SOLID DEUTERIUM ULTRA COLD NEUTRON SOURCE RESEARCH

A. P. Serebrov, V. A. Mityukhlyaev, A. A. Zakharov, A. G. Kharitonov, V. V. Nesvizhevsky, M. S. Lasakov, R. R. Taldaev, A. V. Alduschenkov, V. E. Varlamov, A. V. Vasiliev, G. Greene[1)], T. Bowles[2)]

[1)] *National Institute of Standards and Technology Washington, USA*
[2)] *Los Alamos National Laboratory, USA*

A possibility of increasing of UCN density due to the solid deuterium at cryogenic temperatures was analysed in article [1]. Experimental results of UCN production at a pilot Solid Deuterium Source (SDS) at WWR-M reactor (PNPI) are considered in this article.

A layout of the source is shown in Fig.1. The source chamber (diameter 150 mm, length 300 mm with two elliptical domes) is made from zircalloy. It has volume 6 l. The chamber has double walls (2×0.5 mm) with flowing cold helium between them from cryogenic refrigerator (capacity 150 W at 4.5 K). At cooling the deuterium from a tank (volume 6 m^3) supplies the chamber. The deuterium is condensed and come to a solid state in the chamber. A special technical solution is necessary to decrease the deuterium temperature lower 10–12 K. The problem is a loss of a thermal contact between cold chamber wall and the solid deuterium because of a deuterium volume decreases at cooling. A cooling is possible at some torrs of a vapor pressure. For example, at 12 K the saturated vapor pressure is 0.75 torr, but at 10 K — only 5×10^{-2} torr. A possible technical solution is to place a spiral tube on inner chamber wall to achieve a good thermal contact. However, at first step we did experiments with a simple design. The second step will be with the same design, but with deuterium containing some helium quantity for heat exchange. Only third step will include more complicated chamber design if it will be necessary. The experiments at a temperature level above 13 K are considered at this article.

The most difficult problem is to determine a temperature field in the deuterium. However, the source temperature may be determine with low accuracy by means of residual pressure in the deuterium tank, because of the deuterium system looks like a vapor-pressure thermometer, where the saturated vapor pressure depends on the deuterium temperature. Unfortunately, a relaxation time period for pressure is significant because of a big tank volume. A result is a clear picture of gisteresis phenomenon for UCN yield at different pressures. UCN yield at different pressures at cooling and heating is shown in Fig.2a.

The other vagueness in UCN yield, which was found in experiment, probably is concerned ortho-para changes in deuterium under an influence of cryogenic temperature and reactor radiation. The curve 1 in Fig.2b was obtained at the first experiment of source cooling, at high cooling temp and at low reactor power (2MW). Temperature gain factor for UCN was only 450 times. Next source cooling (curve 2 in Fig.2b) was at low cooling temp at 14 MW reactor power. Temperature gain factor for UCN was 790 times. After heating the deuterium had 95(5% ortho spice and maintained it further. At next cooling of the source the temperature gain factor was 1230 times and didn't increase then. The curve 3 in Fig.2b was obtained at fourth cooling A dependence of UCN yield on ortho-para species is the most real explanation this phenomenon and additional experiment is required.

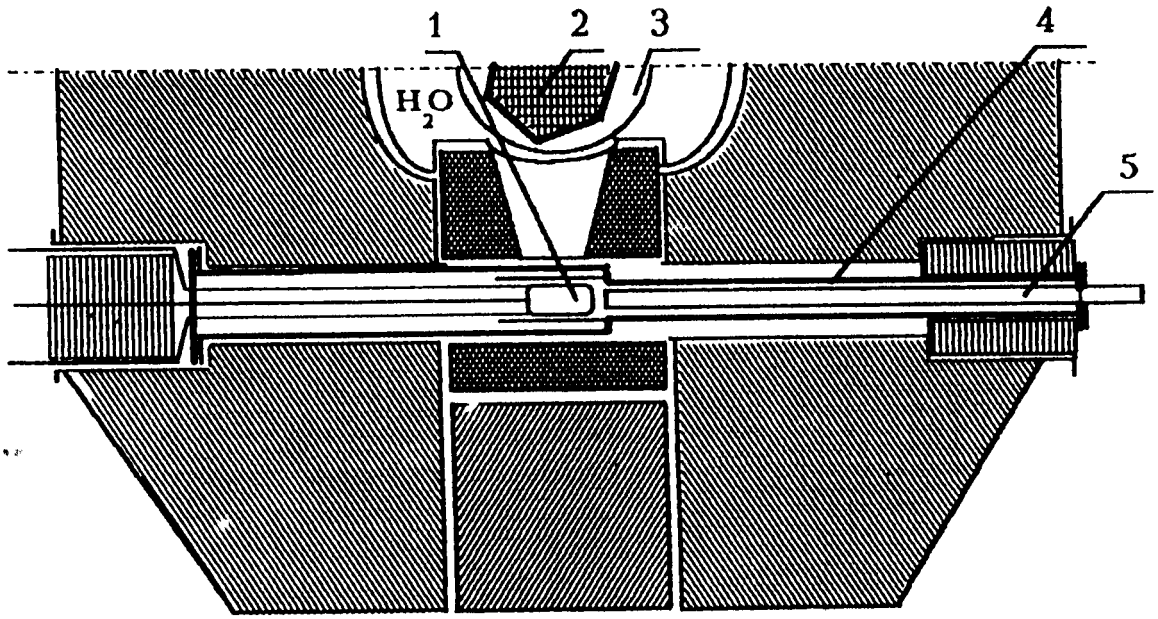

Fig.1. Layout of the solid deuterium source at the reactor. *1* – source chamber with solid deuterium; *2* – reactor core; *3* – beryllium reflector; *4* – vacuum containment; *5* – neutron quide for UCN

One of the evidence problem to achieve high UCN yield is the deuterium limpidity to UCN. Cracks arisen in the solid deuterium because of the temperature strain can cause UCN dissipation. The gain factor does not increase at a decreasing temperature in case of an effective length of neutron way between cracks and impurities is less the one defined by inelastic scattering cross section and capture cross section. To investigate this problem a gain factor was measured simultaneously for UCN at 6 m/s and for very cold neutrons at two ranges of velocities 9.5 m/s and 16.5 m/s. A refraction coefficient depends on neutron velocity and the effective solid deuterium dim because of cracks first of all has to appear for UCN (refraction coefficients at 6 m/s, 9.5 m/s and 16.5 m/s are equals respectively to 0.68, 0.886, 0.964). The curve 3 in Fig.2b is the result of measurements for all above mentioned neutron velocities. There is no a visible difference for neutron velocities at different temperatures. This is mean, that dim does not appear. The neutron ways at 13 K according to calculations are 4 cm, 8 cm and 16 cm for respective velocities 6 m/s, 9.5 m/s and 16.5 m/s. An absence of dependence for gain factor allows to suggest that the limpidity depth of solid deuterium is not less than above-mentioned values. For more detail research of this problem it is necessary to decrease the temperature down to 5–6 K.

Except the UCN yield measurements at cooling and heating by means of refrigerator (Fig.2a) the UCN yield measurements were carried out at heating by means of only reactor radiation without refrigerator. The gain factor was defined more accuracy for solid and liquid deuterium at triple point at this experiment as well as the radiation load. UCN yield and deuterium pressure in a tank during heating at constant heat load are shown in Fig.3. At first 28–30 min (t0-t1) the pressure increases linearly and basically defined by heat of

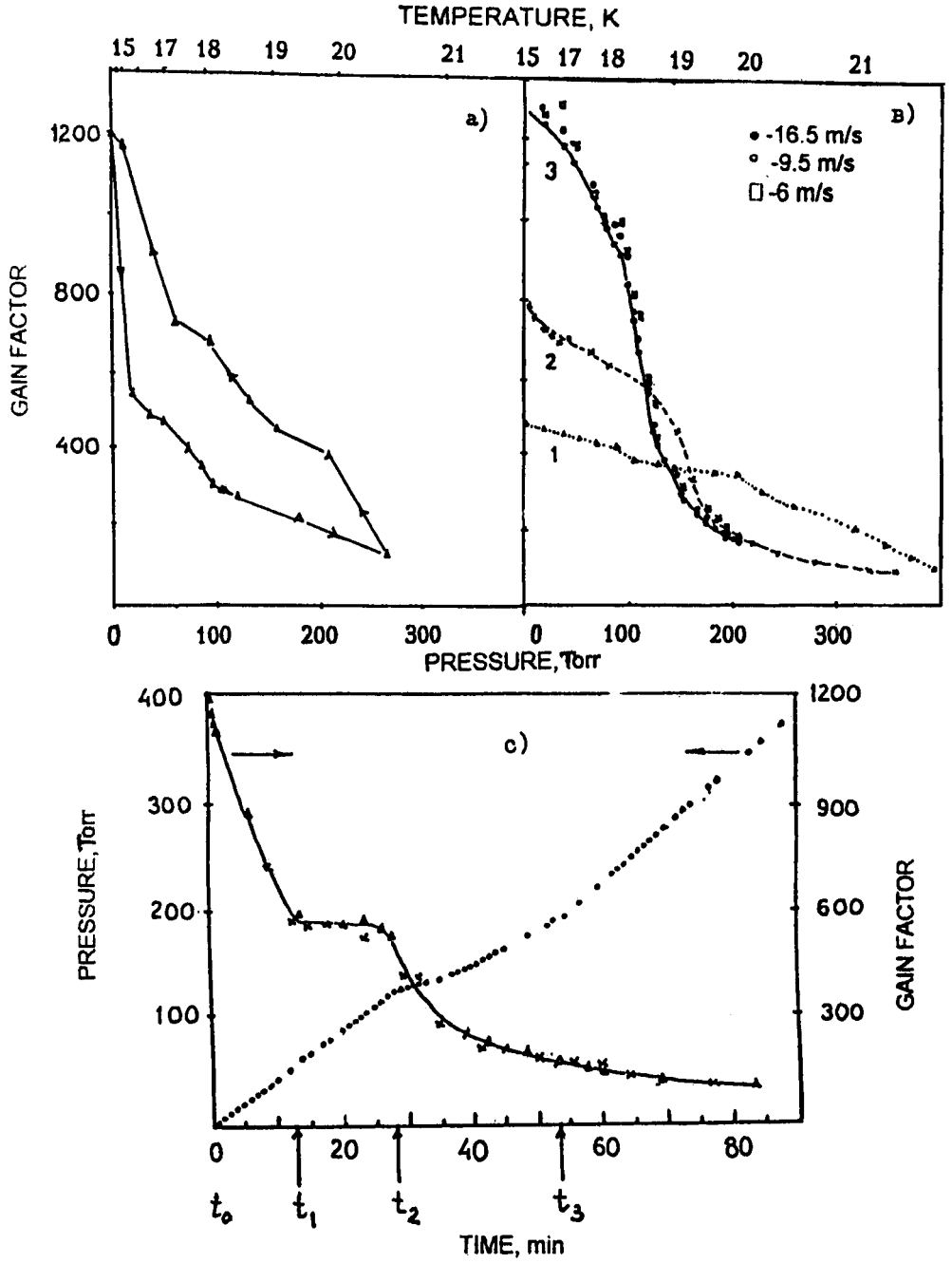

Fig.2. *a*) UCN yield at cooling and heating; *b*) UCN yield at initial coolings; *c*) heating of the source by reactor radiation

sublimation. Amount of heat for solid deuterium heating is negligible. Pressure increases linearly till equlibrium value at triple point (128 torr). During next 25–30 min (t2-t3) deuterium melts simultaneously with heating and avaporasing of liquid. A rate of gas coming into tank decreases because of a part of heat load is used for melting. The process of melting stops at a time t3, after that the rate of gas coming into tank becomes constant and defined by heat of vaporising of the deuterium. A heat load at operating reactor is 36 W and 6 W at shut-down reactor.

There is a plateau between time t1 and t2 in dependence of UCN yield (curve 2 in Fig.2c). The plateau corresponds to triple point. At starting time (t0) at 13–14 K a temperature gain factor was 1230. At time (t1) deuterium has a temperature 18.7 K and keeps it due to sublimation till time (t2), when the pressure in tank achieves the equilibrium sublimation pressure. Temperature gain factor for solid deuterium near by triple point was 500-550. For completely liquid phase at time (t3) when the deuterium has a temperature of 19.5-20 K a gain factor is 120. The further decreasing of a gain factor depends on heating of liquid.

A considerable increasing of a gain factor during crystallization (4-4.5 times) is defined by effect of better neutron thermalization in the solid deuterium than in the liquid deuterium because of a higher interaction cross section due to Bragg upscatering. This effect was observed at measurements of neutron spectra from the source. The time-of-flight spectra before condensation of deuterium (curve 1), after condensation (deuterium in liquid phase, curve 2) and after crystallization (deuterium in solid phase, curve 3) are shown in Fig.3a. The initial neutron spectrum to the source has effective temperature of 600 K. The spectrum becomes smooth due to a thermalisation in deuterium. The difference in thermalisation for liquid and solid phases is observed in range of 4A-6A. There are unregular spectra for solid deuterium due to Bragg reflection. It is important to note, that the structure of reflections is the different for the first and second cooling. That may be connected with ortho-para spices and with a rate of cooling. A neutron spectrum from the solid deuterium source can be represented as a sum of two spectra 56% intensity at effective temperature 180 K and 44% intensity at effective temperature 30 K. A calculation of UCN yield with a pointed shape of spectrum is close to a calculation of yield at effective temperature 100 K. Only neutrons with length of wave more than 3A are capable to convert to UCN by one phonon process. Therefore the growth of the long wave neutrons quota arises the increasing UCN yield at crystallisation of deuterium. The solid deuterium source is more effective also for very cold and cold neutron production. A temperature dependence of a gain factor for the solid deuterium source with volume 6 l (curve 1) and results earlier investigations [2] for a liquid deuterium source with volume 1 l (curve 2) and for a solid deuterium source of 0.15 l volume [3] (curve 3) are shown in Fig.3b as a final analysis of research results. A rise of UCN yield is achieved both the deuterium temperature decreasing and the effective neutron temperature decreasing due to increase of a source volume. Calculation results from the work [1] are represented for the absolute pure deuterium and for the effective neutron temperatures of 40, 100, 300 and 500 K. The solid line 4 is a calculation result for the effective temperature of 100 K and a capture cross section in the deuterium with hydrogen impurity (0.2 v.%) and nitrogen impurity (4.6×10^{-3} v.%).

Next step of investigation is decreasing of the source temperature down to 6–7 K with aim to study capability of increasing of UCN yield. It is necessary to note, that at 6–7 K the heat conductivity of the solid ortho-deuterium increases in order of value. It makes better the source capacity to heat load.

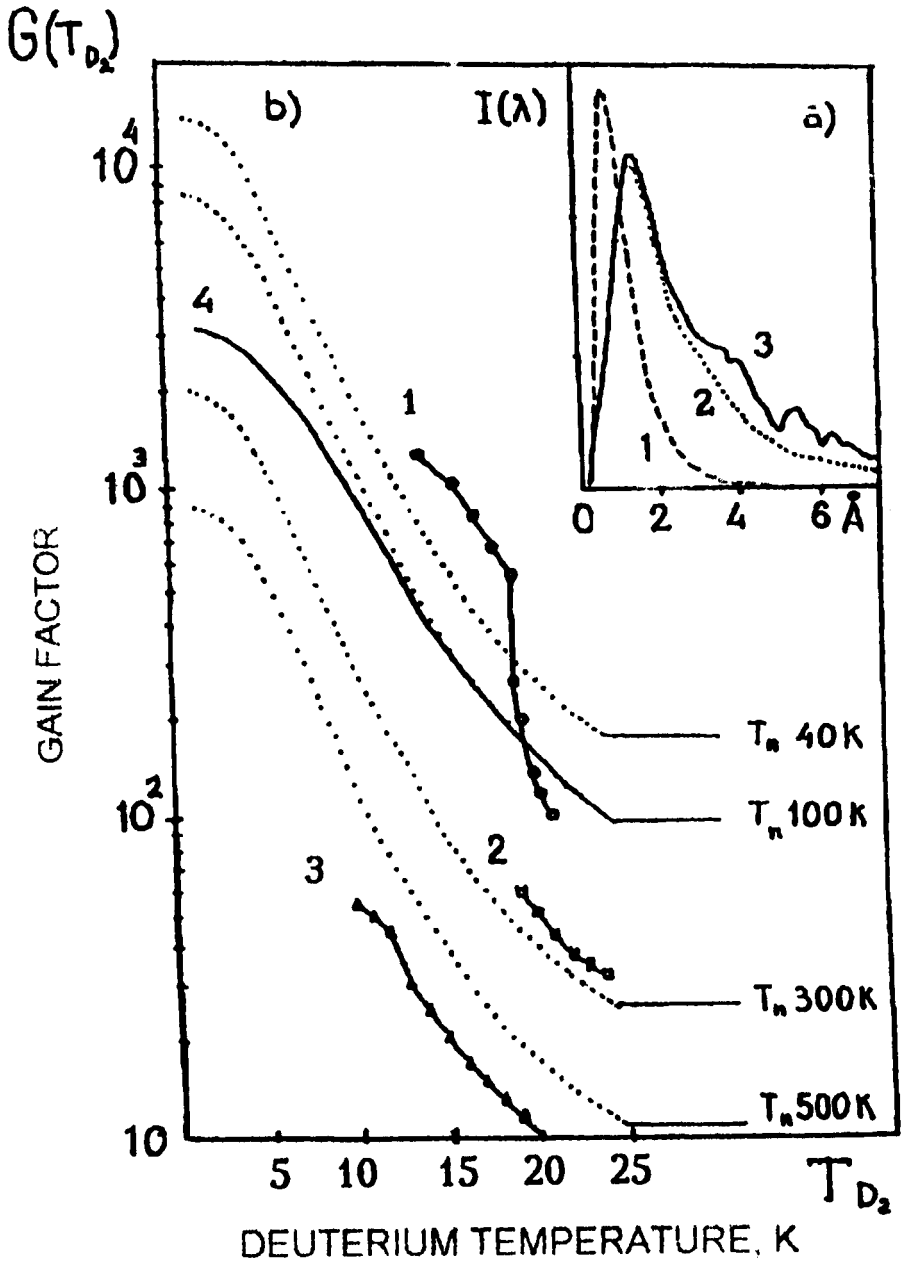

Fig.3. *a*) time-of-flight spectra for deuterium at different phase conditions; *b*) gain factors for deuterium sources with different volumes

The result of investigation can be used for new projects of solid deuterium sources at high flux reactors with heavy water reflectors. A heavy water is a good shield from high energy neutrons and gamma rays. That allows to have a low level of heat load at high flux of thermal neutrons (reactor PIK, Gatchina, reactor ILL, Grenoble). Another possibility is using of solid deuterium sources at neutron spallation sources, where the relation of heat load to neutron flux is better than one for reactors. For example, the solid deuterium source for UCN production is planning to be installed at 1 MW spallation source in Los Alamos (USA).

REFERENCES

1. *Serebrov A.P. et al.*, //JETP Letters, 1994. **59**. 11. 728-733.
2. *Altarev I.S. et al.*, //JETP Lett., 1986. **44**. 6. 345-348.
3. *Altarev I.S. et al.*, //Phys.Lett., 1980. **80A**. 413-416.

COMPUTER SIMULATION OF THE HYDROGEN DISTILLATION AND CECE PROCESS

O. A. Fedorchenko, I. A. Alekseev, V. V. Trenin, V. V. Uborski[1)]

[1)] *JSV "DOL", Moscow*

I. Introduction

There are a number of reports describing computer simulation procedures for cryogenic distillation [1,2] and CECE process [3,4]. These procedures are based either on the successive iteration method, which does not always present adequate stability in achieving convergence, or on the Newton-Raphson method, which needs large computation efforts for the numerical evaluation of the elements of the Jacobian matrix and calculation of its inverse matrix. Another way of looking at these equilibrium stage processes is proposed [5]. It provides stable and relatively rapid solutions of the basic equations for both above-mentioned processes. For example, approximately 10 seconds are required for computation of a seventy tray catalytic exchange column with six components on an IBM PC 486DX 33.

II. Steady-State Procedure for Cryogenic Distillation Column with a Feedback Stream and Catalytic Equilibrator

The mathematical simulation procedure has been developed for a single cryogenic distillation column with a feedback stream and catalytic equilibrator used for hydrogen isotope separation. The computer programme "Cry_En" has been created on its base. Nonidealities of the hydrogen isotope solutions and heat balance are incorporated. The model column for mathematical simulation is shown in Fig.1. The initial data for the computation:
N – the number of theoretical stages; P – pressure in the top of the column [kPa]; ΔP – pressure drop across the column [kPa]; Bot – flow rate of bottom product [kmol/h]; Top – flow rate of top product [kmol/h]; W = Bot + Top – flow rate of the gas external feed stream [kmol/h];
Aw1, Aw2, Aw3 – composition (atomic fractions of protium, deuterium and tritium) in