Neutronic cell calculations using homogeneous models in ETRR-2

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Neutronic calculations play an important role in the safe and efficient operation of research reactors. The accuracy of calculations is dependent to a great extent on the applied computational models representing the core components, especially those of the fuel element. So, two different cell models of ETRR-2 fuel element are proposed and evaluated to adopt the most suitable one for neutronic calculations. The first model represents the fuel element as a repeated identical cell unit of one homogenous zone while the second model represents the same element as a repeated cell unit of three different homogenous zones. WIMSD-4 cell calculation code is used to obtain cell constants of the material properties for each model which are used later as input data in CITVAP diffusion code to calculate the neutronic core parameters. The validation of both models is carried out through a comparison between results of the TECDOC-233 theoretical benchmark and core measurements on one side and those obtained by the calculations for the two models on the other side. The one homogenous cell zone model is a more suitable choice for core neutronic calculations. It has the advantages of giving closer calculated values to the benchmark results and experimental ones of the core parameters. Moreover, the one zone model leads to building a simpler core model.

تلعب الحسابات النيترونية دورا هاما فى أمان التشغيل والاستخدام الأمثل لمفاعلات الأبحاث. وتعتمد دقة هذه الحسابات بشكل كبير على النماذج الحسابية المستخدمة فى تعيين قيم المقاطع العرضية النيترونية لمكونات قلب المفاعل وبخاصة لتلك النماذج الممثلة لوحدة الوقود. وعلى ذلك فقد تم طرح نموذجين مختلفين لوحدة الوقود بمفاعل مصر البحثى الثانى لإجراء الحسابات النيترونية لاختيار النموذج الحسابى الأكثر دقة. يمثل النموذج الأول وحدة الوقود كمنطقة واحدة متجانسة مكونة من خلية متكررة بينما يمثل النموذج الثانى نفس وحدة الوقود بخلية متكرر مكونة من ثلاث مناطق متجانسة. تم استخدام كود الانتقال النيترونى WIMS- D4 مع خيار استخدام طريقة احتمالات التصادم فى الخلية للحصول على قيم الثوابت لهذه الخلايا (المقاطع العرضية النيترونية) ودراستها ثم إعدادها بعد ذلك كمدخلات لكود الانتشار النيترونى CITVAP المخصص لإجراء الحسابات النيترونية لقلب المفاعل. وقد تم تقييم النتائج المحسوبة للعديد من المعاملات النيترونية لكل من النموذجين وذلك بمقارنة تلك النتائج بكل من مثيلاتها فى الـ IAEA-TECDOC-233 theoretical benchmark وأيضا بالنتائج المقاسة لهذه المعاملات لحالات مختلفة لقلب المفاعل. لقد أوضحت المقارنة أن النموذج الحسابى لوحدة الوقود ذو المنطقة الواحدة المتجانسة يعطى نتائج أدق من النموذج الآخر ذو المناطق الثلاث بالإضافة إلى تمثيل قلب المفاعل بشكل أيسر باستخدام هذا النموذج. وكان واضحا من المقارنة أنه لايوجد تغير محسوس فى كل ثوابت الخلية المستخدمة فى كود الانتشار النووى حيث كان الاختلاف أقل من ٣% فى كل المعاملات ماعدا معاملى الانتشار النيترونى ومساحة الانتشار ووصلت نسبة الاختلاف الى أقل من ١٣% مما يؤكد أن الاختلاف بين النموذجين يظهر جليا فى المفاعلات الحرارية عند استخدام نظرية الانتشار النووى فى الكود CITVAP.

Keywords: Cell and core models, Neutronic calculations, Cell constants, Neutron diffusion, Homogenous zones models

1. Introduction

Egypt Second Research Reactor (ETRR-2) is a research thermal reactor in which the reactivity is the most needed parameter to check the operation of the core. In power reactors, power density, flux shape and reactivity are the main concerns of the calculations. The neutronic calculations of the reactor core deal mainly with the solution of the neutron transport equation in space, energy and time. In practice, a solution of this equation for the entire core is not feasible and some approximations must be used. Generally, the engineering data describing the material composition and geometry of the reactor core on one side, and the material properties which are ultimately described by neutron cross sections on the other side are both used in the solution of one of the

approximate forms of the neutron transport equation [1,2]. The philosophy of the calculational line applied in ETRR-2 is to start with small systems, like a fuel plate cell, and to proceed via intermediate systems, like a fuel assembly, then to move towards the entire reactor core [3]. While the size of the considered system increases, one passes from a detailed to a crude representation of the energy and space variables. Hence, the calculations are mainly divided into two steps:

1.1. The first step (cell calculations)

The reactor core is assumed to be divided into cells (repeated structure) and the neutron transport equation is solved in one dimension or two dimensions on the cell level [3]. Space homogenization and energy condensation are performed to generate the macroscopic cross section libraries for every component of the reactor core to be used for the global core calculations (the second step). The zero current boundary condition is used in cell calculations. The burn-up calculations are performed alternatively with the cell calculations where in each burn-up time interval one gets new cell spectrum and hence a new set of cross sections [4]. Usually, each cell calculation code possesses its own multigroup cross section library and one does not have to create a special library for the reactor in question, nevertheless, some reactors contain some isotopes that are not of common use. The ETRR-2 cell calculation code is WIMS-D4 (Winfrith Improved Multigroup Scheme) code [4] where the option of the collision probability method is used. The nuclear data library used for calculation was the original WIMS-D4 library with updates from ENDF/B-IV of Ag, In, Cd, and Gd. [5].

1.2. The second step (core calculations)

One of the approximate forms of the transport equation is used with all the macroscopic cross sections libraries obtained from the first step. The ETRR-2 core calculation code is CITVAP [2], which is an improved version of CITATION II [6]. It solves problems using the finite difference representation of the neutron diffusion theory treating up to three space dimensions with arbitrary group-to-group scattering [6]. The fuel depletion problem is solved and the fuel can be managed for multi-cycle analysis.

Every previous calculation step requires a computational model to represent the system that will be treated in calculations. Therefore, accurate nuclear data, validated codes and adequate models are required to obtain accurate results. In this paper, two different models of the fuel element are proposed and evaluated to adopt the most suitable one for the neutronic core calculations. The first model represents the fuel element as one homogenous zone while the second divides the fuel element into three different heterogeneous zones. Each model is studied by the following two methods:

1. The two fuel models were used to calculate the core neutronic parameters of the benchmark problem stated in the IAEA-TECDOC-233.
2. Comparison between the calculated excess reactivity and the average calculated reactivity at critical state (reactivity calculational error) and the related measured ones for different operating core configurations (Core 1/98 and Core 2/98) during the test period of the commissioning stage and normal operation.

2. Fuel element description

The ETRR-2 core is an array of fuel elements, reflectors, absorber plates, gadolinium injection boxes and irradiation devices. The basic geometric unit in the x-y core array is a square shape of 8.1 x 8.1 cm^2. It can be used for fixing a fuel element, an irradiation device or an empty box. There is a 30-position grid with a 6x5 configuration inside the chimney. The reactor uses MTR fuel type of a square section of (8 x 8) cm. Each fuel element has 19 fuel plates separated from each other by a 0.27 cm coolant channel. The design of fuel element assembly is based on the U_3O_8-Al fuel, which is a Low Enriched Uranium (LEU) fuel element [7] with an enrichment of 19.75 $\%^w$ ^{235}U. The active zone of fuel plate dimensions is 80 cm length, 6.4 cm width and 0.07 cm thickness. The main specifications of the fuel element are given in table 1 [7, 8, 9].

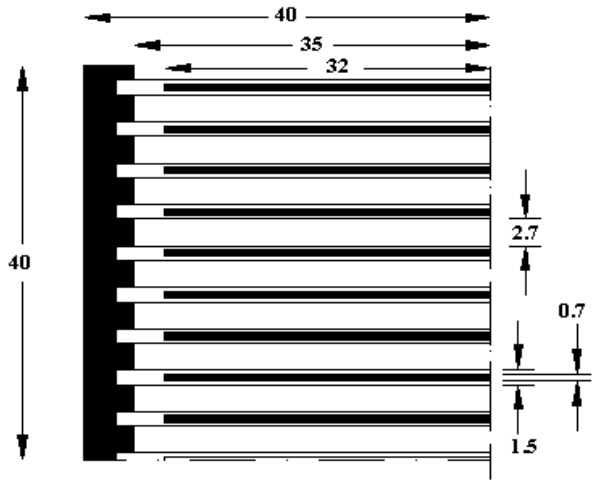

Fig. 1. X-Y scheme of a quarter fuel element (mm).

Table 1
Main specifications of fuel element

Number of fuel plates	19
Enrichment (%)	19.7
Plate thickness (cm)	0.15
Meat thickness (cm)	0.07
Meat width (cm)	6.4
Side plate thickness (cm)	0.5
Side plate width (cm)	8
Meat density (g/cm^3)	4.802
Al density (g/cm^3)	2.7
Weight fraction – U_{235} (%)	12.377
Weight fraction – U_{238} (%)	50.450
Weight fraction – O (%)	11.263
Weight fraction – Al (%)	25.910

3. WIMS data for cell calculations

WIMS-D4 cell code [4, 5] is used in slab geometry for the calculations of the following cell constants for the different core materials:

- The diffusion coefficients (D),
- The absorption cross sections (Σ_a),
- The average number of neutrons produced by thermal fission times fission cross sections ($\nu\times\Sigma_f$) – if burn-up calculation is done,
- The transport cross sections (Σ_{tr}),
- Fission cross sections (Σ_f) and
- The scattering matrix cross sections ($\Sigma_{s\,g\to g'}$)

The dependency of the calculated cell constants on the operating state of the reactor core can be classified into:

1. The nuclear constants of the materials that contain fuel are dependent on temperature, power level and burn-up as well.
2. The nuclear constants of materials that contain water are temperature dependent, mainly because of the water density and spectrum changes.
3. There is a slight dependence of materials that do not contain fuel on power level or burn-up, because of the energy spectrum change, but it is neglected in the calculations.

Table 2 shows the values of some important core data at different core operating states which are used as input data for WIMS code.

4. Fuel cell model of one homogenous zone

The region which consists of the fuel element materials (meat, aluminum clad, water coolant channels and aluminum side plates; (8cm × 8cm) and a half water channel between each two adjacent fuel elements (0.5cm) is represented as identical repeated cell units. In practice, It is so difficult to represent the actual geometry of the cell unit as a computational model in the required input format of the cell calculational code. Therefore, it is common in cell neutronic calculations to build an equivalent repeated cell unit with a simple and regular geometry to be applied. Moreover, this approach also leads to obtaining a relatively simple core model for the next calculation step (core calculations). Fig. 2 shows the fuel element region for modeling, the actual fuel cell unit and the computational cell model with the equivalent dimensions. The equivalent dimensions of meat, aluminum cladding and water channel of the cell model are calculated as follows:

The total area of fuel element region is 65.61 cm^2. The total area of fuel meat, aluminum alloy and water are 8.5121, 19.438 and 37.66 cm^2, respectively. Maintaining the meat thickness (0.035 cm), the equivalent thickness E_t of aluminum and water associated with one half-fuel plate (as required for WIMS input) in the active width of 6.4 cm are:

Table 2
WIMS data for different core states

	Temperature (°K)			Density (g/cm³)			Power Density
	Fuel	Al	H_2O	Fuel	Al	H_2O	(W/g U)
Cold	293	293	293	4.80243	2.7	0.99837	0
Hot Zero Power	353	343	318* 313**	4.80243	2.7	0.99032 0.99238	0
Hot with Power	353	343	318* 313**	4.80243	2.7	0.99032 0.99238	(PD) ***

* Inside the chimney ** Outside the chimney ***PD = (P × 10^6) / (NEF x MUFE)
Where; P is the reactor power (MW), NFE is the number of fuel element, MUFE is mass of uranium per fuel element.

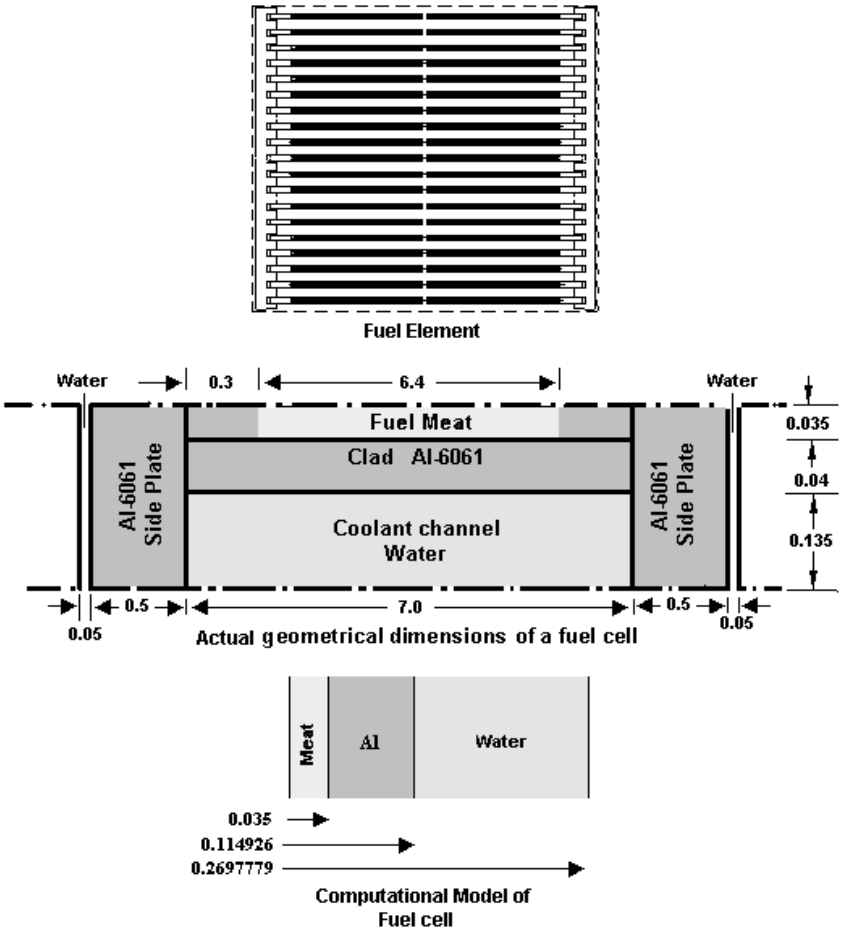

Fig. 2. Fuel cell model of one homogenous zone (all dimensions are in cm).

$$E_{Al\text{-}6061} = \frac{19.438}{19 \times 2 \times 6.4} = 0.079926 \text{ cm},$$

$$E_{Water} = \frac{37.66}{19 \times 2 \times 6.4} = 0.154852 \text{ cm}.$$

The cell constants of each region in the cell model are calculated by WIMS-D4 code. Then the cell constants of the one homogenous zone model are obtained by homogenization of meat, aluminum and water regions. Therefore, this model has only one set of cell constant for the core calculation step.

5. Fuel model of three different homogenous zones

The fuel element region is divided into three different homogenous zones. The region for modeling and the actual fuel cell are the same as in one zone model shown in fig. 2. The dimensions of each zone of the model are calculated as follows:

1. The first zone of the model consists of a homogenous zone of the entire fuel element material region which lies in the active width (the meat width). The dimensions of fuel meat, aluminum cladding and water channel between fuel plates in the first zone are the real geometrical dimensions which are 0.035, 0.04 and 0.135 cm, respectively.
2. The second zone consists of the rest of the aluminum cladding and the water channels in the region between the lateral frame and one end of the active width. There are two identical regions of such zone on both left and right of the first zone. The total area of fuel element clad and the area of water are 1.71 and 3.218 cm^2, respectively. Then the total area of the second zone is 4.928 cm^2 with a volume fraction of aluminum and water 0.347 and 0.653, respectively. The equivalent thickness (E_t) of the second zone associated with one half-fuel plate in the active width is:

$$E_{Zone\text{-}2} = \frac{4.928}{19 \times 2 \times 6.4} = 0.0202631 \text{ cm} \ .$$

3. The third zone consists of a lateral frame and half of the water channel between each two adjacent fuel elements. The model has two identical regions of the third zone on the left and right sides of the second zone. The area of side plate of aluminum is 8 cm^2 and the area of water is 1.61 cm^2. Then the total area of the third zone is 9.61 cm^2 with a volume fraction of aluminum and water 0.8325 and 0.1675, respectively. The equivalent thickness (E_t) of the third zone associated with one half-fuel plate in the active width is:

$$E_{Zone\text{-}3} = \frac{9.61}{19 \times 2 \times 6.4} = 0.0395148 \text{ cm.}$$

Fig. 3 shows the fuel element region for modeling and the fuel cell computational model with the equivalent dimensions of the three homogenous zones cell model.

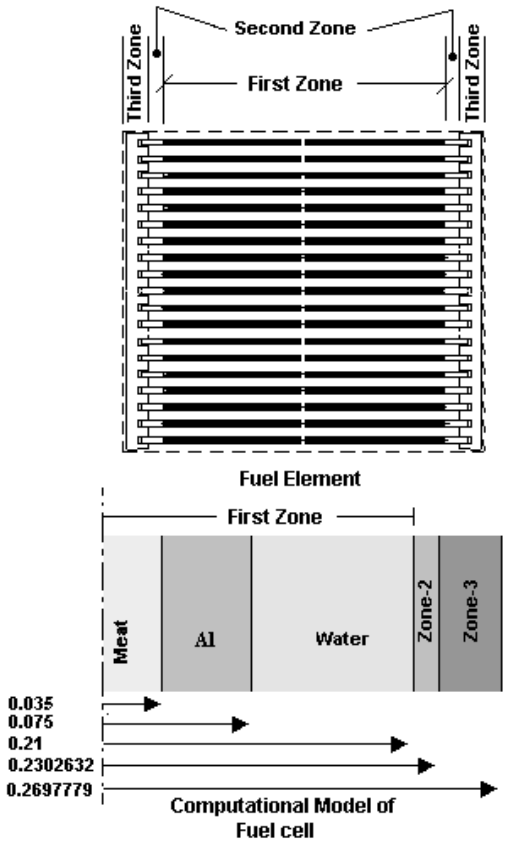

Fig. 3. Fuel cell model of three homogenous zones (all dimensions are in cm).

The cell constants of each region in the computational cell model are calculated through applying the computational model. Then the cell constants of zone-1 of the model are obtained by homogenization of the meat, aluminum and water inside it. Therefore, this model has three sets of cell constants for the core calculation step.

6. Cell constants

Although the calculations at the core level are the only available direct means to analyze the above two investigated models to determine the most suitable one, it is useful to compare between the related values of the cell constants of the two models. The cell calculations for both cell models are carried out in three condensed energy groups namely,

- Fast energy group: 10 MeV to 0.821MeV,

- Epi-thermal energy group: 0.821 MeV to 1.02 eV,
- Thermal energy group: 1.02 eV to 0 eV.

The limits of thermal group are chosen to minimize upscattering to epi-thermal group and to agree with limits proposed by the WIMS code for cell calculations. Tables 3, 4 and 5 show the calculated values of different cell constants for one and three zone models, each table at an energy group. The average value of each cell constants named B of the three-zone model is obtained by summing the product of the cell constant value B_i and the volume fraction (V_i) of its zone as:

$$(B_{ave}) = Sum\ [(B_i) \times (V_i)]\ ;\quad i = 1,2,3.$$

The comparison between values in tables 3, 4 and 5 indicate the following:

1. The average values of the cell constants of the three homogenous zone model B are slightly higher than the related ones for the one homogenous zone model A except for the values of diffusion coefficients. The differences between the Σ_s values of A and B are the highest especially in the epi-thermal and thermal energy groups. On the other hand, the differences between the macroscopic absorption and fission cross sections of A and B are considerably small.

Table 3
The fast cell constants of the two fuel element models

Cell constant	Number of homogenous zone(s)					Difference (%) $\frac{(A) - (B_{ave})}{(A)}$
	One (A)	Three				
		Zone #1 (B_1)	Zone #2 (B_2)	Zone #3 (B_3)	Average (B_{ave})	
D	2.53215	2.4717	1.8956	2.3014	2.3925	5.5%
Σ_a	1.0989E-03	1.2649E-3	5.6213E-4	4.8132E-4	1.1001E-3	- 0.1%
$\nu \times \Sigma_f$	1.6804E-03	2.1386E-3	0	0	1.6725E-3	0.5%
Σ_{tr}	1.3164E-01	1.3486E-1	1.7585E-1	1.4484E-1	1.3933E-1	- 5.8%
Σ_f	6.0605E-04	7.7260E-4	0	0	6.0423E-4	0.3%
$\Sigma_{s\ 1 \to 1}$	6.1203E-02	5.6733E-2	5.7637E-2	8.7410E-2	6.1220E-2	- 0.03%
$\Sigma_{s\ 1 \to 2}$	6.9239E-2	7.6862E-2	1.1765E-1	5.6951E-2	7.7005E-2	-11.2%
$\Sigma_{s\ 1 \to 3}$	0	0	0	0	0	--
D/Σ_a	2.304E+3	--	--	--	2.175E+3	5.6%

Table 4
The Epi-thermal cell constants of the two fuel element models

Cell constant	Number of homogenous zone(s)					Difference (%) $\frac{(A) - (B_{ave})}{(A)}$
	One (A)	Three				
		Zone #1 (B_1)	Zone #2 (B_2)	Zone #3 (B_3)	Average (B_{ave})	
D	9.5281E-1	8.7025E-1	6.1396E-1	1.06902	8.6670E-1	9.0%
Σ_a	6.8978E-3	8.9081E-3	4.7729E-4	5.4383E-4	7.0535E-3	- 2.3%
$\nu \times \Sigma_f$	5.7451E-3	7.4395E-3	0	0	5.7944E-3	- 0.9%
Σ_{tr}	3.4984E-1	3.8303E-1	5.4292E-1	3.1181E-1	3.8460E-1	- 9.9%
Σ_f	2.3579E-3	3.0534E-3	0	0	2.3782E-3	- 0.9%
$\Sigma_{s\ 2 \to 1}$	0	0	0	0	0	--
$\Sigma_{s\ 2 \to 2}$	3.0430E-1	3.3038E-1	4.7180E-1	2.8348E-1	3.3413E-1	- 9.8%
$\Sigma_{s\ 2 \to 3}$	3.86419E-02	4.3739E-2	7.0649E-2	2.7789E-2	4.3424E-2	-12.4%
D/Σ_a	1.381E+2	--	--	--	1.229E+2	11 %

Table 5
The Thermal cell constants of the three fuel element models

Cell constant	Number of homogenous zone(s)					Difference (%) $\frac{(A)-(B_{ave})}{(A)}$
	One (A)	Three				
		Zone #1 (B_1)	Zone #2 (B_2)	Zone #3 (B_3)	Average (B_{ave})	
D	3.0230E-1	2.6589E-1	1.8817E-1	4.3690E-1	2.7326E-1	9.6%
Σ_a	9.2774E-2	1.1814E-1	1.7590E-2	1.3269E-2	9.4638E-2	- 2.0%
$\nu \times \Sigma_f$	1.6438E-1	2.1514E-1	0	0	1.6625E-1	-1.1%
Σ_{tr}	1.1001E+0	1.25367	1.77145	7.6296E-1	1.2198E+0	-10.9%
Σ_f	6.7631E-2	8.8518E-2	0	0	6.8403E-2	-1.1%
$\Sigma_{s\,3\,\to 1}$	0	0	0	0	0	--
$\Sigma_{s\,3\,\to 2}$	1.4143E-4	1.4541E-4	2.0692E-4	1.0445E-4	1.4400E-4	-1.8%
$\Sigma_{s\,3\,\to 3}$	1.00721	1.13539	1.75366	7.4959E-1	1.12505	-11.7%
D/Σ_a	3.258	--	--	--	2.887	11.4 %

2. The variation in the values of the absorption and fission cross sections between A and B can be attributed mainly to the variation of the atomic density of uranium. So, the values of absorption cross sections are lower for the one homogenous zone model than the other.
3. Although the values of Σ_a and Σ_f of A are less than the related values of B, the probability of a fission occurrence due to thermal neutron absorption Σ_f / Σ_a is higher for A than B. This is due to homogenization effect which causes more slowing down and consequently higher fission macroscopic cross sections.
4. There is no up scattering from epi-thermal and thermal energy groups to the fast one or a direct down scattering from fast to thermal group, but there are noticeable values of the self group scattering especially in the thermal group. In fast group, scattering inside the group is almost the same for both models while in epi-thermal and thermal group the effect of separation of regions is clear. Slowing down has less effect in three zones model due to the existence of aluminum region separated from the rest of the cell. The most efficient slowing down occurrs in one zone homogenous model so, it leads to higher values of macroscopic scattering cross section inside the thermal group.
5. The relatively high absorption of thermal neutrons in water can be clearly observed from the value of Σ_a in zone #2 B_2 with respect to B_3 where the water forms about 2/3 of the volume zone while it forms less than 1/5 of zone #3. Moreover, this also gives an indication that the choice of aluminum as a clad and structural material for fuel element is suitable where the thermal neutron Σ_a is very small.
6. The difference in diffusion coefficient and diffusion area $L^2 = D/\Sigma_a$ is less than 12 % and the rest of data parameters that are used in the two models are almost the same. It indicates that this effective difference between the two models is important in thermal reactors and it leads to the difference in reactivity calculations in core.

7. Core calculations

As a result of having two different cell models, there are two corresponding core computational models. The first one considers the entire region of fuel element (8.1x8.1) cm as one homogenous zone and the second considers the fuel region as five homogenous zones with the dimensions (6.4x8.1), 2x(0.3x8.1) and 2x(0.55x8.1)cm. Figs. 4 and 5 are the fuel core models corresponding to the one and three zone cell models, respectively.
The active length (z-direction) is divided into 20 axial segments of 4 cm each. The cell constants of the above two cell models are used as input data in CITVAP diffusion code to calculate the neutronic core parameters such as reactivity, neutron flux, power density, control plate worth, etc. The study of the neutronic validity (at the core calculation level) of the above two models is carried out by the following two methods:

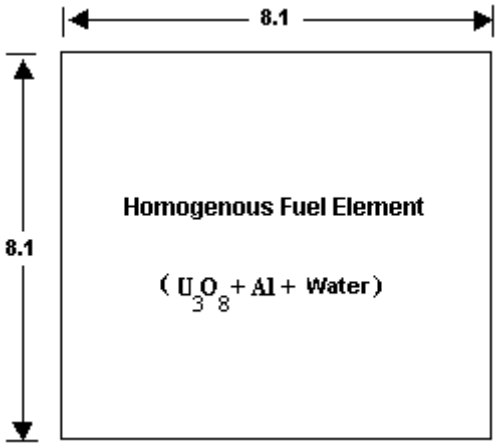

Fig. 4. fuel core computational model of one homogenous region(cm).

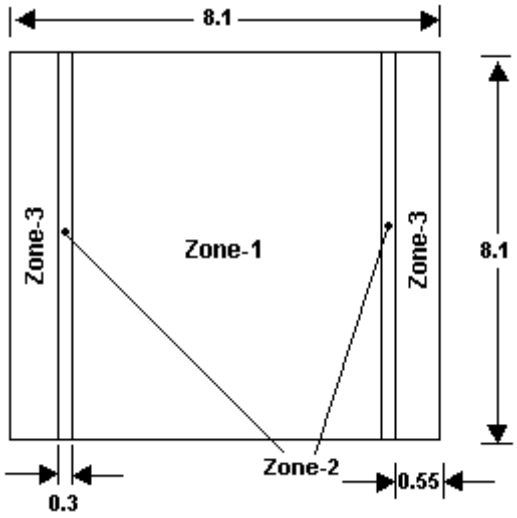

Fig. 5. fuel core computational modelof five homogenous regions(cm).

1. The two fuel models were used to calculate the core neutronic parameters of the theoretical benchmark problem stated in the IAEA-TECDOC-233. The calculated values by Monte Carlo of reactivity of fresh core and at the End Of Cycle (EOC) are compared with the calculated ones using the two different core models.

2. Comparison between the calculated excess reactivity and the averaged calculated reactivity at critical state (reactivity calculational error) and the related measured ones for different operating core configurations (Core 1/98, Core 2/98) during the test period of the commissioning stage.

Tables 6 and 7 show the comparison between results of the benchmark and core measurements on one side and those obtained by the calculations on the other side for the two models.

Table 6 shows that the calculated value of reactivity of fresh core for one homogenous zone of fuel element is almost the same of the related calculated value by Monte Carlo. In addition, the difference between the two values of reactivity at the EOC is not more than 2% while it is about 13% for the fuel model of three homogenous zones. Table 7 shows that the one homogenous zone model gives less calculational error value of criticality determination and more closer values for the excess reactivity. This is expected as the code used for core parameter calculations applies the neutron diffusion theory which is mainly based on Fick's law and is not applicable near system interfaces and material discontinuities. According to the required conditions for accurate applying of Fick's law, it is clear that the one homogenous zone model (more uniform medium and slow varying flux function with position in particular) fulfills relatively these requirements more than the other models. Therefore, the one homogenous zone model is more suitable for the neutronic calculations of the ETRR-2 core.

Table 6
Comparison between the reactivity values of the benchmark and calculated reactivity values using the two homogeneous models

Core parameter	Benchmark calculations (pcm) *	Models calculations (pcm)	Difference (%)
ρ(Fresh)	15896 **	15807 +	< -1
		15013 ++	-6
ρ(EOC)	4580**	4493 +	-2
		3979 ++	-13

* 10 MW-Benchmark for 20% enrichment
** Calculated value by Monte Carlo
\+ One homogenous zone model
++ Three homogenous zone model

Table 7
Comparison between measured and calculated reactivity values

Parameter	Measurement (pcm)		Calculated (pcm)	
	1/98	2/98	1/98	2/98
ρ (Critical)	(0)	(0)	288+ -342++	287+ -338++
Excess reactivity	6833	5595	6690+ 5631++	5318+ 3965++

+ One homogenous zone model ++ Three homogenous zones model

8. Conclusions

The analysis of the obtained cell constants and core parameters for both one and three homogenous zones models shows that:

1. The average values of the cell constants of the three homogenous zone model *B* are slightly higher than the related ones for the one homogenous zone model *A* except for the values of diffusion coefficients. The variation in the values of the absorption and fission cross sections between *A* and *B* can be attributed mainly to the variation of the atomic density of uranium. So, the values of absorption cross sections are lower for *A* than *B*.
2. The probability of a fission occurrence due to thermal neutron absorption Σ_f / Σ_a is higher for *A* than *B*. This is due to homogenization effect which causes more slowing down and consequently lower capture to fission ratio.
3. In fast group, scattering inside the group is almost the same for both cell models while in epi-thermal and thermal group the effect of separation of regions is clear. Slowing down has less effect in three zones model due to the existence of aluminum region separated from the rest of the cell. The most efficient slowing down occurrs in one zone homogenous model so, it leads to higher values of macroscopic scattering cross section inside the thermal group.
4. The relatively high absorption of thermal neutrons in water is clearly observed from the value of Σ_a in zone #2 B_2 with respect to B_3 where the water forms about 2/3 of the volume zone while it forms less than 1/5 of zone #3. Moreover, this also gives an indication that the choice of aluminum as a clad and structural material for fuel element is suitable where the thermal neutron Σ_a is very small.
5. The difference in diffusion coefficient and diffusion area $L^2 = D/\Sigma_a$ is about 12 % while the rest of cell constants are almost the same. It indicates that this difference between the two models is important in thermal reactors and it leads to the difference in reactivity calculations in the core.
6. The one homogenous cell zone model is a more accurate choice for core neutronic calculations. It has the advantages of giving closer values for the core parameters calculations and leading to build a simpler core model.

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