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A Thermal hydraulic Investigation on ADSR Liquid Lead Target

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ABSTRACT

Computational fluid dynamics(CFD) code FLUENT[1] was used to simulate the thermal hydraulic processes occuring in conceptual design of the accelerator-driven subcritical reactor(ADSR) liquid lead target. The purpose of the analysis is to investigate the thermal hydraulic characteristics of liquid lead as ADSR target material with various target geometries and injection locations of proton beam. In the calculation analysis, the local temperature of the liquid lead target rises to the boiling temperature very rapidly. When the proton beam is injected from the bottom of the target system, the duration time to reach the boiling temperature is longer and the temperature distribution is flatter than other cases.

I. INTRODUCTION

Nuclear waste from commercial power plants contains large quantities of plutonium, other fissionable actinides, and long-lived fission products that create challenges for long-term storage and that are potential proliferation concerns. These kinds of high-level radioactive waste can be reduced by transmutation. The ADSR is a high power, accelerator-based transmutation system being designed by Korea Atomic Energy Research Institute(KAERI). The ADSR concept offers the possibility to minimize plutonium, higher actinides, and environmentally hazardous fission products from the waste stream destined for permanent storage. ADSR does not eliminate the need of geologic repositories, but enhances the viability of permanent waste repositories. In addition, ADSR technology gives new concepts that could be relevant for next-generation power producing systems. Some key issues for the target, such as flow distributions, cooling of the target window and local hot spots inside the target region, are related to its thermal-hydraulic performance. The thermal shock resulting from the extremely fast temperature increase during the instantaneous energy deposition in the target is one of the critical issues associated with ADSR technology development. In this study, lead has been chosen as a spallation target material. Because the high heat deposition rate anticipated, the liquid type target is considered to facilitate heat removal.

Ⅱ. CALCULATION AND RESULTS

The ADSR is proposed to have a target system with a high energy of 1 GeV, 20 mA proton beam.[2] Lead and lead-bismuth are considered as the liquid target material because of their heat transport properties and neutronic advantages. We chose lead for the thermal hydraulic study of liquid targets. More than 50% of the beam energy is deposited as heat in the target based on a liquid lead. The target design configuration has a cylindrical geometry with 30 cm in diameter and 50 cm in height. The cylindrical target is divided in 15 cells, 5 sections vertically and 3 sections horizontally. Fig. 1 shows the cell configuration in different cases. Three cases were selected according to the injected beam direction. Table 1 shows the heat deposition rate for each cell calculated by LAHET code.[3] In this calculation, central axis is set to be symmetric and other walls are set to be adiabatic boundaries. Thermal properties of lead for this calculation are shown in table 2. Initial fluid temperature was set by 500℃. The steady state power density of lead target is about 577 MW/m^3. It is assumed that the power density is constant during the calculation and target cooling is not considered. Boussinesq model is used by setting up the calculation with fluid density as a function of temperature. Table 3 shows the calculated results of the elapsed time to reach to boiling temperature and temperature difference between maximun temperature and minimum temperature at that time in each cases. When the proton beam is injected from the bottom of the target, the time to reach the boiling temperature is longer and the temperature distribution is flatter than other cases. Fig. 2~4 present the temperature distribution and the velocity magnitude by the time for each case. As shown in Fig. 2, if the proton beam is injected from the top of the target, the temperature in the target is stratified. But, if the proton beam is injected from the bottom, the temperature is flatter than other cases. In this case, the temperature difference between the maximum and the minimum temperature is 1/3 of case-1 result. Also, the time duration to reach the boiling temperature is longer than that of case-1 by the factor of 2. This result is presented in Fig. 3. The results of case-3 that has the horizontal cylinder geometry and proton beam is injected horizontally are shown in Fig. 4. The results lie in between about two cases.

Ⅲ. CONCLUSIONS

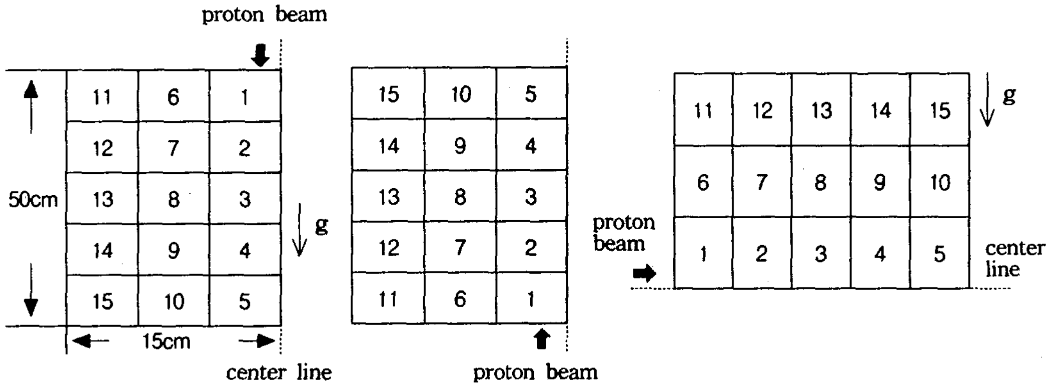
The general CFD code FLUENT was used to simulate the time-dependent two-dimensional thermal and flow distributions in the liquid lead target. In this study, the local temperature of the target rises to the boiling temperature of liquid lead very rapidly. Therefore, if cooling system of target is not applied, this target system cannot be used in ADSR. When the proton beam is injected from the bottom of the target system, the time to reach the liquid lead boiling temperature is longer and the temperature distribution is flatter than other cases. Further study should be performed including a more detailed and comprehensive analysis for both steady state and transient conditions with an appropriate cooling mechanism. The FLUENT model will be expanded to cover the three-dimensional geometry, cooling effects on lead heat transfer and pressure drop, potential for cavitation around corners, and local flow transients resulting from the thermal shock.

Ⅳ. REFERENCES

[1] "FLUENT 4.32", Fluent Inc., Jan. 1995

[2] T.Y. Song et. al., "The Characteristics of Lead and Tungsten Targets Used in the Accelerator-Driven Subcritical Reactor", APAC'98(In Progress), 1998

[3] R.E. Prael et al., User Guide to LCS: The LAHET Code System, Los Alamos National Laboratory, LA-UR-89-3014, 1986



CASE-1. vertically top-down CASE-2. vertically bottom-up CASE-3. horizontally side by side

Fig. 1 Cell numbers of Calculation Domains

Table 1. Heat Deposition Rate for Each Cell

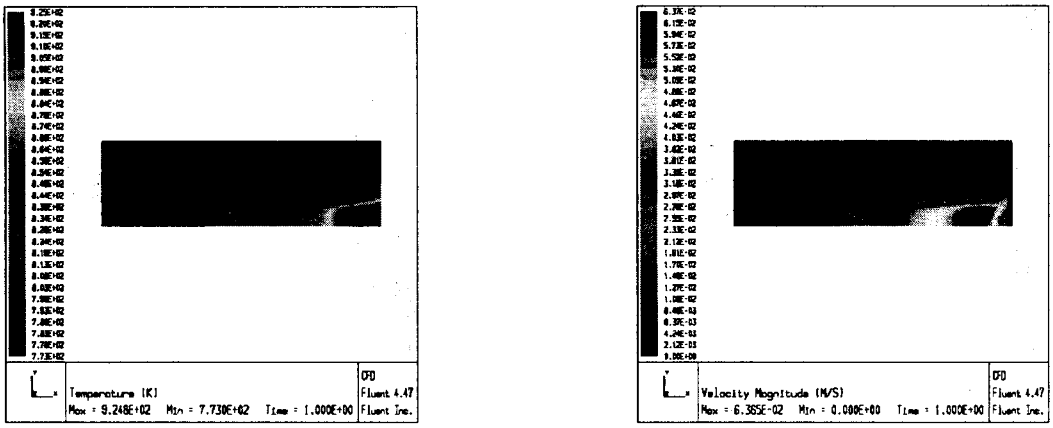
Cell	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Power Density (W/cm^3)	248	149	78	38	19	7	11	10	7	6	0	1	1	1	1

Table 2. Thermal Properties of Lead

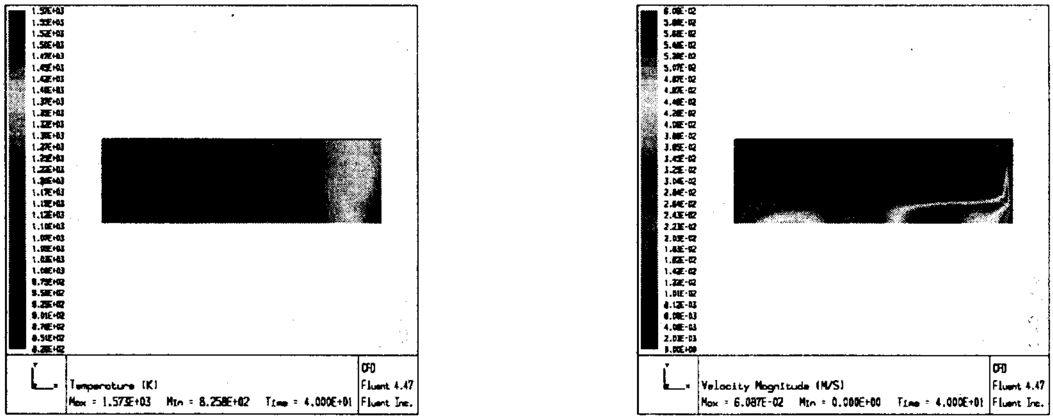
Melting Temperature(°C)	327.4
Boiling Temperature(°C)	1738
Density(kg/m^3)	10540
Viscosity(kg/m · sec)	2.0026E-3
Thermal Conductivity(W/m · K)	16.1
Specific Heat(J/kg · K)	155
Thermal Expansion Coefficient(/K)	1.09E-4

Table 3. Calculated Results of each case

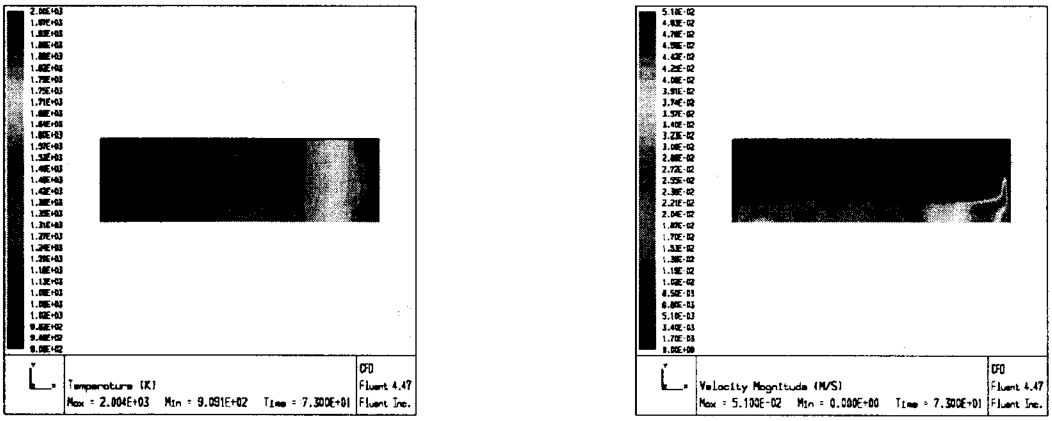
	$T_{boiling}$(sec)	$\Delta T = T_{max} - T_{min}$
Case 1	73	1095
Case 2	154	327
Case 3	127	410



(a) at 1 sec

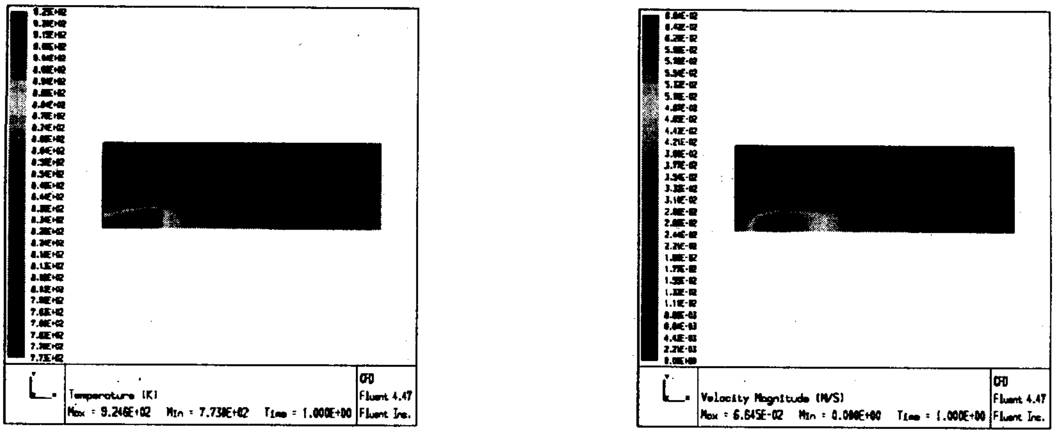


(b) at 40 sec

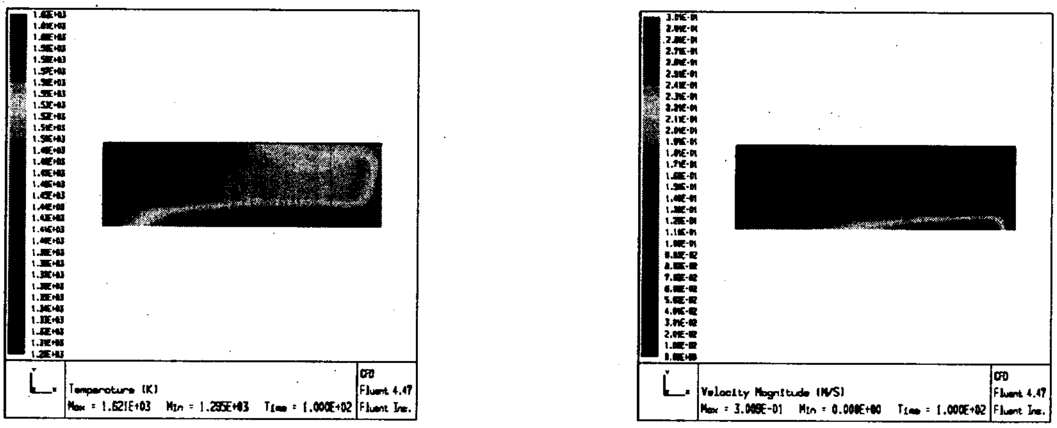


(c) at 73 sec

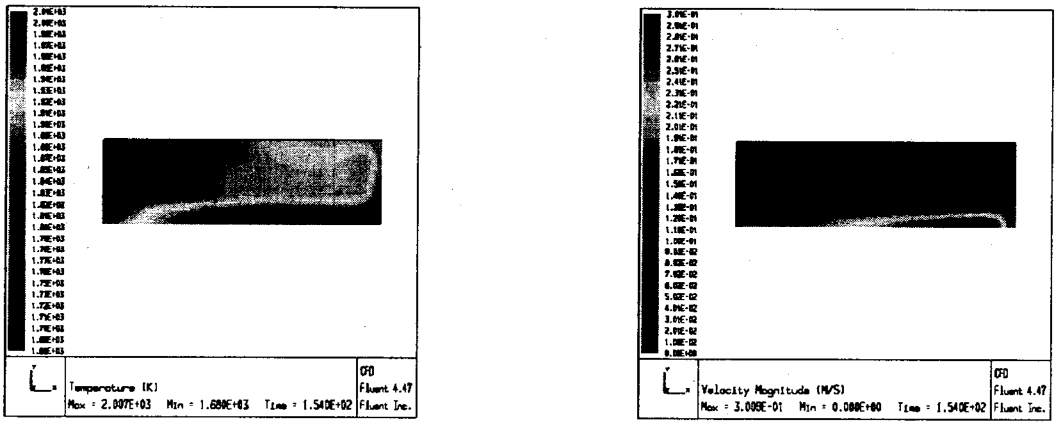
Fig. 2 Temperatures(left column) and Velocities(right column) of Case-1 at 1, 40 and 73 sec



(a) at 1 sec

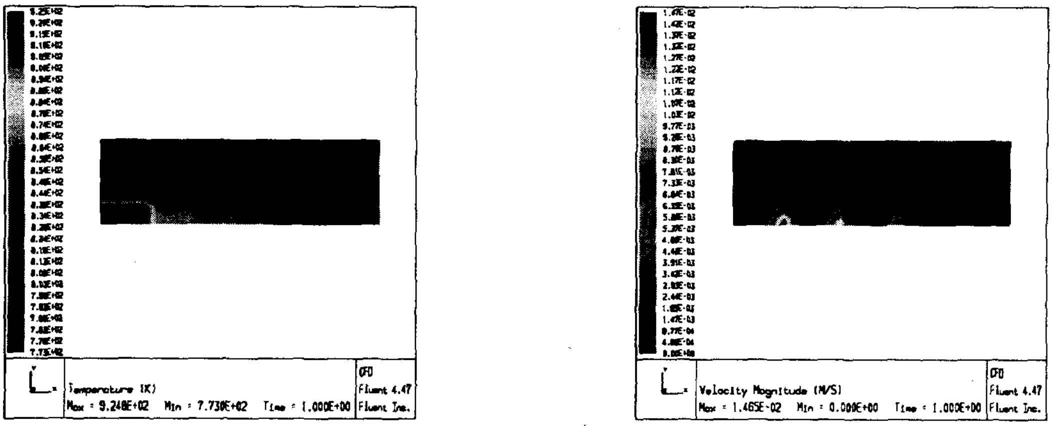


(b) at 100 sec

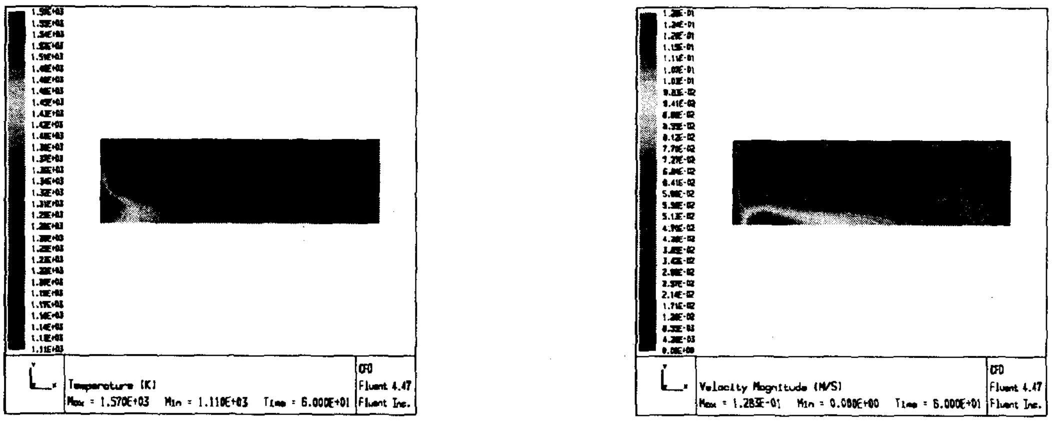


(c) at 154 sec

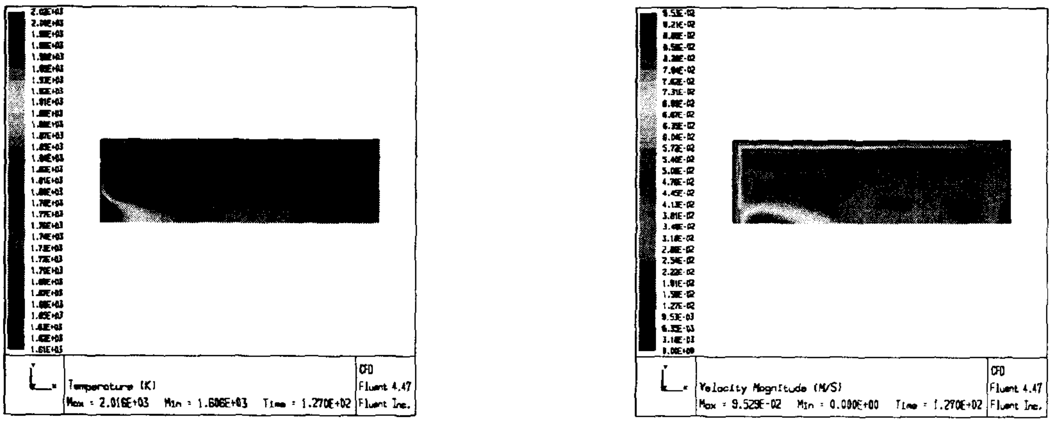
Fig. 3 Temperatures(left column) and Velocities(right column) of Case-2 at 1, 100 and 154sec



(a) at 1 sec



(b) at 60 sec



(c) at 127 sec

Fig. 4 Temperatures(left column) and Velocities(right column) of Case-3 at 1, 60 and 127 sec