Construction of KUR Ultra Cold Neutron Source with a Supermirror Neutron Turbine

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1. Introduction

Ultra Cold Neutrons (UCN) with the velocity below about 10 m/s are recently becoming valuable tools for some kinds of physical experiments, because of their long observation time in a closed vessel of neutron bottle, or their long wavelength comparing to cold or thermal neutrons. However, actual extractions of UCN from the inside of a reactor accompany various extraction losses, due to a number of reflections at non-ideal mirror surfaces in UCN guide tubes, window effects at the ends of guide tubes and so on, and severe intensity decreases of $10^{-2} \sim 10^{-3}$ comparing to those in a source neutron intensity are reported.

To overcome these intensity losses, a special machine called "Neutron Turbine" which converts cold neutrons or Very Cold Neutrons (VCN) to UCN and reconstructs the low energy tail of the spectrum becomes useful[1]. The fundamental principle of neutron turbine is described in Fig. 1. The velocity V_1 of an incident neutron in a laboratory system gives the relative velocity V_r in a rotating wheel of a turbine (Fig. 1 (a)). The neutron with the velocity V_r is transformed to one with a much different direction of the velocity V_r' in the wheel, due to the working of a turbine blade (Fig. 1 (b)). Again returning to the laboratory system, we obtain an exit neutron with the velocity V_1' (Fig. 1 (c)), which can be designed to become UCN. In a turbine in FRM Reactor, Munich, curved copper mirrors are used as the turbine blades[1], and the direction of the neutron velocity is reversed through many times of successive total

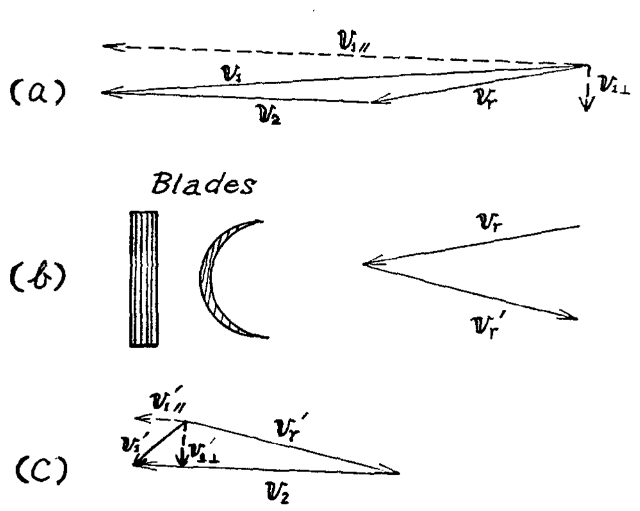

Fig. 1 Working principle of neutron turbine.
(a) at the inlet of turbine blade
(b) working of blade
(c) at the exit of blade

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reflections in the blade. On the other hand, Bragg reflections of cold neutrons in a thermica crystal are used in a turbine at the pulsed spallation source in ANL.[2,3]

In the present paper, we report on the design and construction of another type of a neutron turbine which uses supermirror reflection blades having the shape as shown in Fig. 2. Supermirrors with a critical velocity of reflection of neutrons of about 15 m/s can be readily prepared in our laboratory,[4,5] and therefore a combination of three flat mirrors as shown in the Figure is enough to reverse the direction of incident VCN. A neutron turbine with this type of blades was constructed and set at the exit of a VCN guide tube apparatus in the thermal column of 5 MW Kyoto University Reactor (KUR).

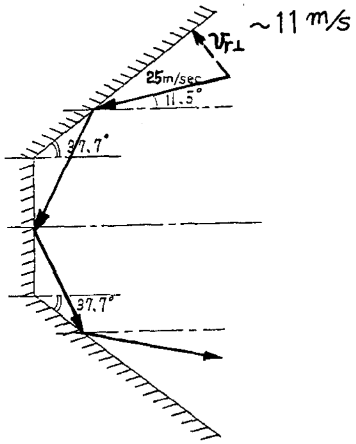

Fig. 2 Performance of the present supermirror turbine blade.

2. Preparation of Supermirror Blades

Supermirror[6] is a neutron mirror consisting of alternative multilayers of two kinds of materials (referred here as N and T) with positive and negative coherent scattering amplitudes, respectively, and further with gradually varied layer thicknesses

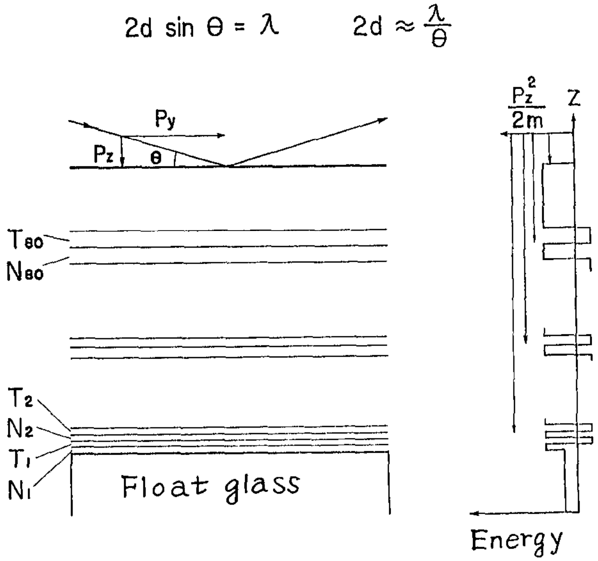

Fig. 3 Layer structure and effective potential in a supermirror.

as shown in Fig. 3. Incident neutrons with long wavelength see a scattering potential with various periodicities in this mirror. As the result, the condition of the Bragg scattering can be satisfied for neutrons in a wide wavelength region at some depth in the multilayers.

In our laboratory, nickel and titanium are used as these mirror materials[4,5] and high quality supermirrors are readily prepared by a vacuum evaporation on a float glass with an electron beam heating of the mirror materials. Some results of design calculations for Ni-Ti supermirrors with various total number of layers are given in Fig. 4. From this Figure, we decided to use Ni-Ti supermirrors consisting of about 170 total layers for our turbine blades having a critical neutron velocity for reflection of about 15 m/s.

The reflectivity of supermirrors thus prepared as turbine blades (size of a mirror is 100 mm^H x 47 mm^W on a 5 mm^t float glass) were measured in the experimental arrangement of Fig. 5 at the thermal neutron beam tube B-1 of KUR. Pulsed neutrons from a chopper (2) are well collimated by a slit (6) and a collimator (7), and reflected by the sample mirror (8) on a holder (9) with a fine adjustment. Reflected neutrons are counted by a detector (11). The time-of-flight spectrum of reflected neutrons devided by that of the incident neutrons gives the reflectivity of the sample mirror.

One of the results obtained from the experimental conditions of chopper speed 1500 rpm, flight path length 6.39 m, and the incident angle of neutrons of 8.30x10^{-3} rad. is given in Fig. 6. In Fig. 6, the abscissa means the neutron wavelength corresponding to the velocity component normal to the mirror surface. Most of mirrors prepared showed similar results with Fig. 6 and satisfy the reflectivities greater than about 70 % in the wavelength region beyond about 260 Å ($\sim$15 m/s).

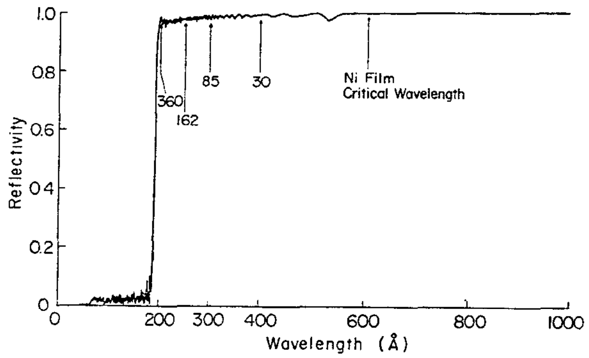

Fig. 4 Theoretical reflectivity calculated for Ni-Ti supermirrors.4) (Numerals mean total number of layers.)

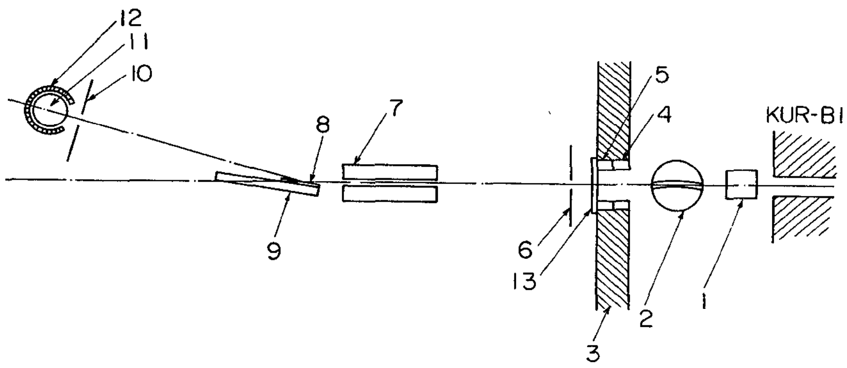

Fig. 5 Experimental arrangement for measurement of supermirror reflectivity. 1; stator slit 2; curved rotor slit 3; heavy concrete shielding 4; boric acid 5; lead 6; cadmium slit 7; collimator 8; sample mirror 9; mirror holder 10; boron carbide slit 11; He^3 detector 12; boron carbide shielding 13; monitor counter.

3. Design and Construction of Neutron Turbine

A simple analysis of neutron motions in our turbine blade with the shape of Fig. 2 is illustrated in a velocity diagram of Fig. 7. Incident neutrons to the turbine are fed by a VCN

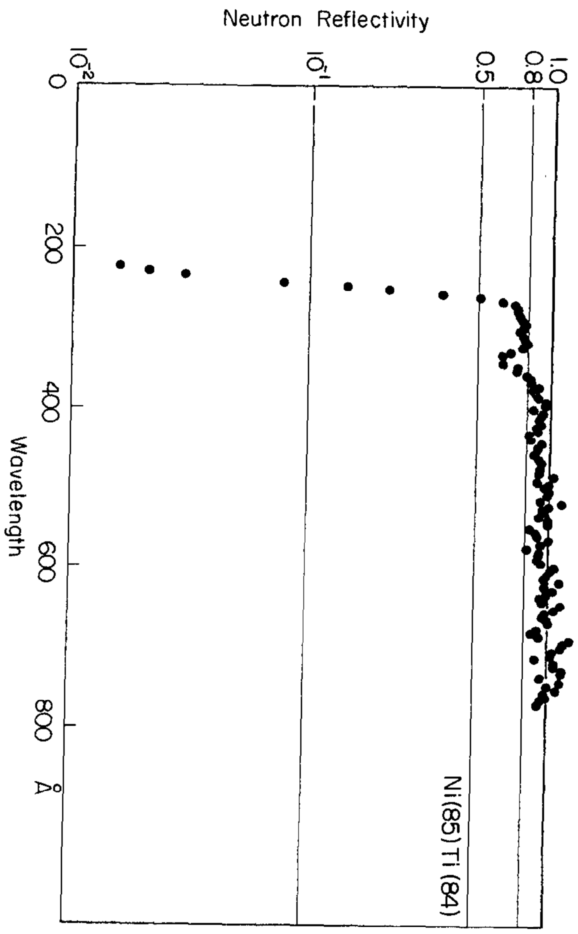

Fig. 6 An example of measured neutron reflectivities of Ni-Ti supermirrors prepared for turbine blades.

guide tube of Ni-coated glass and installed in a reactor. The feeding guide tube in the turbine is adjusted to have a little inclination of an angle of 5.7° to the direction of motion of the blades. Therefore, the velocity vectors of the incident neutrons lie within a band with a total width of about 13 m/s, having the origin at O. Rotating speed of the blade 25 m/s shifts the origin of the neutron velocity from O to O_1 in the system of the relative velocity of neutrons to the blade. Thus, the incident neutrons with the velocity within the hatched region 1 can be reflected by the first reflection plane of the mirrors, and converted into the unhatched region 2. After second and third reflections, similarly, the velocity vectors of the exit neutrons come to lie within another hatched region 4. Again returning to the laboratory system, we can obtain UCN component with the velocity from the origin O at the exit of the turbine.

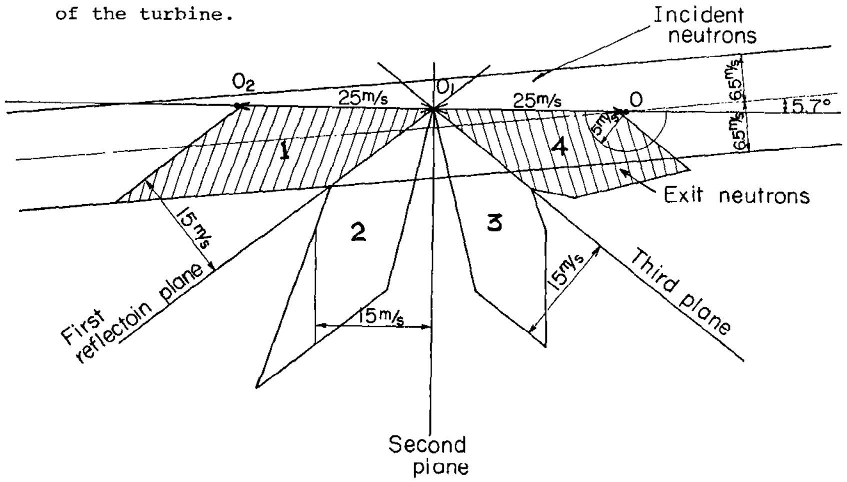

Fig. 7 Velocity diagram showing the working of supermirror turbine blade.

This is one of the simplest analyses of neutron motions in the blade. Concerning actual turbine blades with a finite size, a more sophisticated geometrical analysis is necessary for an exact estimation of the turbine efficiency, taking into consideration about the incident point dependence of the reflection condition for various values of the incident angle. From the result of such an analysis, it can be concluded that about 80 % of incident neutrons to the turbine within a velocity region of 45 m/s ∿ 55 m/s satisfy the reflection condition in our blade.

The essential structure of our neutron turbine is shown in Fig. 8. About 30 turbine blades are fixed around a wheel (3) with a diameter of 100 cm, and the wheel rotates at a speed of about 420 rpm in a vacuum vessel (1), drived from the outside through a non-contact coupling (9). The VCN feeding guide tube (5) has an inner size of $8\ \mathrm{cm}^{H} \times 2\ \mathrm{cm}^{W}$. Exit neutrons from the blades are detected by UCN detectors (7) through a short UCN guide tube (6).

In the first stage of the test run of the turbine, only a few pairs of blades are attached symmetrically on the wheel and the exit neutrons in a pulsed form can be measured. In this case, the parts without the blades on the wheel are shielded by cadmium plates. This test running of the pulsed production of UCN is now being carried out by setting the turbine at the VCN guide tube in KUR described in the next chapter.

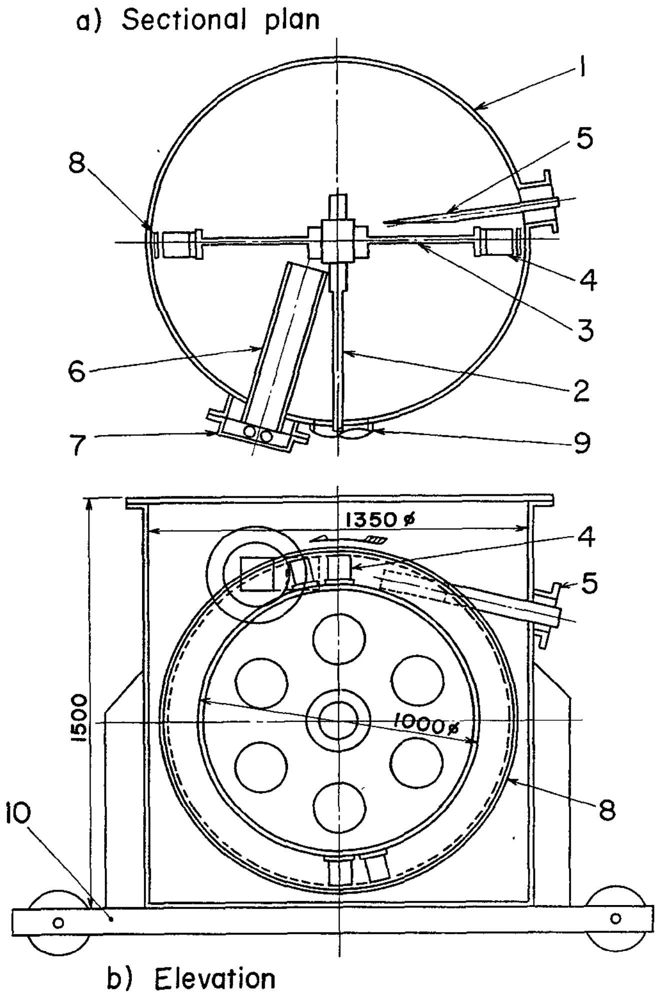

Fig. 8 Essential structure of the supermirror turbine.
1; vacuum vessel 2; driving shaft 3; turbine wheel 4; reflection blades of supermirrors 5; VCN feed guide tube 6; UCN guide tube 7; UCN detectors 8; guard ring 9; non-contact driving mechanism 10; carriage.

4. VCN Guide Tubes at KUR Thermal Column

Our neutron turbine was designed for incident neutrons with the velocity of about 45 ∿ 55 m/s, and therefore a VCN feeding apparatus was also constructed at KUR. The VCN apparatus is S-curved guide tubes consisting of Ni-coated float glass and inserted into a graphite thermal column of $(\phi_{th} \sim 10^{12}$ n/cm^{2}sec$)$ the reactor. The graphite thermal column is selected here as the VCN source because of its high neutron flux with low fast neutron backgrounds and a large illuminating area easily accessible by the guide tube in order to obtain a large glancing angle. The whole arrangement of the apparatus is given in Fig. 9.

The guide tube is curved not only in horizontal direction but also in vertical, in order to decrease the fast neutron background and to fit the height of the entrance window of the turbine. Geometrical parameters of each sections of the guide tubes are listed in Table 1. The ends of each sections are sealed by thin aluminium foils of 0.1 mm^t, and the insides are filled with helium gas in order to eliminate air effects.

In Fig. 9, a simple VCN chopper is inserted in the midway of the guide tube sections for the measurement of the time-of-flight spectra of the exit neutrons. One of the measured spectra is shown in Fig. 10 for the experimental conditions of chopper speed 655 rpm, effective flight path length 3.01 m and the channel width of time analyser 64 μsec. From the present result, the VCN intensity in the velocity region of 45 m/s ∿ 55 m/s at the exit of the guide tube was obtained

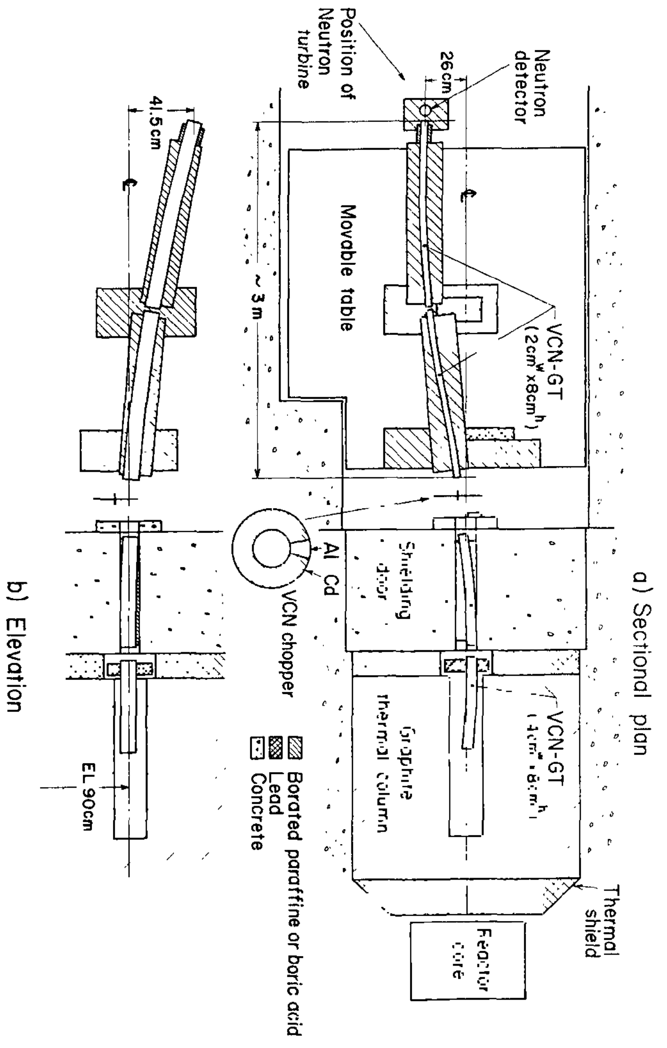

Fig. 9 VCN feeding apparatus for the neutron turbine.

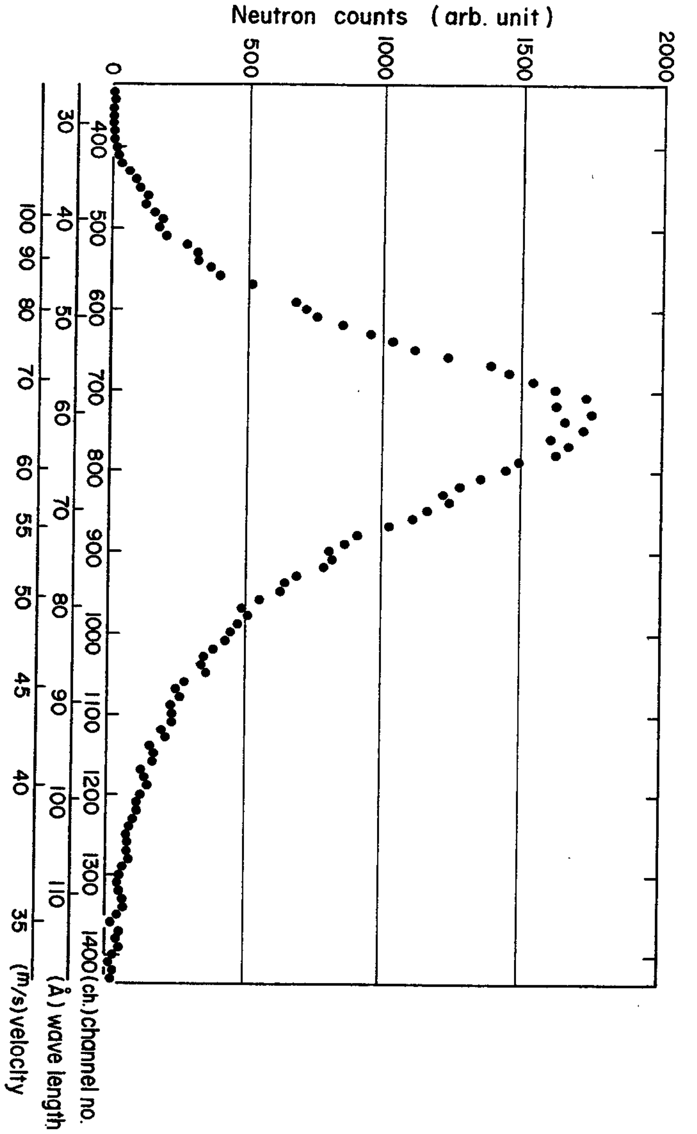

Fig. 10 Measured time-of-flight spectrum of neutrons at the exit of VCN feed apparatus.

Table 1 Parameters of VCN feeding guide tubes.

Sections		Radius of curvature	Width	Charactr. velocity	Minimum length*	Actual length
Former sections		8 m	4 cm	62 m/s	1.6 m	1.9 m
Latter sec-tions	H	8 m	2 cm	88 m/s	1.1 m	1.5m
	V	16 m	8 cm	62 m/s	3.2 m	3.0m

H; horizontal direction V; vertical direction

*; minimum length necessary for stopping direct beam.

to be about 27 n/cm^{2}min., which agreed well with the expected intensity of 35 n/cm^{2}min.. The background counts due to faster neutrons and gamma rays were sufficiently low.

Our turbine is set at the exit of the present VCN guide tube, removing the chopper and eliminating the distance between the guide tube sections in that place. These modifications and a better alignments of the guide tube sections will improve the VCN intensity by at least a factor of 4.

5. Concluding Remarks

The reflectivity of the supermirrors presently used and the geometrical efficiency of the blades give the expected efficiency of our turbine of about 35 %. Therefore, the intensity of the UCN output of the present turbine will become about 0.6 n/cm^{2}sec at the present KUR. Some improvement in the intensity is considered to be possible by decreasing various loss factors in the VCN extraction and VCN guide tubes.

Furthermore, the intensity will be greatly enhanced by the insertion of a liquid deuterium cold source[7] into the present thermal column beam hole which is now under preparation.

Acknowledgements

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