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Summary of Target Workshop A5 on "Energy Deposition and Cryogenic Equipment"

Noboru Watanabe

National Laboratory for High Energy Physics
Oho-machi, Ibaraki, 305 Japan

Klaus Böning

Fakultät für physik, E21 der Technischen Universität München
James-Frank-Strasse, D-8046 Garching, West Germany

Abstract

This note is a summary of the contributions and discussions at the target workshop A5 session where the energy deposition and other topics concerning cold moderator at spallation neutron source, a low temperature irradiation facility at SNQ, and ultra cold neutron sources for spallation sources were discussed.

1. Cold Neutron Moderator

1.1 Energy Deposition of Cryogenic Moderator

This problem was one of the major topics discussed extensively at the last ICANS meeting. Measured value of the energy deposition of the KENS solid methane moderator was almost one order of magnitude larger than the values at other laboratories.1) After the meeting, KENS group found that their earlier measurement was somewhat misleading, and they performed a new measurement.2)3) The result was very much consistent with the measured values at ANL, when differences in proton energy, target material, moderator material, and distance from target to moderator are taken into accounted. The results are summarized in Table I. In the last column of the table, the equivalent values for a reference case of 500 MeV protons on a U-238 target are shown with the following assumptions.

i) Fast neutron slowing down is the predominant heat source in the moderator.6) (A calculated estimate indicates the fraction of the neutron heat is more than 90 % for the reference case.)

ii) The ratio of the neutron yield per proton for the U-238 target bombarded by 500 MeV protons to that by 300 MeV protons is 2.38 which is determined from the measured results of the epithermal neutron beam at ZING-P'.4)

iii) The gain factor of the neutron yield of the U-238 target to the tungsten is 2.

iv) Energy deposition of the solid methane is almost same to that of polyethylene.

Table I Comparison of Energy Deposition of Cryogenic Moderator

Facility	Ep (MeV)	Target Material	Moderator Material/ Temp. (K)	Mod. vol (cm^3)/ Size (cm x cm x cm)	Distance* (cm)	Nucl. Heat (mW/cm^3·μA)	
						Measured	Equivalent value for ref. case**
KENS	500	W	CH_4/20	900/12x5x15	12.1	1.28 2)	2.58
ZING-P'	300	U-238	$(CH_2)_n$/R.T.		11.5	1.2 4)	2.86
ZING-P'	300	U-238	L-H_2	368		0.5 5)	1.2
IPNS-I (calc.)	500	U-238	$(CH_2)_n$			1.54 6)	1.54
IPNS-I (calc.)	500	U-238	L-H_2			0.7 6)	0.7

* Distance between center line of the target and that of the moderator

** 500 MeV protons on U-238 target

Except that the calculated estimates are somewhat smaller than the measured values, agreement between KENS and ZING-P' is excellent. Furthermore, if the value of 1.2 mW/cm^3-μA for liquid hydrogen moderator is multiplied by a factor of 2.2 which is the ratio of the calculated value of the nuclear heat for the polyethylene to that for the liquid hydrogen, we get a value of 2.64 mW/cm^3-μA which is very much close to the measured values of 2.58 or 2.86 for solid methane or polyethylene. We, therefore, believe that we have reached to agreement as far as the energy deposition of the cryogenic moderator is concerned.

1.2 Moderator Material

Choice of moderator material will be one of the most important problems for the design of the cryogenic moderator. As far as neutron beam intensity is concerned, solid methane moderator is superior to liquid hydrogen moderator. A calculated estimate indicates that the ratio of neutron beam intensity from a smaller liquid hydrogen moderator to that from the solid methane moderator of the same size is about 1/2 at 1 eV and about 1/5 at cold neutron region.[9] On the contrary, solid methane is susceptible to certain radiation damage induced by the spallation neutrons. It will, therefore, be interested to show an idea of the safty limit of the proton beam intensity for the solid methane moderator. Fraction of the hydrogen gas in the used methane gas will be an important measure of the radiation damage. A measured value at KENS was 0.14 % after 52 hours operation at full power which corresponds to 0.045 %/μA-day.[2] The concentration of hydrogen gas in the methane moderator after a long operation at Hokkaido University was 7 %.[2] This value will be considered to be still within a safty limit. Hydrogen gas concentration of 7 % corresponds to 155 μA-day operation in 500 MeV spallation neutron source. If we assume one or two weeks as a period of methane gas purging, 10 - 20 μA will be within a safty limit of the proton beam intensity for solid methane moderator. In Table II are summarized the moderator material at various facilities.

Table II Materials for Cryogenic Moderator at Various Laboratories

Moderator Material	Facility
Solid CH_4	KENS, SNS
Liq. CH_4	IPNS
Liq. H_2	IPNS, SNS
Liq. D_2	SNQ, SIN

1.3 Optimal Size and Shape

The grooved moderator was proposed by Bauer to increase the neutron leakage, and discussed extensively at the last ICANS.[7] A measurement on pulse characteristics of a grooved moderator was also reported by Carpenter.[4] In this meeting this topic was continued to discuss, and new measurements of the grooved moderator at room temperature were presented by the German study group in connection with a proposal for a lead reflector.[8)] This type of moderator will be very much useful also for the cryogenic moderator. An attempt for this was performed at IPNS where a grooved surface was realized by a lot of MgO rods installed inside the moderator chamber,[9)] and the measured performance is being anticipated.

Optimization of the size of the cryogenic moderator will be another important problem. Most pulsed neutron laboratories have adopted the moderator size which is a little bit larger than 10 cm x 10 cm x 5 cm. KENS group is thinking the possibility of increasing the lateral size of the present solid methane moderator (12 cm^W x 15 cm^H x 5 cm^T) in order to increase the cold neutron beam intensity.[10)] It seems to me that the sizes of the cryogenic moderators for the pulsed cold neutron source which were already installed or designed are more or less smaller than the optimal size, especially in the case of liquid hydrogen moderator. There will be actual constraints to realize the optimal size, but further optimization studies for the cryogenic moderator size are anticipated.

1.4 Optimal Coupling

Optimal coupling or decoupling of cryogenic moderator with a reflector is also an important problem related to the neutron beam intensity as well as the pulse characteristics. Carpenter proposed a gadolinium decoupler with a cooled beryllium inner reflector which was adopted at IPNS.[11)] The cooled reflector down to about 100 K lays the Maxwellian distribution of neutrons in the reflector below cut-off energy of gadolinium ($\sim$ 0.1 eV) which is lower than that of cadmium ($\sim$ 0.4 eV). This configuration will, therefore, improve the coupling efficiency without any sacrifice in the pulse characteristics.

Coupled moderators were tested at ZING-P' and at KENS (Hokkaido). The coupled hydrogen moderator at ZING-P' provided, by a factor of 2, higher beam intensity of time integrated cold neutrons than the decoupled one by cadmium, but the pulse width in the former was almost two times longer than in the latter.[5)] The result may suggest that the moderator size was not sufficient. Anyhow, the result shows that the coupled moderator is useful for certain classes of experiments such as small angle scattering where the pulse characteristics are not so important. A bench mark test for KENS was also presented where the gain factor of a coupled solid methane moderator to the decoupled one was about 1.5 with 15 % increase in the pulse width.[12)]

A coupled liquid hydrogen moderator with a beryllium reflector filter at the view surface was also tested at ZING-P' which provided further increase in time integrated cold neutron beam intensity.[5)] KENS group has planned to test a solid methane moderator with a para-hydrogen reflector filter.[10)]

1.5 Spectral Distortion

Some spectral distortions such as small peaks or steps appeared in the cold neutron spectrum from the cryogenic moderator were reported by ANL[5)] and KENS[12)] groups, and which were confired to be due to wavelength-dependent attenuation effect in the aluminum wall of the cryostat.

Solid methane exhibits phase transition at about 20 K, but any appreciable spectral distortion was not recognized (KENS).[12)]

2. Low Temperature Irradiation Facility

K. Böning reported on a feasibility study about the realization of a low-temperature irradiation facility (LTIF) at the SNQ. The irradiation temperature of the samples would be either 4.5 K in liquid Helium or 5 - 450 K in He gas. By means of two vertical irradiation tubes of about 8 m length two irradiation positions would be accessible: the position I deep in the D_2O tank with a high and clean thermal neutron flux ($\phi_{th} \approx 1 \cdot 10^{14}$ $cm^{-2}s^{-1}$) and the position II just below the D_2O tank for irradiations with fast neutrons ($\phi_f \approx 2 \cdot 10^{13}$ $cm^{-2}s^{-1}$). Measurements could be done in situ during irradiation as well as after irradiation in an on-line measuring cryostat or after cold transfer in any external lab. The heat production in the samples would always be dominated by the thermal neutrons. The problems of a LTI-facility at the SNQ consist not so much in the flux contamination by high energy neutrons and protons, but mainly in the 100 s^{-1} time structure and in some geometrical constraints. The advantage of the SNQ lies in its relatively weak background of direct γ-radiation (as compared to a reactor) and in its potential of spectrum tailoring. - See also paper in these proceedings.

3. Ultra Cold Neutrons

R. Golub reported on the possible features of a source of ultra cold neutrons (UCN) to be installed at the SNQ. There are two basic concepts for such a UCN source: the Doppler shifter source, where slow neutrons are decelerated by specular or Bragg reflections in a moving frame, and the superthermal source, where this deceleration is realized by excitation of phonons in superfluid liquid Helium. If both types of sources were placed at the ends of identical guide tubes so that the neutron solid angles were the same, the ratio of achievable densities ρ of UCN would be $\rho_{He}/\rho_{Doppler} = 64\ \eta$ since only the Doppler shifter source explicitely uses the time structure which enters through the duty cycle η (being 1/20 at the SNQ). However, the Helium source is able to accept much larger solid angles and so can be installed much closer to the target, profiting by the low γ-background of the spallation process. The result for the SNQ is $\rho_{He}/\rho_{Doppler} = 220$, then, and this considerable advantage of the Helium source should stimulate more effort to reduce the UCN extraction losses to below a factor of 10 and to solve the engineering problems. - See also paper in these proceedings.

M. Utsuro reported on an UCN experiment with a supermirror turbine at KUR and proposed a synchronized supermirror turbine for the UCN source at the pulsed spallation neutron facility which could utilize the neutron flux at pulse peak.[13] As a third method for UCN source, an experiment on direct extraction of UCN from a pulsed cold source was presented. This experiment was performed using a small pulsed neutron source based on a small electron linac, but encouraging data were obtained.[13]

References

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