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# Design Concept of a Seal-off Type 14 MeV Neutron Generator of $10^{11}$ n/s Range

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## 1. Introduction

For completing the DEMO fusion reactor, it is inevitable to asses and to confirm the performance of structure and function materials to be used in harsh thermal and radiation environments of DEMO operated with DT fuels. The wall loading of 14 MeV neutrons produced from DT fusion reactions in DEMO of 2 GW is about 2 $MW/m^2$(~$10^{18}$ n/s·$m^2$). [1] The total neutron fluence during the life time is expected to be around 10 MW·yr/$m^2$ which may cause a damage of ~100 dpa in materials. To estimate the adaptability of candidate materials in a few years, a 14 MeV neutron source with a flux level of 3~5x$10^{18}$ n/s·$m^2$, which is the goal of the IFMIF facility costing more than $1000M, is necessitated. Even in the IFMIF irradiation stand the test piece can have a volume of merely 0.1 L for >50 dpa operation with the total neutron intensity of 1x$10^{17}$ n/s, a practical limit in engineering aspects. [2]

The problem in making an intense neutron generator of beam target type is really not on the neutron production rate, but on the huge heat generated in the target, because the fusion power is only one of thousands of beam power exerted on the target. Needless to say it is impossible to test real size components at actual conditions like that of DEMO. There are two alternative ways; scaling down the test piece to an adaptable size to the available test volume, or specifying the test purpose according to the neutron flux level at hand. In that sense, saying exaggeratedly, any neutron generators of any level can be utilized.

We have a plan to develop neutron generators step by step from a $10^8$ n/s level. The final goal is establishing a 14 MeV neutron irradiation facility at $10^{14}$ intensity level. Up to the $10^{10}$ n/s level, there occurs basically no critical thermal problem, because beam power density is in the range of tens W/$cm^2$. However, to produce neutrons of $10^{11}$ n/s intensity, special cooling design for the target is necessary to withstand the bema power density of around 500 W/$cm^2$(5 MW/$m^2$) depending on the beam size. Through determining the device parameters and operation conditions of a $10^{11}$ n/s system, it is expected to get useful knowledge for developing $10^{14}$ n/s device.

## 2. Basic structure and specifications

The neutron generator designed in a sealed-off type because of tritium safety is mainly composed of an ion source, target, reaction chamber, and getter pump.

### *2-1. Ion Source*

The ion source, which is of an ECR type, has the beam current of maximum 50 mA, and the acceleration energy of 100~300 keV. The extraction part of the ion source has a two-stage configuration; first stage for extraction and second for acceleration. The diameter of the beam extraction aperture is 15 mm. The first gap distance is 5mm and the extraction voltage is 15 kV. The second gap is about 100 mm. If the plasma density is in the $10^{11}$ /$cm^3$ range, the beam current of 50 mA is easily achieved.

### *2-2. Target*

The target is a kind of the drive-in type. [3] 14 MeV neutrons are produced from the DT (D+T→n(14.1)+$^4$He(3.5)) reactions following interactions of impinged fast D and/or T ions with T and/or D atoms embedded in the lattice of the target material. Besides DT reaction, two subsidiary reactions (D+D→n(2.45)+$^3$He(0.82), T+T→2n(7.56)+$^4$He(3.78)) producing relatively slow neutrons at a much less portion are also in existence. The cross-section of the DT reaction has a peak at the energy of around 70 keV (Fig. 1), therefore, the energy of the beam should be 100 keV or more for the maximum neutron yield.

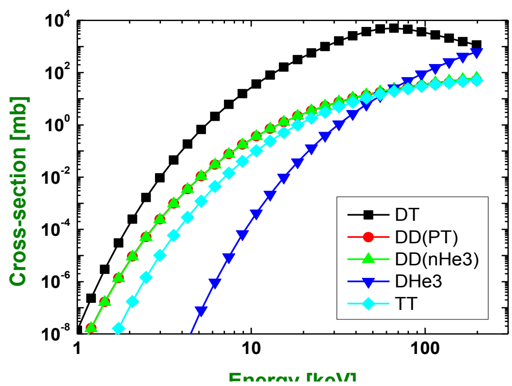


Fig. 1. Major fusion reaction cross-sections as a function of the $D_2$-beam energy, where the target is fixed. [4]

The target is made of a copper plate coated with 100 μm thick titanium film. The beam area on the target is 10 $cm^2$. The cooper plate has a cooling channel of hypervaportron structure for removing effectively >5 $MW/m^2$ thermal power. The flow rate of cooling water is 45 L/min and the flow velocity is 6 m/s.

Titanium is a typical getter material, which can admit excess hydrogen atoms in a metastable hydride form. The maximum atomic fraction is about 0.4 H/Ti. At saturation D/T retention in the target is 1.2x$10^{-4}$ g (~0.55 mbar·L, 0.7 Ci). The time required for saturation is about 90 s.

### *2-3. Reaction Chamber and Getter*

The filling amount of D/T gas in the reaction chamber, whose volume is 2 L, should be much higher than D/T retention in the target, and the initial pressure is reasonably determined to be 1 mbar. Because the operation pressure of the ion source is in the $10^{-3}$ mbar range, a device controlling and maintaining the pressure is necessary. Getter materials can be used for satisfying above requirement. After filling the chamber with $D_2$(50%) and $T_2$(50%) gases, at room temperature, the getter starts pumping the gas, and the base pressure goes down to $10^{-8}$ mbar range. Before operating the ion source, the getter is heated up to a specified temperature depending on the desired vapor pressure to supply the fuels to the ion source.

The getter pump is made of a double-side-coated NEG strip of 2x2 $cm^2$ and 0.5 g. The D/T retention in the getter is $4.4\times10^{-4}$ g (~2 mbar·L, 2.5 Ci), and the absorption concentration of 4 mbar·L/g is far below than the limit to avoid embrittlement, for example, 10 mbar·L/g. The D/T concentration of 4 mbar·L/g looks appropriate for sustaining the vapor pressure at the $10^{-3}$ mbar range, and for a smooth control of the fueling at a moderate temperature of 300℃.

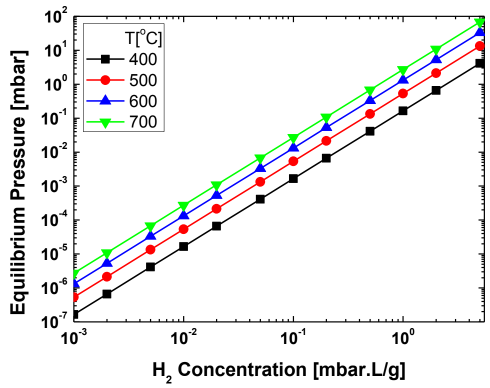


Fig. 2. PCT (pressure-conc.-temp.) curve of St707 getter. The dependency on the concentration is expressed with the Sievert's law, and on the temperature by Arrhenius equation, $P=\rho^2 e^{A-B/T}$ (ρ is the concentration).

Considering the rule that the inventory of tritium in the system should be minimized unless it doesn't exert an adverse effect on the performance of the neutron generator, commercial getters like St707 can be used instead of hydrogen storage getters such as U and ZrCo. St707 manufactured by SAES Getters is one of the most popularly used getter, and has a PCT diagram like Fig. 2.

From Fig. 2, it is recognized that the working pressure of the fuel gas can be controlled in a wide range by changing the temperature and the concentration of the getter.

### *2-4. Neutron Yield*

The neutron yield $G_n$ [neutrons/$cm^3$· s] in the target is expressed as follows;

$$G_n = n_b n_H \int_0^R \sigma v dx \qquad (1)$$

$$n_b = \frac{I_b}{e v_b}, \quad \int_0^R \sigma v dx = \int_{E_b}^0 \frac{\sigma v}{dE/dx} dE$$

Here, $I_b$ is the ion beam current, $n_b$ is the ion density of beam, e is the elementary charge, $v_b$ is the ion initial speed, v is the speed in the matter, $n_H$ is the hydrogen concentration, dE/dx is the energy loss rate, R is the range of ions in the matter, and σ is the cross-section of the DT reaction. $G_n$ is dependent on the beam energy through the reactivity σv and the range R in a complicated manner. Fig. 3 shows the reactivity and the range as functions of the beam energy.

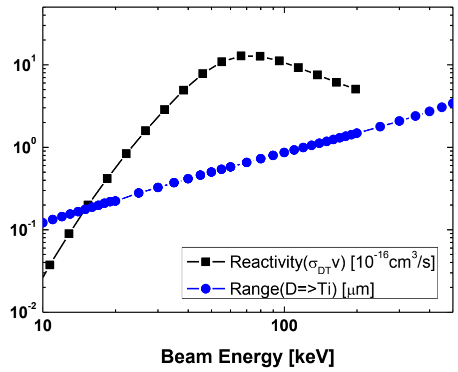


Fig. 3. Variation of reactivity of DT fusion reaction and the range of D ion in Ti with respect to the beam energy. [5]

The 100 keV D and T ions have the range of 0.75 μm and 0.86 μm respectively in Ti. Assuming the concentration of D or T atoms in the layer to be uniform, the neutron production rate is expected to be $7.4\times10^{11}$ n/s for a 100keV/50mA beam, and available neutrons for the test piece can be in the $10^{11}$ n/s range. If the test piece is placed apart from the target by 50 cm, the neutron flux is $2.4\times10^{7}$ n/s·$cm^2$.

### *2-4. Neutron Shield*

The distribution of neutrons from the target is basically isotropic. If the closest access of persons is limited to 5 m from the source, the neutron flux is geometrically reduced to $2.4\times10^{6}$ n/s·$cm^2$. The maximum permissible neutron flux for device operators is 10 n/ s·$cm^2$. [6] Therefore additional reduction factor of 24000 is required. If composite shield material, for example, composed of water, steel, and borated polyethylene, has a neutron removal cross-section of about 0.1/cm, the shield thickness of 1.5 m is sufficient to cope with the regulation.

### *2-5. Gas Cycling*

The D/T gas recycles in sequence through the ion source, target, and getter as described in Fig. 3. The D/T gas flow as a beam of 100keV/50mA is $1.25x10^{-3}$ mbar·L/s. Before saturation of the target with D/T gases, there is practically no desorption from the target, and the getter acts only as a gas holder. After saturation, at the steady state, there is a net flow of D/T gas from the target, according to the beam current subtracted with the diffused flow into the bulk of the target and the loss in fusion reactions. The D/T gas consumption for the reactions is merely $1.5x10^{-8}$ mbar·L/s.

The pumping speed of the getter depends on the surface area and the specific pumping speed (roughly 0.01 L/s·$cm^2$ for hydrogenous gases). The pumping rate of the getter whose area is 8 $cm^2$ is in the range of $10^{-4}$ mbar·L/s. Some absorbed molecules are associatively desorbed ($X+X \rightarrow X_2\uparrow$) from the getter, and at the steady state the desorption rate makes a quasi-balance with the pumping rate. The minute difference between them corresponds to the net loss of D/T gas by fusion reactions in the target.

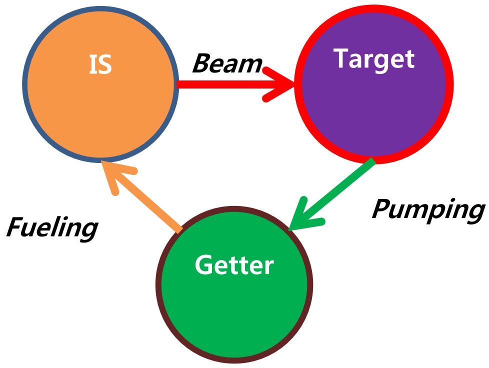


Fig. 2. Major fusion reaction cross-sections as a function of the beam energy, where the target is fixed. [1]

## 3. Conclusions

The major design concepts for the neutron generator with the neutron production rate of $10^{11}$ n/s range were presented. The specifications of the ion source, target and getter have been determined for attaining the goal of the neutron generation rate. Cooling requirement of the target and pumping demand of the getter were also studied.

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