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

The development work at the liquid lead-bismuth target for SINQ

Y. Takeda & C. Gerber

Schweizerisches Institut fur Nuklearforschung

CH-5234 Villigen, Switzerland

1 Introduction

The design concept for the SINQ target is to use Lead Bismuth Eutectic (LBE) in the liquid phase in a vertical cylindrical container, with the proton beam entering from the bottom. Natural convection of LBE is to be utilized to tansport the deposited energy to a heat exchanger at the top.

The thermofluid dynamics of this liquid target is one of the important study subjects for a practical design. Numerical calculations were performed to survey effects related to several design parameters <1>. Flow visualization experiments were also made for studying the total flow behaviour in a small scale water model. Results have been reported in an earlier ICANS proceeding <2>.

2 NACOSPANS - Water experiments

A large scale test rig for a water experiment was fabricated. A glass cylinder of 20 cm diameter and 250 cm height is set in a square aquarium of 45 cm side and 300 cm height. A 40 cm long heating rod is inserted from the bottom which has a heat generation decreasing exponentially with a relaxation length of 30 cm. This gives a first approximation to the expected beam heating. A 15 cm diameter glass tube was prepared to be set in a cylinder as a guide tube to stabilize the flow. Approximately 80 thermocouples in total are set in the apparatus to obtain the temperature distribution of water. Experiments were performed with the aim to obtain temperature distributions, to validate the computer program and finally to deduce the flow behaviour from the temperature distribution through computation.

A) Temperature distributions

Temperature distributions were obtained for various heater powers and water heights.

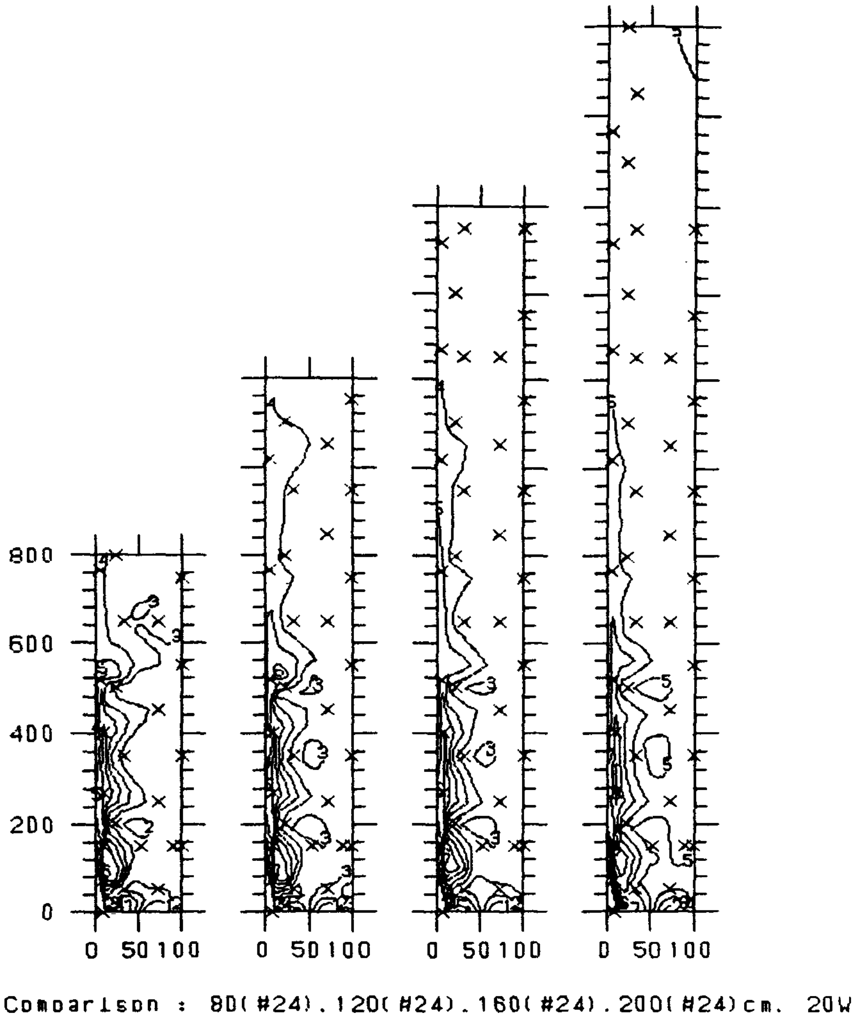

Fig.1 Measured temperature distributions for heights of 80, 120, 160 and 200 cm. Input power is 20 W. Only the half planes are shown (left coordinate coressponds to the center line). Contour lines are for arbitrary unit.

Fig.1 shows examples of distributions for heights of 80,120, 160 and 200 cm. (Heater power, 20 W) For every height, the higher tempearture rising column could be seen in the distribution, however, in the region below the top of the heater the distribution is complicated, showing the stable island of lower temperature. This effect is due to the high aspect ratio of the system and to the existence of the solid surface of the heating rod. This complicated distribution is stronger for higher heater power. From these temperature distributions with temperature islands, we conclude that the flow itself is very complicated, suggesting the existence of bifurcations and some roll structures. Similar patterns of distributions could be seen even in a lower aspect ratio system with lower power.

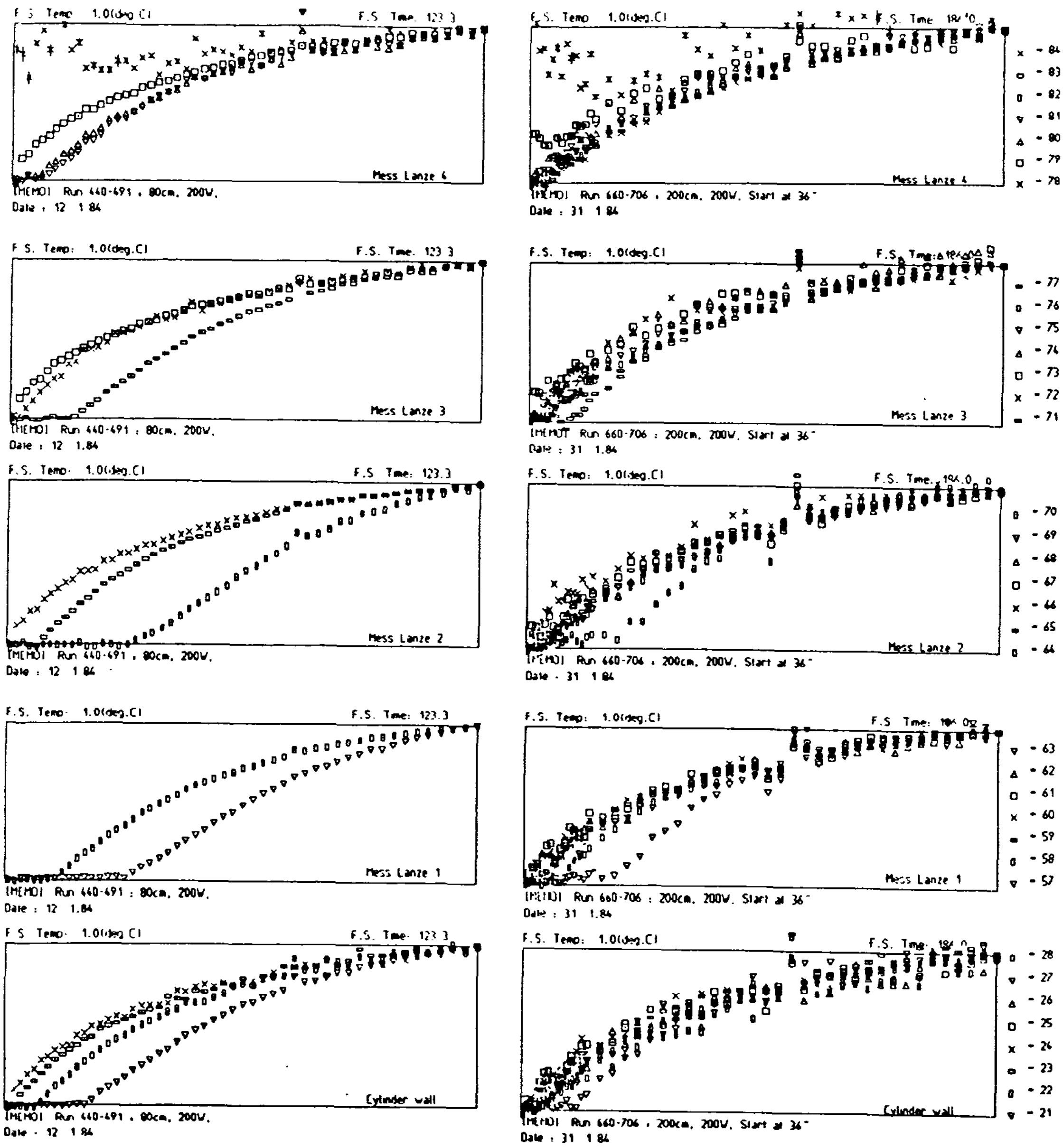

Fig.2 Time variation of the temperature at various positions. Water heights : a-80 cm, b-200 cm, heater power 20 W. Positions of mess lanze in radial direction : 1-72, 2-32, 3-22, 4-5 mm. In the vertiacal direction, the distance between measuring points is 20 cm.

Fig.2 shows the temperature variation at various measuring positions for the systems of heights of 80 and 200 cm. They show splitting lines for the 80 cm system whereas in the 200 cm system lines are almost coalesced. The former shows a rather smooth propagation of temperature increase indicating a smooth circulation but the latter shows the almost simultaneous temperature increases presumably being caused by the roll structure or the chaotic motion of fluids.

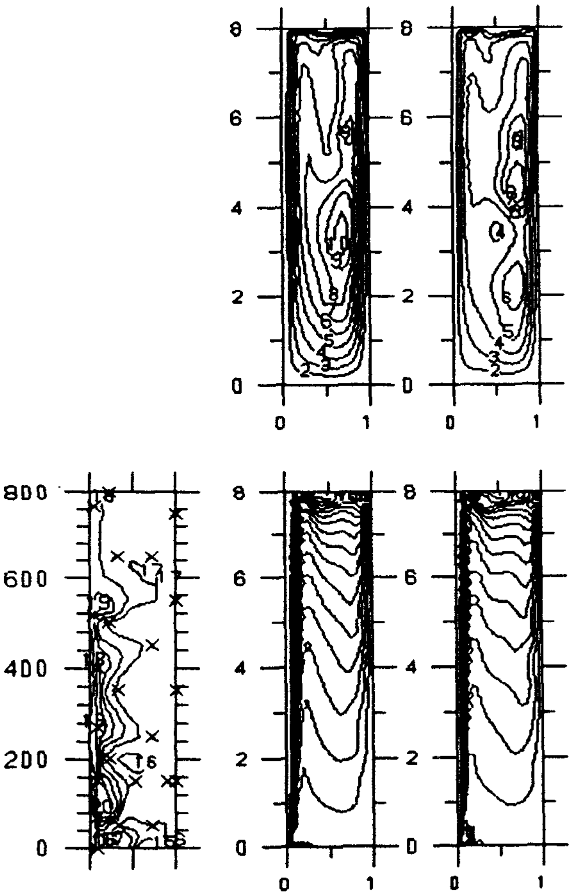

Fig.3 Comparison of (a) measured and (b,c) calculated temperature distributions. Gr : b-1x10^5, c-2x10^5. Upper maps are calculated contour lines of the stream function.

Fig.3 is a comparison of calculated and experimental temperature distributions and streamline contour maps for the corresponding calculations. It was only possible to make calculations with Gr number up to 2x10^5 whereas the experimental Gr value is about 5x10^6. In both cases some bifurcation could be seen at the same position in the system, however, temperature distributions appear to be quite different. We conclude that it is virtually impossible to deduce the flow behaviour from temperature measurements through calculations.

B) Effect of guide tube
Temperature distributions were also measured with a 200 cm guide tube in a system.

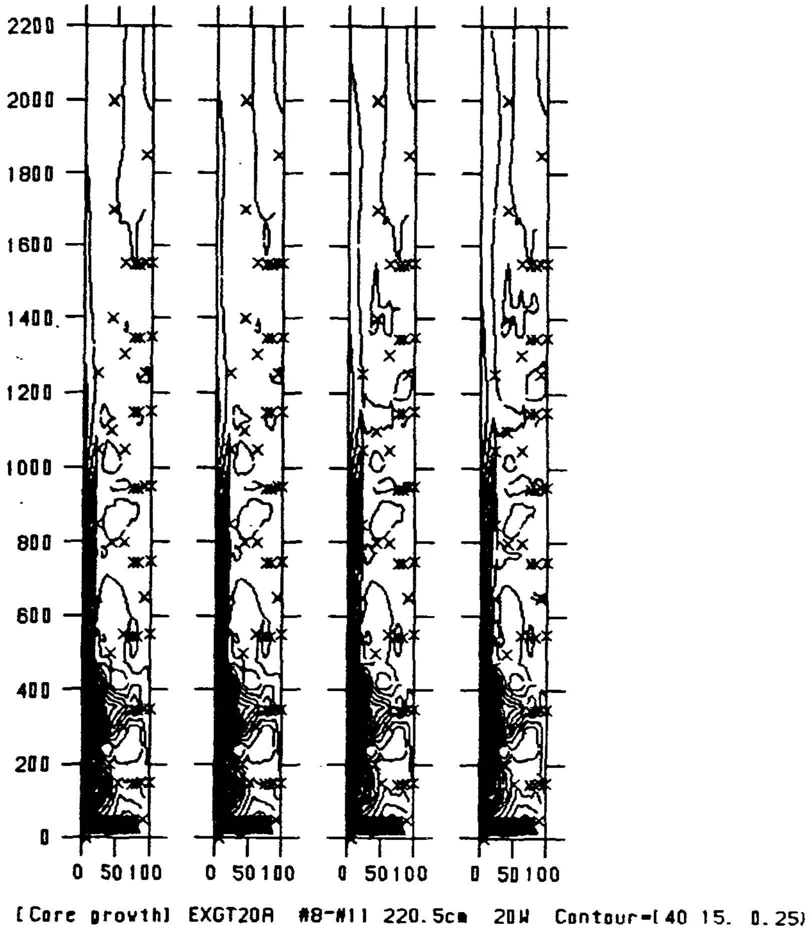

Fig.4 Time variation of temperature distributions. Water height is 220.5 cm, heater power 20 W. Results are from 20 to 30 minutes after the start. Contour lines are for every 1/4 deg. C.

Fig.4 shows part of the time change of these temperature distributions. Although they show complicated distributions with many islands at the lower part of the system, it is clearly seen that a rising column of high temperature is generated, which rises to total height with time. Obviously this result would be caused by the existence of the guide tube which may increase the rising velocity of the fluid and stabilizes the total circulation.

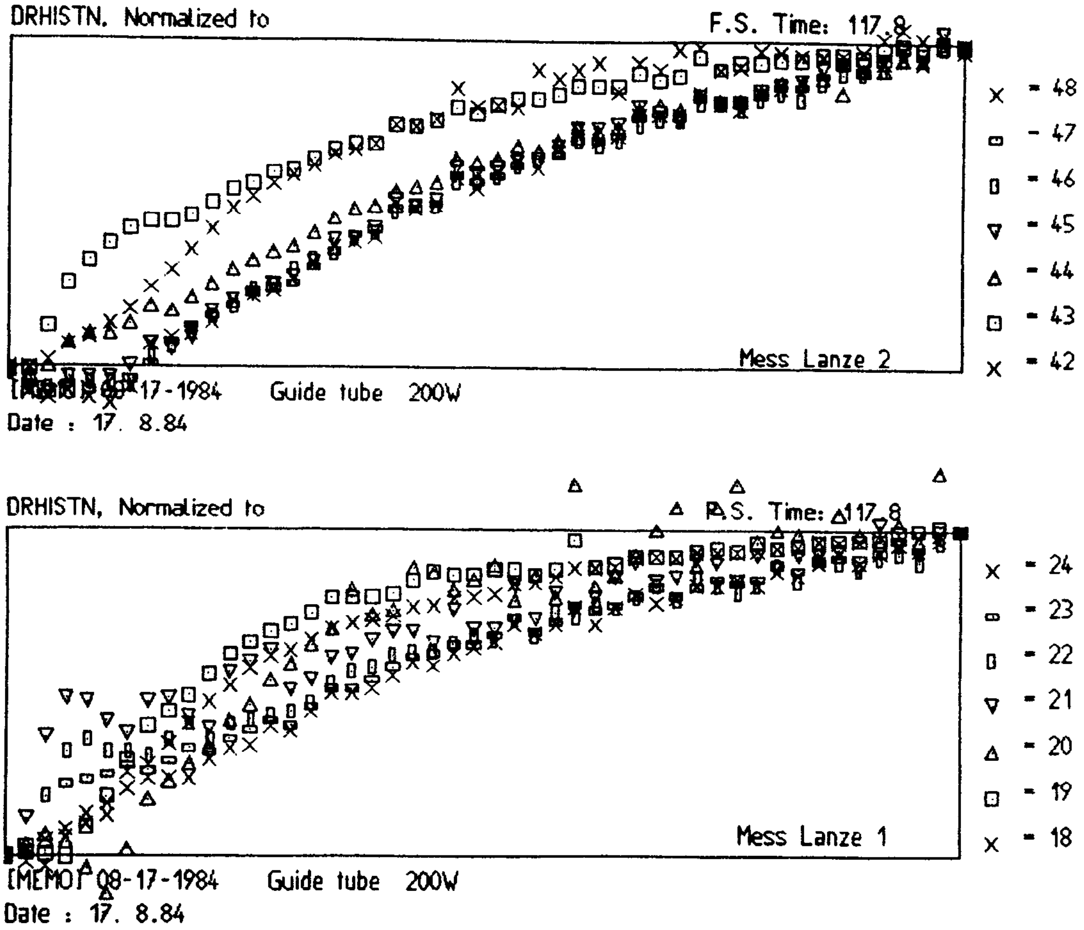

Fig.5 Time variation of the temperature. Mess lanze 1 : inside the guide tube (r=32mm), 2 : outside (91mm).

Fig.5 shows time behaviour of the temperatures inside and outside of the guide tube. At inside, it shows a typical transient behaviour with a small hump immediately after the startup of heating, afterwards the temperature increases monotonically. However, on the outside the temperature changes quite smoothly without any transient characteristics. This also indicates that the guide tube works effectively to stabilize the total circulation of the fluid in the system.

Furthermore, two additional effects were observed; one is a so-called Syphon effect at the top, which is a flow bifurcation. Part of the down-flowing fluid bifurcates, entering back into the guide tube. Another effect is a local circulation which appears in a top plenum. Both effects are strongly related to the position of the guide tube. This should be carefully investigated by a flow visualization experiment which is now prepared.

3 Flow monitoring

From the water experiments described above, we concluded that it is necessary to monitor the flow distribution directly by some other method. Although liquid metal is now extensively used in industry, measurement of flow profiles are not yet properly estabilished. Recently an ultrasound Doppler shift method has been developed for measuring blood flow in human blood vessels. <3> This is a remote measuring technique which has no senser inside the fluid, and could be very suitable also for our target monitoring system. Investigation was made in order to verify its feasibility for general fluid flow and liquid metal flow.

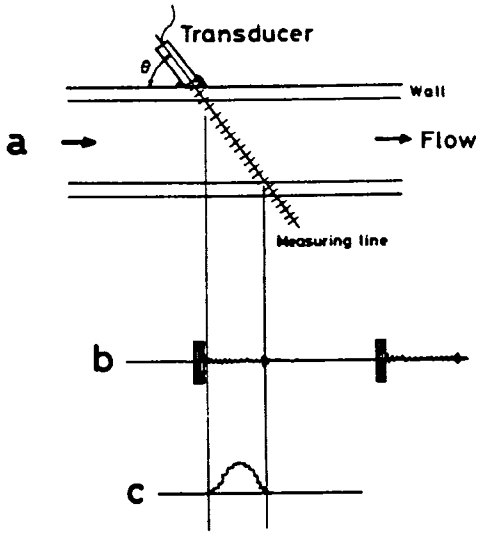

Fig.6 Illustration of the principle of velocity profile measurement by ultrasound Doppler shift method.
a : configuration for measurement, b : echo signal
c : velocity profile obtained.

Fig.6 shows an illustration of its working principle. Pulsed ultrasound echography is used. The basic frequency of the ultrasound is 4.2 MHz, pulse width ca.5 usec and repetition period 122 usec. The received echo is analyzed to derive its Doppler shift frequency as a function of time after the pulse. This method makes it possible to measure the velocity profile along the measuring line as a function of time. One profile can be measured in ca 16 msec and position resolution is ca 0.7 mm. Investigation was made to apply this method to the Poisoulle flow of water in a pipe and Taylor vortex flow in a rotating double cylinder. Details of the experiment and results are described elsewhere <4>.

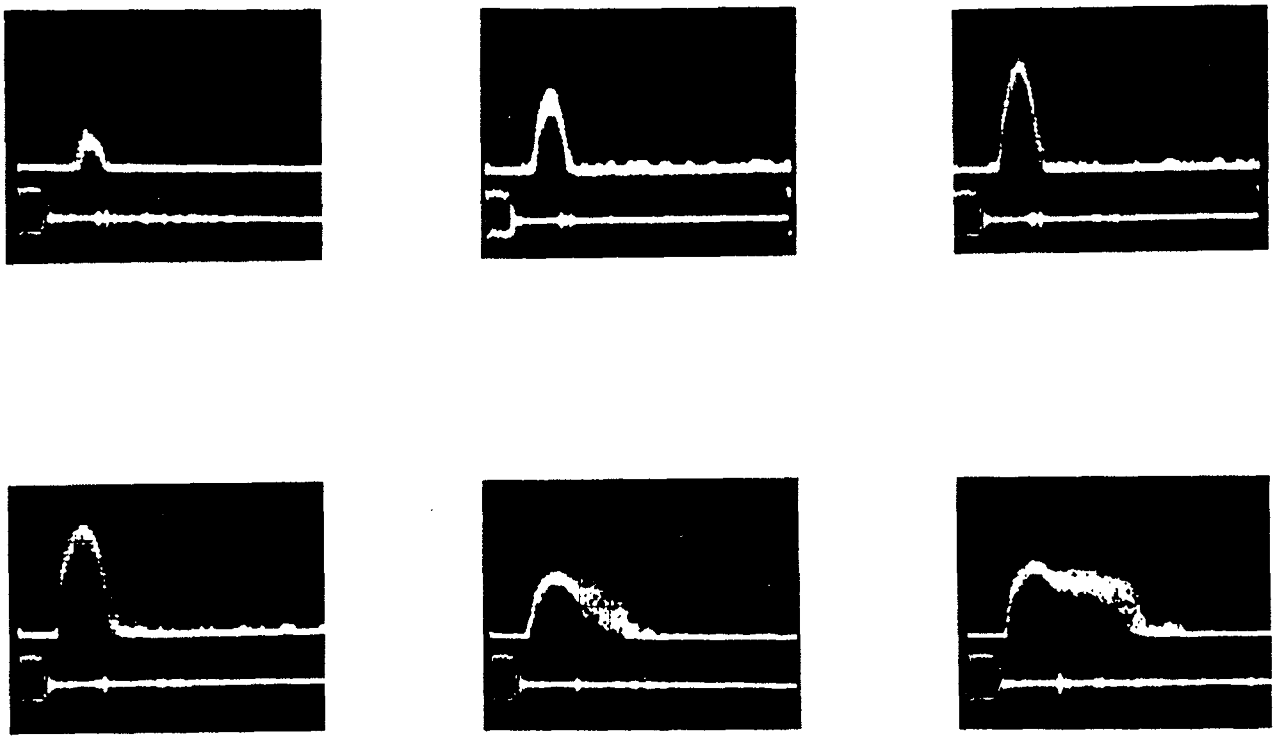

Fig.7 Measured velocity profiles of pipe flow for various Re numbers.

Fig.7 shows examples of change of velocity distributions in a pipe with various Re number.

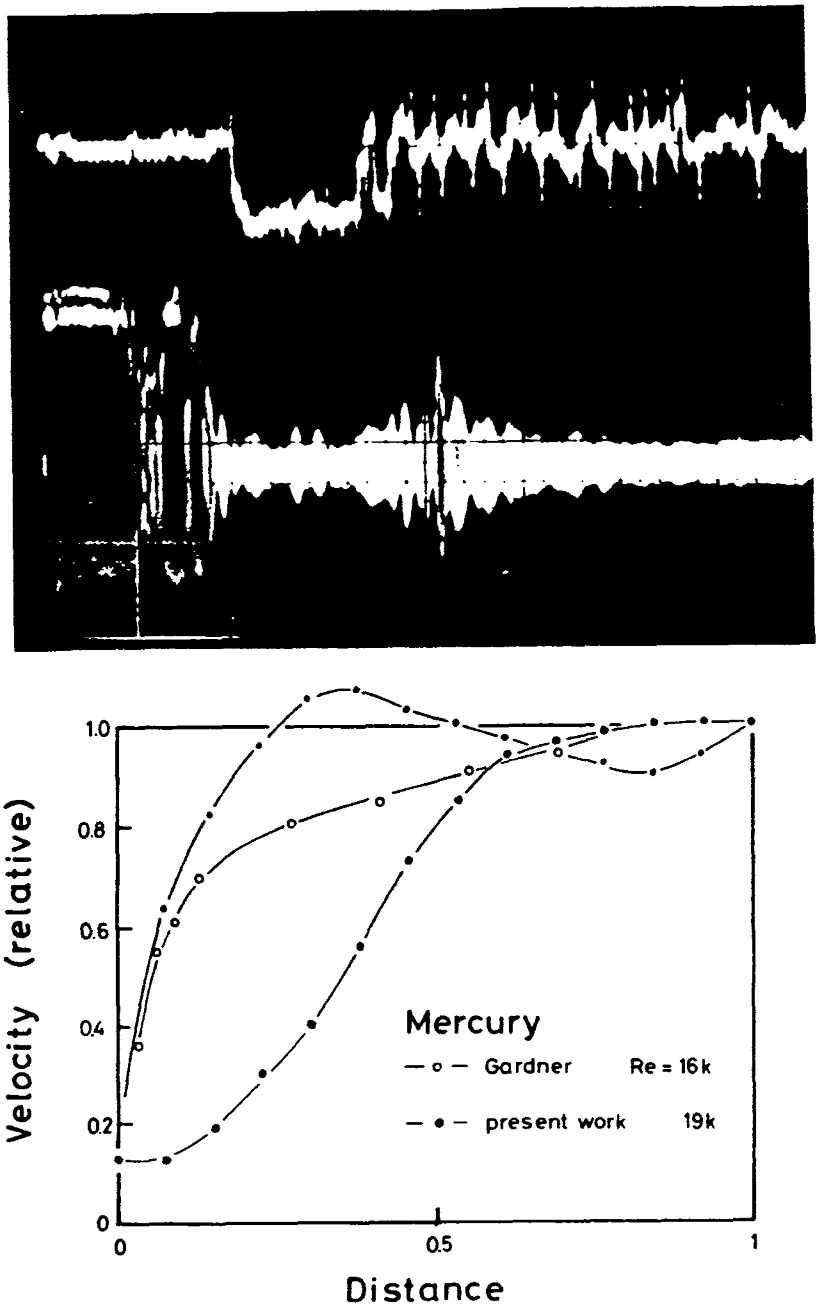

Fig.8 Measured profile of the pipe flow of Mercury.

Fig.8 shows a measured profile of the pipe flow of Mercury and its comparison with the earlier measurement of Gardner & Lukodis by Pitot tube <5>. There is still some disagreement in the profile and some more technical improvement may have to be made for our purpose. However, it was proven that this principle works quite successfully and further development work has been already started in order to use the machine as a target monitoring system.

4 Material study

As a procedure of selecting the target structures materials several tests are planned.

a. Container : Zircalloy 2 & 4 and two kinds of reactor grade Ni free steel were selected as candidate materials for the container and they are to be tested on corrosion properties in high temperature liquid LBE.

b. Window : The window is most heavily loaded by high temperature and proton beam irradiation under contact with LBE. Irradiation tests are under progress at Los Alamos. Results will be reported soon.

c. Heat exchanger : Corrosion and surface contamination by impurity and spallation products may have a significant effects on the heat exchanging properties. Investigations of these effects are planned.

5 Conceptual design

Designing the concept of the target system has been started. The target consists of a double wall containment. The lower part of the target has 190 mm outer diameter and the length is about 1400 mm. The upper part, where the shell and tube type heat exchanger is located, has a diameter of ca. 400 mm and a length of ca. 1600 mm. A guide tube is inserted into the center of the target extending from bottom to top, expecting to stabilize the rising flow of LBE inside this tube. Through the gap of the double wall of the container He gas is circulated for cooling the window and the target itself and for melting LBE before operation is started. At the same time, a part of this He gas is lead to the gas monitoring system in order to monitor leakage of the target container. The empty space above the LBE at the top of the target is to be evacuated in order to extract volatile spallation products generated during the operation.

References

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