Status of the AGS Experiment for Mercury Spallation Target Development

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Abstract

An experimental endeavor for exploitation of a MW class spallation target has been conducted using the AGS accelerator at BN on the neutron production along with the shock wave characteristics in the target, which are induced by a high intensity proton incident. This paper reviews the experiments, which has been carried out since 1997 in an international collaborative framework, namely the ASTE (<u>A</u>GS <u>S</u>pallation <u>T</u>arget <u>E</u>xperiment) collaboration with an emphasis on neutronics measurement, and gives the current status of the results provided through the experiment.

2. Introduction

A strong need of an intense pulse neutron source has been requested from the neutron scattering research. For the development of a MW class accelerator driven spallation neutron source, mercury was identified as a unique choice for the target material from a thermal dynamics point of view. There was, however, a serious concern of a shock wave associated with the high intensity proton beam incident, and an experimental validation was addressed. AGS, an intense proton accelerator at Brookhaven National Laboratory in USA, was identified as a potential source , which is eligible for the all requirements in terms of proton energy and intensity for yielding a shock wave. As the issues was so critical that an international collaborative framework, namely the ASTE (<u>A</u>GS <u>S</u>pallation <u>T</u>arget <u>E</u>xperiment) collaboration was established with participation from EU, US and JA, who are fully involved in their own national projects for the spallation source, e.g., SNS (USA)[1)], ESS (Europe)[2)] and NSP (Japan)[3)]. The primary missions of the AGS experiment were set to provide experimental validation of analytical codes for neutronics, mechanical and thermal-hydraulics quantities associated with GeV proton induced spallation reactions in a mercury target. Since then, experiments have been planned and conducted as maximizing the opportunity and resources as possible This paper gives the current status of the results provided through the experiment with an emphasis on neutronics measurement.

2. Primary Objectives of ASTE

It has been recognized an important step that provides experimental validation of analytical codes for physical, mechanical and thermal-hydraulics quantities associated with GeV proton induced spallation reactions in a mercury target; quantification of all technical responses are strongly requested from the intense spallation pulse neutron source (target, moderator, reflector) development. Issues relevant to the ASTE collaboration are schematically illustrated in Fig. 1.

Fig. 1 Schematic view of the relation of the various nuclear issues associated with the proton induced spallation reaction with the mercury target.

The experimental items were discussed and selected as follows:

1) Measurement of the pressure wave associated with a high intensity proton beam in the mercury target.
2) Measurements of the neutronics characteristics in terms of the spallation neutron production profile along the mercury target, induced radio-activities in mercury samples, neutron leakage spectrum from a light water moderator which is placed adjacent to the target, nuclear heating in the moderator.
3) Development and establishment of measurement techniques for both the numbers of incident protons and the profile of the proton beam on the target.
4) Radiation shielding with a thick iron and concrete for high energy neutron and secondary particles.

3. Overviews of the experimental runs

3.1 The first run

At the first experiment with a bare mercury target, we were in successful, for the first time, in detecting of the shock wave in the mercury target associated with the proton incident.[4] Neutronics measurements in terms of reaction-rate distribution along the mercury target were carried with proton beams of 1.5, 7, and 24 GeV. We have also tested all available proton beam diagnostics in terms of intensity, profile and mean position employing the imaging plate with aluminum activation foils. As a result, the ASTE team established the experimental environment at AGS/BNL and demonstrated the technical capability pertinent to the target development.

3.2 The second run

For the second run, the bare target experiment was repeated in November, 1998, providing final neutronics experimental data on Hg. Finally we have obtained a full set of experimental data for the bare Hg target, at 1.6, 12 and 24 GeV.[5] It should be noted that along with those neutronics data, radio-activities induced in Hg samples that were placed nearby the Hg target were measured. The pressure wave was also measured.

3.3 The third run

According to the initial missions of the ASTE collaboration, we have done the third experiment with a moderator assembly in which a light water moderator with a Pb reflector was placed in the Hg target. The schematic cross sectional view of the target, moderator, and reflector assembly is shown in Fig. 2 with respect to the proton beam. The main focus for that experiment was to measure the moderated neutron spectrum intensity from the moderator. We have applied a newly developed technique, namely the current mode Time-of-Flight (CTOF),[6] for the neutron spectrum measurement. Experimental measurements of the nuclear heating in the moderator were newly tested using thermistors as the thermal sensor. Also, neutronics effect from the new assembly with reflector was examined with respect to the bare target configuration. Along with these, we have done again the pressure wave measurement without reflector.

In the nest section, topics of results are to be given.

Fig. 2. The schematic cross sectional view of the target, moderator, and reflector assembly with respect to the proton beam.

2. Topical results on neutronics experiments

4.1 Measurements of proton beam intensity and profile

The proton incident beams were monitored with a current transformer (CT) for the total beam current, a wire ionization chamber (CHIDORI named by KEK) for a beam profile (X-Y), the Cu activation foil for the total incident proton number using $^{Nat}Cu(n,x)^{24}Na$, the imaging plate (IP) with a aluminum foil which is exposed in the proton beam. Data provided by these monitors were consistent each other and provided important base data for analyzing the measurements of interest. In Fig.3 shows the proton beam profiles obtained with IP for the protons of 1.6, 12 and 24 GeV used in the neutronics experiments with the foil activation measurement. The profiles are of importance in defining the proton beam distribution and positions with respect to the mercury target. With these profiles, the precise experimental analysis can be accomplished. It is notable that the profiles are consistent with the difference in the reaction rates around the target which is to be described in the next sub-section.

Fig. 3. Incident proton profiles measured by the imaging plates using Al foils, which were exposed to the proton beams of 1.6, 12 and 24 GeV at the second experimental run.

4.2 Reaction rate measurements

The first measurement of the neutron production distribution along the_bear _mercury_target__was done in 1997. In order to finalize the data, the measurement was repeatedly carried out in 1998 for the incident proton energies_ of 1.6, 12 and 24 GeV. The measurement was performed with the activation technique and the data are documented in a technical report.[5] ______Experimental errors ranges form ± 5 % to several tens % depending on the activation counting statistics. Note that almost all experimental errors fall within ± 10 %. Thus, substantial experimental analysis can be made very effectively in terms of comparisons of the simulation codes with these experimental data.

In the mean time, various simulation codes that treat the high energy particle reactions and their transports have been widely developed for the nuclear design of the_spallation target system_.[7,8] A code named by NMTC/JAM[9] has been recently developed at JAERI in order to improve the simulation The code is an updated version of NMTC/JAERI97[7] in terms of extension of the proton energy and improving the nuclear cross sections. The experimental analysis for the AGS experiment was performed with the NMTC-/JAM, resulted in demonstration of the code validity as shown in Fig.4, which shows a good agreement between the calculation and the measurement of reaction-rate distributions of the ^{209}Bi(n,4n)^{206}Bi and ^{209}Bi(n,5n)^{205}Bi reactions at the 24 GeV proton run. _For the other reactions at other proton energies, there are reasonable agreements between the calculations and measurements. It is one of direct contribution of the AGS experiments to the code validations needed in the spallation nuclear system development.

Fig. 4 Comparison of the reaction rates of the ^{209}Bi(n,4n)^{206}Bi and ^{209}Bi(n,5n)^{205}Bi reactions between NMTC/JAM calculations and measurements. The calculations with LCS-2.7 are shown for comparison.

2.3 Nuclear heating in the light water moderator

In the experiment with the water moderator and the lead reflector, an attempt to measure nuclear heating rates in the moderator was made applying a micro-calorimetric method*). Signals of temperature rises in the moderator corresponded to the proton beam injection. The result indicated that precise nuclear heating rates can be measured with an accuracy of ± 10 % even the number of proton pulses is limited.

4.4 Neutron spectrum from the moderator

The neutron spectrum leaked from the moderator was measured with a current mode Time of Flight (CTOF) technique.[6)] CTOF was newly developed for this ASTE experiment at AGS, in which number of proton pulses are limited as low as possible from the radiation safety point of view. For this reason, the normal TOF with high frequency pulses could not be applied. CTOF solved this problem and enabled to obtain a neutron spectrum with a single pulse. In Fig. 5, the measured neutron spectrum moderated in the moderator is shown for the 24 GeV proton run.

5. Summary

Experimental analysis is extensively underway for all measurements. The ASTE colla-boration demonstrated being effective and efficient for the spallation target development. Utilizing the unique resource which became available, it is strongly requested to continue the endeavor to arrive at the goal of the ASTE collaboration.

Fig. 5 The measured neutron spectrum from the Water moderator with the detector arrangement.

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