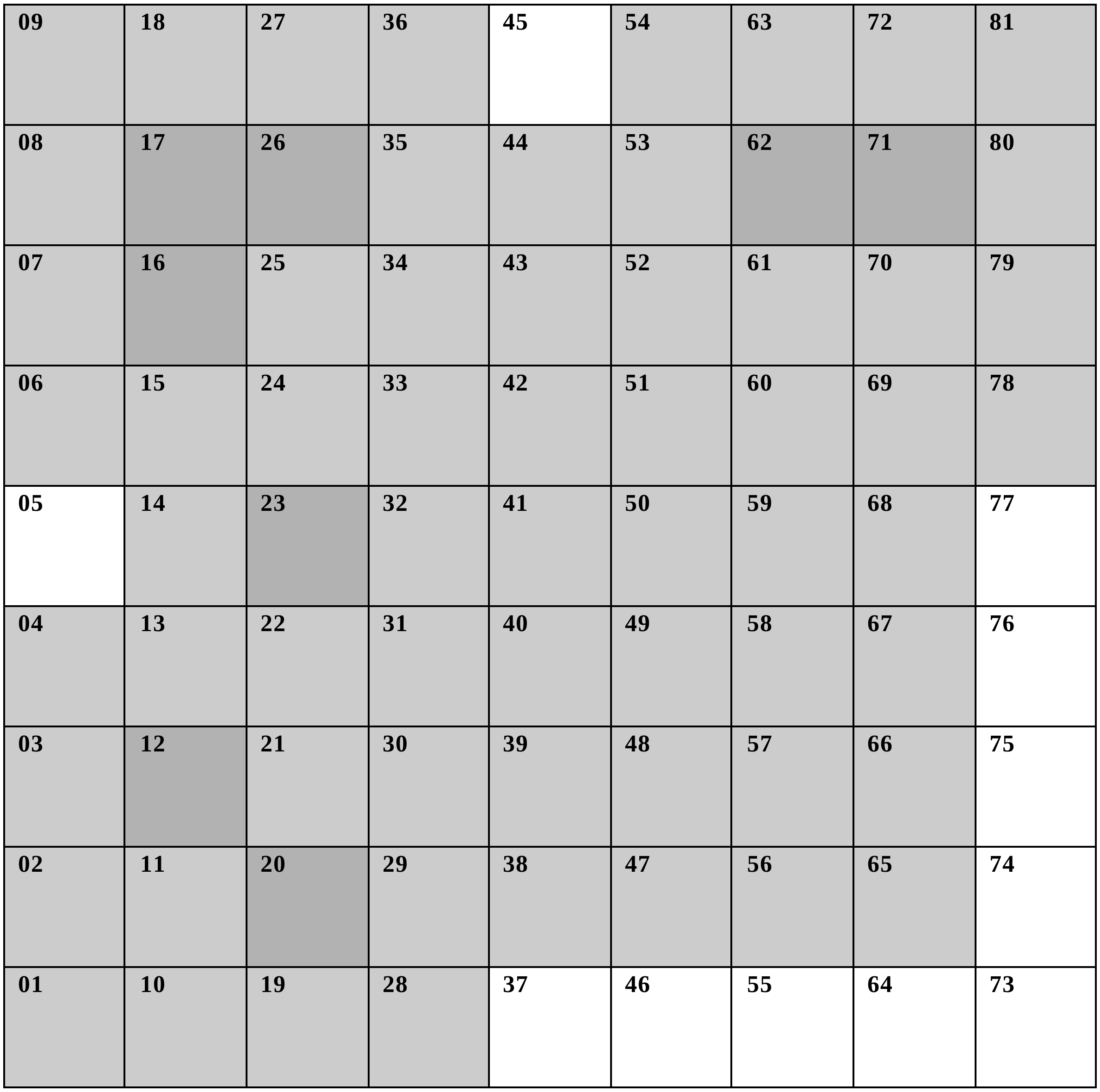
09	18	27	36	45	54	63	72	81
08	17	26	35	44	53	62	71	80
07	16	25	34	43	52	61	70	79
06	15	24	33	42	51	60	69	78
05	14	23	32	41	50	59	68	77
04	13	22	31	40	49	58	67	76
03	12	21	30	39	48	57	66	75
02	11	20	29	38	47	56	65	74
01	10	19	28	37	46	55	64	73

Description:

- Total number of fuel rods: 61
- Rods:

  33, 49 – Zircalloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type: 002)
  42, 40 – removable rods: Zircalloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type: 002)
  31, 51 - Zircalloy-4 Clad PuO_2-UO_2 VIPAC Fuel (type: 003)
  32, 50 – removable rods: Zircalloy-4 Clad PuO_2-UO_2 VIPAC Fuel (type: 003)
  41 – flux thimble

Assembly:	**Plutonium assembly**
Assembly location:	D4
Assembly type:	500
Prototype assembly ID (Saxton project reports):	503-12-1



09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 70
- Rods:

Zircaloy-4 Clad PuO_2-UO_2 VIPAC Fuel (type: 003)
05, 45 – flux thimble
12, 16, 17, 20, 23, 26, 62, 71 – SS304 Clad PuO_2-UO_2 VIPAC Fuel (type: 004)

Assembly: **Uranium assembly**
Assembly location: D5
Assembly type: 300
Prototype assembly ID (Saxton project reports): 503-1-10

09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 71
- Rods:

304-SS Clad UO_2 Pelletized Fuel (type: 001)
77 – flux thimble

Assembly:	**Uranium assembly**
Assembly location:	E1
Assembly type:	800
Prototype assembly ID (Saxton project reports):	503-7-1

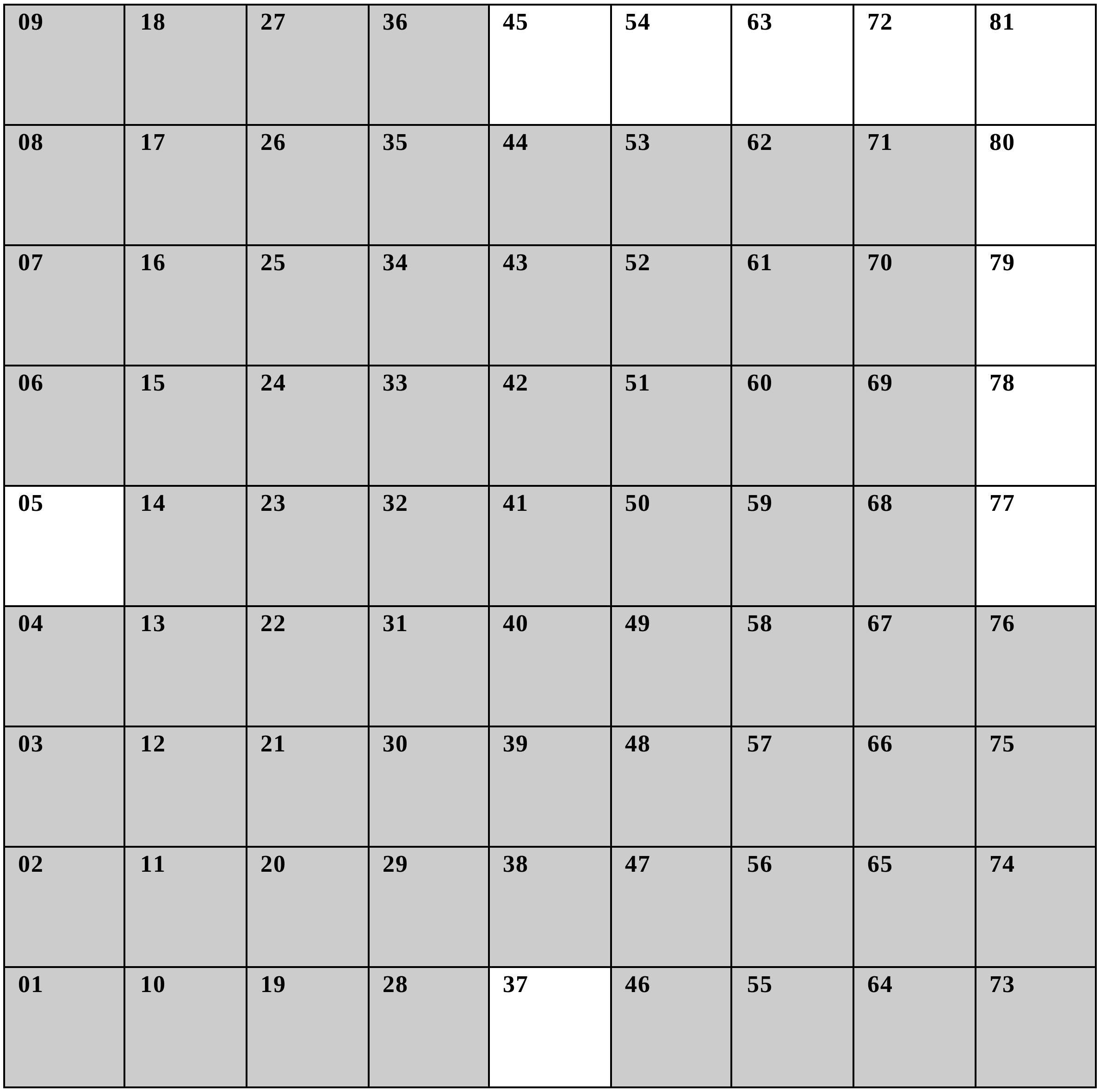
09	**18**	**27**	**36**	**45**	**54** ▨	**63** ▨	**72** ▨	**81** ▨
08	**17** ▨	**26** ▨	**35** ▨	**44** ▨	**53** ▨	**62** ▨	**71** ▨	**80** ▨
07	**16** ▨	**25** ▨	**34**	**43**	**52**	**61** ▨	**70** ▨	**79** ▨
06	**15** ▨	**24**	**33**	**42**	**51**	**60**	**69** ▨	**78** ▨
05	**14** ▨	**23**	**32**	**41**	**50**	**59**	**68** ▨	**77**
04 ▨	**13** ▨	**22**	**31**	**40**	**49**	**58**	**67** ▨	**76** ▨
03 ▨	**12** ▨	**21** ▨	**30**	**39**	**48**	**57** ▨	**66** ▨	**75** ▨
02 ▨	**11** ▨	**20** ▨	**29** ▨	**38** ▨	**47** ▨	**56** ▨	**65** ▨	**74** ▨
01 ▨	**10** ▨	**19** ▨	**28** ▨	**37** ▨	**46** ▨	**55** ▨	**64** ▨	**73** ▨

Description:

- Total number of fuel rods: 49
- Rods:

304-SS Clad UO_2 Pelletized Fuel (type: 001)
77 – flux thimble

Assembly:	**Plutonium assembly**
Assembly location:	E2
Assembly type:	700
Prototype assembly ID (Saxton project reports):	503-12-4



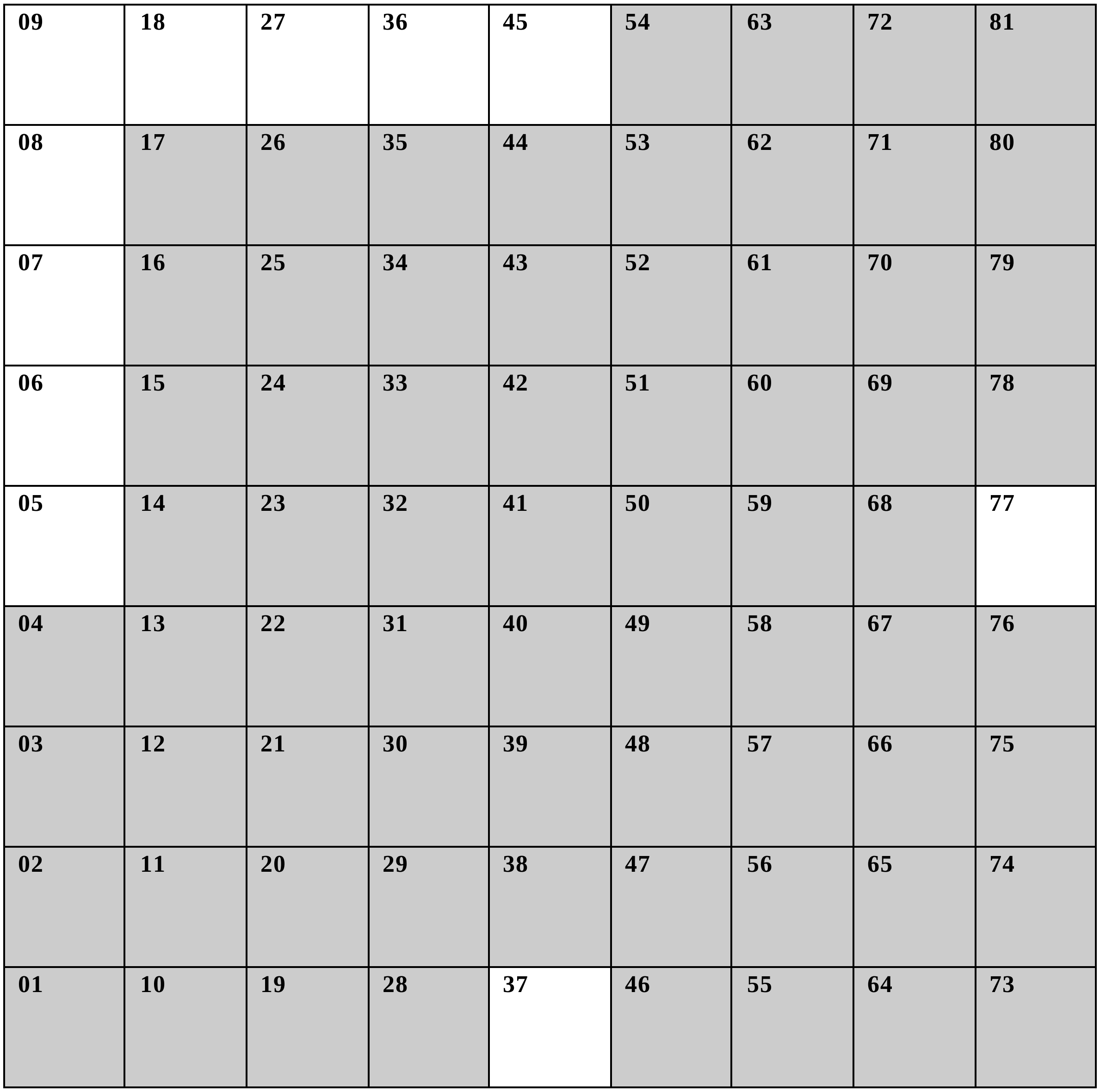
09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 71
- Rods:

Zircaloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type: 002)
05 – removable rod
37 – flux thimble

Assembly:	**Plutonium assembly**
Assembly location:	E3
Assembly type:	300
Prototype assembly ID (Saxton project reports):	503-12-6



09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 71
- Rods:

Zircaloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type: 002)
77 – removable rod
37 – secondary source rod

Assembly:	**Plutonium assembly**
Assembly location:	E4
Assembly type:	100
Prototype assembly ID (Saxton project reports):	503-12-8

09 ▨	**18** ▨	**27** ▨	**36** ▨	**45**	**54**	**63**	**72**	**81**
08 ▨	**17** ▨	**26** ▨	**35** ▨	**44** ▨	**53** ▨	**62** ▨	**71** ▨	**80**
07 ▨	**16** ▨	**25** ▨	**34** ▨	**43** ▨	**52** ▨	**61** ▨	**70** ▨	**79**
06 ▨	**15** ▨	**24** ▨	**33** ▨	**42** ▨	**51** ▨	**60** ▨	**69** ▨	**78**
05	**14** ▨	**23** ▨	**32** ▨	**41** ▨	**50** ▨	**59** ▨	**68** ▨	**77**
04 ▨	**13** ▨	**22** ▨	**31** ▨	**40** ▨	**49** ▨	**58** ▨	**67** ▨	**76** ▨
03 ▨	**12** ▨	**21** ▨	**30** ▨	**39** ▨	**48** ▨	**57** ▨	**66** ▨	**75** ▨
02 ▨	**11** ▨	**20** ▨	**29** ▨	**38** ▨	**47** ▨	**56** ▨	**65** ▨	**74** ▨
01 ▨	**10** ▨	**19** ▨	**28** ▨	**37**	**46** ▨	**55** ▨	**64** ▨	**73** ▨

Description:

- Total number of fuel rods: 72
- Rods:

  Zircaloy-4 Clad PuO_2-UO_2 Pelletized Fuel (type: 002)
  05, 37 – removable rods

Assembly: **Uranium assembly**
Assembly location: E5
Assembly type: 100
Prototype assembly ID (Saxton project reports): 503-10-5

09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 72
- Rods:

304-SS Clad UO_2 Pelletized Fuel (type: 001)

Assembly: **Uranium assembly**
Assembly location: F2
Assembly type: 100
Prototype assembly ID (Saxton project reports): 503-10-3

09 ▨	**18** ▨	**27** ▨	**36** ▨	**45** ▨	**54** ▨	**63** ▨	**72** ▨	**81** ▨
08 ▨	**17** ▨	**26** ▨	**35** ▨	**44** ▨	**53** ▨	**62** ▨	**71** ▨	**80** ▨
07 ▨	**16** ▨	**25** ▨	**34** ▨	**43** ▨	**52** ▨	**61** ▨	**70** ▨	**79** ▨
06 ▨	**15** ▨	**24** ▨	**33** ▨	**42** ▨	**51** ▨	**60** ▨	**69** ▨	**78** ▨
05 ▨	**14** ▨	**23** ▨	**32** ▨	**41** ▨	**50** ▨	**59** ▨	**68** ▨	**77**
04 ▨	**13** ▨	**22** ▨	**31** ▨	**40** ▨	**49** ▨	**58** ▨	**67** ▨	**76**
03 ▨	**12** ▨	**21** ▨	**30** ▨	**39** ▨	**48** ▨	**57** ▨	**66** ▨	**75**
02 ▨	**11** ▨	**20** ▨	**29** ▨	**38** ▨	**47** ▨	**56** ▨	**65** ▨	**74**
01 ▨	**10** ▨	**19** ▨	**28** ▨	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 72
- Rods:

304-SS Clad UO_2 Pelletized Fuel (type: 001)

Assembly: **Uranium assembly**
Assembly location: F3
Assembly type: 700
Prototype assembly ID (Saxton project reports): 503-1-19

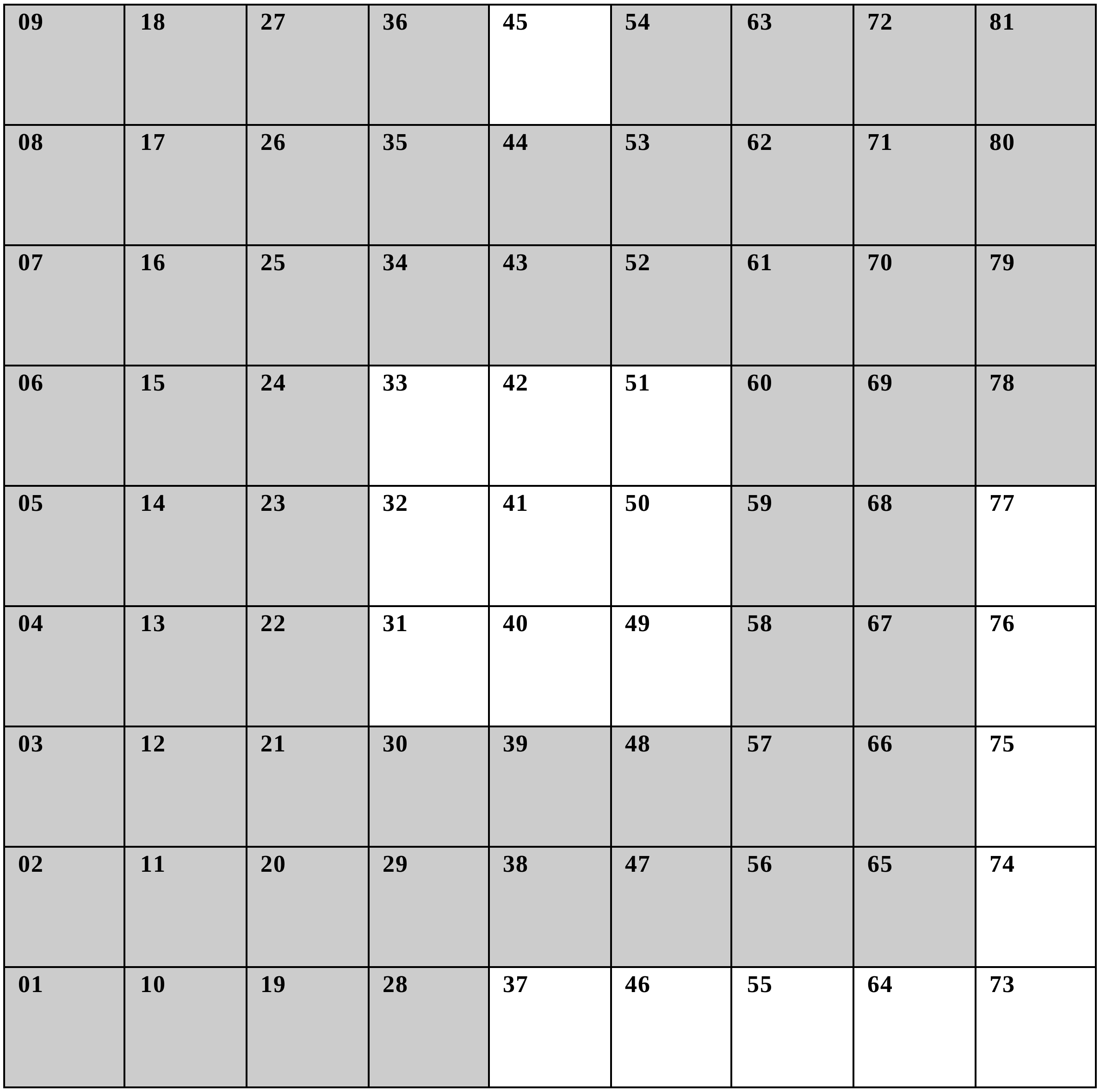
09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 71
- Rods:

304-SS Clad UO_2 Pelletized Fuel (type: 001)
45 – flux thimble

Assembly:	**Uranium assembly**
Assembly location:	F4
Assembly type:	600
Prototype assembly ID (Saxton project reports):	503-1-11



09	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**
08	**17**	**26**	**35**	**44**	**53**	**62**	**71**	**80**
07	**16**	**25**	**34**	**43**	**52**	**61**	**70**	**79**
06	**15**	**24**	**33**	**42**	**51**	**60**	**69**	**78**
05	**14**	**23**	**32**	**41**	**50**	**59**	**68**	**77**
04	**13**	**22**	**31**	**40**	**49**	**58**	**67**	**76**
03	**12**	**21**	**30**	**39**	**48**	**57**	**66**	**75**
02	**11**	**20**	**29**	**38**	**47**	**56**	**65**	**74**
01	**10**	**19**	**28**	**37**	**46**	**55**	**64**	**73**

Description:

- Total number of fuel rods: 61
- Rods:

304-SS Clad UO_2 Pelletized Fuel (type: 001)
45 – flux thimble

4.6. Resonance treatment

The energy dependence of the cross-sections of the HELIOS nuclear data library has been discretized by dividing the energy range of interest, from 20 MeV to 2.540E-04 eV, into a number of broad groups. These cross-sections have been obtained by flux-averaging point cross-sections (more than 100000) with typical reactor spectra. We have used the RES-option of the RUN operator in HELIOS so that different nuclides have been arranged in the same resonance set. We listed below the resonance sets we elected to use:

- ^{238}U – category 1
- Rest of heavy metal nuclides – category 2
- Non-heavy metal nuclides – category 3

5. Measured Parameters and Model Sensitivity Studies

5.1. Characteristic core calculations with HELIOS

A characteristic HELIOS output without burn-up calculations yields:

```
***********************************************
*  Normal End,    No warning messages issued  *
*                                             *
*    Highest memory required by this run:     *
*    735842 data words in module 2 (  9%)     *
*     18321 char words in module 4 (  3%)     *
*    Total CPU time used =    5.00 minutes    *
***********************************************
```

A typical runtime of HELIOS lasted about 9 hours for the most complicated configurations. Every case was computed with a burnup step equal to 500 MWd. Computations were performed without any decoupling schemes (current) in order to obtain a reference solution.

5.2. Sensitivity analysis

Within the framework of this study, some sensitivity analyses were performed in order to estimate the influence of some model characteristics on the K_{eff} of the system. These sensitvity analyses were needed because some of this information was not properly reported in the series of reports of this program. The following characteristics were varied:

- Material of fuel assembly grid
- Structure of the circular cylindrical system
- L-shaped sections containing fuel
- Temperature distribution within fuel rod (see Fig. 11)
- Structure of the control rod

Results of the sensitivity analysis are summarized below. They show changes in the boron endpoint concentrations with changes in the various characteristics. Note that these results are only for the BOL state where there is no fuel burnup and hence, no burnup distribution in the fuel. It is therefore, not too surprising that the boron concentration is not very sensitive to the number of fuel regions. An interesting comparison would be that of the EOL boron concentration with the different number of fuel regions. However, in that case, due to burnup, the distribution of the fuel will depend on radius and obscure the effect being studied - the sensitivity of the boron concentration on the number of regions in the fuel pins. Thus, the EOL comparison was intentionally avoided and is not given in the report because of several reasons:

(a) the idea of the provided comparison was to demonstrate necessity to describe fuel pins as several concentric regions even for BOL state (results show that boron concentration is sensitive to the model), and

(b) it was recognized that comparison for EOL state would show much more significant sensitivity on the fuel pin model, but in the case of EOL state, other factors will influence this sensitivity effect like presence of burnup distribution due to multiple region representation.

This would expand analysis considerably and make it much more complex. As a result, the EOL state was left beyond the scope of the report.

As a result of the sensitivity studies, the following features were used in the calculational model:

- Grid materials as shown in Fig. 12.
- L-shaped sections included or replaced by water according to core configuration.
- 6 concentric regions as shown in Fig. 11.
- Temperature distribution as given below.
- Model B for Control rod as shown below.

In the references, it is mentioned that the control rods had fuel-followed sections but very few details are given as regards to how they were made. Therefore, Model B was utilized.

Conditions:

Model:	Unified Saxton reactor core description
Configuration:	Saxton reactor core II, all control rods out, BOL
Hot conditions:	Thermal power, MWt - 23.5; Temperature, K - 810.928 (fuel); 591.483 (ZR40); 588.706 (SS304); 588.706 (INCONEL, AL); 551.483 (H_2O).

Material of fuel assembly grid

Boron endpoint concentration (ppm)

Grid materials	Boron concentration, ppm	Ratio*
1. SS304 and INCONEL	2398.631	1.000
2. SS304 only	2378.431	0.992
3. INCONEL only	2456.953	1.024
4. AL	2542.324	1.059

*ratio: [1, 2, 3, 4]/[1]

Structure of the circular cylindrical system

Boron endpoint concentration (ppm)

Number of concentric regions (see Fig. 11):	Boron concentration, ppm	ratio*
1. 8 regions	2398.631	1.000000
2. 6 regions	2397.395	0.999485
3. 1 region	2396.409	0.999074

*ratio: [1, 2, 3]/[1]

L-shaped sections containing fuel

Boron endpoint concentration (ppm)

Number of concentric regions (see Fig. 11):	Boron concentration, ppm	ratio*
1. Sections installed	2401.714	1.000000
2. Section places treated as water regions	2398.631	0.998716

*ratio: [1, 2]/[1]

Temperature distribution within fuel rod (see fig. 11)

Average fuel temperature, K: 810.928

Special temperatures for concentric regions (6 region scheme), K:

Region 1 (fraction – 0.45):	1033.229
Region 2 (fraction – 0.15):	986.264
Region 3 (fraction – 0.12):	892.334
Region 4 (fraction – 0.10):	779.618
Region 5 (fraction – 0.09):	657.509
Region 6 (fraction – 0.09):	516.614

Averaged over 6 regions fuel temperature, K: 810.928

Boron endpoint concentration (ppm)

Number of concentric regions (see Fig. 11):	**Boron concentration, ppm**	**ratio***
1. 6 regions	2397.395	1.000000
2. 1 region (average temperature)	2429.547	1.013411

*ratio: [1, 2]/[1]

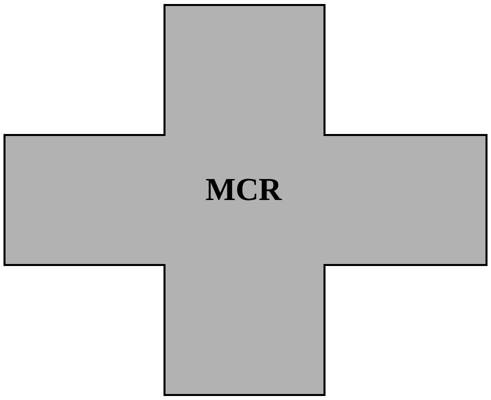
Structure of the control rod

As it was already described above, the reactor used six offset cruciform shaped control rods made of an alloy of silver, indium and cadmium. In the references, it is mentioned that the control rods had fuel followed sections but very few details are given as regards to how they were made. Hence, within the frame of our analysis we consider two models for the description of control rods in the Unified Saxton Reactor Core Model:

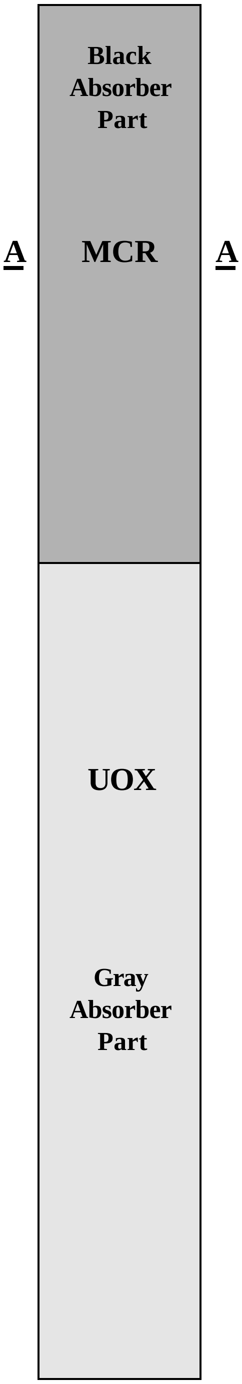
Model A:

Control rod cross section:

A-A



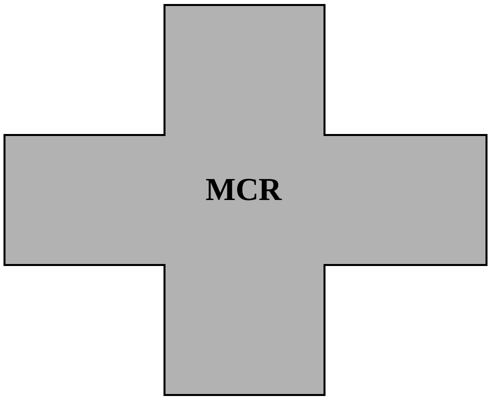
Conditions:	
Rod in: Black Absorber Part (MCR) in the reactor core	Rod out: Gray Absorber Part (UOX) in the reactor core (see Table 2b for composition of UOX)



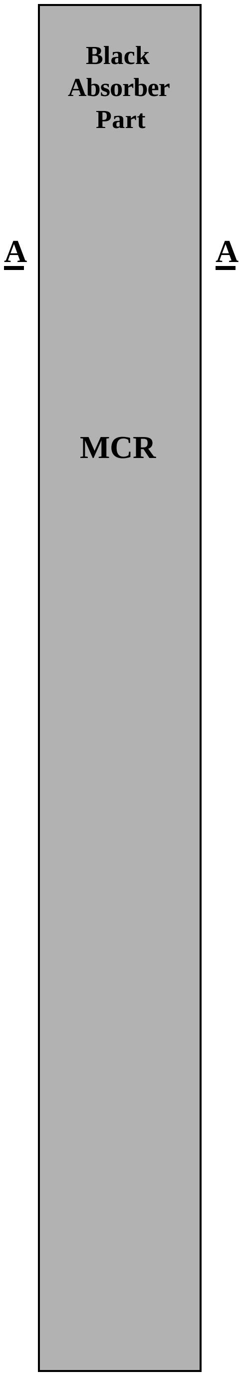
Model B:

Control rod cross section:

A-A



Conditions:	
Rod in: Black Absorber Part (MCR) in the reactor core	Rod out: Space reserved for control rod is filled with water (H2O composition)



Sensitivity analysis of the control rod model influence on the calculated boron endpoint concentrations (ppm):

Core configuration	**Saxton Plutonium Project reports**	**HELIOS calculations**				**Burnup, MWD/MTM**
		Model A for control rod	**ratio***	**Model B for control rod**	**Difference ***	
All rods out	2296	2403.912	1.047	2398.631	1.045	BOL
Rods 1, 3, 4,5 & 6 out, Rod 2 in	1702	1785.398	1.049	1780.803	1.046	
Rods 1, 3, 4 & 6 out, Rod 2 & 5 in	1047	1102.491	1.053	1101.902	1.052	
All rods out	1565	1641.685	1.049	1636.900	1.046	3716
Rods 1, 3, 4,5 & 6 out, Rod 2 in	1037	1089.887	1.051	1086.879	1.048	
All rods out	1266	1328.034	1.049	1326.388	1.048	5715
Rods 1, 3, 4,5 & 6 out, Rod 2 in	796	839.78	1.055	837.153	1.052	
All rods out	683	719.882	1.054	718.492	1.052	10490
Rods 1, 3, 4,5 & 6 out, Rod 2 in	312	329.784	1.057	328.573	1.053	

*ratio: [Model A, Model B]/[Report]

On the basis of these sensitivity analyses, we reached the following conclusions:

- There is constant discrepancy between the computational HELIOS results and experimental results; HELIOS calculations typically overpredict the Saxton characteristics;
- HELIOS results overpredict boron concentrations except when using type 304-SS fuel assembly grid structure;
- Sensitivity studies were performed in order to evaluate the influence of the control-rod model on results. Both models overpredict boron concentration when compared to available experimental information.

Investigation of certain calculational and experimental details were not considered due to funding limitations. Specific notes on the computer models follow:

- Critical boron concentrations were determined by a manual search.
- The calculations were performed at different boron concentrations and the results interpolated to obtain the boron concentration that corresponds to a k_{eff} of unity. (HELIOS does not have an option to perform such criticality searches.)
- According to the Core II description, assembly E-1 is from Core I. E-1 was depleted using the Core I model.
- Though no information on the axial buckling values used in the 2-D HELIOS calculations; several approaches have been studied: zero axial bucklings and bucklings calculated using actual height of the core.
- Though no information on the boron concentrations during the fuel burnup is presented, the SAXTON materials core histories were followed whenever information was found. Power generated in the followers was not included.
- Actual histories of the SAXTON core irradiation were described with very limited amount of information. As a result, only MOL Core III was modeled.
- More results would be useful even if there are not corresponding measurements (boron concentrations or k_{eff} vs. burnup for each core, power distributions at various burnup points, fuel isotopics at various burnup points, rod worths, etc.) The studies did not go in many details and many aspects due to time constraints of the project.

5.3. Saxton reactor Core I

Core I was used as a reference core configuration for the verification of the generalized model of the core geometry. Computations performed during the Saxton project are provided in Table 3.

Table 3. Some characteristics of the Saxton reactor Core I that were calculated with HELIOS and their comparison with calculated results obtained during the Saxton Plutonium Project

Characteristics	**Saxton Plutonium Project reports (Computed, measured not available)**
Effective multiplication factor at BOL conditions:	
• Zero power, all control rods out, cold conditions (293.1500 K)	1.241*
• Zero power, all control rods out, hot conditions (549.8167 K)	1.171*
• Power (20 MWt), all control rods out, hot conditions (549.8167 K)	1.156*
Boron concentration (natural boron), ppm:	
• To shut down the reactor down to K_{eff}=0.97 (all control rods out, zero power):	
Cold (293.1500 K)	2200
Hot (549.8167 K)	2330
• To control at power (20 MW, all control rods out, hot conditions (549.8167 K))	1835
• Approximate concentration for worth of 1%:	
Cold (293.1500 K)	80
Hot (549.8167 K)	110
Estimated control rod worth (average per rod), %	3.8

*Computational results, LEOPARD-PDQ computer code system (Saxton Plutonium Project report)

5.4. Saxton reactor Core II

Saxton Core II achieved criticality on 12/06/65 and started initial power operation on 12/29/65. After operating at initial power levels of 17 MW and 21 MW, it achieved its rated power of 23.5 MW on 02/07/66. From Jan 68 onward, the reactor was operated at an escalated power of 30.6 MW. Control rod 2 was banked to 50.8cm (20 inches). The maximum linear power under these conditions in the mixed oxide fuel was estimated to be 0.60696 kW/cm (18.5 kW/ft). The reactor was operated at this power level until the end of life (EOL).

At the beginning of core life (BOL) and periodically throughout the core life, measurements were made to determine the control rod worth, boron worth and moderator temperature coefficients. A summary of experimental results is available in the Saxton Plutonium Project reports:

- Zero Power BOL Measurements at Ambient Temperature (boron endpoint measurement for all rods out, for rod 2 in, for rod 2 and 5 in, and for rods 2 and 5 in with rods 1 and 6 partially inserted, were made with the reactor at cold conditions);
- Moderator Temperature Coefficient Measurements (experimental determination of differential temperature coefficients at each of the endpoint boron concentrations in the cold condition of the core);
- Cold-to-Hot Rod Reactivity Defects (the reactivity effect associated with heatup/cooldown was measured at two boron concentrations);
- Zero Power Reactivity Measurements at Operating Temperatures (at the beginning of core life and periodically throughout the cycle, measurements were made for all-rods-out and for the following quantities with rod 2 inserted: the boron concentration, the control rod worth for rod 2, the differential boron worth, the differential moderator temperature coefficient, and the xenon worth);

Some experimental results are summarized in Table 4.

Table 4. Saxton reactor Core II experimental information from the Saxton Plutonium Project reports

A. Zero power BOL measurements at certain temperature
(boron endpoint measurement (ppm) for all rods out, rod 2 in, rod 2 and 5 in)

Boron endpoint concentration (ppm)

Core configuration	**Core average Temperature, K**	**Saxton Plutonium Project reports**
All rods out	330.372	2718
Rods 1, 3, 4,5 & 6 out **Rod 2 in**	341.483	2268
Rods 1, 3, 4 & 6 out **Rod 2 & 5 in**	341.483	1742

B. Endpoint measurements at hot conditions (Core average temperature: 549.8167 K)
(Boron endpoint measurement (ppm) for all rods out, rod 2 in, rod 2 and 5 in)

Boron endpoint concentration (ppm)

Core configuration	**Saxton Plutonium Project reports**	**Measured inverse Boron worth (ppm/%)**	**Burnup, MWD/MTM**
All rods out	2296	161	BOL
Rods 1, 3, 4,5 & 6 out, Rod 2 in	1702		
Rods 1, 3, 4 & 6 out, Rod 2 & 5 in	1047		
All rods out	1565	160	3716
Rods 1, 3, 4,5 & 6 out, Rod 2 in	1037		
All rods out	1266	151	5715
Rods 1, 3, 4,5 & 6 out, Rod 2 in	796		
All rods out	683	-	10490
Rods 1, 3, 4,5 & 6 out, Rod 2 in	312		

Four mixed oxide fuel rods (2 pellet and 2 VIPAC type, clad in zircaloy) were irradiated in the peripheral assembly 1E from June 11, 1965 until the end of the year. Operation of this subassembly in the center position commenced on December 28, 1965 and continued until March 31, 1966. Post irradiation evaluation of these fuel rods that had been subjected to average exposure levels of 4500 MWd/MTM and 6100 MWd/MTM peak burnup, was carried out. Though the designed linear power rating was 0.525kW/cm(16 KW/ft), this actual operating linear power during this period was 0.348kW/cm(10.6 KW/ft).

The program for the examination of these rods included:

(a) External examination (visual and by stereo microscope) of four rods for damage, crud, discoloration, weld area corrosion, etc.
(b) Dimensional check of four rods for "bambooing" of cladding at pellet ends, for cladding creep, for cladding ovality etc.
(c) Gamma scan to determine the peak power location
(d) Collection and analysis of fission gases
(e) Sectioning of two rods at peak burnup areas (two cuts per rod for one VIPAC and one pelletized rod)
(f) Metallographic examination of samples from the two cut rods
(g) Determination of the hydrogen content in the cladding in the two cut rods.
(h) Analysis for Cs-137, Sr-90 and Pu/U on samples taken from the area of the four cuts referred to in Item (e)
(i) Mass spectrometric analyses for: U-234, U-235, U-236, U-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-239/U-238, Nd-148

Results are shown in Table 5A and 5B.

Table 5A. Summary of the Radiochemical Analysis Data

Sample	Cs-137(1)	Sr-90(2)	Pu-239/U-238 X 10^2 (atom ratio)	Nd-148/U-238 X 10^6 (atom ratio)
D-BU-1	4.53	1.78	5.576 ± 0.45	115.0 ± 1.1
D-BU-2	4.07	1.7	5.845 ± 0.52	102.2 ± 0.8
X1-BU-1	3.84	1.46	5.951 ± 0.40	97.42 ± 0.8
X1-BU-2	3.6	1.34	5.842± 0.36	87.47 ± 0.67

(1) dpm/gm final Ux10^{-10} on 06-05-67 (± 6 %) (2) dpm/gm final Ux10^{-10} on 06-22-67 (± 68%) dpm/gm = disintegrations per minute per gram of uranium (metal) of burned fuel multiplied by 10^{-10}.

REFERENCES: WCAP 3385-10 and WCAP 1871 and WCAP 3385-12)- see figure 14 for more detailed information.

Table 5B. Summary of alpha spectrometric analyses and for Saxton Core II configuration at EOL (October 18, 1968)

Sample taken from assembly:	C3
Fuel rod lattice position:	50 (see picture on Fig. 14)
Fuel burnup, MWD/MTM:	20450

Characteristics	Saxton Plutonium Project report (alpha spectrometric analyses)
^{238}U weight fraction in total U	0.99398
^{237}Np/^{238}U atom ratio (x 10^4)	1.15
^{236}Pu/^{239}Pu atom ratio(x 10^9)	3.86 ± 0.97
^{238}Pu/^{239}Pu atom ratio(x 10^3)	1.36 ± 0.04
^{241}Am/^{239}Pu atom ratio (x 10^2)	0.812 ± 0.191
^{242}Cm/^{239}Pu atom ratio (x 10^4)	5.48
^{244}Cm/^{239}Pu atom ratio (x 10^4)	1.29

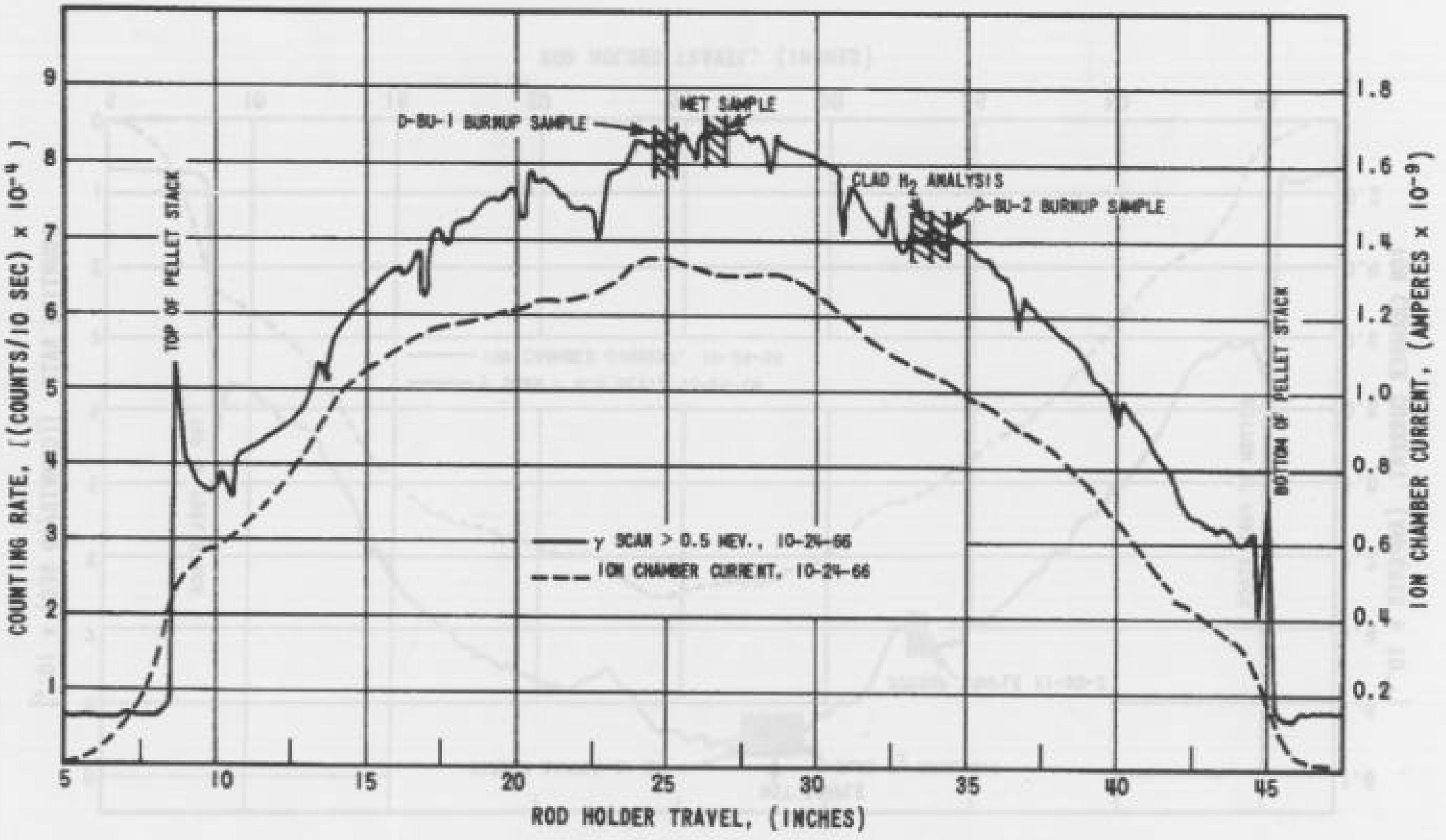


Figure 14: Gamma scan of Saxton Core II rod. Location of the sampling performed for burnup experimental studies

5.5. Saxton reactor Core III

The Core III layout is shown in Fig. 15, and the core relative assembly powers are shown on a core layout in Fig. 16. Original project results are shown in Tables 6 and 7.

Summary of Saxton Core III Operating History Through EOL:

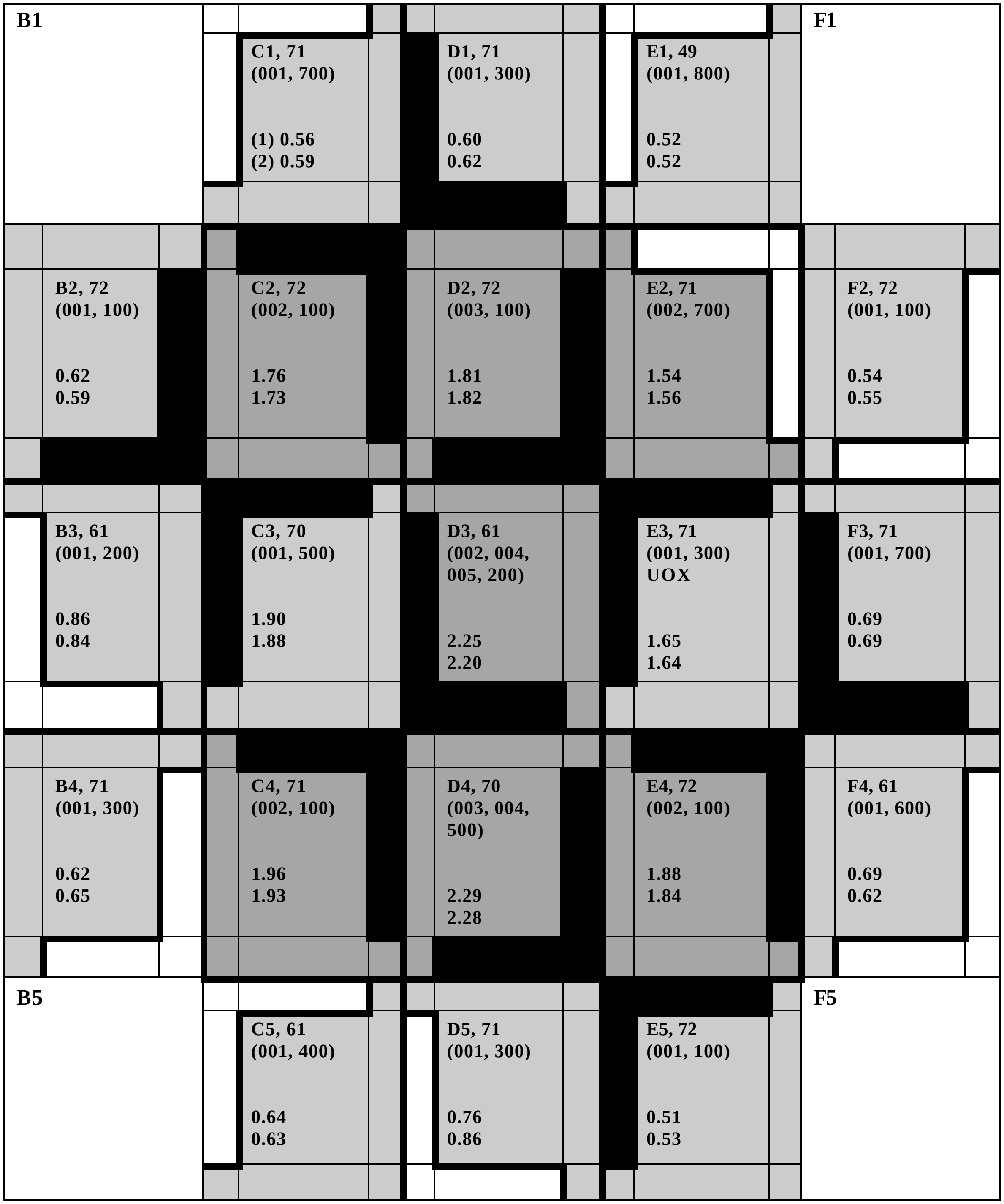
	Through March 31, 1971	During April-May 1972	EOL
Energy Generated, MWd	5352	467	5819
Number of Load Cycles	631	0	631
Peak Linear Power, kW/cm(kW/ft) [a]			
1. Peak Power Rod	0.6955 (21.2)	0.4823 (14.7)	-----
2. Peak Burnup Rod (in Center 3x3)	0.4659 (14.2)	0.3248 (9.9)	-----
3. Peak Burnup Rod	0.3970 (12.1)	0.2756 (8.4)	-----
Peak Pellet Burnup, MWd/MTM[b]			
1. Peak Power Rod	26400	2700	29100
2. Peak Burnup Rod (in Center 3x3)	49200	1800	51000
3. Peak Burnup Rod	45600	1500	47100

(a) Best estimate, thermal basis (thermal=0.974 fission)
(b) Best estimate, fission basis

Saxton Core III power history

Period	Calendar Time	Eff. Full Power Hrs. @ 23.5 MW		Core Energy Production, MWd	Core Burnup, MWd/MTM
		Step	Accumulative		
1	BOL 12/11/69 to 02/12/70	700	700	685	952
2	02/13/70 to 05/14/70	1021	1721	1685	2340
3	08/24/70 to 11/17/70	1000	2721	2664	3700
4	MOL 11/18/70 to 03/12/71	993	3714	3637	5051
5	11/10/71 to 01/31/72	1045	4759	4660	6472
6	EOL 02/01/72 to 05/01/72	1184	5943	5819	8082

The reactor Core III operation phase was successfully completed with the achievement of peak pellet burnups exceeding 50000 MWd/MTM.

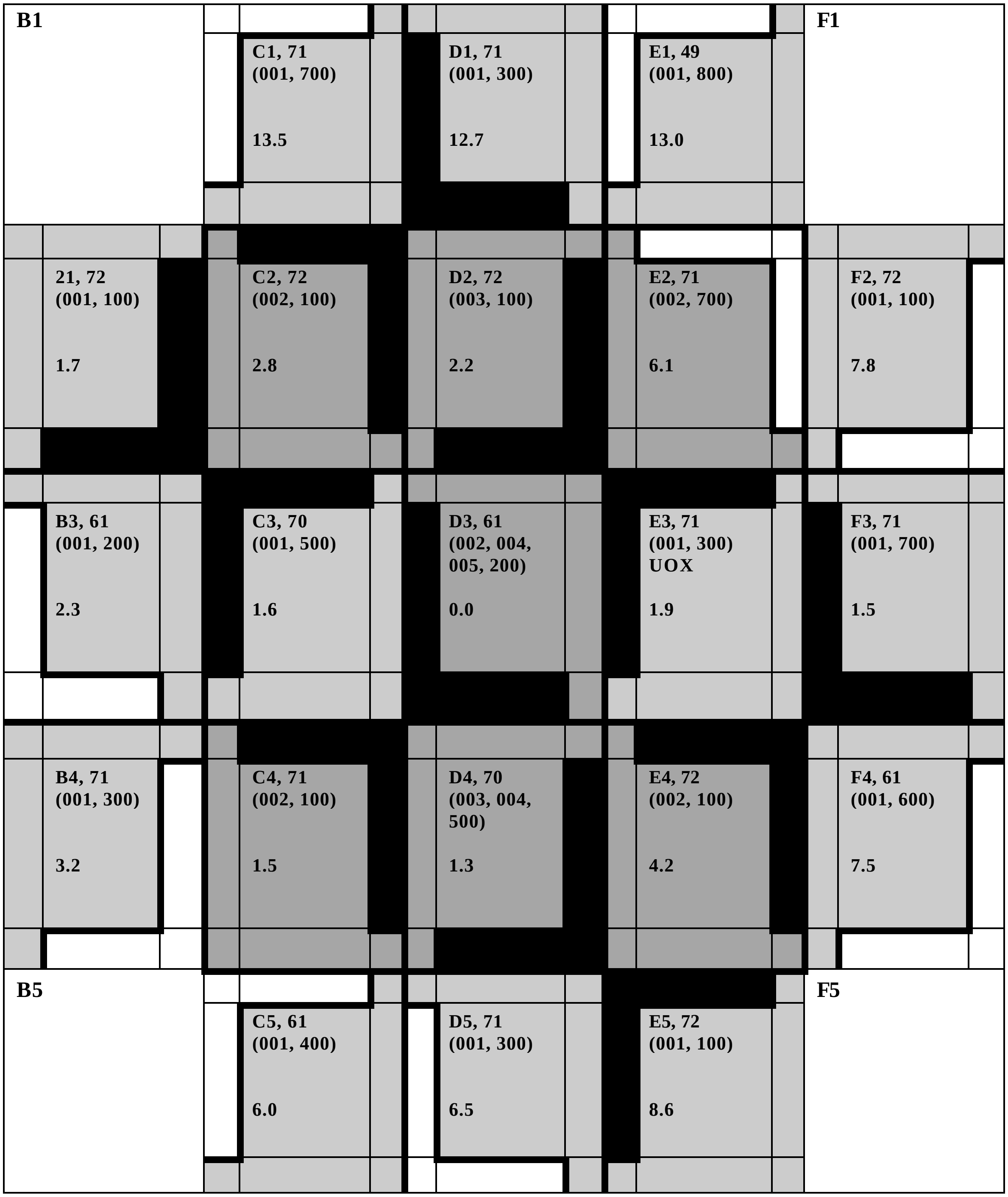


Simplified image of each fuel assembly contains the following information:

- Assembly location (C1, D1, etc.)
- Number of fuel rods per assembly (72, etc.)
- Fuel element type (001, 002, etc.) according to description made above
- Model type of fuel assembly geometry (100, 200, etc..)
- Relative assembly powers:

(1) Measured pre-MOL (01/71)
(2) Measured post-MOL (11/71)

Figure 15: Relative Assembly Powers for Saxton reactor Core model (Saxton partial plutonium Core, Saxton Core III configuration)



Simplified image of each fuel assembly contains the following information:

- Assembly location (C1, D1, etc.)
- Number of fuel rods per assembly (72, etc.)
- Fuel element type (001, 002, etc.) according to description made above
- Model type of fuel assembly geometry (100, 200, etc..)
- Relative assembly powers:

[Measured post-MOL (11/71)-Saxton/LEOPARD/PDQ]/Measured post MOL] X 100

Figure 16: Percent Difference in the Measured and Calculated Relative Assembly Powers for Saxton reactor Core model (Saxton partial plutonium Core, Saxton Core III configuration)

Table 6. Zero power BOL measurements at certain temperature

(boron endpoint measurement (ppm) for all rods out, core average temperature: 549.8167 K)

Boron endpoint concentration (ppm)

Core configuration	**Saxton Plutonium Project reports**
Critical boron, ppm	1082

Table 7. Zero power MOL measurements at certain temperature

(boron endpoint measurement (ppm) for all rods out, core average temperature: 549.8167 K)

Boron endpoint concentration (ppm)

Core configuration	**Saxton Plutonium Project reports**
Critical boron, ppm	591

Table 8 presents a comparison of the results of the mass spectrometric analyses performed on the two burnup samples from rod RR.

Table 8. Summary of the Radiochemical Analysis Data

Sample Location (From the bottom of the fuel rod) cm (in)	**U(Atom %) Abundance**				**Pu (atom %) Abundance**				
	U^{234}	**U^{235}**	**U^{236}**	**U^{238}**	**Pu^{238}**	**Pu^{239}**	**Pu^{240}**	**Pu^{241}**	**Pu^{242}**
27.94 - 29.21 (11.0”–11.5”)	4.31 -3	0.486	0.0506	99.459	0.315	61.411	28.084	8.627	1.563
46.99 - 48.26 (18.5”–19.0”)	4.34 -3	0.476	0.053	99.467	0.346	60.302	28.673	8.984	1.695

Sample Location (From the bottom of the fuel rod) cm (in)	**Atom Ratio**	
	Nd^{148}/U^{238} (x 1e4)	**Pu^{239}/U^{238} (x 1e2)**
27.94 - 29.21 (11.0” – 11.5”)	5.943	3.097
46.99 - 48.26 (18.5” – 19.0”)	6.062	2.972

REFERENCE: WCAP-3385-26

The mass spectrometric analysis for rod RR has been confirmed independently and the obtained burnup results are:

Sample Location (From the bottom of the fuel rod) cm (in)	**Atom Ratio**		**Burnup, MWd/MTM**		
	Nd^{148}/U^{238} (x 1e4)	**Pu^{239}/U^{238} (x 1e2)**	**Heavy Isotope**	**Nd^{148}**	**Percent difference**
27.94 - 29.21 (11.0” - 11.5”)	5.943	3.097	33690	31990	+5.3
46.99 - 48.26 (18.5” - 19.0”)	6.062	2.972	34400	32640	+5.3

The best estimate rod average burnup and peak pellet burnups are 25100 and 33200 MWd/MTM respectively. (44.196 cm (17.4”) from the bottom of the rod).

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6. Conclusions

A study of the neutronics of the Saxton Plutonium Program-Irradiation in the Saxton Reactor was performed. It was confirmed during this analysis, that sufficient data exist to construct a HELIOS model.

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7. Acknowledgments

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9. Appendix

9.1. Group structures of the neutron transport calculations

Total number of energy groups - 190
Average lethargy and average energy per energy group:

```
  1-6.931E-01    2-5.306E-01    3-4.001E-01    4-2.912E-01    5-1.823E-01    6 0.000E+00    7 1.250E-01
    2.000E+07eV    1.700E+07eV    1.492E+07eV    1.338E+07eV    1.200E+07eV    1.000E+07eV    8.825E+06eV

  8 2.500E-01    9 3.000E-01   10 5.000E-01   11 6.500E-01   12 7.500E-01   13 8.000E-01   14 9.000E-01
    7.788E+06eV    7.408E+06eV    6.065E+06eV    5.220E+06eV    4.724E+06eV    4.493E+06eV    4.066E+06eV

 15 1.000E+00   16 1.150E+00   17 1.250E+00   18 1.300E+00   19 1.400E+00   20 1.442E+00   21 1.450E+00
    3.679E+06eV    3.166E+06eV    2.865E+06eV    2.725E+06eV    2.466E+06eV    2.365E+06eV    2.346E+06eV

 22 1.500E+00   23 1.600E+00   24 1.700E+00   25 1.750E+00   26 1.850E+00   27 2.000E+00   28 2.150E+00
    2.231E+06eV    2.019E+06eV    1.827E+06eV    1.738E+06eV    1.572E+06eV    1.353E+06eV    1.165E+06eV

 29 2.250E+00   30 2.300E+00   31 2.500E+00   32 2.650E+00   33 2.750E+00   34 2.800E+00   35 3.000E+00
    1.054E+06eV    1.003E+06eV    8.208E+05eV    7.065E+05eV    6.393E+05eV    6.081E+05eV    4.979E+05eV

 36 3.150E+00   37 3.250E+00   38 3.300E+00   39 3.500E+00   40 3.650E+00   41 3.750E+00   42 3.800E+00
    4.285E+05eV    3.877E+05eV    3.688E+05eV    3.020E+05eV    2.599E+05eV    2.352E+05eV    2.237E+05eV

 43 4.000E+00   44 4.200E+00   45 4.250E+00   46 4.350E+00   47 4.500E+00   48 4.750E+00   49 5.000E+00
    1.832E+05eV    1.500E+05eV    1.426E+05eV    1.291E+05eV    1.111E+05eV    8.652E+04eV    6.738E+04eV

 50 5.250E+00   51 5.500E+00   52 5.625E+00   53 5.750E+00   54 5.875E+00   55 5.950E+00   56 6.000E+00
    5.247E+04eV    4.087E+04eV    3.607E+04eV    3.183E+04eV    2.809E+04eV    2.606E+04eV    2.479E+04eV

 57 6.125E+00   58 6.250E+00   59 6.375E+00   60 6.500E+00   61 6.625E+00   62 6.750E+00   63 6.875E+00
    2.187E+04eV    1.930E+04eV    1.704E+04eV    1.503E+04eV    1.327E+04eV    1.171E+04eV    1.033E+04eV

 64 7.000E+00   65 7.125E+00   66 7.250E+00   67 7.375E+00   68 7.500E+00   69 7.625E+00   70 7.750E+00
    9.119E+03eV    8.047E+03eV    7.102E+03eV    6.267E+03eV    5.531E+03eV    4.881E+03eV    4.307E+03eV

 71 7.875E+00   72 8.000E+00   73 8.125E+00   74 8.250E+00   75 8.375E+00   76 8.500E+00   77 8.625E+00
    3.801E+03eV    3.355E+03eV    2.960E+03eV    2.613E+03eV    2.306E+03eV    2.035E+03eV    1.796E+03eV

 78 8.750E+00   79 8.875E+00   80 9.000E+00   81 9.125E+00   82 9.250E+00   83 9.375E+00   84 9.500E+00
    1.585E+03eV    1.398E+03eV    1.234E+03eV    1.089E+03eV    9.611E+02eV    8.482E+02eV    7.485E+02eV

 85 9.625E+00   86 9.750E+00   87 9.875E+00   88 1.000E+01   89 1.013E+01   90 1.025E+01   91 1.037E+01
    6.606E+02eV    5.829E+02eV    5.144E+02eV    4.540E+02eV    4.006E+02eV    3.536E+02eV    3.120E+02eV

 92 1.050E+01   93 1.062E+01   94 1.075E+01   95 1.087E+01   96 1.100E+01   97 1.113E+01   98 1.125E+01
    2.754E+02eV    2.430E+02eV    2.144E+02eV    1.893E+02eV    1.670E+02eV    1.474E+02eV    1.301E+02eV

 99 1.137E+01  100 1.150E+01  101 1.162E+01  102 1.175E+01  103 1.188E+01  104 1.200E+01  105 1.213E+01
    1.148E+02eV    1.013E+02eV    8.940E+01eV    7.889E+01eV    6.962E+01eV    6.144E+01eV    5.422E+01eV

106 1.225E+01  107 1.237E+01  108 1.250E+01  109 1.262E+01  110 1.275E+01  111 1.287E+01  112 1.300E+01
    4.785E+01eV    4.223E+01eV    3.727E+01eV    3.289E+01eV    2.902E+01eV    2.561E+01eV    2.260E+01eV

113 1.313E+01  114 1.325E+01  115 1.337E+01  116 1.350E+01  117 1.362E+01  118 1.375E+01  119 1.387E+01
    1.995E+01eV    1.760E+01eV    1.554E+01eV    1.371E+01eV    1.210E+01eV    1.068E+01eV    9.422E+00eV

120 1.400E+01  121 1.413E+01  122 1.419E+01  123 1.425E+01  124 1.438E+01  125 1.450E+01  126 1.462E+01
    8.315E+00eV    7.338E+00eV    6.868E+00eV    6.476E+00eV    5.715E+00eV    5.043E+00eV    4.451E+00eV

127 1.475E+01  128 1.488E+01  129 1.500E+01  130 1.512E+01  131 1.525E+01  132 1.538E+01  133 1.550E+01
    3.928E+00eV    3.466E+00eV    3.059E+00eV    2.700E+00eV    2.382E+00eV    2.102E+00eV    1.855E+00eV

134 1.554E+01  135 1.557E+01  136 1.561E+01  137 1.565E+01  138 1.570E+01  139 1.574E+01  140 1.580E+01
    1.790E+00eV    1.726E+00eV    1.659E+00eV    1.595E+00eV    1.525E+00eV    1.457E+00eV    1.381E+00eV

141 1.585E+01  142 1.591E+01  143 1.596E+01  144 1.600E+01  145 1.602E+01  146 1.605E+01  147 1.606E+01
    1.308E+00eV    1.235E+00eV    1.166E+00eV    1.125E+00eV    1.099E+00eV    1.072E+00eV    1.062E+00eV

148 1.607E+01  149 1.608E+01  150 1.610E+01  151 1.613E+01  152 1.615E+01  153 1.617E+01  154 1.621E+01
```

```
    1.053E+00eV   1.043E+00eV    1.014E+00eV    9.920E-01eV    9.710E-01eV    9.506E-01eV    9.100E-01eV

155 1.625E+01   156 1.630E+01   157 1.636E+01   158 1.643E+01   159 1.652E+01   160 1.659E+01   161 1.668E+01
    8.764E-01eV   8.337E-01eV    7.821E-01eV    7.300E-01eV    6.700E-01eV    6.251E-01eV    5.700E-01eV

162 1.675E+01   163 1.680E+01   164 1.692E+01   165 1.699E+01   166 1.715E+01   167 1.726E+01   168 1.732E+01
    5.300E-01eV   5.032E-01eV    4.500E-01eV    4.170E-01eV    3.577E-01eV    3.206E-01eV    3.011E-01eV

169 1.735E+01   170 1.743E+01   171 1.750E+01   172 1.760E+01   173 1.781E+01   174 1.800E+01   175 1.804E+01
    2.907E-01eV   2.705E-01eV    2.510E-01eV    2.277E-01eV    1.844E-01eV    1.523E-01eV    1.457E-01eV
```

```
176 1.831E+01   177 1.862E+01   178 1.882E+01   179 1.898E+01   180 1.911E+01   181 1.927E+01   182 1.946E+01
     1.116E-01eV   8.197E-02eV     6.700E-02eV     5.692E-02eV     5.000E-02eV     4.275E-02eV     3.550E-02eV

 183 1.960E+01   184 1.979E+01   185 2.001E+01   186 2.051E+01   187 2.118E+01   188 2.220E+01   189 2.330E+01
     3.061E-02eV   2.550E-02eV     2.049E-02eV     1.240E-02eV     6.325E-03eV     2.277E-03eV     7.602E-04eV

 190 2.440E+01
     2.540E-04eV
```

9.2. Group structures of the gamma transport calculations

Total number of energy groups - 48
Energy group boundaries (eV):

5.000E+07	-1-	3.000E+07	-2-	2.000E+07	-3-	1.700E+07	-4-	1.400E+07	-5-	1.200E+07	-6-	1.000E+07
1.000E+07	-7-	9.000E+06	-8-	8.000E+06	-9-	7.500E+06	-10-	7.000E+06	-11-	6.500E+06	-12-	6.000E+06
6.000E+06	-13-	5.500E+06	-14-	5.000E+06	-15-	4.500E+06	-16-	4.000E+06	-17-	3.500E+06	-18-	3.000E+06
3.000E+06	-19-	2.666E+06	-20-	2.500E+06	-21-	2.333E+06	-22-	2.000E+06	-23-	1.875E+06	-24-	1.660E+06
1.660E+06	-25-	1.500E+06	-26-	1.330E+06	-27-	1.200E+06	-28-	1.125E+06	-29-	1.000E+06	-30-	9.000E+05
9.000E+05	-31-	8.000E+05	-32-	7.000E+05	-33-	6.000E+05	-34-	5.250E+05	-35-	5.000E+05	-36-	4.500E+05
4.500E+05	-37-	4.000E+05	-38-	3.000E+05	-39-	2.000E+05	-40-	1.500E+05	-41-	1.000E+05	-42-	8.000E+04
8.000E+04	-43-	6.000E+04	-44-	4.500E+04	-45-	3.000E+04	-46-	2.000E+04	-47-	1.000E+04	-48-	1.000E+03

9.3. Overall fission spectrum (HELIOS nuclear data library)

Total number of energy groups - 190

1	0.000006	2	0.000024	3	0.000071	4	0.000194	5	0.001084	6	0.001916	7	0.003854
8	0.002340	9	0.016040	10	0.021314	11	0.019609	12	0.011552	13	0.026700	14	0.031487
15	0.055696	16	0.042072	17	0.022238	18	0.046341	19	0.019936	20	0.003934	21	0.024154
22	0.048697	23	0.048402	24	0.023836	25	0.046490	26	0.065932	27	0.060366	28	0.036900
29	0.017403	30	0.062713	31	0.040034	32	0.023543	33	0.010895	34	0.038074	35	0.023232
36	0.013246	37	0.006038	38	0.020469	39	0.012128	40	0.006812	41	0.003065	42	0.010322
43	0.007805	44	0.001629	45	0.002927	46	0.003674	47	0.004594	48	0.003191	49	0.002202
50	0.001527	51	0.000576	52	0.000480	53	0.000402	54	0.000209	55	0.000127	56	0.000280
57	0.000235	58	0.000198	59	0.000165	60	0.000138	61	0.000115	62	0.000096	63	0.000076
64	0.000062	65	0.000052	66	0.000043	67	0.000036	68	0.000000	69	0.000000	70	0.000000
71	0.000000	72	0.000000	73 through 190 the same as above									

9.4. List of nuclides (HELIOS nuclear data library)

Total number of nuclides in the HELIOS nuclear data library:	271
Number of elements in the HELIOS nuclear data library:	72

Elements in the HELIOS nuclear data library:

1. **Effective nuclide**
2. **Aluminum**
3. **Americium**
4. **Antimony**
5. **Barium**
6. **Boron**
7. **Bromine**
8. **Beryllium**
9. **Carbon**
10. **Cadmium**
11. **Calcium**
12. **Cesium**
13. **Cerium**
14. **Chlorine**
15. **Cobalt**
16. **Copper**
17. **Chromium**
18. **Curium**
19. **Dysprosium**
20. **Erbium**
21. **Europium**
22. **Fluorine**
23. **Gadolinium**
24. **Gold**
25. **Hafnium**
26. **Holmium**
27. **Hydrogen**
28. **Indium**
29. **Iodine**
30. **Iron**
31. **Krypton**
32. **Lanthanum**
33. **Lead**
34. **Lithium**
35. **Lutetium**
36. **Magnesium**
37. **Manganese**
38. **Molybdenum**
39. **Neodymium**
40. **Niobium**
41. **Nitrogen**
42. **Nickel**
43. **Neptunium**
44. **Oxygen**
45. **Palladium**
46. **Phosphorus**
47. **Promethium**
48. **Praseodymium**
49. **Potassium**
50. **Protactinium**
51. **Plutonium**
52. **Rhodium**
53. **Ruthenium**
54. **Strontium**
55. **Silver**
56. **Sulfur**
57. **Silicon**
58. **Sodium**
59. **Samarium**
60. **Tin**
61. **Technetium**
62. **Tellurium**
63. **Tantalum**
64. **Titanium**
65. **Terbium**
66. **Thorium**
67. **Thulium**
68. **Uranium**
69. **Vanadium**
70. **Xenon**
71. **Yttrium**
72. **Zirconium**

The materials that are read from the HELIOS nuclear data library, which could be considered as an external component of the HERMES data base, are specified by their components (nuclides) and the number densities of these components. The nuclide identifiers are of the type 1,000Z+A, where Z is the atomic number and A is the mass in atomic mass units.

A = 000: identifies the element, and A = 1006, 1040, 6001, 8001, 26001, 28001, 40001, and 40002 and 501 < A < 800 have special meanings.

Available information in the HELIOS nuclear data library:

```
0NO.   ISOTOPE    TYPE    AT WEIGHT     ALFA      DELTA   RESONA  ABSORPTION  BURNABLE
GAMMA
                (IDCODE)    (AMU)                         TABLES   XS ONLY    ABSORBER
DATA

1. Effective nuclide:

   1    1           0       1.000      -         -           NO      YES         NO
NO

2. Molybdenium:

   2    42000       0       95.940     0.9592    0.0417      NO       NO         NO
YES
   3    42595       1       94.906     0.9587    0.0421     YES       NO         NO
YES
```

```
   4    42095        0       94.906        -          -         NO       YES          NO
YES
   5    42596        1       95.905        -          -         NO       YES          NO
YES
   6    42597        1       96.906        -          -         NO       YES          NO
YES
   7    42598        1       97.906        -          -         NO       YES          NO
YES
   8    42599        1       98.908        -          -         NO       YES          NO
YES
   9    42600        1       99.908        -          -         NO       YES          NO
YES
```

3. Technetium:

```
  10    43599        1       99.001     0.9604     0.0404      YES        NO          NO
YES
```

4. Palladium:

```
  11    46604        1      103.904        -          -         NO       YES          NO
YES
  12    46605        1      104.905     0.9626     0.0381       NO        NO          NO
YES
  13    46606        1      105.904        -          -         NO       YES          NO
YES
  14    46607        1      106.905     0.9633     0.0374       NO        NO          NO
YES
  15    46608        1      107.904     0.9636     0.0371      YES        NO          NO
YES
```

5. Silver:

```
  16    47107        0      106.905     0.9633     0.0374      YES        NO          NO
YES
  17    47109        0      108.905     0.9639     0.0367      YES        NO          NO
YES
  18    47609        1      108.905     0.9639     0.0367       NO        NO          NO
YES
  19    47710        1      109.906        -          -         NO       YES          NO
YES
  20    47611        1      110.906        -          -         NO       YES          NO
YES
```

6. Indium:

```
  21    49113        0      112.904     0.9652     0.0354      YES        NO          NO
YES
  22    49115        0      114.907     0.9658     0.0348      YES        NO          NO
YES
  23    49615        1      114.907     0.9658     0.0348       NO        NO          NO
YES
```

7. Xenon:

```
  24    54128        0      127.904     0.9692     0.0313       NO        NO          NO
YES
  25    54130        0      129.904     0.9697     0.0308       NO        NO          NO
YES
  26    54631        1      130.906     0.9699     0.0306      YES        NO          NO
YES
  27    54632        1      131.904        -          -         NO       YES          NO
YES
```

```
  28    54633       1      132.906       -         -        NO      YES         NO
YES
  29    54634       1      133.905     0.9706    0.0299     NO       NO         NO
YES
  30    54635       1      134.907       -         -        NO      YES         NO
YES
  31    54636       1      135.908       -         -        NO      YES         NO
YES
```

8. Cesium:

```
  32    55633       1      132.906     0.9704    0.0301    YES       NO         NO
YES
  33    55634       1      133.907       -         -        NO      YES         NO
YES
  34    55635       1      134.906       -         -        NO      YES         NO
YES
  35    55636       1      135.908       -         -        NO      YES         NO
YES
  36    55637       1      136.907       -         -        NO      YES         NO
YES
```

9. Gadolinium:

```
  37    64152       0      151.920     0.9740    0.0263     NO       NO         NO
YES
  38    64154       0      153.921     0.9743    0.0260     NO       NO         NO
YES
  39    64654       1      153.921       -         -        NO      YES         NO
YES
  40    64155       0      154.923     0.9745    0.0258    YES       NO         NO
YES
  41    64655       1      154.923     0.9745    0.0258     NO       NO         NO
YES
  42    64156       0      155.922     0.9747    0.0257    YES       NO         NO
YES
  43    64656       1      155.922     0.9747    0.0257     NO       NO         NO
YES
  44    64657       1      156.924     0.9748    0.0255     NO       NO         NO
YES
  45    64157       0      156.924     0.9748    0.0255    YES       NO         NO
YES
  46    64158       0      157.924     0.9750    0.0253    YES       NO         NO
YES
  47    64658       1      157.924     0.9750    0.0253     NO       NO         NO
YES
  48    64160       0      159.927     0.9753    0.0250     NO       NO         NO
YES
  49    64660       1      159.927       -         -        NO      YES         NO
YES
```

10. Erbium:

```
  50    68166       0      165.930     0.9762    0.0241    YES       NO         NO
YES
  51    68167       0      166.932     0.9763    0.0240    YES       NO         NO
YES
  52    68168       0      167.941     0.9765    0.0238     NO       NO         NO
YES
  53    68170       0      169.935     0.9767    0.0235     NO       NO         NO
YES
```

11. Thulium:

```
  54    69169       0      168.934     0.9766    0.0237     YES       NO         NO
YES
  55    69170       0      170.000     0.9767    0.0235     YES       NO         NO
YES
  56    69171       0      171.000         -         -       NO      YES         NO
YES
```

12. Hafnium:

```
  57    72174       0      173.940     0.9773    0.0230      NO       NO         NO
YES
  58    72176       0      175.941     0.9775    0.0227     YES       NO         NO
YES
  59    72177       0      176.943     0.9776    0.0226     YES       NO         NO
YES
  60    72178       0      177.944     0.9778    0.0225     YES       NO         NO
YES
  61    72179       0      178.946     0.9779    0.0224     YES       NO         NO
YES
  62    72180       0      179.947     0.9780    0.0222     YES       NO         NO
YES
```

13. Thorium:

```
  63    90230       3      230.036     0.9828    0.0174      NO       NO         NO
YES
  64    90232       2      232.033     0.9829    0.0172     YES       NO         NO
YES
  65    90233       3      233.042     0.9830    0.0172      NO       NO         NO
YES
  66    90234       3      234.044     0.9831    0.0171      NO       NO         NO
YES
```

14. Uranium:

```
  67    92232       3      232.033     0.9829    0.0172      NO       NO         NO
YES
  68    92233       3      233.045     0.9830    0.0172     YES       NO         NO
YES
  69    92234       3      234.041     0.9831    0.0171      NO       NO         NO
YES
  70    92235       3      235.044     0.9831    0.0170     YES       NO         NO
YES
  71    92236       3      236.046     0.9832    0.0169     YES       NO         NO
YES
  72    92237       3      237.048     0.9833    0.0169      NO       NO         NO
YES
  73    92238       2      238.051     0.9833    0.0168     YES       NO         NO
YES
```

15. Plutonium:

```
  74    94236       3      236.046     0.9832    0.0169      NO       NO         NO
YES
  75    94238       3      238.049     0.9833    0.0168      NO       NO         NO
YES
  76    94338       3      238.049     0.9833    0.0168      NO       NO         NO
YES
  77    94239       3      239.052     0.9834    0.0167     YES       NO         NO
YES
  78    94240       3      240.054     0.9835    0.0167     YES       NO         NO
YES
```

```
  79     94241      3      241.049     0.9835     0.0166     YES       NO         NO
YES
  80     94242      3      242.058     0.9836     0.0165     YES       NO         NO
YES
```

16. Hydrogen:

```
  81      1001      0        1.008     0.0000    11.0937      NO       NO         NO
YES
  82      1002      0        2.014     0.1132     2.1786      NO       NO         NO
YES
  83      1003      0        3.016        -          -        NO      YES         NO
YES
  84      1006      0        1.008     0.0000    11.0937      NO       NO         NO
YES
  85      1040      0        1.008     0.0000    11.0937      NO       NO         NO
YES
```

17. Lithium:

```
  86      3006      0        6.015     0.5111     0.6712      NO       NO         NO
YES
```

18. Beryllium:

```
  87      4009      0        9.012     0.6404     0.4457      NO       NO         NO
YES
```

19. Boron:

```
  88      5000      0       10.812     0.6900     0.3710      NO       NO         NO
YES
  89      5010      0       10.013     0.6698     0.4008      NO       NO         NO
YES
  90      5011      0       11.009     0.6947     0.3643      NO       NO         NO
YES
```

20. Carbon:

```
  91      6000      0       12.001     0.7160     0.3341      NO       NO         NO
YES
  92      6001      0       12.001     0.7160     0.3341      NO       NO         NO
YES
```

21. Nitrogen:

```
  93     7014       0       14.003     0.7512    0.2861      NO       NO         NO
YES
```

22. Oxygen:

```
  94     8001       0       15.991     0.7784    0.2505      NO       NO         NO
YES
  95     8016       0       15.991     0.7784    0.2505      NO       NO         NO
YES
```

23. Fluorine:

```
  96     9019       0       18.998     0.8100    0.2107      NO       NO         NO
YES
```

24. Sodium:

```
  97    11023       0       22.990     0.8402    0.1741      NO       NO         NO
YES
```

25. Magnesium:

```
  98    12000       0       24.305     0.8482    0.1647      NO       NO         NO
YES
```

26. Aluminum:

```
  99    13027       0       26.982     0.8622    0.1483      NO       NO         NO
YES
```

27. Silicon:

```
 100    14000       0       28.085     0.8672    0.1425      NO       NO         NO
YES
```

28. Phosphorus:

```
 101    15031       0       30.974     0.8788    0.1292      NO       NO         NO
YES
```

29. Sulfur:

```
 102    16000       0       32.064     0.8827    0.1248      NO       NO         NO
YES
```

30. Chlorine:

```
 103    17000       0       35.453     0.8933    0.1129      NO       NO         NO
YES
```

31. Potassium:

```
 104    19000       0       39.102     0.9027    0.1023      NO       NO         NO
YES
```

32. Calcium:

```
 105    20000       0       40.080     0.9050    0.0998      NO       NO         NO
YES
```

33. Titanium:

```
 106    22000       0       47.879     0.9198    0.0836      NO       NO         NO
YES
```

34. Vanadium:

```
 107    23000       0       50.942     0.9245    0.0785      NO       NO         NO
YES
```

35. Chromium:

```
 108    24000       0       51.996     0.9259    0.0769      NO       NO         NO
YES
 109    24050       0       49.946     0.9230    0.0801      NO       NO         NO
YES
 110    24052       0       51.940     0.9259    0.0770      NO       NO         NO
YES
 111    24053       0       52.941     0.9272    0.0756      NO       NO         NO
YES
 112    24054       0       53.939     0.9285    0.0742      NO       NO         NO
YES
```

36. Manganese:

```
 113    25055       0       54.938     0.9298    0.0728      NO       NO         NO
YES
```

37. Iron:

```
 114    26001       0        55.332     0.9303    0.0723      NO       NO          NO
YES
 115    26000       0        55.846     0.9309    0.0716      NO       NO          NO
YES
 116    26054       0        53.939     0.9285    0.0742      NO       NO          NO
YES
 117    26056       0        55.935     0.9310    0.0715      NO       NO          NO
YES
 118    26057       0        56.935     0.9321    0.0703      NO       NO          NO
YES
 119    26058       0        57.934     0.9333    0.0691      NO       NO          NO
YES
```

38. Cobalt:

```
 120    27059       0        58.933     0.9344    0.0679      NO       NO          NO
YES
```

39. Nickel:

```
 121    28001       0        58.722     0.9341    0.0681      NO       NO          NO
YES
 122    28000       0        58.688     0.9341    0.0682      NO       NO          NO
YES
 123    28058       0        57.936     0.9333    0.0690      NO       NO          NO
YES
 124    28059       0        59.118     0.9346    0.0677      NO       NO          NO
YES
 125    28060       0        59.931     0.9354    0.0667      NO       NO          NO
YES
 126    28061       0        60.931     0.9365    0.0657      NO       NO          NO
YES
 127    28062       0        61.928     0.9374    0.0646      NO       NO          NO
YES
 128    28064       0        63.928     0.9393    0.0626      NO       NO          NO
YES
```

40. Copper:

```
 129    29063       0        62.930     0.9384    0.0636      NO       NO          NO
YES
 130    29065       0        64.928     0.9402    0.0616      NO       NO          NO
YES
```

41. Zirconium:

```
 131    40090       0        89.904     0.9565    0.0445      NO       NO          NO
YES
 132    40591       1        90.903       -         -         NO      YES          NO
YES
 133    40000       0        91.220     0.9571    0.0439      NO       NO          NO
YES
 134    40001       0        91.220     0.9571    0.0439      NO       NO          NO
YES
 135    40002       0        91.511     0.9572    0.0437      NO       NO          NO
YES
 136    40593       1        92.906       -         -         NO      YES          NO
YES
 137    40595       1        94.908       -         -         NO      YES          NO
YES
 138    40596       1        95.905       -         -         NO      YES          NO
YES
```

42. Niobium:

```
 139    41093       0       92.903     0.9579    0.0431      NO       NO          NO
YES
 140    41595       1       94.907        -         -        NO      YES          NO
YES
```

43. Ruthenium:

```
 141    44600       1       99.904        -         -        NO      YES          NO
YES
 142    44601       1      100.906     0.9611    0.0396      NO       NO          NO
YES
 143    44602       1      101.904        -         -        NO      YES          NO
YES
 144    44603       1      102.906        -         -        NO      YES          NO
YES
 145    44604       1      103.906        -         -        NO      YES          NO
YES
 146    44605       1      104.908        -         -        NO      YES          NO
YES
 147    44606       1      105.908        -         -        NO      YES          NO
YES
```

44. Rhodium:

```
 148    45103       0      102.905     0.9619    0.0389      NO       NO          NO
YES
 149    45603       1      102.905     0.9619    0.0389      NO       NO          NO
YES
 150    45605       1      104.906     0.9626    0.0381      NO       NO          NO
YES
```

45. Cadmium:

```
 151    48000       0      112.426     0.9650    0.0356      NO       NO          NO
YES
 152    48110       0      109.903     0.9643    0.0364      NO       NO          NO
YES
 153    48610       1      109.903        -         -        NO      YES          NO
YES
 154    48111       0      110.905     0.9646    0.0361      NO       NO          NO
YES
 155    48611       1      110.905        -         -        NO      YES          NO
YES
 156    48112       0      111.903     0.9649    0.0357      NO       NO          NO
YES
 157    48113       0      112.900     0.9652    0.0354      NO       NO          NO
YES
 158    48613       1      112.900        -         -        NO      YES          NO
YES
 159    48114       0      113.903     0.9655    0.0351      NO       NO          NO
YES
```

46. Tin:

```
 160    50000       0      118.685     0.9669    0.0337      NO       NO          NO
YES
 161    50112       0      111.901     0.9649    0.0357      NO       NO          NO
YES
 162    50114       0      113.898     0.9655    0.0351      NO       NO          NO
YES
```

163	50115	0	114.903	0.9658	0.0348	NO	NO	NO	YES
164	50116	0	115.902	0.9661	0.0345	NO	NO	NO	YES
165	50117	0	116.903	0.9664	0.0342	NO	NO	NO	YES
166	50118	0	117.902	0.9666	0.0339	NO	NO	NO	YES
167	50119	0	118.903	0.9669	0.0336	NO	NO	NO	YES
168	50120	0	119.902	0.9672	0.0334	NO	NO	NO	YES
169	50122	0	121.903	0.9677	0.0328	NO	NO	NO	YES
170	50124	0	123.905	0.9682	0.0323	NO	NO	NO	YES
171	50125	0	124.908	-	-	NO	YES	NO	YES

47. Antimony:

172	51000	0	121.758	0.9677	0.0329	NO	NO	NO	YES
173	51500	1	121.758	-	-	NO	YES	NO	YES
174	51121	0	120.904	0.9675	0.0331	NO	NO	NO	YES
175	51123	0	122.904	0.9680	0.0325	NO	NO	NO	YES
176	51625	1	124.905	-	-	NO	YES	NO	YES
177	51627	1	126.907	-	-	NO	YES	NO	YES

48. Neodymium:

178	60642	1	141.908	-	-	NO	YES	NO	YES
179	60643	1	142.910	0.9724	0.0280	NO	NO	NO	YES
180	60644	1	143.910	-	-	NO	YES	NO	YES
181	60645	1	144.913	0.9728	0.0276	NO	NO	NO	YES
182	60646	1	145.913	-	-	NO	YES	NO	YES
183	60647	1	146.916	-	-	NO	YES	NO	YES
184	60648	1	147.917	-	-	NO	YES	NO	YES
185	60650	1	149.921	-	-	NO	YES	NO	YES

49. Promethium:

186	61647	1	146.915	0.9731	0.0272	NO	NO	NO	YES
187	61748	1	147.918	0.9733	0.0270	NO	NO	NO	YES
188	61648	1	147.918	-	-	NO	YES	NO	YES
189	61649	1	148.918	-	-	NO	YES	NO	YES

```
 190    61651       1      150.921        -         -        NO      YES         NO
YES
```

50. Samarium:

```
 191    62647       1      146.915     0.9731    0.0272      NO       NO         NO
YES
 192    62648       1      147.915        -         -        NO      YES         NO
YES
 193    62649       1      148.917     0.9735    0.0269      NO       NO         NO
YES
 194    62650       1      149.917     0.9737    0.0267      NO       NO         NO
YES
 195    62651       1      150.919     0.9738    0.0265      NO       NO         NO
YES
 196    62652       1      151.920     0.9740    0.0263      NO       NO         NO
YES
 197    62653       1      152.922        -         -        NO      YES         NO
YES
 198    62654       1      153.922        -         -        NO      YES         NO
YES
```

51. Europium:

```
 199    63651       1      150.919        -         -        NO      YES         NO
YES
 200    63653       1      152.922     0.9742    0.0262      NO       NO         NO
YES
 201    63654       1      153.922     0.9743    0.0260      NO       NO         NO
YES
 202    63655       1      154.923     0.9745    0.0258      NO       NO         NO
YES
 203    63656       1      155.924        -         -        NO      YES         NO
YES
 204    63657       1      156.925        -         -        NO      YES         NO
YES
```

52. Lutetium:

```
 205    71176       0      175.941     0.9775    0.0227      NO       NO          NO
YES
```

53. Tantalum:

```
 206    73181       0      180.954     0.9781    0.0221      NO       NO          NO
YES
 207    73182       0      181.950     0.9783    0.0220      NO       NO          NO
YES
```

54. Gold:

```
 208    79197       0      196.966     0.9799    0.0203      NO       NO          NO
YES
```

55. Lead:

```
 209    82206       0      205.969     0.9808    0.0194      NO       NO          NO
YES
 210    82207       0      206.978     0.9809    0.0193      NO       NO          NO
YES
 211    82208       0      207.977     0.9810    0.0192      NO       NO          NO
YES
```

56. Protactinium:

```
 212    91231       3      231.035     0.9828    0.0173      NO       NO          NO
YES
 213    91232       1      232.039        -         -        NO      YES          NO
YES
 214    91233       3      233.040     0.9830    0.0172      NO       NO          NO
YES
 215    91234       1      234.043        -         -        NO      YES          NO
YES
```

57. Neptunium:

```
 216    93237       3      237.048     0.9833    0.0169      NO       NO          NO
YES
 217    93238       3      238.051     0.9833    0.0168      NO       NO          NO
YES
 218    93239       3      239.053     0.9834    0.0167      NO       NO          NO
YES
```

58. Americium:

```
 219    95241       3      241.057     0.9835    0.0166      NO       NO          NO
YES
 220    95242       3      242.059     0.9836    0.0165      NO       NO          NO
YES
 221    95342       3      242.059     0.9836    0.0165      NO       NO          NO
YES
 222    95243       3      243.061     0.9837    0.0165      NO       NO          NO
YES
```

59. Curium:

```
 223    96242       3      242.058     0.9836    0.0165      NO       NO          NO
YES
 224    96243       3      243.061     0.9837    0.0165      NO       NO          NO
YES
```

```
 225    96244       3     244.063     0.9837    0.0164      NO       NO          NO
YES
 226    96245       3     245.065     0.9838    0.0163      NO       NO          NO
YES
 227    96246       3     246.067     0.9839    0.0163      NO       NO          NO
YES
```

60. Bromine:

```
 228    35581       1      80.916        -         -        NO      YES          NO
YES
```

61. Krypton:

```
 229    36583       1      82.914        -         -        NO      YES          NO
YES
 230    36585       1      84.912        -         -        NO      YES          NO
YES
```

62. Strontium:

```
 231    38589       1      88.908        -         -        NO      YES          NO
YES
 232    38590       1      89.908        -         -        NO      YES          NO
YES
```

63. Yttrium:

```
 233    39589       1      88.906        -         -        NO      YES          NO
YES
 234    39590       1      89.907        -         -        NO      YES          NO
YES
 235    39591       1      90.907        -         -        NO      YES          NO
YES
```

64. Tellurium:

236	52727	1	126.905	-	-	NO	YES	NO	YES
237	52729	1	128.907	-	-	NO	YES	NO	YES
238	52632	1	131.908	-	-	NO	YES	NO	YES

65. Iodine:

239	53627	1	126.904	-	-	NO	YES	NO	YES
240	53629	1	128.905	-	-	NO	YES	NO	YES
241	53631	1	130.907	-	-	NO	YES	NO	YES
242	53635	1	134.910	-	-	NO	YES	NO	YES

66. Barium:

243	56634	1	133.904	-	-	NO	YES	NO	YES
244	56637	1	136.905	-	-	NO	YES	NO	YES
245	56640	1	139.911	-	-	NO	YES	NO	YES

67. Lanthanum:

246	57639	1	138.906	-	-	NO	YES	NO	YES
247	57640	1	139.910	-	-	NO	YES	NO	YES

68. Cerium:

248	58641	1	140.908	-	-	NO	YES	NO	YES
249	58642	1	141.909	-	-	NO	YES	NO	YES
250	58643	1	142.913	-	-	NO	YES	NO	YES
251	58644	1	143.913	-	-	NO	YES	NO	YES

69. Praseodymium:

252	59641	1	140.907	-	-	NO	YES	NO	YES
253	59643	1	142.911	-	-	NO	YES	NO	YES

70. Terbium:

254	65159	1	158.925	-	-	NO	YES	NO	YES
255	65160	1	158.927	-	-	NO	YES	NO	YES
256	65161	1	160.928	-	-	NO	YES	NO	YES
257	65659	1	158.925	-	-	NO	YES	NO	YES

258	65660	1	158.927	-	-	NO	YES	NO	YES
259	65661	1	160.928	-	-	NO	YES	NO	YES

71. Dysprosium:

260	66160	1	159.925	-	-	NO	YES	NO	YES
261	66161	1	160.927	-	-	NO	YES	NO	YES
262	66162	1	161.927	-	-	NO	YES	NO	YES
263	66163	1	162.929	-	-	NO	YES	NO	YES
264	66164	1	163.928	-	-	NO	YES	NO	YES
265	66660	1	159.925	-	-	NO	YES	NO	YES
266	66661	1	160.927	-	-	NO	YES	NO	YES
267	66662	1	161.927	-	-	NO	YES	NO	YES
268	66663	1	162.929	-	-	NO	YES	NO	YES
269	66664	1	163.928	-	-	NO	YES	NO	YES

72. Holmium:

270	67165	1	164.930	-	-	NO	YES	NO	YES
271	67665	1	164.930	-	-	NO	YES	NO	YES

9.5. List of nuclides with gamma data provided (HELIOS nuclear data library)

Total number of nuclides with gamma data provided in the HELIOS nuclear data library - 270

```
0NO.   ISOTOPE  AT NUMBER                         TEXT
 ---   -------  ---------  ------------------------------------------------
   1    42595     42.00    Gamma data read from HERMES library
   2    43599     43.00    Gamma data read from HERMES library
   3    46608     46.00    Gamma data read from HERMES library
   4    47107     47.00    Gamma data read from HERMES library
   5    47109     47.00    Gamma data read from HERMES library
   6    49113     49.00    Gamma data read from HERMES library
   7    49115     49.00    Gamma data read from HERMES library
   8    54631     54.00    Gamma data read from HERMES library
   9    55633     55.00    Gamma data read from HERMES library
  10    64155     64.00    Gamma data read from HERMES library
  11    64156     64.00    Gamma data read from HERMES library
  12    64157     64.00    Gamma data read from HERMES library
  13    64158     64.00    Gamma data read from HERMES library
  14    68166     68.00    Gamma data read from HERMES library
  15    68167     68.00    Gamma data read from HERMES library
  16    69169     69.00    Gamma data read from HERMES library
  17    69170     69.00    Gamma data read from HERMES library
  18    72176     72.00    Gamma data read from HERMES library
  19    72177     72.00    Gamma data read from HERMES library
  20    72178     72.00    Gamma data read from HERMES library
  21    72179     72.00    Gamma data read from HERMES library
  22    72180     72.00    Gamma data read from HERMES library
  23    90232     90.00    Gamma data read from HERMES library
  24    92233     92.00    Gamma data read from HERMES library
  25    92235     92.00    Gamma data read from HERMES library
  26    92236     92.00    Gamma data read from HERMES library
  27    92238     92.00    Gamma data read from HERMES library
  28    94239     94.00    Gamma data read from HERMES library
  29    94240     94.00    Gamma data read from HERMES library
  30    94241     94.00    Gamma data read from HERMES library
  31    94242     94.00    Gamma data read from HERMES library
  32     1001      1.00    Gamma data read from HERMES library
  33     1002      1.00    Gamma data read from HERMES library
  34     1006      1.00    Gamma data read from HERMES library
  35     1040      1.00    Gamma data read from HERMES library
  36     3006      3.00    Gamma data read from HERMES library
  37     4009      4.00    Gamma data read from HERMES library
  38     5000      5.00    Gamma data read from HERMES library
  39     5010      5.00    Gamma data read from HERMES library
  40     5011      5.00    Gamma data read from HERMES library
  41     6000      6.00    Gamma data read from HERMES library
  42     6001      6.00    Gamma data read from HERMES library
  43     7014      7.00    Gamma data read from HERMES library
  44     8001      8.00    Gamma data read from HERMES library
  45     8016      8.00    Gamma data read from HERMES library
  46     9019      9.00    Gamma data read from HERMES library
  47    11023     11.00    Gamma data read from HERMES library
  48    12000     12.00    Gamma data read from HERMES library
  49    13027     13.00    Gamma data read from HERMES library
  50    14000     14.00    Gamma data read from HERMES library
  51    15031     15.00    Gamma data read from HERMES library
  52    16000     16.00    Gamma data read from HERMES library
  53    17000     17.00    Gamma data read from HERMES library
  54    19000     19.00    Gamma data read from HERMES library
  55    20000     20.00    Gamma data read from HERMES library
  56    22000     22.00    Gamma data read from HERMES library
  57    23000     23.00    Gamma data read from HERMES library
  58    24000     24.00    Gamma data read from HERMES library
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```
  59    24050     24.00    Gamma data read from HERMES library
  60    24052     24.00    Gamma data read from HERMES library
  61    24053     24.00    Gamma data read from HERMES library
  62    24054     24.00    Gamma data read from HERMES library
  63    25055     25.00    Gamma data read from HERMES library
  64    26001     26.00    Gamma data read from HERMES library
  65    26000     26.00    Gamma data read from HERMES library
  66    26054     26.00    Gamma data read from HERMES library
  67    26056     26.00    Gamma data read from HERMES library
  68    26057     26.00    Gamma data read from HERMES library
  69    26058     26.00    Gamma data read from HERMES library
  70    27059     27.00    Gamma data read from HERMES library
  71    28001     28.00    Gamma data read from HERMES library
  72    28000     28.00    Gamma data read from HERMES library
  73    28058     28.00    Gamma data read from HERMES library
  74    28059     28.00    Gamma data read from HERMES library
  75    28060     28.00    Gamma data read from HERMES library
  76    28061     28.00    Gamma data read from HERMES library
  77    28062     28.00    Gamma data read from HERMES library
  78    28064     28.00    Gamma data read from HERMES library
  79    29063     29.00    Gamma data read from HERMES library
  80    29065     29.00    Gamma data read from HERMES library
  81    40000     40.00    Gamma data read from HERMES library
  82    40001     40.00    Gamma data read from HERMES library
  83    40002     40.00    Gamma data read from HERMES library
  84    40090     40.00    Gamma data read from HERMES library
  85    41093     41.00    Gamma data read from HERMES library
  86    42000     42.00    Gamma data read from HERMES library
  87    44601     44.00    Gamma data read from HERMES library
  88    45103     45.00    Gamma data read from HERMES library
  89    45603     45.00    Gamma data read from HERMES library
  90    45605     45.00    Gamma data read from HERMES library
  91    46605     46.00    Gamma data read from HERMES library
  92    46607     46.00    Gamma data read from HERMES library
  93    47609     47.00    Gamma data read from HERMES library
  94    48000     48.00    Gamma data read from HERMES library
  95    48110     48.00    Gamma data read from HERMES library
  96    48111     48.00    Gamma data read from HERMES library
  97    48112     48.00    Gamma data read from HERMES library
  98    48113     48.00    Gamma data read from HERMES library
  99    48114     48.00    Gamma data read from HERMES library
 100    49615     49.00    Gamma data read from HERMES library
 101    50000     50.00    Gamma data read from HERMES library
 102    50112     50.00    Gamma data read from HERMES library
 103    50114     50.00    Gamma data read from HERMES library
 104    50115     50.00    Gamma data read from HERMES library
 105    50116     50.00    Gamma data read from HERMES library
 106    50117     50.00    Gamma data read from HERMES library
 107    50118     50.00    Gamma data read from HERMES library
 108    50119     50.00    Gamma data read from HERMES library
 109    50120     50.00    Gamma data read from HERMES library
 110    50122     50.00    Gamma data read from HERMES library
 111    50124     50.00    Gamma data read from HERMES library
 112    51000     51.00    Gamma data read from HERMES library
 113    51121     51.00    Gamma data read from HERMES library
 114    51123     51.00    Gamma data read from HERMES library
 115    54128     54.00    Gamma data read from HERMES library
 116    54130     54.00    Gamma data read from HERMES library
 117    54634     54.00    Gamma data read from HERMES library
 118    60643     60.00    Gamma data read from HERMES library
 119    60645     60.00    Gamma data read from HERMES library
 120    61647     61.00    Gamma data read from HERMES library
 121    61748     61.00    Gamma data read from HERMES library
 122    62647     62.00    Gamma data read from HERMES library
```

```
123    62649     62.00    Gamma data read from HERMES library
124    62650     62.00    Gamma data read from HERMES library
125    62651     62.00    Gamma data read from HERMES library
126    62652     62.00    Gamma data read from HERMES library
127    63653     63.00    Gamma data read from HERMES library
128    63654     63.00    Gamma data read from HERMES library
129    63655     63.00    Gamma data read from HERMES library
130    64152     64.00    Gamma data read from HERMES library
131    64154     64.00    Gamma data read from HERMES library
132    64160     64.00    Gamma data read from HERMES library
133    64655     64.00    Gamma data read from HERMES library
134    64656     64.00    Gamma data read from HERMES library
135    64657     64.00    Gamma data read from HERMES library
136    64658     64.00    Gamma data read from HERMES library
137    71176     71.00    Gamma data read from HERMES library
138    68168     68.00    Gamma data read from HERMES library
139    68170     68.00    Gamma data read from HERMES library
140    72174     72.00    Gamma data read from HERMES library
141    73181     73.00    Gamma data read from HERMES library
142    73182     73.00    Gamma data read from HERMES library
143    79197     79.00    Gamma data read from HERMES library
144    82206     82.00    Gamma data read from HERMES library
145    82207     82.00    Gamma data read from HERMES library
146    82208     82.00    Gamma data read from HERMES library
147    90230     90.00    Gamma data read from HERMES library
148    90233     90.00    Gamma data read from HERMES library
149    90234     90.00    Gamma data read from HERMES library
150    91231     91.00    Gamma data read from HERMES library
151    91233     91.00    Gamma data read from HERMES library
152    92232     92.00    Gamma data read from HERMES library
153    92234     92.00    Gamma data read from HERMES library
154    92237     92.00    Gamma data read from HERMES library
155    93237     93.00    Gamma data read from HERMES library
156    93238     93.00    Gamma data read from HERMES library
157    93239     93.00    Gamma data read from HERMES library
158    94236     94.00    Gamma data read from HERMES library
159    94238     94.00    Gamma data read from HERMES library
160    94338     94.00    Gamma data read from HERMES library
161    95241     95.00    Gamma data read from HERMES library
162    95242     95.00    Gamma data read from HERMES library
163    95342     95.00    Gamma data read from HERMES library
164    95243     95.00    Gamma data read from HERMES library
165    96242     96.00    Gamma data read from HERMES library
166    96243     96.00    Gamma data read from HERMES library
167    96244     96.00    Gamma data read from HERMES library
168    96245     96.00    Gamma data read from HERMES library
169    96246     96.00    Gamma data read from HERMES library
170     1003      1.00    Gamma data read from HERMES library
171    35581     35.00    Gamma data read from HERMES library
172    36583     36.00    Gamma data read from HERMES library
173    36585     36.00    Gamma data read from HERMES library
174    38589     38.00    Gamma data read from HERMES library
175    38590     38.00    Gamma data read from HERMES library
176    39589     39.00    Gamma data read from HERMES library
177    39590     39.00    Gamma data read from HERMES library
178    39591     39.00    Gamma data read from HERMES library
179    40591     40.00    Gamma data read from HERMES library
180    40593     40.00    Gamma data read from HERMES library
181    40595     40.00    Gamma data read from HERMES library
182    40596     40.00    Gamma data read from HERMES library
183    41595     41.00    Gamma data read from HERMES library
184    42095     42.00    Gamma data read from HERMES library
185    42596     42.00    Gamma data read from HERMES library
186    42597     42.00    Gamma data read from HERMES library
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187    42598     42.00    Gamma data read from HERMES library
188    42599     42.00    Gamma data read from HERMES library
189    42600     42.00    Gamma data read from HERMES library
190    44600     44.00    Gamma data read from HERMES library
191    44602     44.00    Gamma data read from HERMES library
192    44603     44.00    Gamma data read from HERMES library
193    44604     44.00    Gamma data read from HERMES library
194    44605     44.00    Gamma data read from HERMES library
195    44606     44.00    Gamma data read from HERMES library
196    46604     46.00    Gamma data read from HERMES library
197    46606     46.00    Gamma data read from HERMES library
198    47710     47.00    Gamma data read from HERMES library
199    47611     47.00    Gamma data read from HERMES library
200    48610     48.00    Gamma data read from HERMES library
201    48611     48.00    Gamma data read from HERMES library
202    48613     48.00    Gamma data read from HERMES library
203    50125     50.00    Gamma data read from HERMES library
204    51500     51.00    Gamma data read from HERMES library
205    51625     51.00    Gamma data read from HERMES library
206    51627     51.00    Gamma data read from HERMES library
207    52727     52.00    Gamma data read from HERMES library
208    52729     52.00    Gamma data read from HERMES library
209    52632     52.00    Gamma data read from HERMES library
210    53627     53.00    Gamma data read from HERMES library
211    53629     53.00    Gamma data read from HERMES library
212    53631     53.00    Gamma data read from HERMES library
213    53635     53.00    Gamma data read from HERMES library
214    54632     54.00    Gamma data read from HERMES library
215    54633     54.00    Gamma data read from HERMES library
216    54635     54.00    Gamma data read from HERMES library
217    54636     54.00    Gamma data read from HERMES library
218    55634     55.00    Gamma data read from HERMES library
219    55635     55.00    Gamma data read from HERMES library
220    55636     55.00    Gamma data read from HERMES library
221    55637     55.00    Gamma data read from HERMES library
222    56634     56.00    Gamma data read from HERMES library
223    56637     56.00    Gamma data read from HERMES library
224    56640     56.00    Gamma data read from HERMES library
225    57639     57.00    Gamma data read from HERMES library
226    57640     57.00    Gamma data read from HERMES library
227    58641     58.00    Gamma data read from HERMES library
228    58642     58.00    Gamma data read from HERMES library
229    58643     58.00    Gamma data read from HERMES library
230    58644     58.00    Gamma data read from HERMES library
231    59641     59.00    Gamma data read from HERMES library
232    59643     59.00    Gamma data read from HERMES library
233    60642     60.00    Gamma data read from HERMES library
234    60644     60.00    Gamma data read from HERMES library
235    60646     60.00    Gamma data read from HERMES library
236    60647     60.00    Gamma data read from HERMES library
237    60648     60.00    Gamma data read from HERMES library
238    60650     60.00    Gamma data read from HERMES library
239    61648     61.00    Gamma data read from HERMES library
240    61649     61.00    Gamma data read from HERMES library
241    61651     61.00    Gamma data read from HERMES library
242    62648     62.00    Gamma data read from HERMES library
243    62653     62.00    Gamma data read from HERMES library
244    62654     62.00    Gamma data read from HERMES library
245    63651     63.00    Gamma data read from HERMES library
246    63656     63.00    Gamma data read from HERMES library
247    63657     63.00    Gamma data read from HERMES library
248    64654     64.00    Gamma data read from HERMES library
249    64660     64.00    Gamma data read from HERMES library
250    65159     65.00    Gamma data read from HERMES library
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 251    65160     65.00    Gamma data read from HERMES library
 252    65161     65.00    Gamma data read from HERMES library
 253    65659     65.00    Gamma data read from HERMES library
 254    65660     65.00    Gamma data read from HERMES library
 255    65661     65.00    Gamma data read from HERMES library
 256    66160     66.00    Gamma data read from HERMES library
 257    66161     66.00    Gamma data read from HERMES library
 258    66162     66.00    Gamma data read from HERMES library
 259    66163     66.00    Gamma data read from HERMES library
 260    66164     66.00    Gamma data read from HERMES library
 261    66660     66.00    Gamma data read from HERMES library
 262    66661     66.00    Gamma data read from HERMES library
 263    66662     66.00    Gamma data read from HERMES library
 264    66663     66.00    Gamma data read from HERMES library
 265    66664     66.00    Gamma data read from HERMES library
 266    67165     67.00    Gamma data read from HERMES library
 267    67665     67.00    Gamma data read from HERMES library
 268    69171     69.00    Gamma data read from HERMES library
 269    91232     91.00    Gamma data read from HERMES library
 270    91234     91.00    Gamma data read from HERMES library
```

9.6. Description of the HELIOS Input file for the Unified Saxton Reactor Core Model

Within the framework of the recent study the unified model has been created in order to maintain capability to analyze characteristics of the Saxton Partial Plutonium Core (SPPC) while taking into account all system complexities. A Theoretical model called Unified Saxton Reactor Core Model (USRC) was described above in the main report sections.

Original HELIOS input was organized as set of four input files with the following contents:

- Material compositions
- Assemblies differential information
- Reactor core geometry
- Burnup and output flow

Some sections of the HELIOS input file components are presented below:

Material compositions:

```
+SET management.

&ADD      = SET ( 'USRC01.hrf'/ SAXTON; AURORA; &v305A )

! Material compositions: Fuel compositions:     UOX,  MOXP, MOXV;
!                        Non-fuel compositions: SS304, ZR40, INCONEL, AL, MCR, H2O !
! ================================================================================ !

'UOX1'    = MAT ( 10.1800/ 92235, 5.059582;
                           92238, 83.08645;
                           8001,  11.85397)                        !Fuel material !

'MOXP'    = MAT ( 10.3334/ 94239, 5.2649796;
                           94240, 0.4986283;
                           94241, 0.0517829;
                           94242, 2.32732E-03;
                           92235, 0.5895384;
                           92238, 81.7482208;
                           8001,  11.8439409)                     !Fuel material !

'MOXV'    = MAT ( 9.5639/  94239, 5.2649796;
                           94240, 0.4986283;
```

```
                          94241, 0.0517829;
                          94242, 2.32732E-03;
                          92235, 0.5895384;
                          92238, 81.7482208;
                          8001,  11.8439409)                    !Fuel material !


'SS304'   = MAT ( 7.9400/  26054, 3.89670;
                          26056, 62.8161;
                          26057, 1.46390;
                          26058, 0.19830;
                          24050, 0.79310;
                          24052, 15.9030;
                          24053, 1.83790;
                          24054, 0.46610;
                          28058, 6.40250;
                          28060, 2.53200;
                          28061, 0.11140;
                          28062, 0.35990;
                          28064, 0.09410;
                          25055, 2.00000;
                          14000, 1.00000;
                          6000,  0.08000;
                          15031, 0.04570  )                    ! Clad, grid material !
```

```
'ZR40'    = MAT ( 6.5800/  40000, 98.2000;
                           50112, 0.01370;
                           50114, 0.00940;
                           50115, 0.00520;
                           50116, 0.21280;
                           50117, 0.11340;
                           50118, 0.36080;
                           50119, 0.12890;
                           50120, 0.49380;
                           50122, 0.07130;
                           50124, 0.09060;
                           26054, 0.01140;
                           26056, 0.18370;
                           26057, 0.00430;
                           26058, 0.00060;
                           24050, 0.00420;
                           24052, 0.08370;
                           24053, 0.00970;
                           24054, 0.000001 )                     ! Clad material !

'INCONEL' = MAT ( 8.3000/  26054, 0.40000;
                           26056, 6.43000;
                           26057, 0.15000;
                           26058, 0.02000;
                           24050, 0.63000;
                           24052, 12.5600;
                           24053, 1.45000;
                           24054, 0.37000;
                           28058, 49.2000;
                           28060, 19.4600;
                           28061, 0.86000;
                           28062, 2.77000;
                           28064, 0.72000;
                           14000, 2.50000;
                           22000, 2.50000 )                      ! Grid material !

'AL'      = MAT ( 2.7020/  13027, 100.000 )                      ! Grid material !

'MCR'     = MAT ( 9.9271/  47107, 41.1000;
                           47109, 38.9000;
                           49113, 0.63400;
                           49115, 14.4000;
                           48000, 5.00000 )                      ! Control rod   !

'B'       = MAT (  1.8  /  5000,  100.000 )                      ! B             !

'H2O'     = MAT ( 0.7656/  1001,  66.6700;
                           8016,  33.3300 )                      ! Coolant       !

&ADD      = SET ( 'USRC01.hrf'/ SAXTON; AURORA; &v305A )
&MAT      = SET ( 'USRC01.hrf'/ SAXTON; AURORA )

!
! Model
!
```

Geometry

```
$p       = PAR ( "1.4732" )
$rfuel   = PAR("$FuelDiameter/2")
$rhole   = PAR("$HoleDiameter/2")
$rclad   = PAR("$CladDiameter/2")
$rtube   = PAR("$TubeDiameter/2")

$rw      = PAR("$rtube-$TubeThickness")
```

```
Fpin     = CCS($rhole,"$rhole+0.9*$thfu", $rfu,$rclad // hole,fuel,fuel,clad)
Bpin     = CCS($rhole,"$rhole+0.3*$thfu","$rhole+0.5*$thfu","$rhole+0.7*$thfu",
                      "$rhole+0.9*$thfu", $rfu,$rclad
                                        // hole,fuel,fuel,fuel,fuel,fuel,clad)

Gpin     = CCS("0.4*$rw","0.7*$rw",$rw,$rtube /6(2,4)/
                                           tube,tube,tube,tube,tube,tube,tube,
                                                tube,tube,tube,tube,tube,tube,
                                                clad,clad,clad,clad,clad,clad)

pin1      = CCS ( 0.44, $rp1 // fuel,  clad )
pin2      = CCS ( 0.50, $rp2 // fuel,  clad )
pin3      = CCS ( 0.55, $rp3 // water, clad )
pin4      = CCS ( .20, .30, .35, .40, .45, .50, $rp4 //
                  fuel,fuel,fuel,fuel,fuel,fuel, clad )

'1.8'     = STR ( $cell1 )
'2.0'     = STR ( $cell1 )
'2.4'     = STR ( $cell2 )
'2.6'     = STR ( $cell2 )
'3.0'     = STR ( $cell2 )
WP        = STR ( $cell3 )
BA        = STR ( $cell4 )

FPin     = CCS($rhole,$rfu,$rclad // hole,fuel,clad)
BPin     = CCS($rhole,"$rhole+0.3*$thfu","$rhole+0.6*$thfu","$rhole+0.8*$thfu",
                                  $rfu,$rclad // hole,fuel,fuel,fuel,fuel,clad)
GPin     = CCS("0.4*$rw","0.7*$rw",$rw,$rtube //tube,tube,tube,clad)

$D       = PAR("$rtube*3**0.5/2")
$E       = PAR("$rtube/2")
$F       = PAR("$rtube")

$c1       = PAR ( "$delw"           )          !Centre piece: 1st mesh line!
$c2       = PAR ( "2*$delw"         )          !Centre piece: 2nd mesh line!
$c3       = PAR ( "3*$delw"         )          !Centre piece: 3rd mesh line!
$c4       = PAR ( "3*$delw+$w1"     )          !Centre piece: 4th mesh line!

wg        = STR ( (0,0)     (0,$w4)     ($p,$w4)     ($p,0)            !  1- 4 !
                            ("$p/2",0)                                 !  5    !
                  (0,$film) ("$p/2",$film) ($p,$film)                  !  6- 8 !
                  (0,$w1)   ("$p/2",$w1)   ($p,$w1)                    !  9-11 !
                  (0,$w2)   ("$p/2",$w2)   ($p,$w2)                    ! 12-14 !
                  (0,$w3)   ("$p/2",$w3)   ($p,$w3)                    ! 15-17 !
                            ("$p/2",$w4)                               ! 18    !
                  / 4,gap / /        1, 6, 7, 5,film;  5, 7, 8, 4,film;
                   6, 9,10, 7,box;   7,10,11, 8,box;   9,12,13,10,gap;
                  10,13,14,11,gap;  12,15,16,13,gap;  13,16,17,14,gap;
                  15, 2,18,16,gap )

$Fcorn   = PAR((0,"-$c") ($x2,$y2) ($x3,$h3) ($a,$h3) ($a,"-$b")       !  1-5  !
               ("-$a","-$b")  ($x7,$y7)  (0,$h1) ($a,$b)               !  6-9  !
               ( $x10, $y10) ($x11,$h1) ($a,$h1)                       ! 10-12 !
               ( $x13, $y13) ($x14,$h2) ($a,$h2)                       ! 13-15 !
               ( 0,"-$f")("-$d","-$e")("-$d",  $e )                    ! 16-18 !
               ( 0,  $f )(  $d ,  $e )(  $d ,"-$e")                    ! 19-20 !
               / 5,cool / Fpin(0,0)/   1,6,17,16,cool; 6,7,18,17,cool; !  1-3  !
                       7,8,19,18,cool; 8,9,20,19,cool; 9,5,21,20,cool; !  4-6  !
                       5,1,16,21,cool;   6,10, 7,cool;   8,12, 9,cool; !  7-9  !
                       10,13,14,11,shroud;         11,14,15,12,shroud; ! 10-11 !
                       13, 2, 3,14,gap;            14, 3, 4,15,gap   ) ! 12-13 !

$Bcorn   = PAR((0,"-$c") ($x2,$y2) ($x3,$h3) ($a,$h3) ($a,"-$b")       !  1-5  !
```

```
               ("-$a","-$b")  ($x7,$y7)  (0,$h1) ($a,$b)               !  6-9  !
               ( $x10, $y10) ($x11,$h1) ($a,$h1)                       ! 10-12 !
               ( $x13, $y13) ($x14,$h2) ($a,$h2)                       ! 13-15 !
               ( 0,"-$f")("-$d","-$e")("-$d",  $e )                    ! 16-18 !
               ( 0,  $f )(  $d ,  $e )(  $d ,"-$e")                    ! 19-20 !
               / 5,cool / Bpin(0,0) / 1,6,17,16,cool; 6,7,18,17,cool;  !  1-3  !
                      7,8,19,18,cool; 8,9,20,19,cool; 9,5,21,20,cool;  !  4-6  !
                      5,1,16,21,cool;   6,10, 7,cool;   8,12, 9,cool;  !  7-9  !
                      10,13,14,11,shroud;         11,14,15,12,shroud;  ! 10-11 !
                      13, 2, 3,14,gap;            14, 3, 4,15,gap   )  ! 12-13 !
wgx       = STR ( (0,0)     (0,$w2)     ($p,$w2)     ($p,0)            !   1- 4!
                            ("$p/2",0)                                 !   5   !
                  (0,$film) ("$p/2",$film) ($p,$film)                  !   6- 8!
                  (0,$w1)   ("$p/2",$w1)   ($p,$w1)                    !   9-11!
                            ("$p/2",$w2)                               !  12   !
                  / 4,gap / /        1, 6, 7, 5,film;  5, 7, 8, 4,film;
                   6, 9,10, 7,box;   7,10,11, 8,box;   9, 2,12,10,gap )

ng        = STR ( (0,0)     (0,$n3)     ($p,$n3)     ($p,0)            !   1 - 4!
                            ("$p/2",0)                                 !   5    !
                  (0,$film) ("$p/2",$film) ($p,$film)                  !   6 – 8!
                  (0,$n1)   ("$p/2",$n1)   ($p,$n1)                    !  9 - 11!
                  (0,$n2)   ("$p/2",$n2)   ($p,$n2)                    !   12-14!
                            ("$p/2",$n3)                          !node    15   !
                  / 4,gap / /        1, 6, 7, 5,film;  5, 7, 8, 4,film;
                   6, 9,10, 7,box;   7,10,11, 8,box;   9,12,13,10,gap;
                  10,13,14,11,gap;  12, 2,15,13,gap )

ww        = STR ( (0,0)     (0,$w2)   ($w2,$w2) ($w2,0)                !   1- 4!
                  ($film,0) ($w1,0)   (0,$film) ($film,$film)          !   5- 8!
                  (0,$w1)   ($w1,$w1) ($w2,$w1) ($w1,$w2)              !   9-12!
                  / 4,gap / /        1, 9,10, 6,box;   1, 7, 8, 5,film;
                   6,10,11, 4,gap;   9, 2,12,10,gap )

$Fcell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               ("-$d","-$e")("-$d",  $e )(0,  $f )                     !  7-9  !
               (  $d ,  $e )(  $d ,"-$e")(0,"-$f")                     ! 10-12 !
               / 6,cool / Fpin(0,0) / 1,2, 8, 7,cool; 2,3, 9, 8,cool;  !  1-3  !
                       3,4,10,9,cool; 4,5,11,10,cool; 5,6,12,11,cool)  !  4-6  !

$Bcell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               ("-$d","-$e")("-$d",  $e )(0,  $f )                     !  7-9  !
               (  $d ,  $e )(  $d ,"-$e")(0,"-$f")                     ! 10-12 !
               / 6,cool / Bpin(0,0) / 1,2, 8, 7,cool; 2,3, 9, 8,cool;  !  1-3  !
                       3,4,10,9,cool; 4,5,11,10,cool; 5,6,12,11,cool)  !  4-6  !

$Gcell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               ("-$D","-$E")("-$D",  $E )(0,  $F )                     !  7-9  !
               (  $D ,  $E )(  $D ,"-$E")(0,"-$F")                     ! 10-12 !
               / 6,cool / Gpin(0,0) / 1,2, 8, 7,cool; 2,3, 9, 8,cool;  !  1-3  !
                       3,4,10,9,cool; 4,5,11,10,cool; 5,6,12,11,cool)  !  4-6  !

$FCorn   = PAR((0,"-$c") ($x2,$y2) ($x3,$h3) ($a,$h3) ($a,"-$b")       !  1-5  !
               ("-$a","-$b")  ($x7,$y7)  (0,$h1) ($a,$b)               !  6-9  !
               ( $x10, $y10) ($x11,$h1) ($a,$h1)                       ! 10-12 !
               ( $x13, $y13) ($x14,$h2) ($a,$h2)                       ! 13-15 !
               / 5,cool / FPin(0,0) / 13,14,15,12,11,10,shroud;        !  1-2  !
                                       2, 3, 4,15,14,13,gap;           !  3-3  !
                         6,10,7,cool; 7,11,8,cool; 8,12,9,cool)        !  4-6  !

$BCorn   = PAR((0,"-$c") ($x2,$y2) ($x3,$h3) ($a,$h3) ($a,"-$b")       !  1-5  !
```

```
               ("-$a","-$b")  ($x7,$y7)  (0,$h1) ($a,$b)               !  6-9  !
               ( $x10, $y10) ($x11,$h1) ($a,$h1)                       ! 10-12 !
               ( $x13, $y13) ($x14,$h2) ($a,$h2)                       ! 13-15 !
               / 5,cool / BPin(0,0) / 13,14,15,12,11,10,shroud;        !  1-2  !
                                       2, 3, 4,15,14,13,gap;           !  3-3  !
                         6,10,7,cool; 7,11,8,cool; 8,12,9,cool)        !  4-6  !

$FCell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               / 6,cool / FPin(0,0) /            )

$BCell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               / 6,cool / BPin(0,0) /            )

$GCell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               / 6,cool / GPin(0,0) /            )

wn        = STR ( (0,0)   (0,$w4)   ($n3,$w4) ($n3,0)                  !  1- 4!
                  ($film,0) ($n1,0) ($n2,0)                            !  5- 7!
                  (0,$film) ($film,$film)                              !  8- 9!
                  (0,$w1) ($n1,$w1) ($n2,$w1) ($n3,$w1)                ! 10-13!
                  (0,$w2) ($n1,$w2) ($n2,$w2) ($n3,$w2)                ! 14-17!
                  (0,$w3) ($n1,$w3) ($n2,$w3) ($n3,$w3)                ! 18-21!
                          ($n1,$w4) ($n2,$w4)                          ! 22-23!
                  / 4,gap / /        1,10,11, 6,box;   1, 8, 9, 5,film;
                   6,11,12, 7,gap;   7,12,13, 4,gap;  10,14,15,11,gap;
                  11,15,16,12,gap;  12,16,17,13,gap;  14,18,19,15,gap;
                  15,19,20,16,gap;  16,20,21,17,gap;  18, 2,22,19,gap;
                  19,22,23,20,gap )

nw        = STR ( (0,0)   (0,$n3)   ($w4,$n3) ($w4,0)                  !  1- 4!
                  ($film,0) ($w1,0) ($w2,0)   ($w3,0)                  !  5- 8!
                  (0,$film) ($film,$film)                              !  9-10!
                  (0,$n1) ($w1,$n1) ($w2,$n1) ($w3,$n1) ($w4,$n1)      ! 11-15!
                  (0,$n2) ($w1,$n2) ($w2,$n2) ($w3,$n2) ($w4,$n2)      ! 16-20!
                          ($w1,$n3) ($w2,$n3) ($w3,$n3)                ! 21-23!
                  / 4,gap / /        1,11,12, 6,box;   1, 9,10, 5,film;
                   6,12,13, 7,gap;   7,13,14, 8,gap;   8,14,15, 4,gap;
                  11,16,17,12,gap;  12,17,18,13,gap;  13,18,19,14,gap;
                  14,19,20,15,gap;  16, 2,21,17,gap;  17,21,22,18,gap;
                  18,22,23,19,gap )

nn        = STR ( (0,0)   (0,$n3)   ($n3,$n3) ($n3,0)                 !  1- 4!
                  ($film,0) ($n1,0) ($n2,0)                           !  5- 7!
                  (0,$film) ($film,$film)                             !  8- 9!
                  (0,$n1) ($n1,$n1) ($n2,$n1) ($n3,$n1)               ! 10-13!
                  (0,$n2) ($n1,$n2)           ($n3,$n2)               ! 14-16!
                          ($n1,$n3) ($n2,$n3)                         ! 17-18!
                  / 4,gap / dpin ($n3,$n3) 2 /         1,10,11, 6,box;
                   1, 8, 9, 5,film;  6,11,12, 7,gap;   7,12,13, 4,gap;
                  10,14,15,11,gap;  14, 2,17,15,gap )

$BCorn   = PAR((0,"-$c") ($x2,$y2) ($x3,$h3) ($a,$h3) ($a,"-$b")       !  1-5  !
               ("-$a","-$b")  ($x7,$y7)  (0,$h1) ($a,$b)               !  6-9  !
               ( $x10, $y10) ($x11,$h1) ($a,$h1)                       ! 10-12 !
               ( $x13, $y13) ($x14,$h2) ($a,$h2)                       ! 13-15 !
               / 5,cool / BPin(0,0) / 13,14,15,12,11,10,shroud;        !  1-2  !
                                       2, 3, 4,15,14,13,gap;           !  3-3  !
                         6,10,7,cool; 7,11,8,cool; 8,12,9,cool)        !  4-6  !
$FCell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               / 6,cool / FPin(0,0) /            )
```

```
$BCell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               / 6,cool / BPin(0,0) /            )

$GCell   = PAR(("-$a","-$b")("-$a",  $b )(0,  $c )                     !  1-3  !
               (  $a ,  $b )(  $a ,"-$b")(0,"-$c")                     !  4-6  !
               / 6,cool / GPin(0,0) /            )

dpin      = CCS ( $rdi, $rdo / / deti, deto)

cw        = STR ( (0,0)     (0,$d2)   ($aa,$d2) ($aa,0)                !  1- 4!
                  (0,$d1)   ($aa,$d1)                                  !  5- 6!
                  ($ac,$d1) / 4,blade / apin ($ac,$d2) 1 /
                  1,5,6,4,blade )
apin      = CCS ( $rab / / abs)

wing      = CNX ( cw,cw,cw,cw     / (1,3,4)0(2,2,1) /
                  (2,3,4)0(3,2,1) / (3,3,4)0(4,2,1) )         !because k=0!

cc        = STR ( (0,0)     (0,$clong)   ($c2,$clong)             !nodes  1- 3!
                  ($c2,$c2) ($clong,$c2) ($clong,0)               !nodes  4- 6!
                  ($c1,0)   ($c2,0)      ($c3,0)   ($c4,0)        !nodes  7-10!
                  (0,$c1)   ($c1,$c1)    ($c2,$c1) ($c3,$c1)      !nodes 11-14!
                  ($c4,$c1) ($clong,$c1)                          !nodes 15-16!
                  (0,$c2)   ($c1,$c2)    ($c3,$c2) ($c4,$c2)      !nodes 18-20!
                  (0,$c3)   ($c1,$c3)    ($c2,$c3)                !nodes 21-23!
                  (0,$c4)   ($c1,$c4)    ($c2,$c4) ($c1,$clong)   !nodes 24-27!
                  / 6,blade / /       1,11,12, 7,blade;  7,12,13, 8,blade;
                   8,13,14, 9,blade;  9,14,15,10,blade; 10,15,16, 6,blade;
                  11,17,18,12,blade; 12,18, 4,13,blade; 13, 4,19,14,blade;
                  14,19,20,15,blade; 15,20, 5,16,blade; 17,21,22,18,blade;
                  18,22,23, 4,blade; 21,24,25,22,blade; 22,25,26,23,blade;
                  24, 2,27,25,blade )                  !Last is default, blade!

$peri     = PAR ( (0,0)      (0,$p)      ($p,$p)     ($p,0)
                  (0,"$p/2") ("$p/2",$p) ($p,"$p/2") ("$p/2",0) )

$cregs    = PAR ( 1,5,9,12,8,cool; 5,2,6,10,9,cool; 6,3,7,11,10,cool )

$cell1    = PAR ( $peri ("$p/2-$rp1","$p/2") ("$p/2","$p/2+$rp1")
                        ("$p/2+$rp1","$p/2") ("$p/2","$p/2-$rp1")
                        / 4,cool / pin1 ("$p/2","$p/2") / $cregs )

$Fside   = PAR(("-$a","-$b")("-$a",$h3)(  $a, $h3)($a,"-$b")(0,"-$c")  !  1-5  !
               ("-$a",  $b )(   0 ,$h1)(  $a, $b )                     !  6-8  !
               ("-$a",  $h1)(  $a ,$h1)("-$a",$h2)($a, $h2)            !  9-12 !
               ("-$d","-$e")("-$d",  $e )( 0 , $f )                    ! 13-15 !
               (  $d ,  $e )(  $d ,"-$e")( 0,"-$f")                    ! 16-18 !
               / 5,shroud/ Fpin(0,0) / 1,6,14,13,cool; 6,7,15,14,cool; !  1-3  !
                       7,8,16,15,cool; 8,4,17,16,cool; 4,5,18,17,cool; !  4-6  !
                       5,1,13,18,cool;   6, 9, 7,cool;   7,10, 8,cool; !  7-9  !
                                                       11,2,3,12,gap ) ! 10-10 !

$Bside   = PAR(("-$a","-$b")("-$a",$h3)(  $a, $h3)($a,"-$b")(0,"-$c")  !  1-5  !
               ("-$a",  $b )(   0 ,$h1)(  $a, $b )                     !  6-8  !
               ("-$a",  $h1)(  $a ,$h1)("-$a",$h2)($a, $h2)            !  9-12 !
               ("-$d","-$e")("-$d",  $e )( 0 , $f )                    ! 13-15 !
               (  $d ,  $e )(  $d ,"-$e")( 0,"-$f")                    ! 16-18 !
               / 5,shroud/ Bpin(0,0) / 1,6,14,13,cool; 6,7,15,14,cool; !  1-3  !
                       7,8,16,15,cool; 8,4,17,16,cool; 4,5,18,17,cool; !  4-6  !
                       5,1,13,18,cool;   6, 9, 7,cool;   7,10, 8,cool; !  7-9  !
                                                       11,2,3,12,gap ) ! 10-10 !
```

```
$FSide   = PAR(("-$a","-$b")("-$a",$h3)(  $a, $h3)($a,"-$b")(0,"-$c")  !  1-5  !
               ("-$a",  $b )(   0 ,$h1)(  $a, $b )                      !  6-8  !
               ("-$a",  $h1)(  $a ,$h1)("-$a",$h2)($a, $h2)            !  9-12 !
               / 5,cool / FPin(0,0) /   6, 9, 7,cool;   7,10, 8,cool;  !  1-3  !
                                   9,11,12,10,shroud; 11,2,3,12,gap )  !  4-5  !

$BSide   = PAR(("-$a","-$b")("-$a",$h3)(  $a, $h3)($a,"-$b")(0,"-$c")  !  1-5  !
               ("-$a",  $b )(   0 ,$h1)(  $a, $b )                      !  6-8  !
               ("-$a",  $h1)(  $a ,$h1)("-$a",$h2)($a, $h2)            !  9-12 !
               / 5,cool / BPin(0,0) /   6, 9, 7,cool;   7,10, 8,cool;  !  1-3  !
                                   9,11,12,10,shroud; 11,2,3,12,gap )  !  4-5  !
$cell2    = PAR ($peri ("$p/2-$rp2","$p/2") ("$p/2","$p/2+$rp2")
                        ("$p/2+$rp2","$p/2") ("$p/2","$p/2-$rp2")
                        / 4,cool / pin2 ("$p/2","$p/2") / $cregs )

$cell3    = PAR ( $peri ("$p/2-$rp3","$p/2") ("$p/2","$p/2+$rp3")
                        ("$p/2+$rp3","$p/2") ("$p/2","$p/2-$rp3")
                        / 4,cool / pin3 ("$p/2","$p/2") / $cregs )

$cell4    = PAR ( $peri ("$p/2-$rp4","$p/2") ("$p/2","$p/2+$rp4")
                        ("$p/2+$rp4","$p/2") ("$p/2","$p/2-$rp4")
                        / 4,cool / pin4 ("$p/2","$p/2") / $cregs )

$row      = PAR ( !Coupling of 6 structures, the first and last are the
                   wide and narrow gap sides, the others are pin cells.
                   Rotate the wide side by -pi/2, the narrow by pi/2!
                  (1,4,1)$k(2,2,1) / (2,3,4)$k(3,2,1) / (3,3,4)$k(4,2,1) /
                  (4,3,4)$k(5,2,1) / (5,3,4)$k(6,1,4) )
```

```
$x2      = PAR("-($b+$h3)*3**0.5/2")
$x10     = PAR("-($b+$h1)*3**0.5/2")
$x13     = PAR("-($b+$h2)*3**0.5/2")
$y2      = PAR(" ($b+$h3)/2-$c")
$y10     = PAR(" ($b+$h1)/2-$c")
$y13     = PAR(" ($b+$h2)/2-$c")

$x7      = PAR("-$h1*3**0.5/2")
$y7      = PAR(" $h1/2")

$x3      = PAR("3*$p- $AssemblyPitch/(2*3**0.5)")
$x11     = PAR("3*$p-($ShroudOuterDimension-2*$ShroudThickness)/(2*3**0.5)")
$x14     = PAR("3*$p- $ShroudOuterDimension/(2*3**0.5)")
top       = CNX ( ww, wgx,wgx,wgx,wg, wn                 !Rotate 'ww' by -pi/2!
                  / (1,4,1)2(2,2,1) / (2,3,4)0(3,2,1) / (3,3,4)0(4,2,1)
                  / (4,3,4)2(5,12,1)/ (5,3,4)2(6,2,1) )

bot       = CNX ( nw, ng,ng,ng,ng, nn  !rotate 'nw' & 'ng' by pi; 'nn' by pi/2!
                  / (1,1,2)2(2,4,3) / (2,1,2)0(3,4,3) / (3,1,2)0(4,4,3)
                  / (4,1,2)0(5,4,3) / (5,1,2)2(6,1,4) )

row1      = CNX ( wgx, $prow1, ng / $row )
row2      = CNX ( wgx, $prow2, ng / $row )
row3      = CNX ( wgx, $prow3, ng / $row )
row4      = CNX ( wg,  $prow4, ng / $row )

system    = CNX ( top, row1,row2,row3,row4, bot, cc,wing,wing
               / (1-1,2)(1-6,4)$k(2-1,3)(2-6,2) / (2-1,2)(2-6,3)$k(3-1,3)(3-6,2)
               / (3-1,2)(3-6,3)$k(4-1,3)(4-6,2) /(4-1,2)(4-6,3)$k(5-1,14)(5-6,2)
               / (5-1,2)(5-6,3)$k(6-1,4)(6-6,2) /      (1-1,2,4)$k(7,20,26)
               /        (7,2,3)$k(8-1,2,1)      /        (7,5,6)$k(9-4,4,3) )

system    = NEWK( !Adjust corner-gap coupling to k=2!
                  2 / (1-1,1,2) (1-6,4,1) (6-1,4,1) (6-6,1,2) /
                  !Adjust inter-gap coupling to k=0 (wgx with wg gets k=2)!
                  0 / (2-1,1,2) (3-1,1,2)           !Left side! /
                  2 /                     (4-1,1,2) !Left side! /
                  0 / (2-6,3,4) (3-6,3,4) (4-6,3,4) !Right side! )

system    = BDRY( !Diagonal albedo all around!
                  (7,1,1) $k (White) )        !From "cc" corner to "cc" corner!

tov1      = OVLT( $tcool/*-*-**/ $tfuel/*-*-*-fuel )
tos1      = OVST( tov1 )

v40u      = STAT( mos1, dos40, tos1, $pw )
v40c      = STAT( mos2, dos40, tos1, $pw )
v70u      = STAT( mos1, dos70, tos1, $pw )
```

Reactor core geometry

```
$Saxton = PAR( $Layout /
           ( 61,6,1)$k( 73,4,3) / ( 60,6,1)$k( 72,4,3) / ( 59,6,1)$k( 71,5,4) /
           ( 53,4,6)$k( 34,1,6) / ( 96,2,4)$k( 15,1,6) / ( 68,4,6)$k( 16,1,6) /
           ( 74,2,4)$k( 17,1,6) / ( 47,4,6)$k( 18,1,6) / ( 29,2,4)$k( 19,1,6) /
           ( 64,1,2)$k( 63,5,4) / ( 63,1,2)$k( 62,5,4) / ( 62,1,2)$k( 61,5,4) /
           ( 61,1,2)$k( 60,5,4) / ( 60,1,2)$k( 59,5,4) / ( 59,1,2)$k( 58,1,5) /
           ( 10,6,1)$k( 50,1,7) / ( 10,1,2)$k( 65,3,7) / ( 14,2,3)$k( 73,1,7) /
           ( 64,4,5)$k( 65,2,1) / ( 65,4,5)$k( 66,2,1) / ( 66,4,5)$k( 67,2,1) /
           ( 67,4,5)$k( 68,2,1) / ( 68,4,5)$k( 69,2,1) / ( 69,4,5)$k( 70,1,5) /
           ( 64,2,3)$k( 51,6,5) / ( 63,2,3)$k( 50,6,5) / ( 62,2,3)$k( 49,6,5) /
           ( 61,2,3)$k( 48,6,5) / ( 60,2,3)$k( 47,6,5) / ( 59,2,3)$k( 46,1,5) /
           ( 64,3,4)$k( 52,1,6) / ( 65,3,4)$k( 53,1,6) / ( 66,3,4)$k( 54,1,6) /
           ( 67,3,4)$k( 55,1,6) / ( 68,3,4)$k( 56,1,6) / ( 69,3,4)$k( 57,5,4) /
```

```
           ( 64,6,1)$k( 76,4,3) / ( 63,6,1)$k( 75,4,3) / ( 62,6,1)$k( 74,4,3) /
           ( 10,6,1)$k( 50,1,7) / ( 10,1,2)$k( 65,3,7) / ( 14,2,3)$k( 73,1,7) /
           ( 61,6,1)$k( 73,4,3) / ( 60,6,1)$k( 72,4,3) / ( 59,6,1)$k( 71,5,4) /
           ( 64,5,6)$k( 77,3,2) / ( 65,5,6)$k( 78,3,2) / ( 66,5,6)$k( 79,3,2) /
           ( 67,5,6)$k( 80,3,2) / ( 68,5,6)$k( 81,3,2) / ( 69,5,6)$k( 82,1,5) /
           ( 51,3,4)$k( 40,1,6) / ( 51,2,3)$k( 39,6,5) / ( 50,2,3)$k( 38,6,5) /
           ( 49,2,3)$k( 37,6,5) / ( 48,2,3)$k( 36,6,5) / ( 47,2,3)$k( 35,1,5) /
           ( 52,3,4)$k( 41,1,6) / ( 53,3,4)$k( 42,1,6) / ( 54,3,4)$k( 43,1,6) /
           ( 10,6,1)$k( 50,1,7) / ( 10,1,2)$k( 65,3,7) / ( 14,2,3)$k( 73,1,7) /
           ( 23,4,6)$k( 81,1,6) / ( 45,2,4)$k( 19,1,6) / ( 34,4,6)$k( 10,1,6) /
           ( 45,2,4)$k( 23,1,6) / ( 84,4,6)$k( 12,1,6) / ( 55,2,4)$k( 13,1,6) /
           ( 61,6,1)$k( 73,4,3) / ( 60,6,1)$k( 72,4,3) / ( 59,6,1)$k( 71,5,4) /
           ( 53,4,6)$k( 34,1,6) / ( 96,2,4)$k( 15,1,6) / ( 68,4,6)$k( 16,1,6) /
           ( 74,2,4)$k( 17,1,6) / ( 47,4,6)$k( 18,1,6) / ( 29,2,4)$k( 19,1,6) /
           ( 88,3,5)$k( 21,1,7) / ( 32,2,4)$k( 22,1,7) / ( 10,3,5)$k( 24,1,7) /
           ( 11,2,4)$k( 25,1,7) / ( 13,3,5)$k( 27,1,7) / ( 34,2,4)$k( 28,1,7) /
           ( 14,3,5)$k( 30,1,7) / ( 58,2,4)$k( 31,1,7) / ( 65,3,5)$k( 33,1,7) /
           ( 17,2,4)$k( 34,1,7) / ( 34,3,5)$k( 36,1,7) / ( 19,2,4)$k( 37,1,7) /
           ( 21,1,2)$k( 20,7,6) / ( 67,1,2)$k( 23,7,6) / ( 27,1,2)$k( 26,7,6) /
           ( 30,1,2)$k( 29,7,6) / ( 10,1,2)$k( 32,7,6) / ( 36,1,2)$k( 35,7,6) /
           ( 20,2,6)$K( 38,1,1) / ( 20,2,6)$K( 39,1,1) / ( 26,2,6)$K( 40,1,3) /
           (29,2,6)$K(41,17,13) / ( 32,2,6)$K( 42,1,3) / ( 35,2,6)$K( 43,7,3))/
           ( 76,5,6)$k( 88,3,2) / ( 76,6,1)$k( 87,4,3) / ( 75,6,1)$k( 86,4,3) /
           ( 74,6,1)$k( 85,4,3) / ( 73,6,1)$k( 84,4,3) / ( 72,6,1)$k( 83,5,4) /
           ( 77,5,6)$k( 89,3,2) / ( 78,5,6)$k( 90,3,2) / ( 79,5,6)$k( 91,3,2) /
           ( 40,2,3)$k( 29,6,5) / ( 39,2,3)$k( 28,6,5) / ( 38,2,3)$k( 27,6,5) /
           ( 40,3,4)$k( 30,1,6) / ( 41,3,4)$k( 31,1,6) / ( 42,3,4)$k( 32,1,6) /
           ( 88,6,1)$k( 98,4,3) / ( 87,6,1)$k( 97,4,3) / ( 86,6,1)$k( 96,4,3) /
           ( 88,5,6)$k( 99,3,2) / ( 89,5,6)$k(100,3,2) / ( 90,5,6)$k(101,3,2) /
           ( 29,3,4)$k( 20,1,6) / ( 29,2,3)$k( 19,6,5) / ( 28,2,3)$k( 18,6,5) /
           ( 30,3,4)$k( 21,1,6) / ( 31,3,4)$k( 22,1,6) / ( 32,3,4)$k( 23,1,6) /
           ( 98,5,6)$k(108,3,2) / ( 98,6,1)$k(107,4,3) / ( 97,6,1)$k(106,4,3) /
           ( 99,5,6)$k(109,3,2) / (100,5,6)$k(110,3,2) / (101,5,6)$k(111,3,2) /
           ( 20,2,3)$k( 11,6,5) / ( 19,2,3)$k( 10,6,5) / ( 18,2,3)$k(  9,6,5) /
           ( 20,3,4)$k( 12,1,6) / ( 21,3,4)$k( 13,1,6) / ( 22,3,4)$k( 14,1,6) /
           (108,6,1)$k(116,4,3) / (107,6,1)$k(115,4,3) / (106,6,1)$k(114,4,3) /
           (108,5,6)$k(117,3,2) / (109,5,6)$k(118,3,2) / (110,5,6)$k(119,3,2) /
           ( 11,3,4)$k(  4,1,5) / ( 11,2,3)$k(  3,5,4) / ( 10,2,3)$k(  2,5,4) /
           ( 12,3,4)$k(  5,1,5) / ( 13,3,4)$k(  6,1,5) / ( 14,3,4)$k(  7,1,5) /
           (116,5,6)$k(124,5,4) / (116,6,1)$k(123,1,5) / (115,6,1)$k(122,1,5) /
           ( 64,5,6)$k( 77,3,2) / ( 65,5,6)$k( 78,3,2) / ( 66,5,6)$k( 79,3,2) /
           ( 67,5,6)$k( 80,3,2) / ( 68,5,6)$k( 81,3,2) / ( 69,5,6)$k( 82,1,5) /
           ( 51,3,4)$k( 40,1,6) / ( 51,2,3)$k( 39,6,5) / ( 50,2,3)$k( 38,6,5) /
           ( 49,2,3)$k( 37,6,5) / ( 48,2,3)$k( 36,6,5) / ( 47,2,3)$k( 35,1,5) /
           (117,5,6)$k(125,5,4) / (118,5,6)$k(126,5,4) / (119,5,6)$k(127,1,5) )
           (108,6,1)$k(116,4,3) / (107,6,1)$k(115,4,3) / (106,6,1)$k(114,4,3) /
           (108,5,6)$k(117,3,2) / (109,5,6)$k(118,3,2) / (110,5,6)$k(119,3,2) /
```

Burnup and output flow

```
&ADD      = SET ( 'USRC01.hrf'/ SAXTON; ZENITH; &v305A )

C1       = IMP(HELIOS;$Hcase/ $Hfile)
Burnup   = SEL(uburn / status/ C1;   / $calp)
$mapsize = PAR(58;13)
                                             ! Compute the power distribution !
fx       = SEL(fx    / macro/ C1;Maps/ $calp)
kf       = SEL(kf    / macro/ C1;Maps/ $calp)
vo       = SEL(vo    / macro/ C1;Maps)
power    = FOR(fx*kf*vo)

bu       = SEL(bu    / macro/ C1;Maps    / $calp)
rho      = SEL(rho   / micro/ C1;FuelIsos/ $calp)
```

```
ip         = IND(bu / PER:RIEGO)
i1         = IND(bu / RAN:1;;;;)
is         = IND(bu / SOR:)
b1         = FOR(bu^is)
e1         = FOR(@nbE(bu)^is)
r1         = FOR(@nbR(bu)^is)
ia         = IND(e1   / SOR:ascen)
'Max burn' = FOR(((b1^ia)^^ip)^i1)
'at pin'   = FOR(((r1^ia)^^ip)^i1)
```

```
ip       = IND(power / PER:RIEGO)
i1       = IND(power / RAN:1;;;;)
is       = IND(power / SOR:)
p1       = FOR(power^is)
e1       = FOR(@nbE(power)^is)
r1       = FOR(@nbR(power)^is)
ia       = IND(e1   / SOR:ascen)
'Max W/cm' = FOR(((p1^ia)^^ip)^i1)
' at pin'  = FOR(((r1^ia)^^ip)^i1)

ipos     = IND(power / WIND:1.0E-20,/ 1.0)
rho      = FOR(((power*0+rho)^ipos)^^ipos)
powdens  = FOR(power/(rho*vo))
ip       = IND(powdens/ PER:RIEGO)
is       = IND(powdens/ SOR:)
p1       = FOR(powdens^is)
e1       = FOR(@nbE(powdens)^is)
r1       = FOR(@nbR(powdens)^is)
ia       = IND(e1   / SOR:ascen)
'Max W/gU' = FOR(((p1^ia)^^ip)^i1)
'  at pin' = FOR(((r1^ia)^^ip)^i1)

MaxVals  = LIST(Burnup;S/
               'Maximum burnup, power density [W/gU] and linear power [W/cm]';
               'Power peaking factor (ppf) without gamma smearing'
               /E/
               f0:'Max burn'     ;    'at pin'  ;
               f3:'Max W/gU'     ;f0: '  at pin';
               f3:'Max W/cm'     ;f0: ' at pin' ;
               f4: ppf     )

&ADD      = SET ( 'USRC01.hrf'/ SAXTON; ZENITH; &v305A )

$hiso    = PAR(92235; 92236; 92238; 94238; 94239; 94240; 94241; 94242)
$avo     = PAR(0.6023)
ndens    = SEL(nd    / micro/ C1;FuelIsos/ $calp/ $hiso)
aw       = SEL(aw    / micro/ C1;FuelIsos/ $calp/ $hiso)
rho      = SEL(rho   / micro/ C1;FuelIsos/ $calp)
vol      = SEL(vo    / micro/ C1;FuelIsos)

nd       = FOR(@smR(ndens*vol)/@smR(vol))
'g/cm'   = FOR(@smR(vol)*nd*aw/$avo)
'wt%'    = FOR(100 *'g/cm'/@smR(rho*vol))

iu5      = IND(nd /RAN:;1;;;)
iu6      = IND(nd /RAN:;2;;;)
iu8      = IND(nd /RAN:;3;;;)
ip8      = IND(nd /RAN:;4;;;)
ip9      = IND(nd /RAN:;5;;;)
ip0      = IND(nd /RAN:;6;;;)
ip1      = IND(nd /RAN:;7;;;)
ip2      = IND(nd /RAN:;8;;;)

U235     = FOR(nd^iu5)
U236     = FOR(nd^iu6)
U238     = FOR(nd^iu8)
Pu238    = FOR(nd^ip8)
Pu239    = FOR(nd^ip9)
Pu240    = FOR(nd^ip0)
Pu241    = FOR(nd^ip1)
Pu242    = FOR(nd^ip2)

InvNd    = LIST(Burnup;S/
               'Average fuel composition in at/barn-cm'
```

```
/E/
e5:U235; U236; U238; Pu238; Pu239; Pu240; Pu241; Pu242)
```

```
U235     = FOR('g/cm'^iu5)
U236     = FOR('g/cm'^iu6)
U238     = FOR('g/cm'^iu8)
Pu238    = FOR('g/cm'^ip8)
Pu239    = FOR('g/cm'^ip9)
Pu240    = FOR('g/cm'^ip0)
Pu241    = FOR('g/cm'^ip1)
Pu242    = FOR('g/cm'^ip2)

InvG     = LIST(Burnup;S/
               'Average fuel composition in g/cm'
                /E/
                f4:U235; U236; U238; Pu238; Pu239; Pu240; Pu241; Pu242)

U235     = FOR('wt%'^iu5)
U236     = FOR('wt%'^iu6)
U238     = FOR('wt%'^iu8)
Pu238    = FOR('wt%'^ip8)
Pu239    = FOR('wt%'^ip9)
Pu240    = FOR('wt%'^ip0)
Pu241    = FOR('wt%'^ip1)
Pu242    = FOR('wt%'^ip2)

InvRel   = LIST(Burnup;S/
               'Average fuel composition in weight % of initial heavy mass'
                /E/
                f4:U235; U236; U238; Pu238; Pu239; Pu240; Pu241; Pu242)

&ADD      = SET ( 'USRC01.hrf'/ SAXTON; ZENITH; &v305A )
burnup   = SEL(bu    / macro/ C1;Maps/ $calp)
cxfuel   = SEL(vx    / macro/ C1;Maps)
cyfuel   = SEL(vy    / macro/ C1;Maps)
nopins   = SEL(nra   / macro/ C1;Maps)

avpow    = FOR(@smR(power)/nopins)
'power peaking' = FOR(power/avpow)
ppf             = FOR(@mxR('power peaking'))

&ADD      = SET ( 'USRC01.hrf'/ SAXTON; ZENITH; &v305A )

cx       = SEL(vx    / micro/ C1;FuelIsos)
cy       = SEL(vy    / micro/ C1;FuelIsos)
Volumes  = SEL(vo    / micro/ C1;FuelIsos)
Isotopes = SEL(id    / micro/ C1;FuelIsos//$Isos)
'N(fuelpin)' = SEL(nd/ micro/ C1;FuelIsos/ $calp / $Isos)

PinMap   = MAP(;24 /$mapsize /
               'Output for fuel isotopics per pin';
               'Map showing the fuel pin numbers and volumes'
               / cx; cy/   Volumes)

IsoList  = LIST(;S/
                'Fuel isotopics per pin';
                'List of isotope identifiers'  /I/
                 f0:Isotopes)

NdList   = LIST(Burnup /
                'Fuel isotopics per pin';
                'Number densities in atoms/barn-cm per fuel pin and isotope';
                'R-I-E-.-. indicates fuel pin R and isotope I'            /E/
                'N(fuelpin)')
```

10. Acronyms and Abbreviations

AEC	Atomic Energy Commission
BOL	Beginning Of Life
DOE	Department of Energy
EOL	End Of Life
ID	Inner Diameter
In.	Inches (1 inch is 2.54 cm)
MCR	Middle Control Rod
Mils	One thousandth of one inch
MOL	Middle Of Life
MOX	Mixed Oxides or PuO_2 - UO_2
MOXP	Mixed Oxides Pelletized
MOXV	Mixed Oxides Vipac
MWD/t	Megawatt Days per metric ton
NRC	Nuclear Regulatory Commission
OD	Outer Diameter
SPPC	Saxton Partial Plutonium Core
SS	Stainless Steel
TD	Theoretical Density
UOX	Uranium Oxide
USRC	Unified Saxton Reactor Core Model
ZR	Zirconium

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