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12. AGS Spallation Target Experiment (ASTE) Collaboration

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An experiment on mercury spalltaion target with high energy proton beam, called as the AGS Spallation Target Experiment (ASTE) Collaboration, has been performed at Alternating Gradient Synchrotron (AGS) of Brookhaven National Laboratory (BNL) in USA, in cooperation among the laboratories in Japan, Europe and USA. The experimental setup, scope and preliminary results are presented in the paper.

1. Introduction

The spallation target development is one of the key issues for high power spallation neutron sources, such as MW-class projects of ESS in Europe, SNS in USA and NSP in Japan. For such high power beam, mercury target is keenly desired to use against radiation damage of target materials. However, there is very few experience on mercury for use in spallation target matarial, even in a reactor technology field. The spallation target is required for heavy element to get higher neutron yield. On this point, liquid heavy metal is desireble for the heat and radiation resitent material, such as mercury, Pb and Pb-Bi. The mercury has an advantage of neutron yield compared to Pb-Bi as shown in Fig.1, in addition to property of liquid at room temperature. In those liquid target, however, there will exist pressure wave problem caused by prompt temperature rise inside the target due to energy deposition of proton beam. This possibly cause a serious problem for the container so as to exceed a limit of stress.

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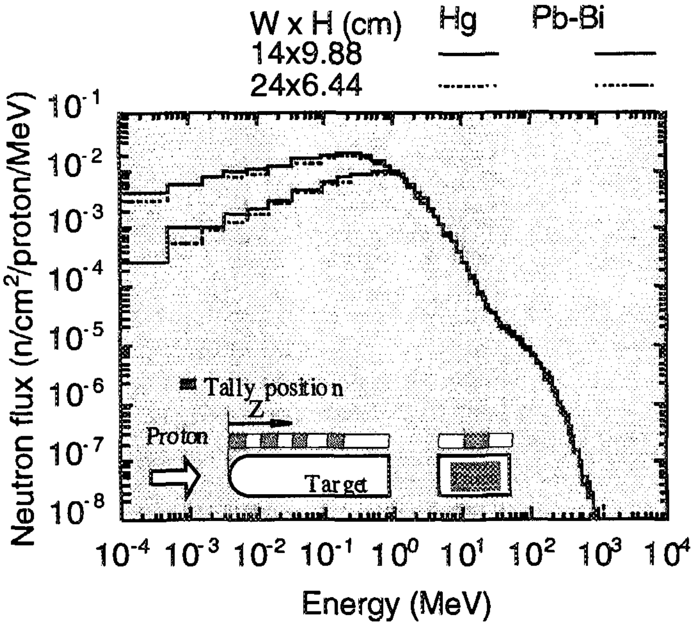


Fig.1 Comparison of neutron spectra produced by Hg and Pb-Bi targets

When the large beam power is instantaneously put into the liquid mercurt, the mercury will expnand spontaneously and make presure wave as shown in Fig.2. Some calculations showed this presuure will exceed the stress limit for the structural materials under ceatain conditions. This is very important phenomena to design the target contaner. To study the pressure wave and simulate a beam power of 5MW class spallation sources, the AGS Alternating Gradient Synchrotron of Brookhaven National Laboratory (BNL) in USA was chosen among the member of three institutes and the collaborative experiment was proposed.[1] Because such 5MW sources have beam power of 100kJ/pulse at the 50 Hz, the peak beam power of 200 kJ/pulse for the AGS at 0.6 Hz is quite enough to study the pressure phenomena by a single pulse. Also As the AGS can change the beam energy by fast extraction from 1.5 GeV to 24 GeV, the experiment covers the energy of JAERI project.

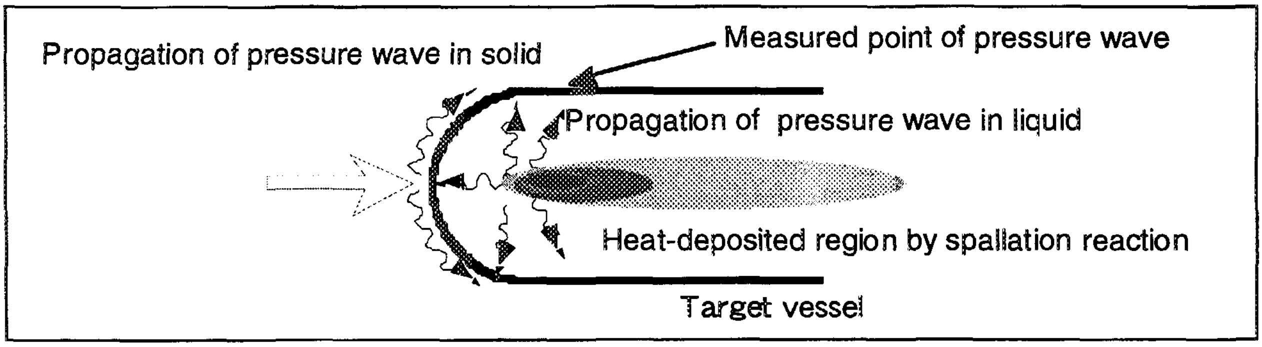


Fig.2 Pressure wave generated inside the mercury target

2. Experimental Setup

The mercury target mockup was placed at the fast extract beam line from the middle

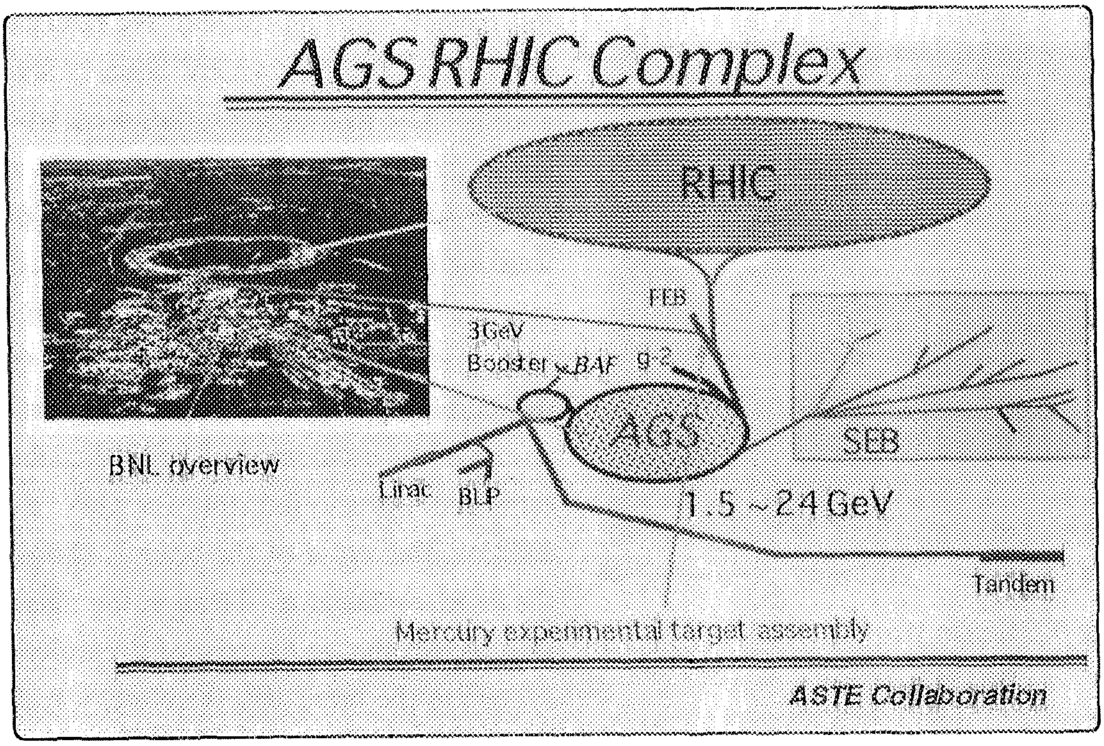
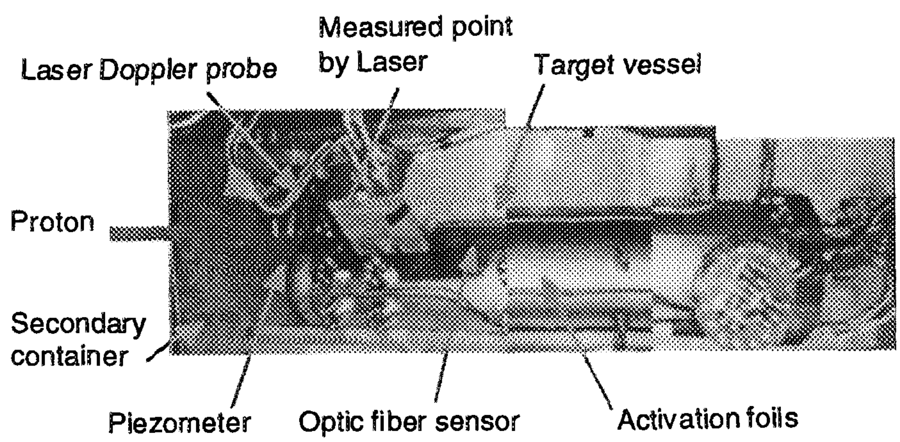


Fig. 3 Location of experimental place at AGS facility

of the RHIC beam transport at AGS facility as shown in Fig.3. The mercury target container as shown in Fig.4 was 130cm long x 20cm diameter and the top suraface of the target was rounded. The target was covered with a safety box to protect unexpected leak of the mercury and installed at the beam line surrounded by concrete blocks. The incident proton beam shape and position were measured by a technique of Al foil activation in combination with imaging plate (Al-IP method). The total incidenty proton numbers were measured by Cu activation



Mercury target : 130 cm in length, 20 cm in diameter
Target vessel : stainless steel of 2.5 mm thickness

Fig.4 Mercury target container

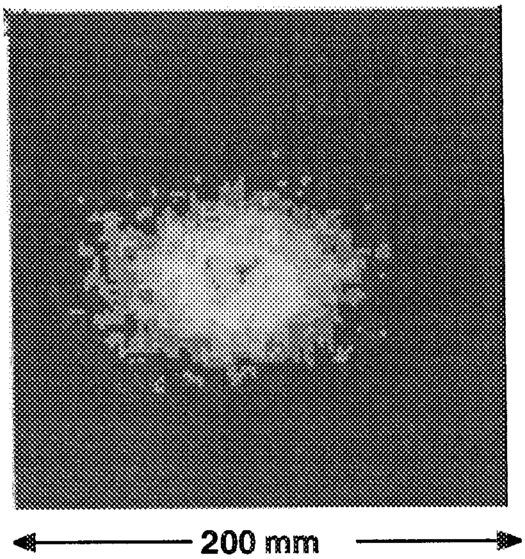


Fig.5 Beam profile of 24 GeV beam

foil method utilizing Cu(n,x)^{24}Na reaction. The result of profile for 24 GeV beam is shown in Fig.5.[2] The measured profiles were worse for lower energies. Specially for 1.5 GeV case the profile was very broad and some of protons were out of the plate. This makes it uncertain to measure the total integrated beam current by the Cu foil activation method. Actually the value of the current transformer located at the upper stream of the beam line was larger than the value estimated by Cu foil for 1.5 GeV case. In addition, the center of the beam is shifted from the target container as shown in the figure. This shift causes the asymmetry of the experimental system to the beam axis, therefore, it makes the calculation analysis of the measurements complicated.

The proton energies were changed from 1.5 GeV to 24 GeV by fast extracting at the middle energy of AGS synchrotron. The present experiment used three energies of 1.5, 7 and 24 GeV for the neutron emission measurement. and 24 GeV single pulse for the pressure and

Table 1 Dosimetry reaction used in the neutron measurement

Dosimetry Reaction	Photon Energy	Threshold (MeV)	Dosimetry Reaction	Photon Energy	Threshold (MeV)
In(n,n')In-115m	336.24 keV	0.5 MeV	Co(n,γ)Co-60	1332.5 keV	
			Co(n,α)Mn-56	1810.7 keV	5.2 MeV
Al(n,α)Na-24	1368.9 keV	4.9 MeV	Co(n,2n)Co-58	810.8 keV	10.5 MeV
			Co(n,3n)Co-57	122.1 keV	19.0 MeV
Nb(n,2n)Nb-92m	934.46 keV	8.9 MeV	Co(n,4n)Co-56	1238.3 keV	30.4 MeV
Nb(n,4n)Nb-90	1129.2 keV	29.1 MeV			
			Fe(n,p)Mn-56	1810.7 keV	4.9 MeV
Au-Foil			Fe(n,p)Mn-54	835 keV	2.2 MeV
Au(n,2n)Au-196	355.65 keV	8.1 MeV	Fe(p,n)Co-56	1238.3 keV	
Au(n,2n)Au-196m	147.77 keV	8.7 MeV			
Au(n,4n)Au-194	328.47 keV	23.2 MeV	Ni(n,p)Co-58	810.8 keV	1 MeV
Au(n,γ)Au-198	411.8 keV		Ni(n,2n)Ni-57	1377.6 keV	12.4 MeV
			Ni(n,np)Co-57	122.1 keV	17.6 MeV
Bi-Foil			Ni(n,2np)Co-56	1238.3 keV	20.0 MeV
Bi(n,4n)Bi-206	803.1 keV	22.6 MeV			
Bi(n,5n)Bi-205	703.5 keV	29.6 MeV	Cu(n,nα)Co-58	810.8 keV	5.9 MeV
Bi(n,6n)Bi-204	899.2 keV	38.0 MeV			
Bi(n,7n)Bi-203	820.3 keV	45.3 MeV			
Bi(n,8n)Bi-202	422.2 keV	54.0 MeV			

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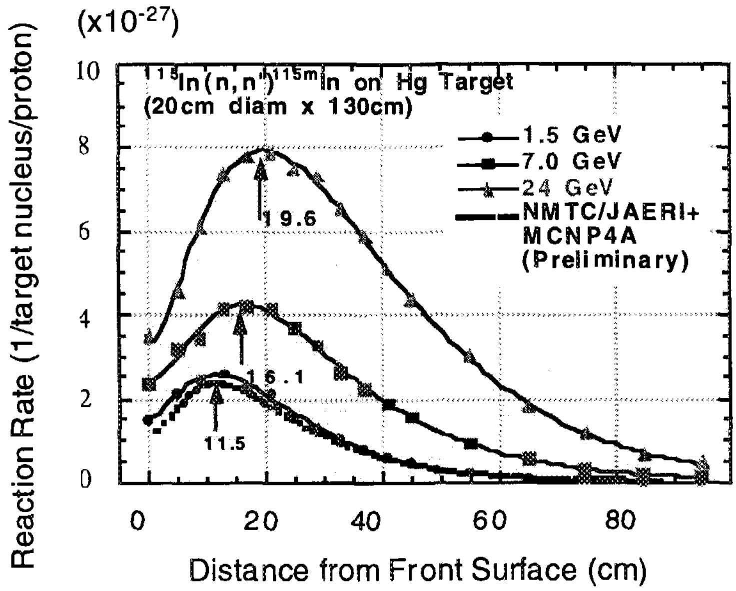

Fig. 6 Measured results of neutron emission from the mercury target

temperature rise experiments.

3. Measurements

The measured items in the first experiment are neutron emission distribution around the target, temperature rise in the mercury and pressure wave at the container. The neutron emission was measured by various kinds of threshold reactions listed in Table 1. To check asymmetry of the detector positions relative to the beam axis, the detectors were set at four directions.[3] The most interest items are the distribution along the beam axis and relative intensity among the different energies. The measured spatial distributions of neutron emission from the container surface along the beam axis are shown in Fig.6 for three incident energies. The results were obtained from the $^{115}In(n,n')^{115m}In$ reaction rate distribution which is sensitive to MeV neutrons. It is seen clearly in the figure that the peak position of neutron emission is shifted with the incident energy from 11.5 to 19.6 cm from the front surface of the target.

For the temperature rise, thermo-couples were used and set inside the container along the beam axis.[4] The out put voltage of each thermo-couples were recorded. From the results, the temperature rise is faster than natural convention of the mercury, so that the measurement was sucesful. However, since this measurement is sensitive to the position of the incident beam, the beam profile monitoring is very important. At the present experiment, single bunch beam was used, but only the time integrated profile was available. Some uncertainty due to beam position was remained

For the pressure wave measurement, three kinds of techniques were applied, i.e., piezo-pressure gauge, laser strain gauge and laser doppler velocity meter. The first method was failed by electric noise by proton beam, and the second method was partially succeeded but still careful assessment is required. While both two method were failed or troubled, the last method using laser doppler shift was succeeded as shown in Fig. 7.[5] In the figure the first pulse at 100 μsec after beam incident was clearly observed andshowed an good agreement with the calculation.

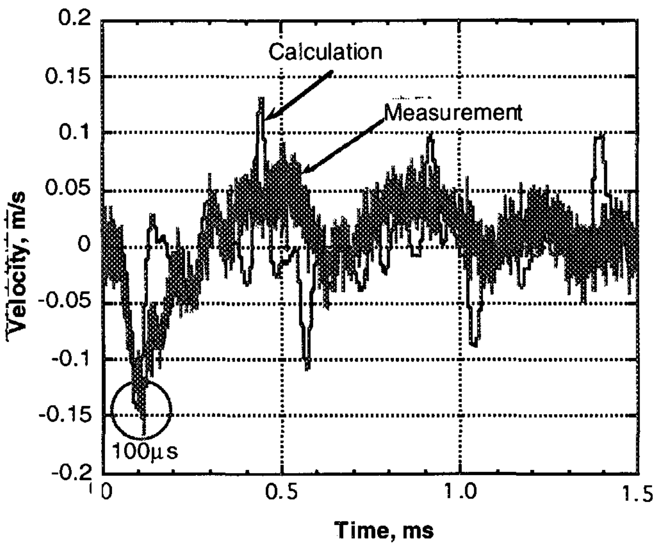

Fig.7 Velocity response measured at the container surface

4. Future plan

A future plan of the AGS collaboration was under discussion and its line up is shown in Fig.8. For the next experimental series, after the beam focusing and beam monitoring are improved to eliminate the uncertainty relating to the beam shape and total beam current, neutron energy spectrum from the mercury and the radioactivity product from the mercury are measured. In the current planning, after those experiments, the target is surrounded by a lead reflector in which the water moderator placed near the target. Then a slow neutron energy spectrum from the moderator will be measured by the TOF method with a current mode time analyzer. At the same time, nuclear heating measurtement inside the H2O moderator is proposed by a carolimetric method. For the further experiment, a shielding experiment for high energy neutrons is planned on very thick concrete or iron utilizing shield structure of the experimental place.

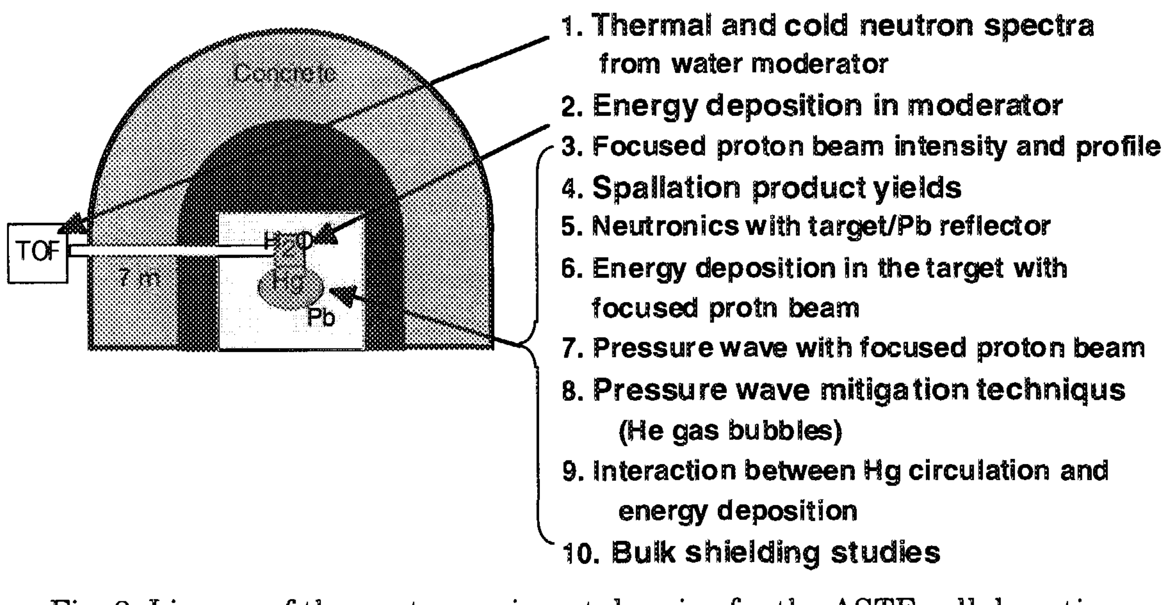

Fig. 8. Line up of the next experimental series for the ASTE collaboration

Acknowledgment

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[5] M. Futakawa, et al., "Measurement of Pressure Wave in Mercury Target", ibid