Neutron producing target for accelerator based neutron source for NCT

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Summary
Neutron producing targets for novel accelerator based neutron source [1, 2] are presented and discussed. Target designs are presented. Results of experiments and simulations are reported.

Introduction
Neutron producing target is one of the main elements of proposed accelerator based facility for neutron therapy [1, 2]. Lithium targets for two modes of neutron beam production are developed. The first one provides kinematically collimated neutrons via near-threshold ^{7}Li(p,n)^{7}Be reaction at proton energies of 1.9 MeV. Reflectors, collimator, and moderators are not used in these conditions of open geometry. Target will be created as a 2 – 3 μm thick lithium layer on the surface of tungsten disk cooled by liquid metal heat carrier. In the second mode, therapeutically useful orthogonal neutron beams are produced at proton energy of 2.5 MeV. 100 μm thick lithium target is needed in this case.
Main problems of lithium neutron producing target are following. i) Heat removal at an energy deposition density higher than 1 kW cm^{-2}. ii) Production of target with lithium layer thickness of 2 – 3 μm.

iii) Evaporation of lithium layer. Cleaning a volume from sprayed lithium. iv) Heavy metal substrate destruction by proton beam. v) Cleaning the target surface from radioactive ^{7}Be isotope.

Liquid metal heat carrier was proposed to cool the target, instead of water. Liquid metal heat carrier allows to keep lower temperature. There is no 100 °C limit on temperature of a surface being cooled. There is no danger in case of coolant leakage into vacuum volume. However, higher pressure drop on cooling channels is needed.

As a result two ways of target design are proposed:

1. Stationary target – a disk 50 mm in diameter with power removal capability of several tens of kilowatts.
2. Rotating target with power removal more than 100 kW.

Results

The first specimen of neutron producing stationary target with liquid metal heat carrier was made (Fig. 1). Steel disk 50 mm in diameter, 3 mm thick, is a proton beam absorber. It is cooled by liquid metal flowing in opposite directions in neighboring channels. A molybdenum plate 0.2 mm thick is diffusely welded on the disk, a proton beam is directed on it.

Fig. 1. Stationary target before assembling.

A system is developed for pumping liquid metal heat carrier including pump, liquid metal circuit with switching systems, heat exchanger, metal velocimeter, and pressure distribution measuring device (Fig. 2). A magnetic clutch was manufactured to provide noncontact transmission of angular momentum to mechanic pump in a liquid metal volume of vacuumed circuit filled with liquid metal.

Fig. 2. Liquid metal cooling system.

A stand was prepared to investigate thermal modes of neutron generating stationary target 5 cm in diameter heated with electron beam with energy of 1.4 MeV, power up to 20 kW. A liquid metal cooling system was prepared and tested. Thermal mode of the target was tested by heating with powerful electron beam and cooling with water or liquid metal (Fig. 3). In the process of examination, the following things were cleared out: i) The calculation results are in good agreement with the measured temperature values for thermocouple placed not under electron beam directly. ii) Thermocouples placed directly under the electron beam do not allow to make precise measurements. iii) Heat removal up to 650 W cm^{-2} was provided using water. iv) Liquid metal cooling allows to maintain lower temperature of the target's surface relatively to water cooling. v) Efficiency of target and cooling system was demonstrated.

Experiment and calculations show the way to improve the target and cooling system. A new variant of stationary target is presented on Fig. 4. In this case a beam absorber is a tungsten disk with channels for cooling. The disk is pressed to titanium body without diffuse welding.

Fig. 3. Target before irradiation by electron beam.

Draft of rotating target with pump for liquid metal coolant and heat exchanger with secondary cooling contour is presented on Fig. 5.
Neutron yield was calculated for various neutron producing targets. It was determined to decrease by 30 % for LiH target, by a factor of 2 for Li_2O target, and by a factor of 3 for LiF as compared with pure Li target.

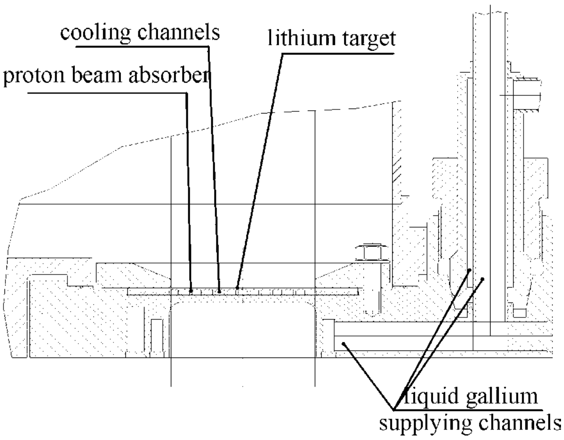
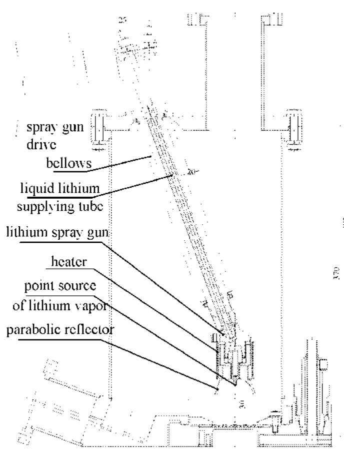


Fig. 4. New variant of stationary target.



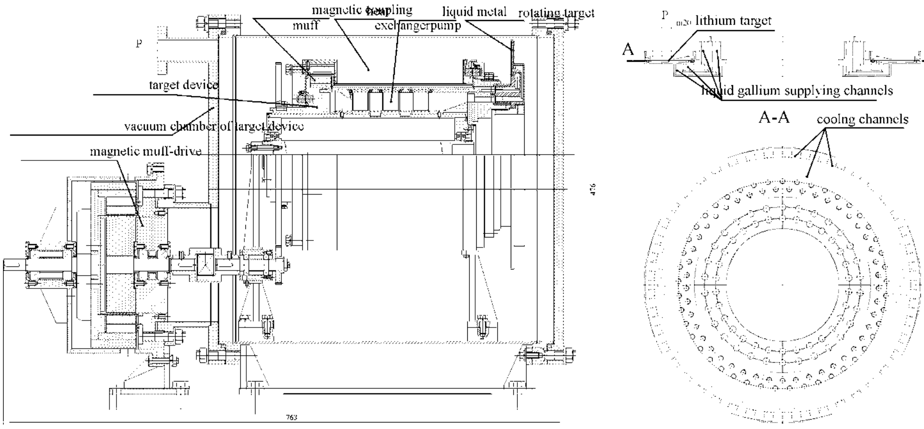


Fig. 5. Scheme of rotating target.

Parameters of system of magnets allowing to scan a beam with required conditions were estimated.

Technique for estimation of tritium accumulation in target materials was developed basing on calculation of spatial energetic density of neutron flow in the target region by Monte-Carlo technique followed by calculation of $^{6}Li(n,\alpha)T$ reaction rate which is the main source for tritium accumulation in target. The accumulation rate was determined to depend essentially on configuration and composition of the materials surrounding the target. Maximum rate of the $^{6}Li(n,\alpha)T$ reaction is at heat and epithermal region of neutron energy. The tritium accumulation was shown not to exceed standard value.

Formation of ^{7}Be radioactive isotope was considered. Dependence of gamma activity of lithium target on neutron yield was defined. Total neutron yield was determined for different proton energies. Calculations showed that at change and storage of the irradiated lithium target, radiation protection and possibly special technology and facilities were necessary.

Conclusions

Two neutron producing targets have been worked. Thermal mode of the stationary target was investigated using electron beam up to tens of kW and both water and liquid metal cooling systems. We are planing to continue investigations and to obtain a neutron beam for therapeutic use.

References

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