grafted human glioblastoma tumor led to their complete cure. A new method for measuring the absorbed dose based on the activation of stable nuclei introduced into the composition of the targeted delivery of boron is proposed and tested. A beam shaping assembly was developed and manufactured, which makes it possible to form a therapeutic beam of neutrons at 2.3 MeV proton energy to the greatest extent satisfying the requirements of BNCT.

Conclusion
The accelerator neutron source created at the Budker Institute of Nuclear Physics provides a beam of epithermal neutrons and provides an opportunity to conduct research in the field of BNCT. The results of biological studies have confirmed the acceptable quality of the neutron beam. At present, the neutron source is being modernized to produce a therapeutic neutron beam to the greatest extent satisfying the requirements of BNCT.

Keyword: accelerator, lithium target, epithermal neutrons

Pa P1 02

In Situ Observations of Blistering of a Metal Irradiated with 2-MeV Protons

Sergey Taskaev[1,2*], Alexander Badrutdinov[3], Timophey Bykov[1,2], Sergey Gromilov[2,4], Yasuo Hugashi[3], Dmitrii Kasatov[1,2], Iaroslav Kolesnikov[1,2], Alexey Koshkarev[1,2], Alexandr Makarov[1,2], Takuya Miyazawa[3], Ivan Shchudlo[1,2], Andrey Shoshin[1,2], Evgeniia Sokolova[1,2], Hirotaka Sugawara[3]

[1]*Budker Institute of Nuclear Physics, Novosibirsk, Russia*
[2]*Novosibirsk State University, Novosibirsk, Russia*
[3]*Okinawa Institute of Science and Technology Graduate University, Onna-son, Okinawa, Japan*
[4]*Nikolaev Institute of Inorganic Chemistry, Novosibirsk, Russia*
E-mail: taskaev.sergey@gmail.com

Introduction
In accelerator neutron sources for BNCT, neutron generation is performed by dumping a proton beam onto a target. In most cases the target is a thin layer of lithium or beryllium deposited on the structural metal. With irradiation of the target by protons, deformation of the surface layer occurs in the form of numerous blisters, which leads to a decrease in thermal conductivity and limits the time of operation. Experimental data on the critical dose of blistering have been extremely scarce and are absent for a proton energy of about

2 MeV. The aim of this study was to investigate the blistering, under 2-MeV proton irradiation, of samples made of copper, beryllium, tantalum and copper-tantalum alloys.

Materials and Methods

A vacuum-insulated tandem accelerator was used to observe in situ blistering during 2-MeV proton irradiation of metallic samples. Samples consisting of copper of different purity, beryllium, tantalum, and tantalum-copper compounds were placed on the proton beam path and forced to cool. The surface state of the samples was observed using a CCD camera with a remote microscope. Thermistors, a pyrometer, and an infrared camera were applied to measure the temperature of the samples during irradiation. After irradiation, the samples were analyzed on an X-ray diffractometer, laser and electron microscopes.

Results and Conclusion

The key results of the performed studies on 2-MeV proton irradiation of different samples as follows:

The blistering threshold of the copper surface depends on the copper purity. The purer the copper, the higher the threshold is. The maximum threshold is 3 10**19 cm**-2; the minimum value is seven times lower.

Once blisters appear on the copper surface, further irradiation does not cause any more surface modification, which can be due to the formation of holes and cracks when blisters emerge.

The attachment of a thin tantalum foil to copper by explosion or diffusion welding as well as soldering is resistant to a heat load of up to 1 kW/cm**2.

Tantalum is much more resistant to the formation of blisters than copper. The threshold of blisters in the form of bubbles or flakes on the tantalum surface exceeds 6.7 10**20 cm**-2. At fluence of 3.6 10**20 cm**-2 the surface is modified in the form of a relief with a characteristic cell size of 1 micron.

During tantalum irradiation, an increase in the sample surface temperature was detected. This could be due to a decrease in the thermal conductivity because of the appearance of cavities and hydrogen incorporation into the tantalum crystal structure.

In relation to the problem of developing target for the accelerator-based epithermal neutron source for BNCT the results mean the following:

Ultra-pure copper can be used to prepare a substrate for the target in the therapy of several patients (approximately 20).

It is not obvious that after the appearance of blisters on the surface of the copper substrate the target cannot continue to be used to generate neutrons. This is because accumulated hydrogen can escape through holes and cracks formed when blisters emerge. Further-

more, a decrease in the thermal conductivity caused by blisters will not be critical for lithium melting.
The application of a thin tantalum layer deposited on the heat-removing copper substrate increases the target resistance to blistering by no less than ten times as compared to the most stable copper substrate.
Proton absorption in the tantalum layer of the target decreases the thermal conductivity due to the formation of cavities and hydrogen incorporation into the tantalum crystal structure, and consequently, leads to a significant increase in the lithium temperature, which can be critical even without surface modification by blisters.

Keyword: blistering, proton, neutron producing target

Pa P1 03

A real-time neutron monitor for BNCT

Kiyotaka Akabori[1*], Hiroki Tanaka[2]
[1]*Sumitomo Heavy Industries, Ltd.*
[2]*Kyoto University Research Reactor Institute*
E-mail: kiyotaka.akabori@shi-g.com

Introduction:
Real-time measurement of thermal neutron flux is desirable to further improve the safety and precision of BNCT. Currently, neutron flux is estimated using the Au radio-activation method. With this method, the flux can be obtained only after a certain period of time. To advance BNCT, we are developing a real-time neutron monitor. The detector in this system consists of a small grain scintillator, an optical quartz fiber, and a photo-multiplier tube. The scintillator is a LiCaAlF6 (Eu doped) crystal whose scintillation decay time is 1.6 μs. Thanks to the tiny crystal mounted at the small detector head, this detector is capable of discriminating neutrons from gamma rays without significantly perturbing the neutron field. In this work, we evaluated the monitor's dynamic range to check whether it can be applied to a BNCT neutron field, which is on the order of 10^9 n/cm^2/s.

Materials and Methods:
Neutron counts were measured with our neutron monitor at several thermal flux between 2×10^7 n/cm^2/s and 2.2×10^9 n/cm^2/s. Thermal neutron fields were produced by the Neutron exposure Accelerator System for Biological Effect Experiments (NASBEE) at the National Institute of Radiological Sciences. The flux was estimated by activating a