

## Project of the borehole neutron generator for the direct determination of oxygen and carbon by activation method

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**Abstract.** The paper deals with application features of borehole neutron generator (BNG) based on the vacuum accelerating tube (AT) with laser-plasma ion source for determination of oxygen isotope  $^{16}\text{O}$  and carbon isotope  $^{12}\text{C}$  by direct activation. The project of pulsed BNG for realization of an activation method in the conditions of natural presence of productive hydrocarbons is offered. The diode system with radial acceleration, magnetic electron insulation and laser-plasma source of deuterons at the anode in a sealed-off vacuum accelerating tube is applied. The permanent NdFeB magnet with induction about 0.5 T for produce the insulating magnetic field in the diode gap is proposed. In the experiments on the model of BNG with the accelerating voltage source ( $\approx 350$  kV), performed by the scheme of Arkadiev-Marx generator, the output of (d, d) neutrons was  $\sim 10^7$  pulse $^{-1}$ .

Nowadays in nuclear-geophysical research of oil borehole great attention is paid to direct determination of carbon and oxygen by using of high-frequency neutron generator (frequency is about 10-20 kHz) with multi-channel gamma-ray spectrometer for inelastic scattering and radiation capture (C/O - logging) [1,2]. Such method has the advantage over classical neutron method of indirect identification of productive fluids based on determination of chlorine deficiency in which result efficiency depends on the salinity degree of water accompanying the oil in the geological layer. However, from the viewpoint of mathematical processing and interpretation of data such method is very difficult to develop for realization by specialists.

The report proposes a project of borehole neutron generator (BNG) on the base of a sealed accelerating tube (AT). With its help you can successfully implement an alternative method of the direct determination of the oxygen isotope  $^{16}\text{O}$  and  $^{12}\text{C}$  carbon isotope in the oil deposits by the use of activating effect as a result of such nuclear reactions as  $^{16}\text{O}(n, p)^{16}\text{N}$  and  $^{12}\text{C}(n, p)^{12}\text{B}$ . These reactions are endothermic with following energies:  $Q_1 = -9.63$  MeV and  $Q_2 = -12.59$  MeV, respectively [3]. Threshold energies of neutrons  $T_1$  and  $T_2$  thus can be determined using equation, which follows from conservation laws of energy and momentum:

$$T_1 = (17/16) |Q_1| = 10.2 \text{ MeV}, T_2 = (13/12) |Q_2| = 13.6 \text{ MeV}.$$

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The dependence of the nuclear cross sections of these reactions  $\sigma_{1,2}$  (in barns) from the neutron's kinetic energy  $T_n$  are easy to calculate, using a root approximation of these dependences near the threshold [4], as well as table data [3]. These cross sections are as follows:

$$\sigma_1 \cong 0.0215 (T_n - 10.23)^{1/2}, \quad \sigma_2 \cong 0.032 (T_n - 13.64)^{1/2}.$$

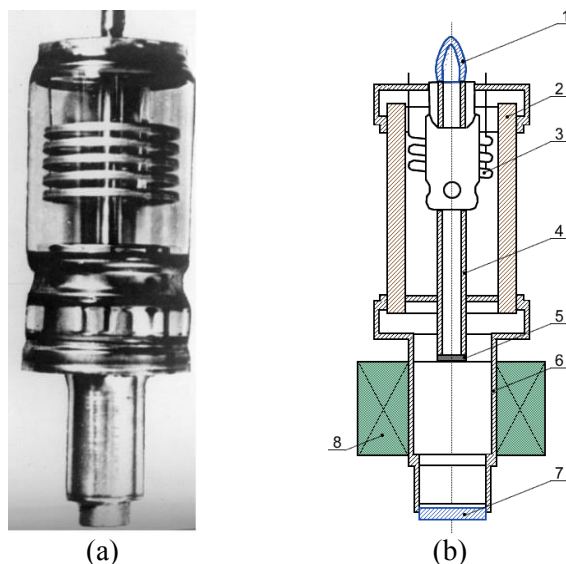
As we can see from these formulas for the neutron energy in range 14 MeV generated by the nuclear reaction  $T(d, n)^4\text{He}$  cross section is increasing with rising of the kinetic energy of deuterons  $T_d$ . In the case of a direct neutron flight, when its motion direction coincides with the motion direction of deuteron, the following formula for cross section of activation can be obtained, if we use the known dependence  $T_n = f(T_d)$  [5]

$$\sigma_1 \cong 0.0215 \{[(14.08 + 0.62T_d)^{1/2} + (0.02T_d)^{1/2}]^2 - 10.23\}^{1/2},$$

$$\sigma_2 \cong 0.032 \{[(14.08 + 0.62T_d)^{1/2} + (0.02T_d)^{1/2}]^2 - 13.64\}^{1/2}.$$

Evaluations made with using these expressions showed that the activation effect would be sufficient for the implementation of these logging methods if  $T_d \geq 0.3\text{MeV}$  and neutron output is more than  $10^{10}$  neutrons per pulse. In addition, the deuterons acceleration should be in the direction perpendicular to the wellbore.

Nowadays the experimental samples of AT with vacuum-arc source of deuterons are developed [6]. They can generate in a full solid angle up to  $10^{10}$  neutrons per pulse. The maximum value of  $T_d$  in such AT does not exceed 0.15 MeV and deuterons are accelerated along the tube and in parallel the axis of wellbore. The  $T_d$  increase due to increasing of the amplitude of the acceleration voltage leads to the insurmountable problems of providing electrical isolation in such neutron devices. In addition to this, the experience of such AT operation showed the significant instability of pulsed neutron yield associated with the deuteron source peculiarities. This instability can reach 50%. In turn, this requires add in the BNG a monitor of the pulse neutron flux, which significantly complicates the logging methods.

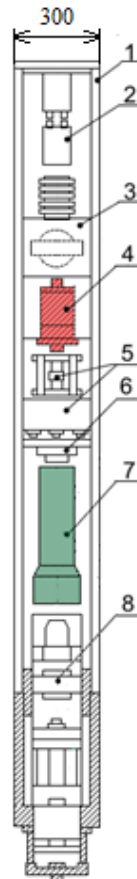


**Figure 1.** The accelerating neutron tube based on the laser-plasma source of neutrons: visual appearance (a); schematic cross section (b)

1 – exhaust tube for AT separation, 2 – insulator, 3 – getter, 4 – anode electrode, 5 – plasma-generating target, 6 – cathode metal-tritium target, forming neutrons, 7 – optical window, 8 – magnetic system.

The above disadvantages can be eliminated and the neutron yield is saved in AT diode system with radial acceleration [7], magnetic isolation of the accelerating gap [8] and laser-plasma source of deuterons. Figure 1 shows a visual appearance and a schematic cross section of such AT. The insulating magnetic field is stationary and is formed by solenoids or annular permanent magnets with the induction vector directed along the axis of AT symmetry for the suppression of electronic conductivity in the diode gap. The magnitude of induction of 0.5 T is the estimation for the critical magnetic field in which the electrons are not to reach the anode and for the amplitude of accelerating

voltage about 150 kV and the cathode radius about 3 cm. Modern technologies based on the compound of NdFeB allow creating the permanent magnets with induction in the end face of up to 1 T. The schematic cross section of the existing laboratory model of BNG based on AT with deuteron laser source is shown in figure 2.



**Figure 2.** The block diagram of the borehole neutron generator

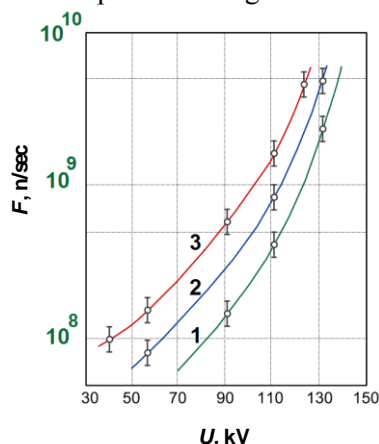
1 – the body, 2 – the capacitive energy storage, 3 – high voltage unit on the basis of the pulse HV transformer or Arkadiev-Marx generator, 4 – the neutron tube, 5 – system to scan the laser beam, 6 – laser-gap switch, 7 – pulse YAG laser, 8 – the module of capacitive energy storage

Laser beam is focused on the plasma-generating target of AT. This target is made in the tablet form from the metal which can dissolve hydrogen and can absorb the deuterium. Plasma containing deuterons falls into the area surrounded by the cylindrical cathode, which is the neutron-producing target. During this time, a short pulse of high voltage is supplied to electrodes of diode synchronously with the laser pulse.

Under the influence of the electric field, deuterons were extracted from plasma and were accelerated perpendicularly the target surface. In the result of bombing by deuterons and the nuclear reaction  $T(d, n)^4\text{He}$  the neutron flux was produced. In this case, the maximum energy of neutrons corresponds to the emission perpendicularly to the axis of AT symmetry. Figure 3 shows the experimental dependence of the neutron flux  $F$  on the amplitude of accelerating voltage  $U$  for the different frequency of the working pulses in AT. This result was received on the experimental model of BNG with the power system based on a high-voltage transformer.

In further experiments, in order to increase the discharge current and accelerating voltage the Arkadiev-Marx generator was suggested. This generator is designed for up to 400 kV amplitude and generates pulses of nanosecond duration. It consists of 30 stages, each with two capacitor type K5-4 connected in parallel with the total capacitor about of the  $C_0 = 2 \times 4700 = 9400$  pF, which stores maximum energy about 1.5 J during a charging voltage of 15–18 kV. Respectively the equivalent capacitance is  $C_0/30 = 310$  pF. The generator's design feature is the use of a spiral geometry for the

serial connection of capacitors and the spark switch. Such geometry ensures a reliable electric strength between input and output of Marx generator without increase of the overall device size.



**Figure 3.** The dependence of the neutron flux  $F$  on the amplitude of accelerating voltage  $U$  (1-12.5 Hz; 2 – 25 Hz; 3 – 50 Hz)

Furthermore, by forming a short high voltage pulse in conjunction with the magnetic isolation of electron we believe that the requirements for high-voltage isolation system of diode can be significantly reduced. In experiments on BNG model we used laser with the energy about 50 mJ [9] and forming the single voltage pulse with amplitude up to 350 kV on the accelerating gap of AT. For these experimental conditions, the expected yield of neutrons ( $d, d$ ) will be  $\sim 10^7$  1/pulse.

In conclusion, should be noted that the increase of laser energy and the decrease of dimensions of laser sources may be achieved in a new series of YAG: Nd lasers and CO<sub>2</sub> lasers. These devices can be able to generate pulses with energies about one joule at frequencies up to 100 Hz. New perspective laser and its combination with magnetic isolation of electrons in the diode gap, as well as new designs of the compact high-power pulsed sources of accelerating voltage clearly show that the creation of an effective BNG is really. In turn, this will allow to use the simple technique of neutron activation with the direct determination of carbon and oxygen.

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## References

- [1] Tropin A N and Enikeeva F H 2002 *Scientific and Practical Conference "Nuclear Geophysics 2002"* (Tver) p 15-16
- [2] Amurskiy A G, Bogolyubov E P and Titov I A 2003 *Proceedings of the conference "The portable neutron generators and based on them technologies"* (Moscow: VNIIA) p 17
- [3] Maslov I A and Luknickiy V A 1971 *Reference book with neutron activation analysis* (Leningrad: Nauka) p 312
- [4] Landau L D and Lifshits E M 1963 *Quantum mechanics, non-relativistic theory* (Moscow: GIFL) p 702
- [5] Bekurts K and Virtc K 1968 *Neutron physics* (Moscow: Atomizdat) p 456
- [6] Bobilev V T, Bogolyubov E P, Ryzhkov V I, Kurdyumov I G and Kuznetsov Yu P 2003 *Proceedings of the conference "Portable neutron generators and based on them technologies"* (Moscow: VNIIA) p 19
- [7] Bespalov D F, Mints A Z, Pleshakova R P and Shikanov A E 1980 *Pulsed neutron generator*. USSR Author's Certificate № 457 406 (priority: 25.12.1972)
- [8] Bespalov D F, Kozlovskiy K I, Tsybin A S and Shikanov A E 1980 *Pulsed neutron tube* USSR Author's Certificate № 766 048 (priority: 27.03.1979)
- [9] Dydychkin V N and Shikanov A E 1991 *Atomic energy* **2** (70) 41-42