The experience from the construction of BNCT facility at the LVR-15 reactor

J. Burian, M. Marek, J. Rataj, S. Flibor
Nuclear Research Institute Rez, plc (NRI),
Rez, Czech Republic

Abstract. The BNCT project at LVR-15 reactor of NRI for treatment of human brain gliomas is before start of clinical trials. A survey of present conditions is included, the attention is devoted to BNCT facility with epithermal neutron beam first of all. The different materials for filter composition were studied, the calculational methods have been used for the determination of neutron and gamma rays in the reactor geometry. Some configurations were experimentally verified. The effort for improvement of epithermal neutron beam parameters in configuration 1998 was concentrated to block of filters remodelling, improvement of collimator-shutter geometry, the choice of optimal reactor core edge configuration. Awaited results from experiment in June 1999 are described.

1. INTRODUCTION

The BNCT interdisciplinary group in the Czech republic decided as a first priority to initiate the glioma clinical trial at the LVR reactor of NRI. The principal aim now is to prepare the Phase I trial, to establish maximum tolerated dose by healthy tissue when irradiating with BSH drug. The activity has been concentrated in this final stage also on improvement of the parameters of the beam. The treatment protocol was prepared and put forward to corresponding authorities for approval.

2. BNCT PROJECT

The development and construction of BNCT facility were realised at **LVR reactor** of NRI Rez. The LVR-15 is a light water reactor with enriched fuel (36 %) and standard thermal power 10 MW. This, on commercial basis running reactor, is used for material testing experiments at water loops and rigs, for radio-pharmaceuticals production, irradiation of silicon crystals, for basic and applied research at horizontal channels, and for BNCT as a source of epithermal neutrons. A beam of epithermal neutrons has been constructed at the LVR empty space of thermal column as described in Fig 1.

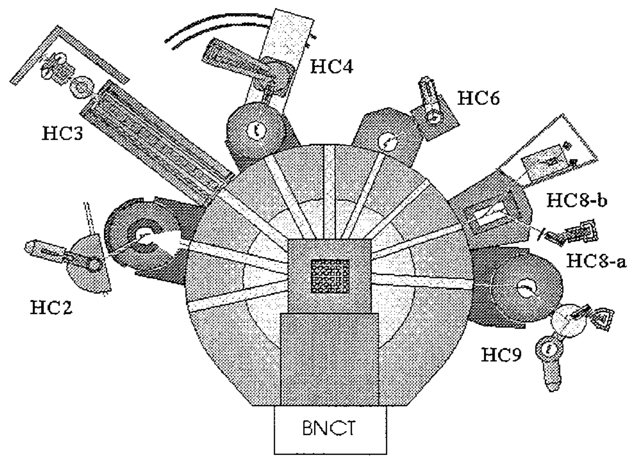

FIG. 10. BNCT at LVR-15 reactor.

The main drawback of our arrangements is a rather long distance between the core and irradiation point (about 4 m).Design principles and development of **epithermal beam** will be described in separate chapter. The monitoring system has been used for **physical dosimetry**, the information from detectors for both neutrons and gamma rays has been collected by an on-line system controlled by a program implemented on a PC. The **irradiation room** from concrete blocks covered by boronated polyethylene is equipped by laser alignment devices, TV camera, intercom, patient treatment table. Outer observation facilities, including PC, TV monitor, beam operating console, communications for patient are installed in **control room.** The internationally-recognised software MacNCTPLAN for computational dosimetry and **treatment planning** is utilised. A **prompt gamma analysis system**, PGA, has been designed and is operated for BNCT purposes at horizontal channel of LVR-15. Good agreement between PGA and standard ICP method was obtained, boron concentration 1 ppm in blood is measurable. The **Protocol** specifying treatment of glioblastoma with BNCT at the LVR has been prepared in details. The domestic supplier Katchem Ltd. is able to produce **boron compound** BSH (as well as L-BPA). The quality of the product is in the agreement with Test of quality control asked in EU project.

3. EPITHERMAL NEUTRON BEAM

For BNCT a high intensity and high quality epithermal neutron beam has to be designed. Low background contamination from fast neutrons and photons has to be reached. Both stochastic methods (as Monte Carlo MCNP code) as well as deterministic method (as TORT discrete ordinates code) can be used as computational tool.

3.1. General principles

Appropriate materials for **filter/moderator** have to offer high resonance scattering cross section in the fast energy range, low cross section in the epithermal range. The filter should absorb thermal neutrons, production of gamma has to be controlled. Acceptable cost of material is supposed. The materials have to be without decomposition in radiation field, without high long term radioactivity, without moisture during long time operation. The following materials as Al, C, S, Al_2O_3, AlF_3, D_2O, $(CF_2)_n$ — Teflon are often used. The combination Al with Al_2O_3 or AlF_3 is very efficient. Cross sections of elements F and O cover the valleys between resonance peaks of Al, due to light mass the moderation is very effective. The appropriate **reflector** can reduce transverse leakage out of the filter, it increases the intensity of the beam. The materials with high scattering cross section and high atomic mass (little energy loss) are used. The lead with low photon production and lower cost is preferred. For **thermal neutron filter** either elements ^{10}B and ^{6}Li with 1/v absorption cross section or Cd with 0.4 eV resonance are appropriate. **Gamma shielding** against fission gammas and gammas from inner parts as Ti, AlF_3, Cd close the configuration usually.

3.2. The configuration 1998

Several assemblies have been designed and experimentally tested during some last years with the aim to determine parameters both of the free beam and the beam inside the phantom [1]. The techniques used for measurement were described in the paper of La Jolla symposium [2]. The configuration 1998 is demonstrated in Fig.2. and described in [3]. Fast neutrons escaping the core and reflector are transported through the empty inner shutter (can be filled by water) to block of filters. Epithermal neutrons are collimated and transferred through the outer shutter to the irradiation point. The block of filters consists of B_4C thin layer, lead-5cm, ten layers aluminium and aluminium fluoride, total thickness 61 cm (35 cm Al, 26 cm AlF_3), lead-11 cm. There is 1 cm Ti and B_4C thin layer just behind Al-C collimator. The characteristics of the beam measured in 1998 are rather low for clinical purposes (Φ_{epi} = 1.82 10^8 n/cm^{2}s for free beam, Φ_{th} = 4.82 10^8 n/cm^2 s, $D_{f.n.}$ = 0.625 Gy/h, D_γ = 1.87 Gy/h in the phantom at depth 2.5 cm).

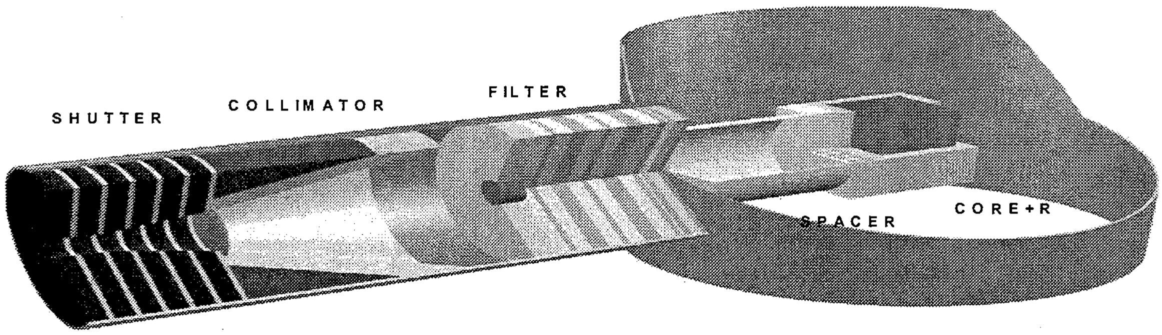

FIG.2. Epithermal neutron beam configuration 1998.

3.3. The configuration 1999

The irradiation time necessary to deliver the treatment dose to the patient at the LVR-15 BNCT facility of configuration 1998 is too long because of the low intensity of the epithermal beam. This was the reason leading to a re-designing of the filter. There are two facts which limit the design. First, the reactor LVR-15 is mostly used for the irradiation of material samples and therefore the core cannot be permanently changed in the way fully satisfying the BNCT requirements. Secondly, the budget which can be used for the new design is limited so that parts of the current filter have to be utilise as far as possible. The final design is therefore a compromise. There were two regions of possible changes which should improve the main characteristics of the beam: — remodelling of core edge, — the changes in the beam parts (filter composition, collimator, shutter).

3.3.1. The core edge

The computational study was realised for the evaluation of different configuration of the core edge. The four fuel elements, air spacers or Be reflectors can be placed to three rows from core to inner shutter. The five variants were taken into consideration, relative fast neutron density flux entering to shutter is understood as coefficient C.

VARIANT	1ST ROW	2ND ROW	3RD ROW	COEFF.
variant 1	air spacers	air spacers	air spacers	C=1
variant 2	Be. refl.	Be refl.	4 fuel el.	C=1.17
variant 3	Be refl.	air spacers	4 fuel el.	C=1.20
variant 4	air spacers	Be refl.	4 fuel el.	C=1.29
variant 5	air spacers	air spacers	4 fuel el.	C=1.56

The influence of the configuration is essential, variant 5 will be used for experimental verification.

3.3.2. The changes in the beam parts.

The **shutter** of configuration 1998 was composed from cylindrical and conical collimators of the total length of 60 cm. It was made of layers of lead and boronated polyethylene. The epithermal neutron flux decreased 80 times when passing through it. The new design of a conical shutter is only 25 cm thick and without the cylindrical part, see Fig.3. Material composition of the walls of conical cavity should ensure a good reflection and low absorption of the epithermal neutrons. Aluminium was supposed to have a good reflective abilities and also to be able shift interacting fast neutron to the epithermal region. As an alternating material lead was also studied. The results shows that the replacement of the 5 cm aluminium by the same thickness of lead resulted in the increase of the epithermal flux by 34%. Additional increase of the wall to 10 cm of lead increased the epithermal flux by 58%. The fast neutron dose ratio to the epithermal neutron was by 5% less in the first case and by 25% in the second.

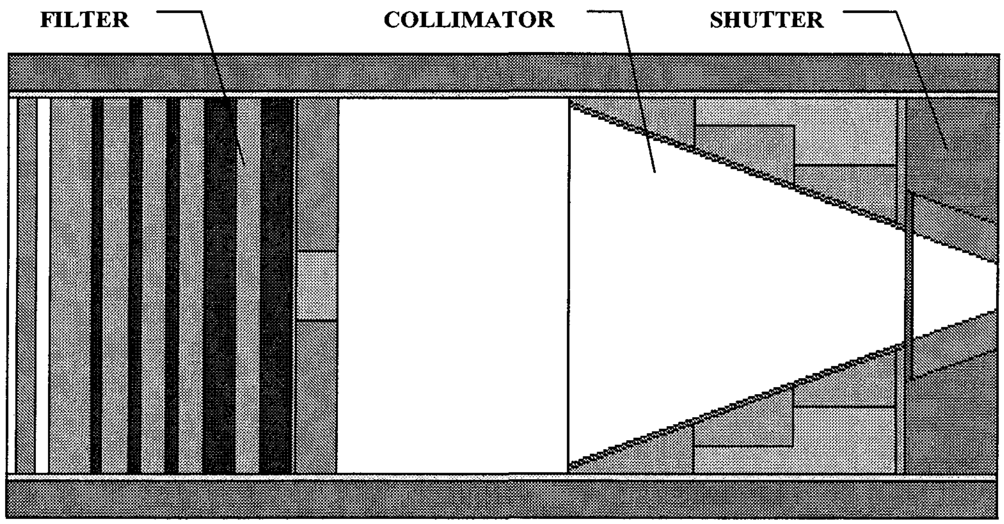

FIG.3. Epithermal neutron beam configuration 1999.

The **beam collimator** is a conical type made of aluminium, the length of it is 90 cm and the diameter changes from 100 cm to 30 cm. To improve its reflecting abilities we tested influence of lead on the inner surface of the collimator. A lead layer of thickness of 10 cm instead of aluminium one resulted in increase of the epithermal neutron flux by 38 %. Even an additional 1 cm layer of lead on the aluminium surface of the collimator caused an increase of 5 %. In the first case the fast neutron dose ratio decreased by 10% and by 3% in the second one. Between the end of filter and the beginning of the collimator there is an empty cylindrical space of 62 cm thick and 1 m in diameter. In case the inner surface of the cylinder had been covered by a 5 cm thick layer of lead the epithermal flux increased by 10 % and fast neutron dose ratio didn't change. In general, a lead layer of 5–10 cm thick on the reflecting surface in the collimating part of the beam filter caused an increase of the epithermal flux in the beam and lowered the fast neutron dose ratio.

In this stage we also tested the influence of material composition and geometrical arrangement of the **beam filter**. The beam filter consists of a cylindrical blocks of 1 m in diameter, the materials Al, AlF_3, S were considered. We tried to optimise the existing set of blocks to receive the maximum epithermal neutron fluxes with acceptable background of fast neutrons. During the study we received some interesting results for sensitivity different materials in our configuration. For example the adding 5 cm of Al at the beginning of the filter decreased epithermal flux by 20%, and 10 cm of Al by 35%. The ratio of fast neutron dose to epithermal neutron decreased by 8% and 30% respectively. Having extended the variant by a 15 cm sulphur block resulted in the reasonable decrease of the epithermal flux by 43% but the fast neutron dose ratio decreased only by 32%. The present heterogeneous design consists of the alternating blocks of Al and AlF_3, totally 40 cm of Al plus 25 cm of AlF_3.

4. CONCLUSION

The new configuration 1999 will be experimentally verified at the end of June. The essential increase of neutron beam parameters is awaited. It's supposed the irradiation time necessary to deliver the treatment dose to the patient at the LVR-15 BNCT facility will be acceptable, it enable the start of clinical trials.

ACKNOWLEDGEMENTS

Supported by Contract GACR 202/97/K038 and IGA - MZ (CR) No.4834-2.

REFERENCES

[1] BURIAN, J., MAREK, M., RATAJ, J., PROKES, K., PETRUZELKA, L., MARES, V., STOPKA, P.: The BNCT facility at NRI reactor in the Czech Republic. Proceedings of 7th Int. Symp. on NCT for Cancer, Zurich, September 1996, Elsevier, Vol.I p.391

[2] MAREK, M., VIERERBEL, L., BURIAN, J.: Determination of geometric and spectral characteristics of BNCT beam (neutron and gamma ray), 8th Int. Symposium on NCT for Cancer, La Jolla, USA, September 1998

[3] BURIAN, J., MAREK, M., RATAJ, J., PROKEŠ, K., NOVÝ, F., TOVARYŠ, F., DBALÝ, V., HONZÁTKO, J., TOMANDL, I., KRÍZ, O.: The BNCT project in the Czech Republic before the start of clinical treatment, 8th Int. Symposium on NCT for Cancer, La Jolla, USA, September 1998