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OPERATION AND LIFE OF SODITRON NEUTRON TUBE FOR INDUSTRIAL ANALYSIS

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The SODITRON neutron tube is a small sealed D-T accelerator being used for neutron production. It can work either in continuous or pulsed mode. This ceramic neutron tube utilizes a Penning type ion source, a D-T gas reservoir, and a tritiated target. Extraction and acceleration of ions is possible up to 100 kV. Neutron emission at 14 MeV is adjustable up to 2.10^8 n/s in average value, or up to 10^5 n/µs during 10 µs pulses. Life testing has demonstrated an average tube lifetime between 500 hours and 4000 hours or more, depending on working conditions. Tube lifetime is strongly related to neutron output, duty cycle, high voltage level, temperature, housing, etc. The use of the SODITRON tube in industrial applications such as on-line inspection of materials is now possible as an alternative to isotopic neutron sources.

INTRODUCTION

The need for a small-size high-reliability and long-life neutron tube is strong when considering applications such as transuranic waste assay in reprocessing plants, or on-line inspection of raw material in industry. The cost of a measurement is related to the lifetime of the tube and to its replacement at end of life. It is the reason for which the SODITRON tube was developed, with two characteristics: a long life, and an easy to change capability by the user. As a consequence, the tube is mechanically strong and shows no tritium contamination in normal operating conditions (under 60°C).

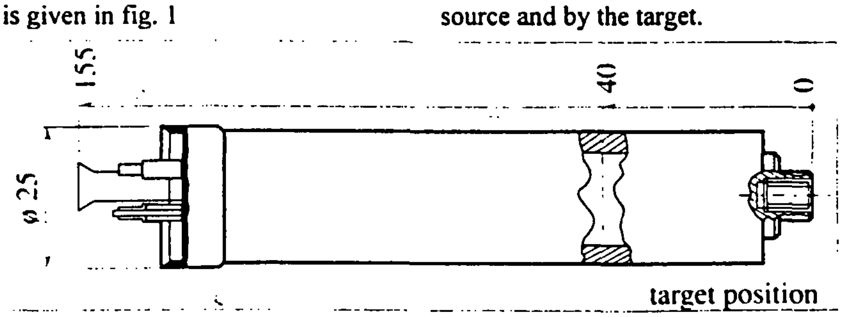
The SODITRON is a 25 mm diameter ceramic tube which runs without external magnet. It is operated either in continuous or in pulsed mode, and it emits 14 MeV neutrons from D-T fusion reaction up to 2.10^8 n/s. Details for the tube operation and life experience are given here. Life-limiting mechanisms are discussed below.

TUBE DESCRIPTION

A schema of the tube is given in fig. 1

The SODITRON neutron tube is a metal-ceramic vacuum-sealed component. Inside the envelope are an ion source, an accelerating gap, a target, and a gas reservoir/getter device. A mixture of deuterium and tritium is stored partly in the reservoir, partly in the target. Tritium is a β emitter radioactive gas, with a half life of 12.3 years. During storage, pressure is lower than 1.3 x 10^{-3} Pa (10^{-5} torr). When using the tube, gas reservoir is heated in such a way that the pressure in the tube increases at a level which determines the peak target current, then the neutron emission.

The ion source is a gas discharge cold cathode ion source, Penning type. A magnetic field, supplied by an internal permanent magnet, is used for a high ionization rate of the deuterium/tritium gas. Ion source bias is 2 kV. Gas pressure is stabilized by the heated reservoir at the suitable level, up to 1.3 Pa (10^{-2} torr). This kind of source may be used either in continuous mode, or in pulsed mode, depending on the gas pressure, the required peak output, and the power which can be dissipated by the ion source and by the target.



(Dimensions mm)

Fig. 1 : The SODITRON neutron tube

CP392, *Application of Accelerators in Research and Industry*, edited by J. L. Duggan and I. L. Morgan
AIP Press, New York © 1997

The accelerating gap is located between the extracting electrode of the ion source and the accelerating electrode with a hole for penetration of the ion beam in the target area. This tube is designed for negative high voltage applied to cathode and target, up to -100 kV, either continuous or pulsed.

The target substrate is an electrode hidden behind the accelerating electrode. Target is a film of titanium hydride, loaded with a mixture of deuterium and tritium. Under bombardment of the deuterium (D) and tritium (T) ion beam, the target emits neutrons from three reactions :

$$D + T \rightarrow {}^4He + n\ (14\ MeV) \quad (1)$$
$$D + D \rightarrow {}^3He + n\ (2.5\ MeV) \quad (2)$$
$$D + D \rightarrow T + H \quad (3)$$

Fusion reactions (1) and (2) are very neutron profilic, especially (1) representing more than 95 % of the neutron output. Reaction (3), equally probable with (2), does not deliver neutrons, but gives tritium atoms, as the origin of additional neutrons from reaction (1). As a consequence, emitted neutrons are mainly at 14 MeV. A more complete description is given in ref. 1.

OUTPUT AND LIFETIME

When heated by a typical 1A current, the gas reservoir delivers DT gas pressure inside the tube. For pulsed mode, the ion source is pulsed with up to 2 kV pulse through an impedance providing up to 1A source current. Generated ions are extracted by an electrode with a hole, and accelerated across the gap to reach the target with a high energy. Using a target bias of -100 kV continuous (or pulsed), the energy of the ions is between 40 and 100 kV, depending on tube pressure and ion type : D_2^+, D^+, T^+, DT^+, ... The target substrate is electrically insulated from the accelerating electrode permitting the target to be biased and to suppress secondary electrons. Then tube current is reduced in the 20 to 100 μA range on average, with instantaneous value up to 100 mA. Neutron output is then in the 2.10^7 to 2.10^8 n/s range on average, with peak output up to 10^{11} n/s. Neutron output is proportional to tube current and varies nearly as the third to fourth power of the high voltage.

Lifetime tests were conducted during laboratory off-hours overnight and weekends. Continuous high voltage was applied : at 90 kV, then 95 kV later while output was slightly decreasing, and so on in such a way that neutron output remains over a threshold level.

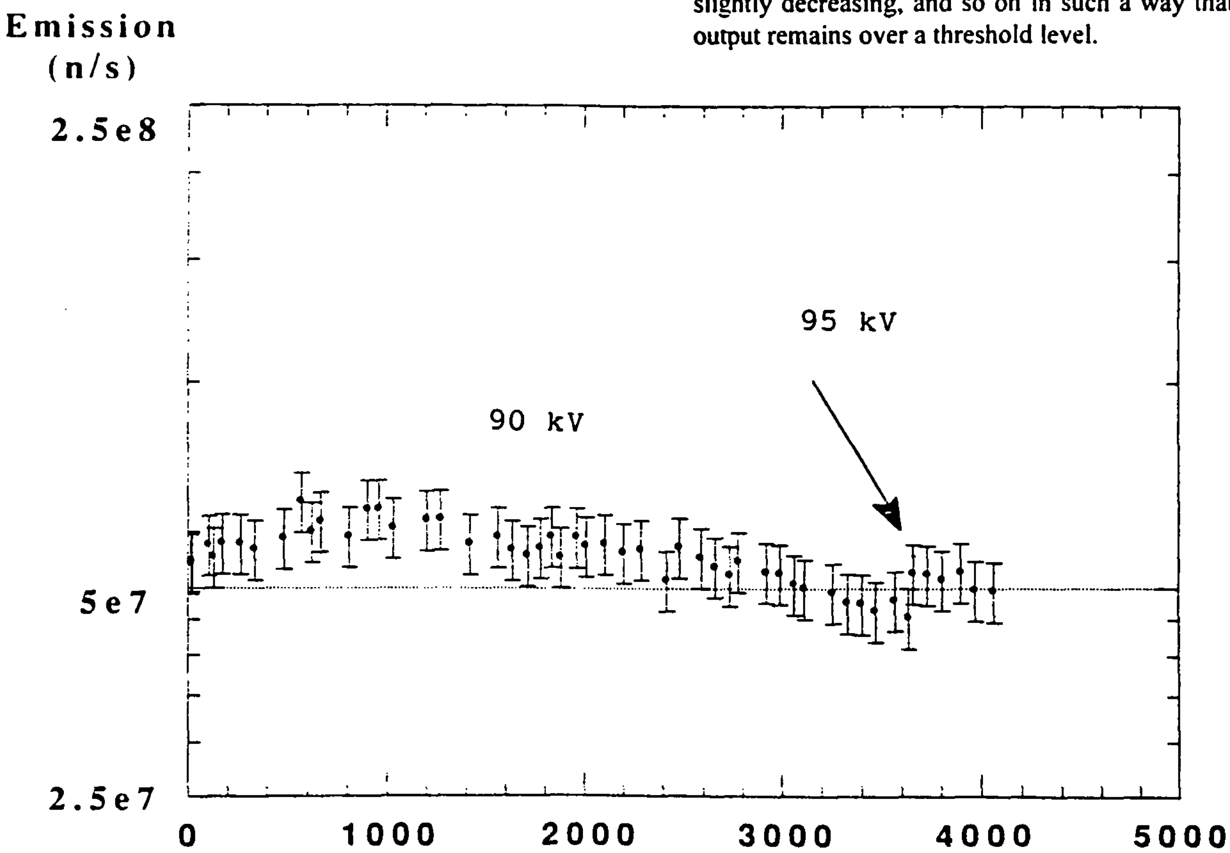


Fig. 2 : life test record of a SODITRON neutron tube at 5×10^7 n/s

Tests were performed at different duty cycle and average output, and in different configurations (test geometry, electrical insulation, ...). The neutron output was measured using the copper activation method, allowing only fast neutrons and rejecting scattered neutrons.

We have observed a very extended lifetime when using the tube at high duty cycle, in the 5 to 10 % or more, with a very stable output. The tube can be operated at 90 kV with a 80 μA current, leading to an average output of 2×10^8 n/s during more than 1000 hours. One tube was tested at 90 kV with a 20 μA current, for an average output of 5×10^7 n/s : lifetime is higher than 4000 hours, and tube is still running (fig. 2). We have observed that the high voltage breakdown probability is low (one arc per 20 hours in this case), but is increasing when the external metallic housing diameter is small. At a very low duty cycle, typically 0.2 %, obtained for example with 20 μs pulses at 50 p.p.s., the neutron emission is decreasing with an exponential shape : half emission is reached at 300 hours, or 40 % of initial emission at 600 hours.

DISCUSSION

The factors of lifetime limitation include reservoir capacity, target degradation, metal sputtering, and helium generation.

The last point does not seem to be a problem, while ^3He build up from tritium decay and ^4He from DT fusion reaction (and ^3He from DD fusion reaction) are remaining trapped in the replenisher and in the target. Less than 1 % of helium is in a gaseous form into the tube, and resultant pressure is small compared to the D-T pressure in the tube during operation. Up to now, even after one year on the shelf, tubes are running correctly. Of course, shelf life is expected to be a few years but we are in the process of verifying it. The stability of output in operation leads us to conclude that helium build up has only a very small effect.

The gas reservoir capacity seems to be adequate as we have never observed any trouble in that way, with the exception for a technological defect experienced on one tube at the beginning of our production. Optimization of reservoir and target technology allows operation of the tube during a long time with less than 3.3 Curie of tritium (120 GBq).

The target degradation is a function of the beam density at the target position. Post mortem examination of a tube, tested at low duty cycle then at high peak power density, showed a relatively strong focalization of the beam. The depletion of the target seems to be due to sputtering and to helium or impurities implantation. Some cross tests at different duty cycles on the same tube show that at higher duty cycle the beam does not exhibit excessive focalization. This life limiting factor is important but now well controlled for this tube.

Metal sputtering and deposition on insulating walls may lead to enhanced surface breakdowns, which induce wall damage or even wall punchthrough. This is to be considered as a possible life limiting factor, especially when using the tube in a small diameter housing.

CONCLUSION

The SODITRON neutron tube has been demonstrated now as a reliable and long life tube, suitable for industrial applications. This tube is now used in nuclear waste management operations as well as in chemical weapons inspection equipment (ref. 2), and will be soon installed on a raw material analyzer (ref. 3).

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