ION LINEAR ACCELERATOR AS A SOURCE OF NARROW-BEAMED NEUTRONS

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For creation of intensive fast neutron sources based on accelerators of charged particles one usually applied the beams of accelerated protons or deuterons which bombard the targets consisting of the elements of comparatively low atom masses (^2H, ^3H, ^7Li, ^9Be, ^{11}B, ^{12}C). Asymmetry of angular distribution of these neutrons is small. For many researches and applied problems the directed neutron beams are necessary which can be obtained by collimating the neutron flux. Unfortunately, this procedure leads to significant decrease of neutron flux efficiency and to necessity to create accelerators with a beam power of tens and even hundreds kW.

The distinctive features of angular distributions of neutrons in the laboratory system are determined mainly by kinematics of nuclear reactions used for neutron generation. Increasing the energy of accelerated particles leads to increased asymmetry, and the neutron beam becomes more extended in the direction of the momentum of initial accelerated particles. It occurs due to increasing the mass center velocity of nuclear reactions.

Directionality of the neutron beam can also be obtained at the energies of accelerated protons or deuterons near the threshold of nuclear reactions at the target-nuclei being heavier than deuterium. It follows from the fact that in this energy region there is an angle of neutron in the laboratory system, which is limited kinematically and as a result the output neutrons are directed forwards. However, under these conditions the cross-sections of the reactions are small, and for obtaining the intense neutron beams very high currents of accelerated particles are necessary.

We suggest another way for obtaining the directed neutron beams which does not require operation at the near-threshold region with small cross-sections of reaction. In the suggested scheme the above mentioned reactions can be used but kinematically inverted in the laboratory system (in the system of center-of-mass they are the same reactions). In this case the nuclei of the target and a bombarding particle interchange their positions. The center-of-mass velocity in this version is higher than that in the former version (with the identical energies of the particles in the system of center-of-mass in both schemes). In this case there is a boundary angle of the neutrons in the laboratory system even for energies considerably higher than the threshold energy, and a possibility occurs to obtain high intense directed neutron beams with suitable currents of accelerated particles.

We propose to create a lithium ion accelerator for producing of a directed neutron beam on the base of the existing linear accelerator of multicharged ions (MILAC). The $^1H(^7Li,n)\,^7Be$ reaction above threshold in a hydrogen containing target can be useful for this purpose. At bombarding energies of lithium ions of 17 MeV a resonance cross section region is captured.

The boundary neutron angle in the $^1H(^7Li,n)\,^7Be$ reaction as a function of the lithium ion energy is represented in the figure.

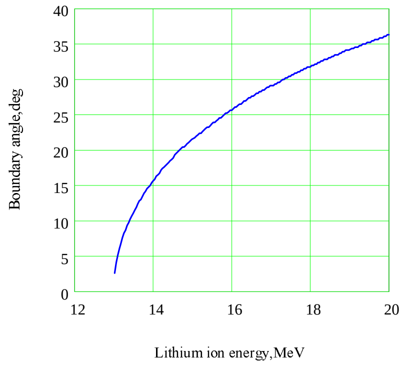

Fig. Neutron boundary angle versus lithium ion energy

This dependence shows that the boundary angle of a neutron corresponding to maximum energy of lithium ions of 17MeV does not exceed 30^o. The lithium ions will decelerate as they penetrate through the thick target, and they will have energies from zero to maximum, but only energies more than threshold (12.95MeV) will give a yield of neutrons from $^1H(^7Li,n)\,^7Be$ reaction. The neutrons will be radiated in the cone with a half-angle 29^o. We note that in the proton accelerator version the neutron flux have no directionality [1,2]. It is a main advantage of the lithium accelerator version that allows one to rise an efficiency of the neutron beam use. Neutron energies are expanded to 4MeV.

It is supposed to create a new accelerating structure for energy of lithium ions of 17 MeV with the alternating phase focusing (APF) and the moving bunch center that provides considerable capture both in radial and in longitudinal motions. The accelerator is based on the effective interdigital H-structure, and will have a smooth energy control.

At the first stage it is assumed to create an accelerator with the lithium current of 0.5 mA. Further, it will be increased to 1.5 mA. For creation of such an accelerator most of the existing equipment of MILAC accelerator could be used: RF equipment, vacuum system, a main part of the injector, control system, working areas. The choice of such scheme of the accelerator is stipulated by the large rate of acceleration, availability of the ready equipment, experience in development and creation of such systems, simplicity of manufacturing and also existing industrial basis.

The proposed neutron source could be constructed in the short time with the minimal financial contribution, and to provide investigations in this field. The evaluations show that it can be created in about two years, and the financial contribution of $100,000 is necessary for this purpose.

The neutron beam with above-mentioned parameters may be used for many applications. For example in nuclear medicine: radioisotope production, boron neutron capture therapy (BNCT) of the malignant tumors and so on. At the present time the Ukrainian medicine has not enough radioisotopes for diagnostics of various diseases and treatment of malignant diseases. Ukrainian medical researchers are taking an active interest in the BNCT method which was accepted as a most promising in treatment of malignant diseases, especially some brain tumors which are incurable at the present time. There is a number of large medical institutions interested in development of this method, and are ready for cooperation in this area.

Creation of the neutron source needs some upgrading of existing systems, creation of a new accelerating section and creation of the radiation protection. A special hydrogen containing target with the cooling system is necessary for removal of the heat power of 10kW. For the purpose of BNCT it is necessary to create the output system which provides moderation, reflection and filtering of the neutron beam like those of the reactor based sources [3].

The parameters of a designed lithium accelerator are shown in the Table.

Main parameters of linear lithium ion accelerator

	The name of a parameter and unit		
1	Input energy of ions,	keV	18.75
2	Output energy of ions,	keV	2500
3	Mass-to-charge ratio, A/q		7
4	Operating frequency	MHz	47.25
5	Electric field in gaps,	MV/m	9
6	Aperture of drift tubes, mm		16-28
7	Length of accelerating structure,	m	4.7
8	Number of drift tubes		57
9	Number of focusing regions		8
10	Number of bunching regions		9
11	Radial acceptance	π mm mrad	1.2
12	Longitudinal capture,	deg.	120
13	Energy spread (for $\Delta W_{in.}$=1%)	%	1.5
14	Longitudinal of output bunch	deg	20
15	Pulse RF power	kW	400
16	Duty factor	%	2.5
17	Average beam current	mA	0.5

Mathematical simulation shows that the total neutron yield from a water target will be about $5\cdot10^{11}$ n/mQ, and about $2\cdot10^{11}$ n/mQ from a TiH target with a surface density about $1\cdot10^{11}\cdot$n/cm$^2\cdot$mA$\cdot$s and $4\cdot10^{10}\cdot$n/cm$^2\cdot$mA$\cdot$s, respectively at, the distance of 5cm from the target.

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