ICANS-XIV
14th Meeting of the International Collaboration
on Advanced Neutron Sources
June 14-19, 1998
Starved Rock Lodge, Utica, Illinois, USA

Structural and Hydraulic Study on Cold Source Moderator

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ABSTRUCT

In this paper, a concept of thin-walled structure for a cold source moderator applicable to a MW-scale target system is outlined, and stress and hydraulic analyses as well as flow visualization experiments carried out to improve the concept are introduced.

1. INTRODUCTION

In the Neutron Science Project of the Japan Atomic Energy Research Institute (JAERI), a 5MW neutron scattering facility is planed to be constructed first, where high intensity neutrons are generated at a target by spallation reaction between target materials and the proton beam. Since technology of a MW-scale target system has not been established yet, development of the 5 MW target system is one of the most difficult technical challenges in this project.

One of the key components consisting of the target system is a cold source moderator using supercritical hydrogen, which affects directly a neutron yield. Representative structure of the cold source moderator is that used at the ISIS [1]. **Figure 1** shows a first concept of the cold source moderator based on the ISIS moderator. Supercritical hydrogen flows into the inner vessel through the inlet pipe inserted in the vessel, and flows out through the outlet channel between the inlet pipe and the outer pipe which is welded at the top of the vessel. To investigate feasibility of this concept, structural and hydraulic analyses as well as flow visualization experiments using a water loop were carried out. This paper introduces analytical and experimental results, and outlines the vessel structure of the cold source moderator.

2. ANALYSIS ON STRUCTURAL STRENGTH

Thickness of the vessel is required to be as thin as possible in order to keep high neutron transmission rates relating to a high neutron yield. One of the major technical issues in the design of the cold source moderator is to keep structural strength of the moderator vessel under a supercritical condition of hydrogen, 1.5MPa and 20K. Forging aluminum alloys are usually used for vessel materials of the cold source moderator. To get a prospect of the allowable thickness of forging aluminum alloys, stress analyses were carried out under following conditions:

Inner vessel size	:	120mm wide, 120mm high, 50 mm long and 3 mm thick 180mm in curvature radius of curved surfaces
Temperature	:	20K
Internal pressure	:	1.5MPa
Vessel material	:	Forging aluminum alloy - A6061, A5083 and A2014

A multi-purpose structural analysis code, ABAQUS-Standerd Vr.57, was used to analyze stress distributions. Then, the simulation model was divided into 4800 elements using the 3-D quardrilateral shell element.

Figure 2 shows one of analysis results of stress distributions on the inner and the outer vessel surfaces. As seen in the figure, the maximum value of the Mises stress which indicates the sum of membrane and bending stresses is 93MPa on the outer surface and 112MPa on the inner surface, respectively. The maximum displacement is only 0.5mm, which occurs at the center of the curved surface.

Figure 3 illustrates stress-strain curves of forging aluminum alloys proposed for the vessel materials. A6061 (Al-Mg-Si-Cu-Cr) and A5083 (Al-Mg-Mn-Cr) are used widely for cryogenic vessels. A2014 (Al-Cu-Mg-Mn-Si) is used as a structure material of liquid hydrogen/oxygen fuel tanks of rockets. It can be seen that the design stress of A2014 alone exceeds the maximum Mises stress shown in Fig.2. However, the maximum Mises stress decreases as the vessel thickness increases. In the case of 5mm of the vessel thickness, the maximum Mises stress decreases to a value less than the design values of A6061 and A5083.

Figure 4 shows the neutron transmission rate as a function of wavelength for above candidate materials. As seen in the figure, the neutron transmission ratio of A2014 of 3mm thick is better than A6014 and A5083 of 5mm thick by 2%. It might be deduced that a main factor affecting the transmission rate is the thickness of the moderator vessel.

3. HYDRAULIC ANALYSIS AND FLOW VISUALIZATION

Hydrogen temperature rise affects the neutron yield, and moreover, has the potential to change the supercritical state into the liquid state. In the liquid state of hydrogen, there is some possibility that an excessive pressure fluctuation caused by local boiling gives serious damages to the thin-walled moderator vessel. From these viewpoints, it is desirable to control the temperature rise less than 3K. Since the temperature rise depends on the flow pattern in the vessel, hydraulic analysis and flow visualization experiments were carried out to clarify the flow patterns.

The hydraulic analysis was carried out with a computational fluid dynamics code, STAR-CD, under the water flow conditions to learn a typical flow pattern. A simulation model was the simplified two-dimensional model whose dimensions were 25mm of the inlet pipe diameter, 60mm of the outer pipe diameter and 10mm of distance from the nozzle of inlet pipe to the bottom plate. **Figure 5** shows one of analysis results obtained under low inlet water velocity of 2m/s, where the Reynolds number (Re) is 56,000; Re is around 10^6 under the supercritical hydrogen condition. It can be seen that the recirculation flow caused by the jet blowing out from the inlet pipe nozzle is generated around the inlet pipe. More intensive recirculation flow will occur at higher Re. Since the intensive recirculation flow has a potential to cause vibrations of the inlet pipe and the vessels, the flow-induced vibrations will be necessary to taking into accounts in the moderator design for keeping the structural strength.

To verify analysis results, flow patterns were visualized with a particle image velocimeter using a laser pulse sheet (PIV system) under the water flow conditions. **Figure 6** shows a flow diagram and an outer view of the test apparatus. The moderator is simulated with two acrylic cylinders whose dimensions are the same as those of the simulation model. In the experiments, small amounts of fluorescence micro particles (10 μm) were mixed with water as the tracer. **Figure 7** shows one of pictures taken at around 70ms intervals using the PIV system. Processing a series of 50 pictures, a velocity distribution in the vessel was visualized. **Figure 8** shows a vector and contour maps of velocity distribution in the bottom region of the vessel. The measured flow pattern agrees very well with the analysis result. Also, from the measured result, a low velocity region can be clearly seen on the bottom surface below the nozzle of the inlet pipe. This low velocity region will be possible to affect the temperature rise of hydrogen.

On the basis of stress analysis and flow visualization results, the moderator vessel was modified as shown in **Fig.9**. The vessel is a thin-walled structure supported with thin frames and inner plates to keep the vessel strength. The vessel materials is the aluminum alloy such as A2014. Dimensions of the vessel are 120mm wide, 120mm high, 50mm long and 3mm thick. A twisted tape is installed inside the inlet pipe so as to suppress the low velocity region by the swirl flow caused by the twisted tape. Then, most of supercritical hydrogen flows through the inlet pipe towards the bottom of the vessel, but small amounts of flow bypass through small holes located at the bottom half of the inlet pipe to suppress recirculation flow. It is necessary to verify this concept through R&Ds on thermal hydraulics and structural strength.

4. CONCLUDING REMARKS

From stress analyses and neutronic calculations, forging aluminum alloy A2021 was found to be a most likely candidate material for a cold source moderator vessel, which can make a vessel thickness thin down to 3mm under a supercritical hydrogen condition of 1.5MPa and 20K so as to allow high neutron transmission rate. It is necessary to optimize a thin-walled structure for the cold source moderator vessel through R&Ds on neutronics, thermal-hydraulics, and mechanical structure.

Acknowlegement

We are grateful to A. T. Lucas (ORNL) for helpful advice on the cold source moderator.

References

[1] T. A. Broome, Proceedings of International Worlshop on Cold Source Moderators for Pulsed Neutron Sources, Argonne National Laboratory(1997).

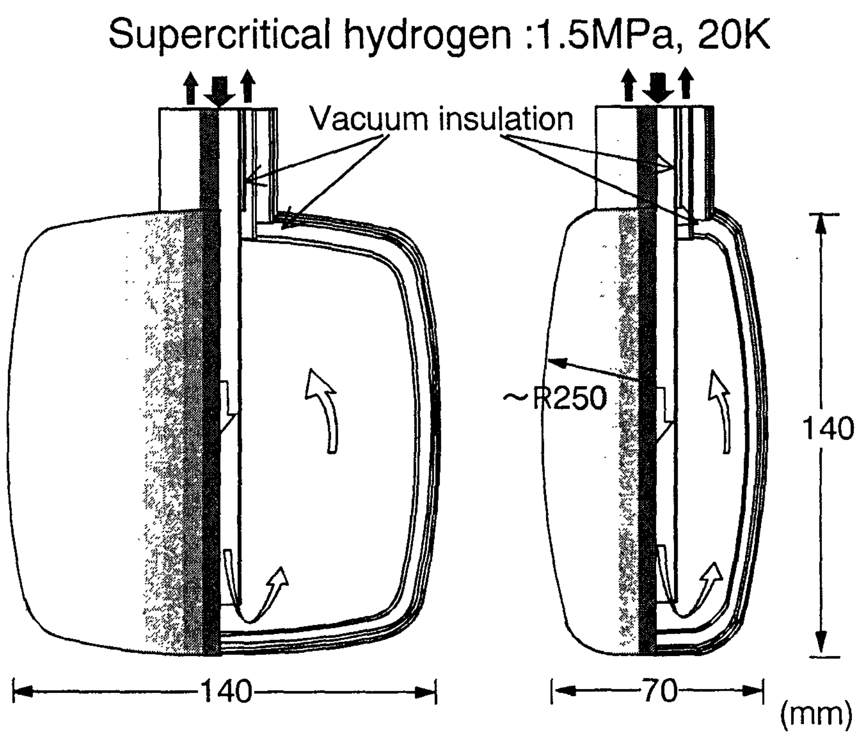
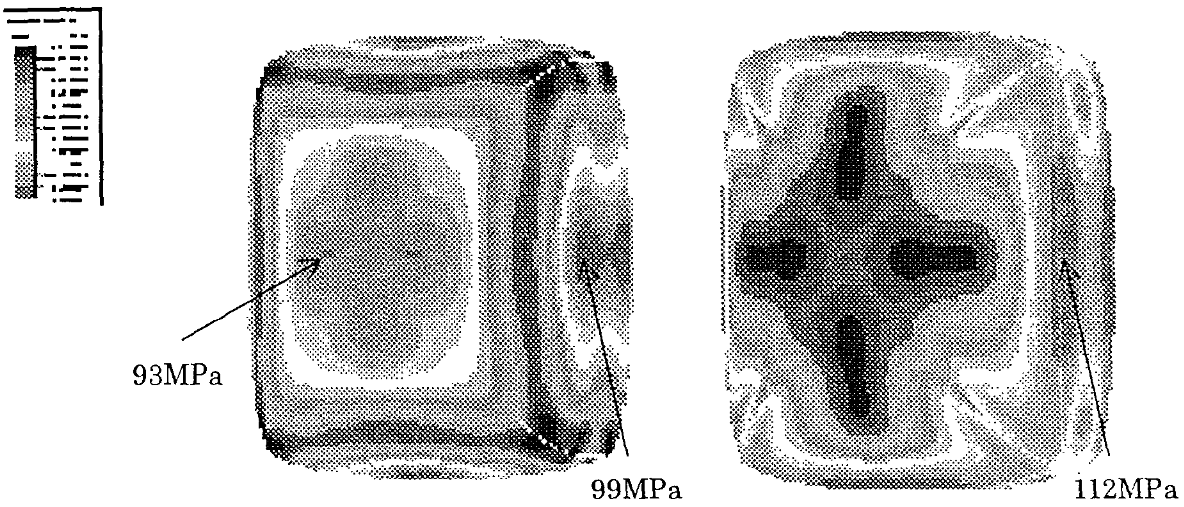


Figure 1 First concept of the cold source moderator



(a) Outer surface (b) Inner surface

Figure 2 Stress distributions on inner and outer vessel surfaces
(Vessel thickness : 3mm, Inlet pressure : 1.5Mpa, Material : aluminum alloy)

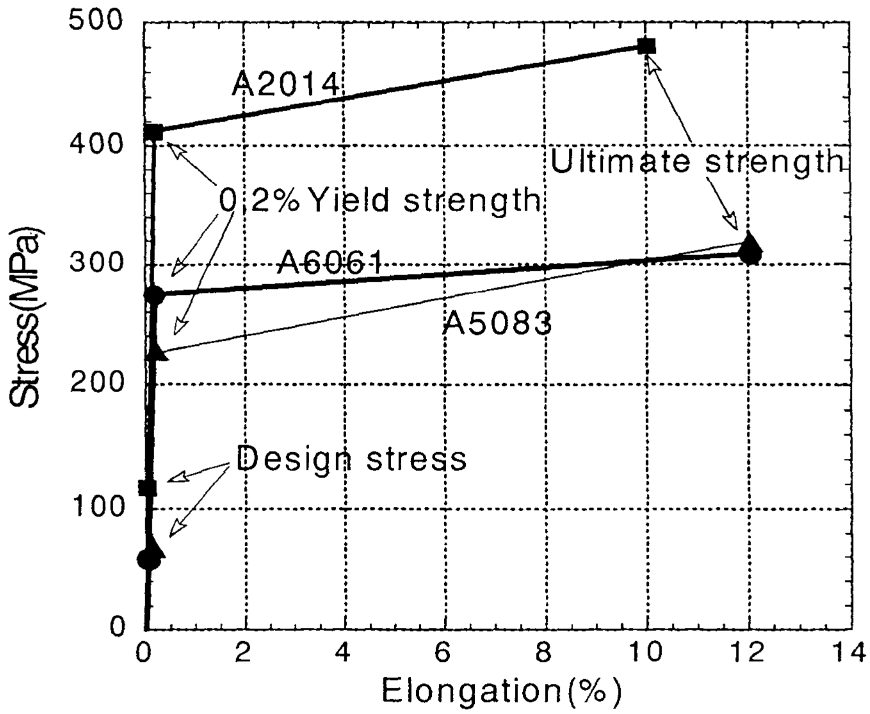


Figure 3 Design stresses and stress-strain curves of candidate aluminum alloys

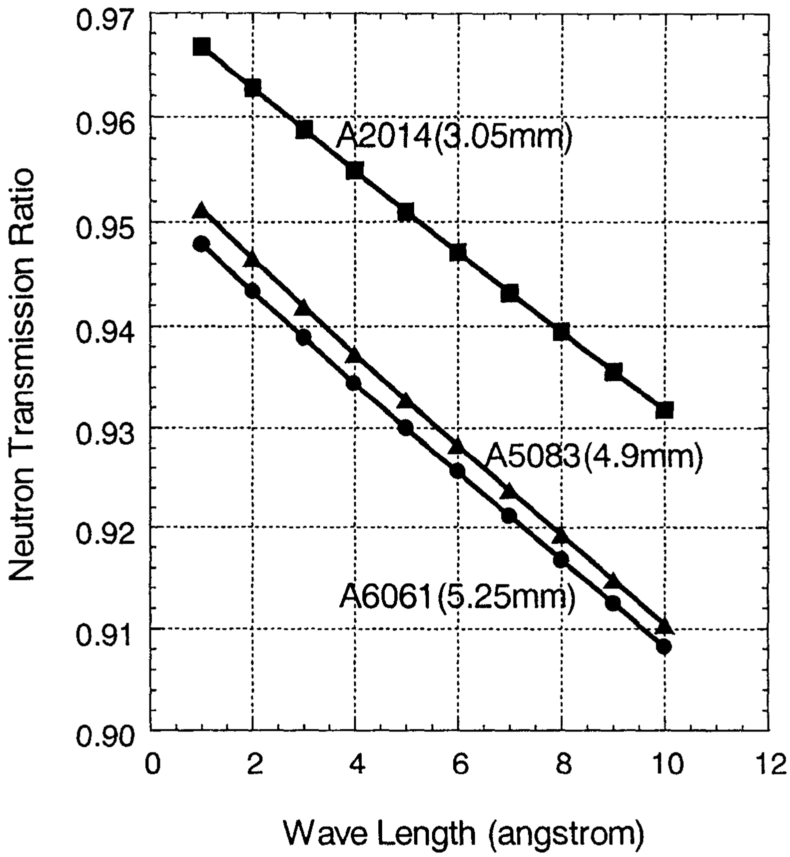


Figure 4 Neutron transmission ratio for candidate materials as the function of wave length

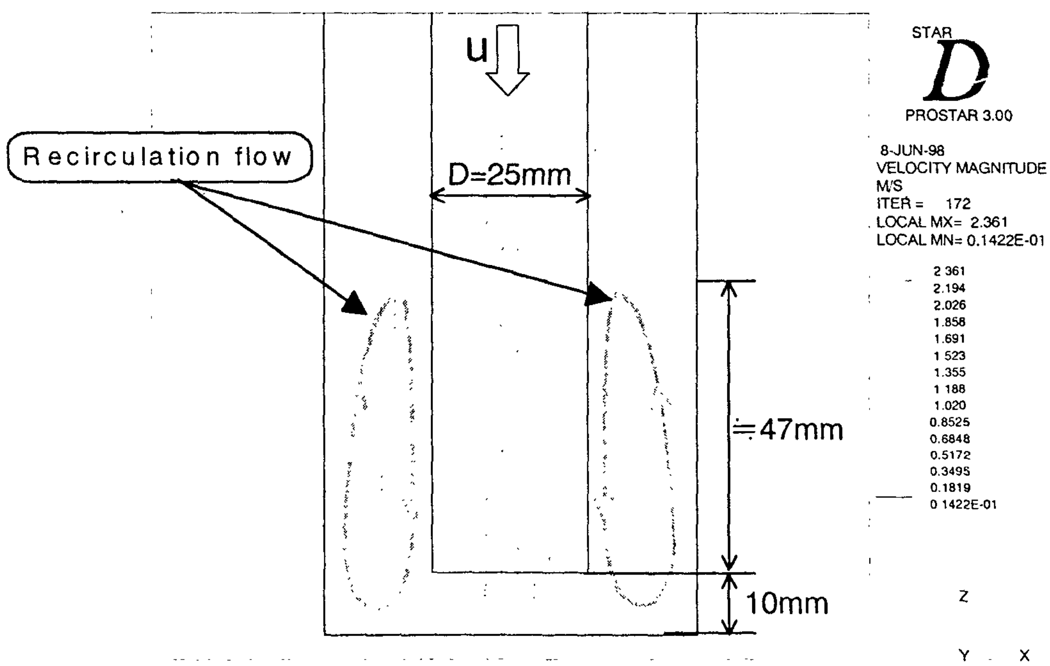
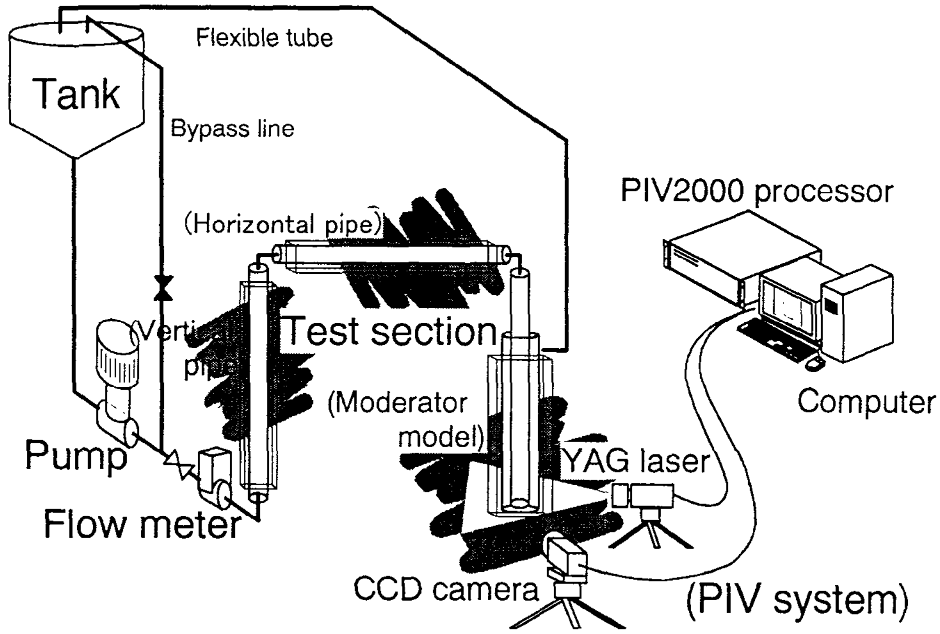
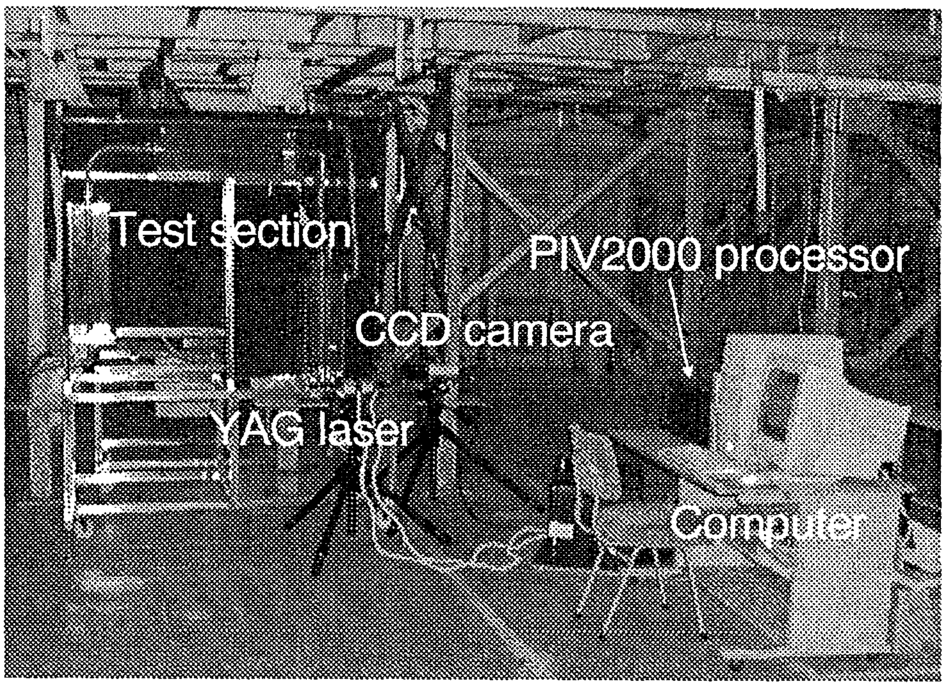


Figure 5 Analysis result obtained under low inlet velocity of 2m/s
(Fluid : water, Re = Du/ν = 56,000)



(a) Flow diagram of flow apparatus
(Water flow rate = ~500 l/min)



(b) Outer view

Figure 6 Experimental apparatus for flow pattern measurement

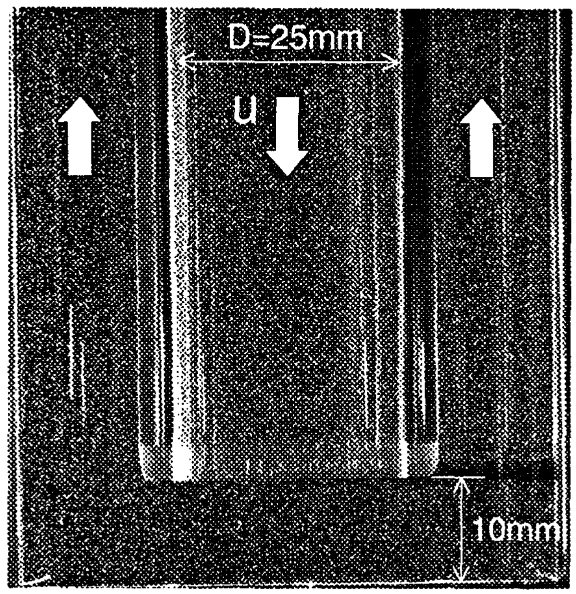


Figure 7 One of pictures taken at around 70ms intervals using PIV

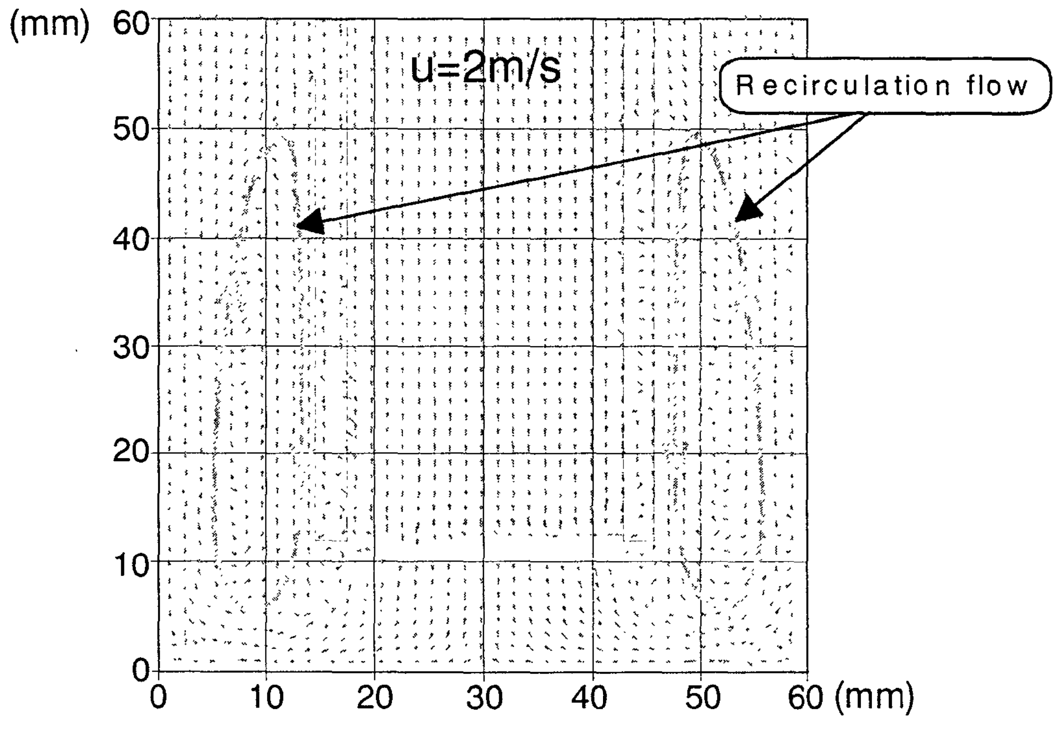


Figure 8(a) Vector map of water velocity measured by PIV

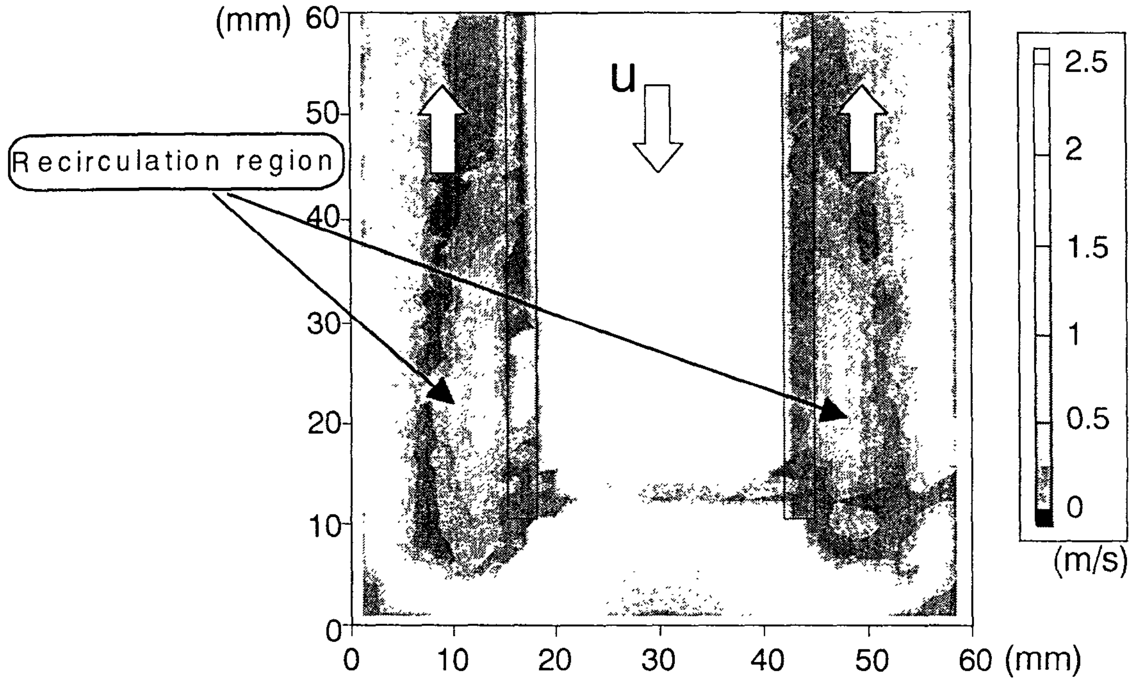


Figure 8(b) Contour map of measured velocity

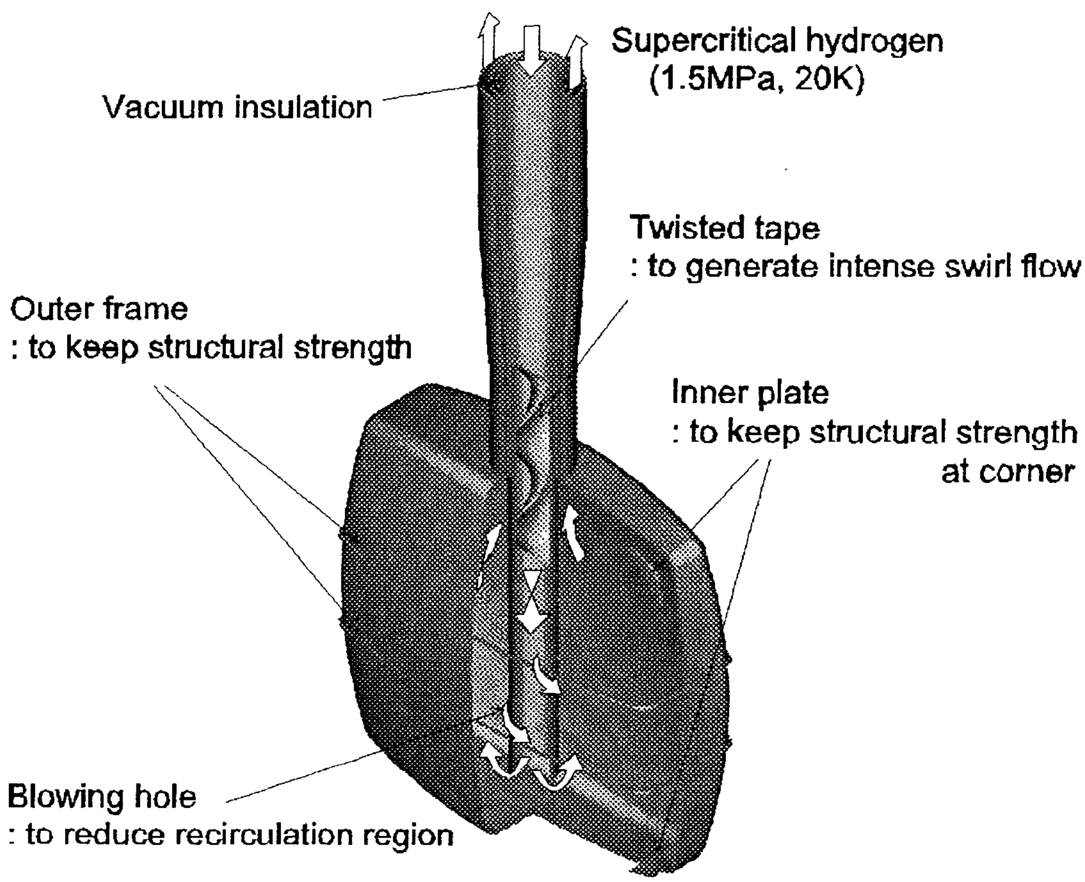


Figure 9 Modified concept of the cold source moderator