Proceedings of the Reactor Physics Asia 2015 (RPHA15) Conference
Jeju, Korea, Sept. 16-18, 2015

Development of High Intensity D-T fusion NEutron Generator (HINEG)

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1. Introduction

Fusion energy becomes essential to solve the energy problem with the increase of energy demands. Although the recent studies of fusion energy have demonstrated the feasibility of fusion power, it commonly realizes that more hard work is needed on neutronics and safety before real application of fusion energy, especially on validation of fusion nuclear data and fusion neutron transport in complicate medium, irradiation damage and activation test of fusion material in D-T fusion neutron environment and environmental impact and radiation biological effect of fusion neutron [1]. All of these researches are demanded for high intensity D-T neutron generators. For example, the mechanism research of irradiation damage requires the intensity up to 10^{14} n/s, in order to reach 2.0 DPA/fpy. However the intensity of D-T neutron generators on operation around the world is lower than 10^{13} n/s, such as 5×10^{12} n/s in the FNS and 10^{13} n/s in the SNEG-13, which is severely restricting the research capability.

In our institute, High Intensity D-T fusion NEutron Generator (HINEG) project was proposed. HINEG project is divided into two stages. At the first stage, a D-T fusion neutron generator with both steady and pulse neutrons (HINEG-I) will be developed. The intensity will reach 10^{12} n/s. At the second stage, a high intensity D-T fusion neutron generator will be developed. The intensity will reach 10^{14} n/s. In this paper, the design and progress of HINEG will be described.

2. Description of the Actual Work

HINEG-I has two beam lines (Fig.1). The intensity of the steady beam could reach 10^{12} n/s. For the pulse beam, the full width at half maximum (FWHM) is smaller than 1.5 ns. HINEG-I can be used for the basic research for fusion neutron science. HINEG-I can also be utilized in nuclear technology applications, such as neutron radiography, neutron activation analysis, neutron radiation detection and so on. The design of HINEG-I have been finished. The core equipment, such as 50 mA ion source, 350kV/150 mA accelerator tube, and 10^{12} n/s rotating tritium target, have also be developed. At present, the ion source and Low energy beam transformer have been installed and tested (in Fig.2). The current of ion beam at the end of LEBT is up to 50 mA. The experiment hall building has been completed, and the supporting systems including the experimental measurement, licenses, radiation protection and so on are in smooth progress. The assembling and testing of HINEG-I will be finished at the end of this year.

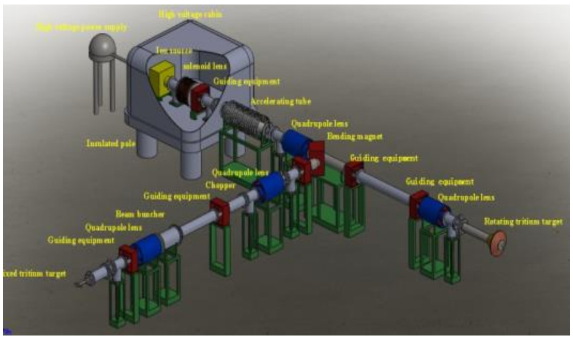

Fig. 1: Layout of HINEG-I

Fig.2: The LEBT of HINEG-I

HINEG-II is a steady D-T fusion neutron generator with intensity of 10^{14}n/s. In order to get so high intensity, we need to get more than 500mA deuteron beam on the target with 400 keV, while the diameter of the footprint will be between 20-30 mm. Therefore, a concept of multi-accelerators array is proposed (Fig.3), each of these accelerators is equipped with a 200 mA ion source, which is installed (with its associated LEBT) inside a HV cabinet and connected to a HV accelerator column. Meanwhile, in order to avoid several of beam instabilities occurred due to coupled beams, we have adopted a method of four beamlines targeting directly to obtain more than 500 mA deuteron ion beam. Through simulation, we find that the convergence beam still has a Gaussian like distribution, and the convergence beam density is higher than the single one.

At present, the concept design of HINEG-II has been finished. The challenges of HINEG-II are mainly in the high heat dissipation of tritium target.

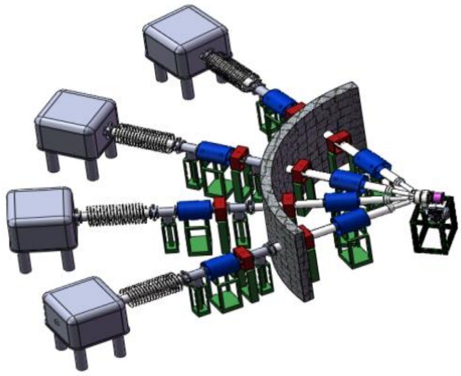

Fig. 3: Layout of HINEG-II

During the operation of HINEG-II, the power of D+ ion beams hitting on the tritium target can be reached to 200 kW. The temperature must be controlled bellow 200 ^{o}C in order to prevent the diffusion of tritium. It means that the heat flux density on the footprint of the target would be up to 50-200 kW/cm^2, given the target diameter of 1-2 cm. To enhance the heat transfer capacity of tritium target system, jet array, spraying impingement, and nano-fluid cooling enhancement technologies are explored. A high heating target experiment platform have been developed (Fig. 4), and the technology verified experimental results show that the temperature of tritium target can be controlled under 180 ^{o}C, while the beam current on the tritium target is bigger than 500 mA. The comparison of the experimental and the theoretical results (Fig. 5) indicated that the heat transfer capability can reach to 57 kW/(m^2 • K), which has verified the feasibility of the cooling technologies.

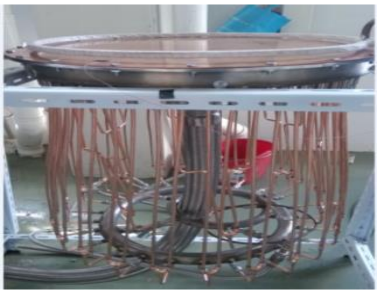

Fig. 4: Experiment platform for cooling technology of high heating target

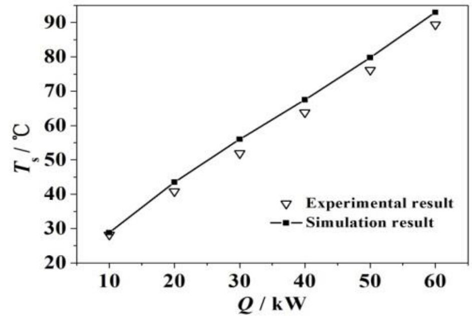

Fig. 5: Comparison of experimental and numerical simulation results of high heating target

3. Experiments Plan

HINEG-I concentrates on basic research of neutronics, including 1) generate high quality neutron cross section data, and 2) verification and validation the software used to design and analysis of the advanced nuclear energy system. At the early stage, the main proposed experiments are measuring the (n, p), (n, t), (n, ^{3}He) and (n, α) reactions of elements such as Cu, Fe, W and Ni etc. The materials' service performance and aging process in reactor are closely correlated with the above mentioned reactions since they generate gases. It is also proposed to measure the (n, γ) reaction of Fe, Li and Pb to provide accurate data for shielding design of ITER TF foil. Besides, perform the integral neutronics test experiments to verify the design of SuperMC(Super Monte Carlo simulation program), which is developed by FDS team and has been widely used for advanced nuclear energy system design and analysis including the ITER, Lead-cooled Fast Reactor and Accelerator Driven-System etc.

HINEG-II aims to study the characteristics of nuclear system component, including the engineer test of component's neutronics performance and mechanism of material radiation damage. The proposed experiments are: 1) Neutronics experiments on fusion and fission module mock-up, such as the Helium-Cooled Ceramic Breeder Test Blanket Module and Dual Functional Lithium-Lead Test Blanket Module mock-up test on tritium breeding and nuclear heat deposit. 2) Study the radioactive properties of CLAM (China Low Activation Martensitic steel), which is selected as structure material of China ITER program, to verify whether it fulfill the ppm low dose activity requirement or not. 3) Study the irradiation damage mechanism of CLAM and 15-15Ti stainless steel, which is selected as the CLEAR (China LEAd-based research Reactor) structure material. With the combination of heating field, stress field and Pb-Li/Pb-Bi medium environment, establish the irradiation damage data base and support the evolution of material's service performance in the DT fusion environment of ITER.

Besides, HINEG can be also used for applied technology research, such as fast neutron radiography, medical isotope production and fast neutron activation analysis.

4. Summary

In this paper, the design and progress of HINEG project is presented. HINEG-I has both steady and pulse beams. The intensity of the steady beam is up to 10^{12} n/s. The FWHM of pulse beam will less than 1.5 ns. The assembling and testing of HINEG-I will finished at the end of this year. HINEG-II is a steady D-T fusion generator. The intensity is 10^{14} n/s. In order to achieve so high intensity, multi-accelerators array and high heating load rotating tritium target will be used. HINEG-II will be finished at the end of 2020.

HINEG could be used in the areas of fusion nuclear data and fusion neutron transport in complicate medium, irradiation damage and activation test of fusion material, and so on. HINEG project will greatly promote the advanced nuclear energy, especially the development of fusion research in our country.

Acknowledgements

This work is supported by the Strategic Priority Science & Technology Program of the Chinese Academy of Sciences (NO. XDA03040000) and ITER 973 Program (No. 2014GB112001). We would further like to thank the great help from the other members of FDS Team in this research.

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