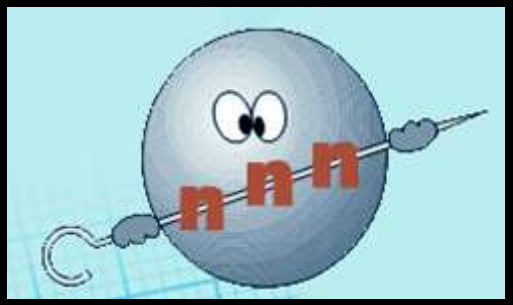
In the name of Allah
the most beneficent the most merciful



Fundamental activities in setting up of Tehran research reactor BNCT facility

Y. Kasesaz, E. Bavarnegin* and M. Golshanian
Nuclear Science and Technology Research Institute, Iran

Dubna, Russia, May 2017

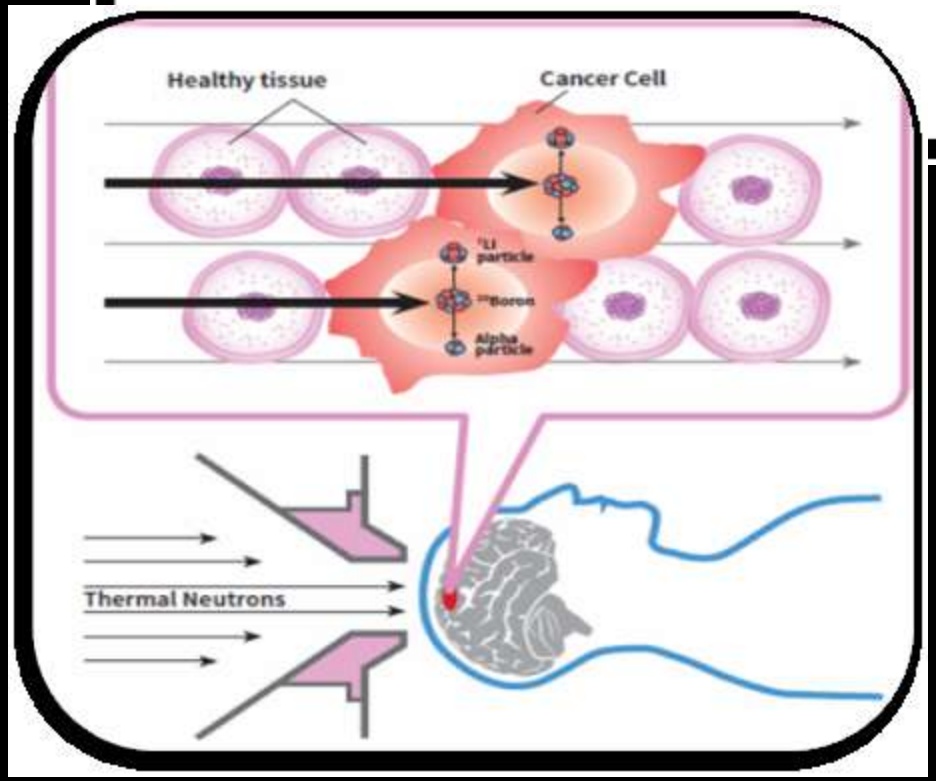
BNCT Principle

$$[^{10}_{5}B] + [^{1}_{0}n] \rightarrow [^{11}_{5}B]^{*}$$

$$[^{11}_{5}B]^{*} \rightarrow [^{4}_{2}He] + [^{7}_{3}Li] + 2.79\ \text{MeV}\ (6.1\%)$$

$$[^{11}_{5}B]^{*} \rightarrow [^{4}_{2}He] + [^{7}_{3}Li]^{*} + 2.31\ \text{MeV}\ (93.9\%)$$

$$[^{7}_{3}Li]^{*} \rightarrow [^{7}_{3}Li] + \gamma\ (0.48\ \text{MeV})$$



BNCT Principle

Some BNCT clinical trials around the world

Clinical trial in Taiwan

Recurrent ethmoid sinus carcinoma in the nose

Reference: Wang, Ling-Wei, et al. "Fractionated BNCT for locally recurrent head and neck cancer: experience from a phase I/II clinical trial at Tsing Hua open-pool reactor." *Applied Radiation and Isotopes* 88 (2014): 23-27.

Some BNCT clinical trials around the world

Clinical trial in Japan

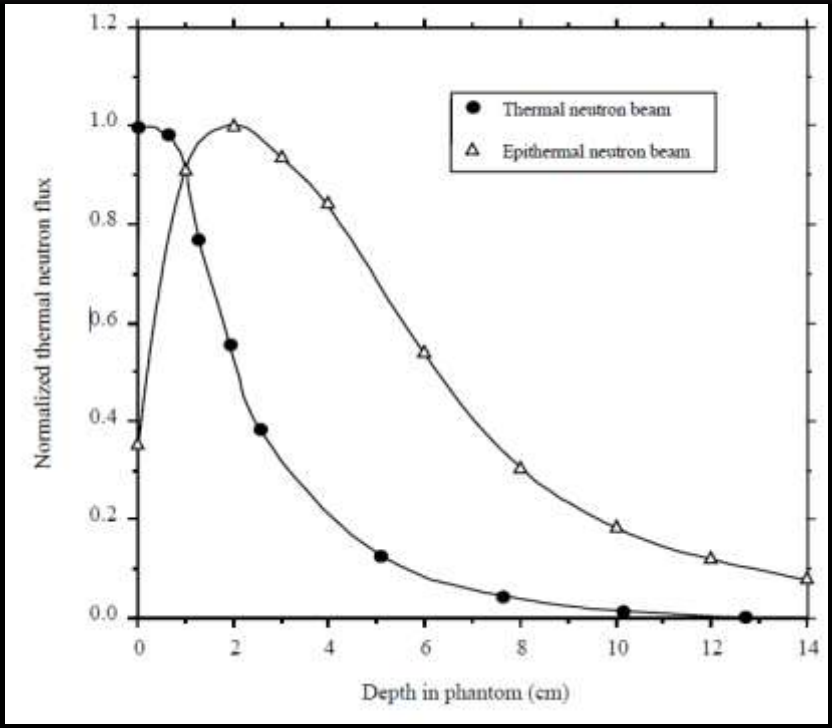
Reference: Kato, Itsuro, et al. "Effectiveness of BNCT for recurrent head and neck malignancies." *Applied Radiation and Isotopes* 61.5 (2004): 1069-1073.

Some BNCT clinical trials around the world

Clinical trial in Finland

Reference: Kankaanranta, Leena, et al. "Boron neutron capture therapy in the treatment of locally recurred head and neck cancer." *International Journal of Radiation Oncology* Biology* Physics* 69.2 (2007): 475-482.

The qualified neutron beam for BNCT



In BNCT, we need an adequate thermal neutron within the boron labeled tumor cells

Comparison of thermal neutron flux-depth distributions for different incident neutron energies

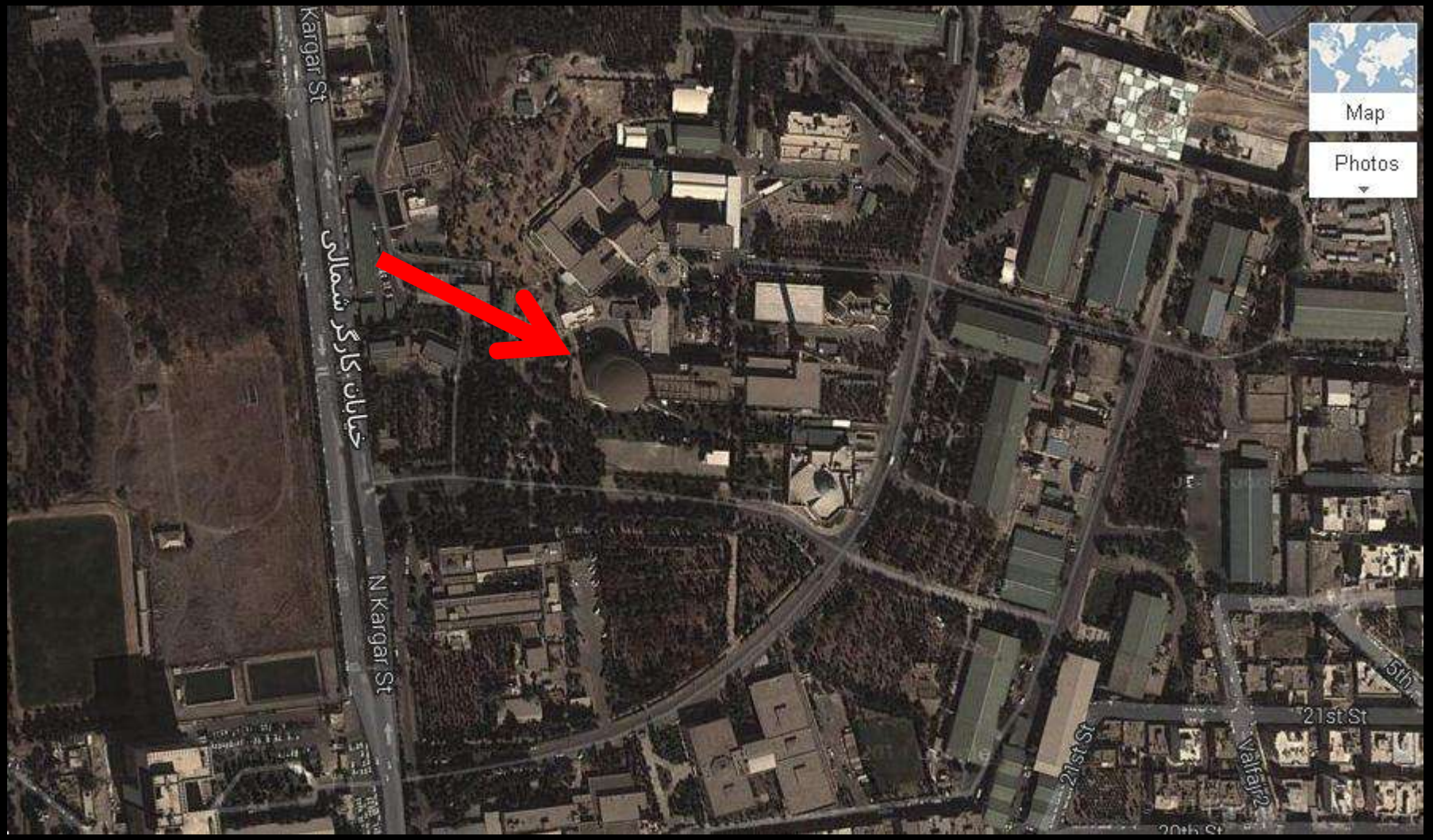
neutron beam parameters recommended by the IAEA for BNCT

Thermal BNCT		Epithermal BNCT	
Parameter	Recommended value	Parameter	Recommended value
$\phi_{thermal}$ ($cm^{-2}s^{-1}$)	$>10^9$	$\phi_{thermal}$ ($cm^{-2}s^{-1}$)	$>10^9$
$\phi_{thermal}/\phi_{total}$	>0.9	$\phi_{thermal}/\phi_{total}$	>20
$D_{fast}/\phi_{thermal}$ ($Gycm^2$)	$<2\times10^{-13}$	$D_{fast}/\phi_{thermal}$ ($Gycm^2$)	$<2\times10^{-13}$
$D_{gamma}/\phi_{thermal}$ ($Gycm^2$)	$<2\times10^{-13}$	$D_{gamma}/\phi_{thermal}$ ($Gycm^2$)	$<2\times10^{-13}$

Fast energy E>10keV
Epithermal energy 0.5 eV<E<10keV
Thermal energy E<0.5 eV

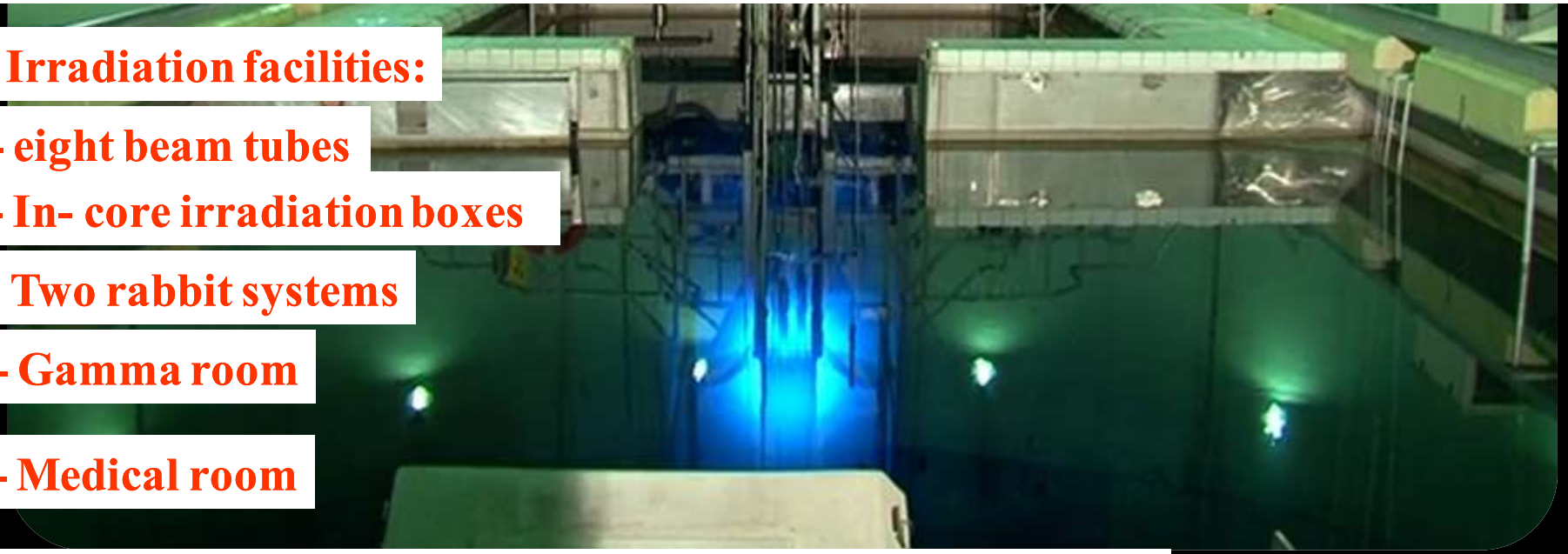
BNCT activities in Tehran Research Reactor (TRR)

Tehran Research Reactor (TRR)

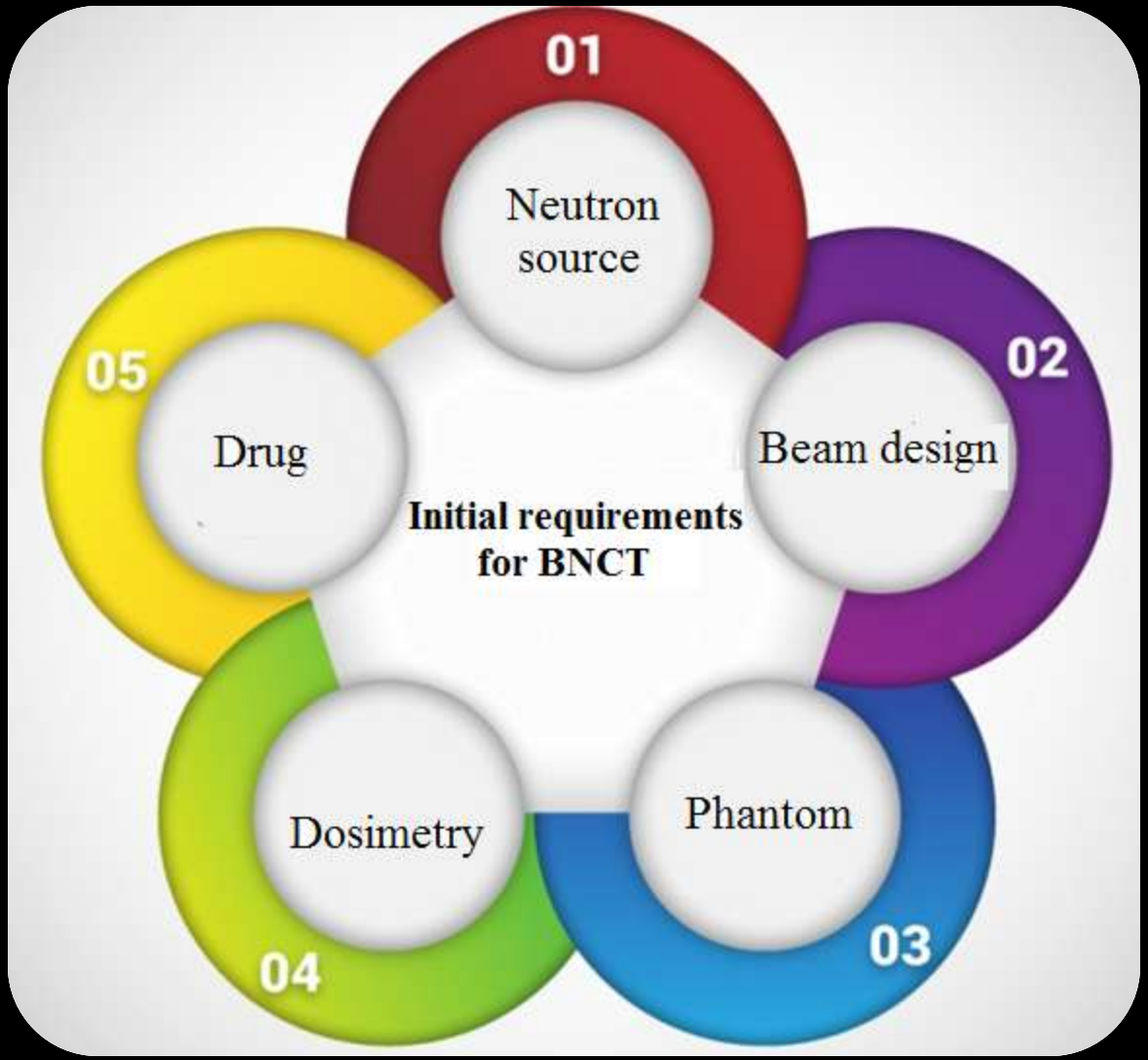


Tehran Research Reactor (TRR)

- TRR is a 5 MW MTR (Material Test Reactor)
- It is a pool type research reactor
- Its fuel assemblies contain low enriched uranium fuel
- Plates are in the form of U3O8 Al alloy
- The reactor pool has two major parts, a stall-end and an open pool.
- The reactor core can operate in both parts of the pool for different purposes.



- Irradiation facilities:
- eight beam tubes
- In- core irradiation boxes
- Two rabbit systems
- Gamma room
- Medical room
- Main applications: radioisotopes production and training


01
Neutron source
02
Beam design
03
Phantom
04
Dosimetry
05
Drug
Initial requirements for BNCT

BNCT researches in Tehran Research Reactor (TRR)

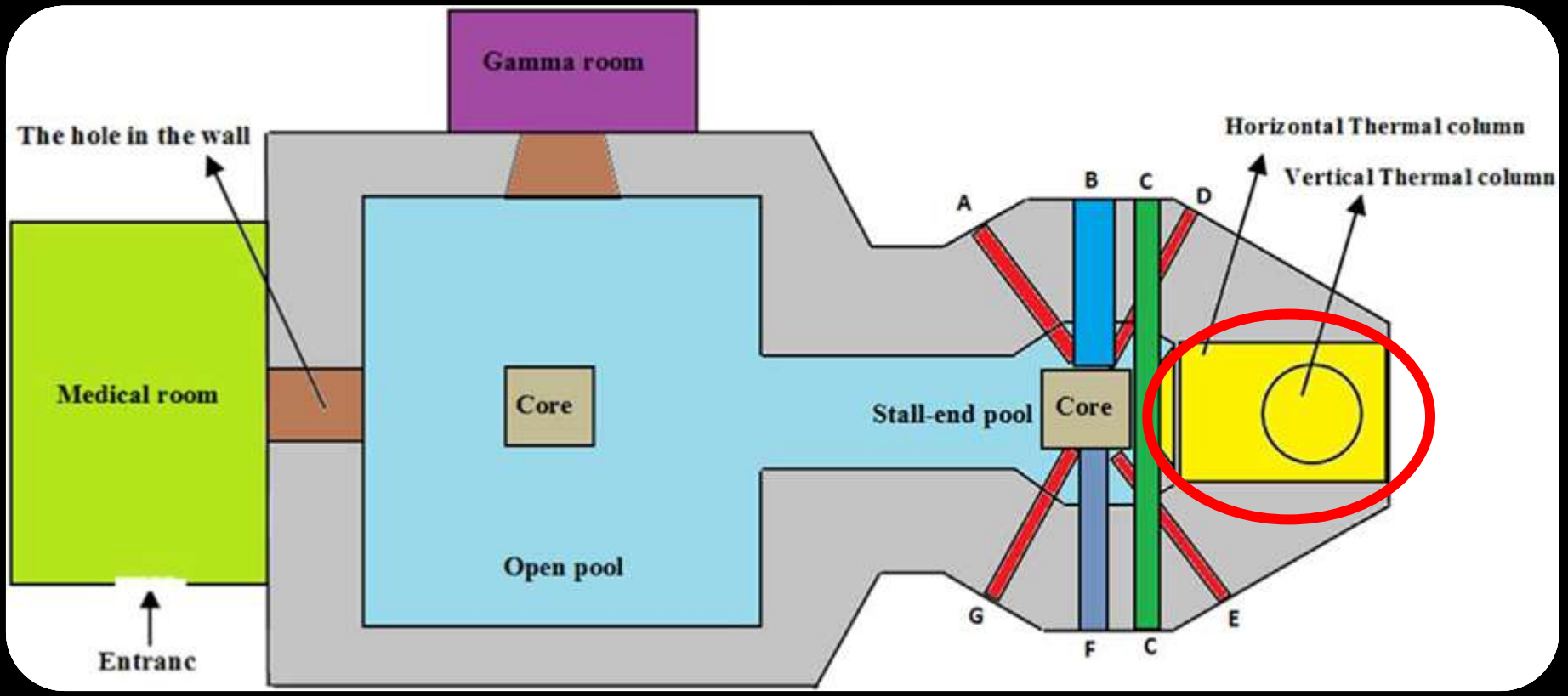
BNCT research in Iran was initiated in 1990s by Prof. Pazirandeh and Dr. Marashi. Their research was focus on the use of A-beam tube of Tehran Research Reactor (TRR) to produce a proper neutron beam for BNCT.

The results showed that the neutron flux at none of the beam exits is sufficient for BNCT. Since then, no attempt was made to design a proper neutron beam at TRR.

BNCT researches in TRR were restarted by Dr. Kasesaz in 2010 and many efforts have been performed including: feasibility study, beam design, construction of a phantom and etc..

Step1: feasibility study

Tehran Research Reactor (TRR)

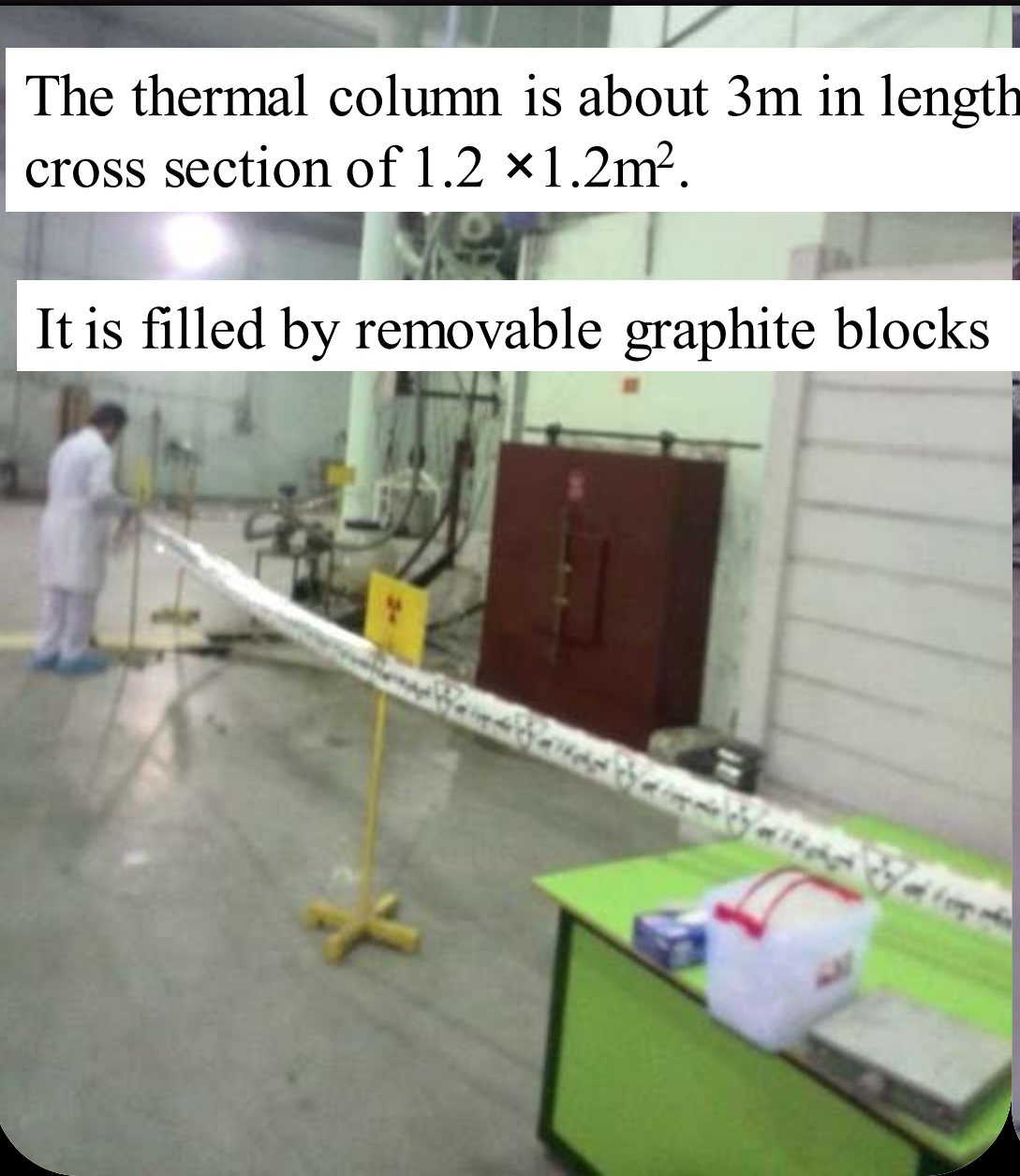


It has been shown that the thermal column of TRR is the best section which can be adapted for BNCT

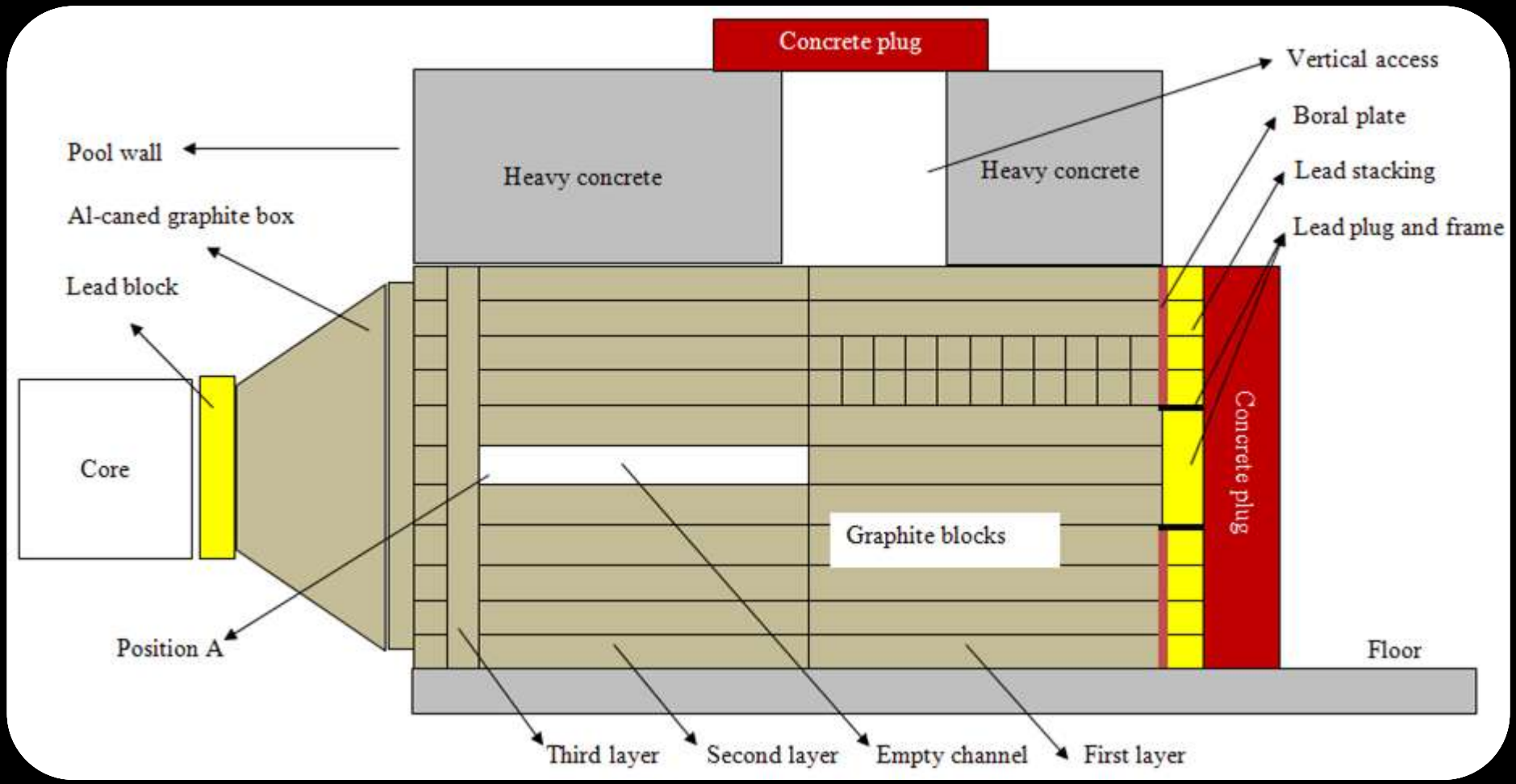
The thermal column structure

The thermal column is about 3m in length with a wide square shape cross section of 1.2 ×1.2m^2.

It is filled by removable graphite blocks



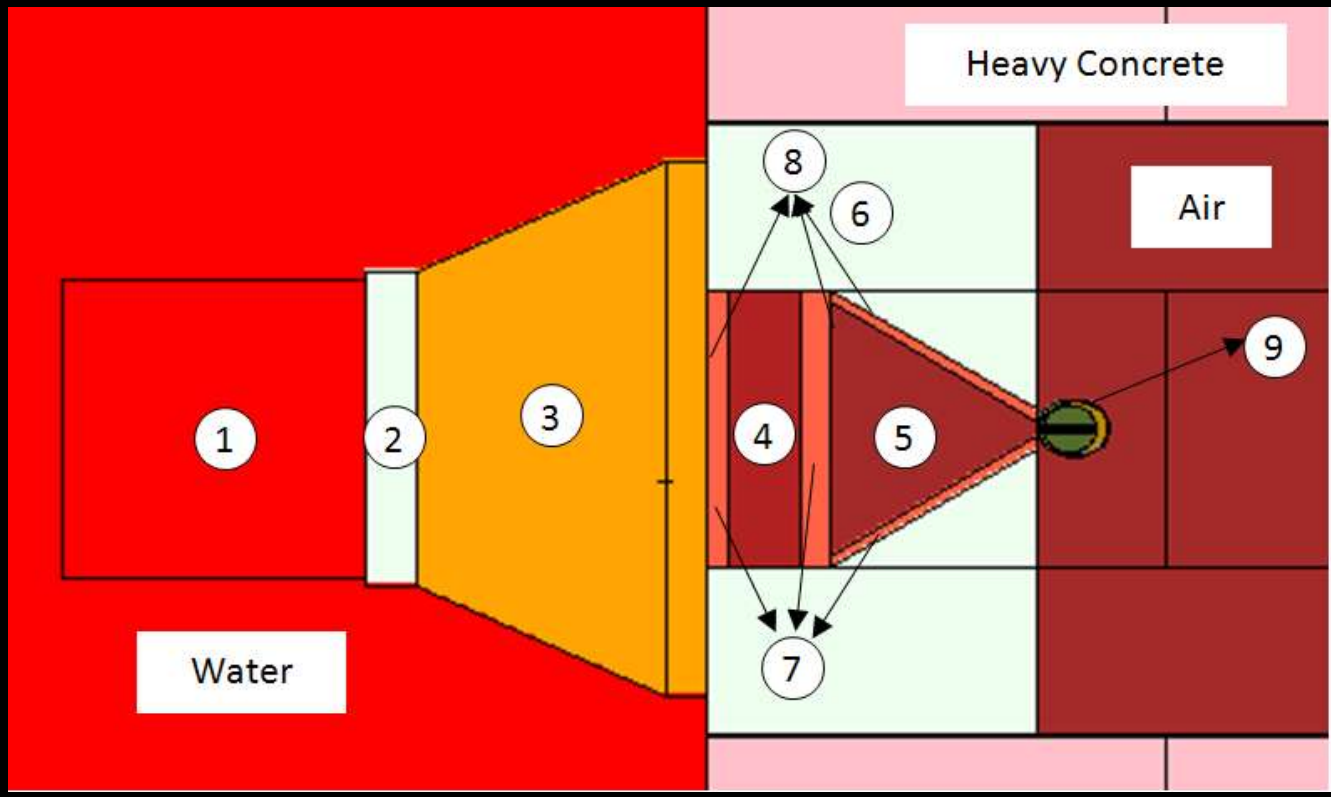
The thermal column structure



Step2: design of an epithermal neutron beam

Designed epithermal neutron beam in thermal column

MCNP geometry,
(1) Core,
(2) Pb block,
(3) Al-caned graphite box,
(4) Moderator,
(5) air filled collimator,
(6) Pb Reflector,
(7) Bi gamma shield,
(8) Cd filter,
(9) Phantom.



Designed epithermal neutron beam in thermal column

Comparison of neutron beam parameters of the designed beam and other facilities

BNCT beam port parameters	IAEA limit	THOR	FiR-1	R2-0	TRR
$\varphi_{epi}\left(10^9 \frac{n}{cm^2\ s}\right)$	>1	1.69	1.2	1.43	0.65
$\frac{\dot{D}_{fast}}{\varphi_{epi}}(10^{-13}\ Gy\ cm^2)$	<2	2.8	3.3	8.3	2.2
$\frac{\dot{D}_{gamma}}{\varphi_{epi}}(10^{-13}\ Gy\ cm^2)$	<2	1.25	0.9	12.6	2.1
$\frac{\varphi_{thermal}}{\varphi_{epi}}$	<0.05	–	–	–	0.04

Comparison of in- phantom parameters of the designed beam and other facilities

Facility	ADDR (cGy/min)	AD (cm)	TD (cm)	TT (min)	Tumor: normal tissue ^{10}B concentration (ppm)
THOR (Liu et al., 2004)	50	8.9	5.6	25	65:18
FiR-1 (Binns et al., 2002)	45	9	5.8	30	65:18
R2-0 (Binns et al., 2002)	67	9.7	5.6	20	65:18
TRR	49	7.5	4.9	25	65:18

Removing graphite blocks

Removing graphite blocks






Designed epithermal neutron beam in thermal column

Main Challenges of construction process

- ✓ In practice, due to the high gamma dose caused by activated materials in the reactor structure, it was impossible to remove all graphite blocks from the thermal column in order to produce an epithermal neutron beam.

- ✓ However the thermal column of TRR has been modified to provide an appropriate thermal neutron beam for BNCT.

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

A feasibility study of the Tehran research reactor as a neutron source for BNCT

Yaser Kasesaz [a,*], Hossein Khalafi [a], Faezeh Rahmani [b], Arsalan Ezzati [a], Mehdi Keivany [a], Ashkan Hosnirokh [a], Mehrdad Azizi [a], Shamami Mahdi Monshizadeh [a]

[a] Nuclear Science and Technology Research Institute (NSTRI), Tehran, Iran
[b] Department of Radiation Application, Shahid Beheshti University, Tehran, Iran

ELSEVIER journal homepage: www.elsevier.com/locate/apradiso

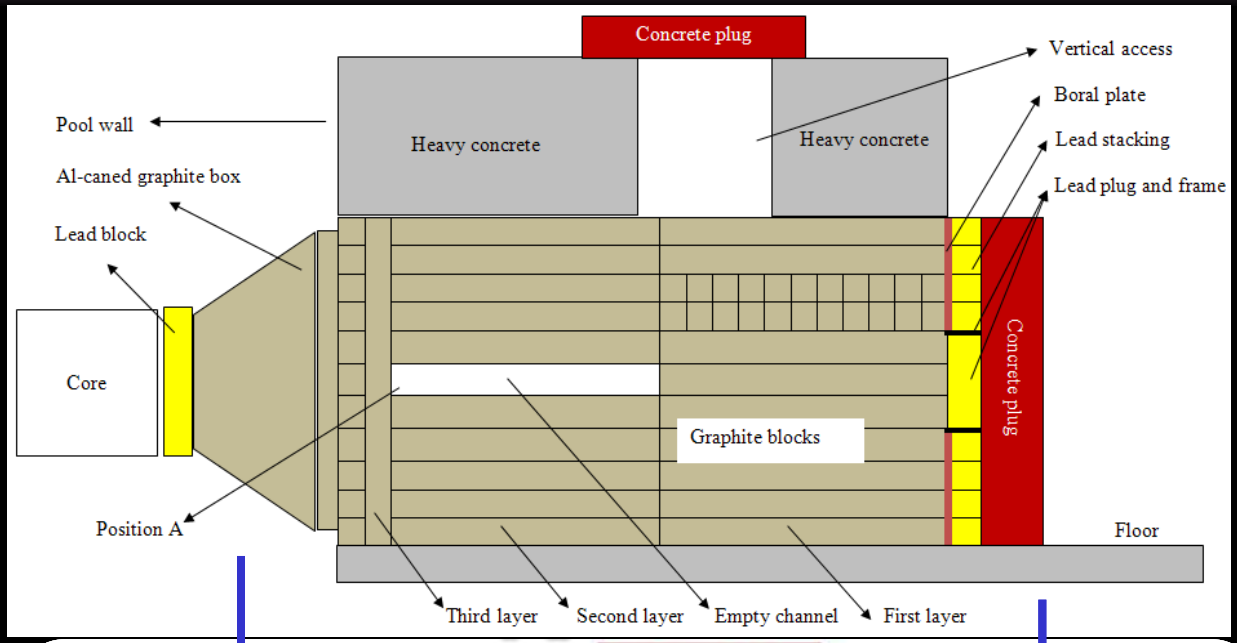
Design of an epithermal neutron beam for BNCT in thermal column of Tehran research reactor

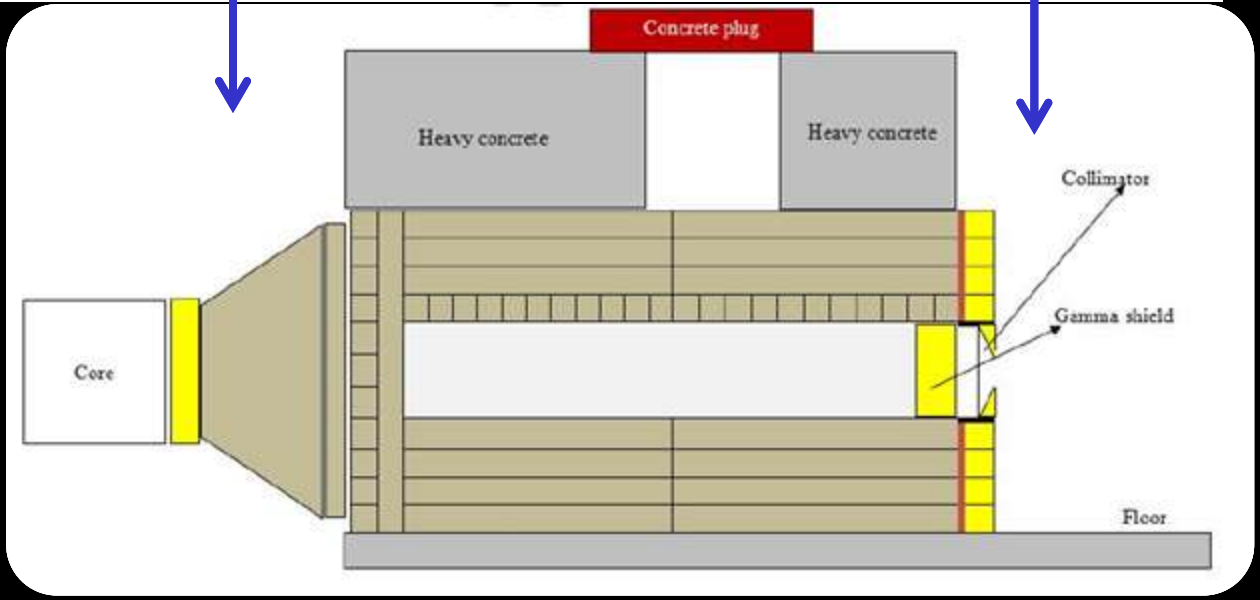
Yaser Kasesaz [a], Hossein Khalafi [a,*], Faezeh Rahmani [b]

[a] Nuclear Science and Technology Research Institute (NSTRI), Atomic Energy Organization of Iran (AEOI), Islamic Republic of Iran
[b] Department of Radiation Application, Shahid Beheshti University, Islamic Republic of Iran

Step3: construction of a thermal neutron beam

The prepared thermal neutron beam





The prepared thermal neutron beam

The prepared thermal neutron beam

Properties of constructed thermal neutron beaam

Facility	Reactor power (MW)	$\phi_{thermal}$[a] ($\times 10^9$n cm^{-2} s^{-1})	$\phi_{thermal}/\phi_{toto}$	$D_{gamma}/\phi_{thermal}$ ($\times 10^{-13}$ Gy cm^2)
IAEA recommended value[b]	–	> 1	> 0.9	< 2
RA-3[c]	10	9	0.99	1.73
JRR-2[a]	10	1.1	0.99	1.21
JRR-4 (Mode 1)[a]	3.5	2	0.96	5
JRR-4 (Mode 2)[a]	3.5	0.6	0.99	3.24
TRR (our work)	5	0.56 ± 0.09	0.99	2.8

[a] $E_{thermal} < 1$ eV.
[b] IAEA-TECDOC-1223 (2001).
[c] Miller et al. (2009).

The prepared thermal neutron beam

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Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

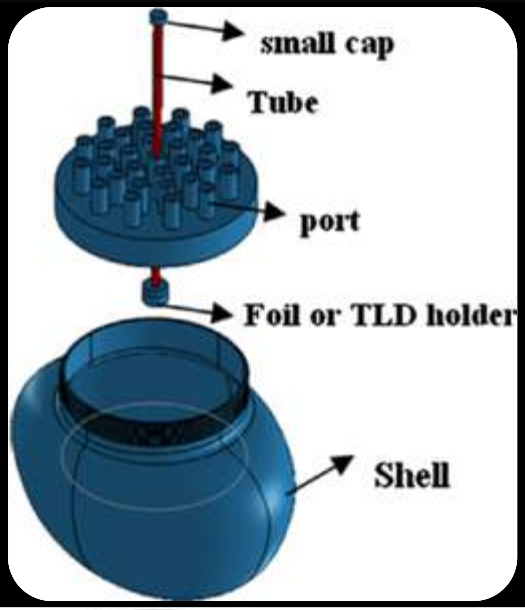
Design and construction of a thermal neutron beam for BNCT at Tehran Research Reactor

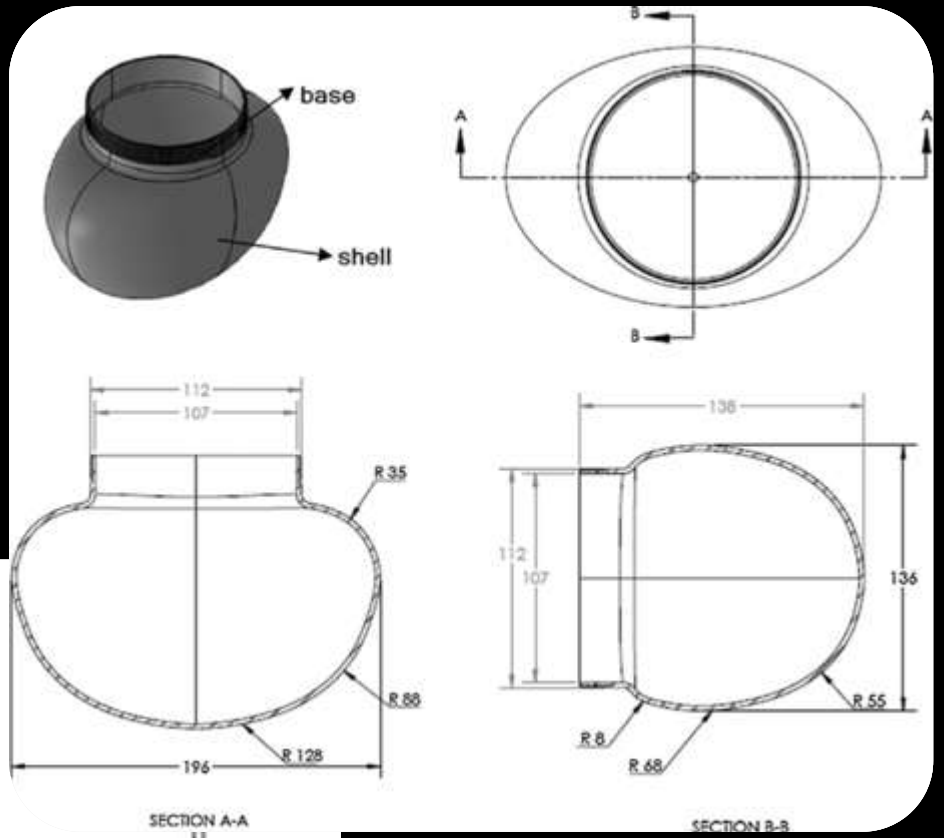
Yaser Kasesaz [a], Hossein Khalafi [a,*], Faezeh Rahmani [b], Arsalan Ezzati [a], Mehdi Keyvani [a], Ashkan Hossnirokh [a], Mehrdad Azizi Shamami [a], Sepideh Amini [a]

[a] *Nuclear Science and Technology Research Institute (NSTRI), Iran*
[b] *Department of Physics, K. N. Toosi University of Technology, Iran*

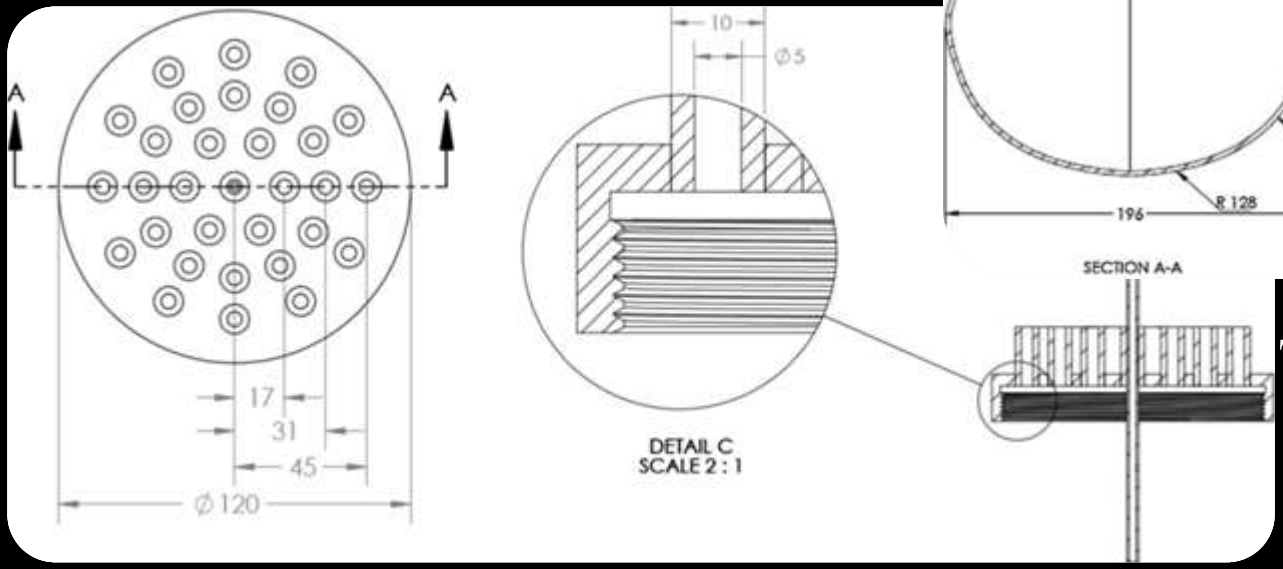
Step4: construction of a head phantom

Construction of a head phantom





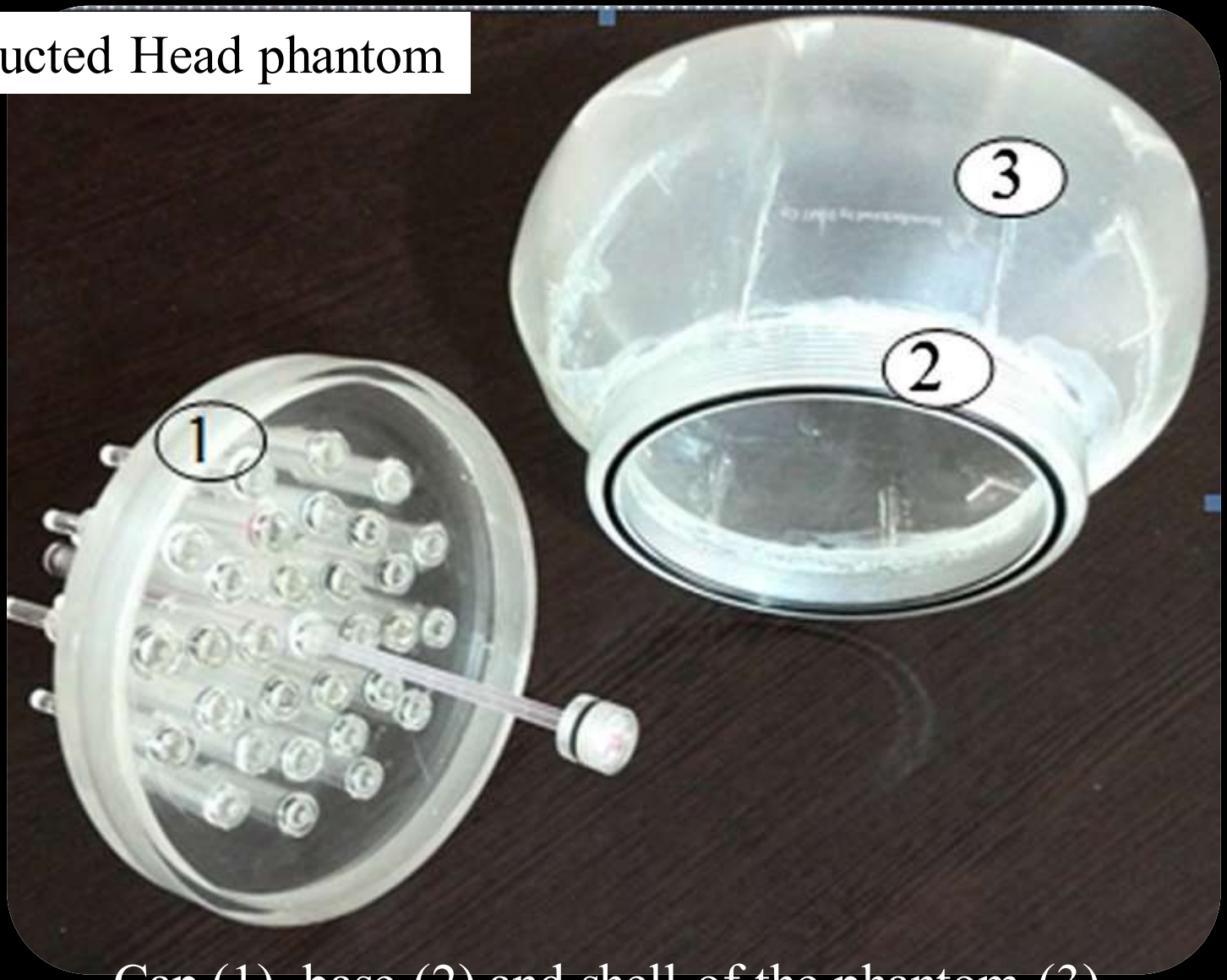
The phantom shell plan.



Phantom cap plan.

Construction of a head phantom

Constructed Head phantom

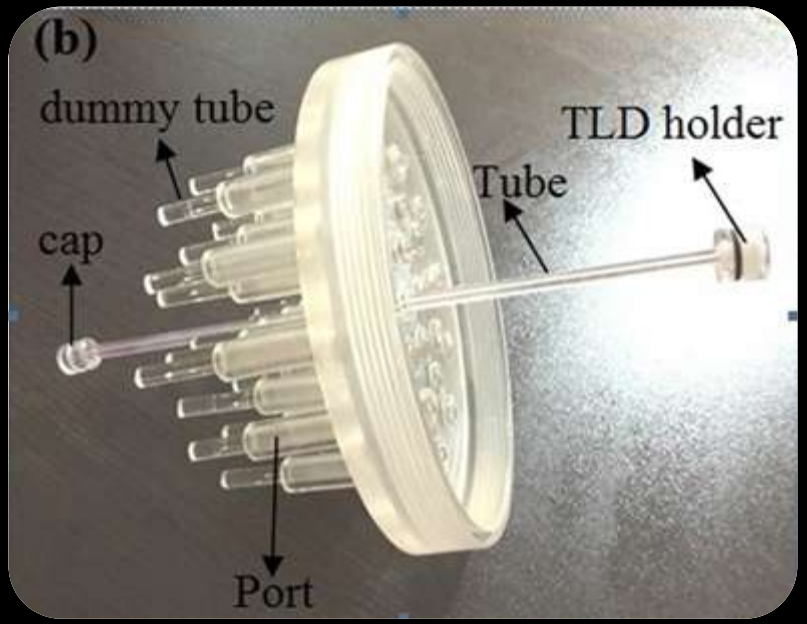


Cap (1), base (2) and shell of the phantom (3).

Construction of a head phantom

(a) Foil and TLD holders

Different parts of the phantom



(b) view of insertion of dosimeter carrier tube in the port

Construction of a head phantom

(1) Head phantom shell,
(2) acrylic tubes,
(3) TLD holder,
(4) foil holder,
(5) tumor place,
(6) cap for sealing the tubes,
(7) dummy tubes.

Construction of a head phantom

Position of the head phantom in front of the constructed thermal neutron beam

Construction of a head phantom

THE THREE DIMENSIONAL MAP OF DOSE COMPONENTS IN A HEAD PHANTOM FOR BORON NEUTRON CAPTURE THERAPY

by

Elham BAVARNEGIN [1], *Alireza SADREMOMTAZ* [1*], *and Hossein KHALAFI* [2]

[1]Department of Physics, University of Guilan, Rasht, Iran

Measurement 89 (2016) 145–150

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Construction of a head phantom for mixed neutron and gamma field dosimetry in TRR

Elham Bavarnegin [a,b], Hossein Khalafi [b], Alireza Sadremomtaz [a], Yaser Kasesaz [b,*]

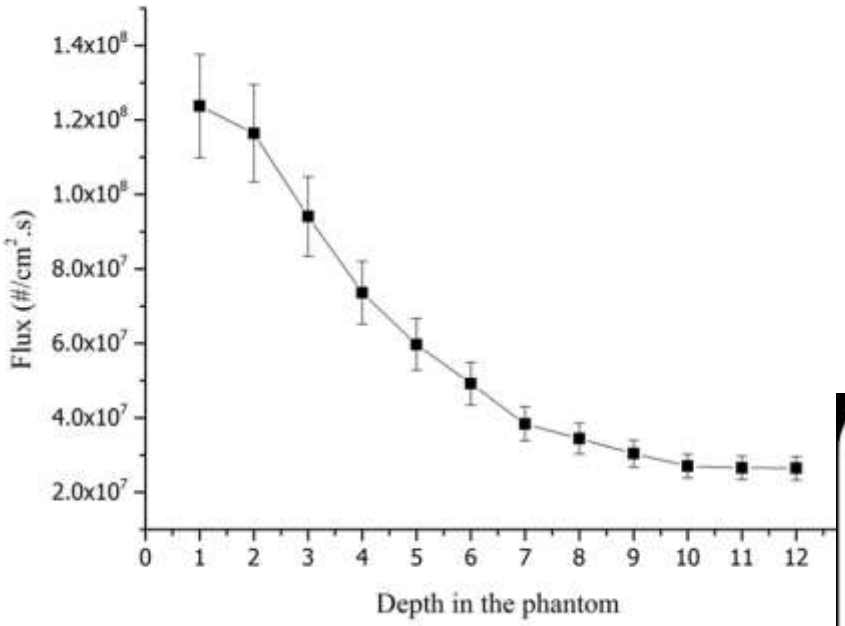
[a] *Department of Physics, University of Guilan, Rasht, Iran*
[b] *Nuclear Science and Technology Research Institute (NSTRI), Tehran, Iran*

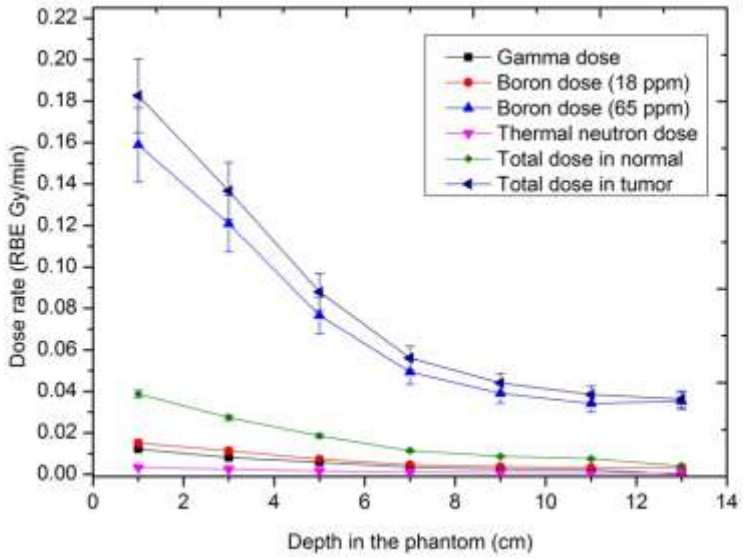
Step5: dosimetry study

dosimetry studies

The head phantom has been filled with water containing 18 and 65 ppm 10B for normal and tumor tissue, respectively, and then has been irradiated in TRR BNCT beam.

dosimetry studies





dosimetry studies

Original Article

Measurement of in-phantom neutron flux and gamma dose in Tehran research reactor boron neutron capture therapy beam line

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Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Measurement and simulation of the TRR BNCT beam parameters

Elham Bavarnegin [a,b], Alireza Sadremomtaz [b], Hossein Khalafi [a], Yaser Kasesaz [a,*], Mohadeseh Golshanian [a], Hossein Ghods [a], Arsalan Ezzati [a], Mehdi Keyvani [a], Mohammad Haddadi [a]

[a] Nuclear Science and Technology Research Institute (NSTRI), Tehran, Iran
[b] Department of Physics, University of Guilan, Rasht, Iran

ARTICLE INFO

ABSTRACT

dosimetry studies

The head phantom was filled with a N-isopropylacrylamide (NIPAM) gel was irradiated using TRR BNCT beam line, and then was imaged by a magnetic resonance scanner. Eventually, the R2 maps were obtained in different slices of the phantom.

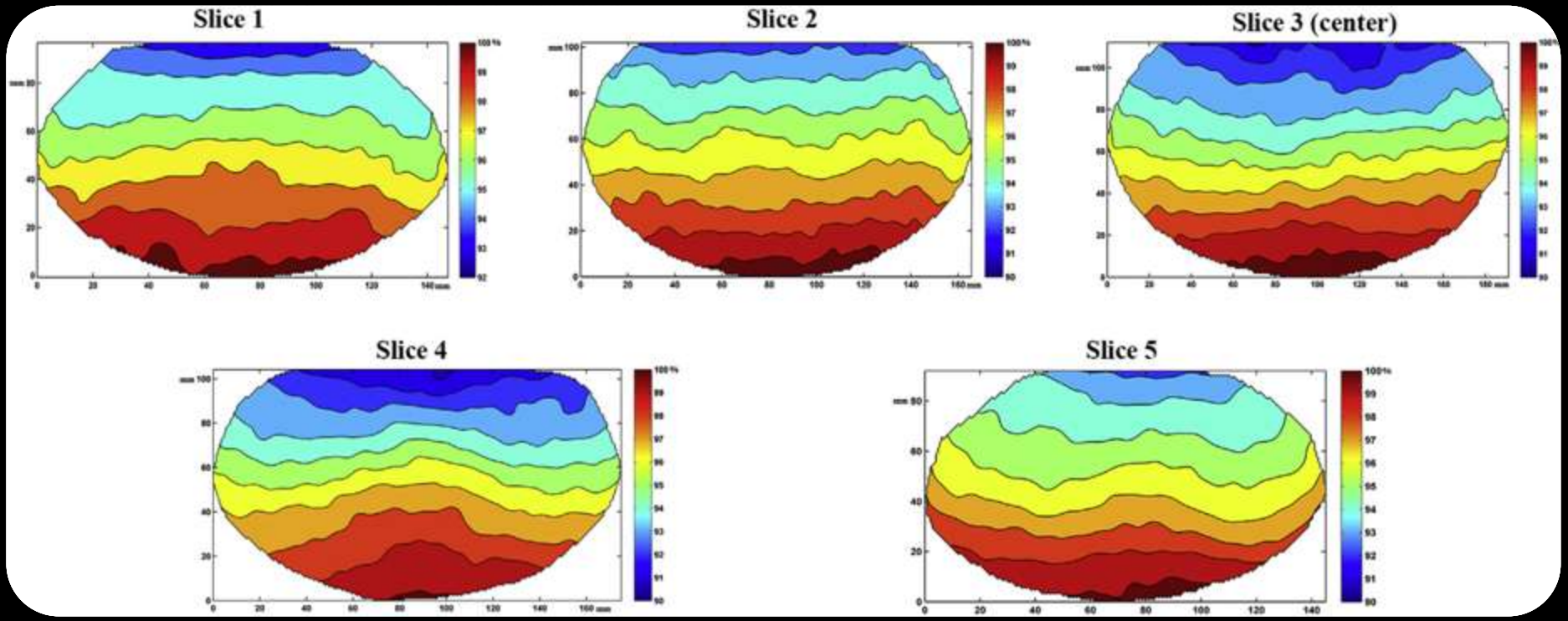
dosimetry studies

The head phantom containing NIPAM gel.

dosimetry studies

The phantom containing NIPAM polymer gel were imaged by a 1.5-T Siemens MR scanner 24 hours after irradiation.

dosimetry studies



Relative dose response of N-isopropylacrylamide (NIPAM) gel in different slices of the head phantom. Results are normalized to the maximum R2 value.

dosimetry studies

Nuclear Engineering and Technology 49 (2017) 189–195

Available online at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

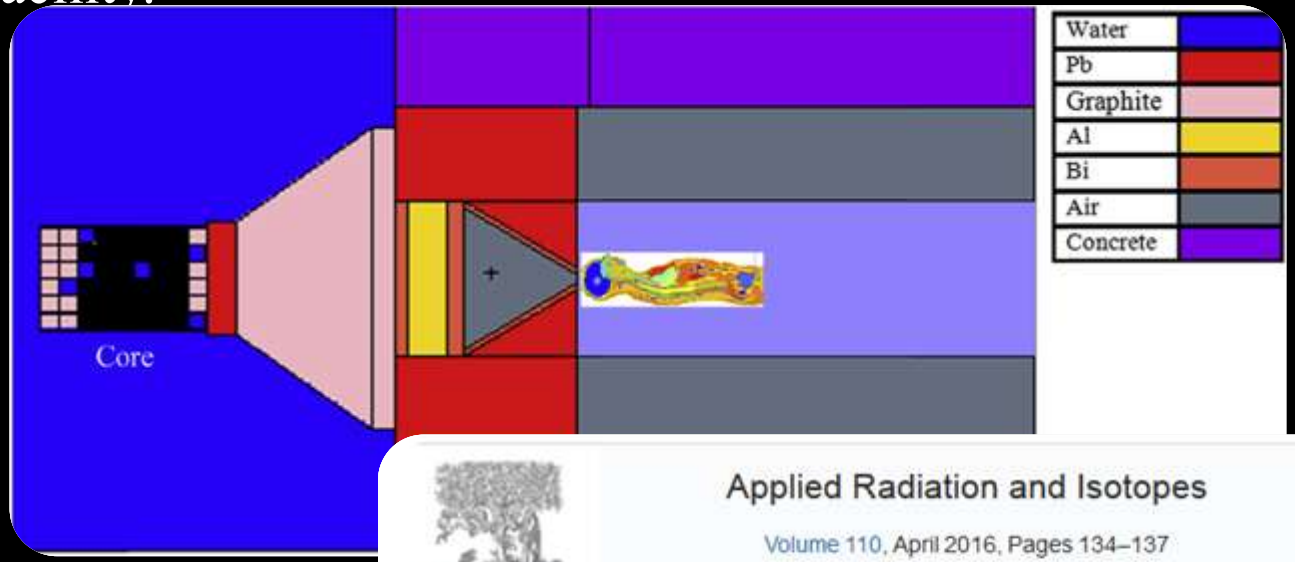
Original Article

Investigation of Dose Distribution in Mixed Neutron-Gamma Field of Boron Neutron Capture Therapy using N-Isopropylacrylamide Gel

Elham Bavarnegin [a,b], *Hossein Khalafi* [b], *Alireza Sadremomtaz* [a], *Yaser Kasesaz* [b], *and Azim Khajeali* [c,d,e,*]

Some other BNCT researches in TRR

- ✓ Dose analysis during BNCT at epithermal beam considering the model of TRR epithermal beam facility. The aim of this work is to get some experiences in dosimetry and also to analyse the performance of the facility.



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Applied Radiation and Isotopes

Volume 110, April 2016, Pages 134–137

Cover image

Evaluation of the effective dose during BNCT at TRR thermal column epithermal facility

Hossein Jarahi[a], Yaser Kasesaz[b], , , Seyed Mohsen Saleh-Koutahi[a]

Show more

http://doi.org/10.1016/j.apradiso.2016.01.012

Some other BNCT researches in TRR

- ✓ Feasibility study of using TRR medical room for BNCT.
- ✓ Synthesis of a new ^{10}B-drug.
- ✓ In TRR, dosimetry researches are focused on the use of polymer gel dosimetry method such as MAGIC-A polymer gel and NIPAM polymer gel which were studied practically for BNCT in TRR.

Some references:

- ✓ Khajeali, A., et al., *Role of gel dosimeters in boron neutron capture therapy*. Applied Radiation and Isotopes, 2015.
- ✓ Khajeali, A., et al., *Capability of NIPAM polymer gel in recording dose from the interaction of 10 B and thermal neutron in BNCT*. Applied Radiation and Isotopes, 2015. **105**: p. 257-263.
- ✓ Abtahi, S., et al., *An investigation into the potential applicability of gel dosimeters for dosimetry in boron neutron capture therapy*. INTERNATIONAL JOURNAL OF RADIATION RESEARCH, 2014. **12**(2): p. 139-149.
- ✓ Abtahi, S., M. Zahmatkesh, and H. Khalafi, *Investigation of an improved MAA-based polymer gel for thermal neutron dosimetry*. Journal of Radioanalytical and Nuclear Chemistry: p. 1-14.

Step4: Prospective BNCT plans at TRR

Prospective BNCT plans at TRR

1) Use of the constructed thermal BNCT beam for the biological studies.

2) Design and construction of a new epithermal BNCT beam (base on medical room) for the clinical trials.

3) Design and construction of a biological sample holder and an automatic system to send a sample to the irradiation position.

4) Design and construction of a system to measure a boron concentration in a blood sample using the neutron activation analysis method based on the pneumatic system.

5) Design and construction of an irradiation room at the thermal BNCT beam exit for animal treatment.

6) Getting some experience in different related fields such as mixed filed dosimetry, neutron measurement, boron concentration measurement, etc.

BNCT research in Tehran Research Reactor (TRR)

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Progress in Nuclear Energy

Volume 91, August 2016, Pages 107–115

Cover image

BNCT project at Tehran Research Reactor: Current and prospective plans

Y. Kasesaz[a], E. Bavarnegin[a, b], M. Golshanian[a, c], A. Khajeali[d], H. Jarahi[e], S.M. Mirvakili[a], H. Khalafi[a]

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http://doi.org/10.1016/j.pnucene.2016.04.010

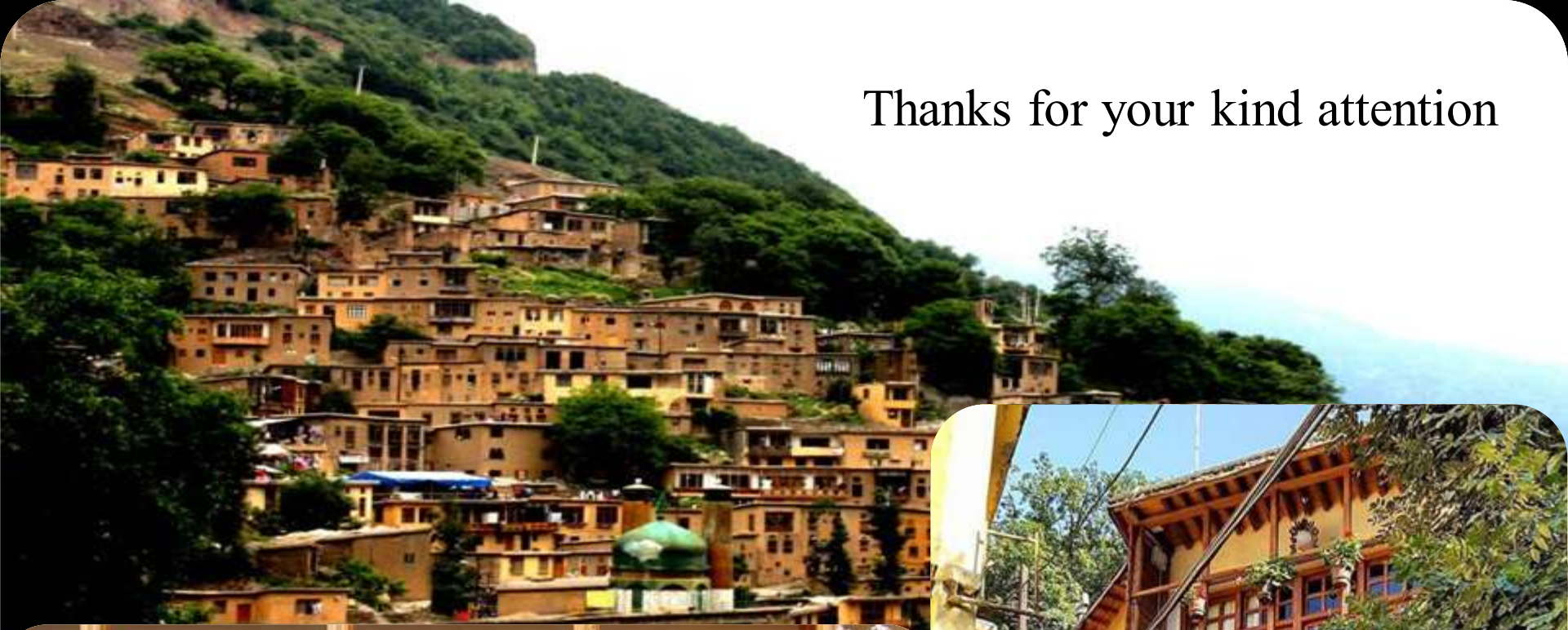
Conclusions

- ✓ Todays we have a good opportunity to consider TRR as a BNCT research centre in Iran.

- ✓ The theoretical and experimental investigations show that TRR has a very good potential for being considered as a pilot facility for BNCT research in the Middle East and could be facilitated for clinical applications

In memory of our dear nuclear scientists

Thanks for your kind attention



Masuleh

a nice city in Gilan province in Iran