Optimization of UCN source based on He-II super-thermal method and spallation neutron source

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Since the first observation of ultra cold neutrons (UCNs) in the mid 60th they have been used for fundamental physics research through the measurement of, for example, the β decay life time. Precision measurements of these physical parameters are very important in nuclear, particle physics and cosmology. However, because of experimental difficulty in producing a sufficient amount of UCNs, a poor statistics has prevented us from studying the above physics precisely. The motivation of the present method is to use a spallation neutron source for He-II superthermal UCN production.[1] UCN production rate exceeds the paformances of the existing sources. The idea of our method is to use production of spallation neutrons by 400 MeV proton beam from the RCNP cyclotron and cooling by a liquid (300K), and solid D_2O (20K) and a subsequent He-II[1].

A basic design of our UCN source is schematically shown in Fig. 1. Clindrical He-II bottle is surrounded by 20-K cold neutron and 300-K thermal neutron moderators of heavy water A lead target is surrounded by a lead shield and placeed under the modertors. Since this design can allow a large collection solid angle for neutrons emitted from the spallation target together with application of the superthermal method.

An important factor to determine the UCN density is a storage time of UCNs in a UCN bottle. The storage time is usually limited by an upscattering in the He-II, at a UCN bottle wall and β-decay life time of neutron. Since the up-scattering process in the He-II becomes serious at a higher temperature, it is of crucial importance to design an experimental setup with a low γ heating in the He-II bottle.

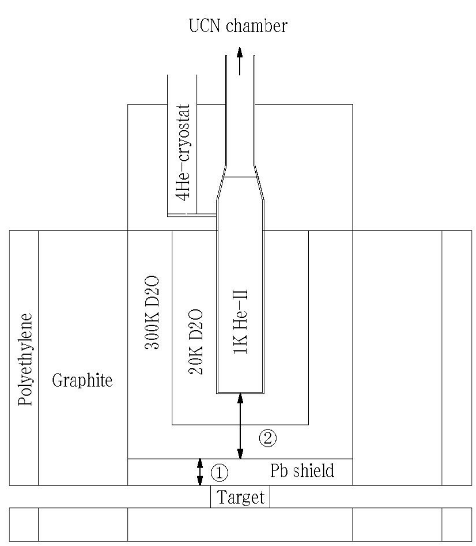

Fig.1 Basic configuration of UCN source

For optimization of our UCN source by changing a thickness of the lead shield (①), and a total thickness of the liquid (300K) and solid (20K) D_2O (②) in Fig. 1, we employed a Monte Carlo simulation code, LCS which was developed at LANL. Calculated results are shown in Fig. 2 for a UCN production rate (open circles) and heat deposit on the He-II bottle (crossed points), where 400-MeV 1 μA proton beam from RCNP cyclotron is assumed. Both the UCN production rate and heat deposit seem to be proportional to an inverse of lead shield thickness. This suggests that the heat deposit due to the target γ ray is less important. This allows us to increase a UCN intensity by using a thin lead shield without an additional heat deposit.

A UCN production rate (open circles) and heat deposit (crossed points) plotted as a function of the total thickness of liquid(300K) and solid(20K) D_2O moderator are shown in Fig. 3. A dependence similar to Fig. 2 is shown when the moderator thickness is larger than 20cm, whereas the heat deposit shows a steep increase when the moderator thickness is smaller than 15cm. The origin of this phenomenon is understood as follows: When the moderator thickness is small, a rate of a high energy neutron component which is not moderated by the liquid (300K) and solid (20K) D_2O moderators becomes significant. As a result, an additional heating by this component is induced in the He-II bottle, which results in a steep increase of heating. In our optimization we fixed a thickness of the moderators at 15cm, where we fixed 10cm for a liquid, and 5cm for a solid D_2O moderator since a solid D_2O is more sensitive to the neutron damage.

In conclusion, we can expect a UCN density over 400 UCNs/cm^3 if we assume the wall loss rate is 100 s. This value is orders of magnitudes larger than 1 UCNs/cm^3 presently available at ILL, Grenoble[4].

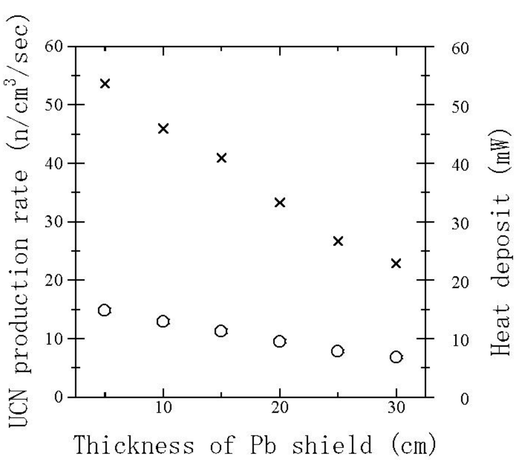

Fig. 2 UCN production rate (open circle) and heat deposit (crossed point) as functions of lead thickness.

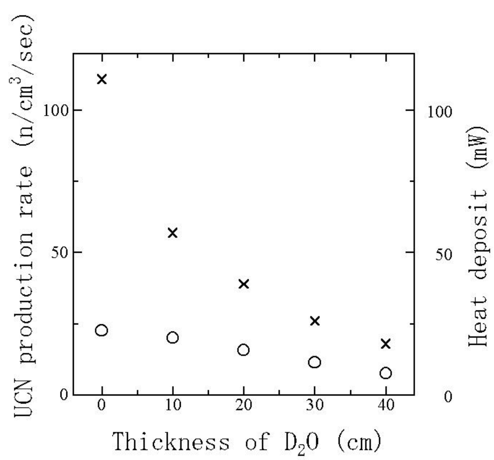

Fig.3 UCN production rate (open circle) and heat deposit (crossed point) as functions of total moderator thickness.

References

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