KENS COLD NEUTRON SOURCE

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§1. KENS Cold Neutron Source

This paper summarizes the experimental results obtained during stationary operation of the KENS cold neutron source over a period of about three months.

A side view of the cold neutron source as finally constructed is shown in Fig. 1. The moderator dimensions of $120^W \times 50^D \times 150^H \text{mm}^3$ were determined from the results of a mock-up experiment performed in 1978$^{1)}$. The moderator case of pure aluminum is 4 mm in thick except for the wall behind the surface from which the cold neutrons are extracted. This wall has a greater thickness of 7 mm in order to increase the moderator cooling efficiency. The separation between the bottom of the moderator case and the upper surface of the target is only 17 mm. The heat exchanger consists of a Cu block which is suspended from the top of the cryostat by a thin stainless steel rod. The total height of the cryostat is 290 mm and the moderator section is surrounded by Be reflectors decoupled by Cd sheets. The complete cold neutron source assembly consists of separate systems for cooling, methane gas circulation, vacuum pumping and safety control. A PGH-105 cryo-generator with a cooling power of 40 W (at 15 K) is used to cool He gas which is then transferred to the heat exchanger through a 7 m long transfer tube. The temperature of the He gas can be controlled to some extent by a heater inserted in the cryo-generator. Details of the safety control system were already been described in a previous report$^{1)}$.

§2. Moderator Cooling and Nuclear Radiation Heating

The temperature of cold moderator could be reduced from ambient to 16.8 K in about two hours. By this rapid cooling, however, all the methane gas in the reservoir tank could not be condensed into the moderator case. The moderator case temperature was controlled to be around 100 K by the heater until all the methane gas in the reservoir tank was liquified, followed by further cooling to the lowest temperature. The cooling process which is now usually followed is illustrated in Fig. 2. The temperature of the methane is monitored by a hydrogen pressure thermometer placed inside the moderator. At the lowest temperature of 16.8 K, the temperature of the moderator remains constant to within ±0.15 K as shown in Fig. 3.

The moderator temperature was found to rise by one degree, when the full proton beams (4.8×10^{11}ppp x 38 p/2.5 sec) is incident on the target, as illustrated in Fig. 3. The amount of heat deposited inside the moderator by nuclear radiation was estimated from the decrease in moderator temperature with time after the irradiation was ceased. Let us suppose that the constant heat q (watt) is generated inside the moderator by the irradiation and that, under equilibrium conditions, the created heat flows to the heat exchanger on the moderator case through a connecter with thermal conductance $\bar{K}$.

After cessation of an irradiation, the temperature variation of the methane moderator $\Delta T(t)$ is then given by the following differential equation

$$q = \bar{K}\cdot\Delta T + C\frac{d(\Delta T)}{dt}\ , \tag{1}$$

where C is the heat capacity of the methane moderator. The variation of heat loss by thermal radiation can be neglected because it is less than 10^{-4} watt/K at 20 K. A solution of equation (1) is the relation

$$\Delta T = g(1-e^{-ht})\ , \tag{2}$$

with $g=q/\bar{K}$ and $h=\bar{K}/C$.

Values of g=1.0 K and $h=1.44 \times 10^{-3}S^{-1}$ were then determined by simple analysis of our experimental results as displayed in Fig. 4. The heat capacity C is given by $C=P_0VC_0$ where P_0 and C_0 refer to the density and specific heat of solid methane at 20 K, respectively and V is the volume of the moderator.

Using the values of $P_0=0.522\ g\cdot cm^{-3}$, $V=900\ cm^3$ and $C_0=1.59\ J\cdot g^{-1}\cdot K^{-1}$ the heat capacity was estimated to be $747\ J\cdot K^{-1}$ and the heat q deposited by irradiation was therefore calculated as $q=g\cdot h\cdot C=\underline{1.2\ \text{watt}}$ for 7.3×10^{12} proton/sec. This result is in good agreement with the value estimated from the mock-up experiment$^{1)}$.

§3. Energy and Time Spectra of the Emitted Cold Neutrons

Cold neutron energy spectra for the two different moderator temperatures of 20 K and 30 K were determined by measuring the TOF spectrum of the incoherent elastic scattering from a Vanadium metal sample. (Fig. 5) The spectra have maxima at 3.0 meV (35 K in neutron temperature) and at 3.5 meV (41 K) for the moderator temperatures of 20 K and 30 K respectively. The disagreement between the moderator and neutron temperatures suggests that the size of the KENS cold neutron source is insufficiently large to moderate completely the incoming spallation neutrons. The relationship between the size of the moderator and the descrepancy between the neutron and the moderator temperatures were examined using data from the cold neutron sources of KUR$^{2)}$ and Hokkaido University$^{4)}$ as well as that at KENS. (Fig. 6) The figure clearly indicates that the neutron temperatures from the thin moderators of KENS or Hokkaido Univ. are higher than those from the thicker moderator of KUR.

The time spectra of emitted cold neutron at selected neutron energies were also determined by measuring Bragg diffraction from a mica crystal. The crystal was placed at a distance of 7 m from the source and the detector was fixed at a angle $2\theta_B = 160^{\circ}$. Five diffraction peaks with different indices were observed from which the time spectra corresponding to five different incident neutron wavelengths were determined. The observed pulse shape is characterized by three parameters α, β and γ as shown in Fig. 7. The rise time, β, is defined as the interval between the times at which $0.1(t_1)$ and $0.9(t_2)$ of the peak intensity is found. The decay time, α, is obtained from the exponential decay of the pulse after it passes the maximum. The third parameter, γ, is the full time width at half maximum. The values for these parameters which were determined at the five different incident neutron energies are plotted against neutron energy and wavelength in the lower part of the figure 7. The rise time β is found to increase linearly with the wavelength λ. The pulse time width, γ, appears to be proportional to the neutron energy E, and it has an approximate value of 100 μsec for cold neutrons with E = 5.5 meV(5 Å). The value of the decay time, α, is nearly independent of neutron energy.

§4. Radiation Damage and Induced Activity

The radiation damage induced by the spallation neutrons is a crucial question for the methane moderator. The extent of methane decomposition after one week's operation (corresponding to 52 hours of full power operation) was determined using gas chromatograph by Kondoh3). The methane gas restored to the reservoir tank was found to contain about 0.14% of hydrogen after the moderation of about 1.4×10^{18} spallation neutrons. The concentration of hydrogen in the methane moderator of Hokkaido University was reported to be about 7% after the moderation of about 1.8×10^{18} fast neutrons4). This is some fifty times larger than that found at KENS suggesting that the decomposition in the Hokkaido cold neutron source mainly occurs through γ-ray irradiation, an inevitable consequence of using an electron LINAC. The presence of tritium H^3 was also detected at 9×10^{-6} μCi/cm^3. This level is reasonably low compared with H^3 natural abundance (2×10^{-6} μCi). About 60% of the produced H^3 occurs in the form of hydrogen molecules. No other radioactive nuclei could be detected.

The induced activity of the moderator cryostat was also measured with a survey meter after a cooling period of sixty days following stoppage of the proton beam. Prior to the cooling, the cryostat had been subjected to the irradiation by about 1.4×10^{18} spallation neutrons. The measured radio activity levels are given in Fig. 8. A maximum radiation level of 60 mR/hr was detected on the bottom surface of the cryostat which lies closest to the tungsten target. It is not yet known which materials in the cryostat are responsible for this induced activity.

References

1) Y. Ishikawa and S. Ikeda, KENS Report I (1980) 19
2) K. Sumita, EURATOM Report EUR 4954 e (1971) 287
3) K. Kondo This proceedings
4) K. Inoue Private Communication

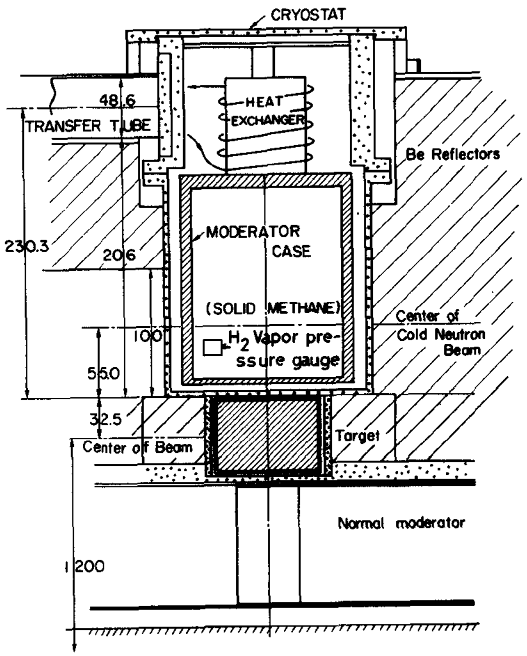
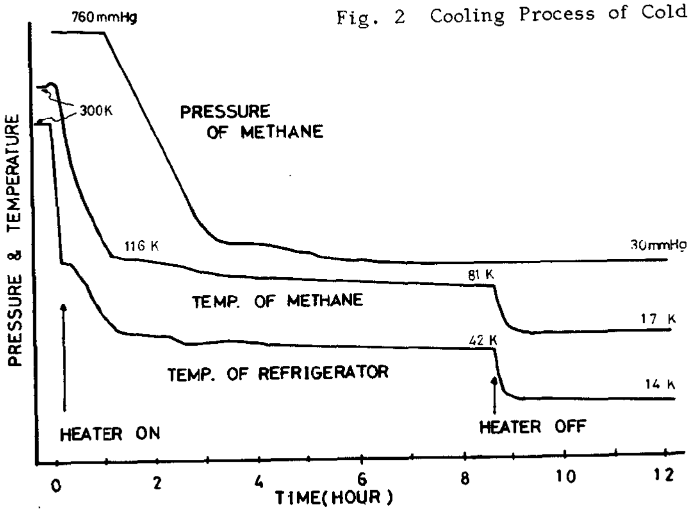


Fig. 1 Side View of KENS Cold Neutron System

Fig. 2 Cooling Process of Cold Moderator



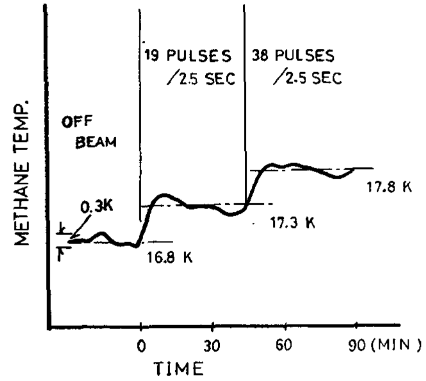


Fig. 3 Temperature Variation of Methane Moderator

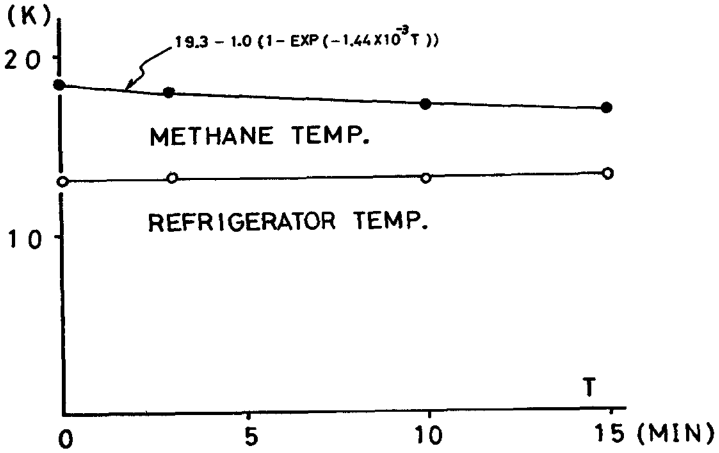


Fig. 4 Decrease in Moderator Temperature with time after Cessation of an Irradiation

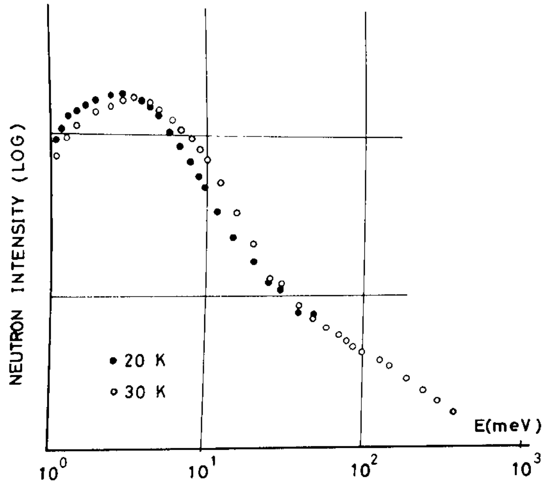
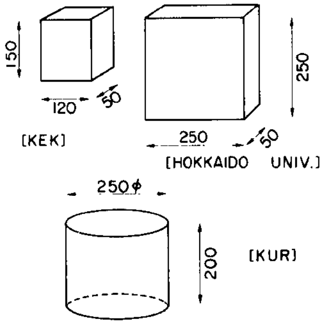


Fig. 5 Energy Spectra of Emitted Cold Neutrons

[MODERATOR SIZE (mm)]



[NEUTRON TEMPERATURE]

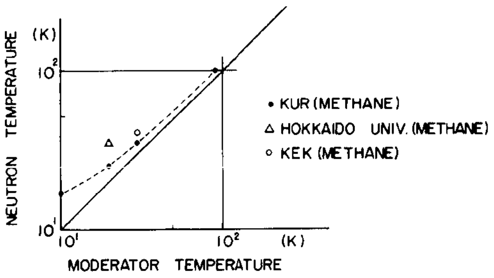


Fig. 6 Moderator Size and Neutron Temperature

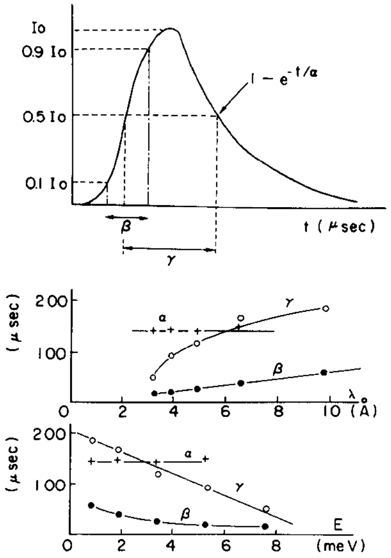


Fig. 7 Time Spectra of Emitted Cold Neutrons

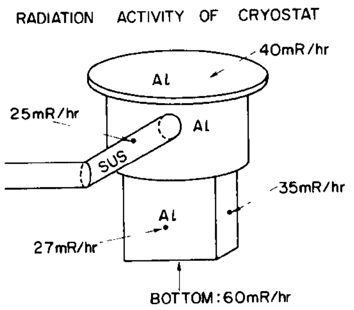


Fig. 8 Induced Activity of Moderator Cryostat