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14 MeV Neutron Generator – Literature Review

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Abstact:

A 14 MeV neutron generator described in this paper.Neutrons are produced in D-T, D-D,T-T reactions. The production of 14 MeV neutrons from DD neutrons generator resulting from tritium build up from d(d,p)t reaction in the target under 30mA, 300 KeV deuteron beam, bombarding a water-cooled, rotating target, size of beam spot on target is 1.8 cm is obtained. An estimate of the capital cost 14 MeV neutron generators for radioisotope production.

1. Introduction

Sealed tube neutron generators are small particle accelerators which exploit either the $^{2}H+^{2}H=^{3}He+n+3.3MeV$ ($\overline{E_n} = 2.5MeV$) or $^{2}H+^{3}H=^{4}He+n+17.6MeV$ ($\overline{E_n} = 14.1\ MeV$) fusion reactions to produce fast neutrons [1].
In order to test operating neutron generators special test facilities are usually constructed that provide shielding to protect staff personnel from neutron radiation. In principle, radiation protection could be achieved by operating the neutron generators in large open spaces and maintaining a large distance between personnel and the operating neutron generators rather than using shielding; however, limited floor space and difficulty in securing physical access to the generators being tested limits this route in a manufacturing environment [1].

Several reports describing custom built shield facilities for neutron generators, including both experiments and simulations, have been described in the literature [10-13]. As a reference tool the National Council on Radiation Protection and Measurements (NCRP) has published a report which provides guidance and general rules of thumb for designing neutron generator shields.

Several other references also provide useful guidance for designing and analyzing neutron generator radiation shielding [14-16]. In most cases, neutron generator shield designers have opted to use concrete for shield facilities because of its relatively modest cost and its structural characteristics in construction. Other materials frequently encountered in neutron generator shields include polyethylene and paraffin (either cast-in place or as modular blocks, with or without boron) as well as water shielding in large holding tanks (with hollow test chambers inside)[1].

2. Neutron generator concept

In a neutron generator a high-voltage is applied to extract a D^{+}/T^{+} beam from an ion source and to accelerate it towards the target where neutrons are

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produced in D–T, D–D, or T–T reactions. The neutron yield increases with acceleration voltage, limited by HV breakdown across the acceleration gap, and with beam current, limited by the ion source output and the ability of the target to handle the beam power[2].

In the generator described here a high beam current is extracted from an RF-driven ion source and

accelerated towards the target. The generator is operated with a D–T gas mixture and a beam-loaded target, i.e. the D^+/T^+ beam is driven into the target matrix, for achieving acceptable lifetimes. The requirements of a sealed tube for tritium operation posed several design challenges including UHV compatible construction, low pressure ion source operation, and the need to limit the tritium inventory[2].

Neutron generator components are a gas reservoir and pressure regulator for supplying the D/T gas mixture and keeping a stable pressure inside the tube, and an ion getter pump for the removal of helium and other contaminant gases [2].

The expected 14 MeV neutron yield for a 100 keV, 50% T^+ /50% D^+ beam impinging on a fully loaded Ti-target (TiDT) is about 2.2×10^{13}n/C. However, extrapolation from our experimental results for beam-loaded D–D generators gives about half that value, likely due to an incomplete beam-loading of the titanium layer[3].

3. System description

3.1Ion source

The ion source is of a duoplasmatron type. It allows extraction of up to 50 mA do deuteron beam under 8A arc current and 15 kV extraction voltage. A comparatively large expansion cup (Ø = 19.5 mm) is adopted in order to increase the ion emission area and improve the ion emission condition. The magnetic property, electrical potential and geometry of the expansion cup can all affect the optical properties of the beam[4].

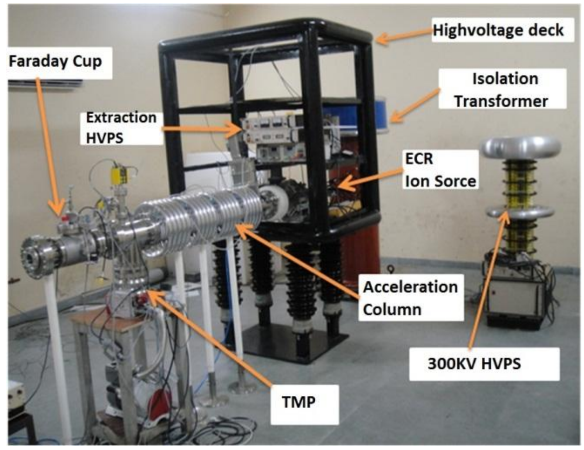

Figure 1: 14 MeV neutron generator system description.

Figure 2: 14 MeV neutron generator.

3.2 Beam acceleration and transport system

The accelerating and focusing system consists of a beam extraction system, a high-gradient accelerating tube, a space charge lens and a magnetic quadruple triplet lens[5].

The accelerating tube is of an air insulation type; with eight HV porcelain rings, and a total length of 88 cm. The anode and cathode are separated by a distance of about 8 cm, and a third electrode, a flat plate, is placed in the middle of the gap. The average gradient in the active region is about 38 kV/cm [5].

The anode is also used as an extraction electrode at the side of the ion source, so that there is almost no low-energy drift region. The space charge lens, which is composed of a negative electrode and a mirror magnetic field, is located just behind the cathode. A high electron density up to 5 x 10^{15} e/m^3 is estimated to be trapped in the area of the space charge lens. The experiments have shown that this compact accelerating and focusing system is favorable to minimize the beam divergence caused by the space charges in the beam, and therefore, to raise the efficiency of the beam transport and decrease the load of the heating from the accelerating tube due to the secondary electrons and stray ions[5].

3.3HV supply

The HV supply is a 4-stage symmetrical Cockcroft Walton circuit driven by a thyristor inverter power supply of 2.5 kHz. At this frequency, a high power, high-voltage transformer can be made easily and the power dissipation is rather small [6]. Some calculations on short circuit transient processes of the multiplier circuit were carried out. According to calculations, protection resistors of different resistance are connected to each condenser and rectifier in series respectively. Therefore, the power dissipation in each rectifier due to overcurrent is approximately equal. A reliable protection of the HV supply has been realized in the case of smaller protection resistances. The rectifier rack, protection resistors and eight equipotential rings are all assembled in an epoxy-resin glass-clothed cylinder filled with transformer oil in order to improve insulation and heat dissipation [5].

3.4Vacuum pumping and tritium scrubbing system

Two turbo molecular pumps are alternatively used to evacuate the systemduring the operation, approximately 15% of the tritium in the target will be released into the accelerator vacuum system [7]. In order to minimize tritium release to the environment, a tritium scrubbing system is used. The exhaust from all forepumps on the accelerator and target storage box are pumped into two stainless steel tanks with a 1.1 m^3 volume, and is then passed through two stages of tritium scrubbers in series in which the hydrogen is oxidized to water. Afterwards, it is absorbed by a molecular sieve column after cooling. These treatments can reduce the tritium concentration by a factor of 10°. The gas pumped out from the scrubbers is exhausted to atmosphere by air blast dilution through a 20 m high stack. Two tritium gas monitors fitted to the outlet and inlet port of the scrubbers can continuously monitor the tritium concentration in the gas. If the concentration is higher than the restriction value, the gas will be pressed back into the tanks, and it will go through a second run[5].

4. Production

For D-D generators utilizing deuterated titanium targets and operating at voltages of 200 keV or below, most of the reactions will occur within 0.5 pm of the surface of the target. This distance is significantly less than the ranges of the charged particle products in the target material. Moreover, there will be a tendency for any accumulated tritium to be displaced by further deuterium bombardment. Thus a precise calculation of the buildup of the charged reaction products in the target would prove quite involved. We may make a rough estimate of the upper limit of this buildup if we assume all of the charged reaction products remain within the target. In terms of an assumed constant production rate $\varnothing_{dd}$ of the 3 MeV neutrons from the D-D reaction, the number$n_t$of tritium atoms in the target will be:

$$n_t < \varnothing_{dd} T \text{………….. (1)}$$

where T is the accumulated bombardment time over the life of the target. This number should be compared to the number of target deuterons:

$$n_d = \rho_d RA \text{……………. (2)}$$

where pd is the volume number density of the deuterium atoms in the target (about 6 X $10^{22}\,cm^{-3}$ if we assume a 1 : 1 loading of a deuterated-titanium target). for example, for a D-D neutron generator with a total production rate of 10^8 3 MeV neutrons/s, after 1000 h of operation, we estimate, using eq. (1) that:

$n_t < 3.6 \times 10^{14}$ ………….. (3)

which should be compared to:

$n_d = 3 \times 10^{17}$ ……………. (4)

where we have taken R = 0.5 μm and A = 0.1 cm^2.

Thus the initially pure deuterated target will contain at most contamination of 0.1% of tritium. Since the D-T cross section is about one hundred times that of the D-D cross section for energies less than 200 KeV, a 0.1% concentration of tritium in the target will result in 10% of the total neutron output being 14 MeV neutrons from the D-T reaction. In terms of the present example the 10^8 3 MeV neutrons/s will be accompanied by $10^7$14 MeV neutrons/s[8].

The presence of a small component of a 14 MeV neutron flux to the output of a neutron generator which is assumed to produce only 3 MeV neutrons presents a potentially serious systematic error to any fast neutron activation analysis involving the generator. This systematicError may be expressed by comparing the yieldof a given reaction assuming a pure 3 MeV neutron flux to the yield assuming a mixed flux of 3 MeV and 14 MeV neutrons:

$Y_3/Y_{3+14}=(\sigma_3 Ø_3)/(\sigma\delta_3 Ø_3+\sigma_{14} Ø_{14})$….(5)

In the case where there is a buildup of tritium in the target of a D-D neutron generator, the systematic error noted above can be accounted for using eq. (e) or can be eliminated altogether by replacement of the target [8].

Due to the high energy of the neutrons (n, 2n), (n, p)and (n, α) reactions are possible. By means of thesenuclear reactions a whole host of radionuclides whichare impossible to produce with thermal neutronsbecome available which can be produced by 14 MeV neutrons. Due to the fact that the crosssections for the 14MeV reactions are relatively low and the fluxes available are several orders of magnitude lower than those available with nuclear reactors and cyclotrons, large quantities of material should be activated in order to obtain useful quantities of radionuclides[9].

Fortunately it is no problem to irradiate large quantities of material. It is, however, important to develop procedures to separate the radionuclides from the large bulk of target material rapidly andwith high separation efficiency. Two factors assist in developing separation procedures. One is that the radioisotopes produced by (n, p) and (n,α) reactions differ chemically from the target material; the other is that the reaction energies involved are such that the atoms undergoing nuclear reactions have a high probability of being torn from their parent molecules in the target [9].

5. Capital outlay and operating costs

Table1. 14MeVneutron generator

Capital cost of installation		$
Pit 2 ft in diameter, 9 ft deep		5,000
Lined with concrete sewer pipe		
Basic generator, control, power		32,000
Supplies and vacuum pump		
Spares	5,000	
Pneumatic transfer system		9,000
Total capital investment		51,000
Annual operating expenses		
Monthly tube replacement@$1900		22,800
Per tube		
Spared and maintenance/yr		2,000
Power/yr		500
Annual total operating costs		25,300

An exact cost analysis of a 14 MeV neutron generator system for radioisotope production depends on the type of generator in question. Table 1 gives an approximate cost breakdown of capital cost of installation and annual operating expenses.

6. Referances

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