IEEE Transactions on Nuclear Science, Vol.NS-22, No.3, June 1975

DESIGN OF AN INTENSE FAST NEUTRON SOURCE

J.D. Hepburn, J.H. Ormrod and B.G. Chidley

Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario Canada

Summary

The design of a 4×10^{12} s^{-1} source of 14 MeV neutrons is described. The neutrons are produced by the $T(d,n)^4He$ reaction using a 25 mA, 300 keV beam of atomic deuterons bombarding a water-cooled, rotating drum-shaped titanium-tritide target. The drum dimensions are chosen to give at least a 100-hour half-life for the neutron source strength.

Introduction

This paper describes a 4×10^{12} s^{-1} D-T neutron source currently under construction at the Chalk River Nuclear Laboratories. It is to be used for neutron dosimetry, materials activation and spectral studies of inelastically scattered neutrons. However, the source specifications are compatible with the requirements of a neutron therapy installation[1] (specifically a few x 10^{12} s^{-1}, a beam spot diameter not greater than 20 mm, and a target lifetime in excess of 100 hours).

The generator produces neutrons by the reaction $T(d,n)^4He$ using a 25 mA deuteron beam incident on a titanium-tritide target. This approach has been used at several installations[2,3,4,5]. Our target differs from their geometry in that the active surface is on the outer cylindrical surface of a rotating drum which can be translated along its axis of rotation, in front of the beam, to allow use of three target tracks covering the total area of 5×10^4 mm^2.

The beam from a von Ardenne duoplasmatron ion source is accelerated through a potential of 300 kV, then a $\pi/3$ bending magnet separates the atomic ion component. Use of the analyzed deuteron beam prolongs the target lifetime[6].

The auxiliary power supplies for the ion source are located in the high voltage power supply oil tank. This arrangement minimizes the number of components supported by the accelerating column and keeps the power supplies away from areas of high fast neutron flux. Connections to the ion source run through wires inside the hollow center conductor of a high voltage co-axial cable insulated by sulfur hexafluoride gas. The cable outer conductor forms, with a cylinder surrounding the complete ion source-accelerating column assembly, the sulfur hexafluoride pressure vessel.

Construction of most of the components is now complete, and preliminary assembly and testing are in progress.

Design Details

Ion Source and Accelerating Column

Figure 1 is a plan view of the accelerator and analyzing magnet, in which the ion source and accelerating column are shown sectioned. The von Ardenne duoplasmatron ion source is similar to that used in other experiments[7], except that the plasma aperture plate is insulated from both the anode and source can. A 40 mA mixed beam is required to give 30 mA of atomic ions, of which up to 5 mA can be lost in beam defining electrodes. This beam is produced using a 0.45 mm diameter anode aperture and a 10 mm diameter plasma aperture. Table 1 lists the ion source parameters as measured on an ion source test stand.

Table 1: Ion Source Parameters for a von Ardenne Duoplasmatron

Parameter	Value
a. Fixed Parameters	
plasma aperture (mm)	10.0
anode aperture (mm)	0.45
gas flow (atm cm^3/min)	1.05
b. Operating Range	
coil current (A)	0.4-1.4
arc current (A)	4-12
extraction voltage (kV)	20-25
total extracted current (mA)	4-40
c. Typical Operating Point	
coil current (A)	1.4
arc current (A)	11.3
extraction voltage (kV)	25
extracted current (mA)	40
ion distribution (D_1^+, D_2^+, D_3^+) (%)	75, 20, 5
beam emittance invariant, taken on 95% of total beam current (π mm mradians)	1.3

The beam from the ion source is accelerated through a two-gap structure. The extraction electrode, located 15 mm from the source can, is held approximately 20 kV below the ion source potential, which is 300 kV. The remaining potential appears across a single 100 mm gap to ground potential.

The ceramic rings (94% Al_2O_3) that form the column vacuum jacket are 33 mm long and each supports a 50 kV potential difference. The titanium plates separating the ceramic rings have titanium skirts on them to shield the rings from the beam. The column is graded by two chains of six 400 MΩ metal

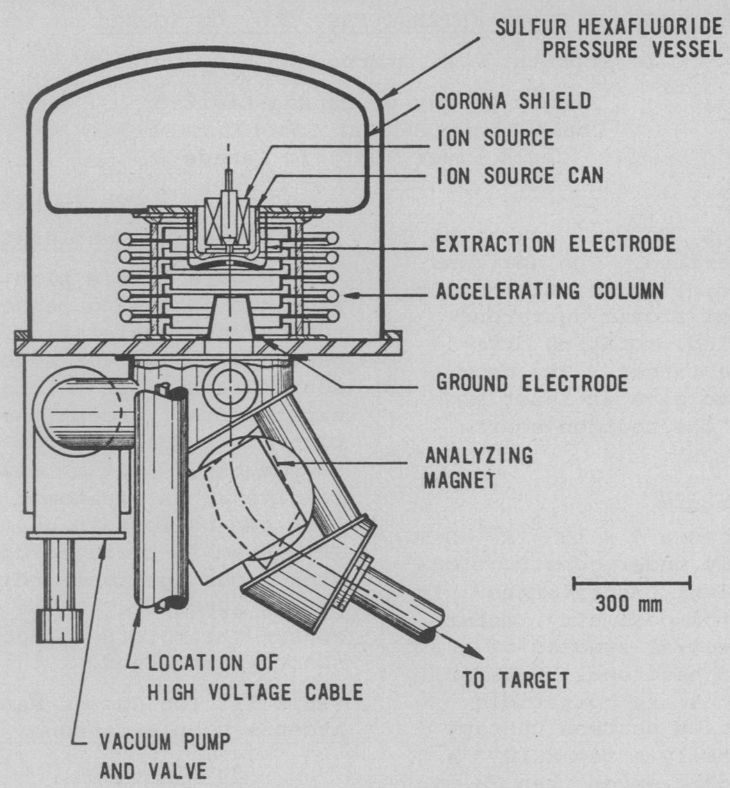

Figure 1: Sectioned plan view of the accelerator. The target, shown in Figure 3, is located 1.5 m from the exit edge of the analyzing magnet.

oxide resistors located between the electrodes, outside of the ceramic rings. The column uses polyvinyl acetate as the ceramic to titanium bonding agent. The ion source and the top of the column are surrounded by a large corona shield which houses the D_2 source gas supply and terminates the high voltage cable. The column and shield are shown in Figure 2.

Power Supplies

The beam energy of 300 keV was chosen as a compromise between power supply size and reliability on the one hand, and neutron production efficiency and target lifetime on the other.

Five power supplies are required for accelerator operation. Power for beam acceleration comes from a 50 mA, 300 kV oil-insulated supply. The 1 mA, 25 kV (variable) extraction electrode bias supply is part of the same unit. The three auxiliary power supplies required to operate the ion source are located in an oil-tight perspex box immersed in the high voltage power supply oil tank. Operation of the supplies is monitored by a TV camera placed on top of the oil tank. The camera views illuminated meters, which are located inside the box, through a port in the oil tank lid. The 35 A, 2 V filament supply has variac control and the 2 A, 200 V coil supply and the 15 A,

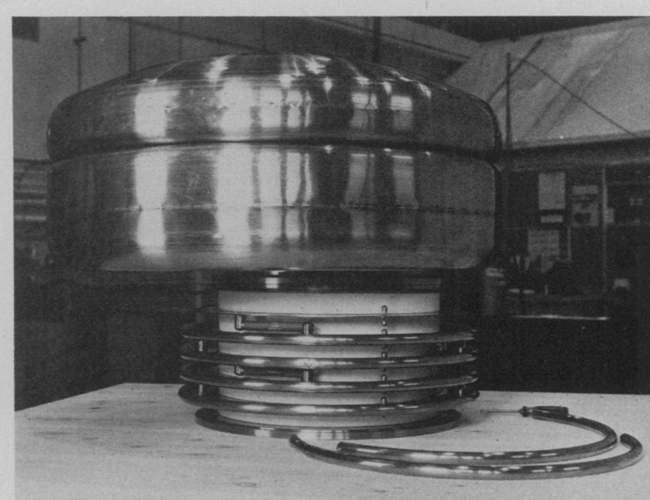

Figure 2: Accelerating column and corona shield. The shield is offset to permit connection to the high voltage cable (which is not shown).

100 V arc supply are series transistor regulated. Metal-oxide varistors and ferrite toroids protect the solid state devices from transients generated during high voltage arcdowns. A prototype of the arc supply has successfully operated a duoplasmatron ion source and withstood arcdowns of 135 kV.

High Voltage Cable

The 4.8 m long high voltage cable has a 42 mm OD inner conductor, and a 128 mm ID outer conductor. The rigid inner conductor is supported by the accelerating column and by a lucite window located at the power supply oil tank wall. The highest electrical stresses in the system occur at this window. A pressure of 350 kPa ($\approx$ 50 psia) is maintained on the sulfur hexafluoride gas side of the window to prevent surface flashovers, while on the oil side a 250 mm long sleeve surrounds the projecting inner conductor.

Ion Optics

The extractor electrode and the front of the ion source have Pierce[8] geometry, but adjustments in the beam current and extraction voltage about the nominal values will be used to control beam focussing.

The analyzing magnet uses non-normal entry and exit angles, and will provide sufficient horizontal and vertical focussing to yield the required 10 mm radius on target if the beam is space charge neutralized between the magnet and target. A range of input beam conditions can be accommodated by pole rotations, pole translations, and adjustments to the magnetic field intensity.

A collimator, quadrant aperture and retractable Faraday cup comprise the beam defining and diagnostic assembly located immediately in front of the target, as shown in Figure 3.

Figure 4 shows the calculated vertical and horizontal beam envelope radii plotted against the beam trajectory, together with the positions of the accelerator components.

Target

Figure 3 shows a simplified view of the target assembly. The active target surface is a 10 $\mu g/mm^2$ thick, 66 mm wide ribbon of titanium tritide ($TiT_{1.2}$) on the outer surface of a 245 mm OD drum which rotates at 1100 rpm. A bare strip of copper is left beside the titanium tritide ribbon in order that neutrons from the $D(d,n)^3He$ reaction can be produced using deuterium implanted by the beam as target material. Target cooling is supplied by water flowing between a stationary baffle and the inside of the rotating drum. The shear forces and large relative water velocity provide effective heat transfer, thus preventing thermal decomposition of the target surface. The instantaneous beam power is 24 W/mm^2; the average beam power is $\sim$ 0.64 W/mm^2, and the expected peak temperature difference between the target surface and the cooling water is 36^{o}C. Two ports allow samples up to 20 mm diameter to be placed as close as 20 mm from the target. The ports are adjacent to the beam line, in the horizontal plane.

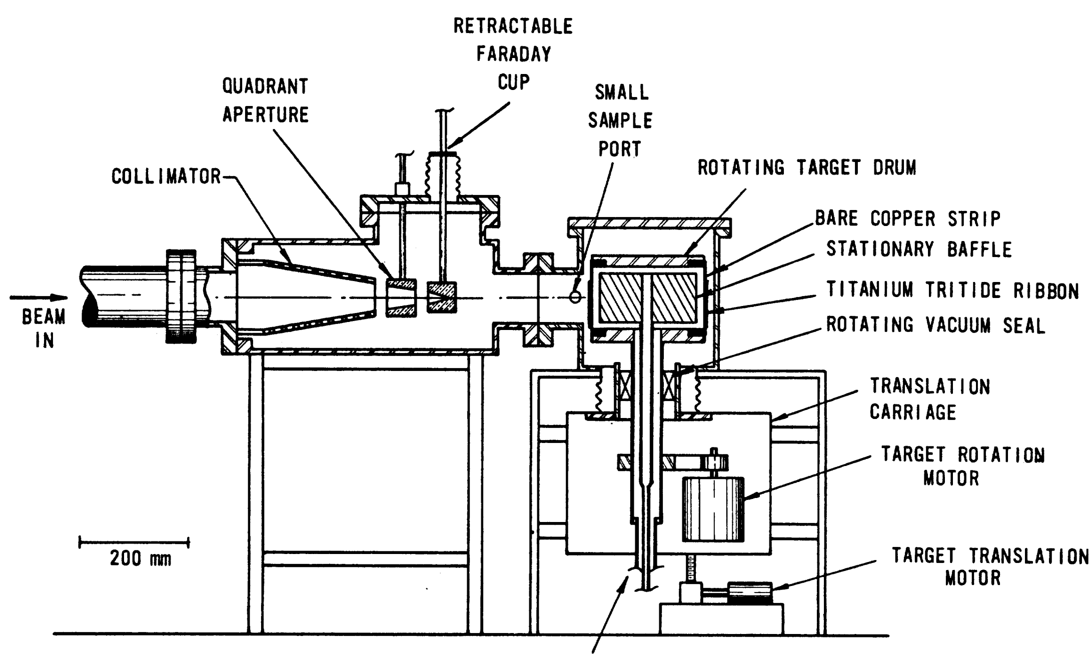

Figure 3: Simplified cross-sectional view of the beam defining apparatus and target assembly. The target is 1.5 m from the analyzing magnet shown in Figure 1.

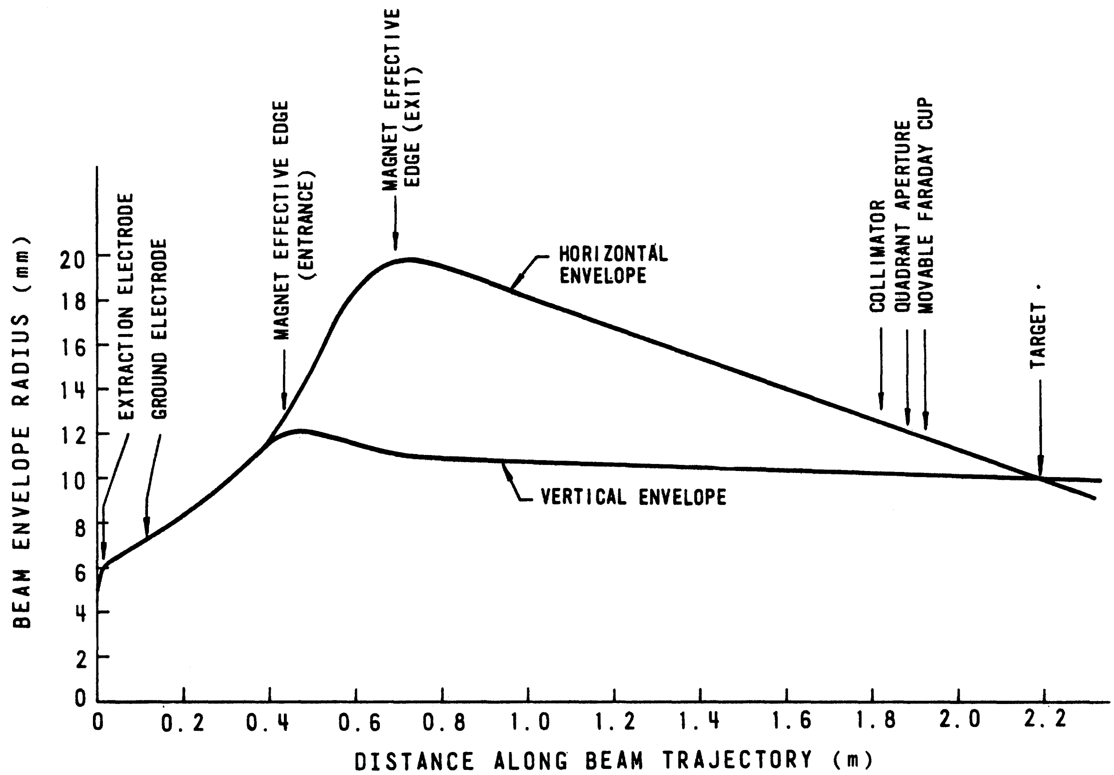

Figure 4: Predicted beam envelope radii along the beam trajectory, together with the positions of the accelerator components

Current Status

Fabrication of accelerator components is complete with the exception of the target assembly. However one target drum has been completed and sent to an outside manufacturer for tritiation. The power supply and high voltage cable package has been assembled and is being tested. The control system wiring is complete. The ion source, accelerating column and corona shield have been assembled.

First beam tests, without the tritiated target, are expected soon; target tests will commence later in the year.

References

1. M. Catterall et al, Brit. J. of Radiology 44, 603, 1971.
2. R. Booth and H.H. Barschall, Nucl. Instr. Methods 99, 1, 1972.
3. R. Booth, Nucl. Instr. Methods 120, 353, 1974.
4. AEG facility being installed at Hamburg, Germany.
5. J.E. Broers-Challiss et al, IAEA Symposium on Neutron Monitoring, Vienna 1972.
6. J.H. Ormrod, Can. J. Phys. 52, 1971, 1974.
7. J.H. Ormrod, M.D. Snedden and J. Ungrin, Atomic Energy of Canada report AECL-4224, 1972.
8. J.R. Pierce, Theory and Design of Electron Beams, Van Nostrand Co., Princeton, N.J. 1954.