THERMAL NEUTRON FLUX DISTRIBUTION IN ET-RR-2 REACTOR THERMAL COLUMN

by

Mahmoud M. IMAM[1] and Hassan ROUSHDY[2]

The thermal column in the ET-RR-2 reactor is intended to promote a thermal neutron field of high intensity and purity to be used for following tasks: (a) to provide a thermal neutron flux in the neutron transmutation silicon doping, (b) to provide a thermal flux in the neutron activation analysis position, and (c) to provide a thermal neutron flux of high intensity to the head of one of the beam tubes leading to the room specified for boron thermal neutron capture therapy. It was, therefore, necessary to determine the thermal neutron flux at above mentioned positions. In the present work, the neutron flux in the ET-RR-2 reactor system was calculated by applying the three dimensional diffusion depletion code TRITON. According to these calculations, the reactor system is composed of the core, surrounding external irradiation grid, beryllium block, thermal column and the water reflector in the reactor tank next to the tank wall. As a result of these calculations, the thermal neutron fluxes within the thermal column and at irradiation positions within the thermal column were obtained. Apart from this, the burn up results for the start up core calculated according to the TRITION code were compared with those given by the reactor designer.

INTRODUCTION

ET-RR-2 is a multi-purpose research reactor of the MTR type designed by the Argentinean company INVAP. The reactor was constructed in co-operation with Egypt and went critical at the end of 1997 [1]. The reactor is 22 MW strong, with uranium fuel enriched to 19.7%. It is cooled and moderated by light water reflected by beryllium. The reactor core is situated in an open tank. The first core of the reactor consists of 29 fuel elements of three distinct types. In addition to the standard fuel elements (type F1), two other types (F2 and F3) with lower U-235 contents were used:

– 7 fuel elements of 404.7 gm U-235 per element (type F1),

– 8 fuel elements of 148.2 gm U-235 per element (type F2), and

– 14 fuel elements of 209 gm U-235 per element (type F3).

Position 15 within the core is occupied by a cobalt irradiation device. A zircalloy chimney and an external grid array with a total of 114 available locations for the beryllium block, beryllium reflector elements, aluminum and water elements surround the core. A part of the external grid array is occupied by the beryllium block situated at one end of the core. Opposite to it, next to the external grid, is the graphite thermal column with its locations for the beryllium reflector and aluminum elements. The thermal column itself is a graphite block covered with aluminum measuring: $122.5 \times 113.5 \times 62.5$ cm. The thermal column is shielded from the core with 10 cm of lead and from the tank wall with 10 cm of bismuth. Three vertical holes of cylindrical shape, each with a diameter of 22 cm and depth of 50 cm, are located in the thermal column. They are indicated by A, B, and C in Fig. 1. Figure 2 shows a vertical section in the thermal column.

The two positions, A and B, are to be seen as neutron transmutation silicon doping positions,

Authors' addresses:
[1] Atomic Energy Authority, Cairo, Egypt
[2] Department of Eng., Math. and Physics, Faculty of Engineering, Cairo University, Giza, Egypt

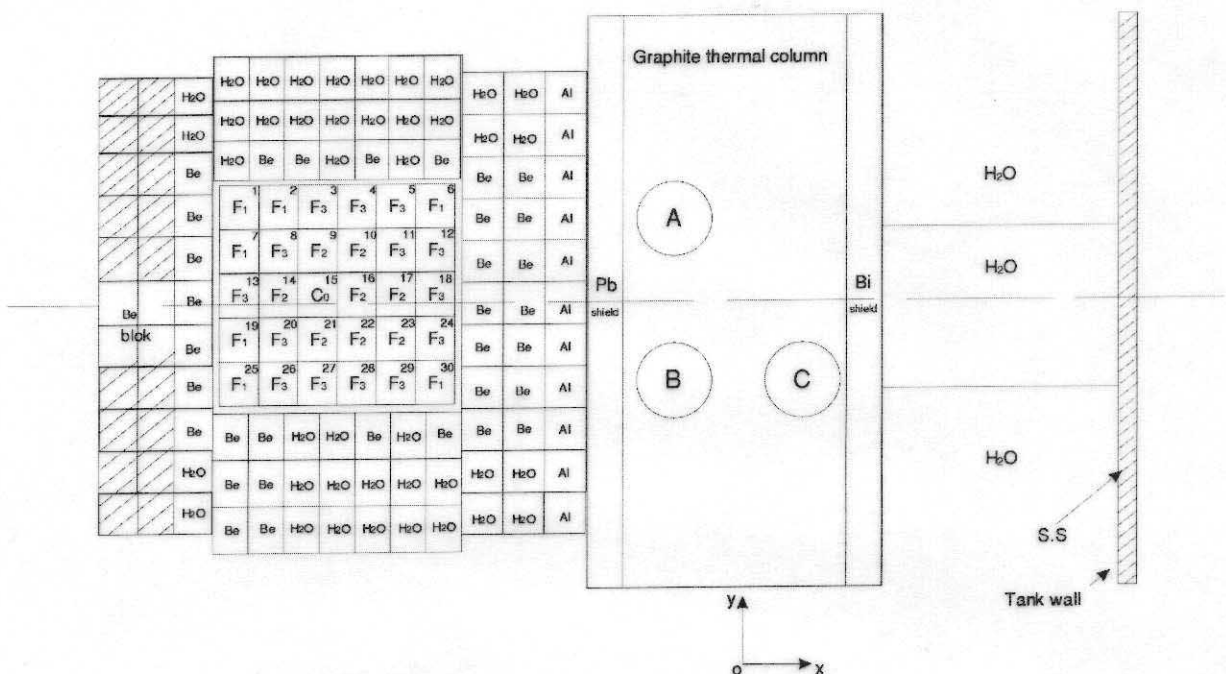E-mail address of corresponding author:
roushdy@hotmail. com (H. Roushdy)

Figure 1. Reactor system from beryllium block to reactor tank

while position C is used for neutron activation analysis. Figure 1 shows the reactor system from the beryllium block to the reactor tank wall. The reactor tank is made of stainless steel (S.S).

FIRST START UP OF ET-RR-2 REACTOR CORE

Figure 1 gives the initial fuel loading of the first core of the ET-RR-2 reactor which consists of

Figure 2. Vertical section in graphite thermal column

three types of fuel elements. According to the proposed fuel management scheme for operating the reactor [2], from the time it went critical up to the present, the reactor was in operation for a part of a cycle lasting arround 6.7 full power days. After that, the following fuel movements were achieved:
– fresh fuel element in $6 \rightarrow 5 \rightarrow 11 \rightarrow 16 \rightarrow$ out, and
– fresh fuel element in $30 \rightarrow 29 \rightarrow 28 \rightarrow 22 \rightarrow$ out.

Thus, two fresh fuel elements of the standard F1 type were inserted in positions 6 and 30 and two fuel elements corresponding to positions 16 and 22 within the core removed. The external grid configuration was also changed because a certain number of beryllium reflectors were inserted in order to insure the availability of irradiation locations and so as to allow the build up of an operating fuel cycle lasting at least 15 full power days.

RESULTS AND IMPLICATIONS

All calculations carried out according to the TRITON code [3, 4] were based on the Hanson-Roach sixteen energy groups cross section library [5, 6].

Table 1 gives the burn up results of the fuel at different positions within the core as given by the reactor designer INVAP [7] and as calculated according to the TRITON code applied. The comparison between the two results shows that the TRITON calculations carried out in our work have,
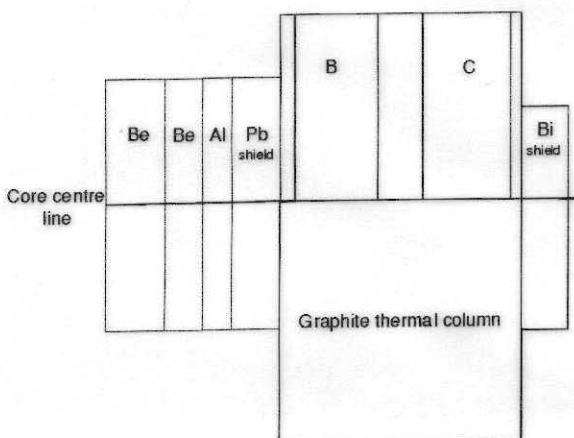
**Figure 3. Thermal flux along the re-
actor system from beryllium block
to reactor tank along x-direction**

*1 – Beryllium block, 2 – Beryllium reflector,
3 – Reactor core chimney, 4, 5, 6, 7, 8, and 9
– Fuel elements in position 25, 26, 27, 28, 29,
and 30 respectively, 10 – Aluminum element,
11 – Lead shield, 12 – Graphite thermal
column, 13, 14 – Irradiation position B and C
in thermal column, 15 – Bismuth shield, 16 –
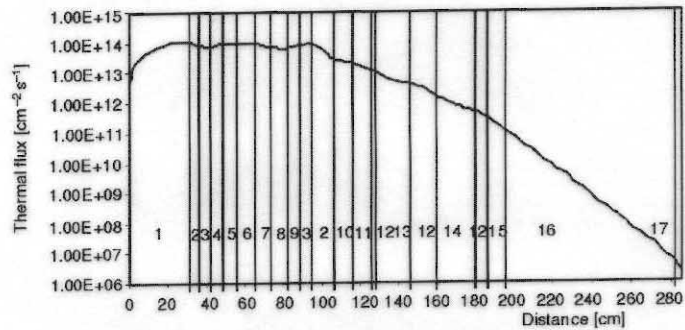Water reflector, 17 – Stainless steel tank wall*

Table 1. Burn up results

2.13* 1.78**	2.20 1.89	2.75 2.72	2.81 2.79	2.49 2.68	2.05 1.81
2.51 2.17	3.03 3.24	3.53 4.05	3.42 3.98	2.97 3.42	2.71 2.98
2.96 3.19	3.44 4.25	Co	3.62 4.54	3.24 4.16	2.82 3.18
2.45 2.16	3.01 3.27	3.44 4.20	3.36 4.13	3.07 3.77	2.63 2.87
2.09 1.79	2.51 2.60	2.69 2.84	2.63 2.77	2.37 2.44	1.88 1.66

*   Burn up % by TRITON
** Burn up % by INVAP

to a great extent, reflected the results obtained by
the reactor designer. Calculations for this verifica-
tion were based on neither the same reactor com-
puter code nor the cross section library used by the
reactor designer. The said agreement in burn up
results verifies the accuracy of our flux calculation
results. For the first time ever, thermal neutron flux
calculations in the graphite thermal column of the
ET-RR-2 reactor have been executed – a fact never
calculated or experimentally measured before.

Figure 3 shows the thermal neutron flux along
the reactor system, starting with the beryllium block
passing through the reactor core, the external irradia-
tion grid, graphite thermal column and the water
reflector, up to the reactor tank wall. Longitudinally,
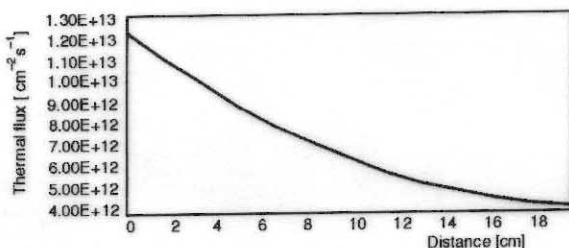this flux covers a distance of more than 2.8 meters.

Figures 4 and 5, respectively, show the thermal
neutron flux in the longitudinal direction at irradiation
positions B and C within the thermal column.

Figures 6, 7, and 8, respectively, show the
thermal neutron flux in the vertical direction at
irradiation positions A, B, and C within the thermal
column. The thermal flux in the vertical direction at
these positions is at its maximum at the bottom and
at its minimum value at the top.

The average thermal neutron flux at the three-
irradiation positions (A, B, C) within the thermal
column is as follows:
– at position A: $4 \cdot 10^{12}$ cm^{-2}s^{-1},
– at position B: $4 \cdot 10^{12}$ cm^{-2}s^{-1}, and
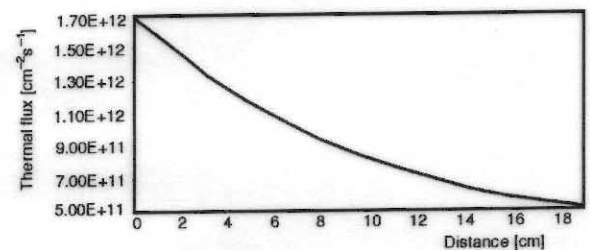– at position C: $0.5 \cdot 10^{12}$ cm^{-2}s^{-1}.

**Figure 5. Thermal flux inside the irradiation position
C in thermal column along x-direction**

**Figure 4. Thermal flux inside the irradiation position
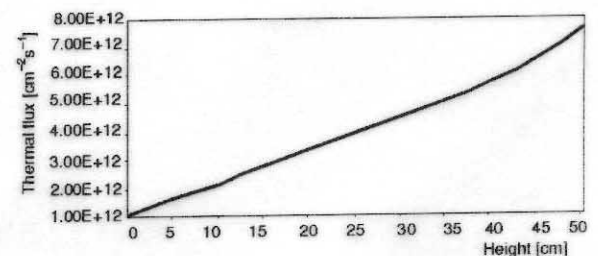B in thermal column along x-direction**

**Figure 6. Thermal flux inside the irradiation position
A in thermal column along z-direction from top to
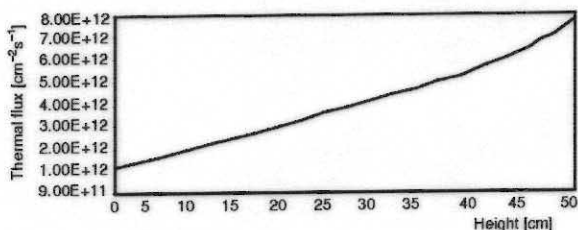bottom**

Figure 7. Thermal flux inside the irradiation position B in thermal column along z-direction from top to botttom
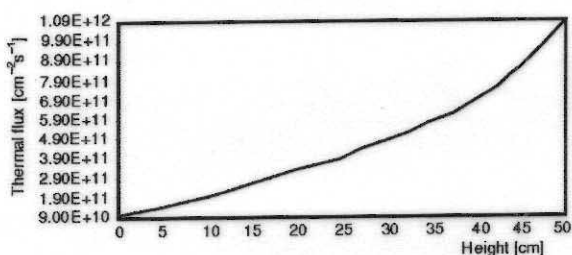

Figure 8. Thermal flux inside the irradiation position C in thermal column along z-direction from top to bottom

Therefore, positions A and B are to be seen as neutron transmutation silicon doping positions, while position C is an adequate position for sample irradiation used in neutron activation analysis.

CONCLUSION

This is the first time ever that the thermal neutron flux within the thermal column of an ET-RR-2 reactor was calculated. It has never been calculated or experimentally measured before. Owing to the results of the work here presented, the thermal neutron flux at the three-irradiation positions within the thermal column is now known.

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Махмуд М. ИМАМ, Хасан РУЖДИ

РАСПОДЕЛА ФЛУКСА ТЕРМИЧКИХ НЕУТРОНА У ТЕРМИЧКОЈ КОЛОНИ ET-PP-2 РЕАКТОРА

Термичка колона реактора ET-PP-2 остварује поље термичких неутрона високог интензитета и чистоће са циљем да обезбеди термичке неутроне за следеће процесе: (а) допирање силицијума поступком неутронске трансмутације, (б) позициону анализу неутронском активацијом, и (в) терапију засновану на захвату термичког неутрона бором. Отуда је било потребно да се одреди просторна расподела флукса термичких неутрона. У овом раду, флукс неутрона у реакторском систему ET-PP-2 (језгро, брилијумски блок, термичка колона и водени рефлектор) одређен је применом тродимензионалног дифузионог кода ТРИТОН са урачунатим изгарањем. Као резултат, израчунат је термички неутронски флукс у термичкој колони и у просторима за озрачивање унутар колоне. Поред овога, упоређено је изгарање почетног језгра реактора рачунато програмом ТРИТОН са подацима датим од стране пројектанта реактора.