**Proceedings of the Eighth Meeting of the International Collaboration on Advanced Neutron Sources (ICANS-VIII)
8-12 July 1985, Rutherford Appleton Laboratory Report RAL-85-110**

# Mock-Up Experiments for KENS-I' Cold Moderator

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Abstract

A mock-up experiment has been performed for the KENS-I' solid methane cold moderator in order to establish the method for removing the neutron heating of order of 20 W deposited inside solid methane. It has been suggested that the insertion of 0.5 mm Aℓ plates with a distance of 10 mm can keep the moderator temperature below 20 K by employing the present refrigerator (PGH, 105)

## 1. Introduction

The cold neutron moderator and the experiments employing cold neutrons are one of the most important success of the KENS, because it gave a promissing aspect of the spallation neutrons even for the cold neutron scattering[1). Therefore the installation of the cold neutron moderator is also indispensable for the KENS-I' where the neutron intensities are expected to be increased by a factor 8. Since the heat deposit in the KENS-I' becomes quite substantial, we carried out a mock-up experiment of the cold moderator to find the best method for removing the heat deposit.

We have reported in a paper[2)] presented in the previous ICANS meeting at Chalk River the result of successful operation of the grooved cold moderator as well as the heat deposit we estimated for two different types of cold moderators used in KENS-I. The estimation was made from the temperature rise of hydrogen thermometer by neutron heating and the results are reproduced in Table 1 with a slight modification. We should remark here that the heat deposit was order of 1.5 W in a flat moderator, but it increased to 5 W in a grooved one. The increase is partly due to the increase of volume, but mainly because of the decrease of the effective thermal conductance of solid methane. In the course of present mock-up experiment, we also found that our previous estimation of head deposit of 1.2 W was underestimated as will be described later. The revised value of heat deposit was somewhat 16 W $\sim$ 20 W for the flat moderator and it would go up to 50 W $\sim$ 60 W for the grooved moderator. Therefore we need to establish the method for removing the heat deposit corresponding to 20 $\sim$ 60 W in the KENS-I' cold moderator.

## 2. Mock-up experiments

Mock-up experiments have been performed by employing the KENS-I flat cold moderator, the layout of which is shown in Fig. 1. The solid methane was cooled by a heat exchanger placed at the top of the moderator case and methane was cooled by thermal contact with the moderator case wall made by pure Aℓ. The neutron heating was simulated by electric heater plates embedded inside the solid methane.

The heaters' positions were determined so that the temperature gradient attained by them became identical to that we can expect for neutron heating. The heat deposit Q(x,y,z) will obey an exponential function,

$$Q\ (x,y,z) = Ae^{-\Sigma z}\ , \tag{1}$$

with A given by

$$A = \frac{q\Sigma}{1-e^{-\Sigma \ell_z}}\ , \tag{2}$$

where q (w) is heat power, $\Sigma = 0.31\ cm^{-1}$ , macroscopic cross section of neutrons and $\ell_z = 15$ cm is a total length of the moderator. Fig. 2 displays the temperature distribution observed for a given heat power. It was found from the figure that, with a heating power of 15 W, the maximum temperature at a central position almost attained to 60 K, but the temperature rise was rather small near the moderator case wall where the hydrogen thermometer was located.

In order to improve the situation, we inserted in solid methane an Aℓ wire lattice of 10 x 10 $mm^2$ with 1 mmϕ Aℓ, the top of the wires being screwed to the top of the moderator case. The results are shown in the lower part of Fig. 3, indicating that the temperature increase is substantially reduced, but still not enough for the KENS-I' cold moderator.

In Fig. 4 we plotted the temporal evolution of the temperatures at various different positions, when a heat deposit was supplied to solid methane with Aℓ lattices. The results are quite instructive; the temperature increase was relatively small at the position of heat exchanger 2, the coolant temperature was still less than 20 K even if the heat power went up to 20 W. However the temperature of moderator case wall, 3 or 8 rose to 30 K, suggesting the existence of a large resistance between the heat exchanger and moderator case. The increase of the temperature inside solid methane was of course quite of significance.

## 3. Simulation calculation

In order to find a better solution, we have made a three dimensional calculation based on the differential equation of heat transport given by

$$\frac{\partial T}{\partial t} = \frac{K}{C\rho} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + \frac{Q(x,y,z)}{C\rho} \quad , \tag{3}$$

where Q (x,y,z) is given by eq (1), K,C. and $\rho$ being thermal conductivity, specific heat and density respectively.
In case of solid methane with $A\ell$ wires, K and $C\rho$ are replaced by averaged values $\bar{K}$ and $\overline{C\rho}$ defined by

$$\begin{aligned} \bar{K} &= S_{A\ell}K_{A\ell} + S_{me}K_{me} \qquad (S_{A\ell} + S_{me} = 1), \\ \overline{C\rho} &= S_{A\ell}C_{A\ell}\rho_{A\ell} + S_{me}C_{me}\rho_{me} \quad , \end{aligned} \tag{4}$$

where $S_{A\ell}$ and $S_{me}$ are the relative cross sections of $A\ell$ and methane in a unit area perpendicular to the direction of heat flow. Therefore the temperature T(x,y,z) obtained by this calculation gives an average temperature of a given small area (1 x 1 $cm^2$). For K, C and $\rho$ of $A\ell$ and solid methane, we used the reported values at each temperature.

The results of temperature distribution calculated by this equation for 1.2 W heat deposit are compared with observation in Fig. 5, where "1. neutron simulation" corresponds to the case where eq (1) was used for Q (z), while "2. heater simulation" represents the case of actual heater's heating. The agreement between the calculation and observation is quite satisfactory in three directions, assuring the computer simulation calculation we made. In Fig. 6 (a) we plot the temporal evolution of the temperature at a middle part of solid methane obtained by simulation calculation, which is quite similar to what was observed by the mock-up experiment, giving also a good support to our simulation calculation. Note that the simulation calculation does not agree with the temperature increase of the hydrogen thermometer as shown in Fig. 5(b). The final temperature rise is only 0.7 K for 1.2 W heat deposit, while the simulation calculation expects the rise of 1 K for this heat deposit. The discrepancy may be due to the thermometer tube made by copper which decreases the temperature of the thermometer by heat flow through it. The results suggest that the heat deposit corresponding to the temperature increase of 1.0 K of the hydrogen thermometer should be modified from 1.2 W to 1.8 W which is listed as "corrected values" in

Table 1.

The comparison of the calculation and observation was also done for higher heat deposit of 10 W in Fig. 7. The agreement between the calculation and observation is again reasonably good in both cases of without and with Aℓ wires, suggesting the correctness of the values of parameters we adopted in the calculation. Note, however, that the calculation of the case with Aℓ wires does not agree with the observation, if we assume that the wires contact perfectly with the moderator case wall which we assumed to be 16.5 K. The thermal contact of the wire to the case wall would not be good in our experiment. Therefore we assumed that there is a thermal resistance between the wire and case, the value of which was determined so as to explain the experimental data for a given heat deposit. The result with this calculation (NC) explains well the observed temperature distribution as well as the dependence of the maximum temperature on supplied heat power as shown in Figs. 7 and 8 respectively.

The results of calculation in different cases are summarized in Fig. 8, where we shows the results of two cases of inserting 1 mm$\phi$ Aℓ wires and 0.5 mm Aℓ plates. We found that either Aℓ wires with a lattice of 5 x 5 $mm^2$ or 0.1 mm Aℓ plates placed in a distance of 10 mm satisfies the requirement that the temperature of solid methane should be less than 20 K for the heat deposit of 20 W. The latter case is recommanded because it has a better packing factor than the former case and is easy to fabricate.

## 4. Conclusion

We have found that the insertion of 0.5 mm Aℓ plates with a distance of 10 mm can keep the solid methane temperature below 20 K for the heat deposit of 20 W, if we can keep the temperature of moderator case wall at 18.5 K and makes the plates good thermal contact with the wall. In order to realize this situation, the moderator case should be cooled more directly and the present refrigerator (PHG 105) has an enough cooling power for it. We need, however, to give up the grooved moderator, because the insertion of Aℓ plates is not simple for this moderator. Furthermore our refrigerator power would not be enough to keep solid methane in the grooved moderator below 20 K. In addition to it, the grooved moderator was found not suitable for the high resolution powder spectroscopy which uses the cold moderator. The decrease of the intensity by adopting the flat moderator can be partly remedied by improving the reflector system.

We should note finally that the insertion of Aℓ sponge (Duocel Foam Metal) is one of the most convenient method to increase the effective thermal conductivity of solid methane as successfully adopted for the IPNS solid methane cold moderator[3) ] We have, however, decided not to adopt this method because we doubt if a curious phenomenon of "burps", phenomenon of a sudden increase of local temperature and pressure which occurs once a day in the IPNS cold moderator[3)], would be related with the use of this Aℓ sponge. It is almost sure that the "burps" is related with the hydrogen gas created by radiation decomposition which may be accelerated by the presence of Aℓ sponge. Further studies will be required to examine this possibility.

References

1) Y. Ishikawa, Y. Endoh and K. Inoue, Proc. Conf. Neutron Scattering in the nineties IAEA (Vienna) (1985) 285.

2) Y. Ishikawa, S. Ikeda, N. Watanabe, K. Kondo, K. Inoue, Y. Kiyanagi, H. Iwasa and K. Tsuchihashi, Proc. ICANS-VII (Chalk River) (1983).

3) J. Carpenter private communication.

Table 1

Heat Deposit in Cold Moderators in KENS-I by Nuclear Radiation[2)]

| | Flat Moderator (Jul. 1980) | Flat Moderator (Feb. 1983) | Grooved Moderator (Jul. 1983) |
|---|---|---|---|
| Proton Intensity (current I, μA) | $7.3 \times 10^{12}$ protons/sec (1.2) | $8.0 \times 10^{12}$ protons/sec (1.3) | $6.5 \times 10^{12}$ protons/sec (1.0) |
| Volume V ($cm^3$) | 900 | 900 | 1,544 |
| Bottom Area S ($cm^2$) | 60 | 60 | 131 |
| Temperature Rise (K) | 1.0 | 1.4 | 2.0 |
| Thermal Conductance K(J/K·sec) | 1.08 | 1.09 | 2.46 |
| Total Heat Deposit q (W) | 1.2 | 1.7 | 4.9 |
| Normarized Heat Deposit (= $q/N\eta I$) ($mW/cm^3 \cdot \mu A$) | 1.11 | 1.44 | 2.75 |
| Corrected Heat Deposit* q (W) | 1.8 | 2.4 | 6.9 W |

* corrected based on the present mock-up experiment

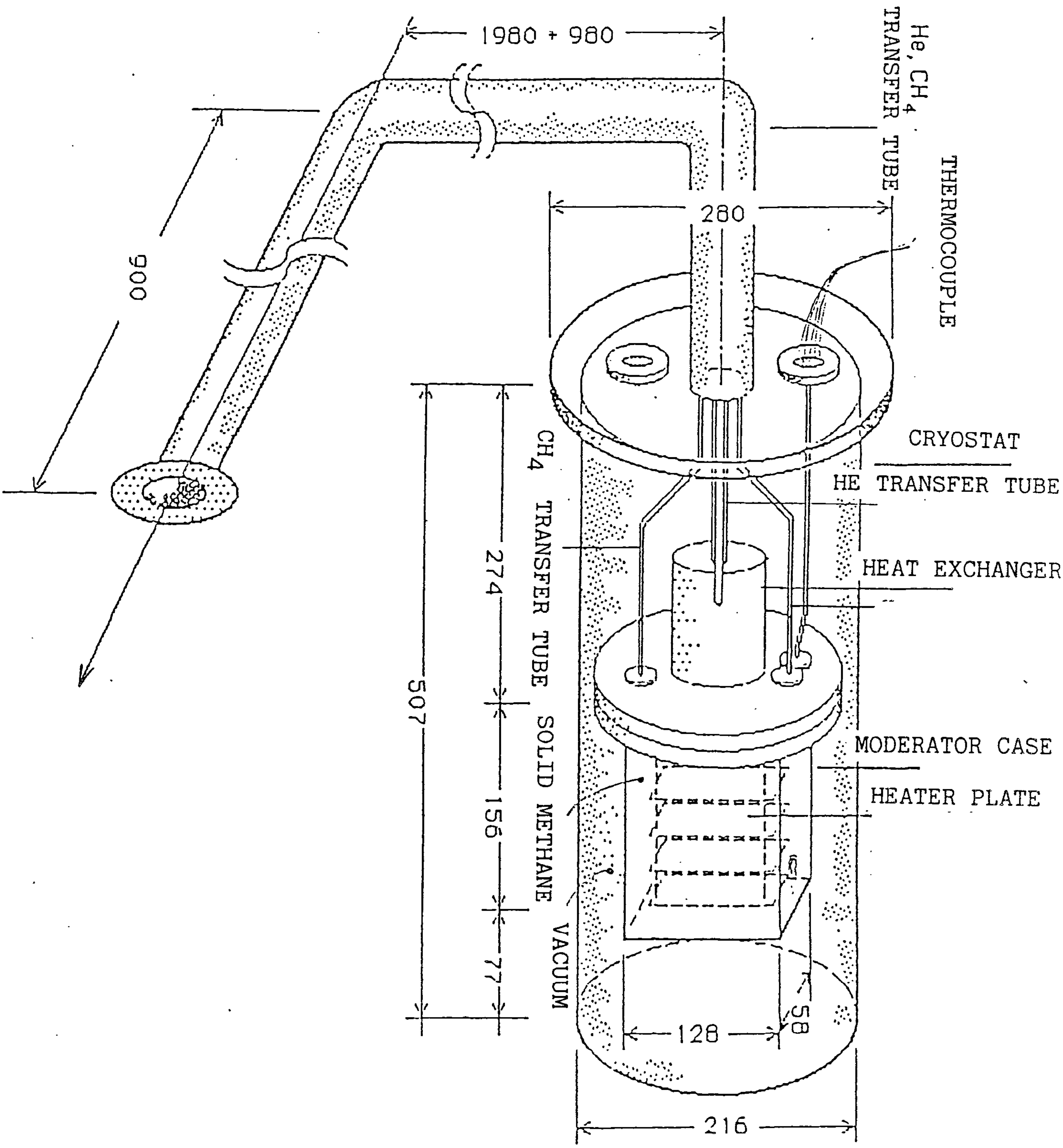


Fig. 1 Layout of mock-up experiment

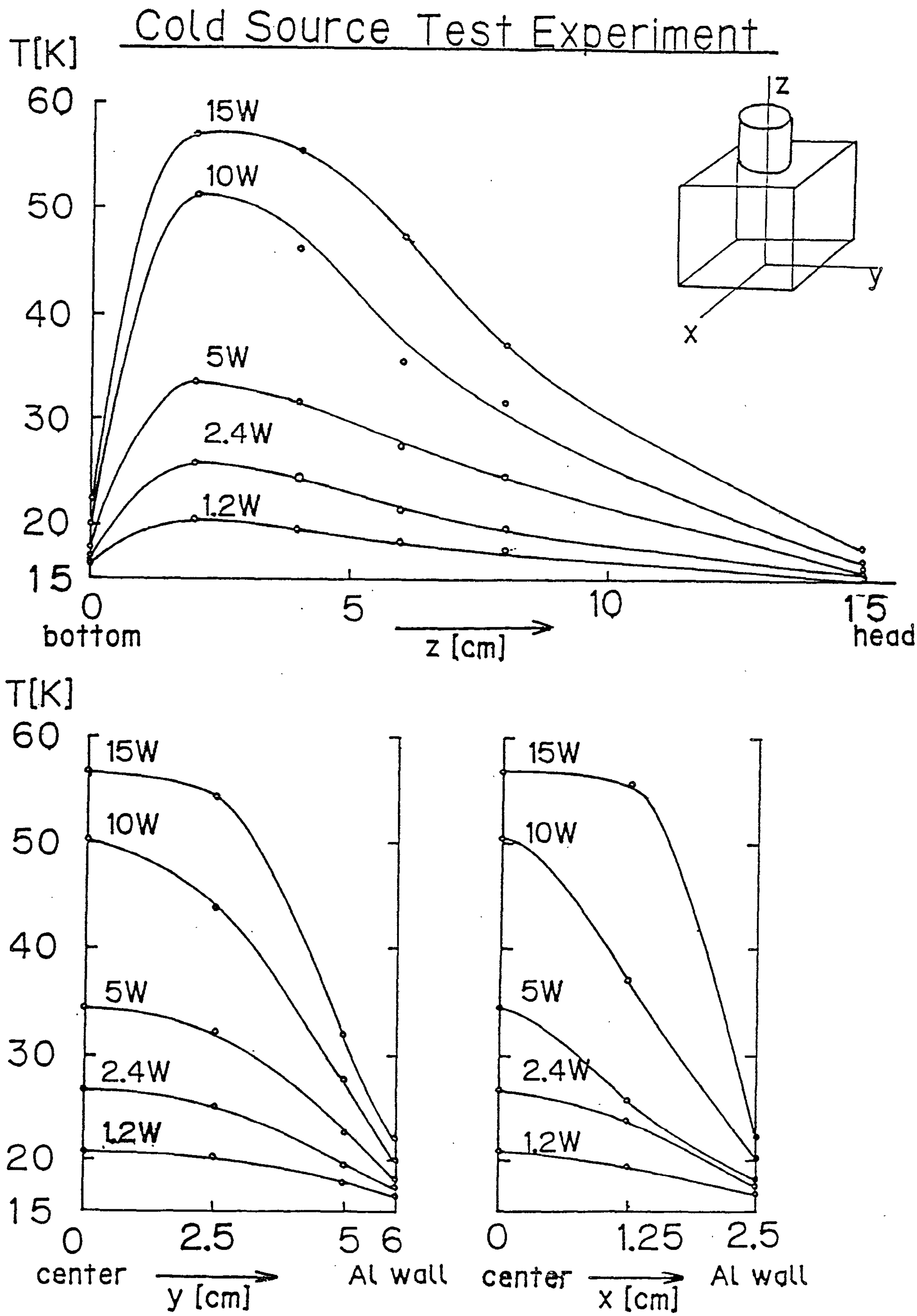


Fig. 2 Temperature distribution inside solid methane when a heat deposit is given by electric heaters

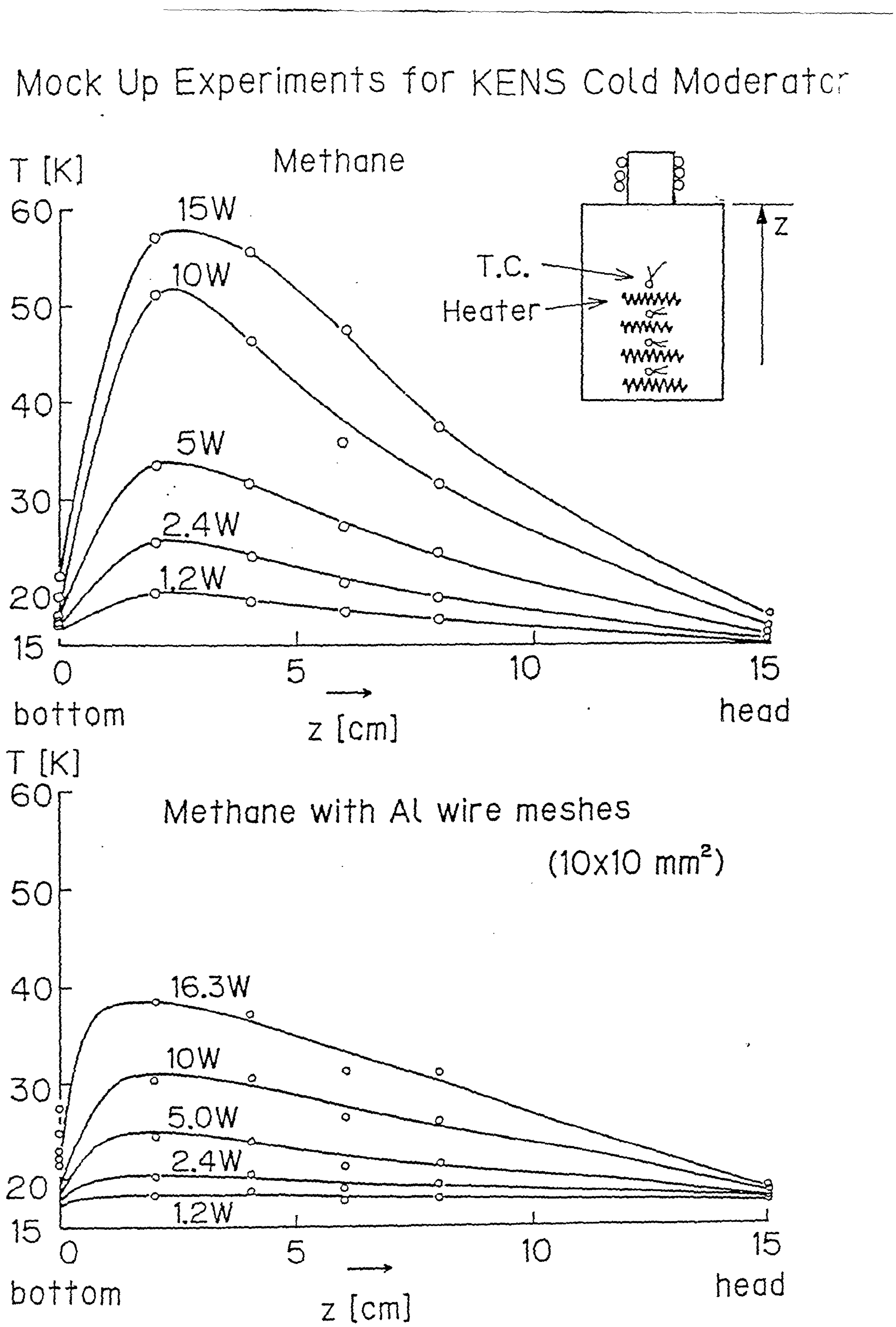


Fig. 3 Temperature distribution of solid methane with 1 mmφ Aℓ wire lattice when a heat deposit is supplied by electric heater. (lower figure)

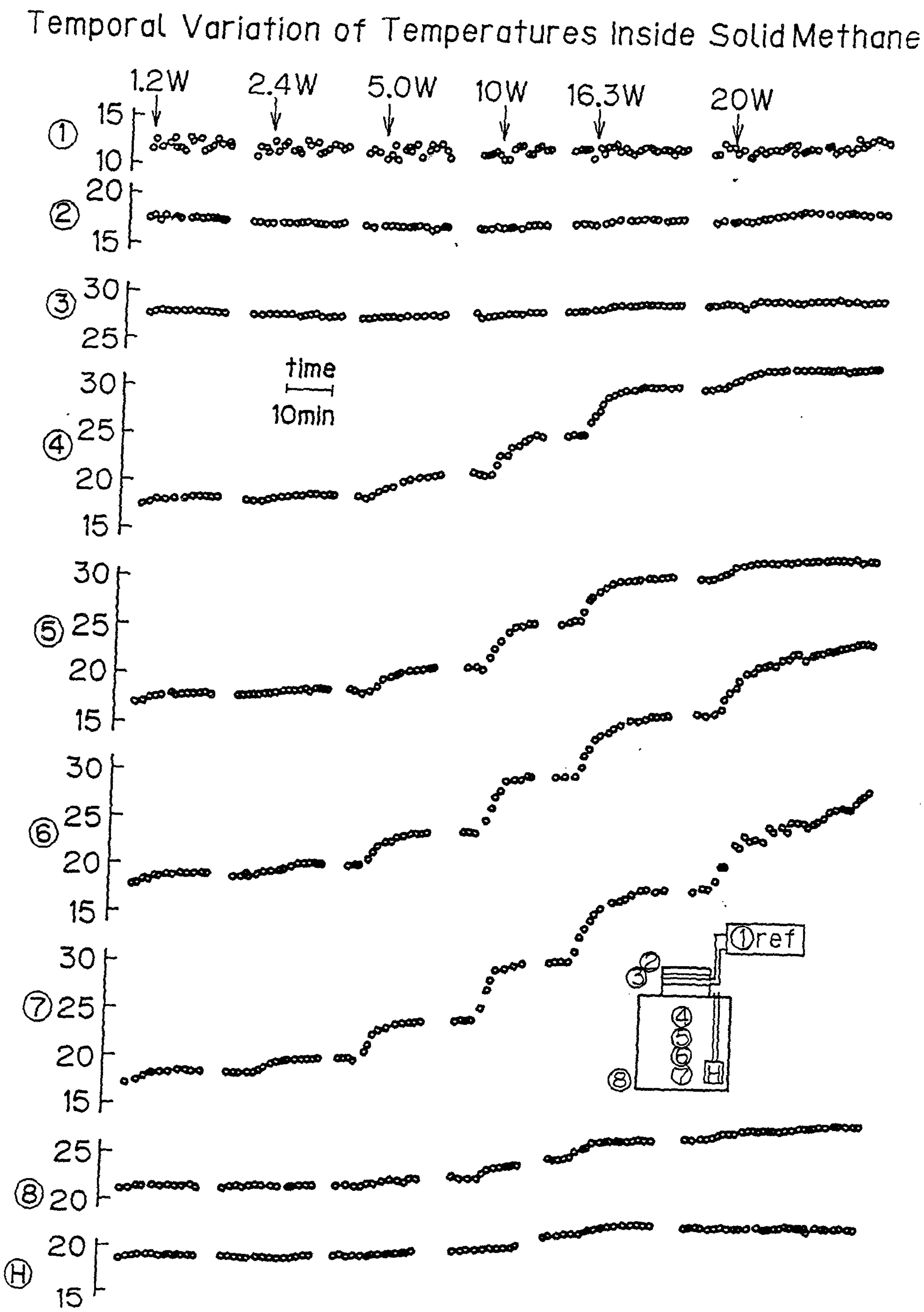


Fig. 4 Temporal evolution of temperatures at several positions inside solid methane marked by numbers in the figure when a heat deposit is given by electric heaters.

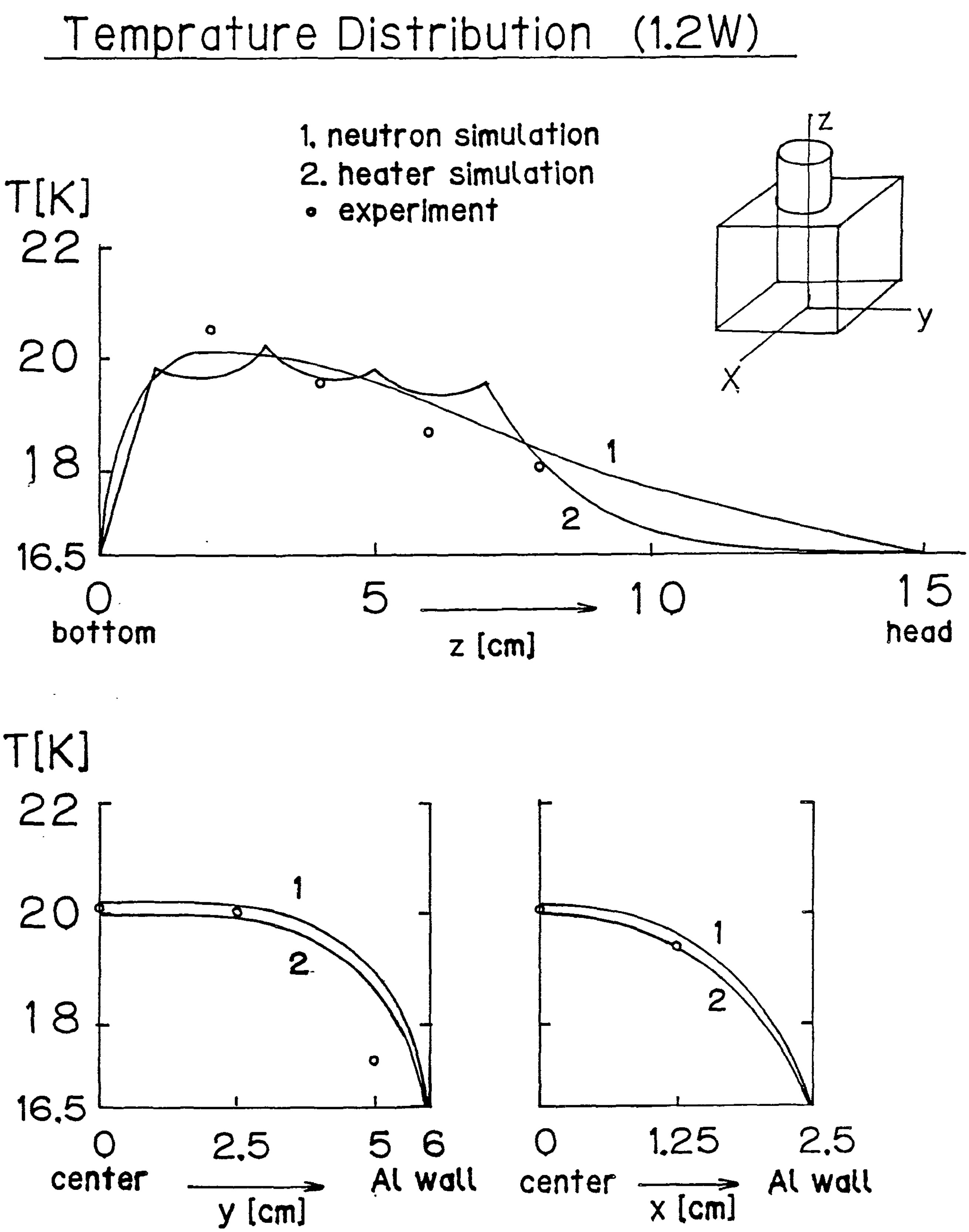


Fig. 5 Temperature distribution of solid methane estimated by three dimensional calculation of heat transport equation (eq(3)) and comparison with observation (o) for Q = 1.2 W.

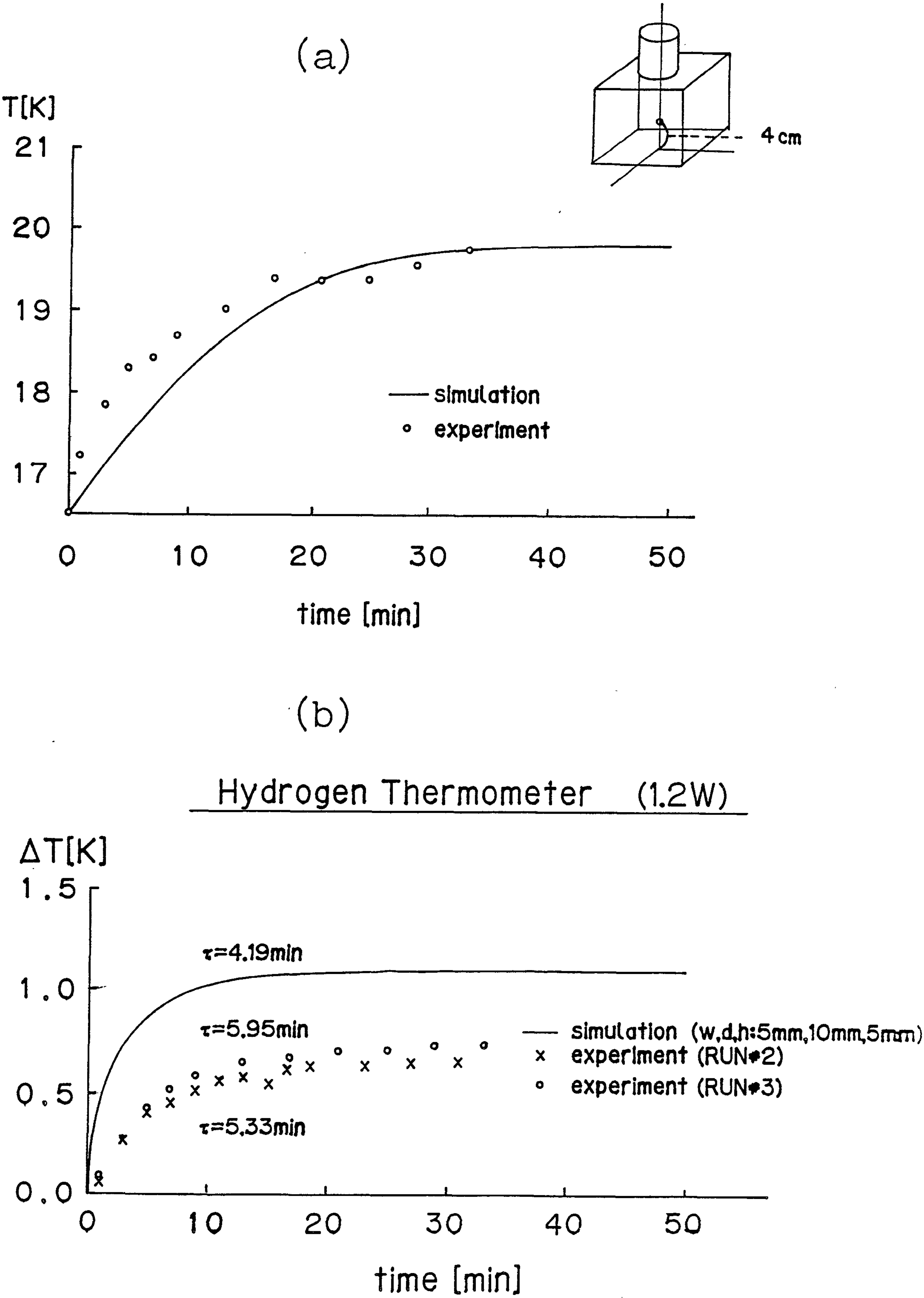


Fig. 6 Temporal variation of temperature measured (a) by hydrogen thermometer and (b) by a thermo-junction at the center and comparison with three dimensional simulation calculation based on eq (3) (solid lines)

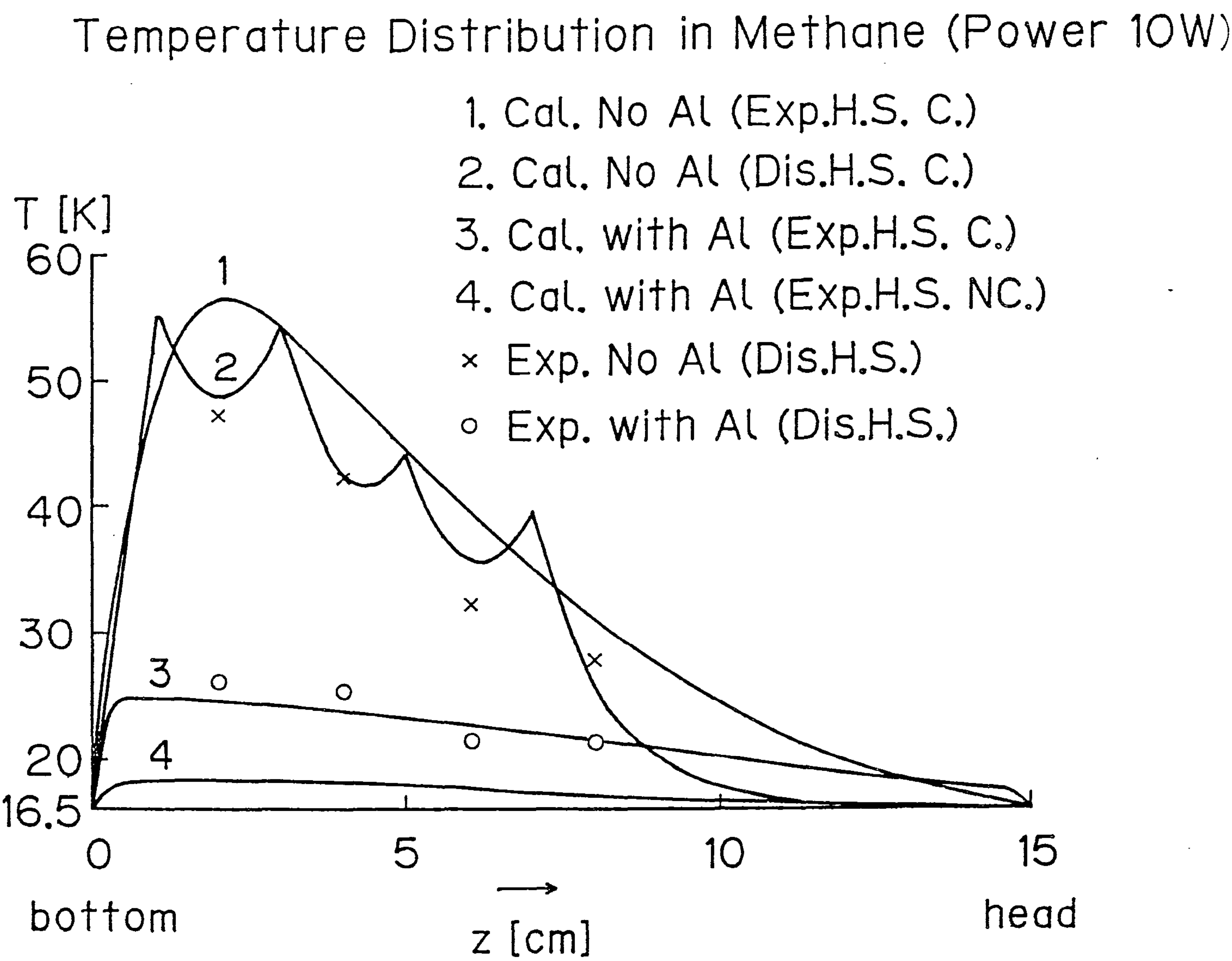


Fig. 7 Temperature distribution of solid methane estimated by three dimensional simulation calculation based on eq (3) for Q = 10W and comparison with observation.

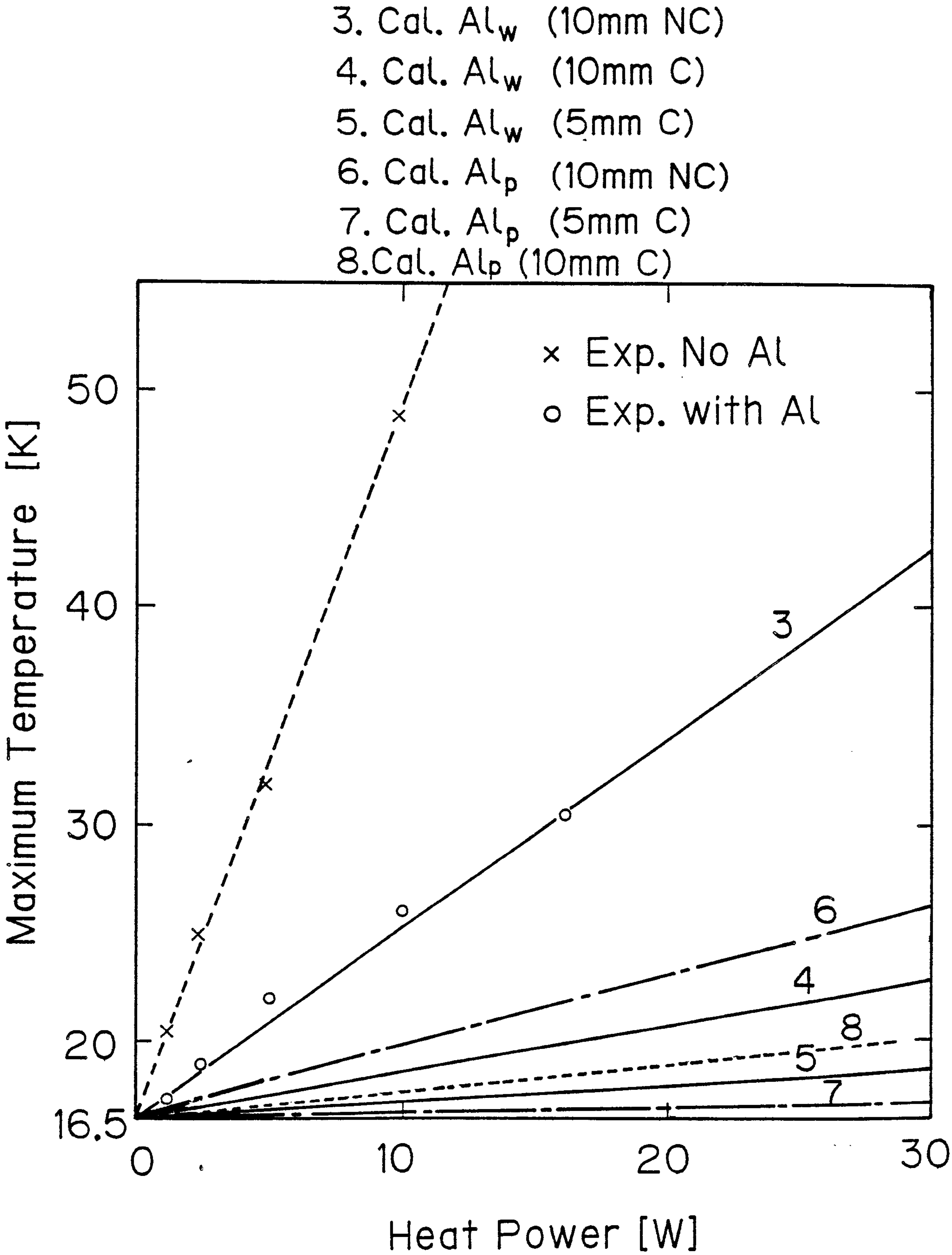


Fig. 8 Calculated maximum temperature of solid methane with various cooling devices plotted against heat deposit.