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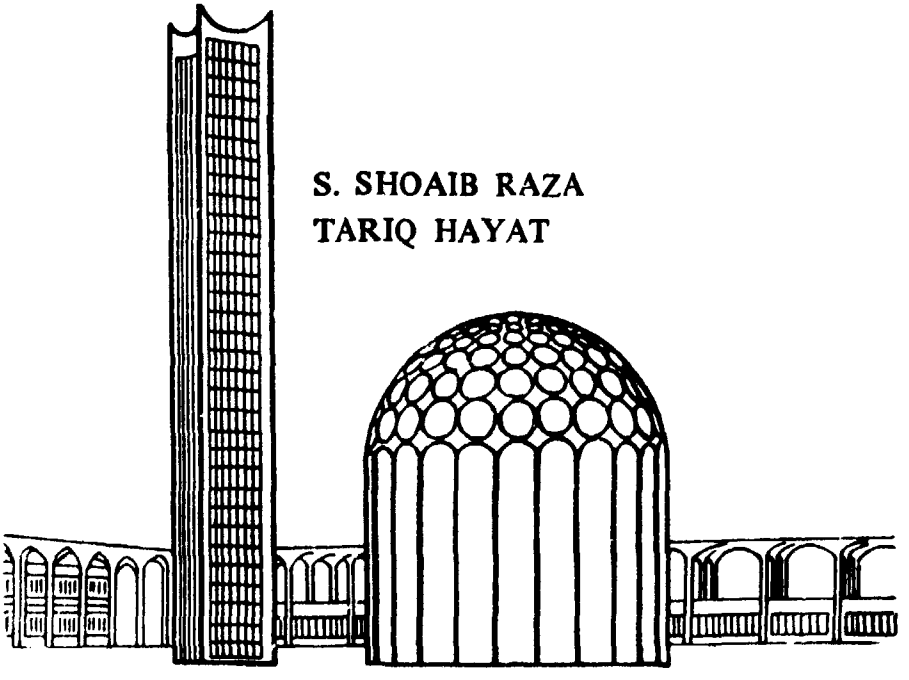

NUCLEAR ENGINEERING DIVISION
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ABSTRACT

Neutronic analysis of the Ford Nuclear Reactor low enriched uranium core has been carried out to gain confidence in the computing methodology being used for Pakistan Research Reactor-1 core conversion calculations. The computed value of the effective multiplication factor (Keff) is found to be in good agreement with that quoted by others.

INTRODUCTION

The core conversion programme of Pakistan Research Reactor (PARR) from the use of Highly Enriched Uranium (HEU) fuel to the use of Low Enriched Uranium (LEU) fuel is in progress. In order to validate the methodology which is being used for the reactor physics calculations in this programme, an analysis has been done for the initial LEU core of Ford Nuclear Reactor (FNR).

The design parameters for the fuel elements of FNR are given in Table-1 and the core configuration is shown in Fig. 1. The FNR at the University of Michigan is a 2 MW swimming pool reactor and is serving as a test reactor for LEU fuel. Its fuel has an enrichment of 19.75% ^{235}U. It contains 19 standard fuel elements (SFE) and 4 control fuel elements (CFE). The FNR is chosen for this analysis because of the following reasons;

1. It is similar to PARR, as both are swimming pool type reactors and use UAl_x-Al MTR-type fuel elements.

2. Its design parameters along with calculated and measured results were available in literature [1,2,3].

METHOD OF CALCULATIONS

The neutronic analysis of FNR has been performed by using the computer codes WIMS-D [4] and CITATION [5]. A flow diagram for these calculations is shown in Fig. 2. WIMS-D along with its pre- and post-processors (developed locally) was used to generate group constants for the fuel, clad and coolant regions etc. Pre-processor of WIMS-D (PPW1) [6] is a computer program to calculate region-wise isotopic number densities for plate type fuel geometry. The small curvature in the fuel plates has been ignored for calculation purpose. WIMS-D solves the neutron transport equation for one dimensional region with reflective boundaries on both sides, such that a unit cell out of an infinite lattice can be analyzed. For this the edge border, side plate portion and water gap between two fuel elements, in the direction parallel to fuel meat (Fig. 3) are homogenized.

The unit cell used in the calculations for the fuel area in SFE and CFE is shown in Fig.4. The water gap between two fuel elements in the direction normal to fuel meat and end portion of the fuel elements are distributed in the coolant regions of the entire fuel element to have true one dimensional slab representation of the infinite lattice. The region-wise number densities of different materials in fuel

elements are shown in Table-2.

Macroscopic group constants i.e., diffusion coefficients, removal cross-sections, absorption cross-sections, fission cross-sections and the scattering matrices were calculated by WIMS-D (Table. 3.1-3.2). Since the cell was symmetric about the centre line, only one half of the cell was analyzed. These cross-sections were also used for the fuel area in CFE. For non-fuel area (control area) seperate treatment was done.

A super cell was made to calculate the group constants for control area in the CFE. To calculate the neutron spectrum in WIMS-D the unit cell must contain some fissionable material, therefore one fuel cell was added on both sides of the control area, in the super cell (Fig. 5). Because of symmetry, only one half of the cell was analyzed. Macroscopic group constants for control area were seperated from those of super cell using PPW2 (Table. 3.3-3.4). PPW2 takes its input from WIMS-D and provides condenced group constants for one or more regions, as required.

For light water reflector, group constants were calculated by using an extended fuel cell (Fig. 6). This includes one fuel cell surrounded by 10 cm water on both sides. For heavy water reflector same cell was used as that for light water reflector except that heavy water is used

instead of light water. These cells were also analyzed by WIMS-D and group constants for only the reflector regions were obtained using PPW2 (Table. 3.5-3.8).

The WIMS-D calculations mentioned above have been performed in 5 energy groups. The energy boundaries for the 5 groups are given in Table.4.

The macroscopic group constants calculated by WIMS-D were fed to CITATION for performing three dimensional neutronic analysis of FNR cold clean core. To determine the neutron multiplication factor CITATION solves the neutron flux eigen-value problem using finite difference diffusion theory approximation of neutron transport equation by direct iteration method.

A mesh structure chosen for point flux calculations is shown in Fig. 7. In X-Y plane mesh spacing is given with reference to the fuel elements. 5 mesh points have taken for the reflector on each side of the core. In Z-direction a total of 38 mesh points have been taken into account, out of these 28 points have been taken for active height of fuel element (60 cm) and the rest 10 mesh points have been taken for light water reflector on top and bottom of the core.

The neutron multiplication factor (Keff) calculated by CITATION is compared with values quoted in literature [2,3].

RESULTS & DISCUSSION

The Keff of FNR LEU cold clean core has been computed to be 1.0054. A comparison of this value with the reported values is given in Table 5. The calculated value is 0.09% (90 pcm) higher than the experimentally measured value [2] and is about 0.17% (170 pcm) higher than the reported value for 3-D fine mesh calculations [3]. The agreement seems to be quite reasonable. However the reason for this slight discripancy may be the use of different data base for calculation of group constants. In the reported results the analysis was made by using the EPRI-CELL code and ENDF/B-IV data files.

From this agreement it can be concluded that the methodology being used for neutronic calculations at PINSTECH regarding PARR core conversion programme is quite satisfactory.

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Table-1:- Design Parameters of FNR

Standard fuel elements (SFE) in the core	19
Control fuel elements (CFE) in the core	4
Fuel plates per SFE	18
Fuel plates per CFE	9
U-235 loading per SFE	167.02 g
U-235 loading per CFE	83.27 g
Active height of fuel plates	60.0 cm
Width of fuel plates	6.71 cm
Curvature of fuel plates	14.0 cm
Width of fuel meat	6.0 cm
Width of side plate	7.993 cm
Thickness of meat	0.0779cm
Thickness of clad	0.039 cm
Thickness of side plate	0.475 cm
Thickness of guide plate (CFE)	0.287 cm
Side plate to side plate inside dimension	6.517 cm
Uranium density in fuel meat	3.8 g/cc

TABLE-2:- NUCLIDE NUMBER DENSITIES FOR VARIOUS REGIONS

ISOTOPES	FUEL REGION	CLAD REGION	COOLANT REGION	GUIDE PLATE REGION	CONTROL ROD REGION
235 U	6.6049-04	0.0	0.0	0.0	0.0
238 U	2.6100-03	0.0	0.0	0.0	0.0
27 AL	5.0901-02	5.72800-02	7.0715-03	5.6874-02	7.2213-03
1 H	2.1149-03	2.11490-03	5.8760-02	2.1149-03	5.8561-02
16 O	1.0574-03	1.05740-03	2.9380-02	1.0574-03	2.9275-02

* in units of 10^{24} /cc.

TABLE-3.1:- GROUP CONSTANTS FOR THE FUEL AREA

GROUPS	DIFFUSION COEFFICIENT (cm)	Σ-REMOVAL $^{-1}$ (cm)	Σ-ABSORPTION $^{-1}$ (cm)	Σ-FISSION $^{-1}$ (cm)
1	2.53527	7.22010-02	7.64410-04	9.02610-04
2	1.17947	8.65380-02	4.68560-04	5.06380-04
3	1.28255	8.16440-02	9.90590-03	6.51840-03
4	0.91719	4.16010-01	2.73500-02	4.27460-02
5	0.56577	2.57110-02	7.86410-02	1.28700-01

TABLE-3.2:- SCATTERING MATRIX FOR THE FUEL AREA

WITH ZERO SELF SCATTERING

GROUPS	GROUP-1	GROUP-2	GROUP-3	GROUP-4	GROUP-5
1	0	7.1800-02	4.0061-04	0	0
2	0	0	8.6529-02	6.9934-06	1.4338-06
3	0	0	0	6.8146-02	1.3498-02
4	0	0	1.5532-03	0	4.1446-01
5	0	0	0	2.5771-02	0

TABLE-3.3:- GROUP CONSTANTS FOR THE CONTROL AREA

GROUPS	DIFFUSION COEFFICIENT (cm)	Σ -REMOVAL $^{-1}$ (cm)	Σ-ABSORPTION $^{-1}$ (cm)	Σ-FISSION $^{-1}$ (cm)
1	2.47007	8.25550-02	5.00020-04	1.10821-04
2	1.02336	1.06850-01	8.18420-05	5.33713-05
3	1.05136	1.08140-01	1.92130-03	6.68034-04
4	0.67768	6.32020-01	8.88880-03	4.43692-03
5	0.42719	2.72200-02	2.36640-02	1.23262-02

TABLE-3.4:- SCATTERING MATRIX FOR THE CONTROL AREA

WITH ZERO SELF SCATTERING

GROUPS	GROUP-1	GROUP-2	GROUP-3	GROUP-4	GROUP-5
1	0	8.2073-02	4.3188-04	0	0
2	0	0	1.0684-01	8.6524-06	1.7745-06
3	0	0	0	9.0241-02	1.7897-02
4	0	0	1.2542-03	0	6.3077-01
5	0	0	0	2.7221-02	0

TABLE-3.5:- GROUP CONSTANTS FOR THE LIGHT WATER REFLECTOR

GROUPS	DIFFUSION COEFFICIENT (cm)	Σ -REMOVAL $^{-1}$ (cm)	Σ -ABSORPTION $^{-1}$ (cm)	Σ -FISSION $^{-1}$ (cm)
1	2.30750	1.06770-01	0.51375-03	0
2	0.78225	1.47334-01	0.21899-06	0
3	0.55945	1.46808-01	0.98251-03	0
4	0.27318	8.98822-01	0.75728-02	0
5	0.14531	3.54080-02	0.19723-01	0

TABLE-3.6:- SCATTERING MATRIX FOR THE LIGHT WATER REFLECTOR

WITH ZERO SELF SCATTERING

GROUPS	GROUP-1	GROUP-2	GROUP-3	GROUP-4	GROUP-5
1	0	0.10661	0.6605-03	0	0
2	0	0	0.14732	0.1195-04	0.2452-05
3	0	0	0	0.12247	0.2434-01
4	0	0	0.1342-02	0	0.89748
5	0	0	0	0.3541-01	0

TABLE-3.7:- GROUP CONSTANTS FOR THE HEAVY WATER REFLECTOR

GROUPS	DIFFUSION COEFFICIENT (cm)	Σ-REMOVAL -1 (cm)	Σ-ABSORPTION -1 (cm)	Σ-FISSION -1 (cm)
1	2.37740	9.05570-02	0.19712-04	0
2	1.18470	3.62520-02	0.13627-06	0
3	1.26450	1.86501-02	0.15197-05	0
4	1.06370	1.45794-01	0.13027-04	0
5	0.81533	5.77230-03	0.32721-04	0

TABLE-3.8:- SCATTERING MATRIX FOR THE HEAVY WATER REFLECTOR

WITH ZERO SELF SCATTERING

GROUPS	GROUP-1	GROUP-2	GROUP-3	GROUP-4	GROUP-5
1	0	0.9056-01	0	0	0
2	0	0	0.3625-01	0	0
3	0	0	0	0.1743-01	0.1218-02
4	0	0	0.2942-03	0	0.14550
5	0	0	0	0.5772-02	0

Table-4:- 5-group energy boundaries

Groups	Energy range	Remarks
1	Above 0.821 Mev	Fast
2	821 Kev - 5.53 Kev	Resonance
3	5.53 Kev - 0.625 ev	Resonance
4	0.265 ev - 0.140 ev	Thermal
5	Below 0.140 ev	Thermal

Table-5:- Comparison of Keff values

SOURCE	Keff
MEASURED *	1.0045
ANL *	1.0037
PINSTECH	1.0054

* Reference [2,3]

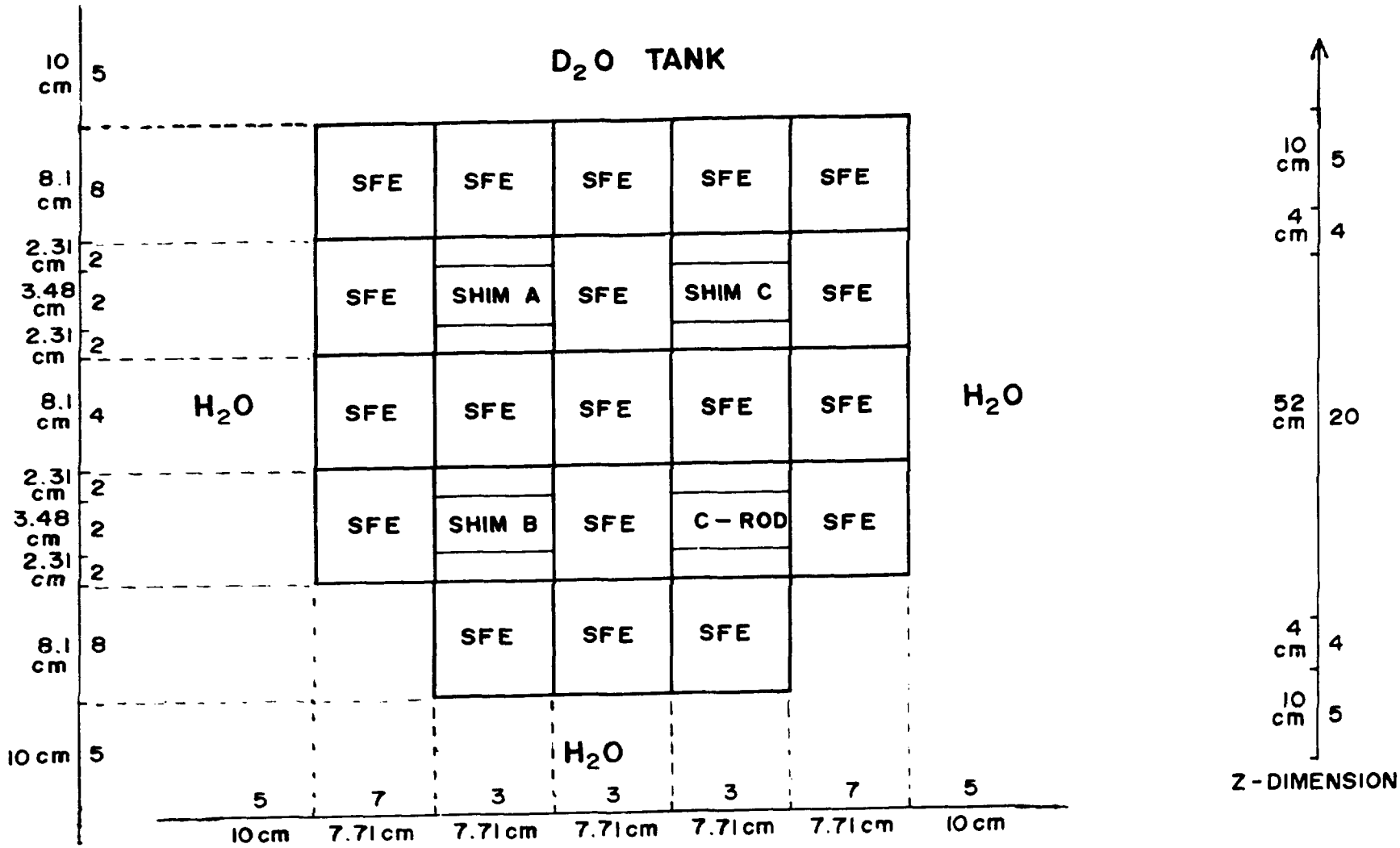


FIG. 1 –FORD NUCLEAR REACTOR LEU CRITICAL CORE CONFIGURATION

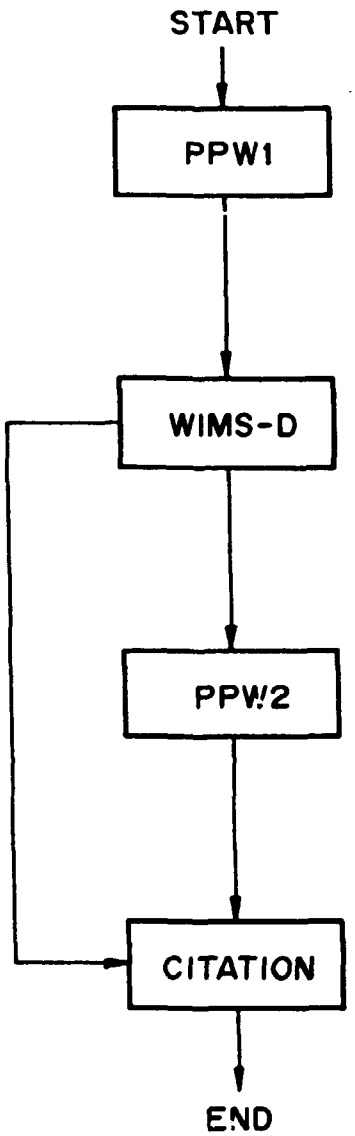


FIG. 2 FLOW DIAGRAM SHOWING THE COMPUTATIONAL SCHEME

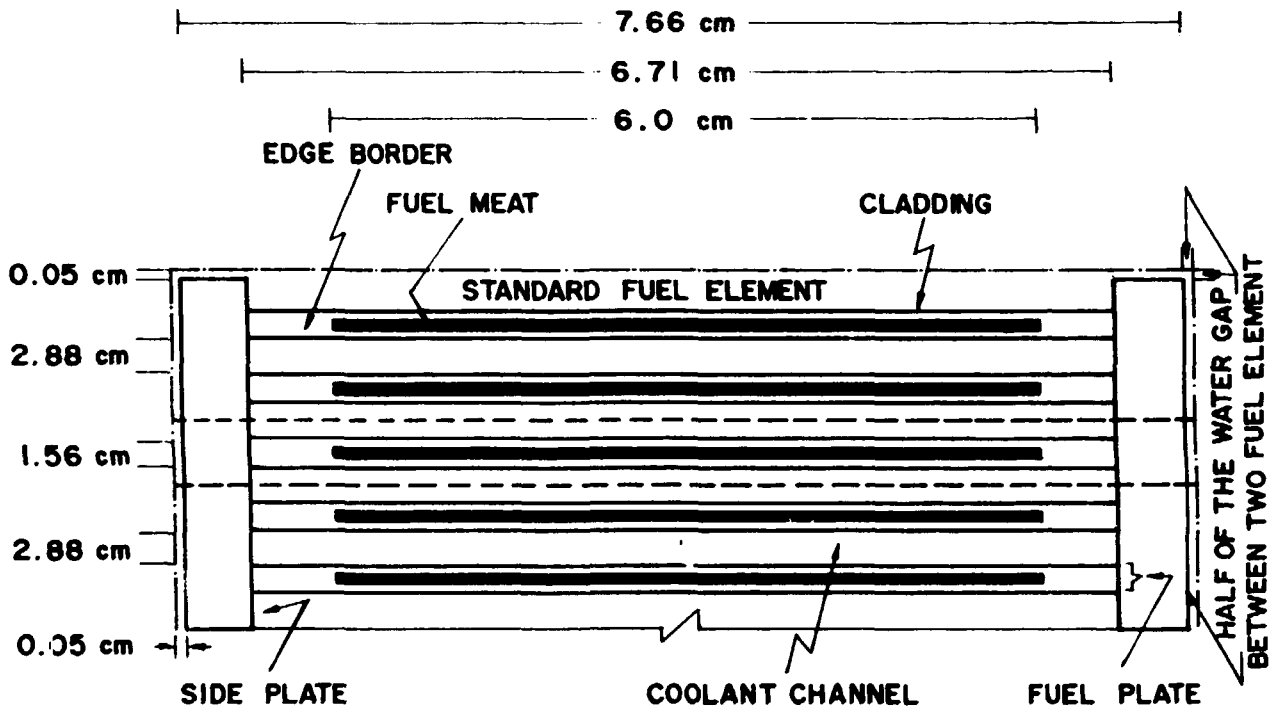


FIG: 3. CELL BOUNDARY FOR FUEL AREA IN SFE AND CFE

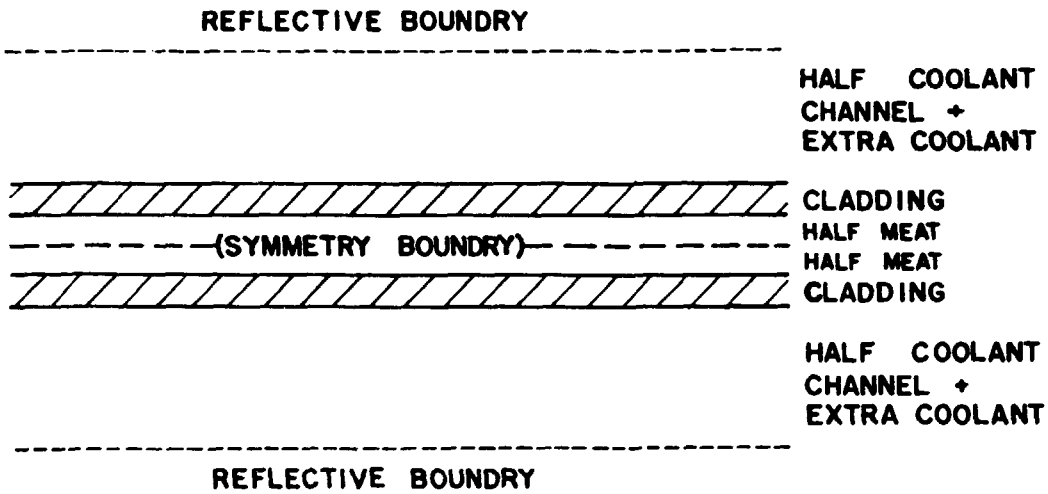
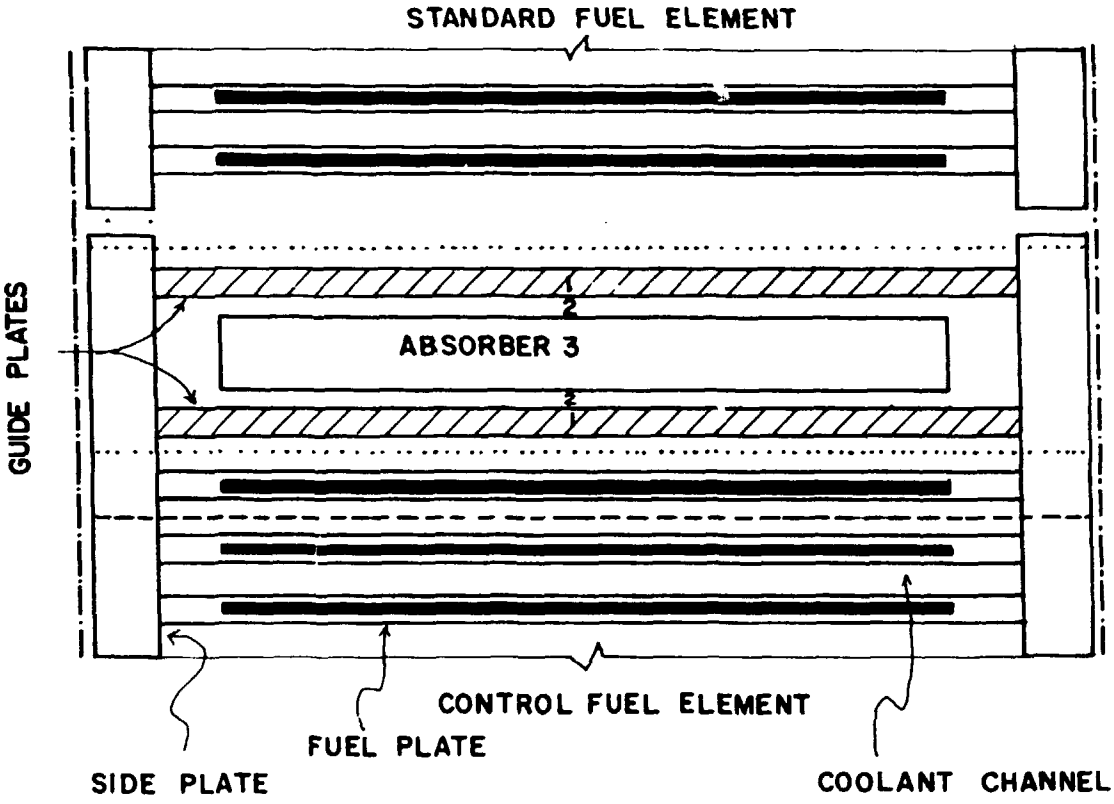


FIG: 4. ONE DIMENSIONAL CELL FOR LATTICE CALCULATIONS FOR FUEL AREA IN SFE AND CFE.



1 = CONTROL ROD GUIDE PLATE

2 = WATER GAP

3 = SPACE FOR CONTROL ROD MOVEMENT

SUPER CELL BOUNDRY — — — — — — — — — — — — —

CONTROL AREA BOUNDRY . . . . . .

FUEL ELEMENT BOUNDRY —·—·—·—·—·—·—·—·—·—

FIG: 5 SUPER CELL BOUNDARY AND CONTROL AREA IN CFE

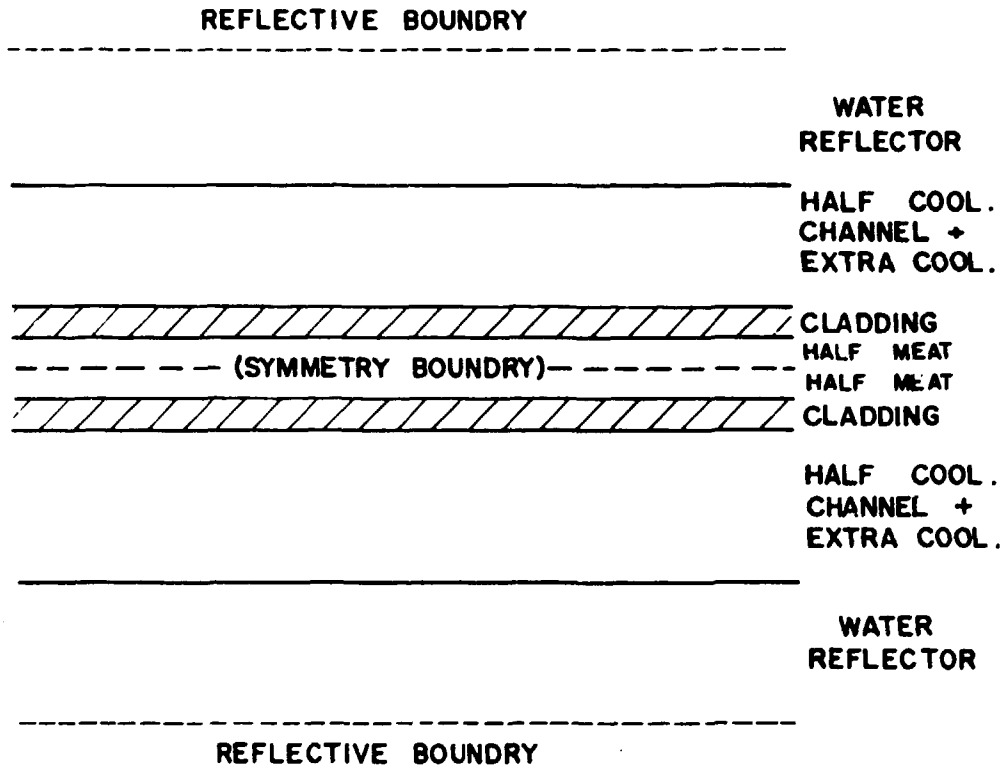


FIG: 6. ONE DIMENSIONAL CELL FOR LATTICE CALCULATIONS FOR NEUTRON REFLECTOR REGION.