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Abstract: Cryogenic targets (H_2, D_2 and ^4He) have been built for use in the study of photonuclear reactions with π sr spectrometer, TAGX at the 1.3 GeV Tokyo electron synchrotron. A new type of vacuum jacket fabricated from plastic honeycomb core and Mylar skins has been used in the target system for more than 5000 hours. The average radiation thickness and the average density of this jacket are measured to be 3.3×10^{-3} X_0 and 0.15 g/cm^3, respectively.

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1. Introduction

The TAGX collaboration studies the photonuclear reactions with the photon beam at E_γ < 1.2 GeV at the Institute for Nuclear Study, University of Tokyo. For these experiments, a large acceptance, multiparticle spectrometer, TAGX[1] has been built in the tagged photon beam channel with 20% duty cycle [2,3]. As shown in Fig. 1, the central part of this spectrometer consists of a set of thin plastic scintillation counters as the inner hodoscope, two semi-cylindrical drift chambers for charged particle trackings and another set of plastic scintillation counters as the outer hodoscope. The drift chambers sit in a magnetic field ($B_{max} \approx 5$ kG) to determine the particle momentum from the reconstructed trajectory. A cyclotron magnet, modified to fit the detector system, is used. A set of counters made of thick plastic scintillators is located at the outside of the magnet to serve as neutron detectors. The system has an geometrical acceptance of π sr for charged particles ($\pi^\pm$, p, d) and 0.8 sr for neutrons.

This versatile detection system imposes certain constraints on the geometry of the cryogenic targets for the hermetic layout of the detectors around the target. Firstly, the liquid reservoir on the magnet yoke is connected to the target cell through a long tube. The large acceptance of the detector requires that the wall of the vacuum chamber (to be called 'vacuum jacket') for the target should be thin and uniform over the entire region facing to the detectors. Further, low cross sections (μ barns and less) for the photonuclear reactions demand high areal density targets to keep the counting rates at an acceptable level.

Taking the photon beam dimensions (2 cmϕ) and the incident flux of 2 x 10^5 γ/s into account, we require that the target shape is a vertical cylinder of 5 cmϕ and 9 cm in height to get reasonable counting rates and to ensure that the beam is fully intercepted by the target. The magnet has a central hole of 12 cmϕ in the circular pole, which could be used for target installation with advantage (see Fig. 1).

As we are interested in the detection of hadrons at low momenta, it is also necessary that the walls of the vacuum chamber is uniform to ensure that the energy losses of the outgoing particles are not dependent on directions. Usually, this feature is accomplished with thin Mylar windows on the metalic vacuum jacket[4,5]. However, our setup precludes the use of supporting poles or ribs along the cylindrical surface. The wall of the vacuum jacket must be mechanically strong to be self-supporting. Although metalic jackets satisfy the strength criterion, they have large values of the radiation length to produce high background due to the conversions of photons into e^+e^- pairs. As to be discussed below, we found that a honeycomb sandwich structure made of plastic is an attractive alternative to the metals as it offers a mechanically stronger structure with much less material.

The design and performance of the vacuum jacket are described in sections 2 and 3, respectively. The structure and performance of the liquid ^{4}He target during the experiment with the photon beam is presented in section 4, and the conclusions are found in section 5.

2. The vacuum jacket of honeycomb sandwich structure

2.1 Choice of material for vacuum jacket wall

The present vacuum jacket is required to withstand a pressure difference of at least $\Delta p_c = 2.5$ kg/cm^2 to be reasonably assured that it would function well under the experimental conditions. Our experimental arrangement requires a cylindrical vacuum jacket with outer diameter of 10 cm and height of 15 - 18 cm. Since aluminum and stainless steel are usually used as wall materials for self-supporting vacuum jackets of liquid targets [6,7], we calculated the wall thickness for these materials in our geometry. For long thin walled cylinders of radius r and thickness t without end reinforcements, the collapsing pressure difference is given by[8]

$$\Delta p_c = \frac{E}{4(1 - \sigma^2)} \left(\frac{t}{r}\right)^3 \quad ,$$

where E and σ are Young's modulus and Poisson's ratio of the material, respectively. Table 1 shows the thicknesses of aluminum and stainless steel walls that would meet our requirements. As the hadronic background and electromagnetic background are proportional to the material thickness in units of g/cm^2 and radiation lengths, respectively, it is clear that aluminum is superior to stainless steel. Our aim was to develop a vacuum jacket with better mechanical properties and yet contribute less background than aluminum. A sandwich structure made from a plastic honeycomb[9,10,11] core is a candidate for such a vacuum jacket. We have investigated the performance of vacuum jackets of this type.

2.2 Method of fabrication

A schematic view of the vacuum jacket of honeycomb sandwich structure is shown in Fig. 2. It is made from NOMEX plastic honeycomb sheet* of 1 cm thickness. The dimensions are 8.0 cm, 10.1 cm and 13.0 cm for the inner diameter, outer diameter and height, respectively. Mylar sheets of 200 μm thickness are glued on to the inner and outer sides of cylindrical surfaces with Araldite**. Brass rings for assembly were glued onto the two circular ends of the vacuum jacket, and the bottom end was sealed off with a brass plate, whereas the top end was attached to the aluminum pipe of the vacuum chamber. We have fabricated seven jackets for the following tests.

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* NOMEX honeycomb of Dupont Corp., distributed in Japan by Showa Hikoki Corp.

** AW106, HV9530 of CIBA-GAIGY Corp.

3. Performance of the vacuum jacket

3.1 Pressure loading test

In real experiments, the target have to be filled and emptied several times at least. To ensure the safety for these operations, a pressure loading test was done. A schematic view of the test bench is given in Fig. 3. The vacuum jackets, each in turn, were subjected to an external pressure difference of 1 kg/cm^2 by evacuating for an arbitrary period of time and then unloaded. In the above procedure, the pressurizing tank was kept at a pressure of 1 kg/cm^2. This pressure loading sequence has been repeated many times for each jacket. None of the jackets showed any visible deformation. A typical sequence of these tests is shown in Fig. 4. To get the values of the collapsing pressures, each jacket was evacuated and externally pressurized till it collapsed as shown in Fig. 4. It shows the loading and unloading sequences for 70 hours, after that a higher pressure was applied to collapse at 3.5 kg/cm^2. Figure 5 shows the collapsing pressure of seven pieces of test jackets, where the collapsing pressure is plotted against the number of times the loading sequence is repeated. The interest is to see if the collapsing pressure for a test jacket depends on the loading history. For the tests, the number of evacuation varied from one to one hundred. As to be seen in the figure, the collapsing pressure is independent of the loading history. For our samples, the values range from 2.8 kg/cm^2 to 4.0 kg/cm^2, and all of them are sturdier than our design goal of 2.5 kg/cm^2. It was thus concluded that the vacuum jacket would operate safely for pressure differences of up to 2.5 kg/cm^2 and would also withstand the emptying and refilling procedures.

3.2 Effective thickness of the wall

The average density was obtained to be 0.15 g/cm^3 by measuring the volume and the weight of a piece of the honeycomb sandwich structure. The effective radiation thickness of 3.3 x 10^{-3} X_0 was measured by the photon absorption method. From Table 1, it is clear that an aluminum wall of similar strength would be at least twice as dense and about four times in radiation thickness. Consequently, the hadronic background and electromagnetic background would be significantly lower in the case of the honeycomb sandwich structure.

4. Liquid ^{4}He target

4.1 Structure of the liquid ^{4}He target

We have employed a liquid ^{4}He target of the transfer type [4]. Figure 1 shows an overall schematic view of the target and the TAGX. The target cell of 5.0 cmφ is connected to the liquid ^{4}He reservoir of 3.6 l capacity through a copper pipe of dimensions 98 cm x 1.9 cm x 0.05 cm (length x diameter x thickness). The target cell is enclosed in the vacuum jacket, which is attached to the vacuum chamber with a 96 cm long neck, made of aluminum. This system was evacuated to 1 x 10^{-6} torr pressure. These long connecting pipe and neck were dictated by the TAGX geometry. This, in turn, necessitates a good thermal insulation to keep the liquid ^{4}He consumption rates reasonably low both for economical reason and the frequency of transfers. The target cell and the connecting pipe were wrapped with aluminized Mylar sheet. The connecting pipe was also enclosed in a coaxial cooling pipe of stainless steel (side wall tank), filled with liquid nitrogen. A disk type tank, filled with liquid nitrogen, is set under the target cell[4]. The consumption rate of liquid ^{4}He was about 0.5 l/hr. An earlier design at this institute for the experiment by Fujii et al.[4] with much shorter dimension for the connecting pipe, operated with a consumption rate of 0.36 l/hr. In view of the differences in size and geometry, the increased consumption rate was acceptable. The target refilling needed about 15 minute interruption in the data taking every seven hours. At each filling, about 8 liters of liquid ^{4}He was used up including the losses during the transfers. In our case, neither the amount of liquid ^{4}He loss nor the frequency of transfers was impractical. The liquid levels were continuously monitored by four Allen-Bradley 105Ω - 1/8 W resistors set in the target system: one in the target cell and the other three at the bottom, middle and top of the liquid ^{4}He reservoir.

4.2 Performance of the target

The present liquid ^{4}He target has been quite satisfactorily employed in a measurement of the photonuclear processes on the ^{4}He nucleus at intermediate energies. The experimental run extended over 2000 hours of beam time. During this run, the target was emptied and refilled several times without any problem.

Besides this experiment, the same vacuum jacket has been used for 3000 hours of running time for a measurement with a liquid D_2 target.

To estimate the amount of background events from the vacuum jacket, we determined the reaction point for $\gamma d \rightarrow \pi^- pX$ events by the track reconstruction using the drift chambers. An example of the reaction point distribution of these events projected onto the horizontal plane for liquid D_2 target runs is shown in Fig. 6. It is clear that the events originating in the target cell are clearly separated from those coming from the vacuum jacket. The latter is 1.6% of the events from the target volume, and these background events can be eliminated by applying a cut in the reaction point distribution.

5. Discussion and conclusions

A cryogenic target with a honeycomb sandwich structure vacuum jacket was developed for use in the investigation of intermediate energy photonuclear reactions with a large acceptance, multi-particle spectrometer, TAGX. Despite the large dimensions of the target system due to the features of the spectrometer, the rate of liquid ^{4}He consumption was rather moderate. It is found that the present system is easy to handle and strong. And the background rate is lower than an aluminum jacket of comparable strength. We judge the fabrication of this vacuum jacket is easier and cheaper than the systems using walls made of beryllium [12], titanium[13], inconel[13], and an aluminum alloy[14], which were recently used as beam pipes of colliders or as cells of high pressure gas target.

Cryogenic targets with a new type of vacuum jacket made from honeycomb sandwich structure operated well over 5000 hours of experimental periods. Similar system would be of interest for experiments at the intermediate energy facilities.

Acknowledgments

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Table 1 Calculated thickness of vacuum jacket. A collapsing pressure difference of 2.5 kg/cm^2 is assumed for aluminum and stainless steel. For honeycomb sandwich structure, the measured values are listed.

	Thickness		Radiation length
Material	(cm)	(g/cm^2)	(X_0)(x 10^{-3})
Aluminum	0.12	0.32	13
Stainless steel	0.09	0.71	51
Honeycomb sandwich structure	1.0	0.15	3.3

Figure captions

Fig. 1 A vertical cross sectional view of the TAGX. The liquid ^{4}He target is schematically illustrated together.

Fig. 2 A schematic view of the honeycomb sandwich structure vacuum jacket. The core is 1 cm thick NOMEX plastic honeycomb. Skins are 200 μm thick Mylar films.

Fig. 3 A schematic view of the test bench for pressure loading test. An external pressure is loaded by evacuating the test jacket.

Fig. 4 A sequence of the pressure loading test. The evacuation of the jacket was repeated with random durations. Finally, the test jacket was evacuated and pressurized till it collapsed.

Fig. 5 Collapsing pressure of seven pieces of test jackets. The abscissa is the number of times the loading sequence is repeated. The lowest value of collapsing pressure was 2.8 kg/cm^2.

Fig. 6 Reaction point distribution in the reaction of $\gamma d \rightarrow \pi^- pX$. The arrow represents the direction of the photon beam (x) incident upon the D_2 target which is a vertical cylinder of 5 cmϕ. y is normal to x in the horizontal plane. A cluster of points seen upstream is due to reactions in the wall of vacuum jacket, while events occurred in the downstream wall were not accepted by the trigger condition.

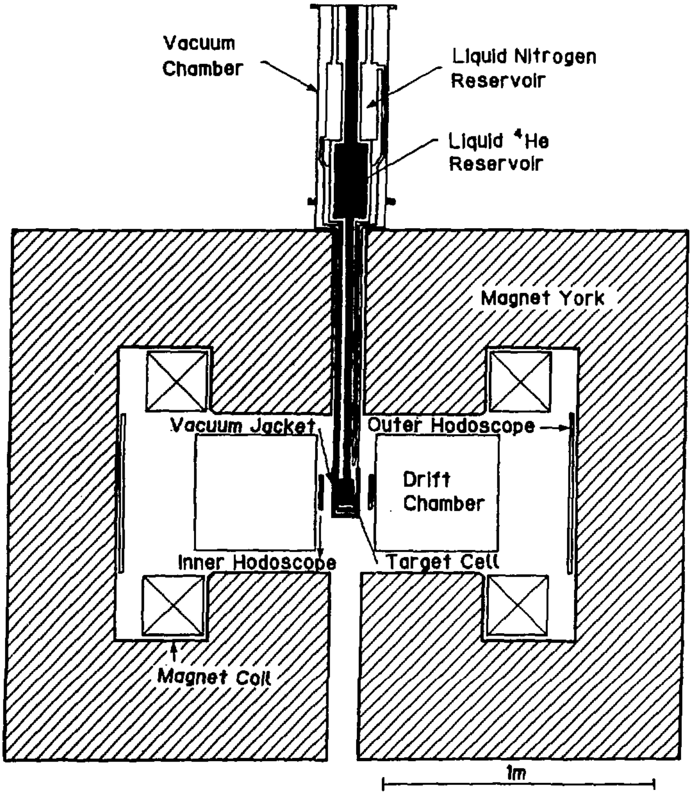
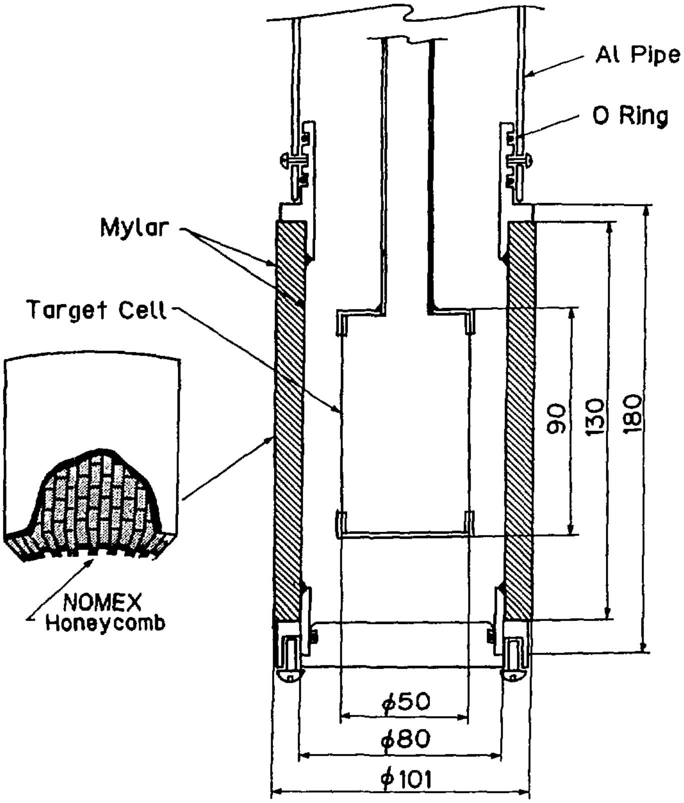

Vacuum Chamber
Liquid Nitrogen Reservoir
Liquid ^{4}He Reservoir
Magnet York
Vacuum Jacket
Outer Hodoscope
Drift Chamber
Inner Hodoscope
Target Cell
Magnet Coil
1m

Fig. 1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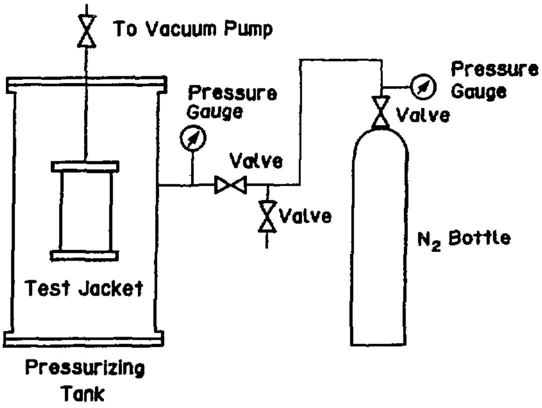
O Ring
Mylar
Target Cell
NOMEX
Honeycomb
90
130
180
ϕ50
ϕ80
ϕ101

Fig. 2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Pressure Gauge
Pressure Gauge
Valve
Valve
Valve
Test Jacket
N_2 Bottle
Pressurizing Tank

Fig. 3

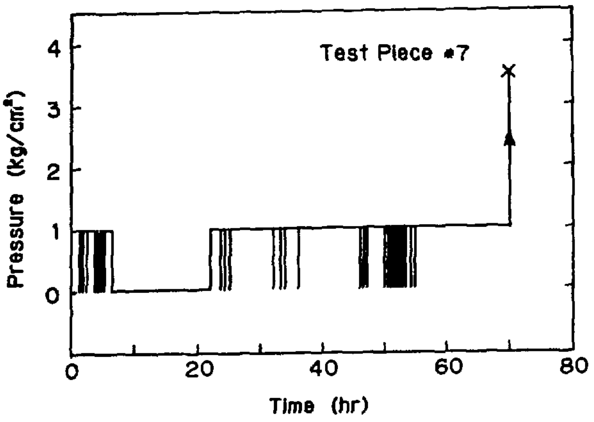
Test Piece #7
Pressure (kg/cm²)
0
1
2
3
4
0
20
40
60
80
Time (hr)

Fig. 4

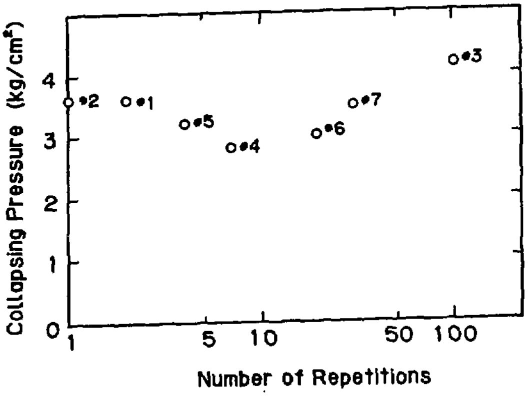
Collapsing Pressure (kg/cm²)
0
1
2
3
4
1
5
10
50
100
Number of Repetitions
#2
#1
#5
#4
#6
#7
#3

Fig. 5

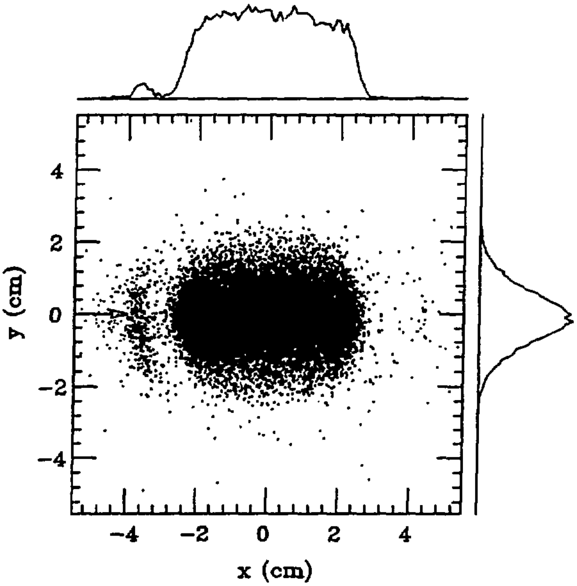

Fig. 6