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Numerical Investigations on Thermal Stratification and Striping Phenomena in Various Coolants

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Numerical Investigations on Thermal Stratification and Striping Phenomena in Various Coolants*

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Abstract

It is important to study thermal stratification and striping phenomena for they can induce thermal fatigue failure of structures. This presentation uses the AQUA code, which has been developed in Japan Nuclear Cycle Development Institute (JNC), to investigate the characteristics of these thermal phenomena in water, liquid sodium, liquid lead and carbon dioxide gas.

There are altogether eight calculated cases with same Richardson number and initial inlet hot velocity in thermal stratification calculations, in which four cases have same velocity difference between inlet hot and cold fluid, the other four cases with same temperature difference. The calculated results show: (1) The fluid's properties and initial conditions have considerable effects on thermal stratification, which is decided by the combination of such as thermal conduction, viscous dissipation and buoyant force, etc., and (2) The gas has distinctive thermal stratification characteristics from those of liquid because for horizontal flow in the transportation of momentum and energy, the drastic exchange usually happens at the hot-cold interface for liquid, however, the buoyancy and natural convection make the quick exchange position depart from the hot-cold interface for gas.

In thermal striping analysis, only the first step work has been finished. The calculated results show: (1) the vertical flow has some difference in thermal stratification characteristics from those of horizontal flow, and (2) For deep thermal striping analysis in the calculated area, more attention should be paid to the center area along Z-direction for liquid and small velocity area for gas.

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各種の冷却材を用いた場合の温度成層化現象および サーマルストライピング現象についての数値的検討 *

(研究報告書)

Yang Zumao**、村松 壽晴***

要　旨

原子炉構造物に熱疲労を与える温度成層化現象およびサーマルストライピング現象について、その熱流動上の特徴を把握することは、原子炉設計の観点から重要である。本研究では、核燃料サイクル開発機構で開発された多次元熱流動解析コード AQUA を用い、水、ナトリウム、鉛および炭酸ガスを冷却材として用いた場合の熱流動上の特徴を数値解析により抽出する。

温度成層化現象については、リチャードソン数 Ri をパラメータとして合計 8 ケースを解析し、以下の結果を得た。

(1) 流体物性および計算初期条件は、同現象を支配する浮力、熱拡散などの効果に大きな影響を与える。

(2) 炭酸ガスを用いた場合の熱流動上の特徴は、この他の流体を用いた場合のそれらと大きな違いを示し、特に温度成層界面近傍における運動量および熱量の交換特性に関する差異が顕著である。

サーマルストライピング現象については、同現象を特徴づける熱流動上の特徴の内、温度ゆらぎ振幅の空間分布特性についての評価を行い、以下の結果を得た。

(1) 高乱流条件である今回のサーマルストライピング解析結果は、前記の温度成層化現象で抽出された特徴と比較して、違いが認められた。

(2) 今後の温度ゆらぎ周波数の検討では、炭酸ガスを冷却材を用いた場合に低流速領域での特徴把握に、その他の冷却材を用いた場合に剪断流領域での特徴把握に注意を払う必要がある。

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1 Introduction

In general, thermal stratification and thermal striping phenomena can happen when two different temperature materials meet. For examples, the inserted feed-water pipes connect with drum wall in a boiler, the feed-water and steam in steam generator (SG), the hot sodium fluid from the fuel assembles (F/As) with the cold sodium fluid from the control rods(C/Rs) at the core exit of liquid metal cooled fast breeder reactors (LMFBRs). These thermal phenomena are related to the unequilibrium process in energy and momentum transportation and needing a long time to reach final equilibrium, so the initial temperature and velocity, the boundary conditions and the properties of materials influence them, and it is very important to study them because they can induce thermal fatigue failure of structure materials such as the vessels of boilers, reactors and chemical containers. Usually there are two kinds of methods to study the characteristics of the above thermal progresses, i.e. experimental test and theory analysis. The previous work was focused on experimental study, but in experiments, thermal engineers found there were many shortcomings: first, a large scale experimental model is needed; second it is very difficult to obtain adequate amounts and quality of data. Therefore, this method results in an increase of the cost and time. With the development of the numerical calculation, it is possible to use computer programs to simulate the above complex thermal phenomena. In Japan, sets of computer codes have been developed to evaluate thermal stratification and thermal striping phenomena and their influences on structures. These codes include four thermohydraulics computer programs AQUA, DINUS-3, THEMIS and BESMSET, which are represented by a time- and volume-averaged transport analysis, a direct numerical simulation of turbulence flows, a direct simulation Monte Carlo (DSMC) analysis of continuous fluid flows and a boundary element analysis of structures, respectively, and two thermomechanics computer programs FINAS and CANIS, which are formulated by thermoelastic mechanics and fracture mechanics, respectively[1,2].

The author, as a Science and Technology Agency (STA) program candidate for half a year, concentrates his research work on only using AQUA code to analyze thermal stratification and thermal striping in different coolants.

2 Numerical Methods in AQUA Code

In AQUA code, besides using time- and volume-averaged methods to build up transport equations, the algebraic stress turbulence model(ASM) equations are implemented to well simulate turbulent flows. The code solves mass, momentum and energy conservation equations simultaneously in a finite difference form. The higher -order accurate scheme was applied to approximate the convection terms in conservation equations.

2.1 Basic Equations[3]

Transient, time-averaged mass, momentum and energy equations are given by:

$$\frac{\partial}{\partial t}\rho+\frac{\partial}{\partial x_j}(\rho u_j)=0 \qquad (2\text{-}1)$$

$$\frac{\partial}{\partial t}\rho u_i+\frac{\partial}{\partial x_j}(\rho u_j u_j)=-\frac{\partial}{\partial x_i}p+\frac{\partial}{\partial x_j}[(\mu_l+\mu_t)\frac{\partial}{\partial x_j}u_i]+R_i \qquad (2\text{-}2)$$

$$\frac{\partial}{\partial t}\rho h+\frac{\partial}{\partial x_j}(\rho u_j h)=Q+\frac{\partial}{\partial x_j}[(\lambda_l+\lambda_t)\frac{\partial}{\partial x_j}T] \qquad (2\text{-}3)$$

Indices i, j=1,2,3 refer to the coordinate directions, i.e. x, y, and z directions in the Cartesian coordinate system.

2.2 Turbulence Models[3]

The ASM turbulent models are the following:

[Turbulent Kinetic Energy, k]

$$\frac{\partial}{\partial t}\rho k+\frac{\partial}{\partial x_l}\rho u_l k=\frac{\partial}{\partial x_l}(C_k\rho\frac{k}{\varepsilon}\overline{u_k u_l}\frac{\partial k}{\partial x_k}+\mu_l\frac{\partial k}{\partial x_l}) \qquad (2\text{-}4)$$
$$+P^{'}+G^{'}-\rho\varepsilon$$

[Dissipation Rate of k,ε]

$$\frac{\partial}{\partial t}\rho\varepsilon+\frac{\partial}{\partial x_l}\rho u_l\varepsilon=\frac{\partial}{\partial x_l}(C_\varepsilon\rho\frac{k}{\varepsilon}\overline{u_i'u_l'}\frac{\partial\varepsilon}{\partial x_i}+\mu_l\frac{\partial\varepsilon}{\partial x_l})$$
$$+C_{\varepsilon1}\frac{k}{\varepsilon}(P'+G')(1+C_{\varepsilon3}\frac{G'}{P'+G'})-C_{\varepsilon2}\rho\frac{\varepsilon}{k}\varepsilon) \qquad (2\text{-}5)$$

[Intensity of Temperature Fluctuation, $\overline{\theta'^2}$]

$$\frac{\partial}{\partial t}\rho\overline{\theta'^2}+\frac{\partial}{\partial x_j}\rho u_j\overline{\theta'^2}=\frac{\partial}{\partial x_l}(-C_\theta\rho\frac{k}{\varepsilon}\overline{u_j'u_l'}\frac{\partial\overline{\theta'^2}}{\partial x_j}+\frac{\lambda}{C_p}\frac{\partial\overline{\theta'^2}}{\partial x_l})$$
$$-2\rho\overline{u_j'\theta'}\frac{\partial T}{\partial x_j}-2C_{\theta1}\rho\frac{k}{\varepsilon}\overline{\theta'^2} \qquad (2\text{-}6)$$

[Reynolds Stress, $-\overline{u_i'u_j'}$]

$$-\overline{u_i'u_j'}=\frac{k}{C_{R1}\varepsilon}\frac{(C_{R2}-1)P_{ij}+(C_{R3}-1)G_{ij}-\frac{2}{3}\delta_{ij}(C_{R2}P'+C_{R3}G'+(C_{R1}-1)\varepsilon)}{1+(\frac{P'+G'}{\varepsilon}-1)/C_{R1}} \qquad (2\text{-}7)$$

[Turbulent Heat Flux, $-\overline{u_i'\theta'}$]

$$-\overline{u_i'\theta'}=\frac{k}{C_{T1}\varepsilon}\frac{-(\overline{u_i'u_j'}\frac{\partial T}{\partial x_j}+\overline{u_j'\theta'}\frac{\partial u_i}{\partial x_j})-(1+C_{T3})\beta g_i\overline{\theta'^2}-C_{T2}\overline{u_m'\theta'}(\frac{\partial u_i}{\partial x_m})}{1+(\frac{P'+G'}{\varepsilon}-1)/C_{T2}} \qquad (2\text{-}8)$$

Where

$$P'=-\rho\overline{u_i'u_j'}\frac{\partial u_i}{\partial x_j}$$
$$G'=-\beta g_i\overline{u_i'\theta'}$$
$$P_{ij}=-\overline{u_i'u_l'}\frac{\partial u_j}{\partial x_l}-\overline{u_j'u_l'}\frac{\partial u_i}{\partial x_l} \qquad (2\text{-}9)$$
$$G_{ij}=-\beta(g_i\overline{u_j'\theta'}+g_j\overline{u_i'\theta'})$$

These equations are characterized by disuse of such turbulence parameters as turbulent kinetic viscosity ν_t and turbulent heat conductivity λ_t, both of which are based on the Boussinesq's eddy diffusivity hypothesis. The model constants appearing in the above equations were set to the following standard values. As for the boundary treatment of the turbulent kinetic energy k and its dissipation rate ε, the logarithmic of velocity near boundary wall are used.

Ck	Cε	Cε1	Cε2	Cε3	Cθ	Cθ1	CR1	CR2	CR3	CT1	CT2	CT3
0.11	0.15	1.44	1.92	0.7	0.13	0.62	2.3	0.5	0.4	3.2	0.5	0.5

As for the intensity of temperature fluctuation $\overline{\theta'^2}$ on wall boundary, where a constant wall temperature could be specified by input data, the following local equilibrium condition could be assumed.

$$\overline{\theta'^2} = -\frac{2}{C_{\theta 1}}\frac{k}{\varepsilon}\overline{u_l\theta'}\frac{\partial T}{\partial x_l} \qquad (2\text{-}10)$$

2.3 Numerical Scheme[4]

Only the implicit numerical scheme used in AQUA code is described here.

[Momentum equation]

$$a_0^u u_0 - \sum_{l=1}^{6} a_l^u u_l - b_0^u + \gamma v_m \Delta y_0 \Delta z_0 (P_2 - P_0) = 0 \qquad (2\text{-}11)$$

Where

$$a_0^u = \{\rho_m \gamma_{x0} / \Delta t + \gamma_{x0}(\partial \rho / \partial t)/2\} V_m + \gamma_{x0}\{[-\overline{F_{x1}},0] + [\overline{F_{x0}},0]$$
$$[-\frac{1}{2}\overline{F_{y3}},0] + [-\frac{1}{2}\overline{F_{y23}},0] + [\frac{1}{2}\overline{F_{y0}},0] + [\frac{1}{2}\overline{F_{y2}},0] + [-\frac{1}{2}\overline{F_{z5}},0] + [-\frac{1}{2}\overline{F_{z25}},0]$$
$$+[\frac{1}{2}\overline{F_{z0}},0] + [\frac{1}{2}\overline{F_{z2}},0]\} + D_e^u + D_w^u + D_n^u + D_s^u + D_t^u + \gamma v_m V_m R_x$$

$$a_1^u = \gamma_{x1}[\overline{F_{x1}},0] + D_w^u$$
$$a_2^u = \gamma_{x2}[-\overline{F_{x0}},0] + D_e^u$$
$$a_3^u = \gamma_{x3}\{[\frac{1}{2}\overline{F_{y3}},0] + [\frac{1}{2}\overline{F_{y23}},0]\} + D_s^u \qquad (2\text{-}12)$$
$$a_4^u = \gamma_{x4}\{[-\frac{1}{2}\overline{F_{y0}},0] + [-\frac{1}{2}\overline{F_{y2}},0]\} + D_n^u$$
$$a_5^u = \gamma_{x5}\{[\frac{1}{2}\overline{F_{z5}},0] + [\frac{1}{2}\overline{F_{z25}},0]\} + D_b^u$$
$$a_6^u = \gamma_{x5}\{[-\frac{1}{2}\overline{F_{z0}},0] + [-\frac{1}{2}\overline{F_{z2}},0]\} + D_t^u$$
$$b_0^u = \{\rho_m \gamma_{x0} / \Delta t + \gamma_{x0}(\partial \rho / \partial t)\} V_m u_0^u + \gamma v_m V_m \rho_m g_x$$

[Continuum equation]

$$V_0\gamma_{v0}(\frac{\partial}{\partial t}\rho)^i - A_{x1} < \rho >_w^i .u_1^{i+1} + A_{x0} < \rho >_e^i .u_0^{i+1} - A_{y3} < \rho >_s^i .v_3^{i+1}$$
$$+A_{y0} < \rho >_n^i .v_0^{i+1} - A_{z5} < \rho >_b^i .w_5^{i+1} + A_{z0} < \rho >_t^i .w_0^{i+1} = \delta_0\gamma_{v0}V_0 \quad (2\text{-}13)$$

[Energy equation]

$$a_0^h h_0^{i+1} - \sum_{l=1}^{6} a_l^h h_l^{i+1} - b_0^h = 0 \quad (2\text{-}14)$$

Where

$$a_1^h = [F_{x1}, 0] + D_w$$
$$a_2^h = [-F_{x0}, 0] + D_e$$
$$a_3^h = [F_{y3}, 0] + D_s$$
$$a_4^h = [-F_{y0}, 0] + D_n$$
$$a_5^h = [F_{z5}, 0] + D_b \quad (2\text{-}15)$$
$$a_6^h = [-F_{z0}, 0] + D_t$$
$$a_0^h = \sum_{l=1}^{6} a_l^h + \gamma_{v0}V_0\rho_0 / \Delta t + \gamma_{v0}V_0 S_p$$
$$b_0^h = \gamma_{v0}V_0\rho_0 / \Delta t . h_0^n + \gamma_{v0}V_0 S_c$$
$$Q \equiv S_c - S_p h_0^{i+1}$$

[Pressure equation]

$$a_o^P P_0^{i+1} - \sum_{l=1}^{6} a_l^P P_l^{i+1} - b_0^P = \delta_0 V_0 \gamma v \quad (2\text{-}16)$$

Where,

$$a_1^P = A_{x1} < \rho >_w^i .d_1$$
$$a_2^P = A_{x0} < \rho >_e^i .d_2$$
$$a_3^P = A_{y3} < \rho >_s^i .d_3$$
$$a_4^P = A_{y0} < \rho >_n^i .d_4$$
$$a_5^P = A_{z5} < \rho >_b^i .d_5 \quad (2\text{-}17)$$
$$a_6^P = A_{z0} < \rho >_t^i .d_6$$
$$a_0^P = \sum_{l=1}^{6} a_l^P$$
$$b_0^P = V_0\gamma v_0(\frac{\partial}{\partial t}\rho)^i + A_1 < \rho >_w^i \hat{u}_1 - A_2 < \rho >_e^i \hat{u}_2 + A_3 < \rho >_s^i \hat{v}_3$$
$$-A_4 < \rho >_n^i \hat{v}_4 + A_5 < \rho >_b^i \hat{w}_5 - A_6 < \rho >_b^i \hat{w}_6$$

3 Thermal Stratification Analysis

3.1 Purpose

Analyze the influence of the fluid's properties and initial conditions on thermal stratification

3.2 Calculation Conditions

3.2.1 Geometry Conditions

The calculated area is a rectangular with 1 meter in X-direction and 0.2 meters in Z-direction, the cold fluid with a larger velocity enters the area from bottom half height and the hot fluid with a lower velocity from up half height horizontally. The rectangular is divided 100 same meshes along X-direction and 40 meshes along Z-direction. There are no structure parts immersed, so there are 4,000 two-dimensional non-structured meshes altogether (See Fig.3-0).

3.2.2 Initial and Boundary Conditions

In calculations, four kinds of liquids are used as the working fluids, i.e., water (H_2O), liquid sodium (Na), liquid lead (Pb) and carbon dioxide (CO_2). Each fluid has two calculated cases and there are eight cases altogether. All the cases have the same inlet Richardson number (*Ri*) and hot initial inlet velocity, whereas, four cases have same inlet velocity difference (or same cold initial inlet velocity) and the other four with same inlet temperature difference. The average inlet temperature of H_2O, Na, Pb and CO_2 is 50°C, 460°C, 480°C and 390°C, respectively (see Table 3-1).

The outlet surface has a continuative velocity, the bottom surface with a constant velocity, the near surface with an initial velocity given by the boundary value initialization card, the top and far surface with a free slip boundary. Except for inlet surface, the other surfaces are adiabatic.

In certain temperature range, the properties of water and liquid sodium are directly calculated with AQUA code, however, the straight-line approximations with temperature for liquid lead and carbon dioxide gas are given in the input data.

Table 3-1 Calculating Initial Conditions for Thermal Stratification

CASE		fluid	Ri	T_H(°C)	T_C(°C)	u_H(m/s)	u_C(m/s)	Re_H
CASE1	CASE11	H_2O	2.0	58.00	42.00	0.033	0.117	13225.5
	CASE12	Na		472.63	447.37	0.033	0.117	21617.6
	CASE13	Pb		492.63	467.37	0.033	0.117	36119.0
	CASE14	CO_2		392.39	387.62	0.033	0.117	175.5
CASE2	CASE21	H_2O		60.00	40.00	0.033	0.127	13628.4
	CASE22	Na		470.00	450.00	0.033	0.108	21630.5
	CASE23	Pb		490.00	470.00	0.033	0.108	35940.6
	CASE24	CO_2		400.00	380.00	0.033	0.205	172.3

3.3 Calculated Results

The velocity field, normalized mean temperature (T_n), turbulent kinetic energy and its dissipation rate, turbulent viscosity, turbulent conductivity and normalized temperature fluctuation intensity (T_{Zn}) distributions in a part of calculated area (X from 0 to 0.8m and Z with whole height) are shown in from Fig.3-01 to Fig.3-14 respectively.

The normalized velocity (V_{nl}) in X- and Z-direction, normalized mean temperature, kinetic energy and its dissipation rate, turbulent viscosity and normalized temperature fluctuation intensity distribution at constant X values (X is equal to 0.2m, 0.4m, 0.6m and 0.8m respectively) are shown in from Fig.3-15 to Fig.3-56 respectively.

The normalized temperature fluctuation intensity at the interface between hot and cold flows is shown in Fig.3-57.

The normalized temperature gradients along Z-direction ($\frac{dT_n}{dZ}$) at the interface between hot and cold flows are shown in Fig.3-58.

The definitions of the terms used in this chapter are as follows:

Richardson number

$$Ri = \frac{g\beta L(T_{hi} - T_{ci})}{(V_{ci} - V_{hi})^2} \tag{3-1}$$

Reynolds number

$$\mathrm{Re} = \frac{VL\rho}{\mu} \tag{3-2}$$

Normalized temperature:

$$T_n = \frac{T - T_{ci}}{T_{hi} - T_{ci}} \tag{3-3}$$

Normalized velocity:

$$V_{nl} = \frac{V_l - V_{hi}}{V_{ci} - V_{hi}} \qquad (3\text{-}4)$$

Normalized temperature fluctuation intensity:

$$T_{Zn} = \frac{\sqrt{T_Z}}{T_{hi} - T_{ci}} \qquad (3\text{-}5)$$

Temperature gradient along Z-direction

$$\frac{dT_{(K)}}{dZ} = \frac{T_{(K+1)} - T_{(K-1)}}{2(\Delta Z)} \qquad (3\text{-}6)$$

Normalized temperature gradient along Z-direction

$$\frac{dT_{n(K)}}{dZ} = \frac{T_{n(K+1)} - T_{n(K-1)}}{2(\Delta Z)} \qquad (3\text{-}7)$$

Where

g, Gravitational acceleration, [m/s**2]

L, Inlet height, [m]

β, Volume expansion coefficient, [1/°C]

ρ, Fluid density, [kg/m**3]

μ, Dynamic viscosity, [Pa.s]

T_{ci}, Cold flow inlet temperature, [°C]

T_{hi}, Hot flow inlet temperature, [°C]

T, Mean Temperature, [°C]

V_{ci}, Cold flow inlet velocity, [m/s]

V_{hi}, Hot flow inlet velocity, [m/s]

V_l, X-, Y-, Z-direction velocity component respectively, [m/s]

T_Z, Temperature fluctuation intensity, [(°C)^2]

$T_{(K-1)}$, Temperature at (K-1), [°C]

$T_{(K+1)}$, Temperature at (K+1), [°C]

$T_{n(K-1)}$, Normalized temperature at (K-1)

$T_{n(K+1)}$, Normalized temperature at (K+1)

ΔZ, Z-direction mesh size, [m]

3.4 Discussion

From Fig.3-01, Fig.3-08, Fig.3-15, Fig.3-16, Fig.3-21 and Fig.3-22, the liquid fluids (water, liquid sodium and liquid lead) have similar velocity (or normalized velocity) distributions, whereas the carbon dioxide gas has different velocity (or normalized velocity) distributions from those of liquid fluids. As for same liquid, the almost same normalized velocity distributions are obtained in from Fig.3-17 to Fig.3-19 and from Fig.3-23 to Fig.3-25, some difference for the carbon dioxide gas is shown in Fig.3-20 and Fig.3-26. The above phenomena can be explained that in the transportation of momentum buoyant force has more effects on gas than liquid flow and CASE2 has larger hot and cold inlet velocity difference than that of CASE1 for the carbon dioxide gas.

From Fig.3-02, Fig3-09, Fig.3-27 and Fig.3-28, each fluid has its special normalized mean temperature distributions. As for same liquid, the almost same normalized mean temperature distributions are obtained in from Fig.3-29 to Fig.3-31. Some difference for the carbon dioxide gas is shown in Fig.3-32. The above phenomena can be explained that many factors (such as thermal conduction, viscous dissipation, etc.) have some effects on the exchange of energy between cold and hot fluids and the distributions are decided by the combination of these factors. For gas the natural convection caused by buoyant force has important influence on the heat transfer between hot and cold fluids.

The larger values of turbulent kinetic energy and its dissipation rate, normalized temperature fluctuation intensity are concentrated in the interface area between hot and cold fluids except for carbon dioxide gas and near the bottom area (Shown in Fig.3-03, Fig.3-04, Fig.3-07, Fig.3-10, Fig.3-11, Fig.3-14, from Fig.3-33 to Fig.3-38, from Fig.3-39 to Fig.3-44, and from Fig.3-351 to Fig.3-56). These coincide with Nature law because for horizontal flow the drastic exchange of momentum and energy usually happen at the hot-cold interface for liquids, as for gases the buoyancy and natural convection often drive the drastic exchange positions departure from the hot-cold interface.

In calculated temperature range, liquid sodium and lead have same thermal conductivity in number range and big difference in dynamics viscosity; therefore, large difference in normalized temperature fluctuation intensity is shown in Fig.3-57. As for water and liquid sodium, same dynamic viscosity in number range and large difference in thermal conductivity also make different distributions in normalized temperature fluctuation intensity, however, the former is more different than the later. For the liquids, normalized temperature fluctuation intensity increases to peak values in a short distance and then decreases to stable values along the flow direction, however, for the gas the distributions reach peak values almost near the inlet and decrease to stable values in a very short distance. The properties and initial conditions also make large difference among peak values.

As for normalized temperature gradient (Shown in Fig.3-58), the properties and initial conditions make large different distributions near inlet section: Water and liquid lead decrease from large values to low and stable values in a longer distance while carbon dioxide gas and liquid sodium in a shorter distance. The difference decreases along the flow direction and normalized temperature gradient reaches almost same stable values near outlet section.

Each fluid has its particular calculated turbulent properties and in a way these coincide with the real properties of fluids (Shown in Fig.3-05, Fig.3-06, Fig.3-12, and Fig.3-13 and from Fig.3-45 to Fig.3-50).

3.5 Conclusions

From above analysis, the following conclusions can be obtained,

1) The fluid's properties and initial conditions have considerable effects on thermal stratification, which is decided by the combination of such as thermal conduction, viscous dissipation and buoyant force, etc.

2) Gases have distinctive thermal stratification characteristics from those of liquids because for horizontal flow in the transportation of momentum and energy, the drastic exchange usually happens at the hot-cold interface for liquid, however, the buoyancy and natural convection usually make the quick exchange positions depart from the hot-cold interface for gas.

4 Thermal Striping Analysis

4.1 Purpose

To calculate the spatial intensity distributions of flowing parameters and identify the larger temperature fluctuation region in order to supply boundary conditions for deep thermal striping analysis.

4.2 Calculation Conditions

4.2.1 Geometry Conditions

The calculated area is an irregular cube with some parts being cut, 0.054 meters in X-direction, 0.0015 meters in Y-direction and 0.04 meters in Z-direction. The cold and hot fluids with same velocity enter the area from the center of bottom surface vertically. The cube is divided 108 same meshes along X-direction, 3 meshes along Y-direction and 80 meshes along Z-direction. There are no structure parts immersed, so there are 25,080 three- dimensional non-structured meshes altogether (See Fig.4-0).

4.2.2 Initial and Boundary Conditions

In calculations, the same four kinds of liquids as thermal stratification analysis are used as the working fluids. Each fluid has only one calculated case and there are four cases altogether. All the cases have the same Reynalds number (Re) and temperature difference between the hot and cold fluid. The average temperature of H_2O, Na, Pb and CO_2 is 50°C, 300°C, 380°C and 240°C, respectively (see Table 4-1).

The outlet surface has a continuative mass flow, the inlet surface with a constant velocity, the near surface with a free slip boundary, the other surfaces with constant velocity explicitly specified by the boundary value initialization cards. Except for the inlet surface, the other surfaces are adiabatic.

The properties of fluids are treated same as thermal stratification analysis.

Table 4-1 Calculating Initial Conditions for Thermal Striping

Fluid	T_{av}(°C)	T_H(°C)	T_C(°C)	Re	V(m/s)
H_2O	50	70	30	25,510	2.85
Na	300	320	280	25,510	2.0
Pb	380	400	360	25,510	1.14
CO_2	240	260	220	25,510	125

4.3 Calculated Results

The velocity field, normalized mean temperature (T_n), turbulent kinetic energy and its dissipation rate, turbulent viscosity, turbulent conductivity and normalized temperature fluctuation intensity (T_{Zn}) distributions in the whole calculated area are shown in from Fig.4-01 to Fig.4-28 respectively.

The normalized temperature fluctuation intensity at the interface between hot and cold flows is shown in Fig.4-29.

The temperature gradient along Z-direction ($\frac{dT}{dZ}$) at the interface between hot and cold flows is shown in Fig.4-30.

The definitions of the terms used in this chapter are same as the former chapter.

4.4 Discussion

Even though there is large difference in inlet velocity between liquids (water, liquid sodium and liquid lead) and carbon dioxide gas for hot and cold flows, the similar velocity fields are obtained in from Fig.4-01 to Fig.4-04 in calculated area except for the center triangular part near the top surface, where two eddy flows are formed for liquids but only one for carbon dioxide gas.

In figures From Fig.4-05 to Fig.408, each fluid has its particular normalized mean temperature distribution, especially in the center area along Z-direction.

There are similar turbulent kinetic energy and its dissipation rate distributions with same number range for liquids, a larger different distribution with larger number range for carbon dioxide gas (shown in from Fig.4-09 to Fig.4-12 and from Fig.4-13 to Fig.4-16). The main cause for these distributions is due to large velocity difference between liquids and gas. The large values are concentrated in the center area along Z-direction for all the fluids, which are reasonable for vertical flow the drastic exchange of energy always happen in the mixing area of hot and cold flows.

Each fluid has particular calculated turbulent viscosity and turbulent conductivity, which are larger than those of real fluid's properties (Shown in from Fig.4-17 to Fig.4-20 and from Fig.4-21 to Fig.4-24), however, turbulent viscosity is much larger than turbulent conductivity comparing with those of real fluid's properties. For turbulent viscosity the larger values are concentrated in the center area along Z-direction, which means the drastic viscous dissipation happen in this area; whereas, the large turbulent conductivity values are concentrated for liquids in the center area and for carbon dioxide gas in some smaller velocity area, which means the drastic thermal conduction happen in this area and the large velocity of gas has some influence.

Which normalized temperature fluctuation intensity distributions are similar among liquids and different for gas is shown in From Fig.4-24 to Fig.4-28. The larger values are concentrated for liquids in the center area along Z-direction and for gas in some smaller velocity area; however, the values of gas are much smaller than those of liquids. Different properties of liquids only make a little difference but properties of gas and big velocity make a large difference.

Along Z-direction, normalized temperature fluctuation intensity at the interface between hot and cold flow for liquid increases from very small value to large peak value in the first half height and then decreases from large peak value to very small value in the second half height, however, the gas reaches small peak value almost near the inlet and then quickly decreases to near zero value and keep constant (Shown in Fig.4-29)

Along Z-direction, temperature gradients at the interface between hot and cold flow have similar tendency to increase and decrease in the middle section but have very difference in near bottom section and top section (Shown in Fig.4-30).

4.5 Conclusion

From the first step calculation of thermal striping analysis and above discussions, the following conclusions can be obtained:

(1) The vertical flow has some difference in thermal stratification characteristics from those of horizontal flow (See the former chapter). The fluid's properties and initial conditions also have some effects on thermal stratification of vertical flow.

(2) For thermal striping analysis in the calculated area, more attention should be paid to the center area along Z-direction for liquids and small velocity area for gas.

5 Conclusions

From the thermal stratification analysis and first-step thermal striping analysis, we can get the following conclusions:

(1) Thermal stratification characteristics vary with different fluids and flow directions.

(2) Initial conditions have some effects on thermal stratification.

(3) For thermal striping analysis, more attention should be paid to the interface area between hot and cold flows for liquids and small velocity area for gas.

ACKNOWLEDGEMENT

During the passed half year, I received many kinds of help and support in Thermohydrolic Research Group, OEC, JNC. I wish to give my thanks to my adviser Dr. Muramatsu for his guiding work and my colleague Mr. Murakami for his helping me solve the problems I met in my calculating work. I also wish to thank Mr. Suda and the other members of our working office and group, especially Dr. Yamaguchi and Ms. Iwai. Due to their kindness, I spent a good time in Japan.

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3. T. MURAMATSU and H. NINOKATA, Investigation of Turbulence Modeling in Thermal Stratification Analysis, Nuclear Engineering and Design 150(1994) 81- 93.
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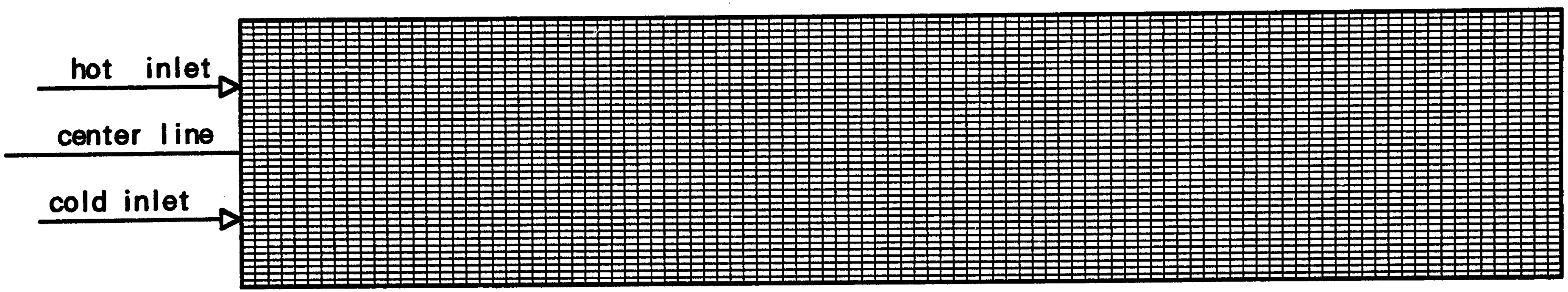
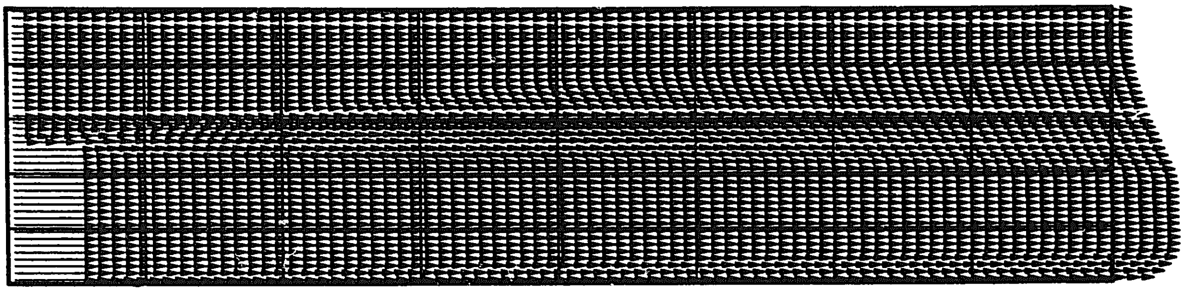
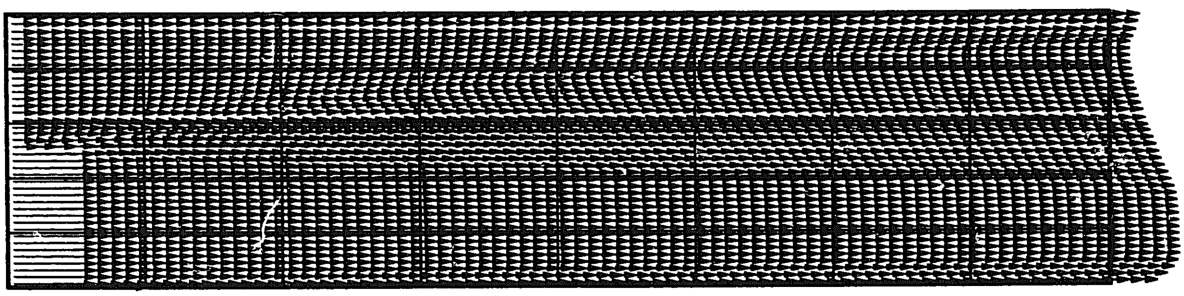


Fig.3-0 mesh arrangement for thermal stratification

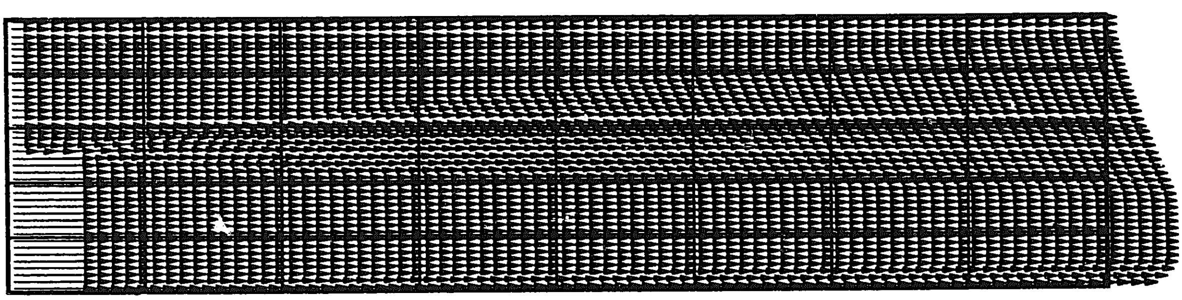
CASE11: H20(Vhi=0.033m/s.Vci=0.117m/s;Thi=58℃,Tci=42℃)



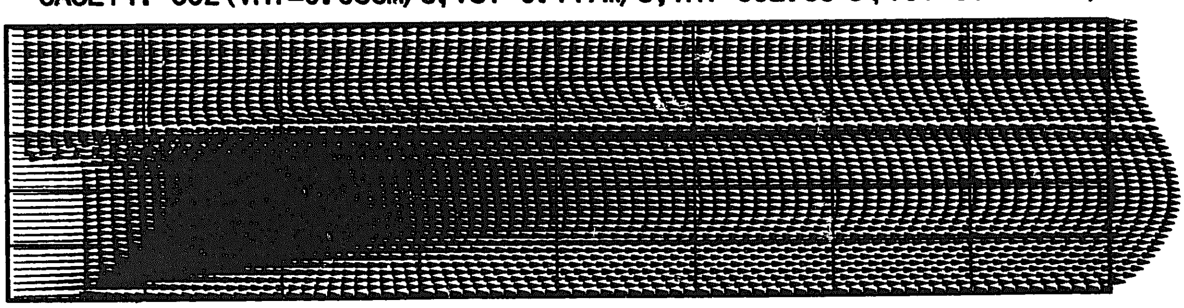
CASE12: Na(Vhi=0.033m/s,Vci=0.117m/s;Thi=472.63℃,Tci=447.37℃)



CASE13: Pb(Vhi=0.033m/s,Vci=0.117m/s;Thi=492.63℃,Tci=467.37℃)



CASE14: C02(Vhi=0.033m/s,Vci=0.117m/s;Thi=392.39℃,Tci=387.62℃)



0.101m/s

Fig.3-01 CASE1(Ri=2,DV=0.084m/s): velocity field

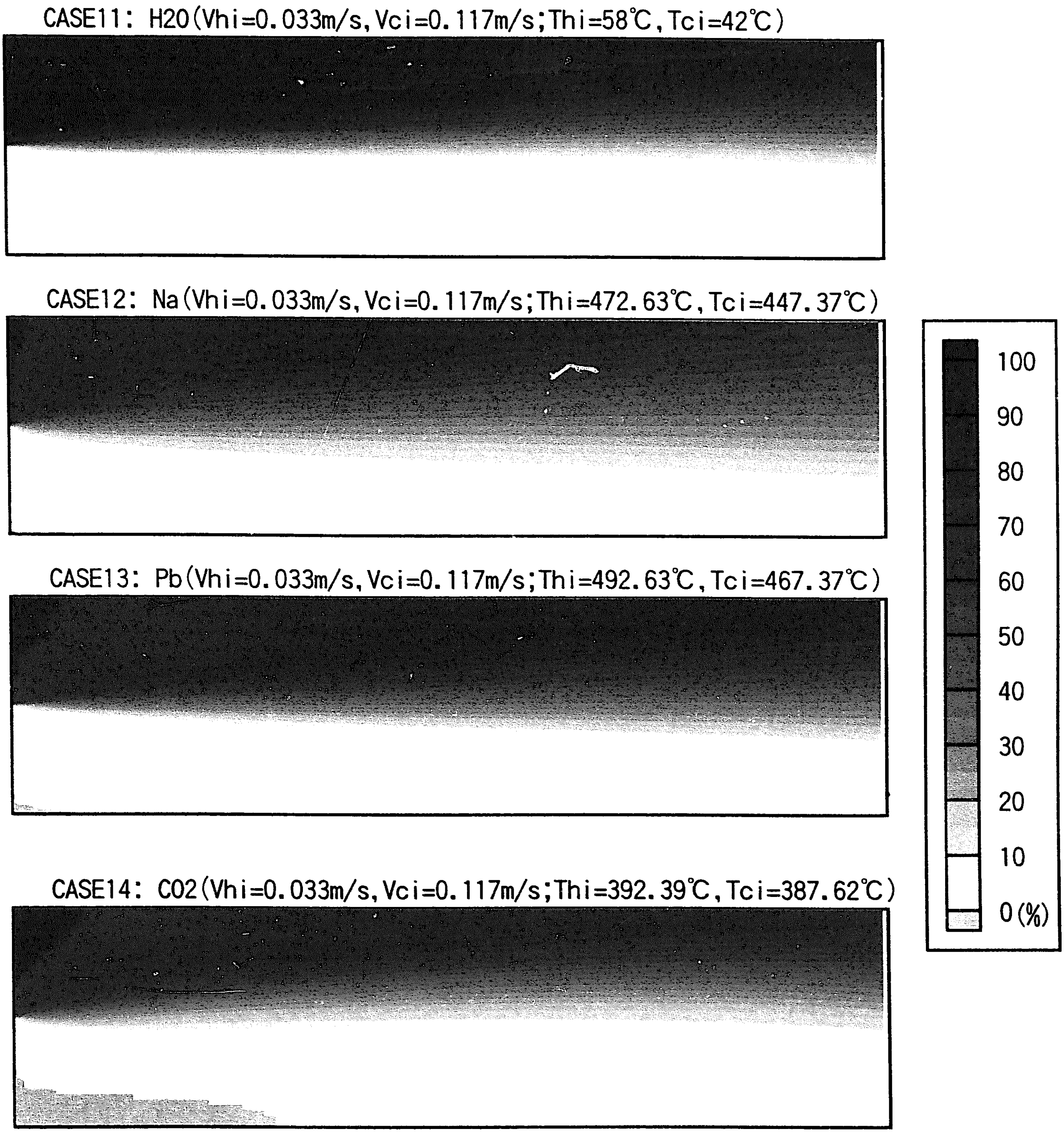


Fig.3-02 CASE1(Ri=2,DV=0.084m/s): normalized mean temperature

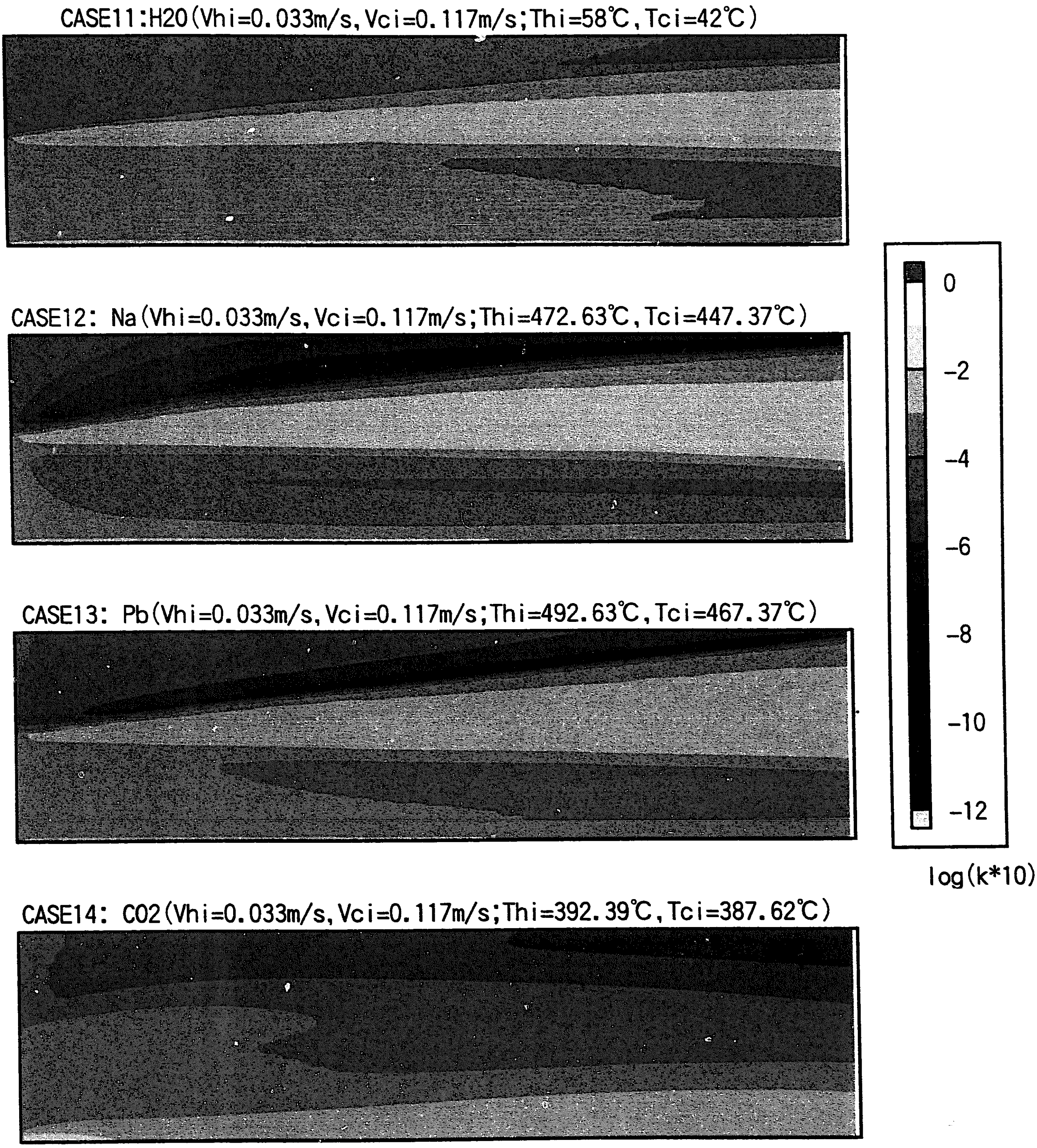
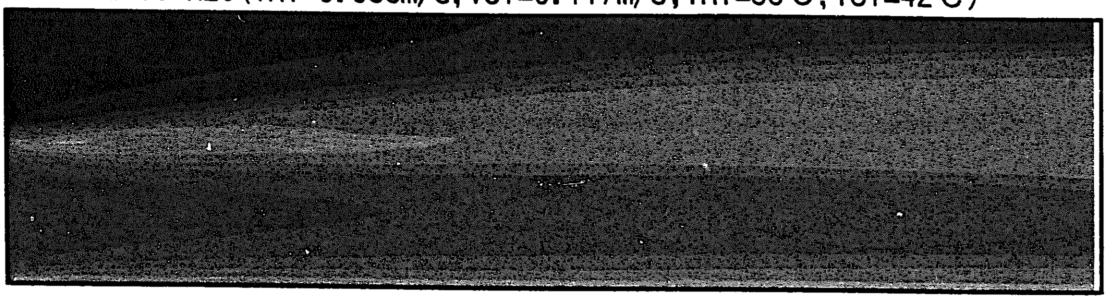
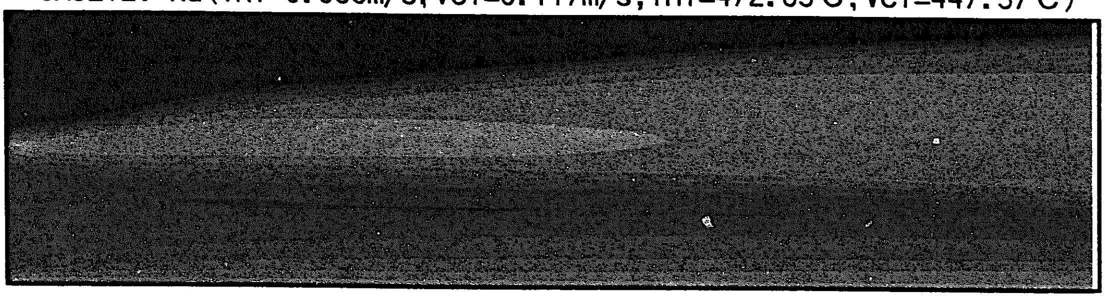


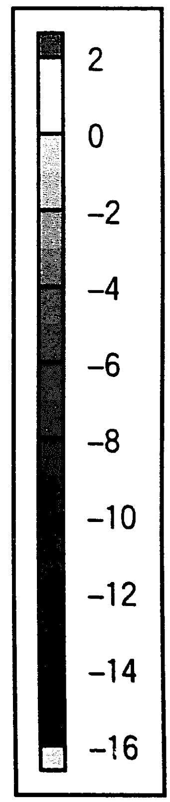
Fig.3-03 CASE1(Ri=2,DV=0.084m/s):turbulent kinetic energy(K)

CASE11: H2O(Vhi=0.033m/s, Vci=0.117m/s; Thi=58℃, Tci=42℃)



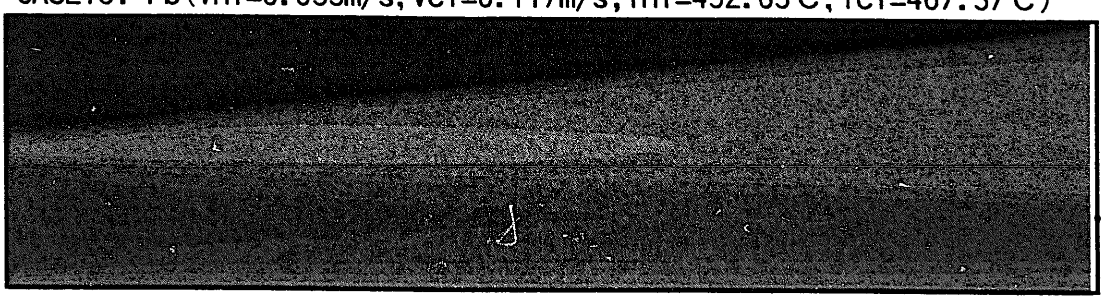
CASE12: Na(Vhi=0.033m/s, Vci=0.117m/s; Thi=472.63℃, Vci=447.37℃)





log(ε *10)

CASE13: Pb(Vhi=0.033m/s, Vci=0.117m/s; Thi=492.63℃, Tci=467.37℃)



CASE14: CO2(Vhi=0.033m/s, Vci=0.117m/s; Thi=392.39℃, Tci=387.62℃)

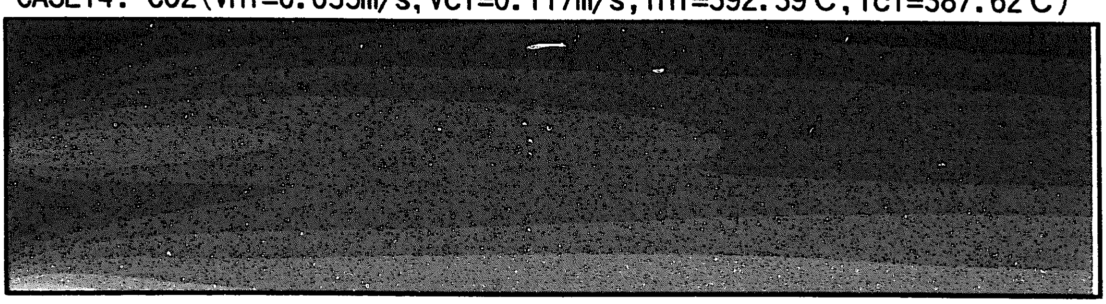


Fig. 3-04 CASE1(Ri=2, DV=0.084m/s): dissipation rate of K(ε)

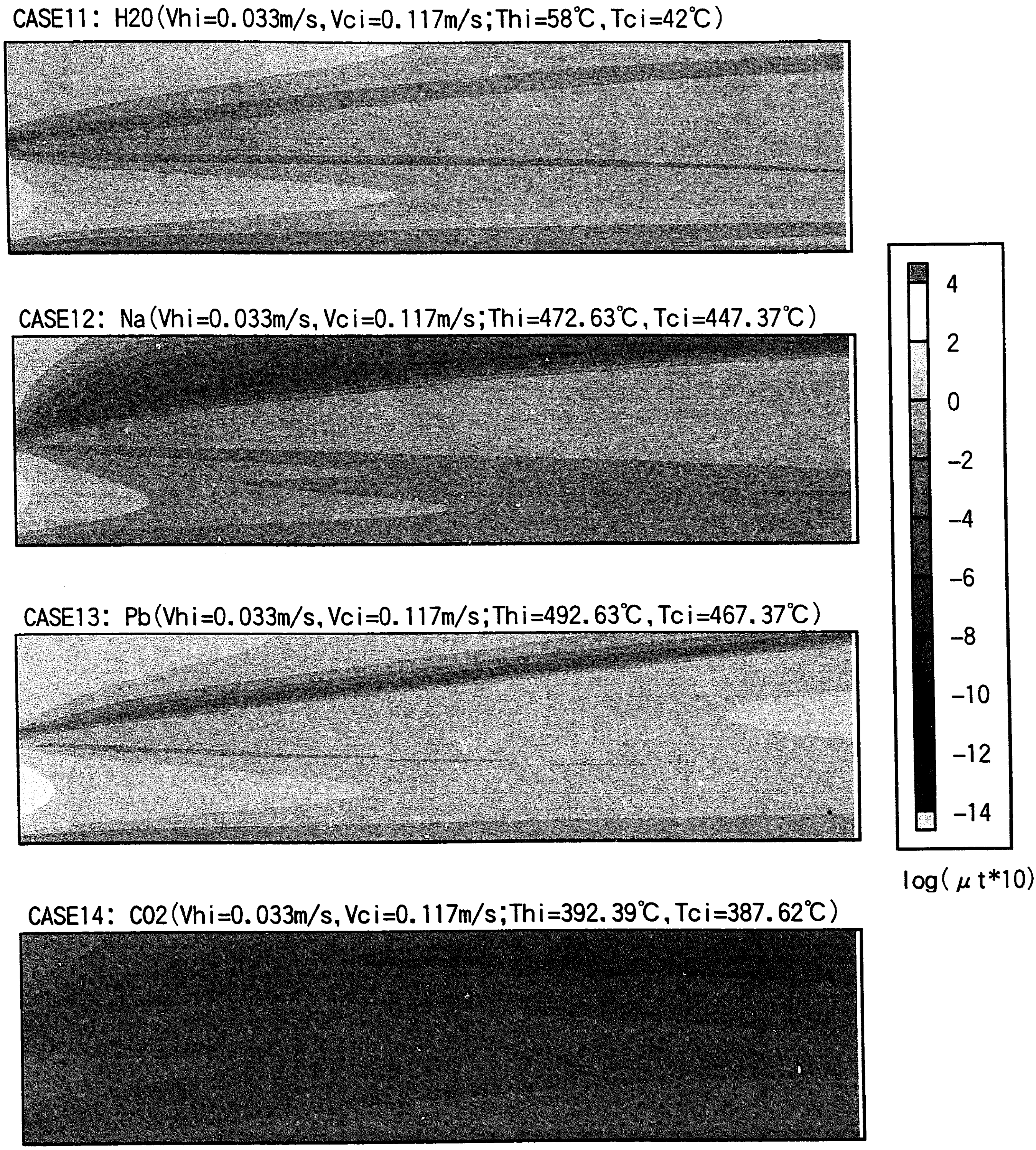


Fig. 3-05 CASE1(Ri=2, DV=0.084m/s): turbulent viscosity(μt)

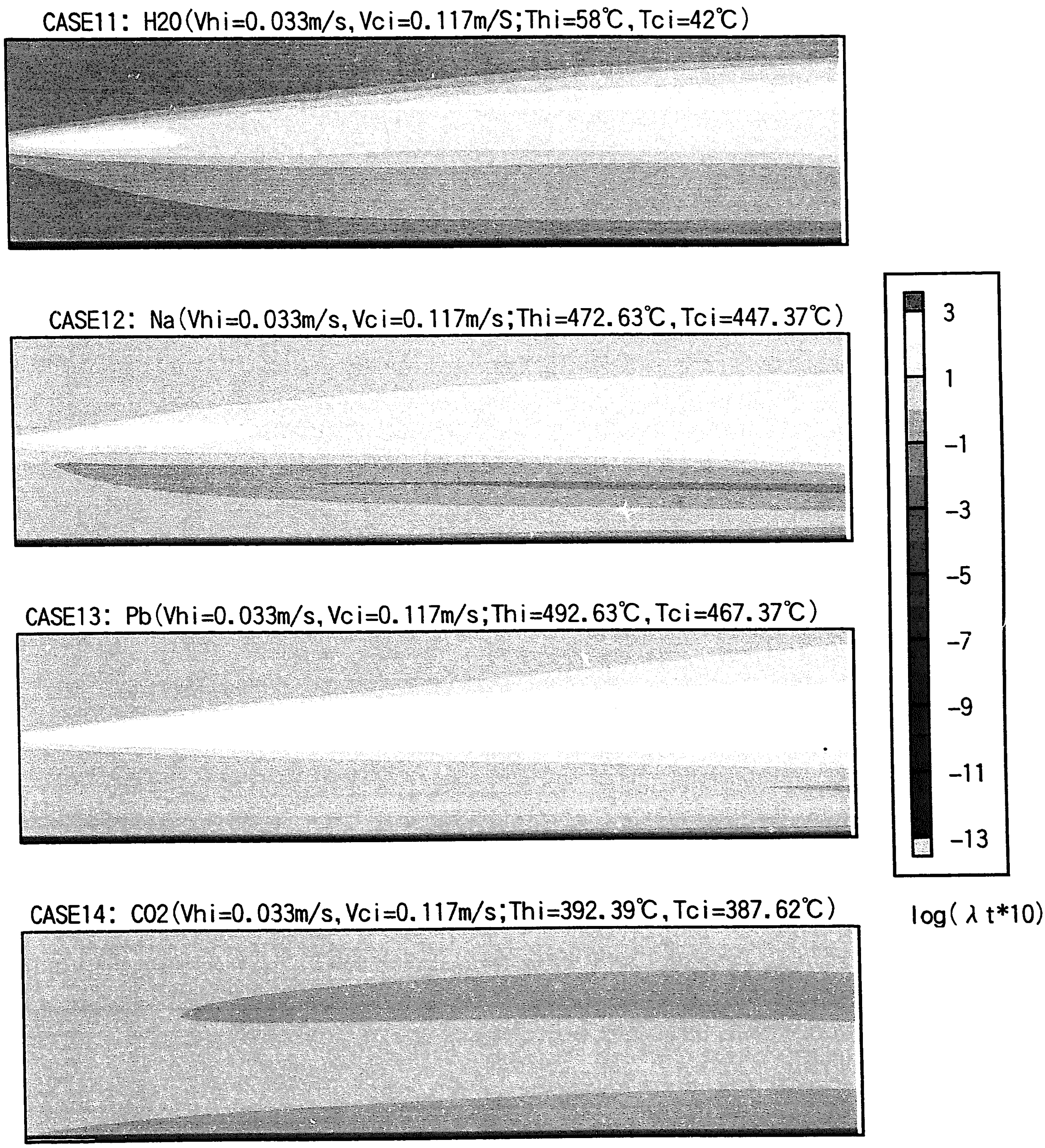


Fig. 3-06 CASE1(Ri=2, DV=0.084m/s): turbulent conductivity(λt)

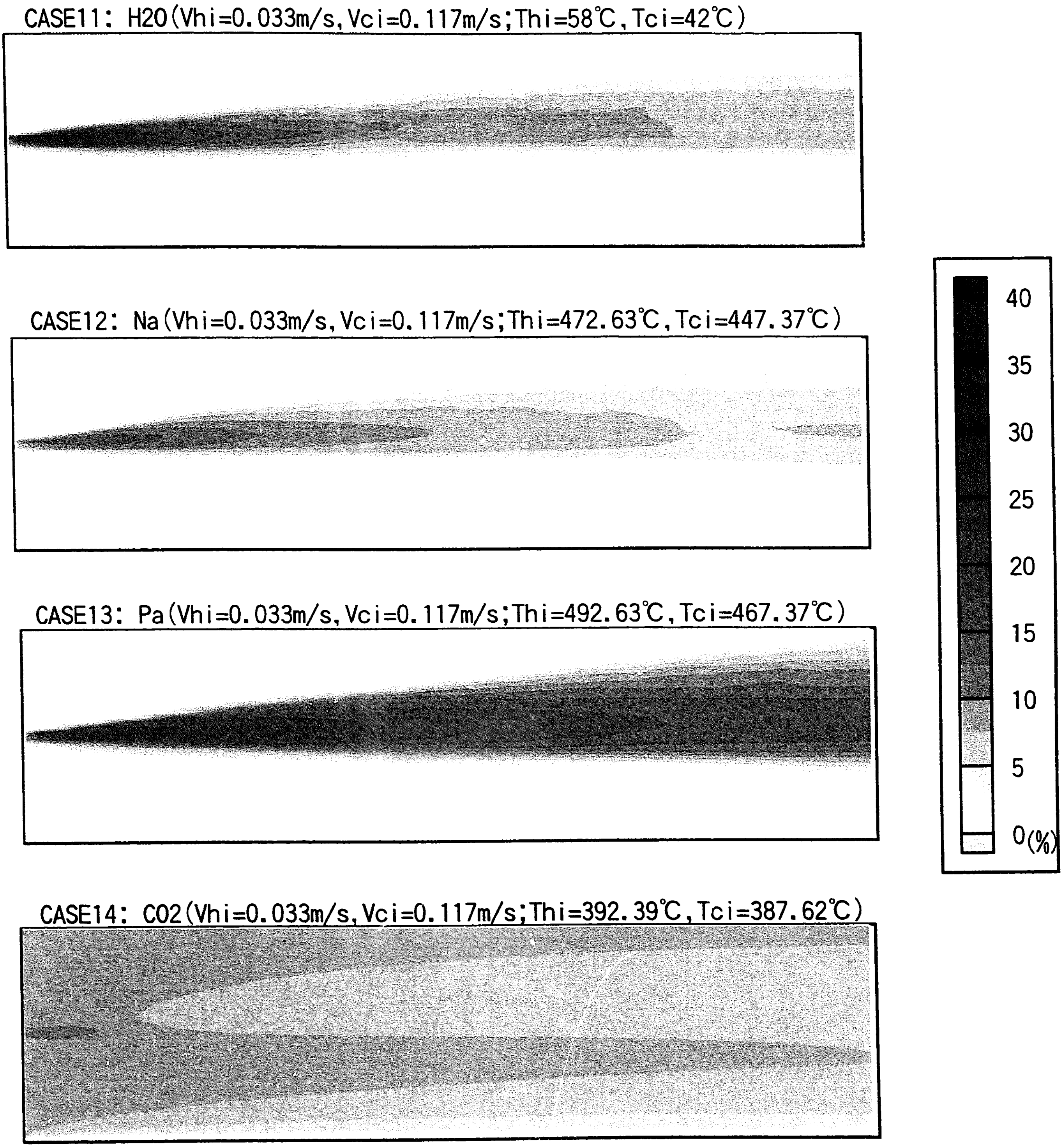
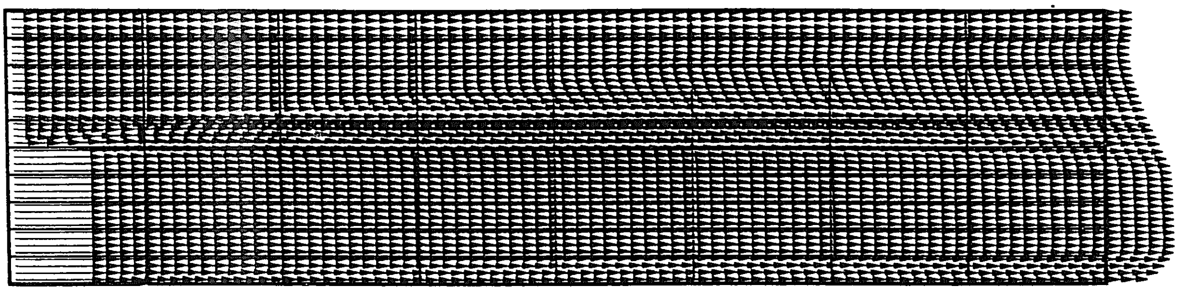
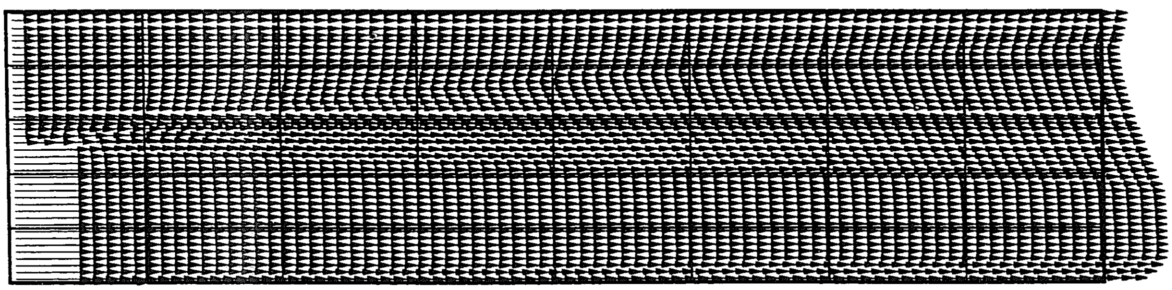


Fig.3-07 CASE1(Ri=2,DV=0.084m/s) normalized temperature fluctuation

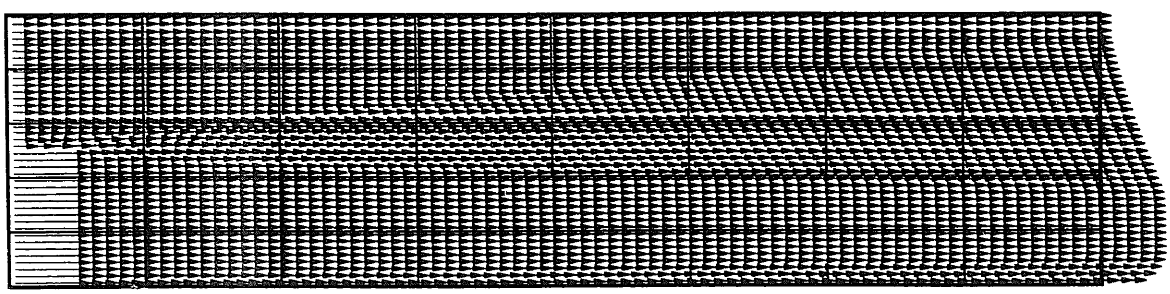
CASE21: H20(Vhi=0.033m/s, Vci=0.127m/s; Thi=60℃, Tci=40℃)



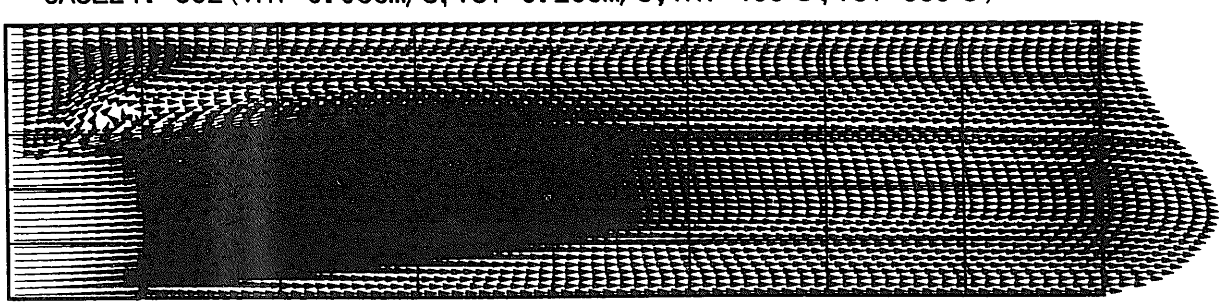
CASE22: Na(Vhi=0.033m/s, Vci=0.108m/s; Thi=470℃, Tci=450℃)



CASE23: Pb(Vhi=0.033m/s, Vci=0.108m/s; Thi=490℃, Tci=470℃)



CASE24: C02(Vhi=0.033m/s, Vci=0.205m/s; Thi=400℃, Tci=380℃)



0.101m/s

Fig. 3-08 CASE2(Ri=2, DT=20℃): velocity field

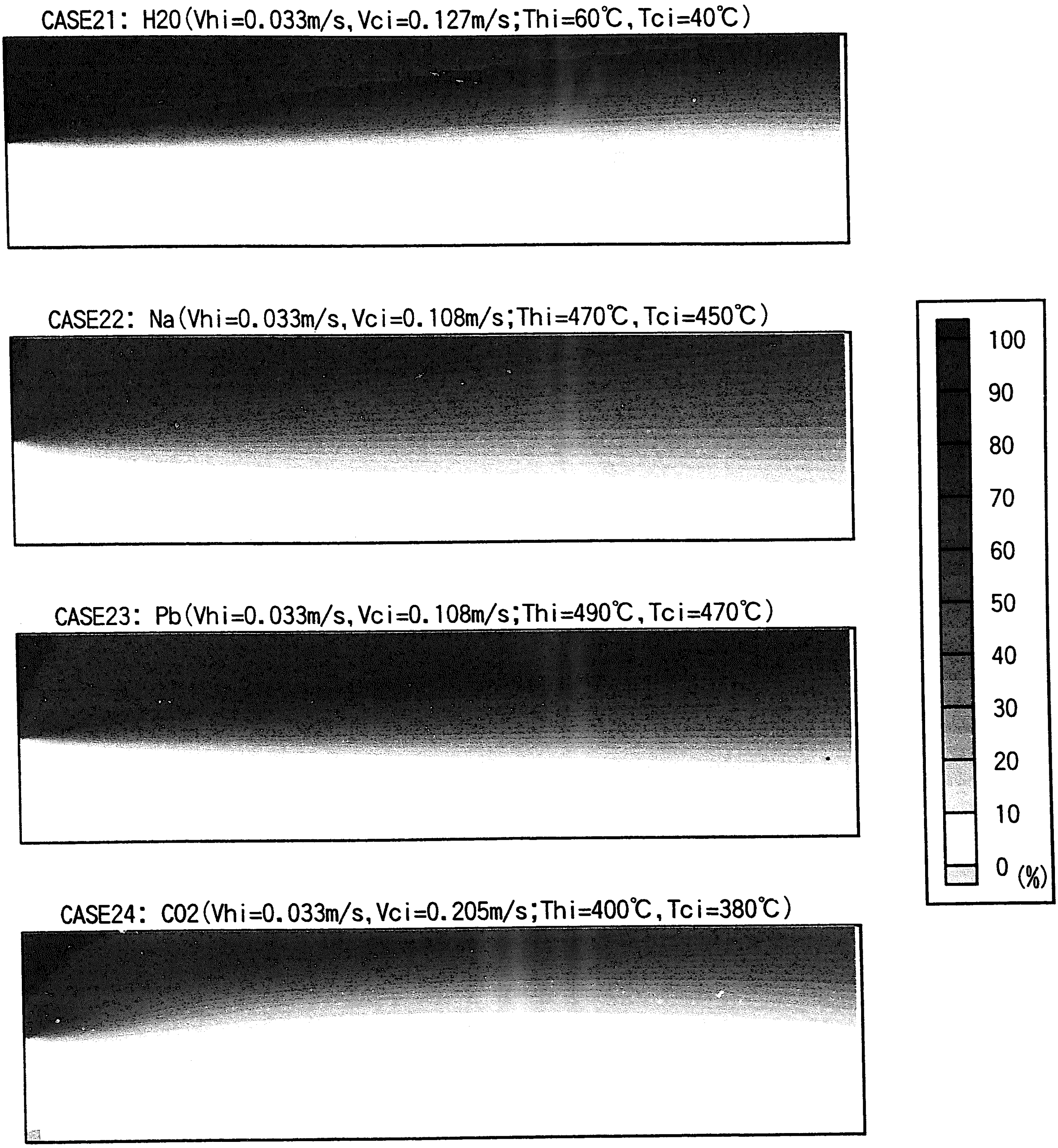


Fig. 3-09 CASE2(Ri=2, DT=20℃): normalized mean temperature

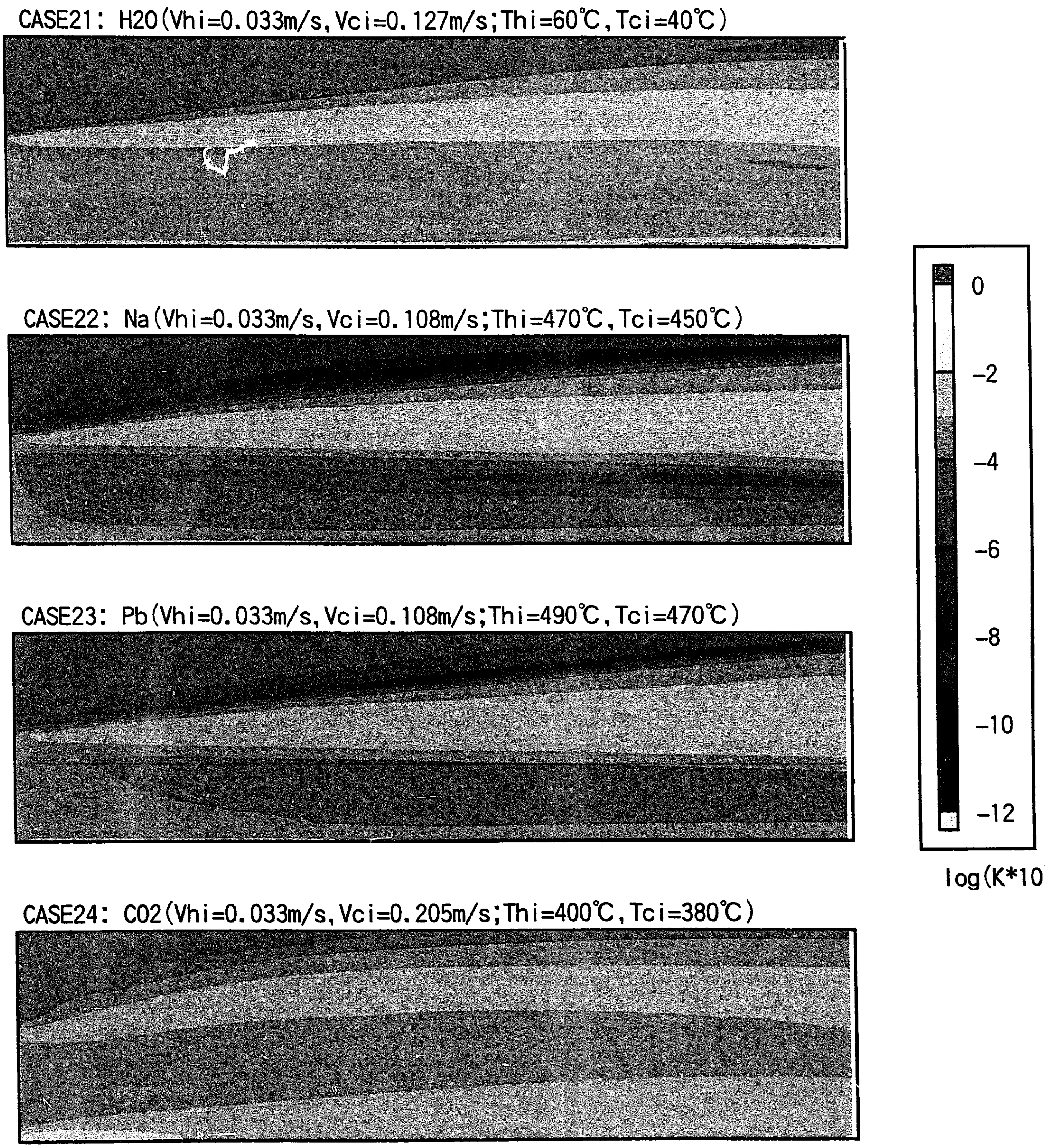


Fig.3-10 CASE(Ri=2,DT=20℃): turbulent kinetic energy(K)

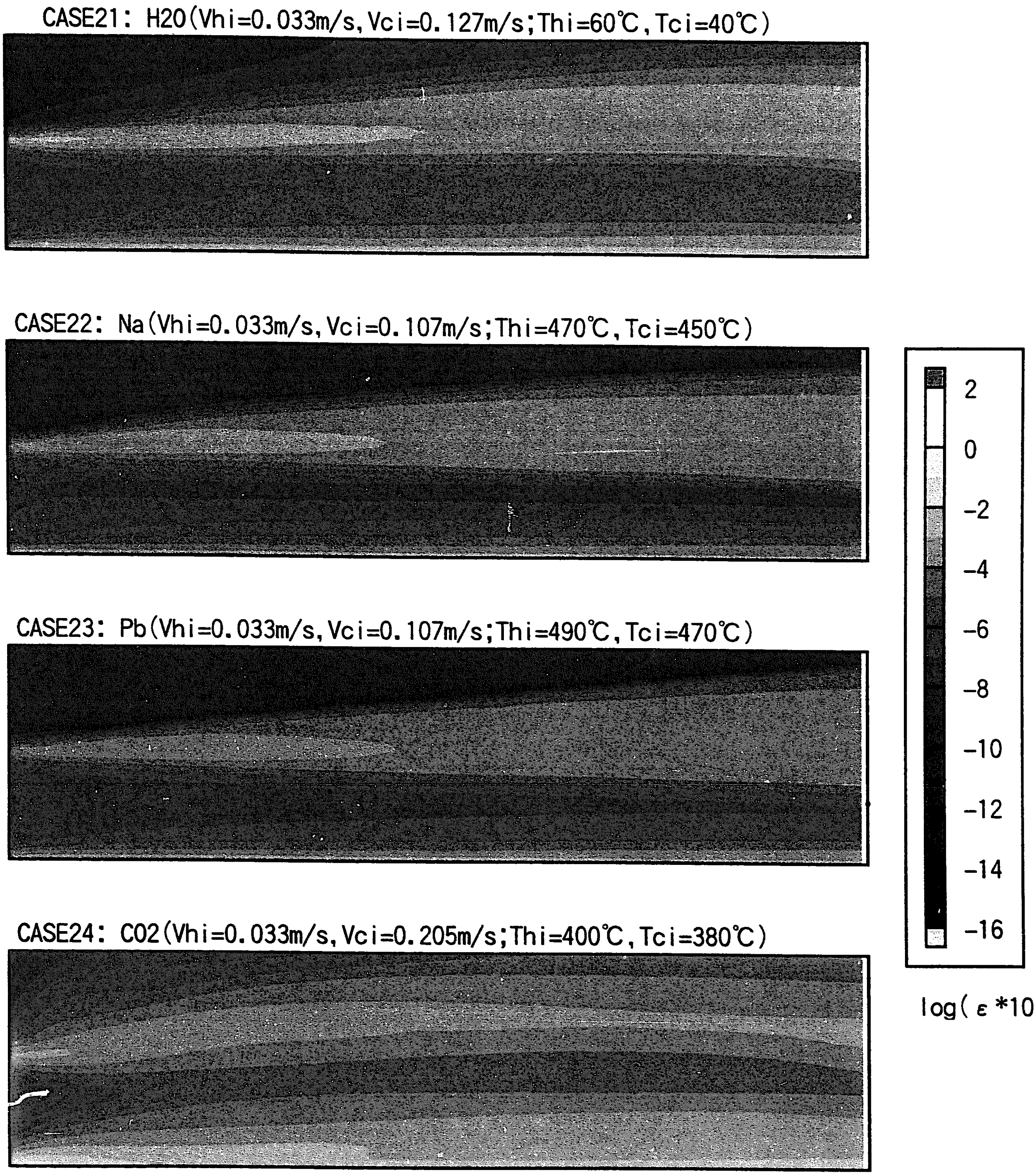


Fig. 3-11 CASE2(Ri=2, DT=20℃):dissipation rate of K(ε)

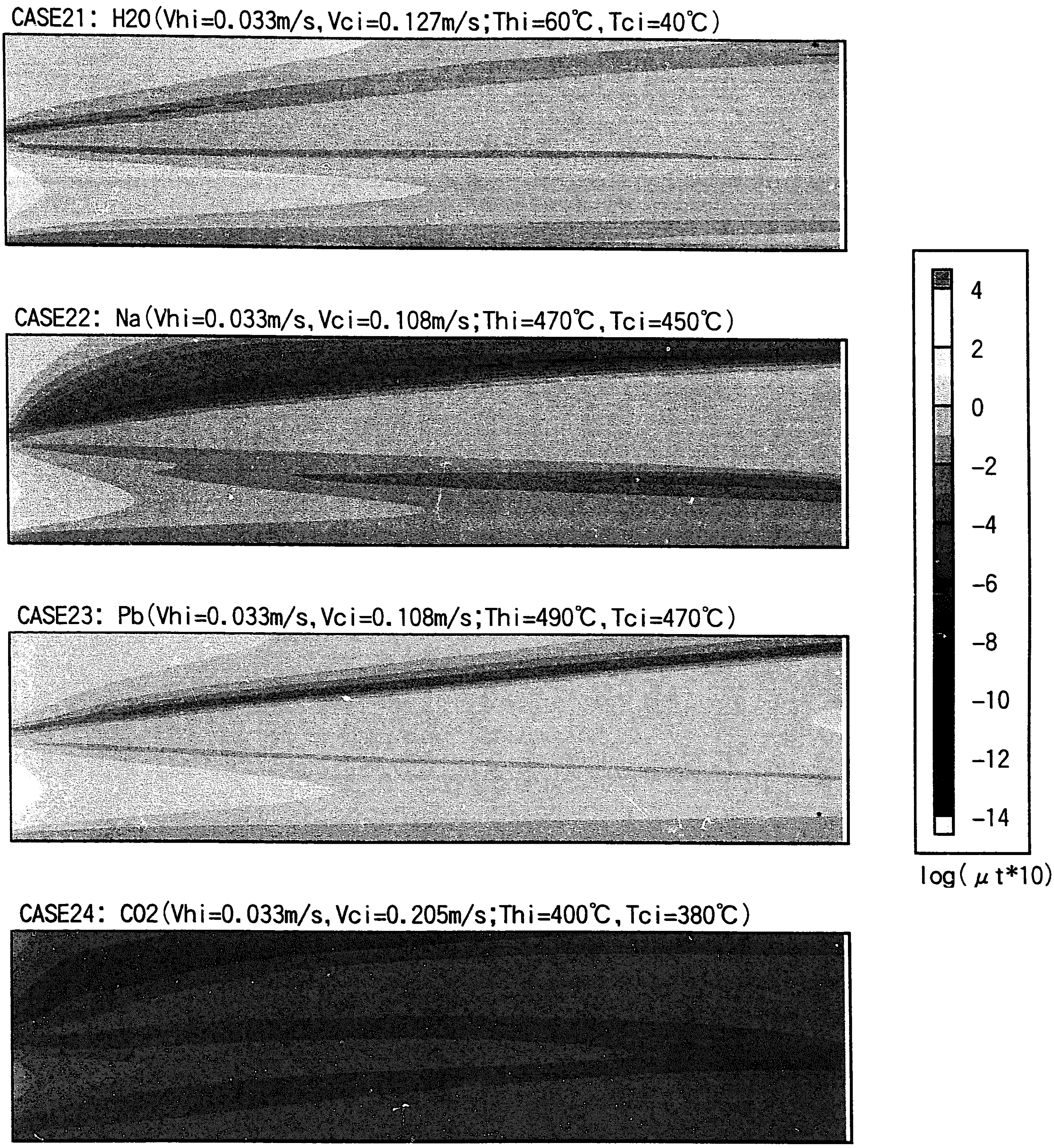


Fig.3-12 CASE2(Ri=2,DT=20℃):turbulent viscosity(μt)

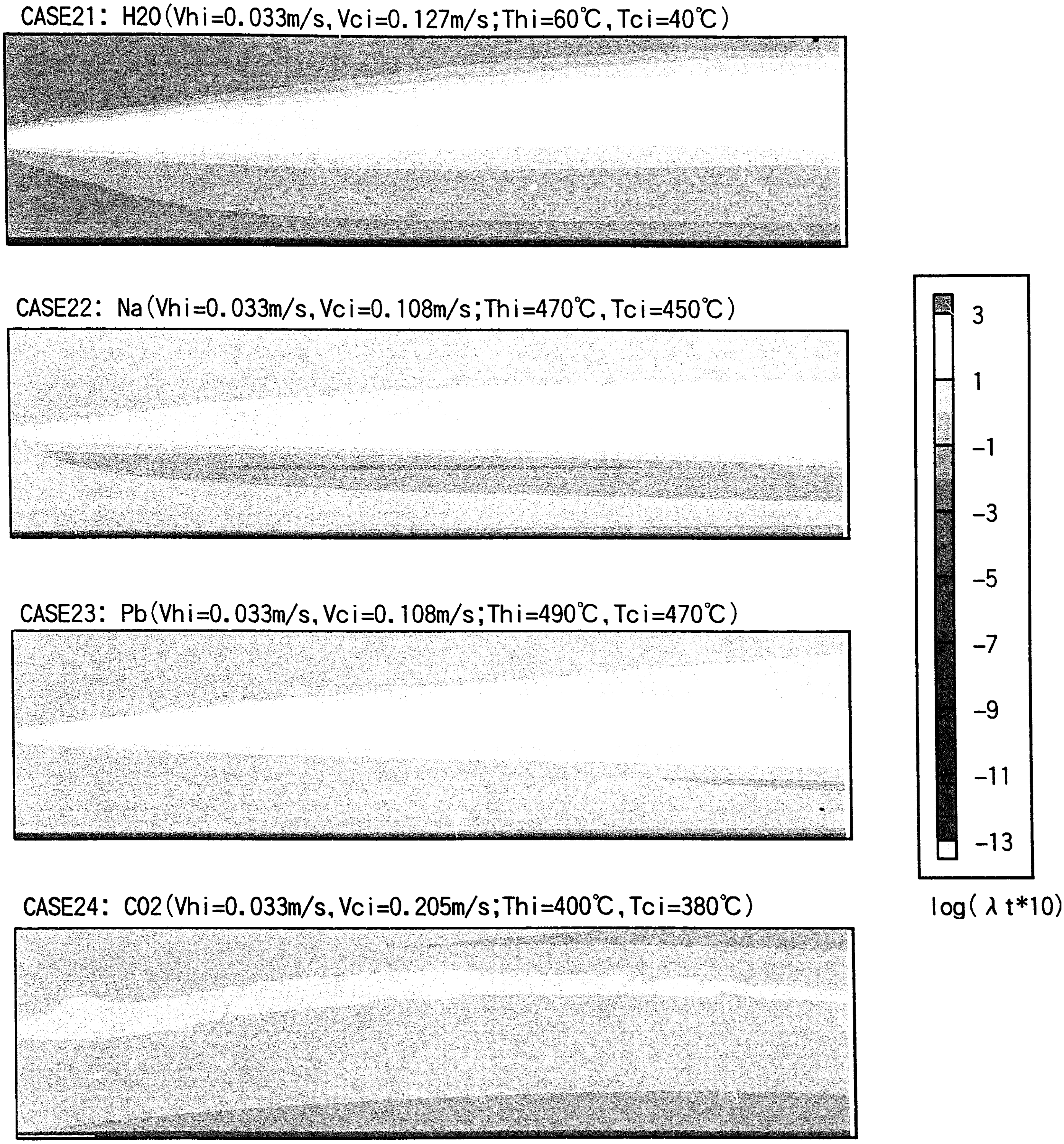


Fig.3-13 CASE2(Ri=2,DT=20℃): turbulent conductivity(λt)

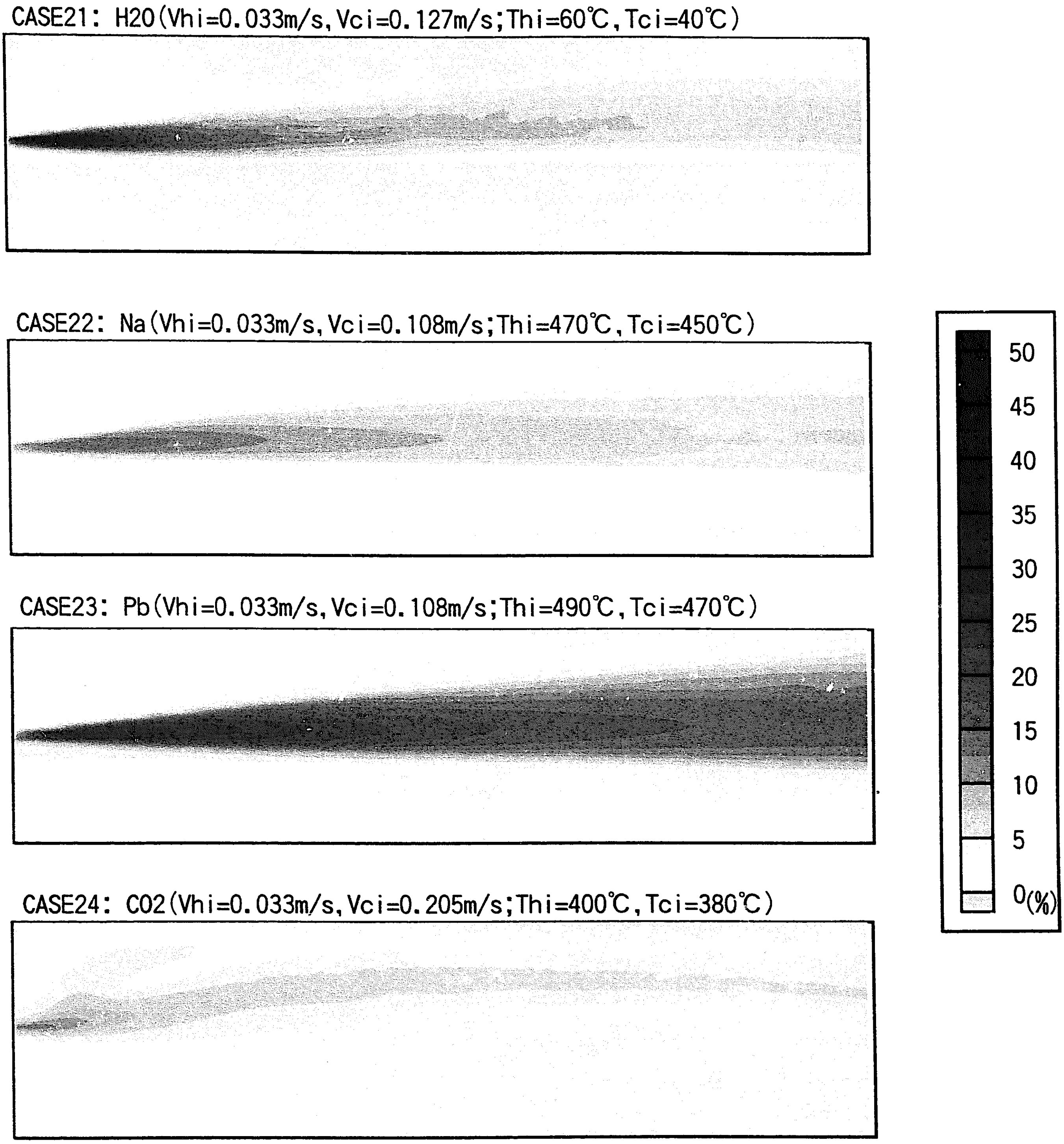


Fig.3-14 CASE2(Ri=2,DT=20℃) normalized temperature fluctuation

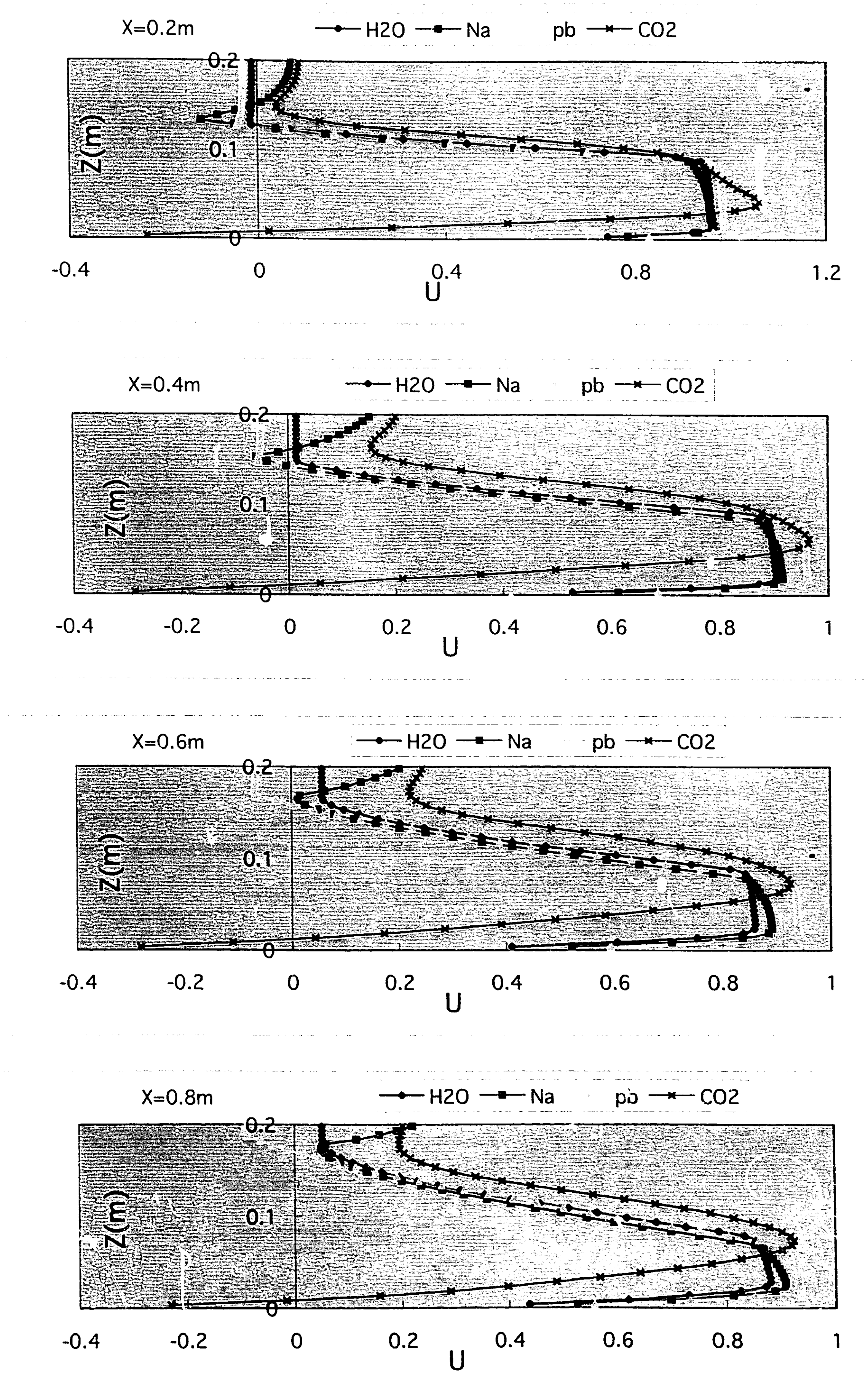


Fig.3-15CASE1(Ri=2,DV=0.084m/s):X-direction normalized velocity

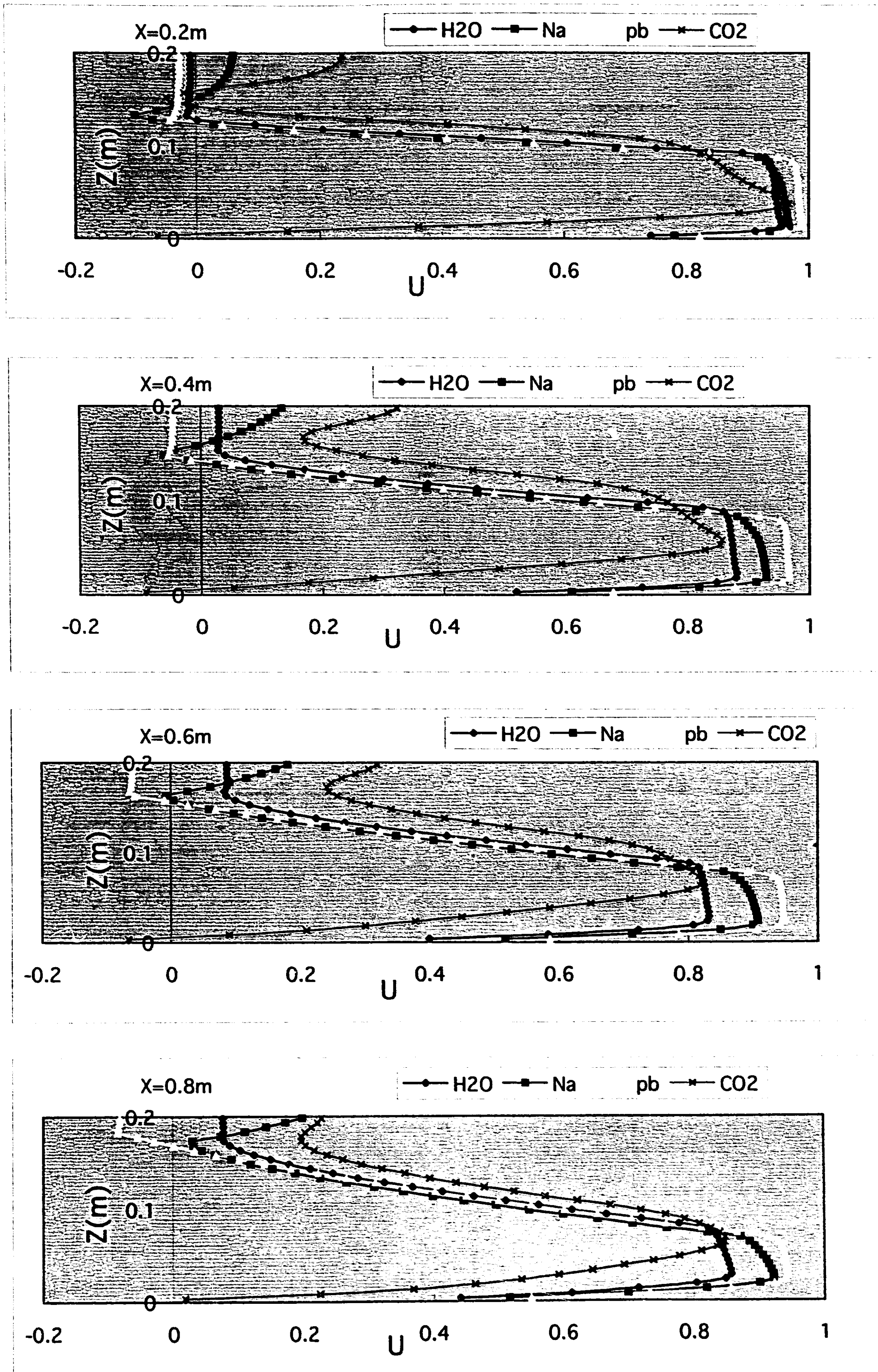


Fig.3-16 CASE2(Ri=2,DT=20℃): X-direction normalized velocity

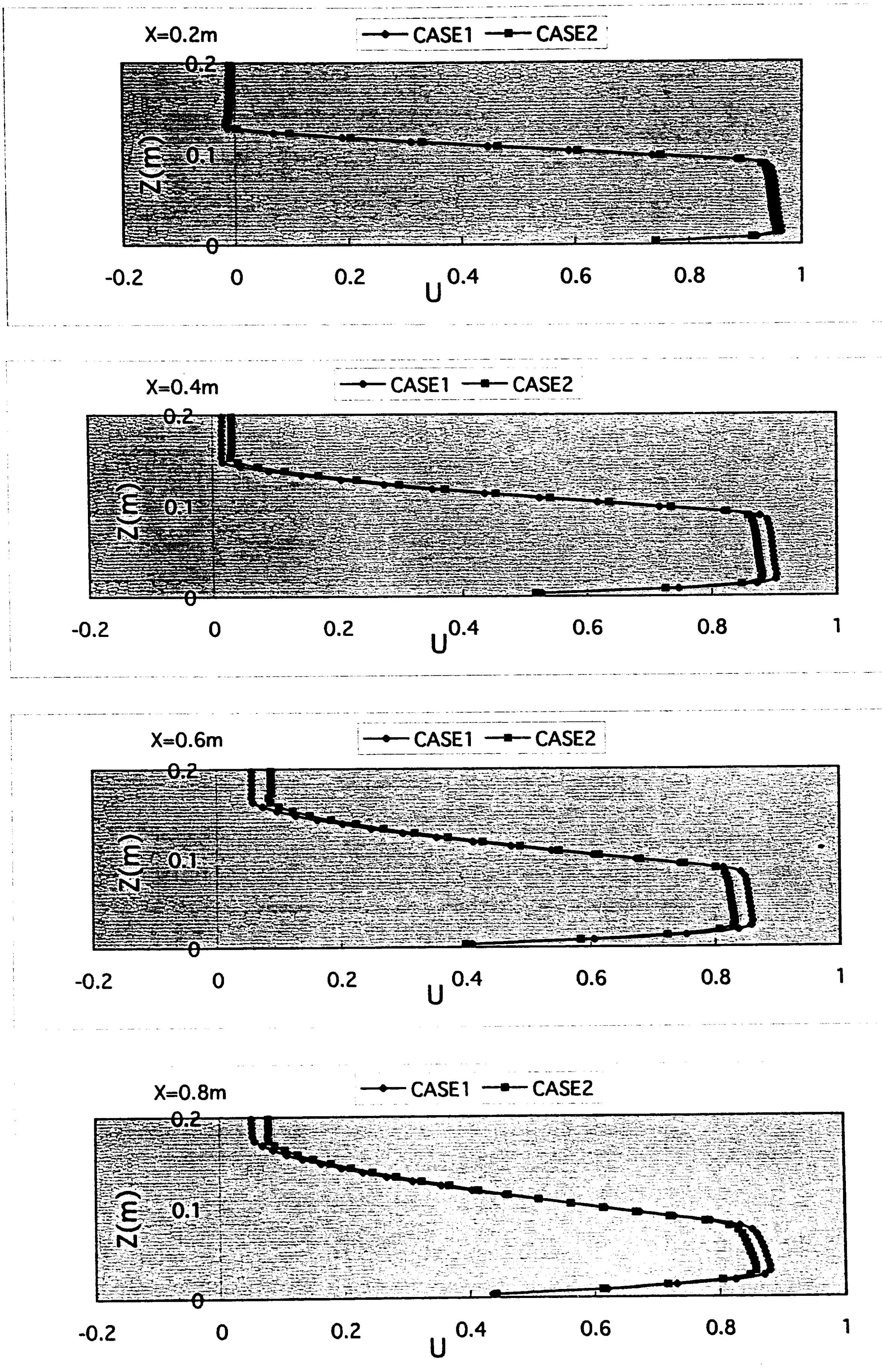


Fig.3-17 H2O: X-direction normalized velocity

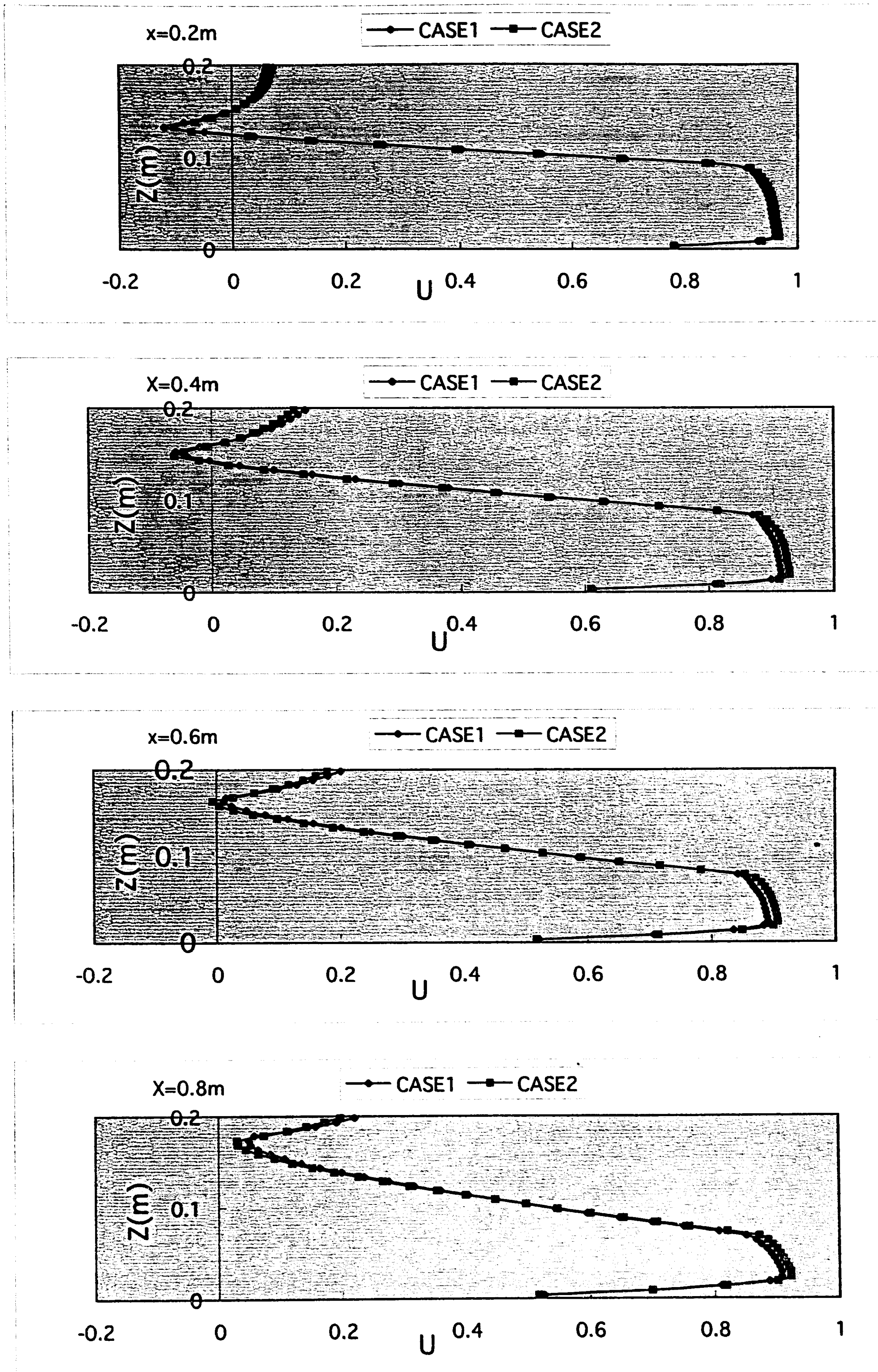


Fig.3-18 Na: X-direction normalized velocity

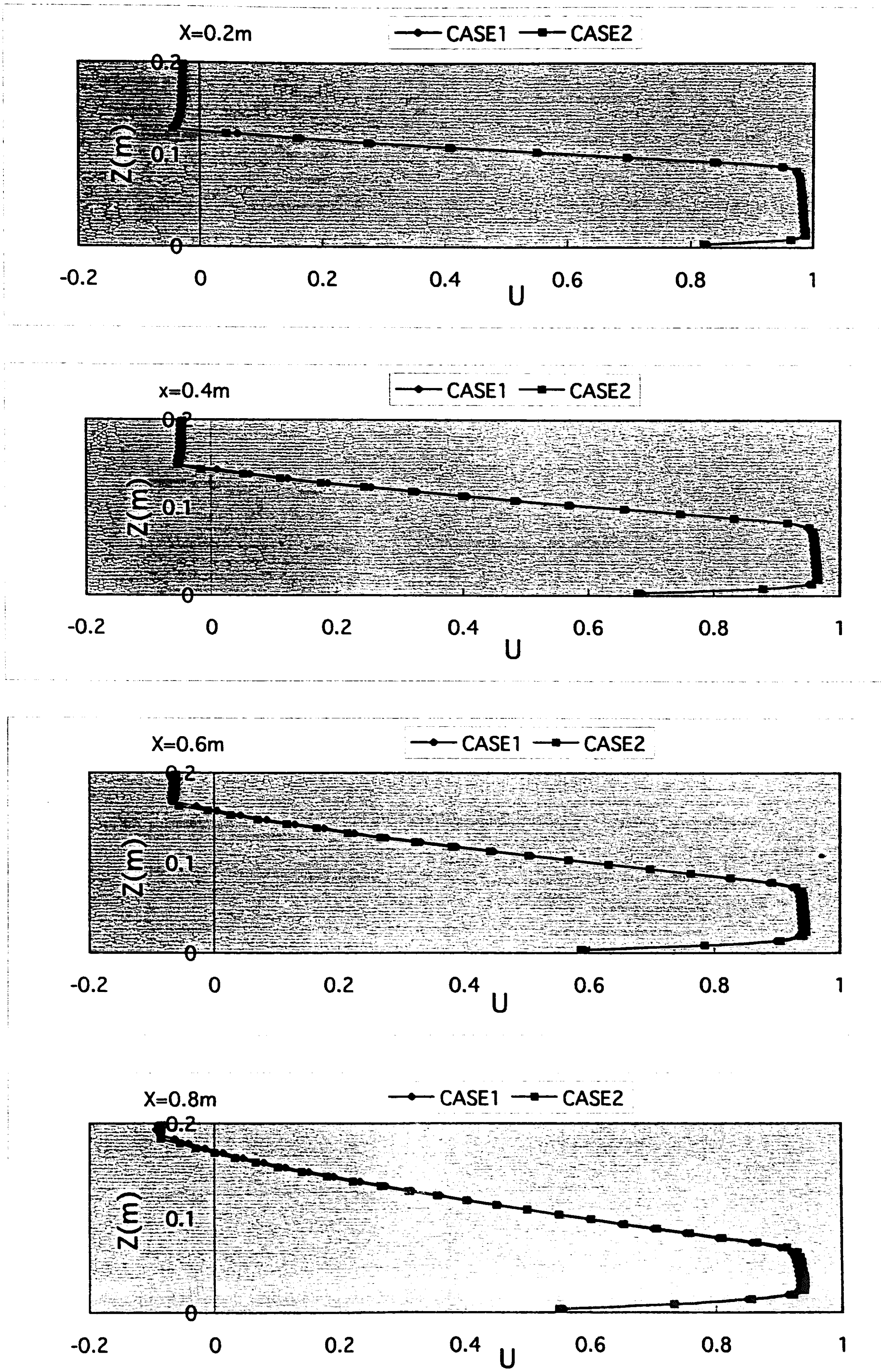


Fig.3-19 Pb: X-direction normalized velocity

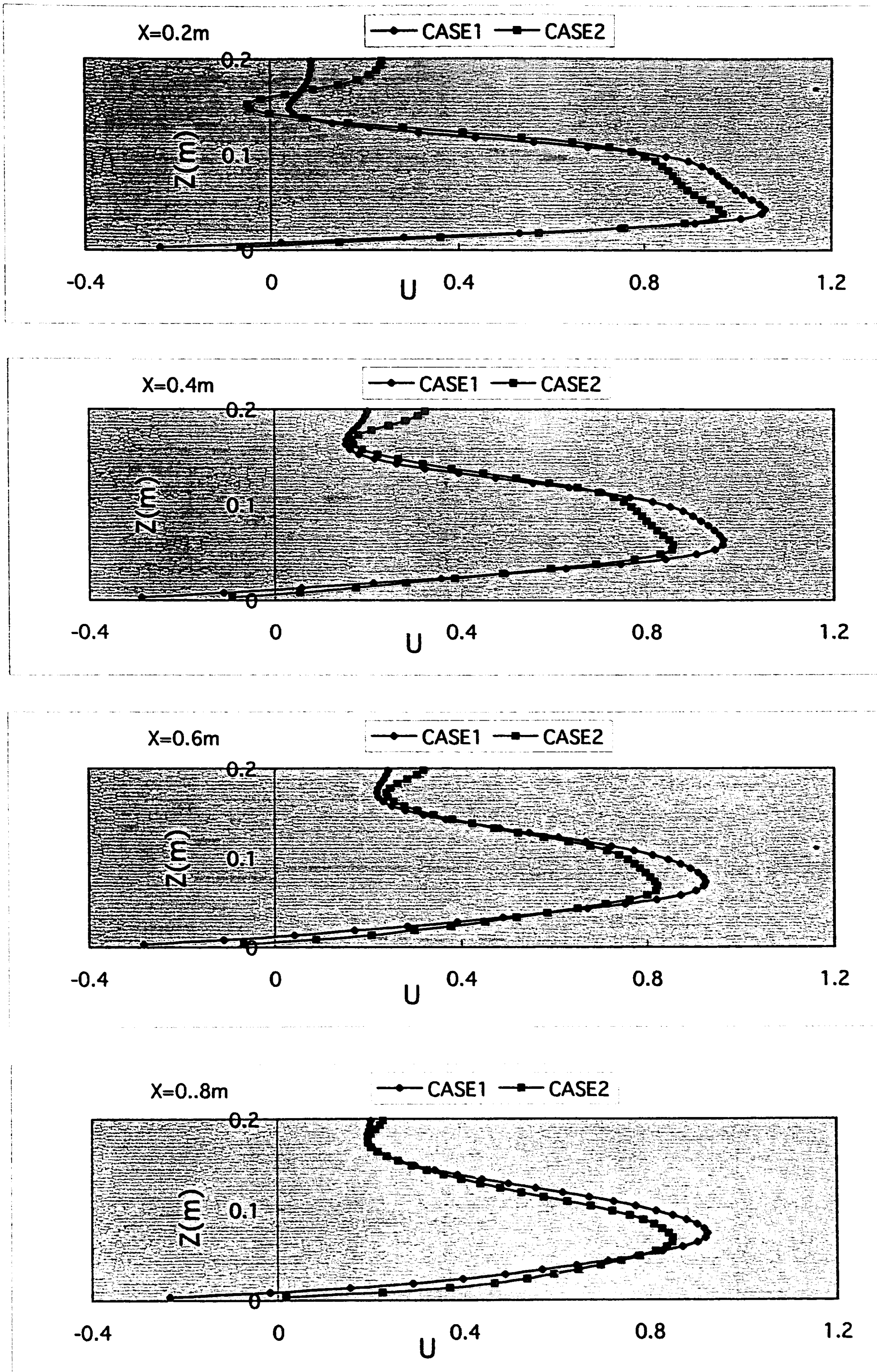


Fig.3-20 CO2: X-direction normalized velocity

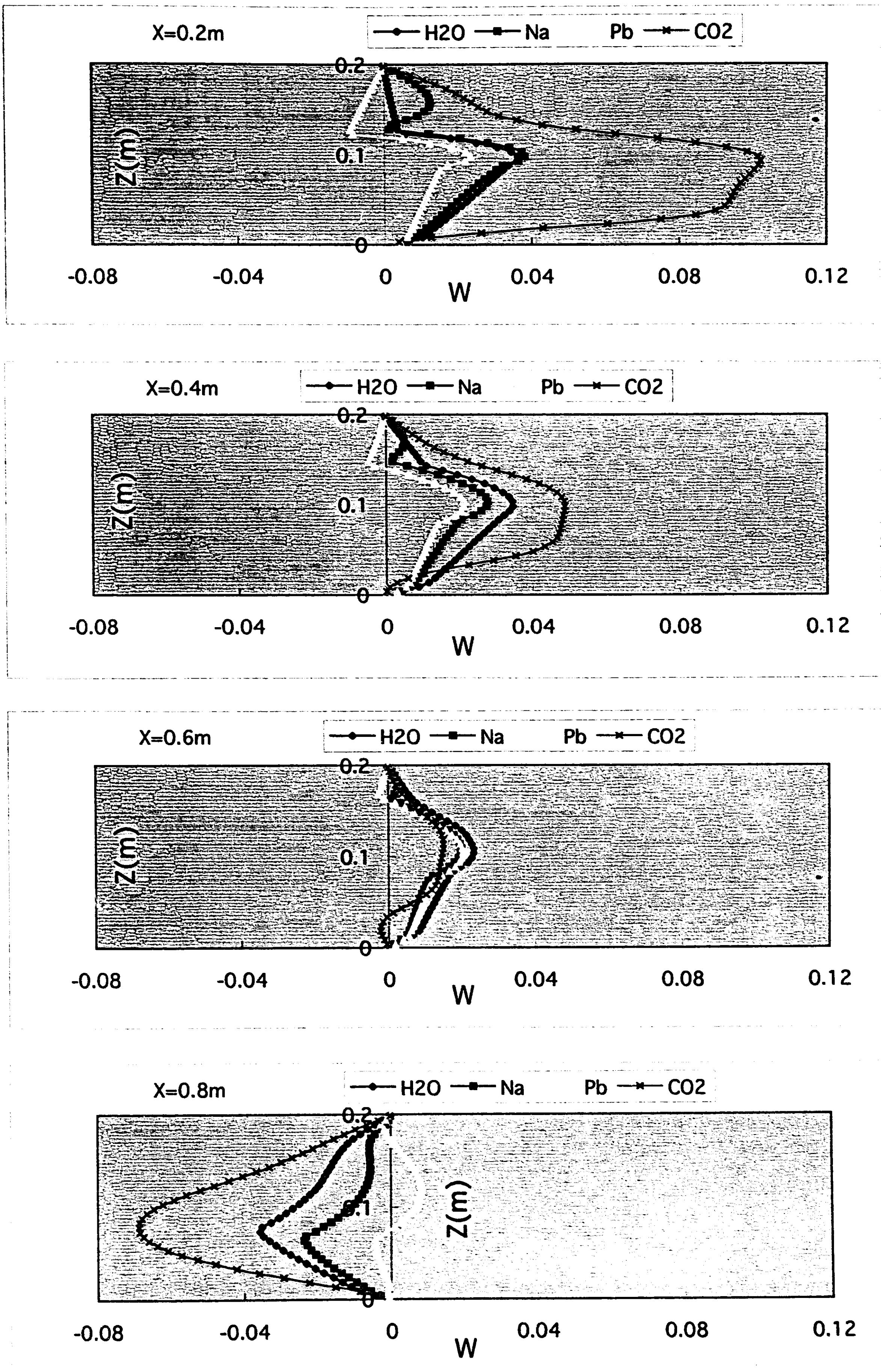


Fig.3-21CASE1(Ri=2,DV=0.084m/s):Z-direction normalized velocity

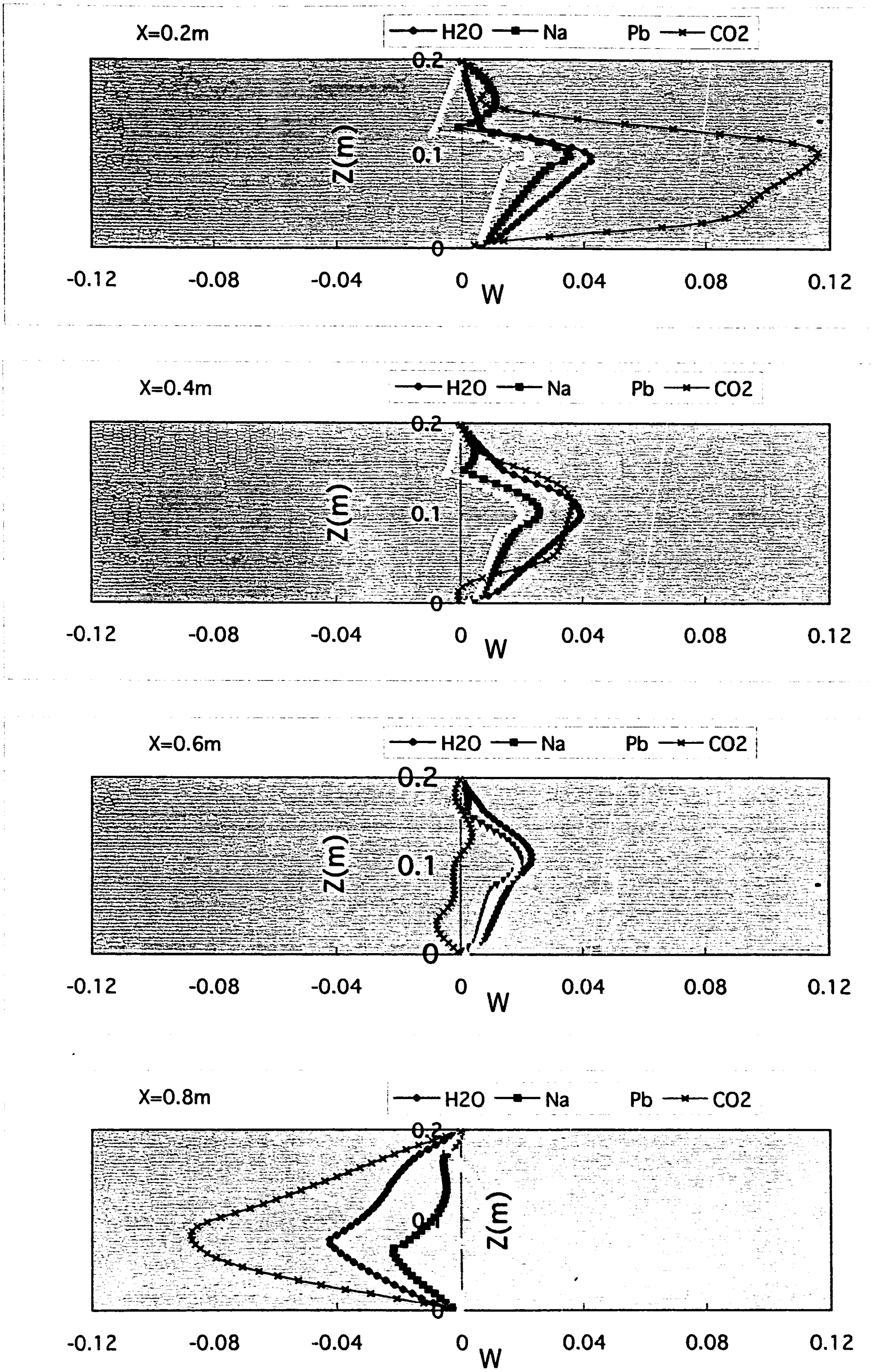


Fig.3-22 CASE2(Ri=2,DT=20℃): Z-direction normalized velocity

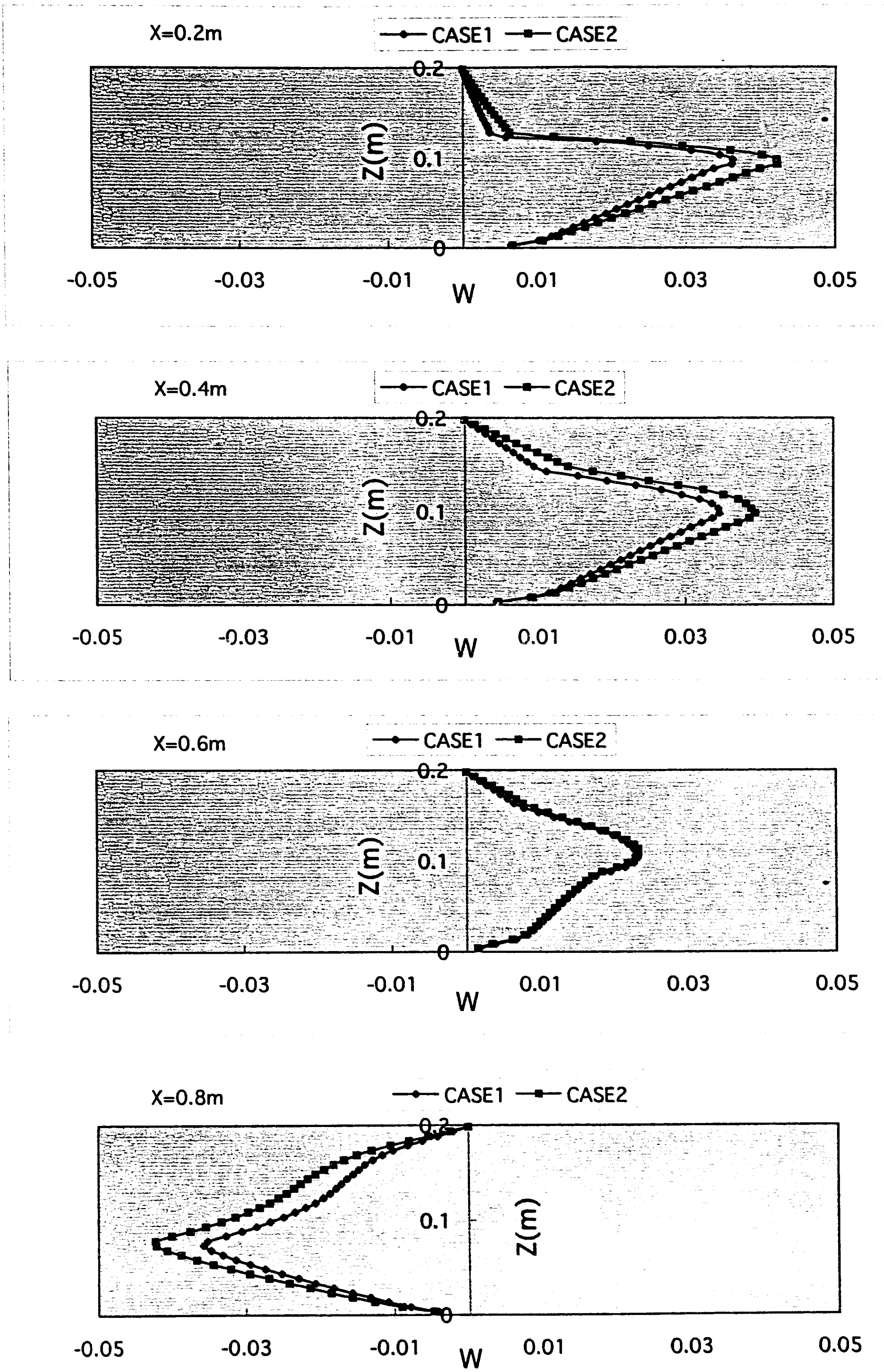


Fig.3-23 H2O: Z-direction normalized velocity

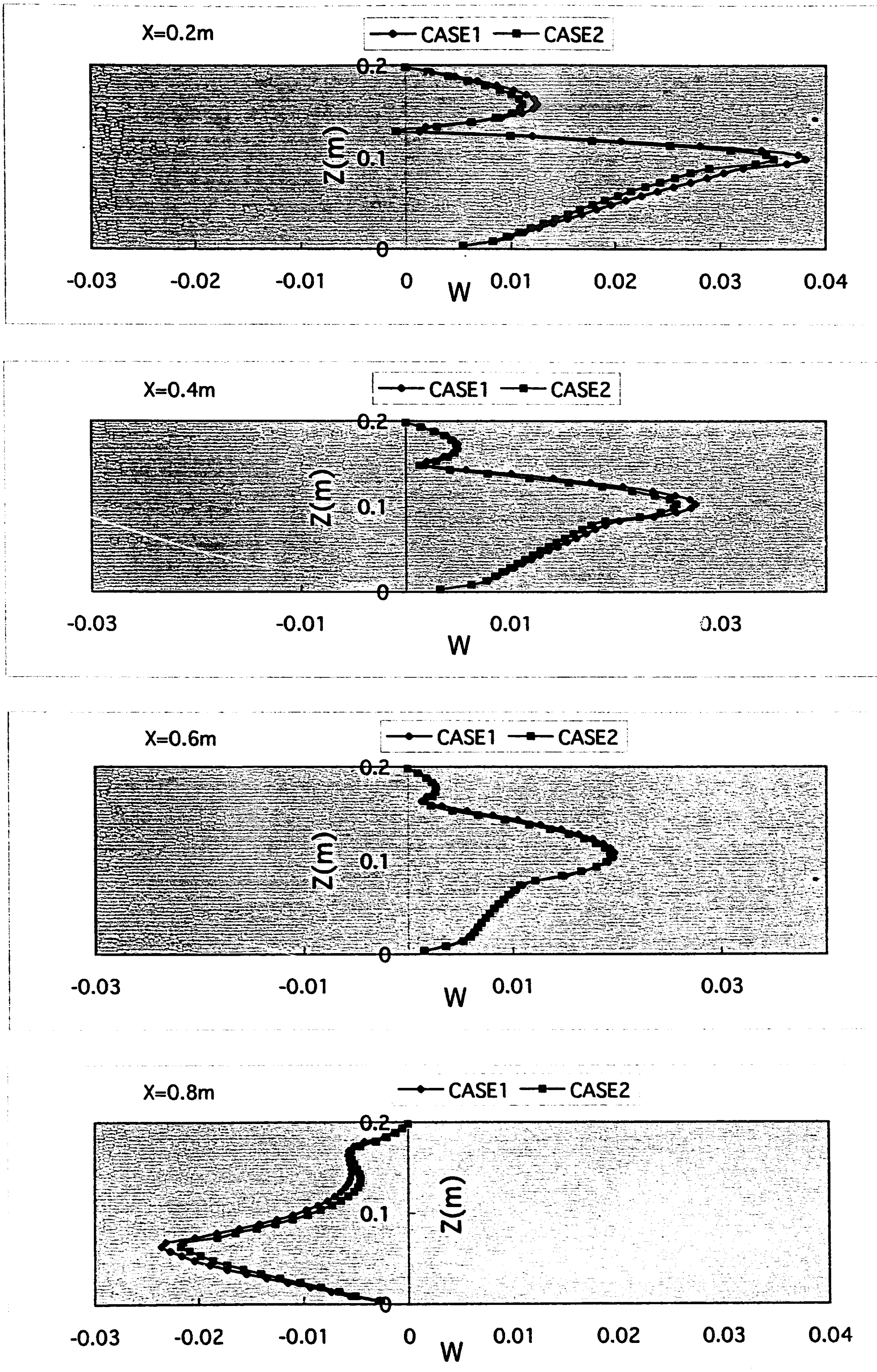


Fig.3-24 Na: Z-direction normalized velocity

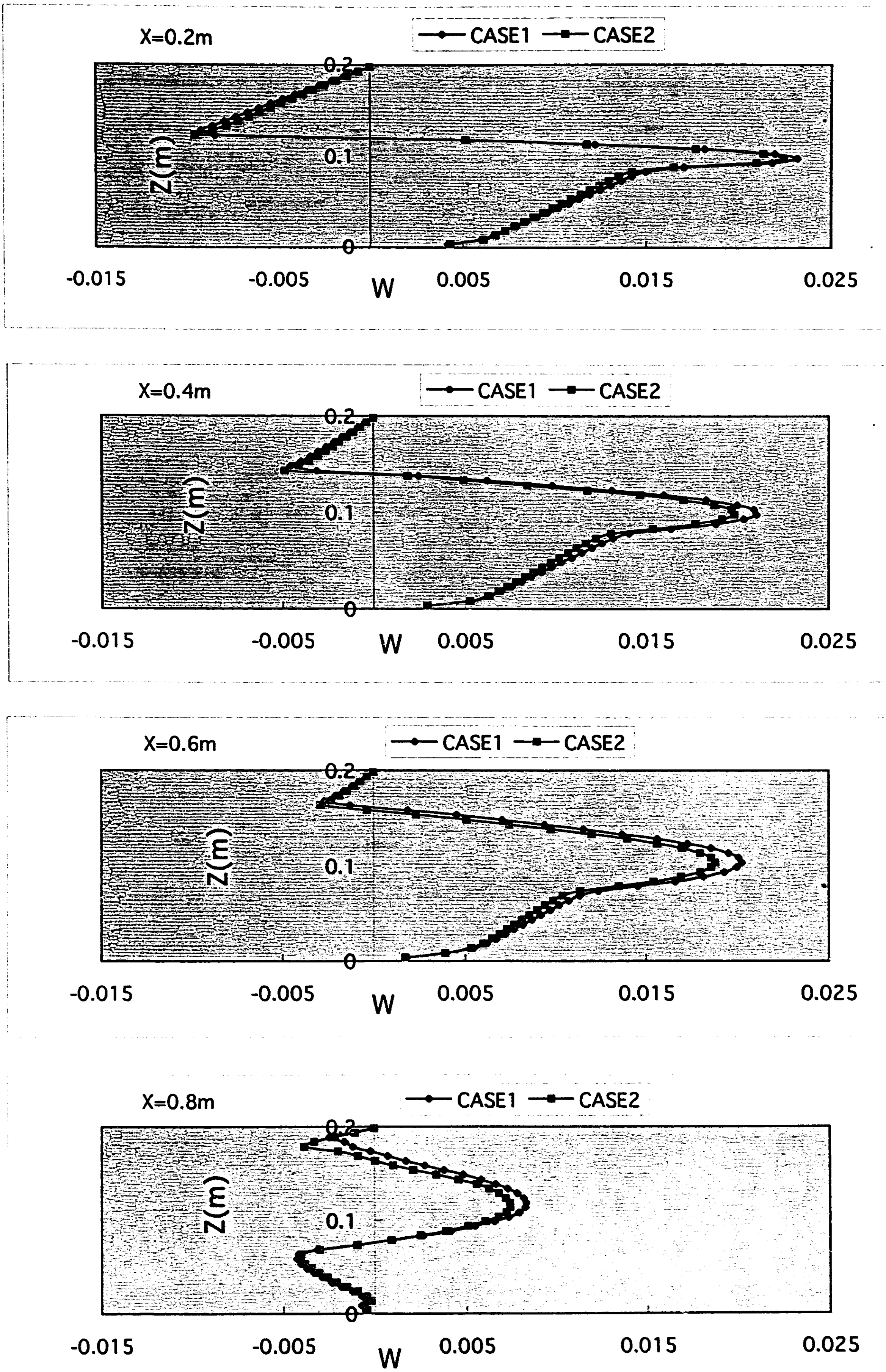


Fig.3-25 Pb: Z-direction normzlized velocity

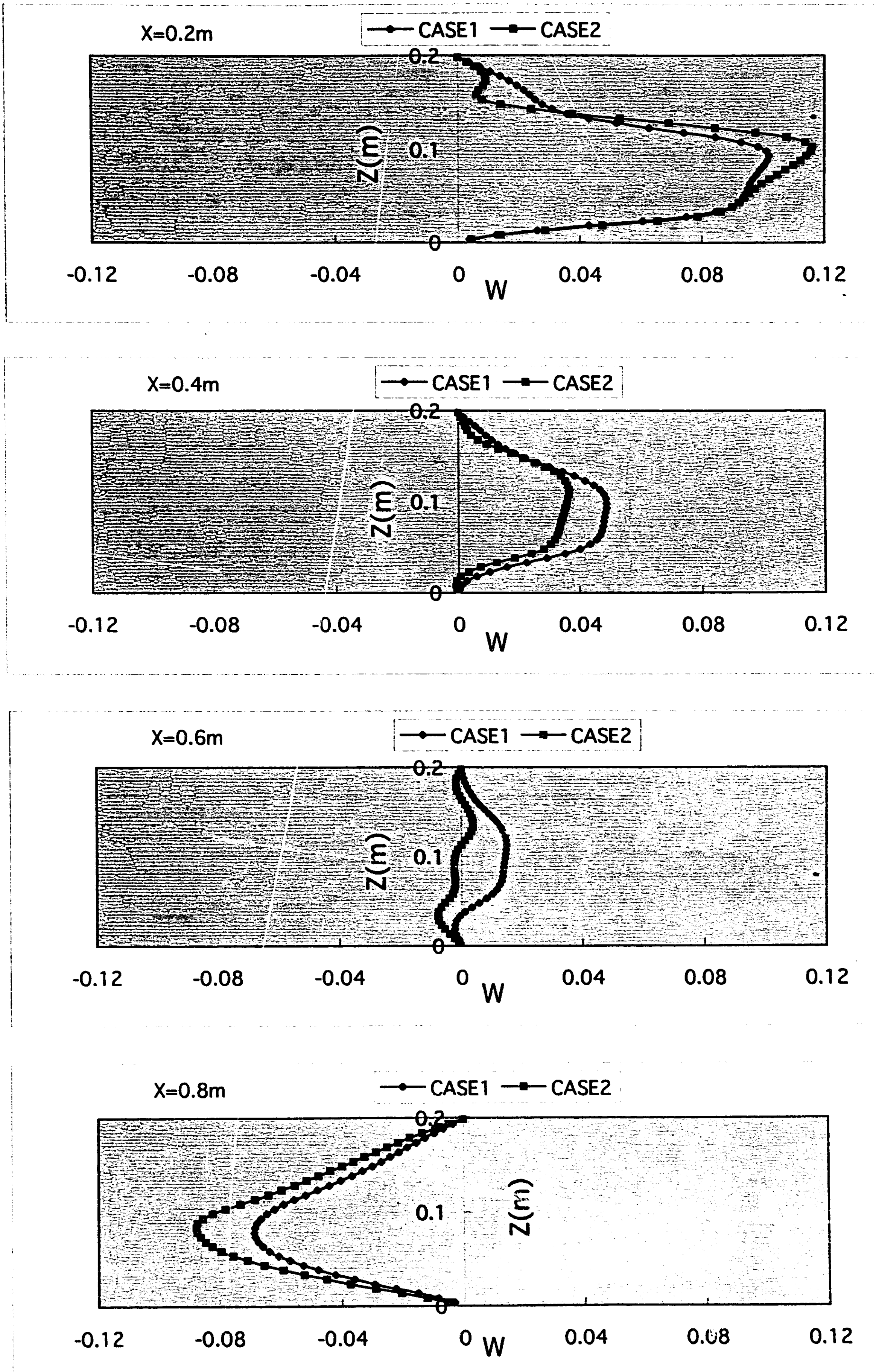


Fig.3-26 CO2: Z-direction normalized velocity

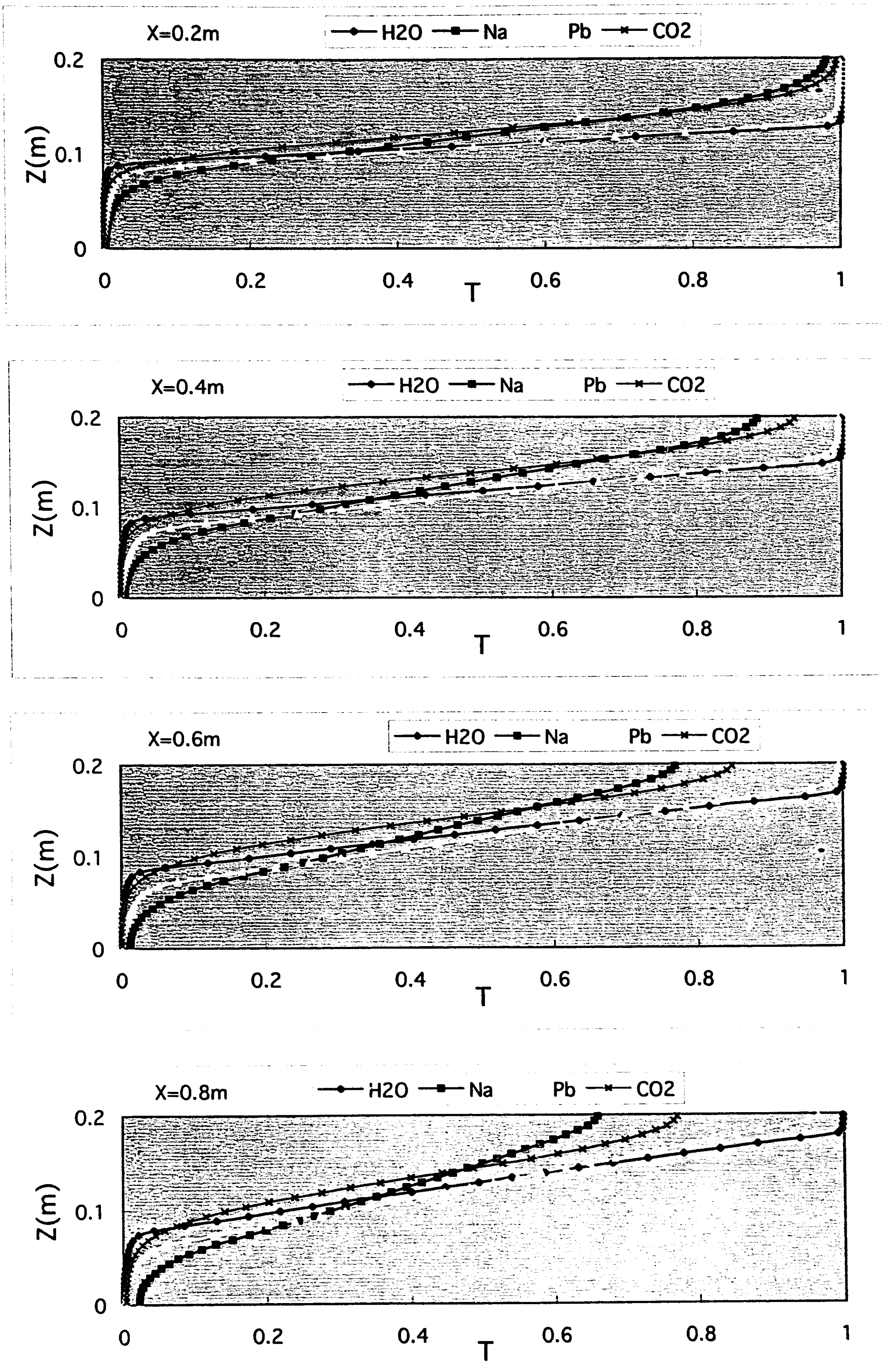


Fig.3-27 CASE1(Ri=2,DV=0.084m/s):normalized mean temperature

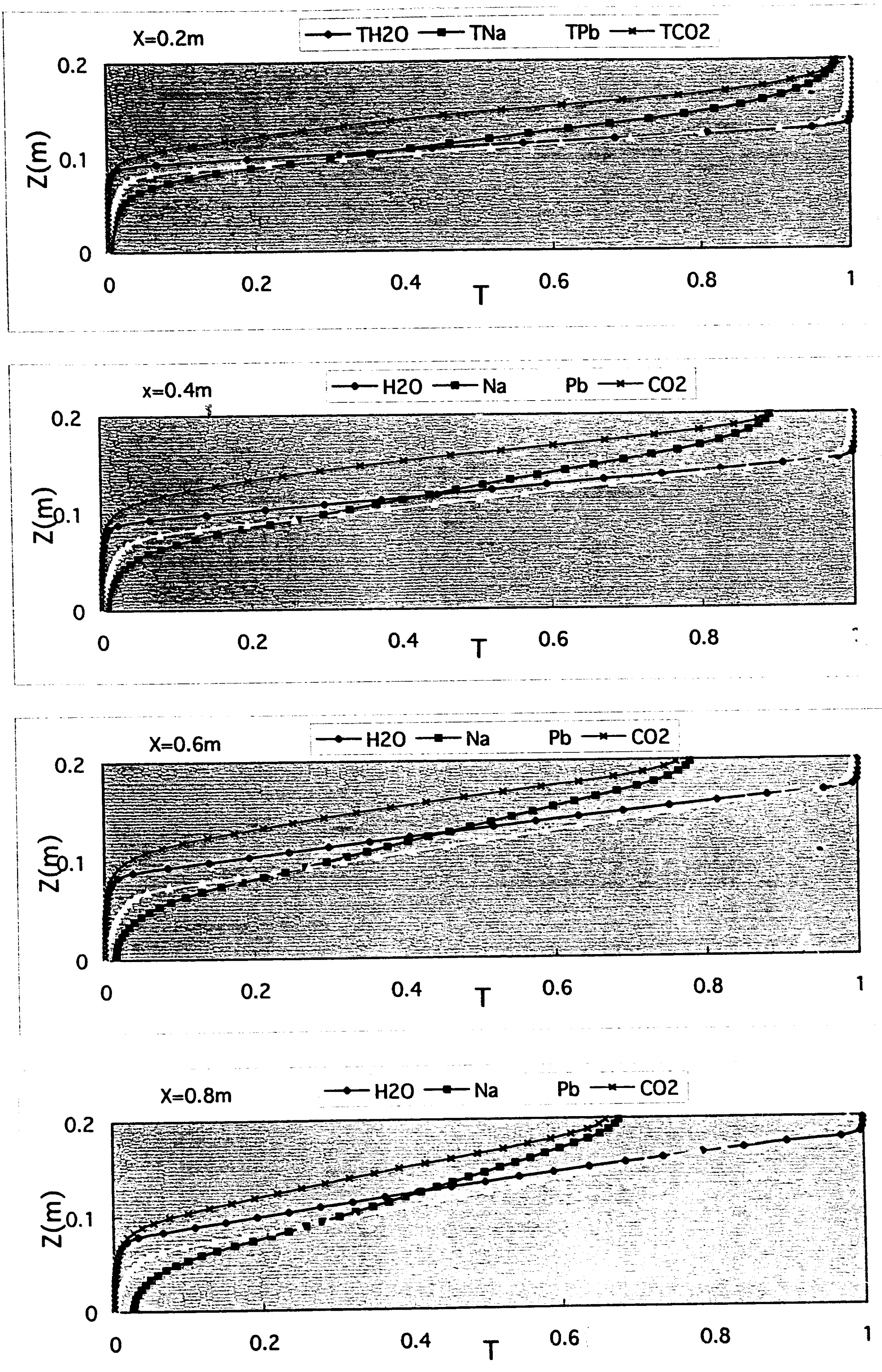


Fig.3-28 CASE2(Ri=2,DT=20℃): normalied mean temperature

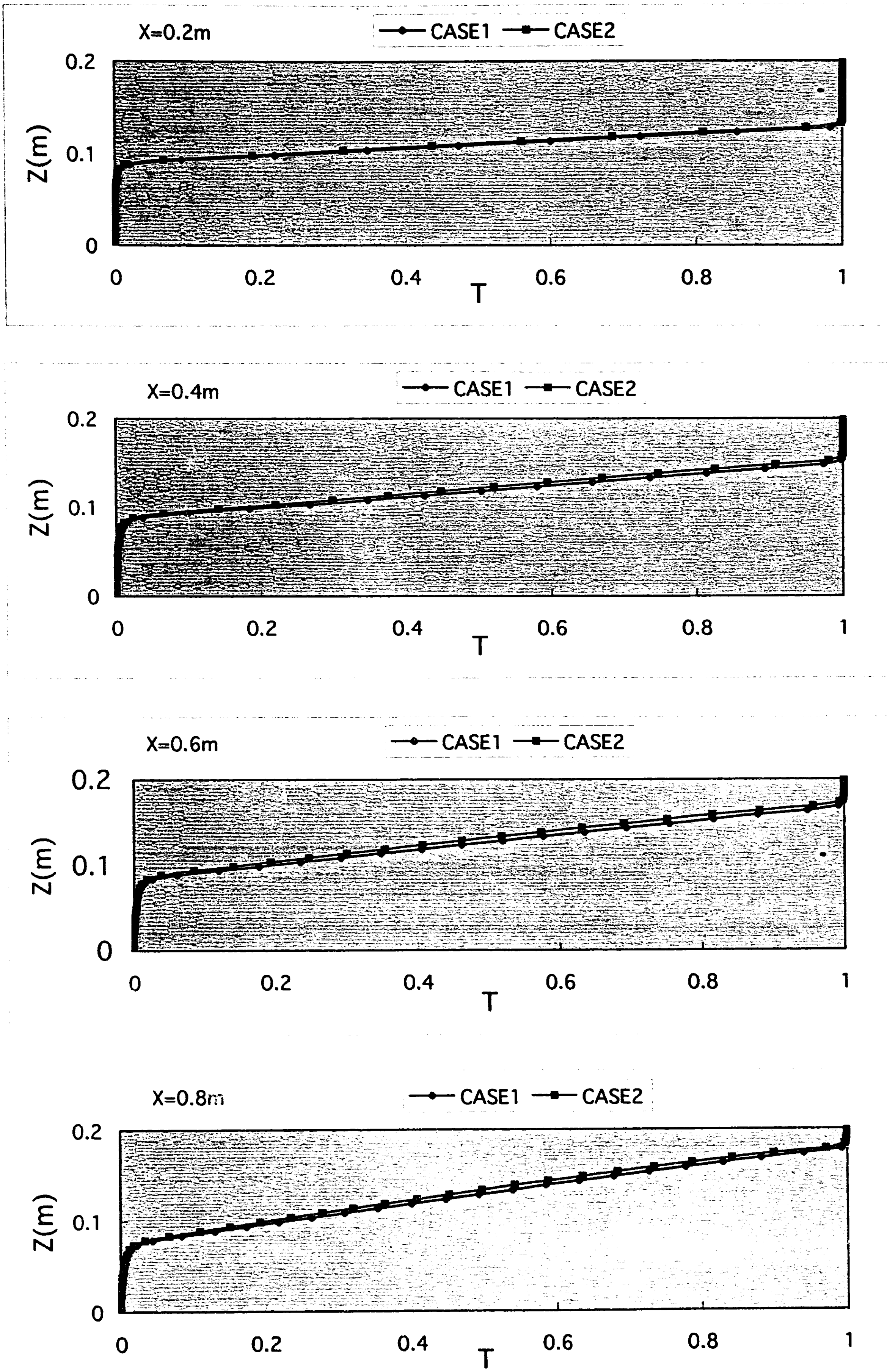


Fig.3-29 H2O: normalized mean temperature

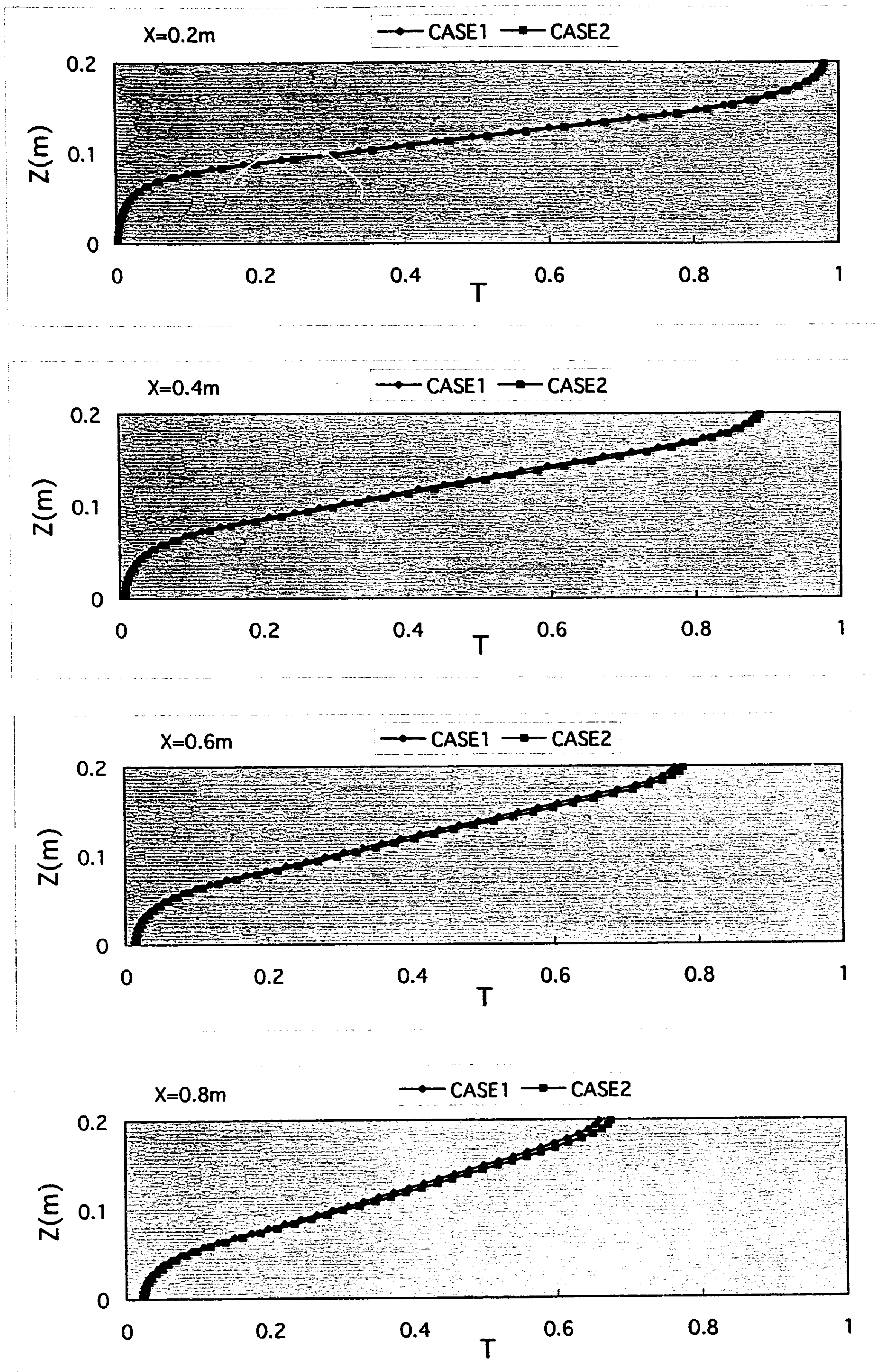


Fig.3-30 Na: normalized mean temperature

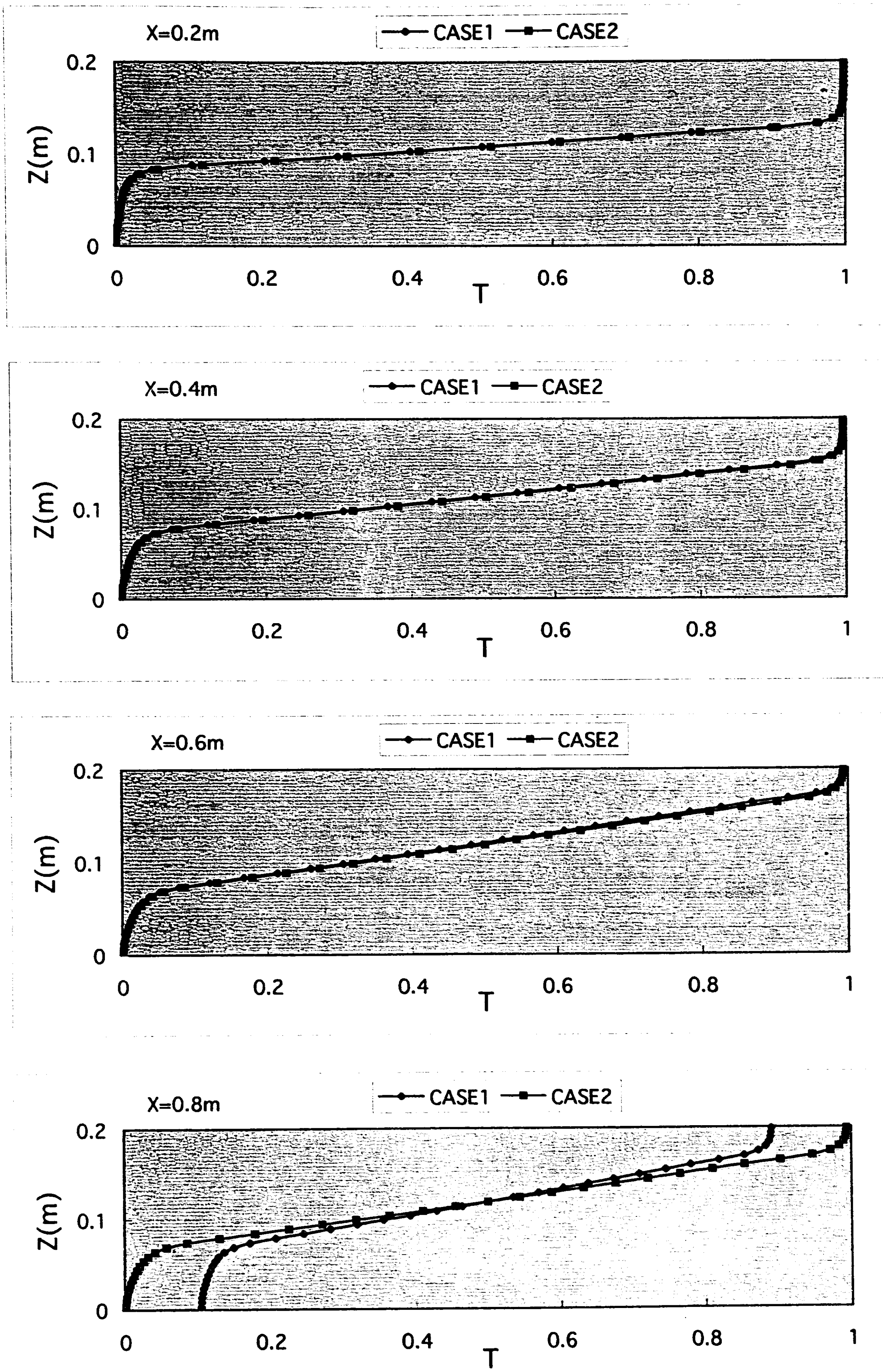
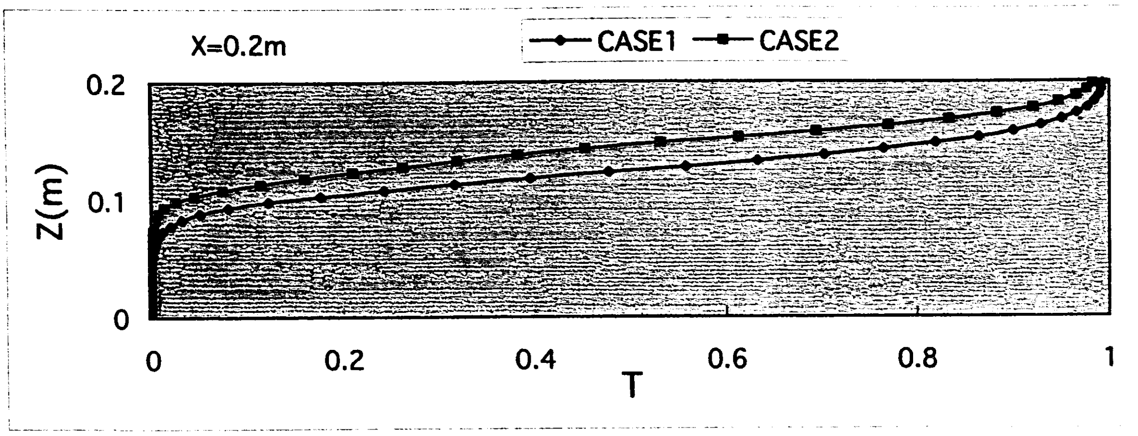
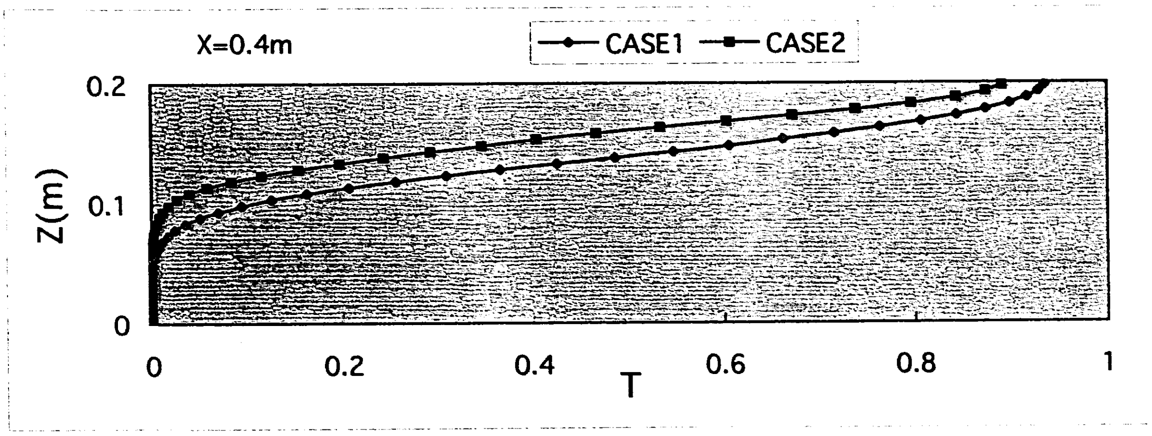
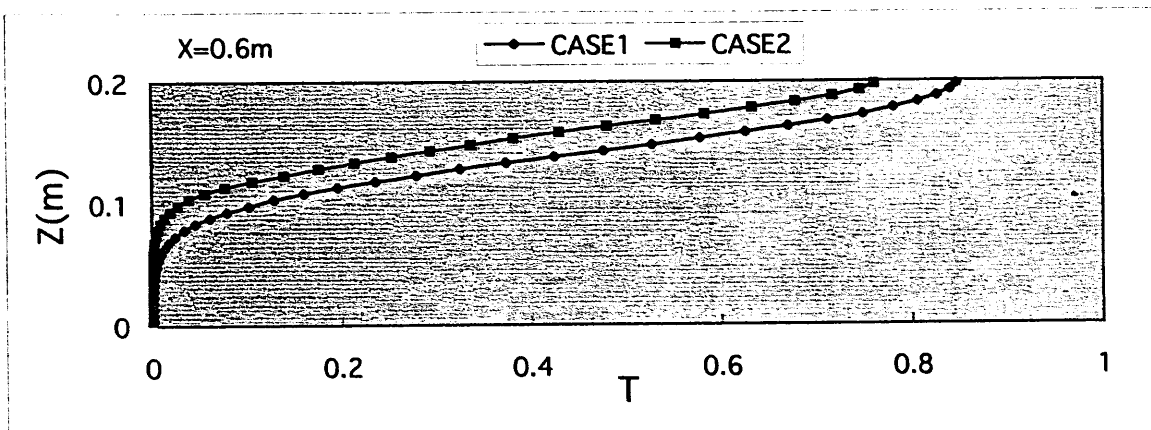


Fig.3-31 Pb: normalized mean temperature







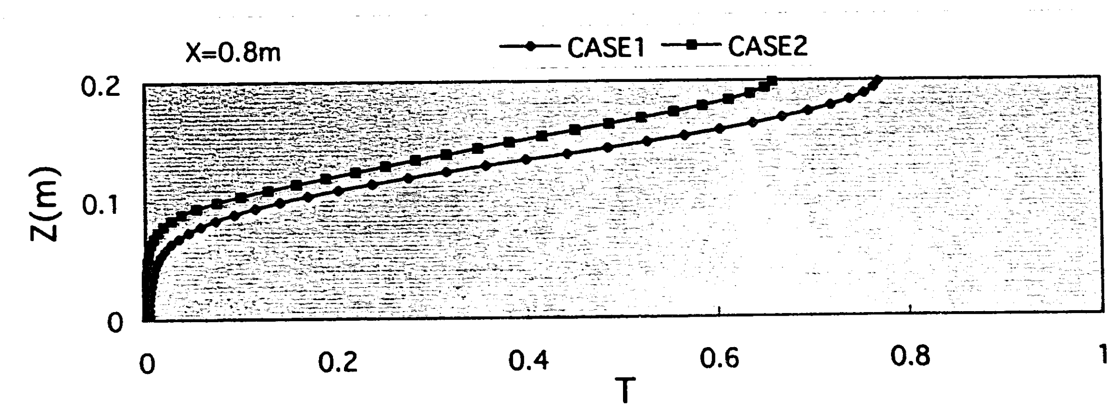


Fig.3-32 CO2: normalized mean temperature

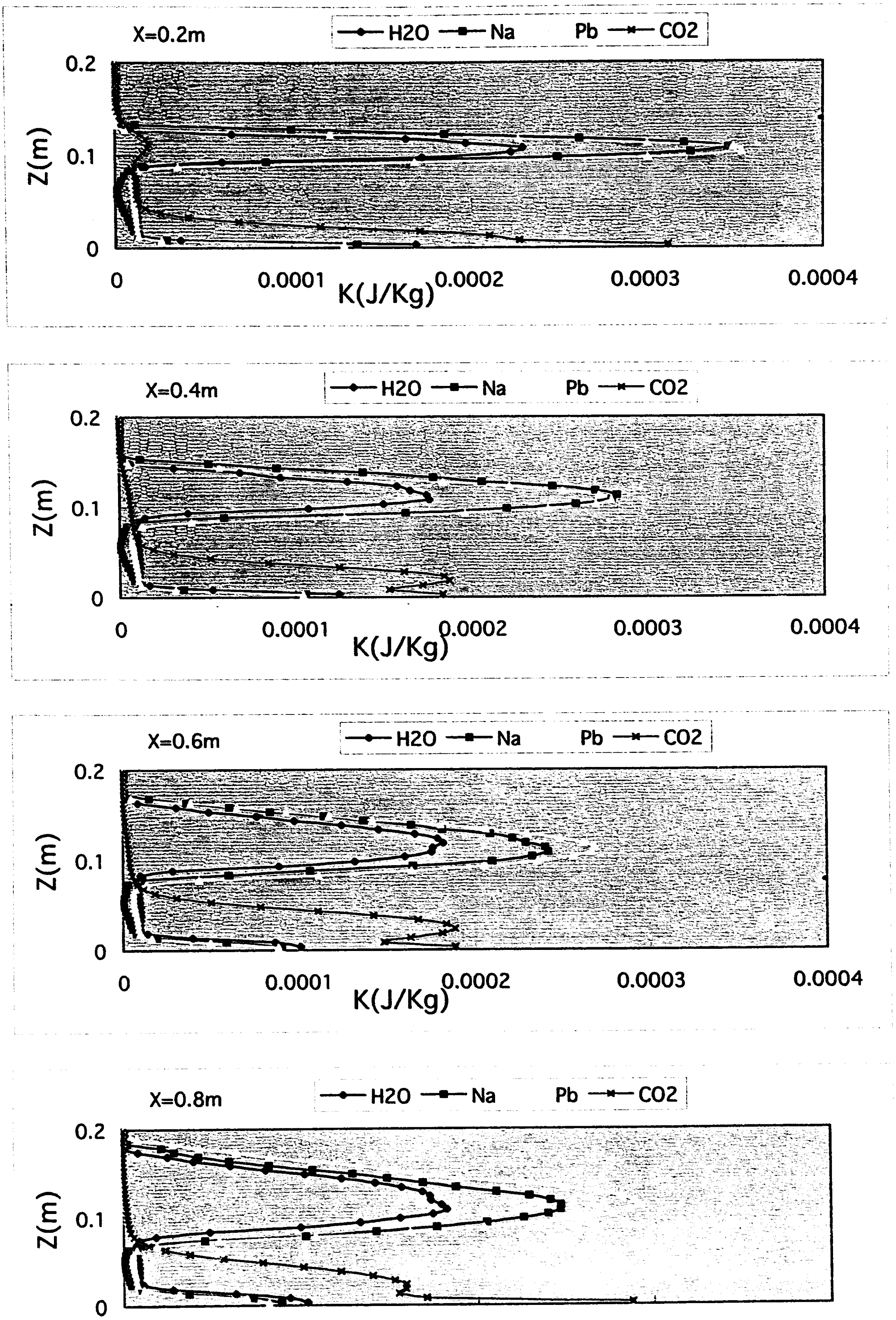


Fig.3-33 CASE1(Ri=2,DV=0.084m/s): turbulent kinetic energy(K)

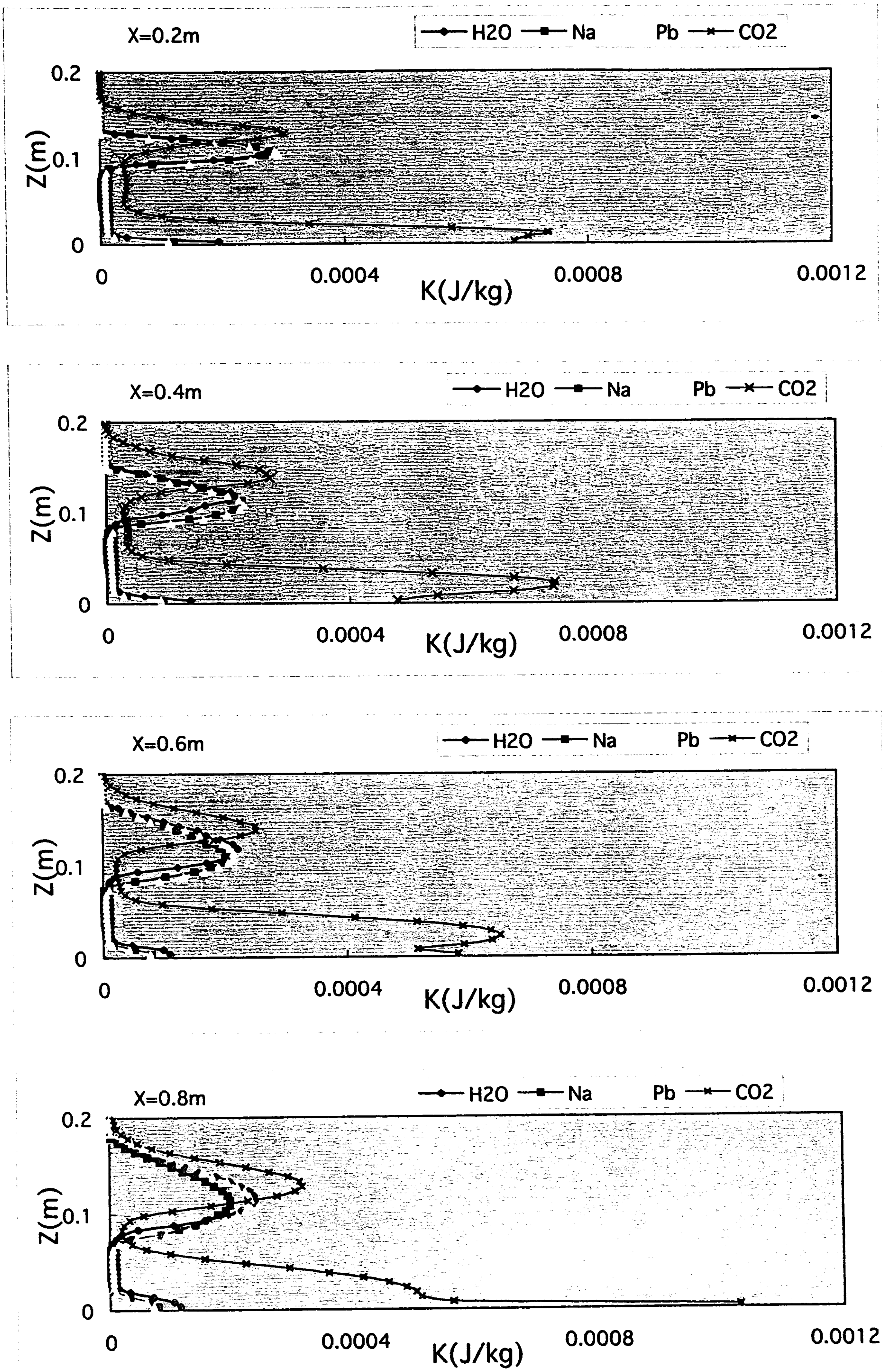


Fig.3-34 CASE2(Ri=2,DT=20℃): turbulent kinetic energy(K)

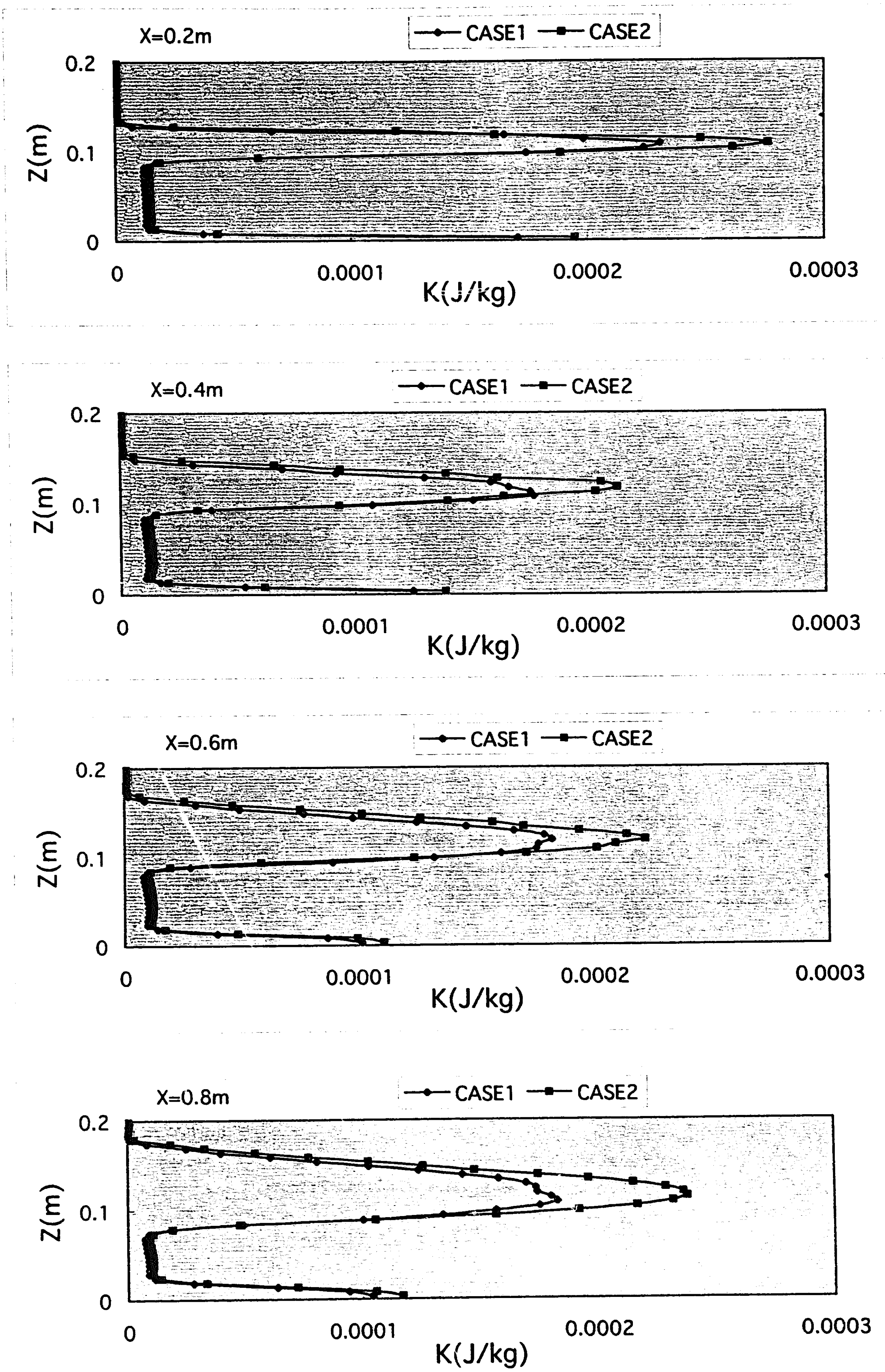


Fig.3-35 H2O: turbulent kinetic energy(K)

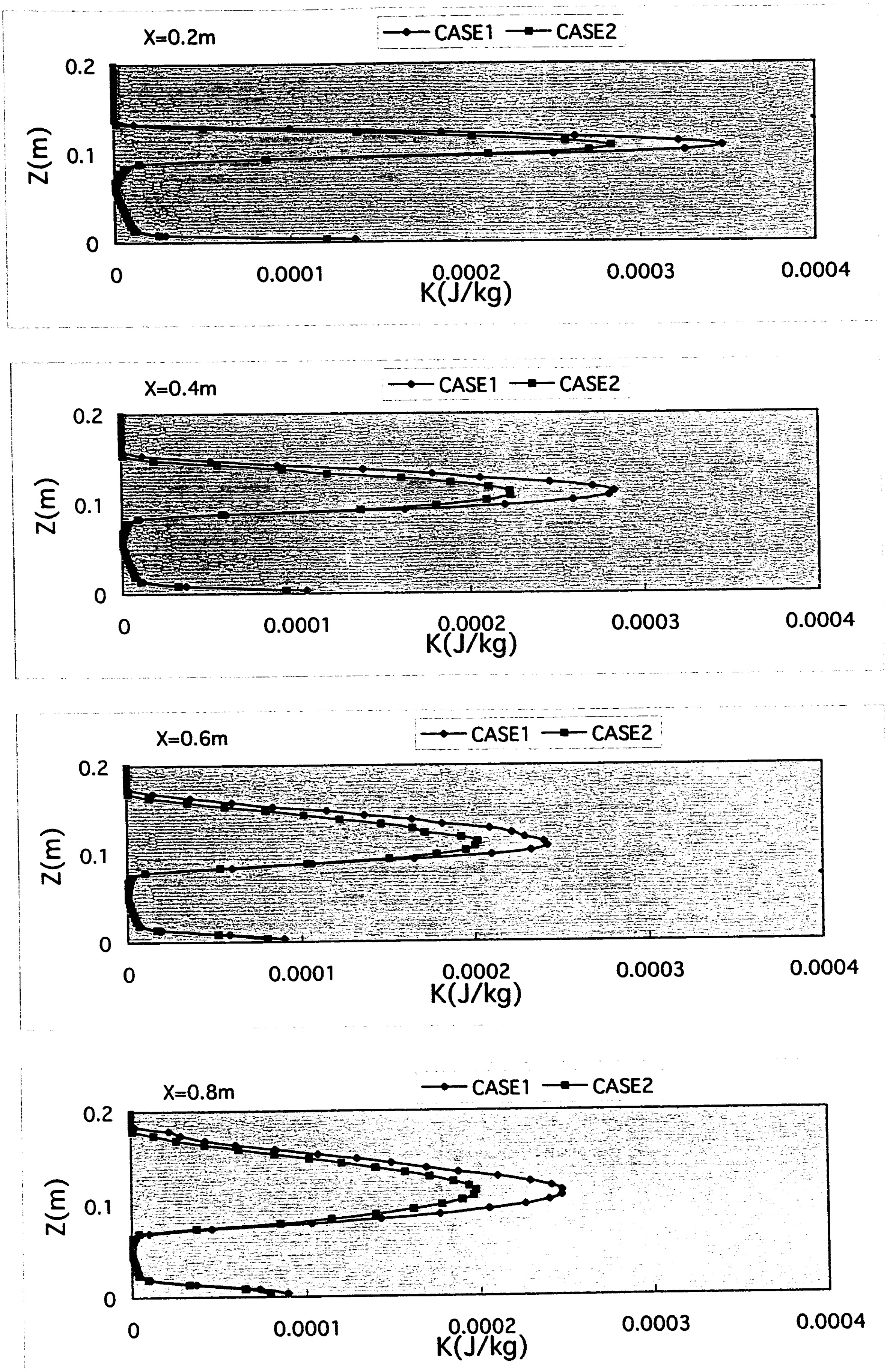


Fig.3-36 Na: kurbulent kinetic energy(K)

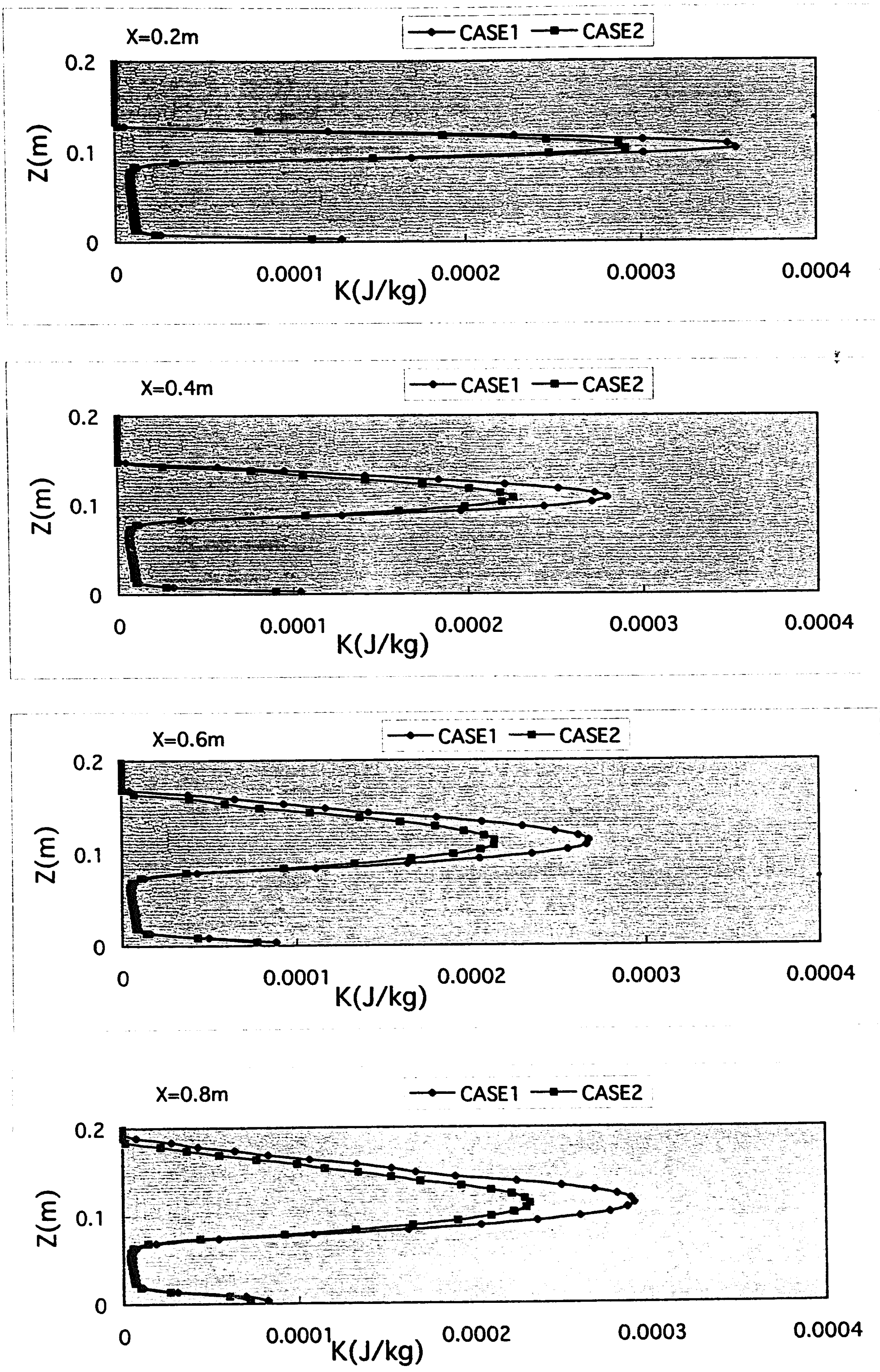


Fig.3-37 Pb: turbulent kinetic energy(K)

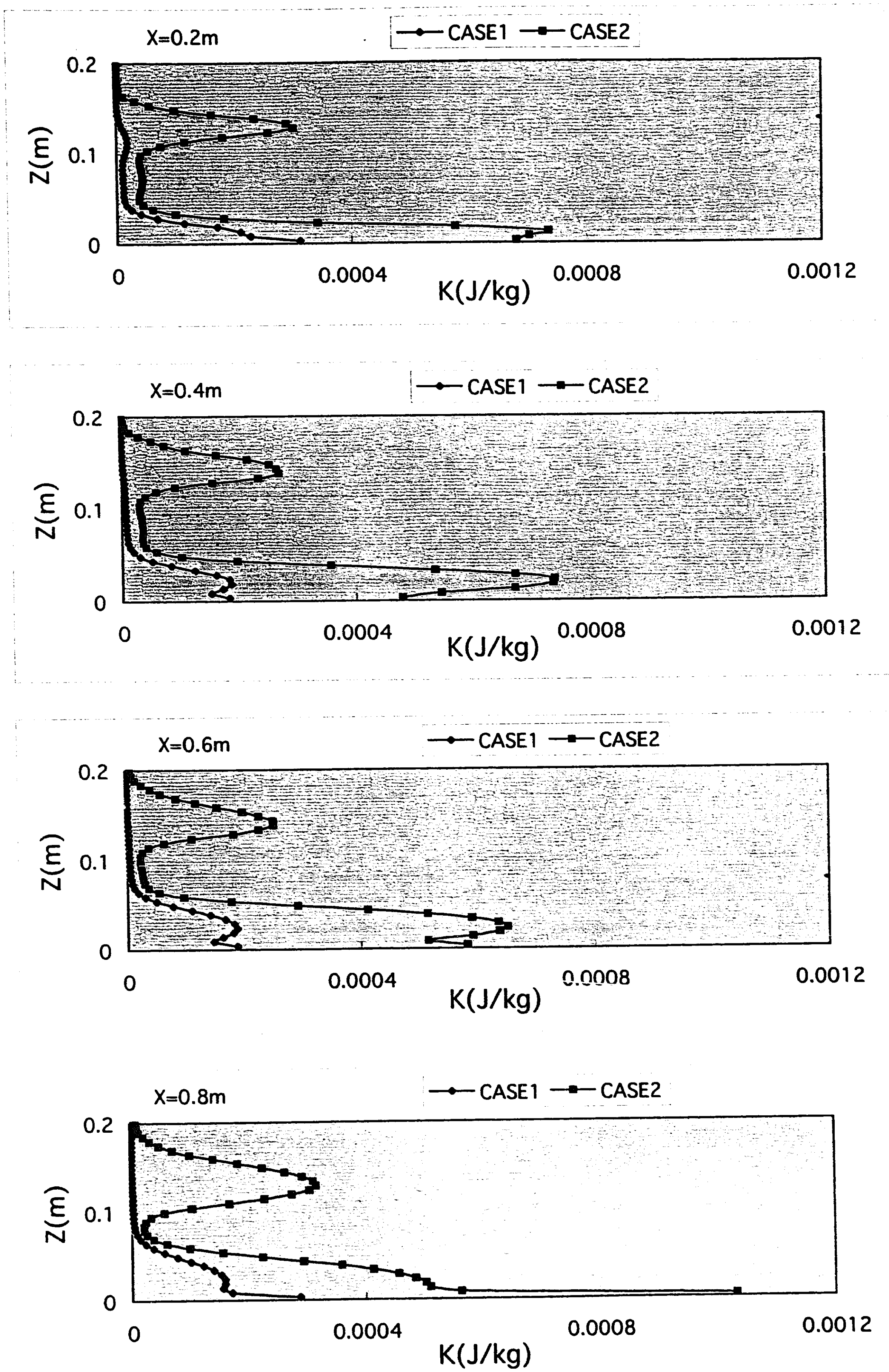


Fig.3-38 CO2: turbulent kinetic energy(K)

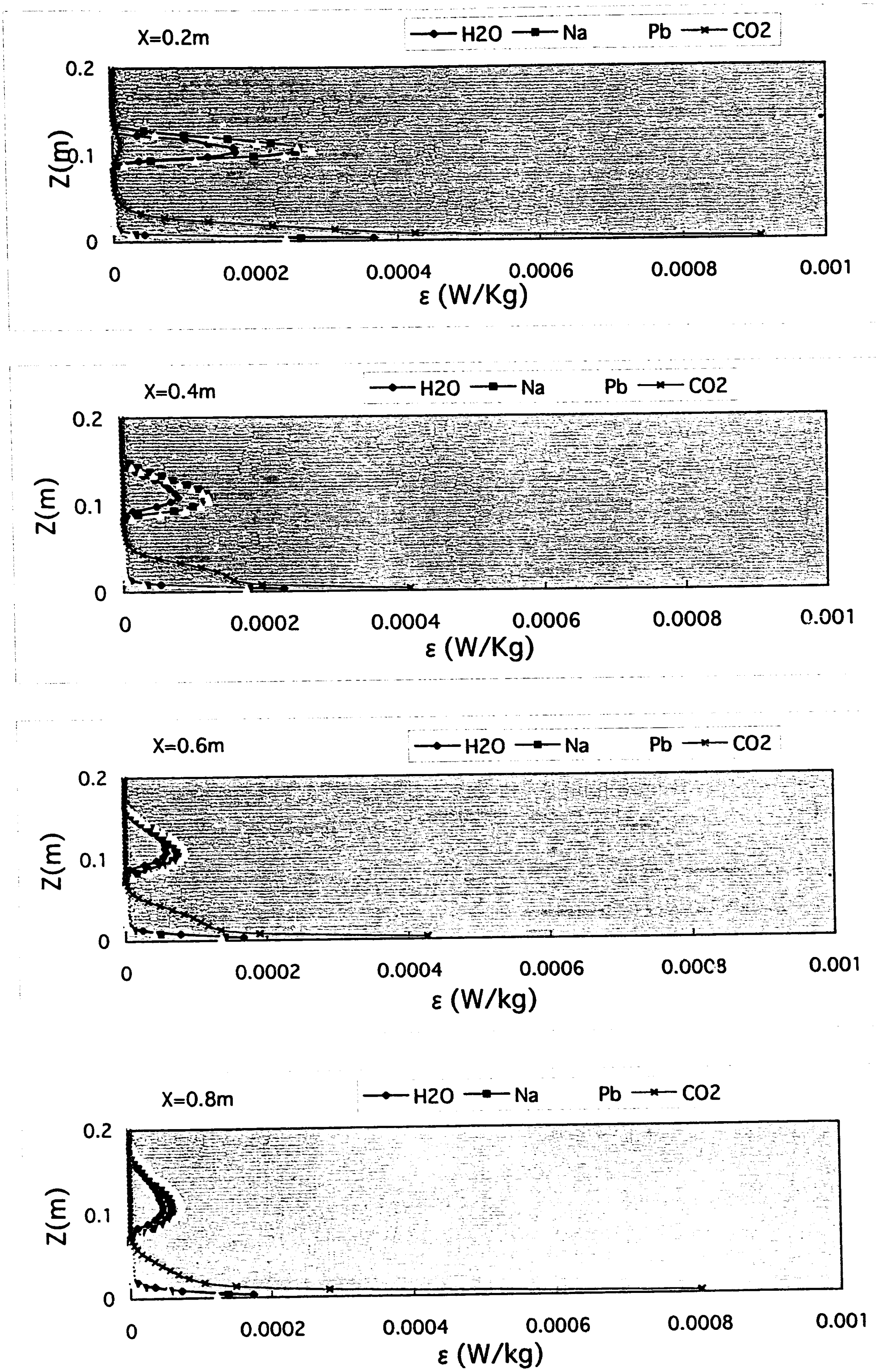


Fig.3-39 CASE1(Ri=2,DV=0.084m/s): dissipation rate of K(ε)

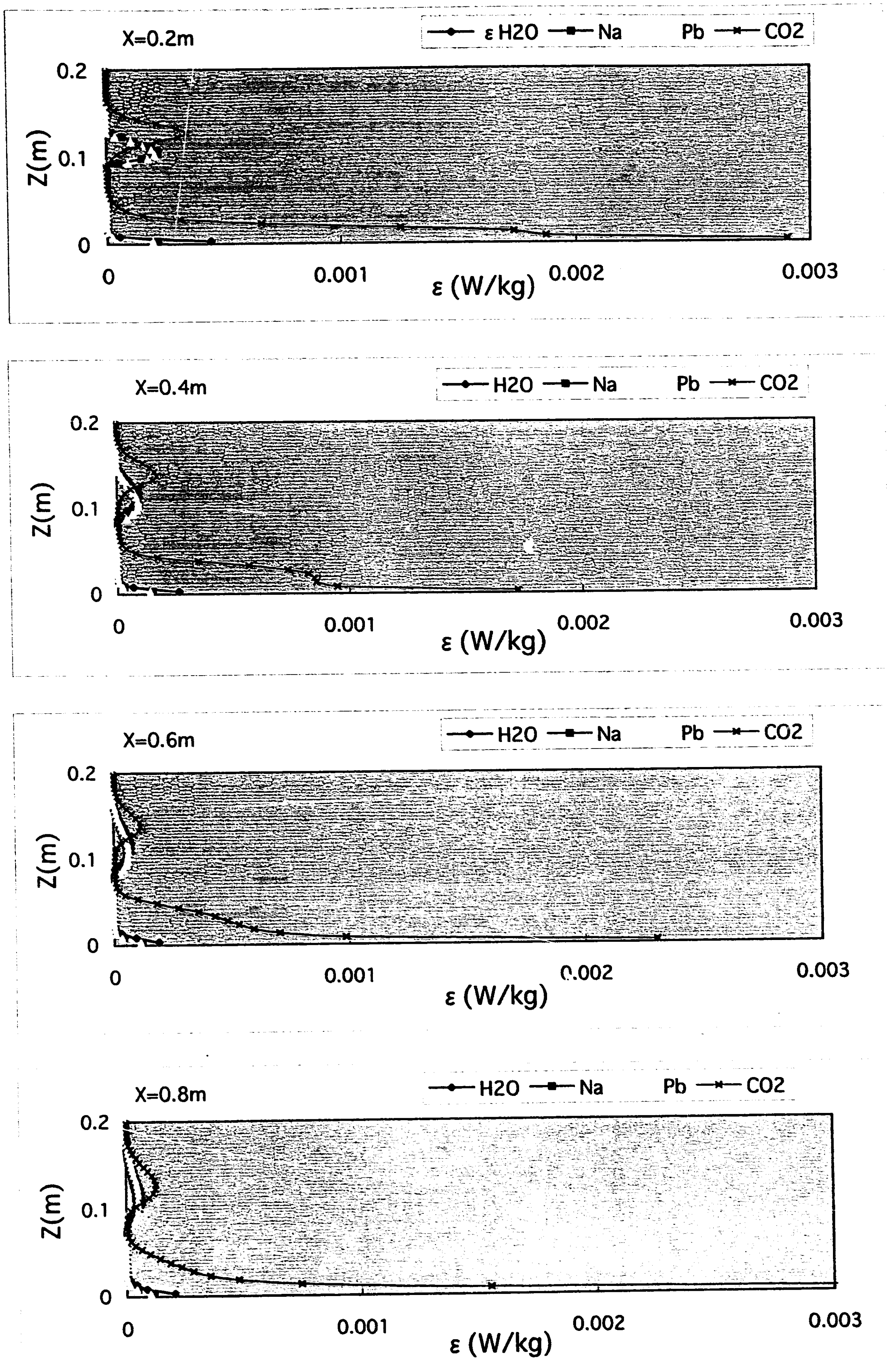


Fig.3-40 CASE2(Ri=2,DT=20℃): dissipation rate of K(ε)

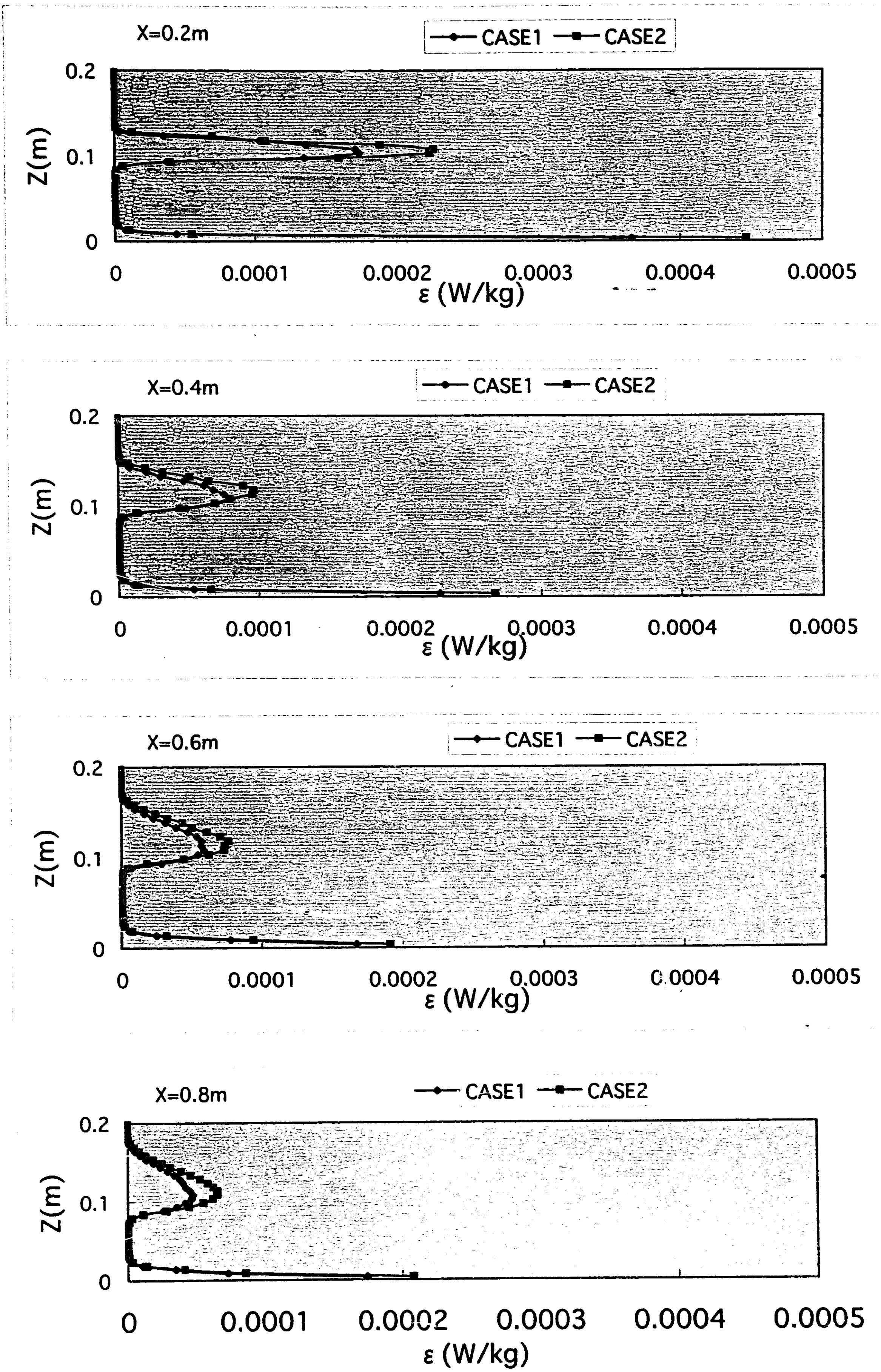


Fig.3-41 H2O: dissipation rate of K(ε)

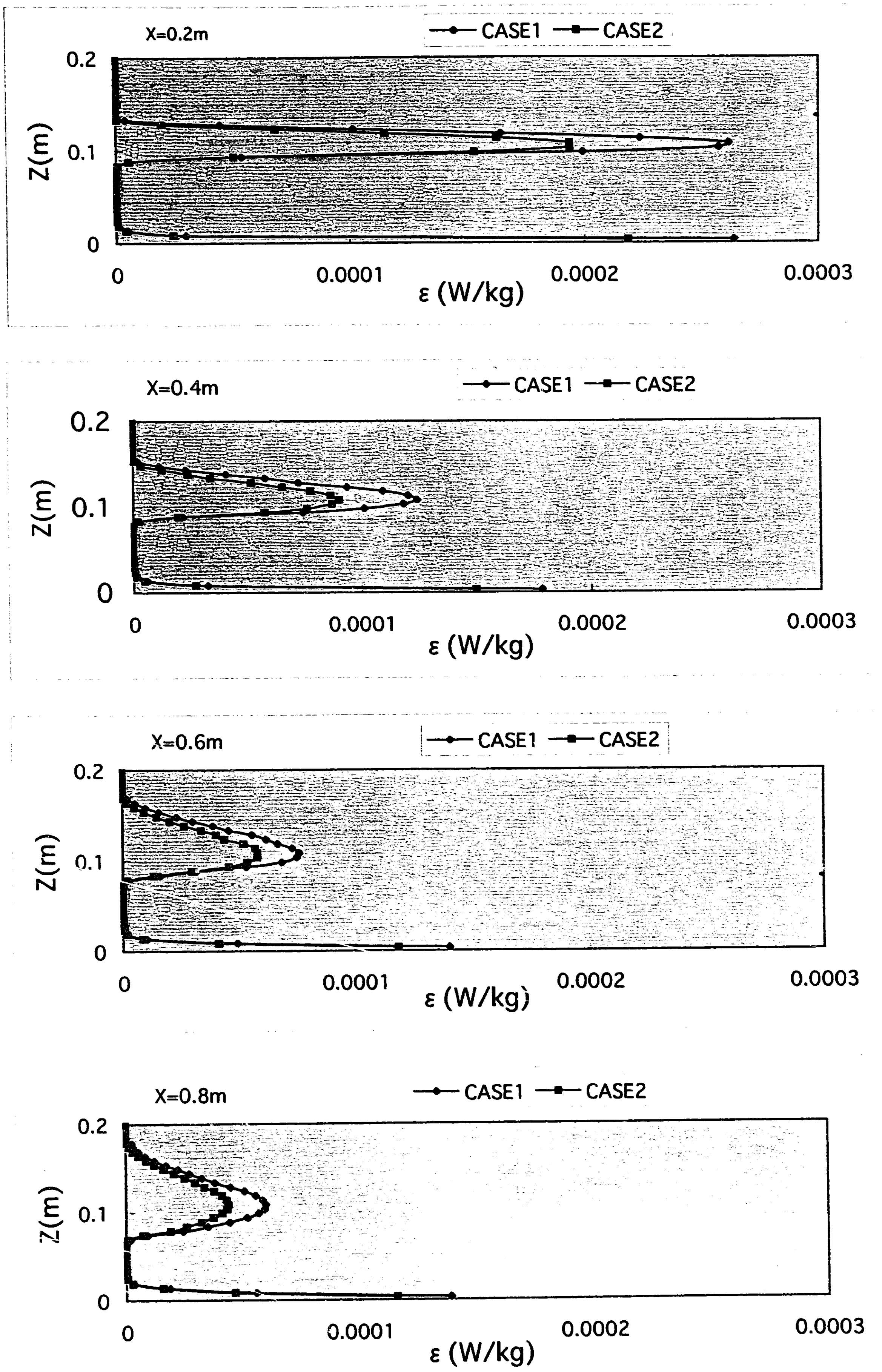


Fig.3-42 Na: dissipation rate of K(ε)

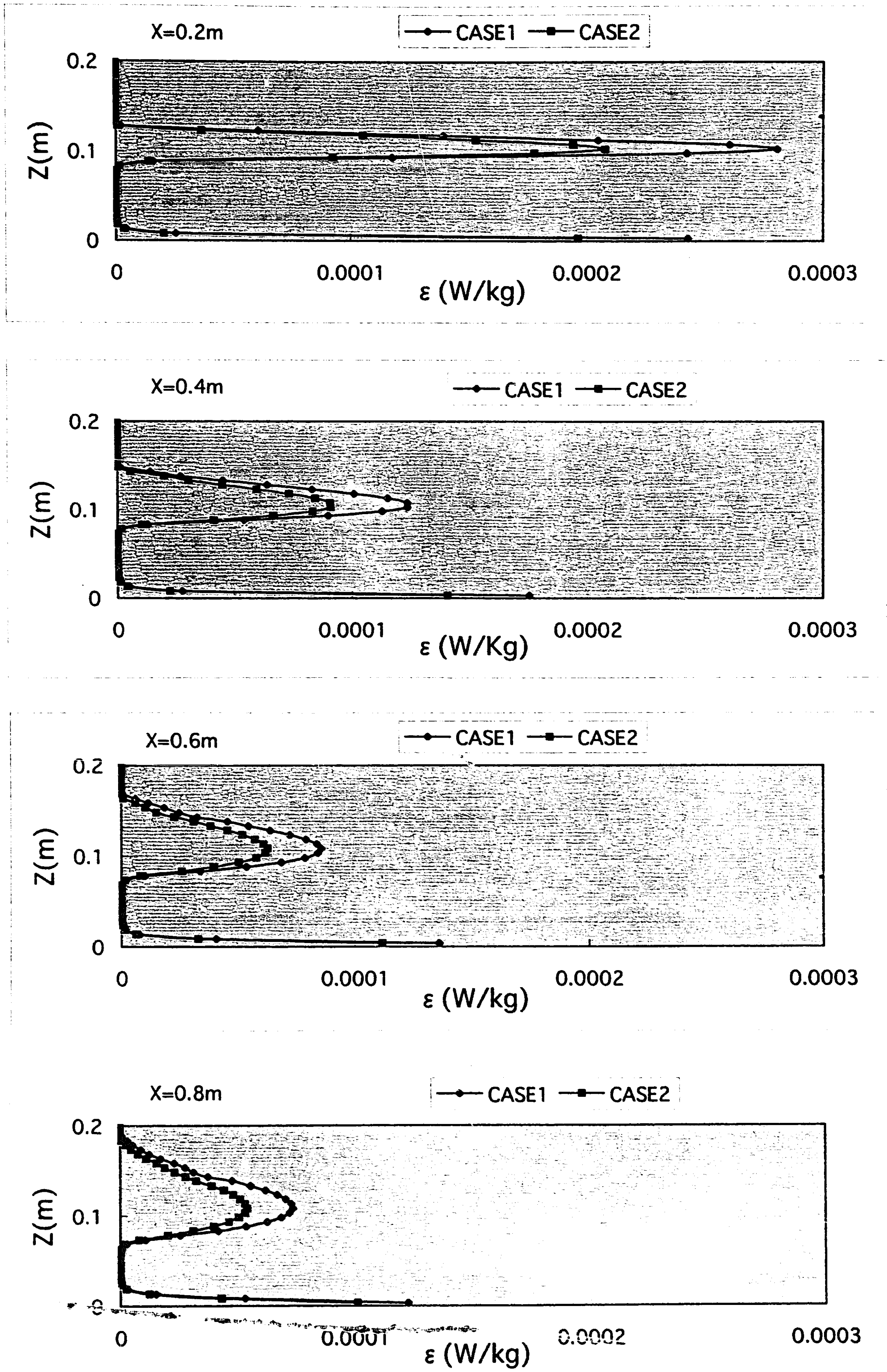


Fig.3-43 Pb: dissipation rate of K(ε)

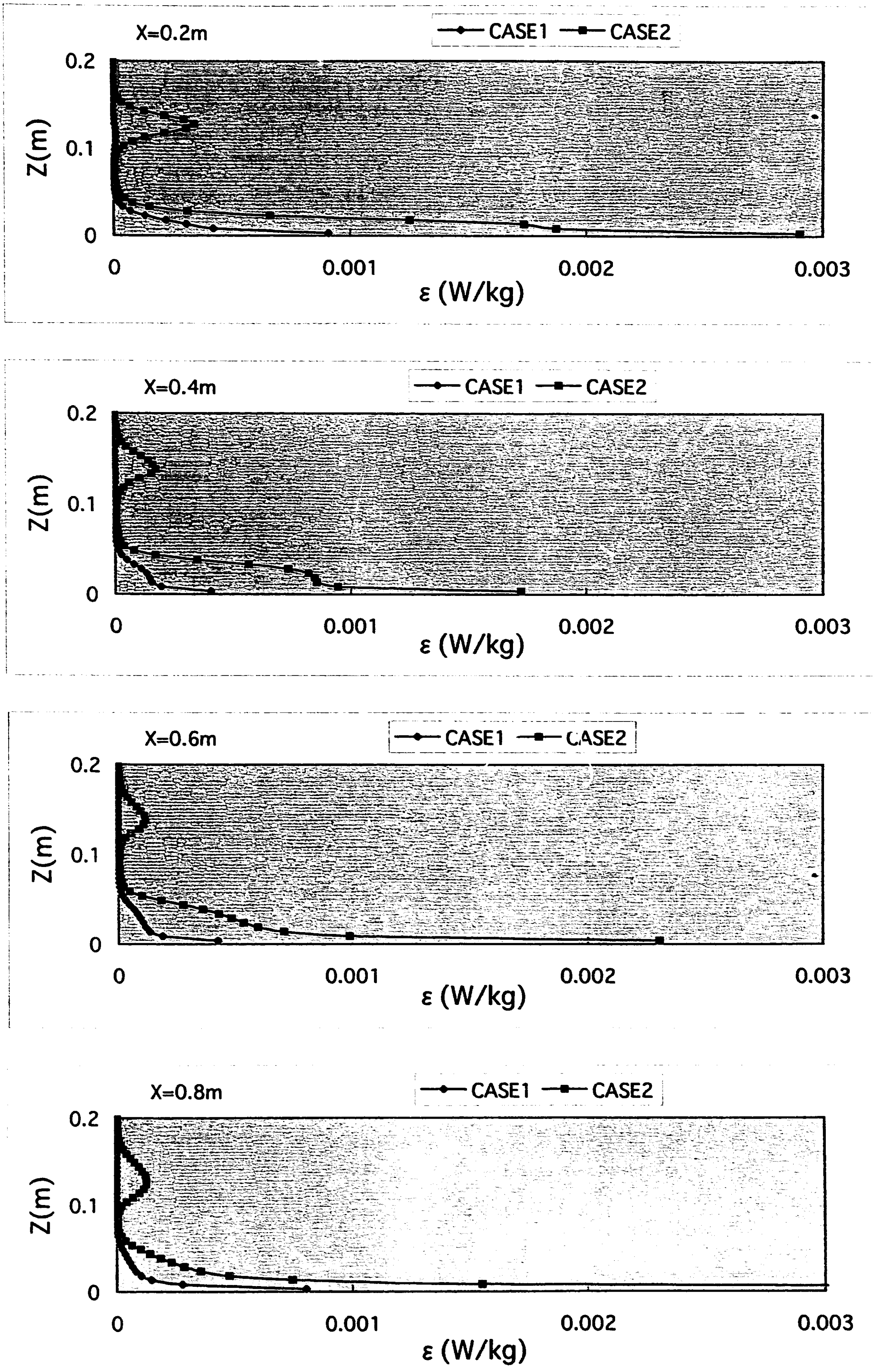


Fig.3-44 CO2: dissipation rate of K(ε)

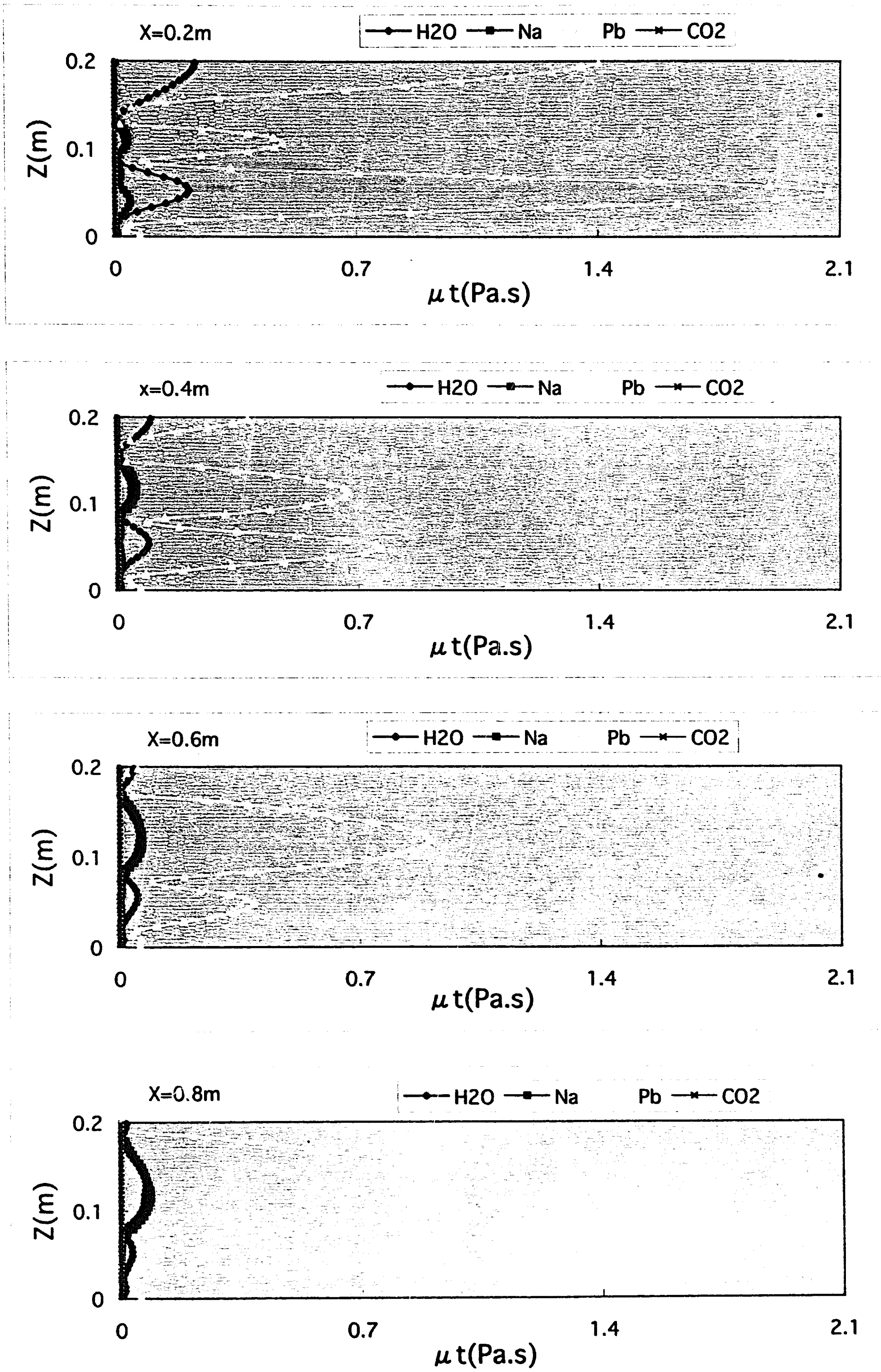


Fig.3-45 CASE1(Ri=2,DV=0.084m/s): turbulent viscosity(μt)

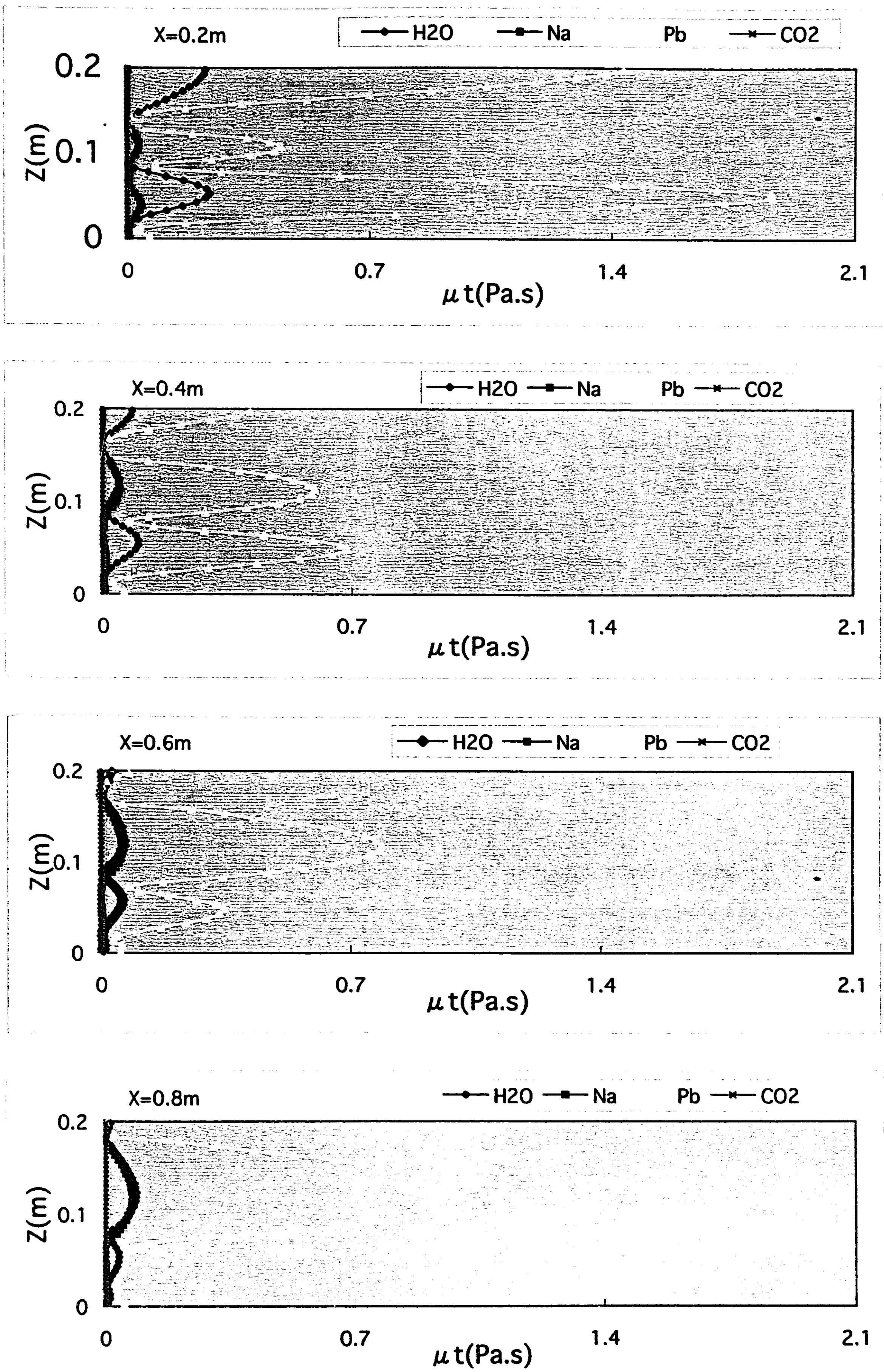


Fig.3-46 CASE2(Ri=2,DT=20℃): turbulent viscosity(μt)

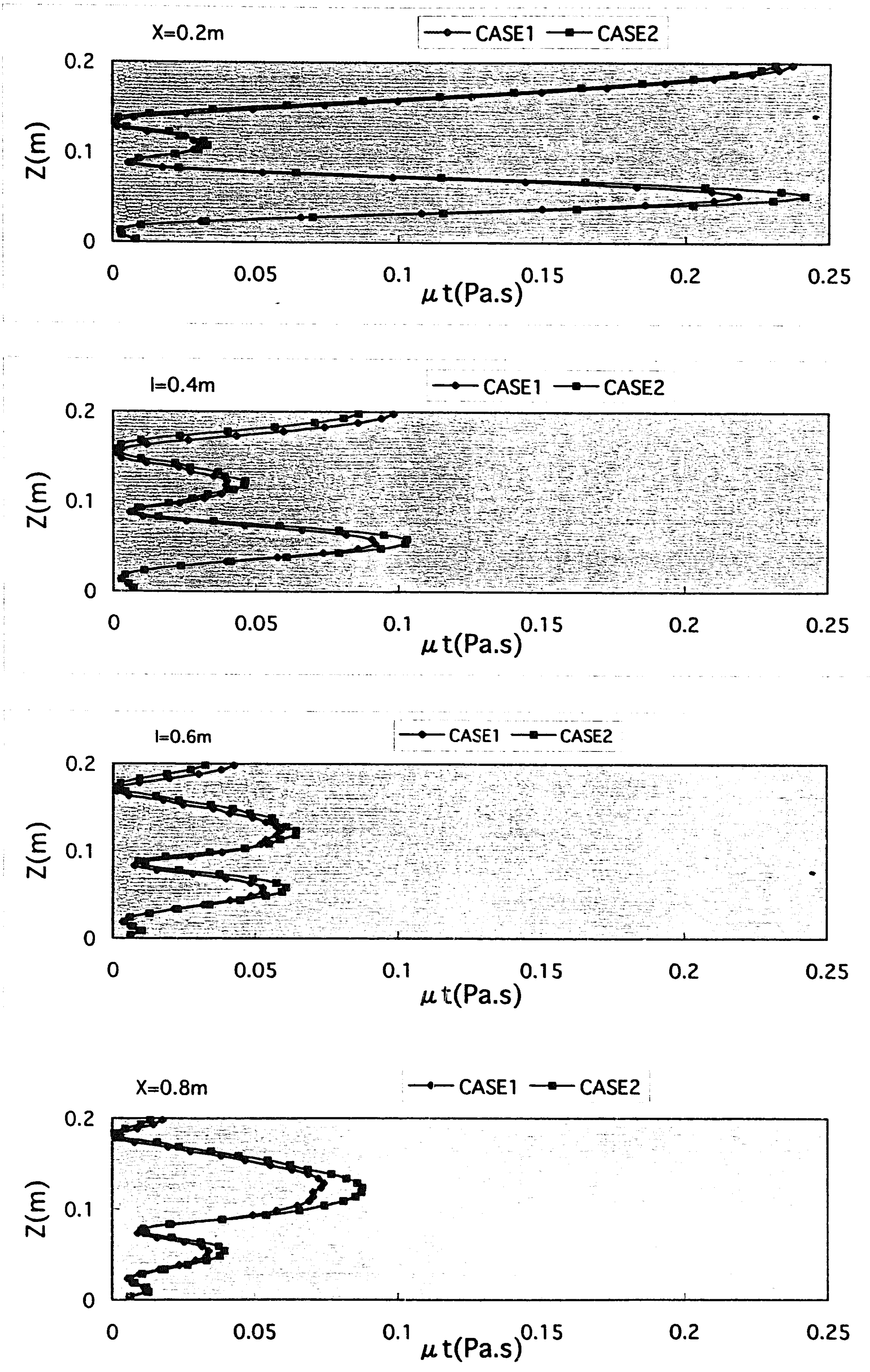


Fig.3-47 H2O: turbulent viscosity (μt)

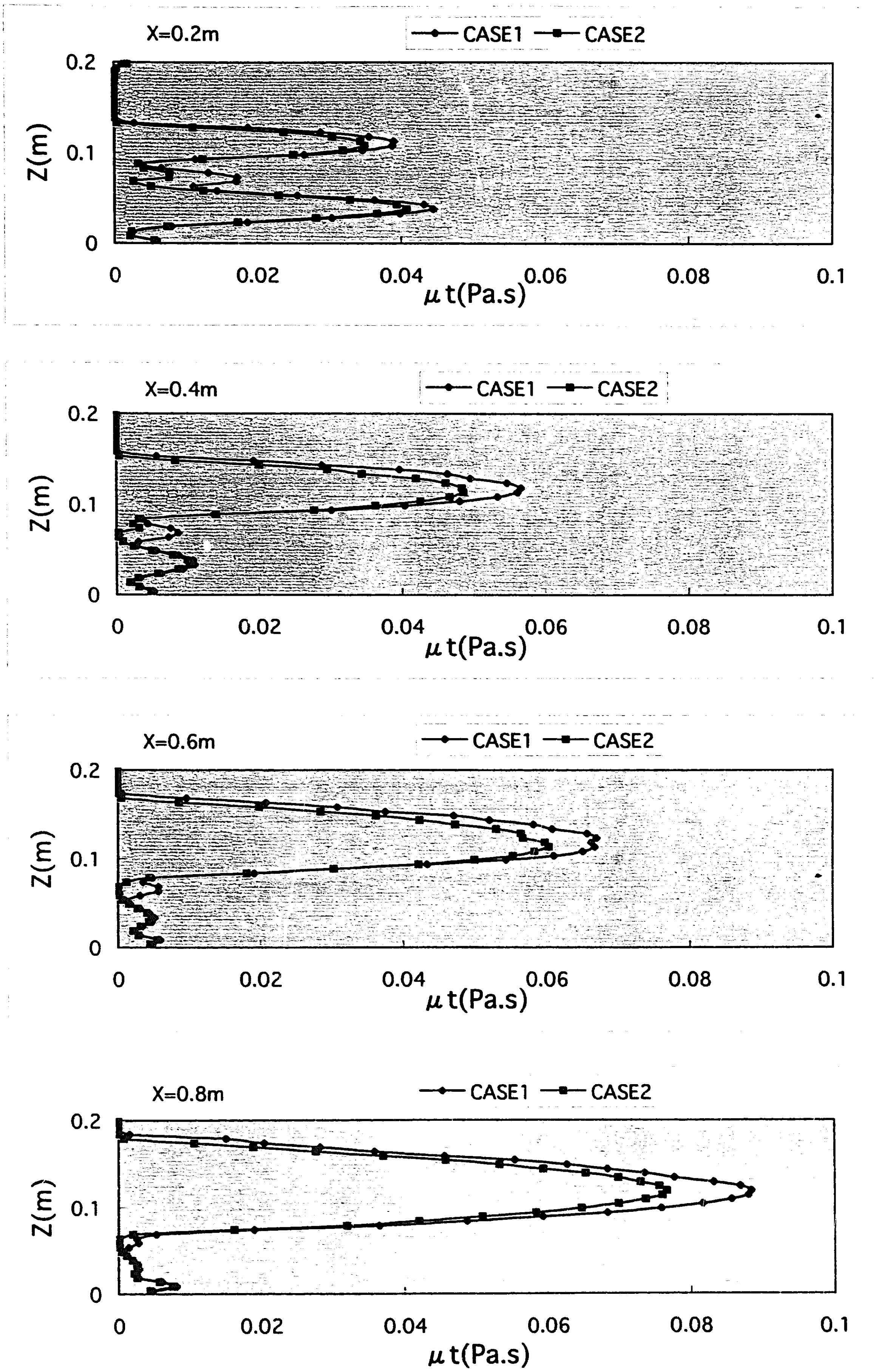


Fig.3-48 Na: turbulent viscocity(μ t)

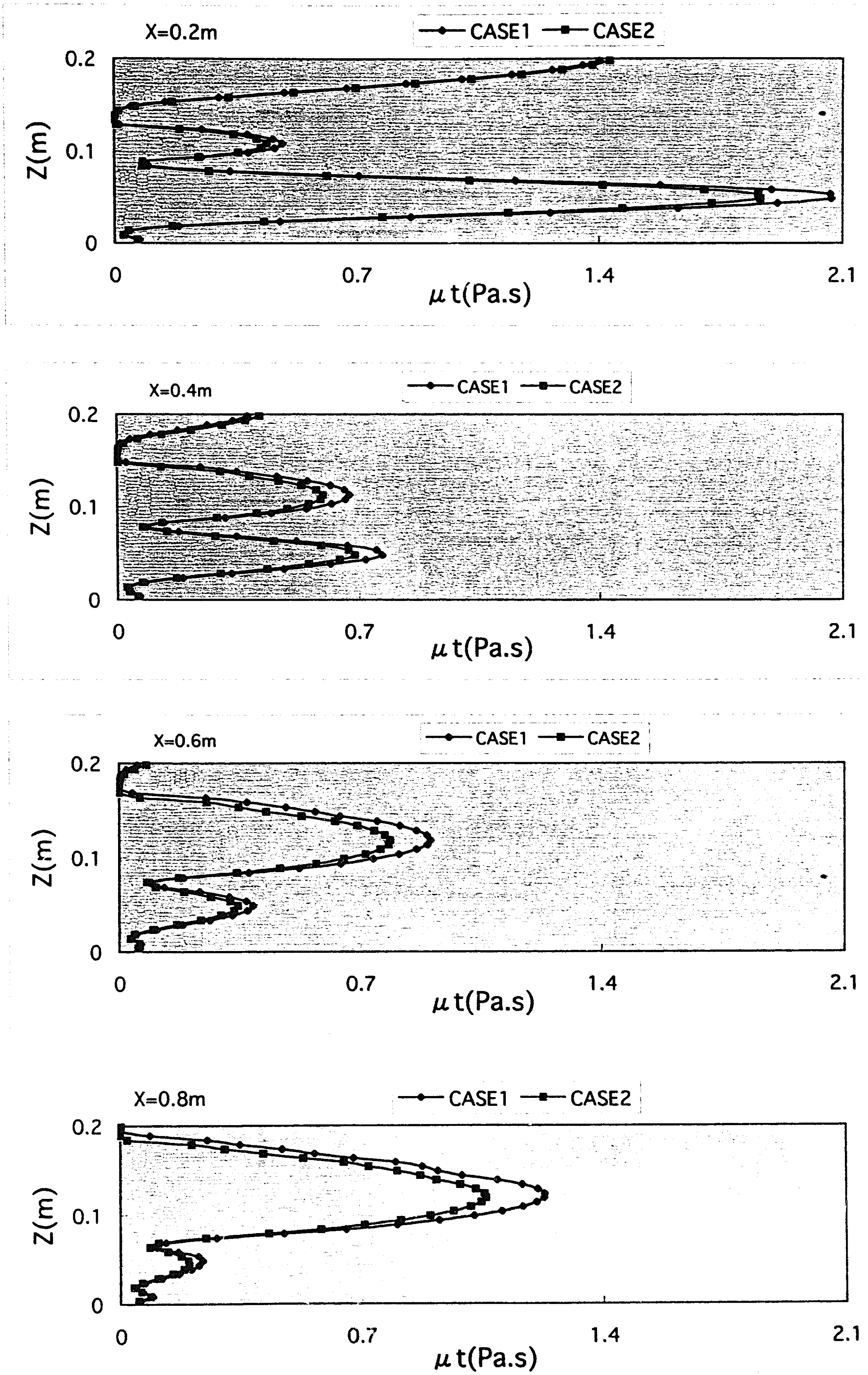


Fig.3-49 Pb: turbulent viscosity(μt)

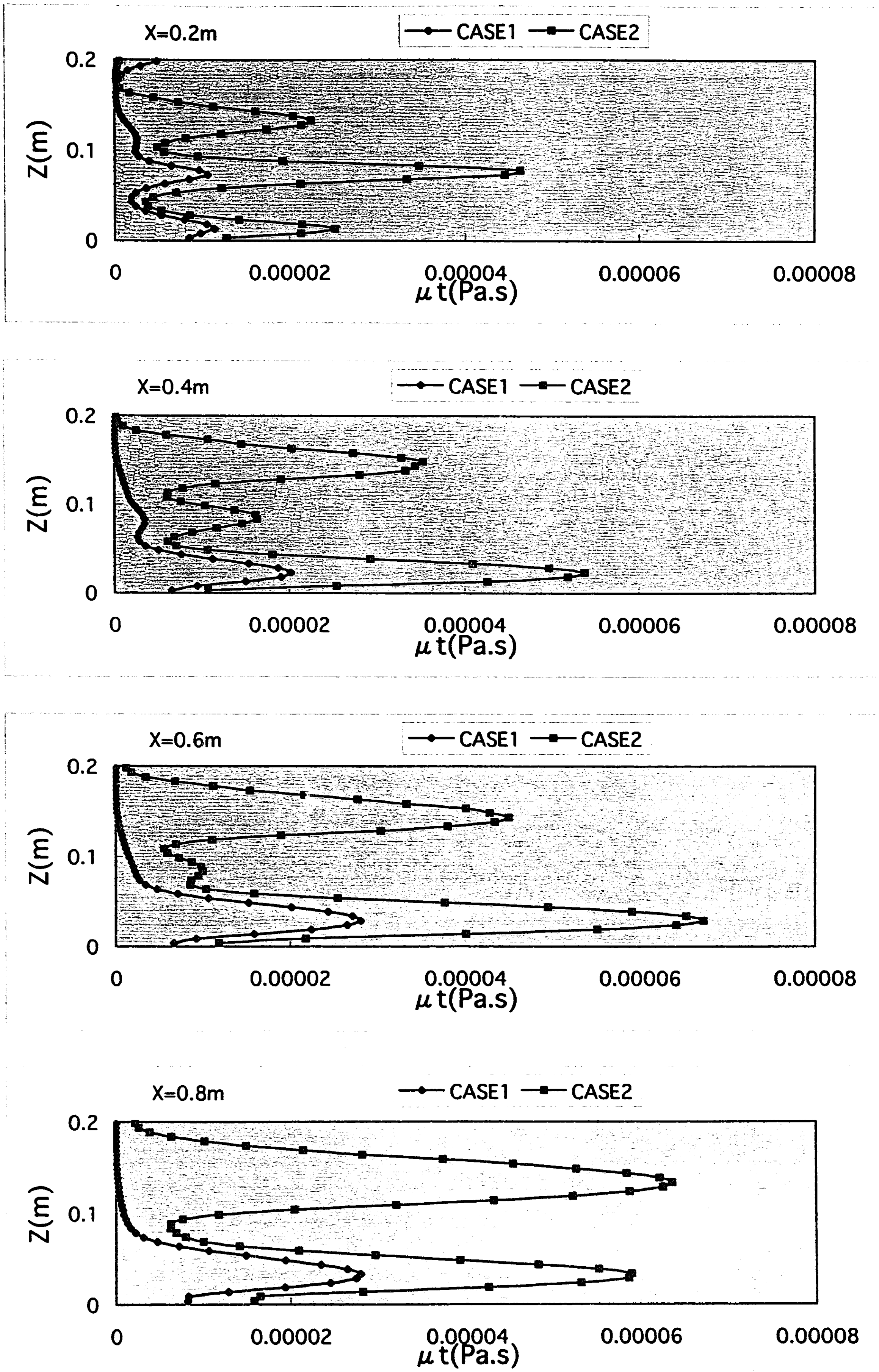


Fig.3-50 CO2: turbulent viscosity(μ t)

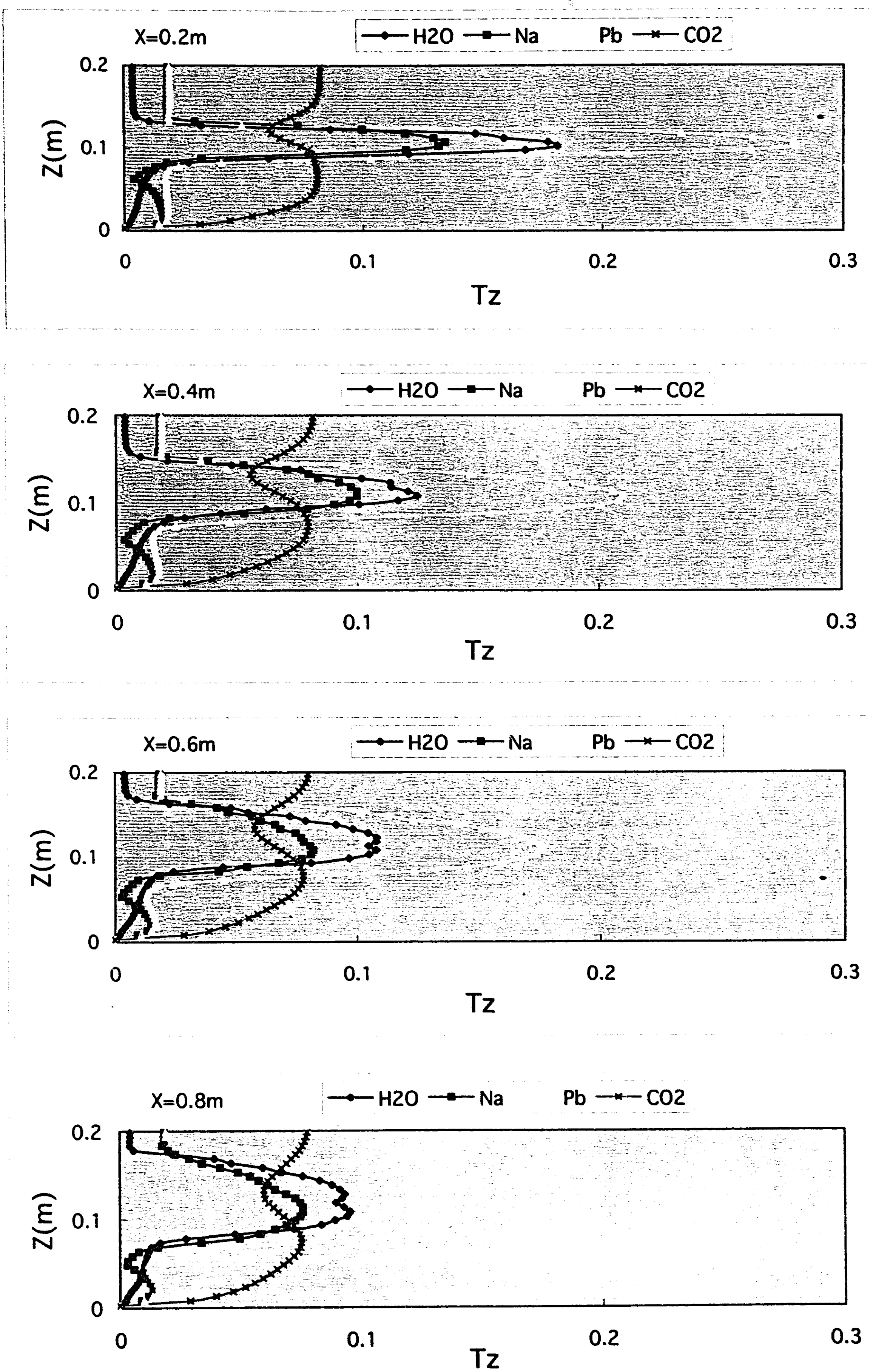


Fig.3-51 CASE1(Ri=2,DV=0.084m/S): normalized temperature fluctuation

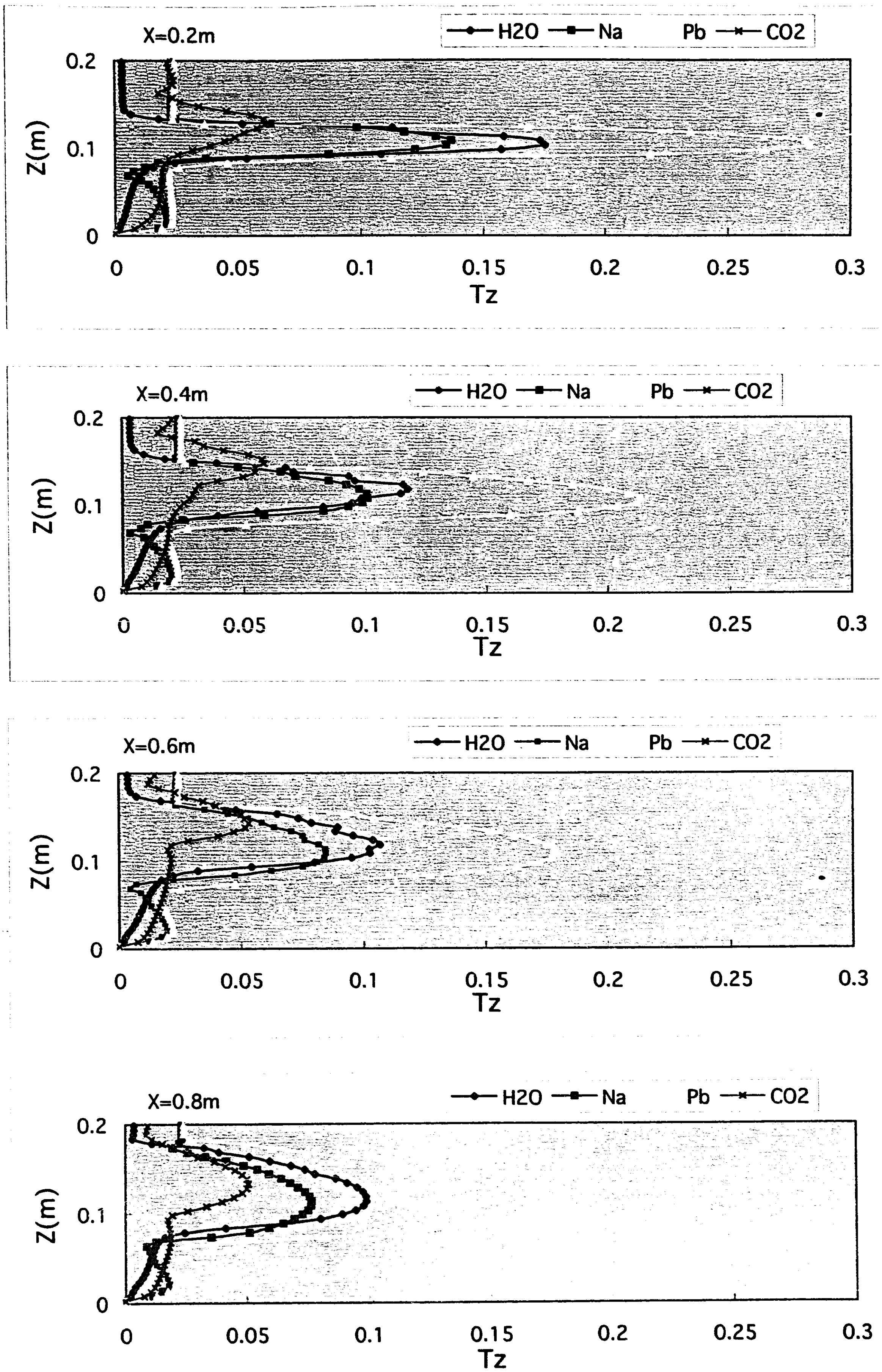


Fig.3-52CASE2(Ri=2,DT=20℃): normalized temperature fluctuation

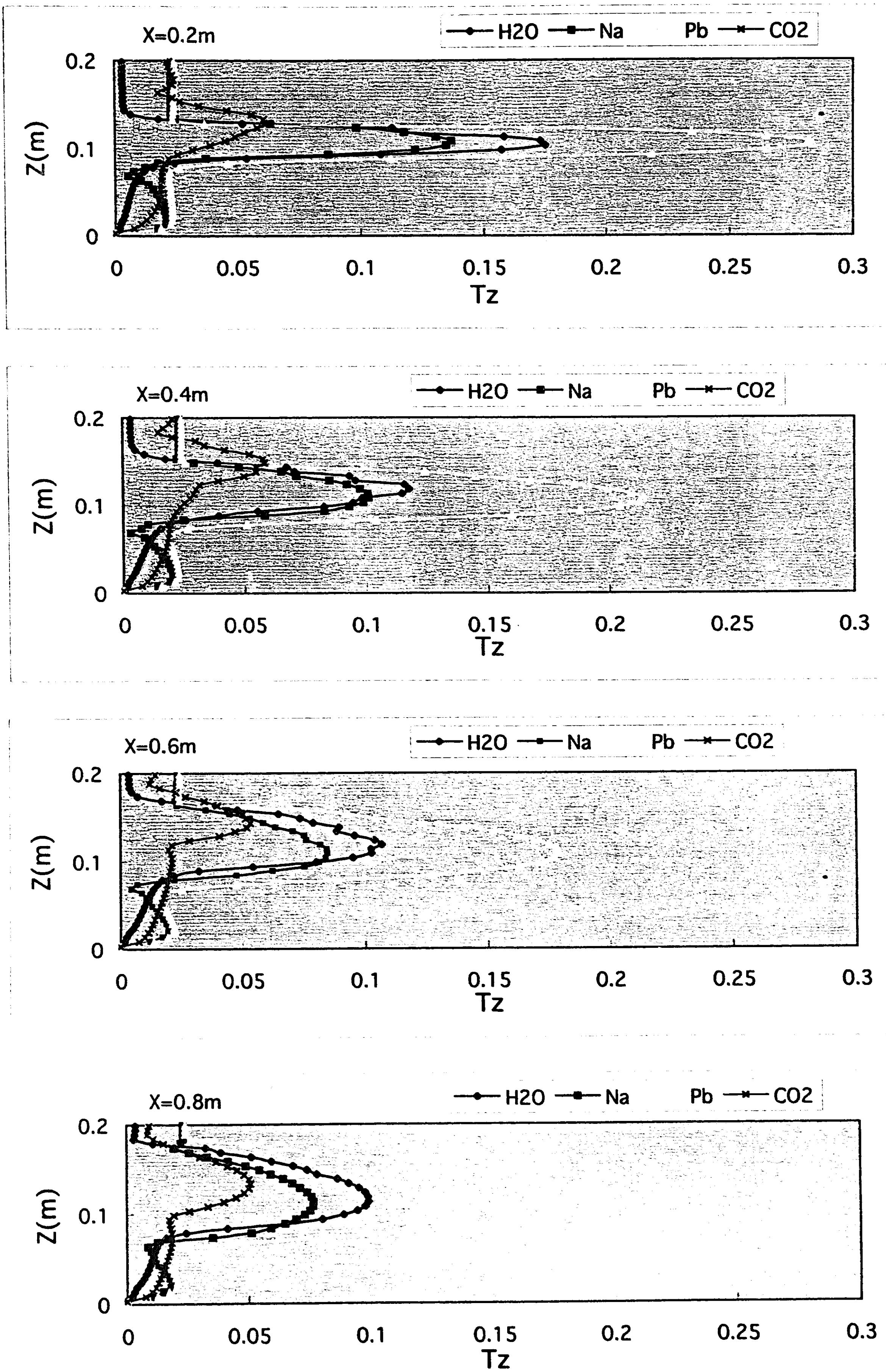


Fig.3-52CASE2(Ri=2,DT=20℃): normalized temperature fluctuation

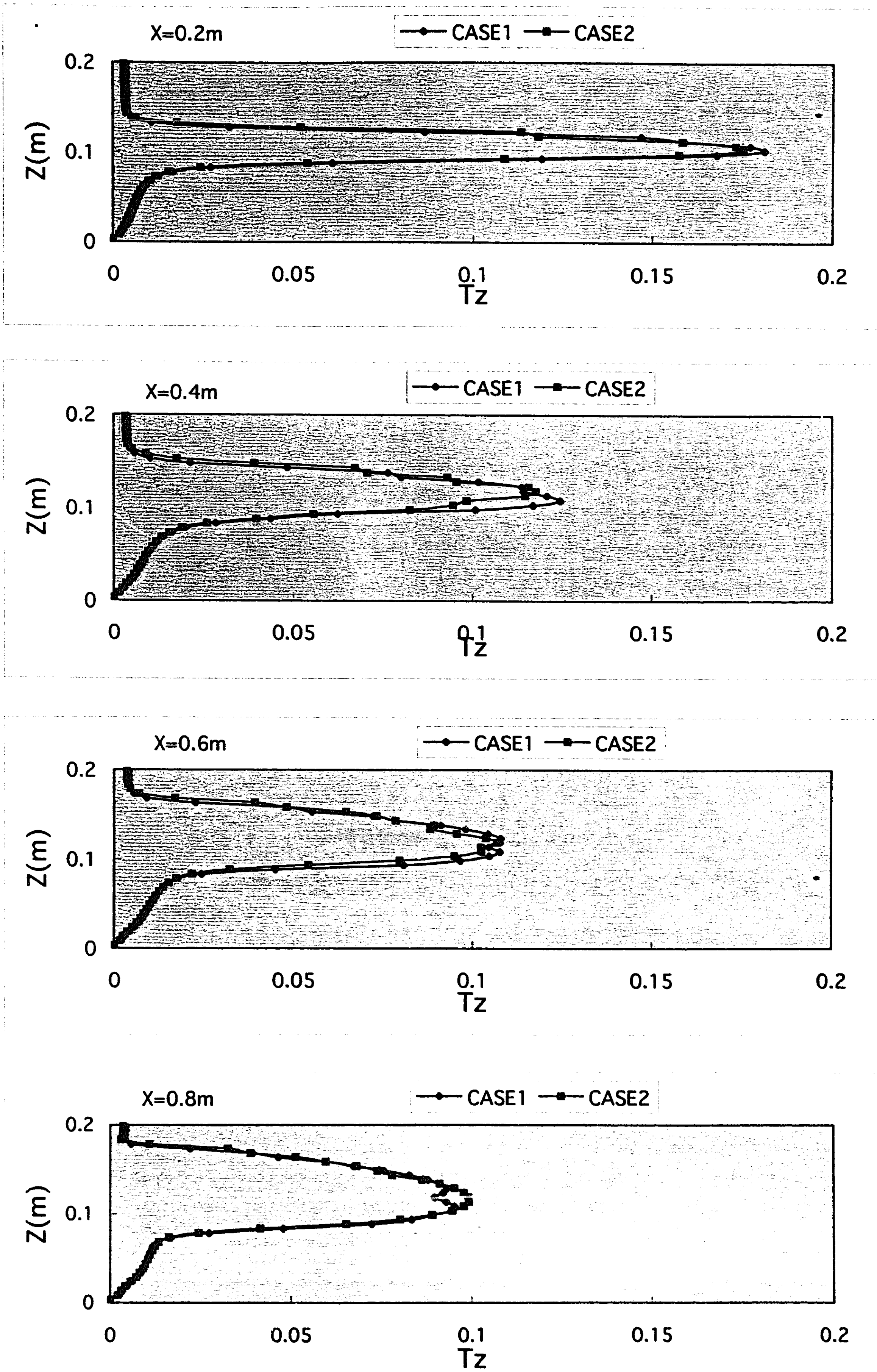


Fig.3-53 H2O: normalized temperature fluctuation

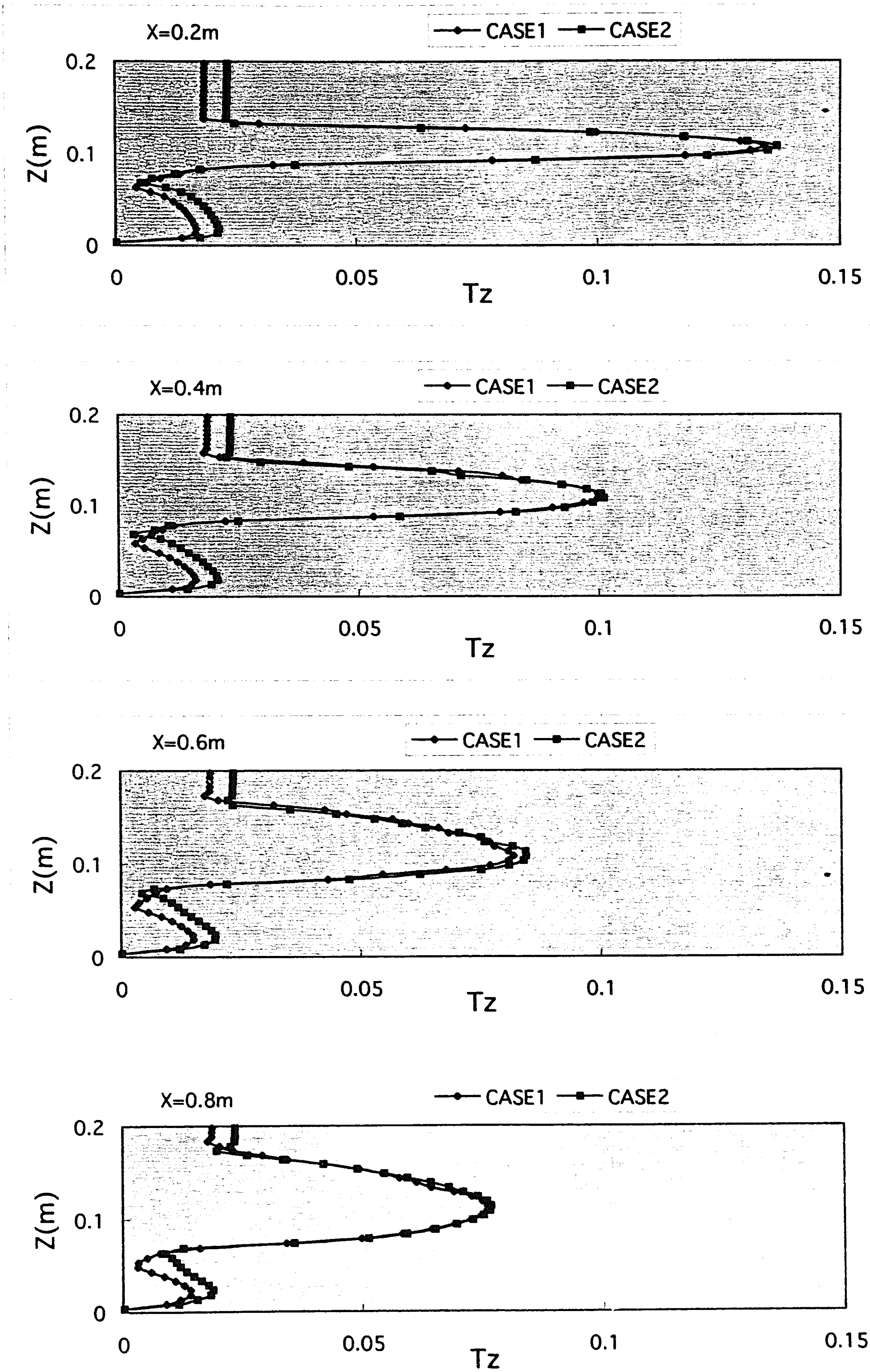


Fig.3-54 Na: normalized temperature fluctuation

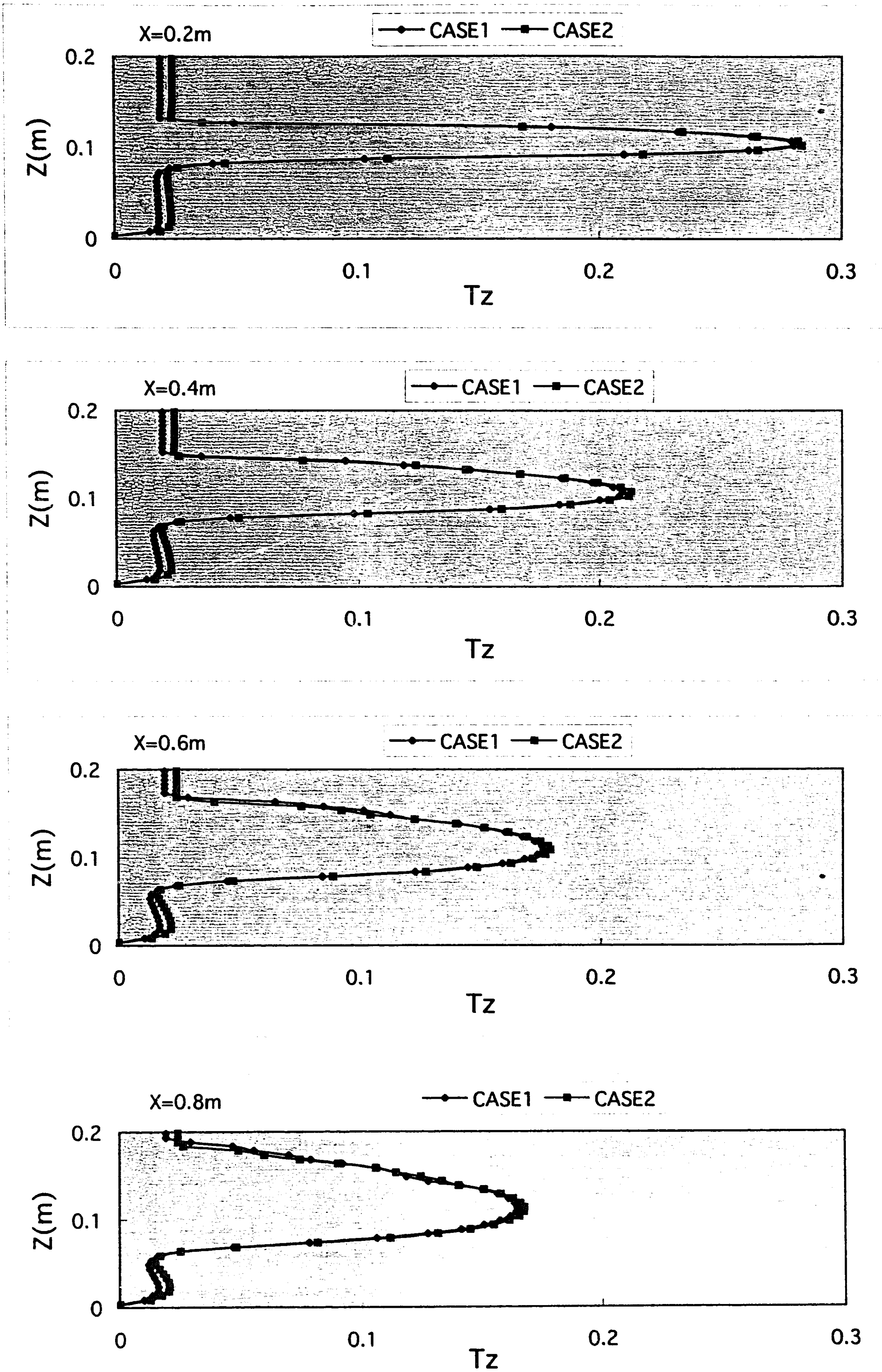


Fig.3-55 Pb: normalized temperature fluctuation

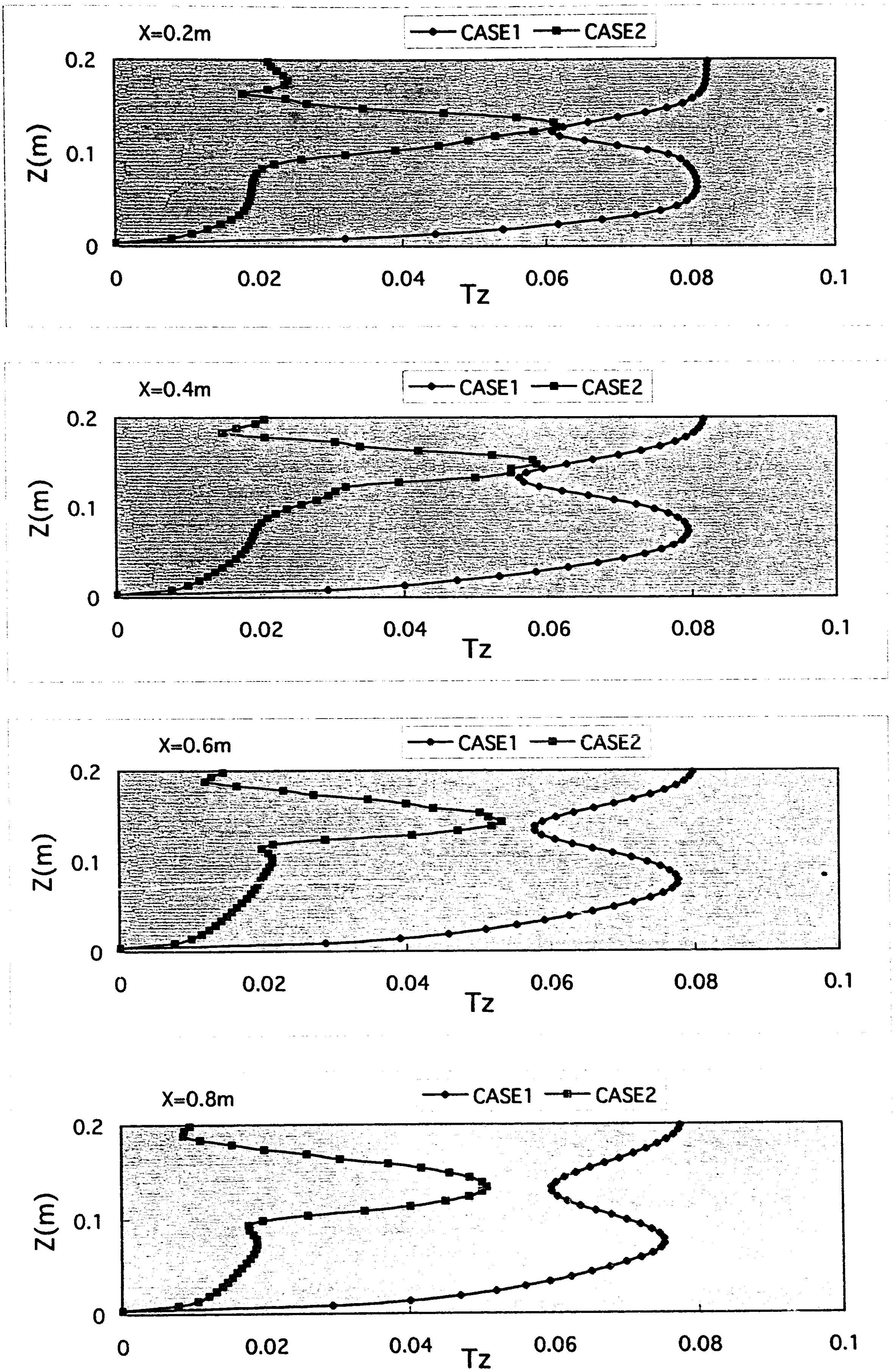


Fig.3-56 CO2: normalized temperature fluctuation

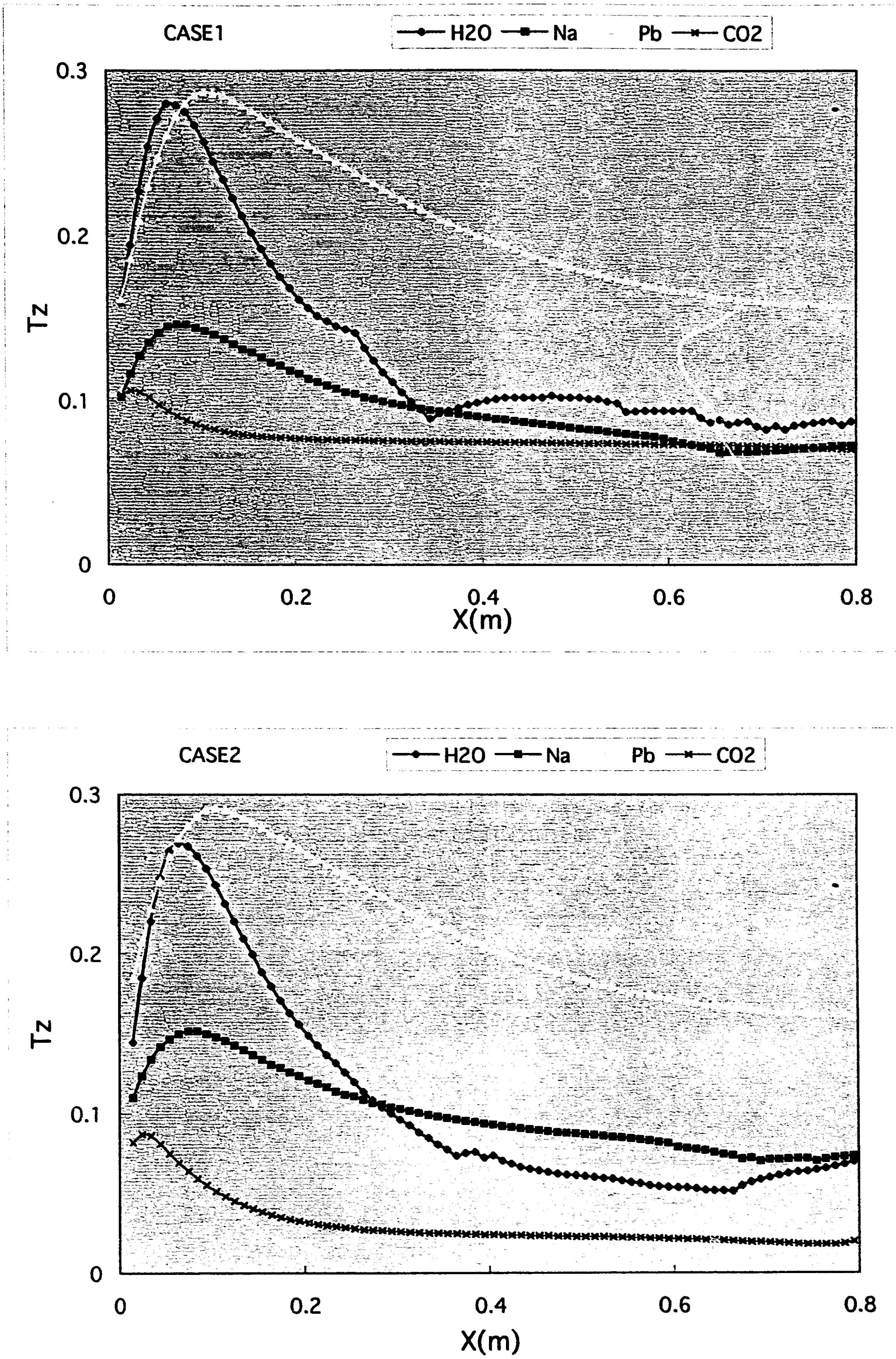
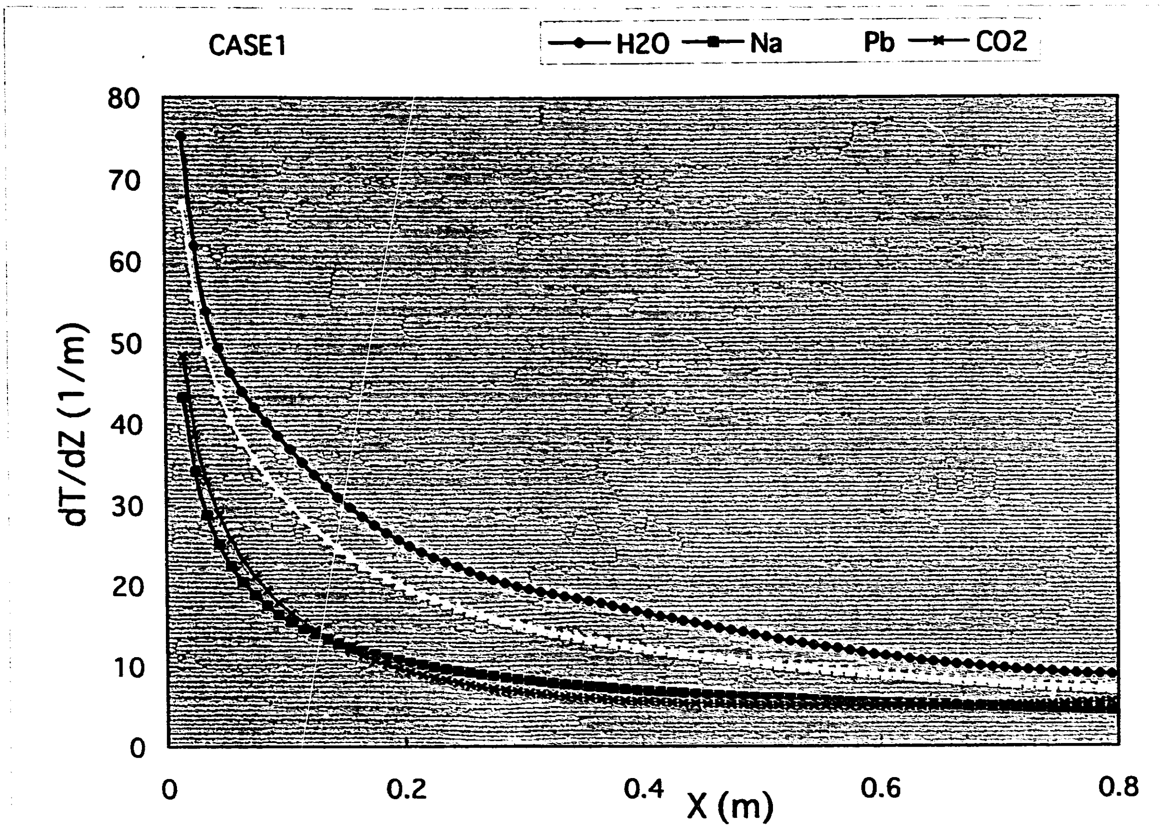


Fig.3-57 normalized temperature fluctuation at the interface between hot and cold flows



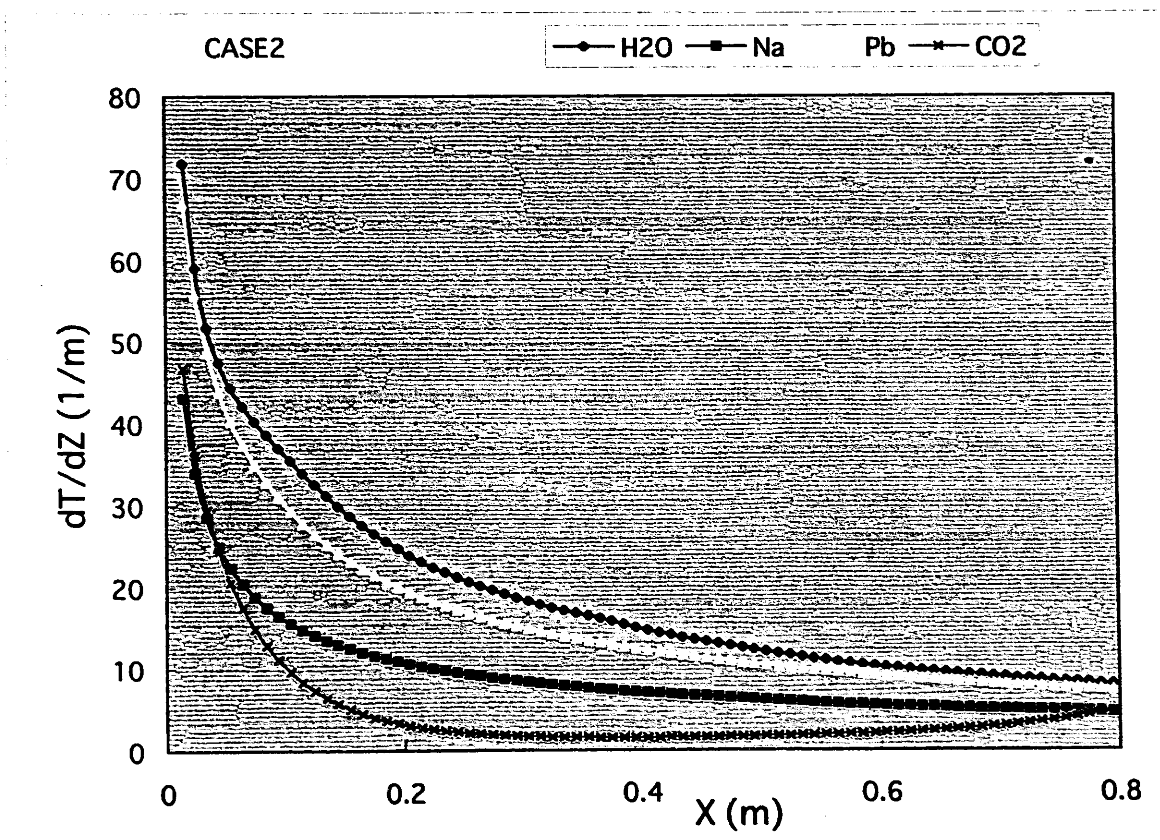


Fig.3-58 normalized temperature gradient at the interface between hot and cold flows

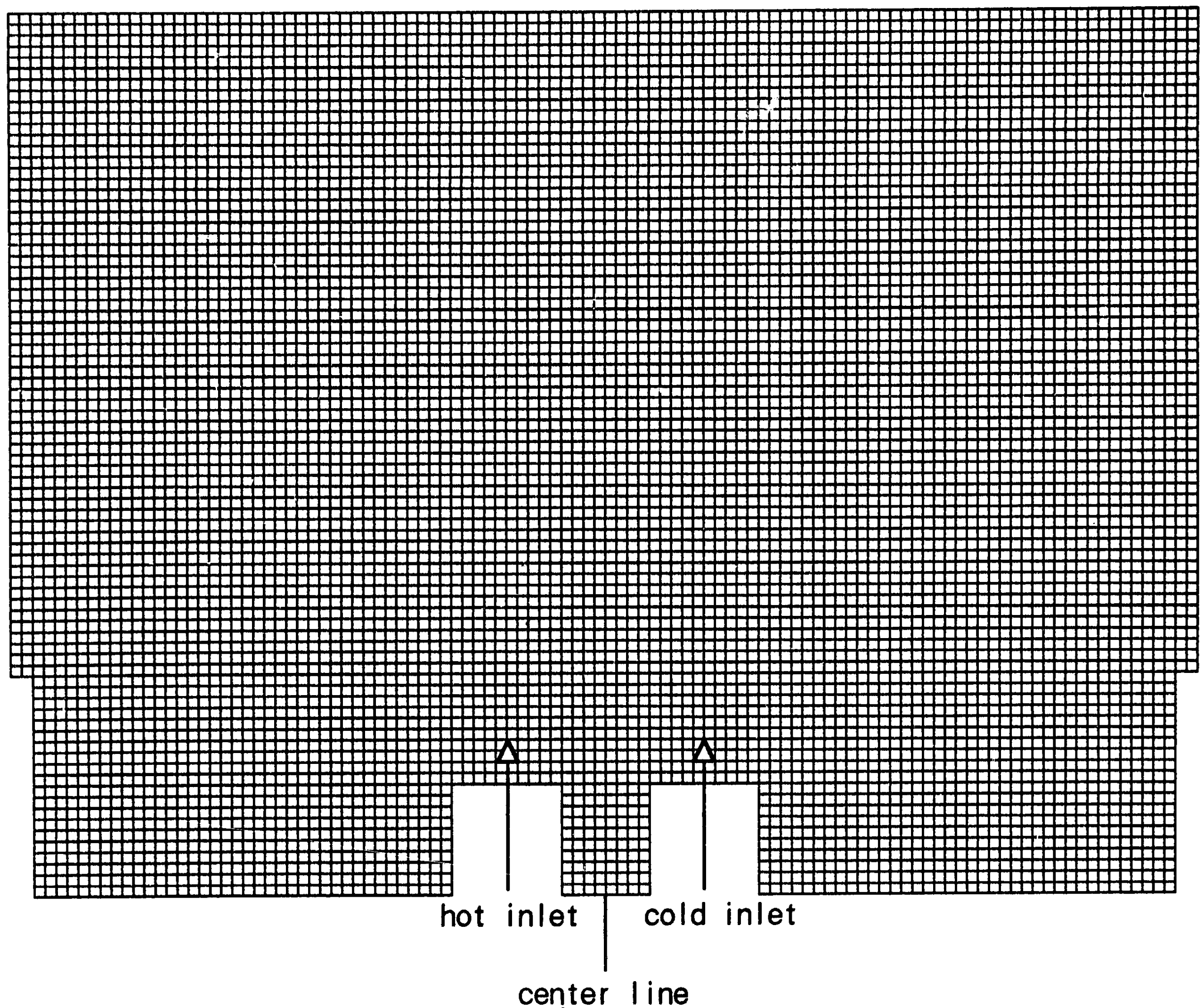


Fig.4-0 mesh arrangement for thermal striping

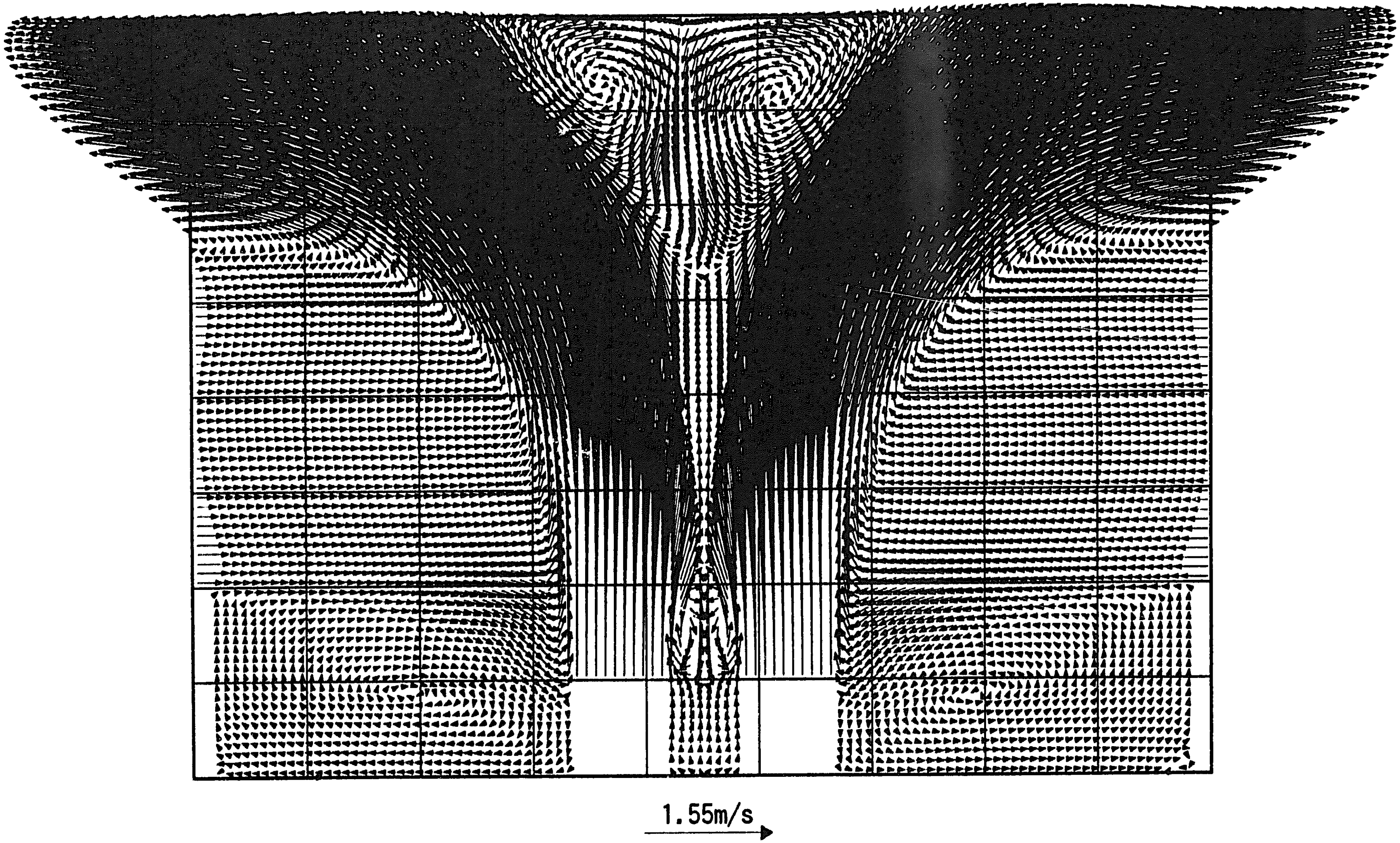


Fig.4-01 H20: velocity field

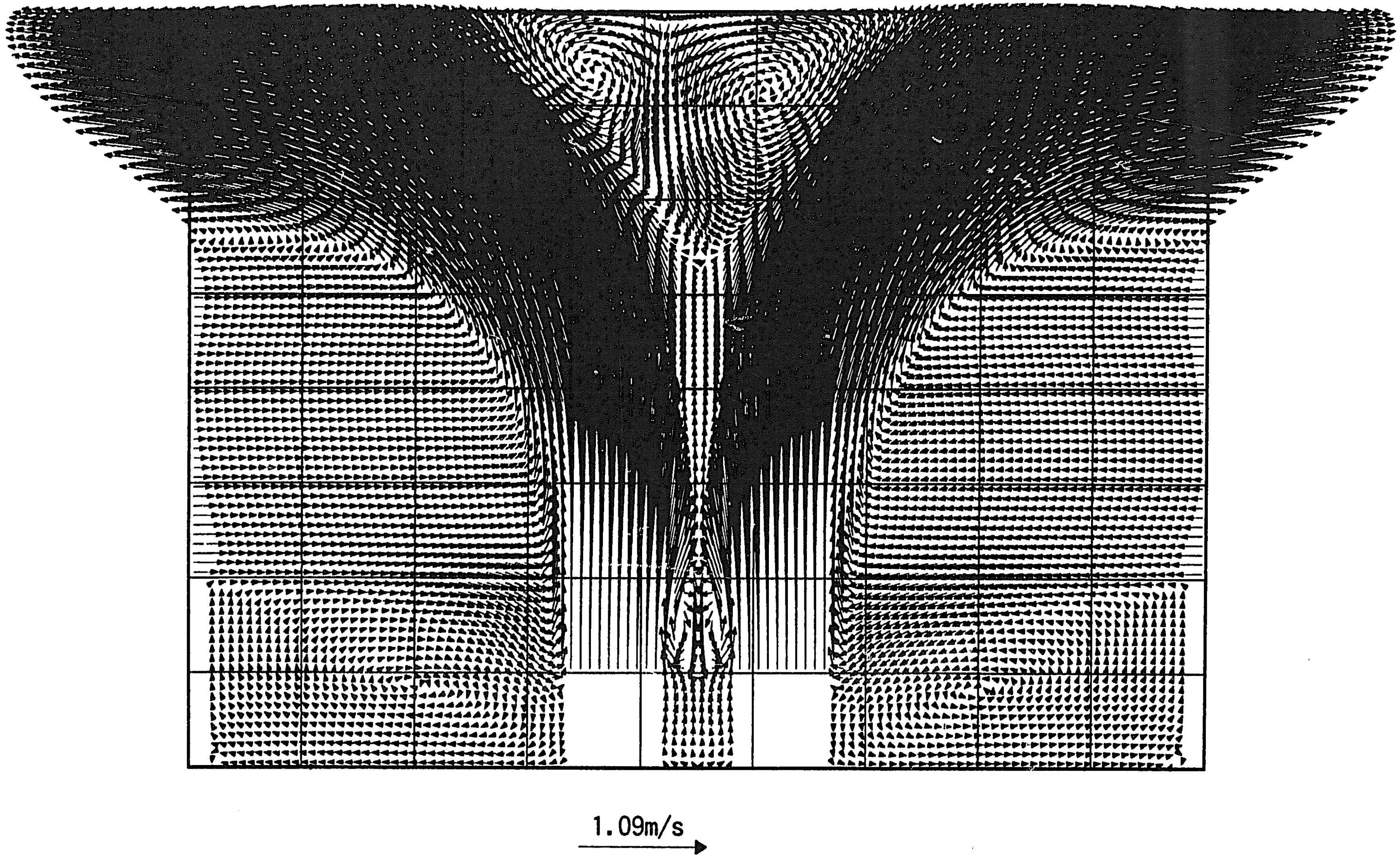


Fig.4-02 Na: velocity field

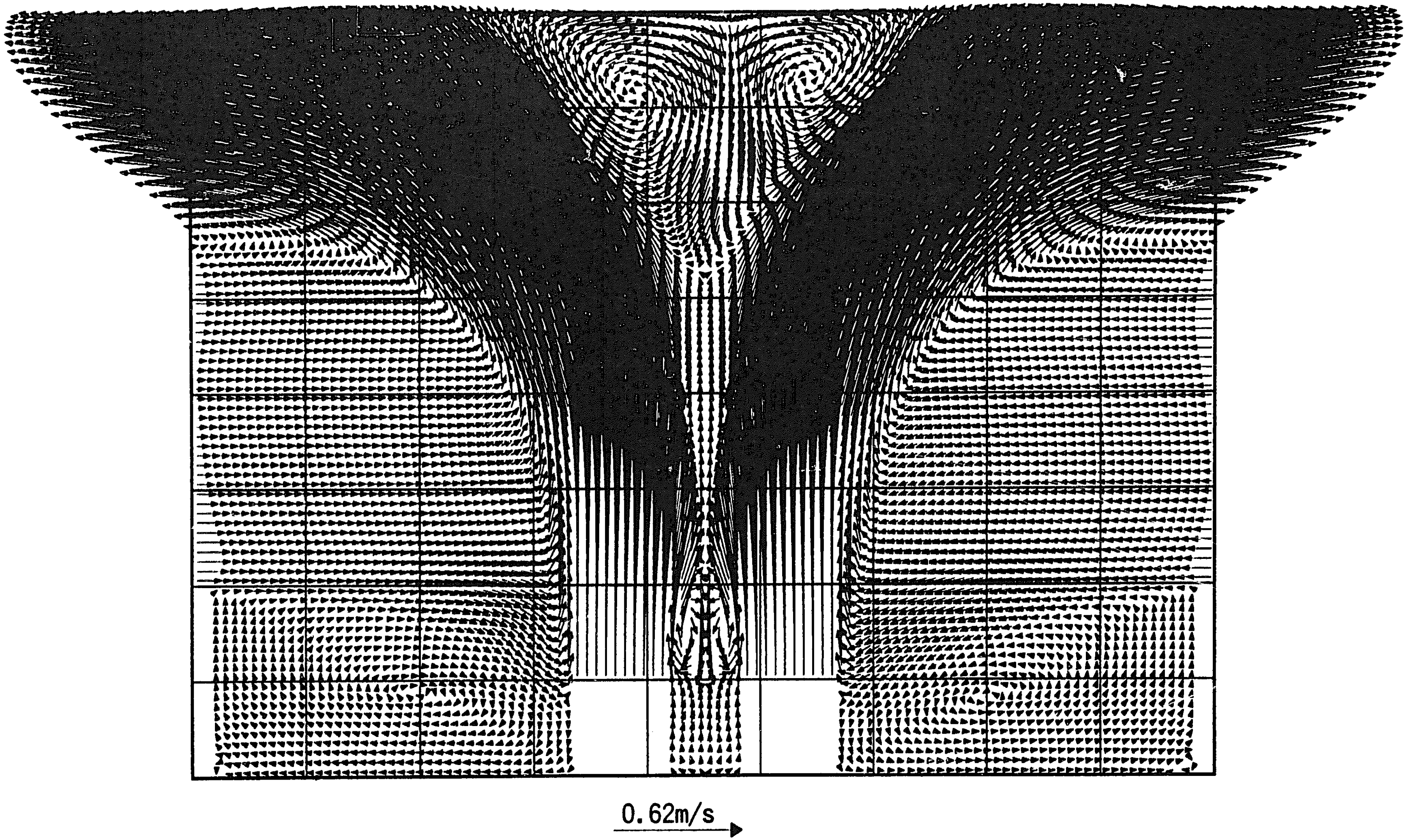


Fig.4-03 Pb: velocity vector

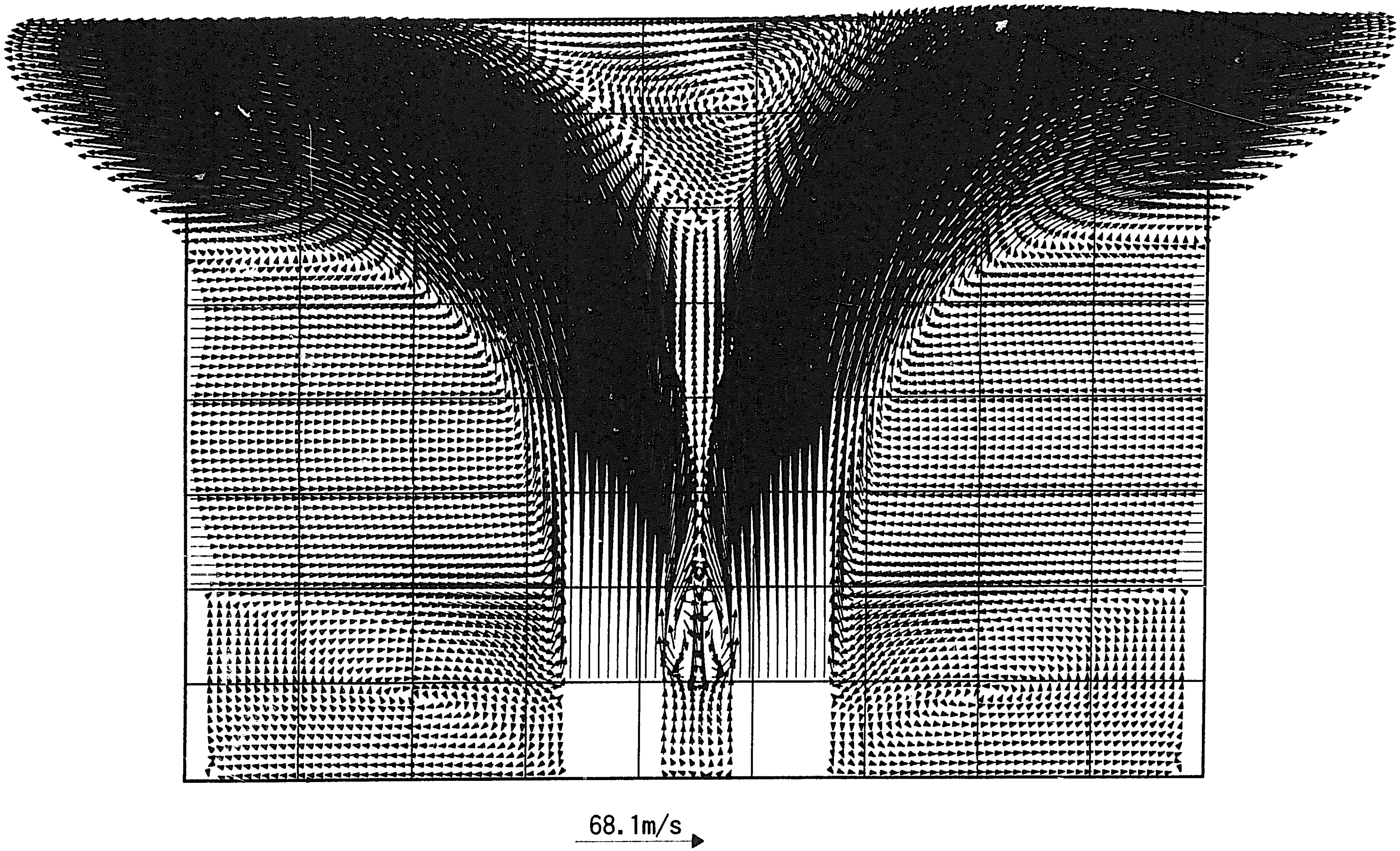


Fig.4-04 C02: velocity field

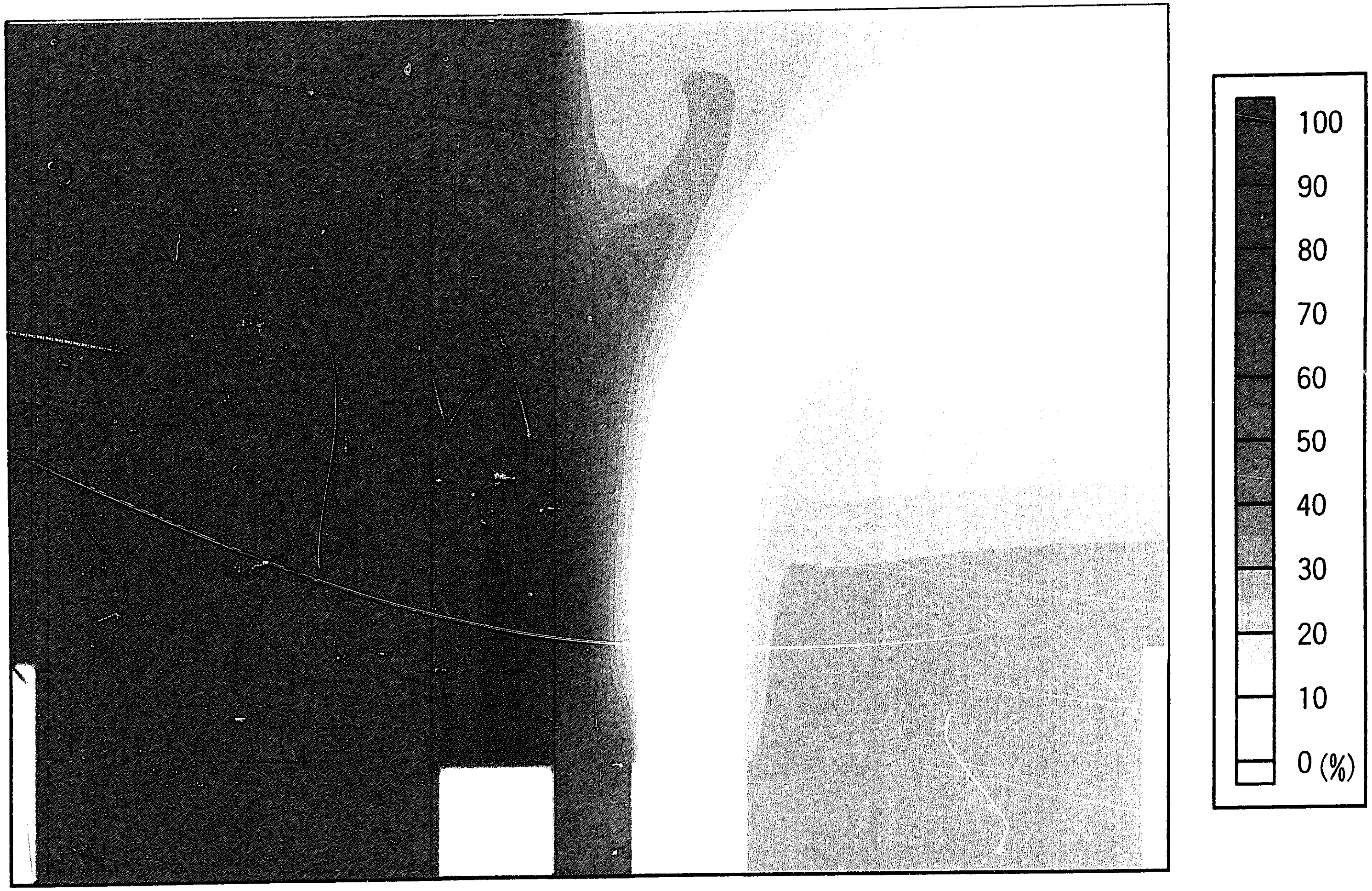


Fig.4-05 H20: normalized mean temperature

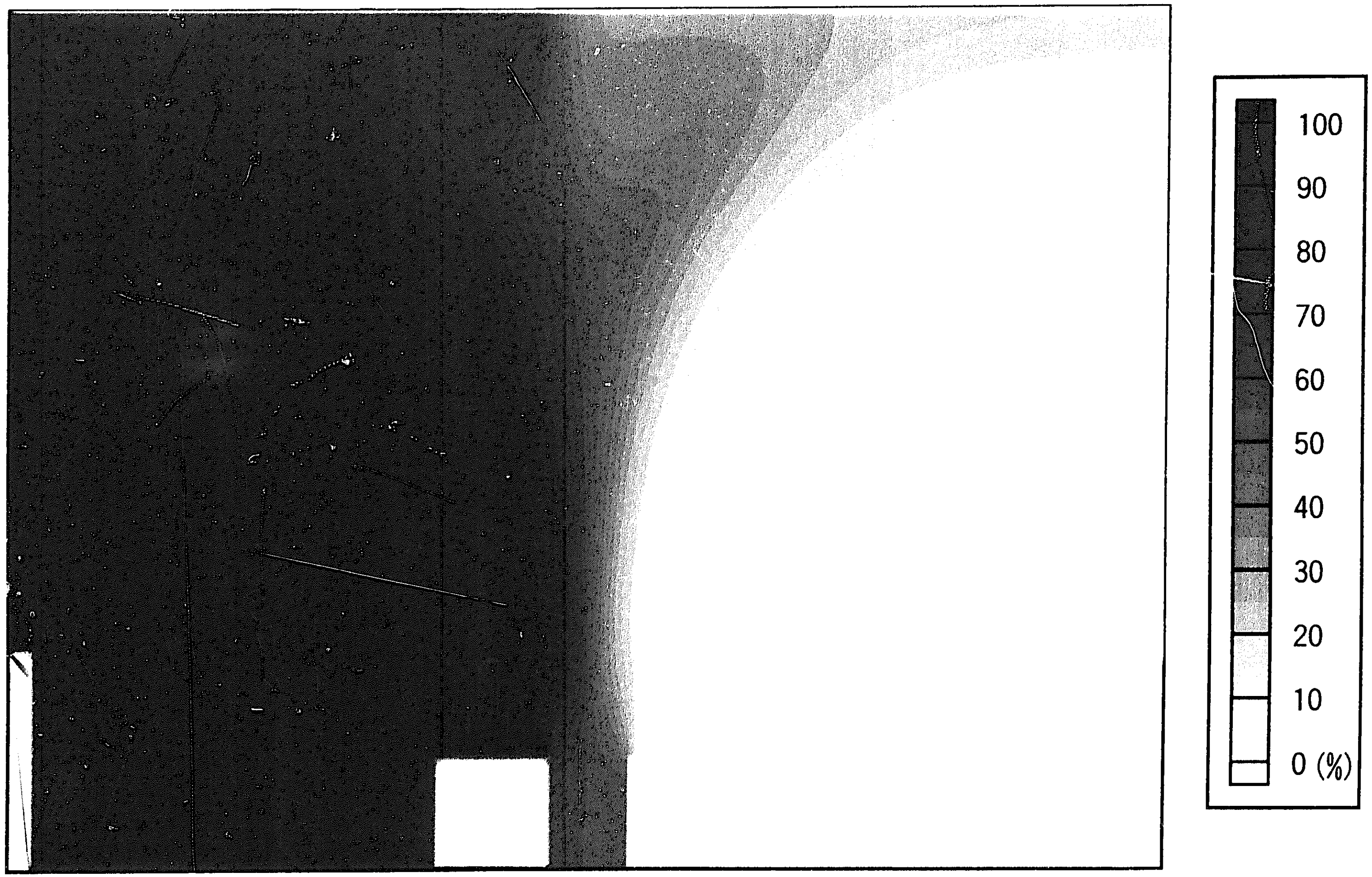


Fig.4-406 Na: normalized mean temperature

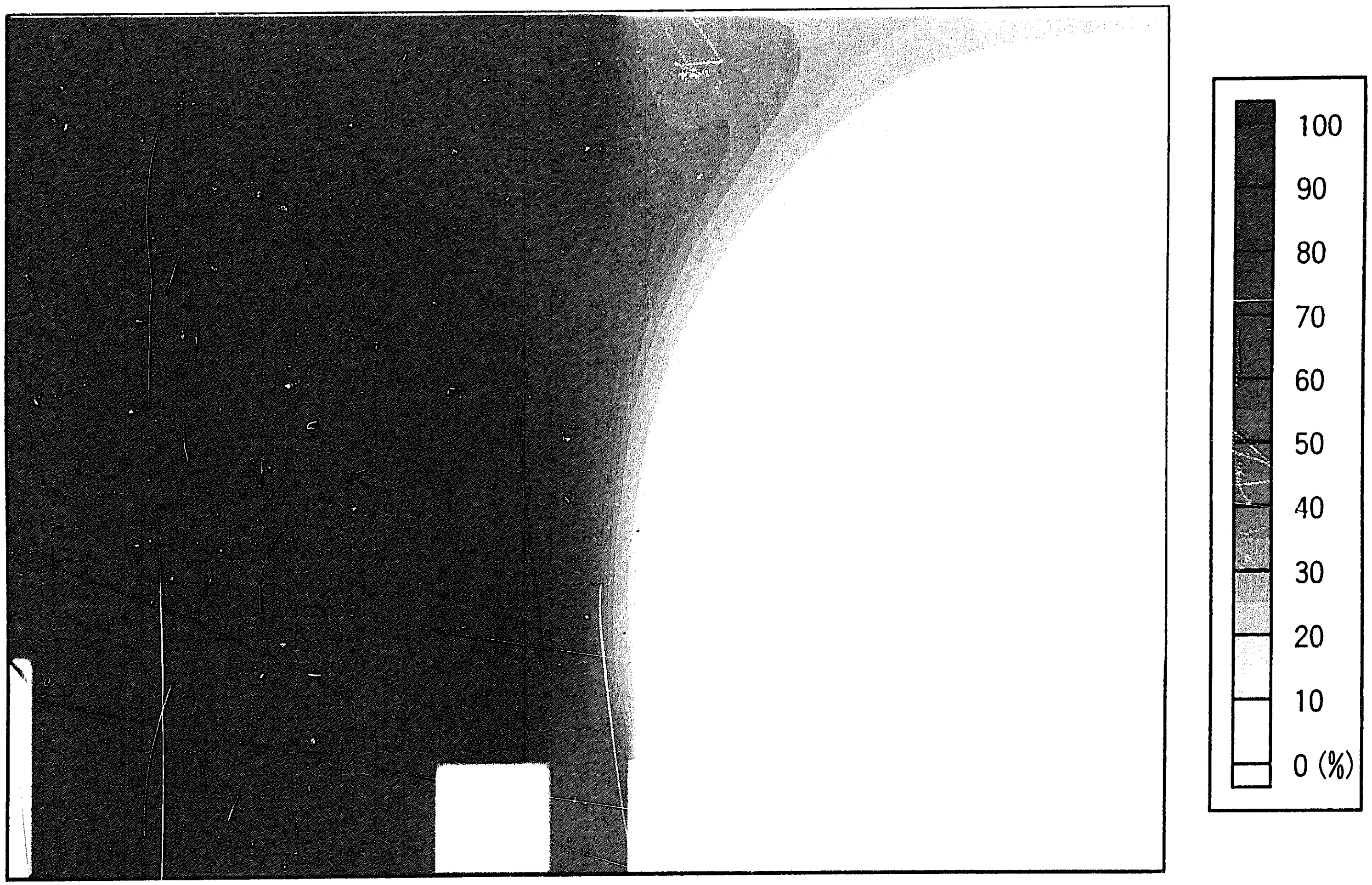


Fig.4-407 Pb: normalized mean temperature

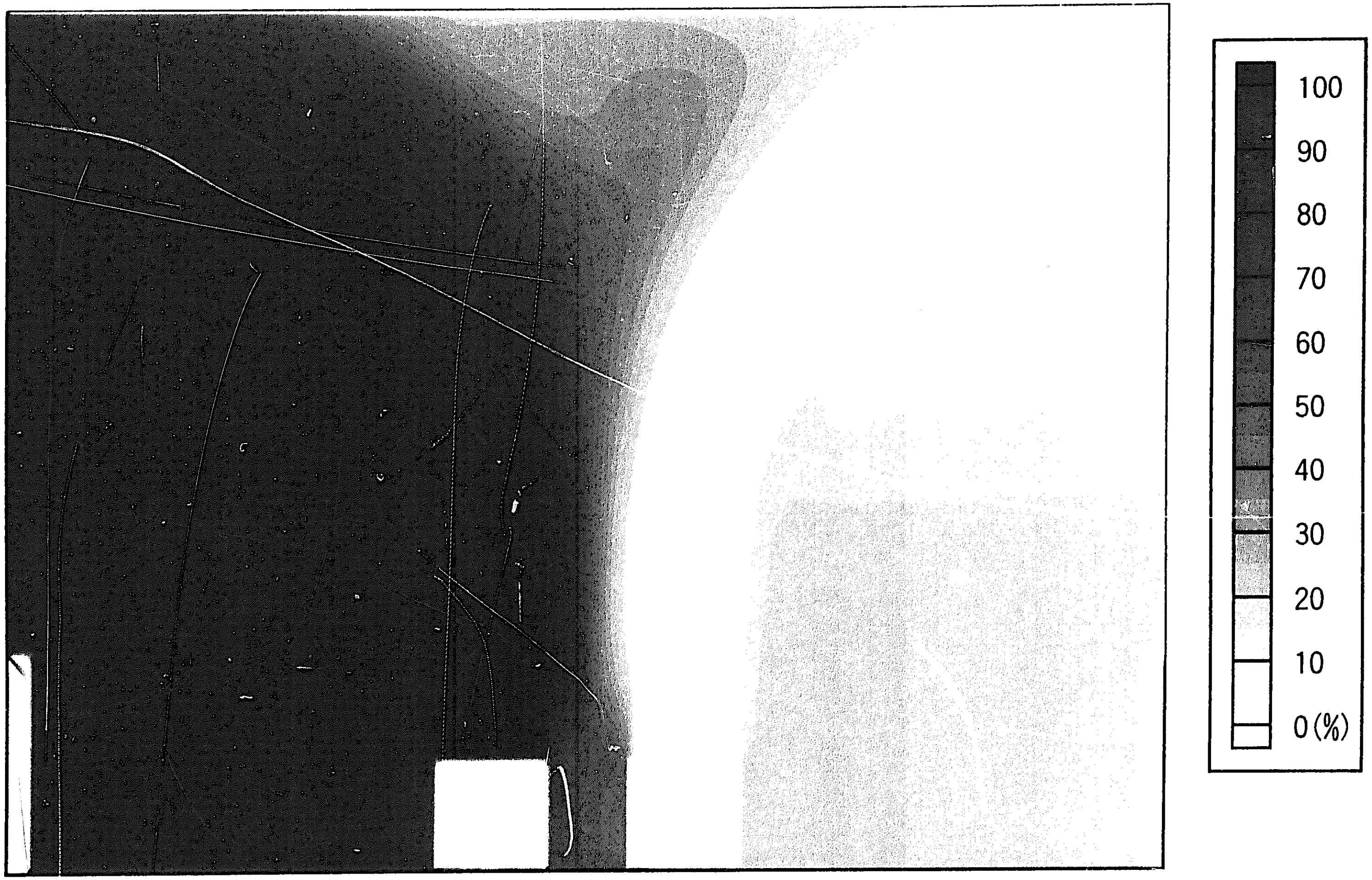


Fig.4-08 C02: normalized mean temperature

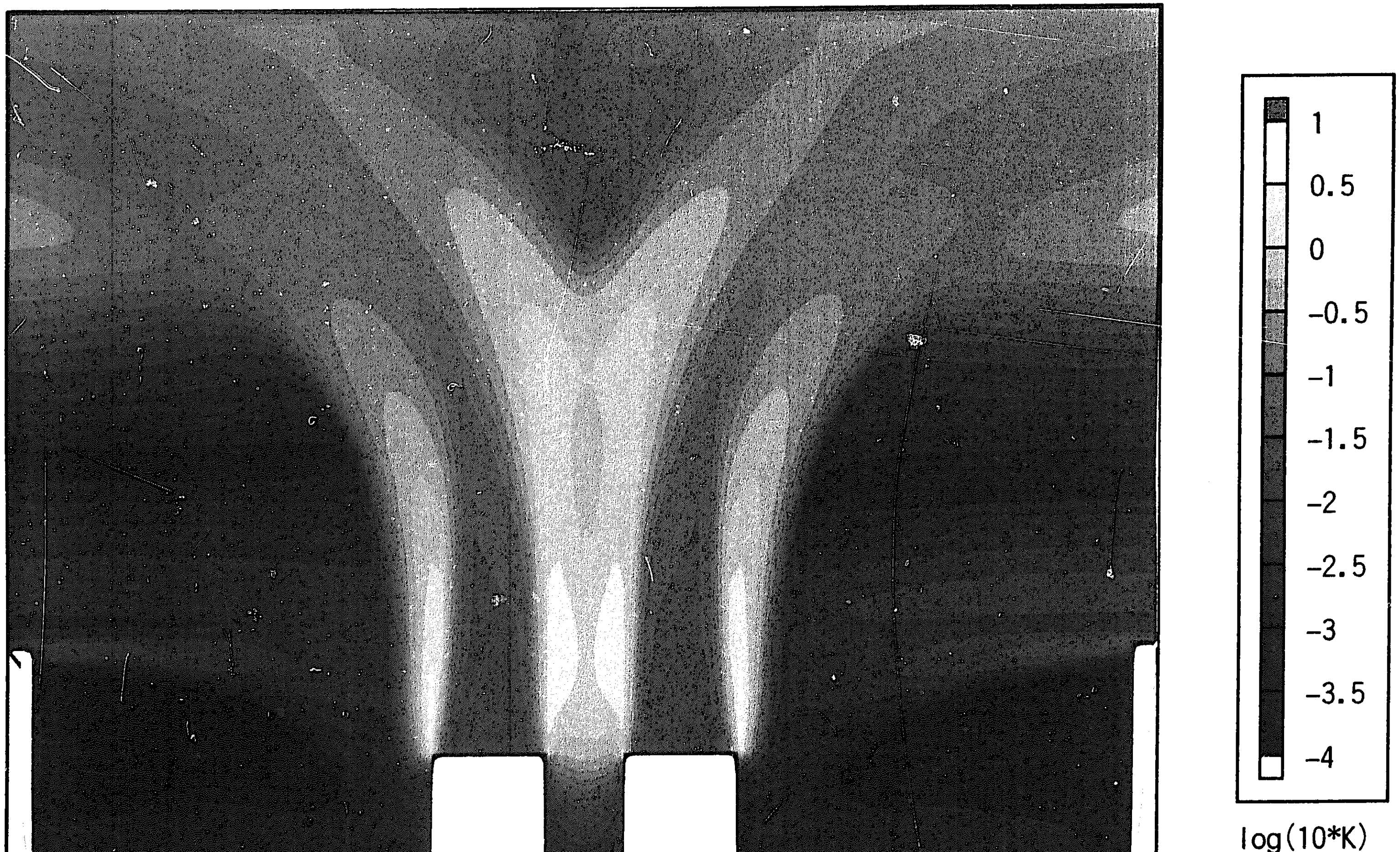


Fig.4-09 H20: turbulent kinetic energy(K)

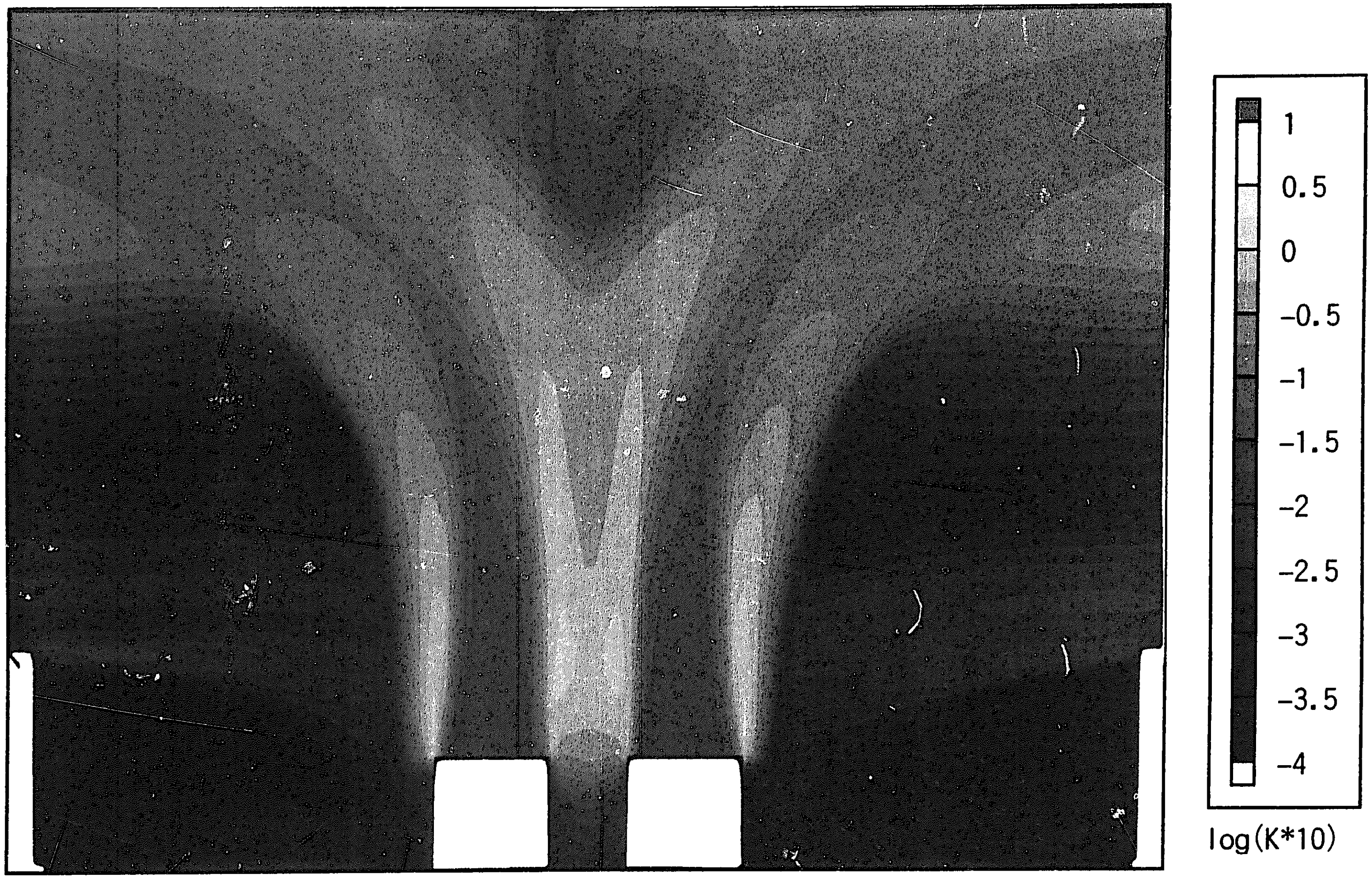


Fig.4-10 Na: turbulent kinetic energy (K)

Fig.4-11 Pb: turbulent kineyic energy (K)

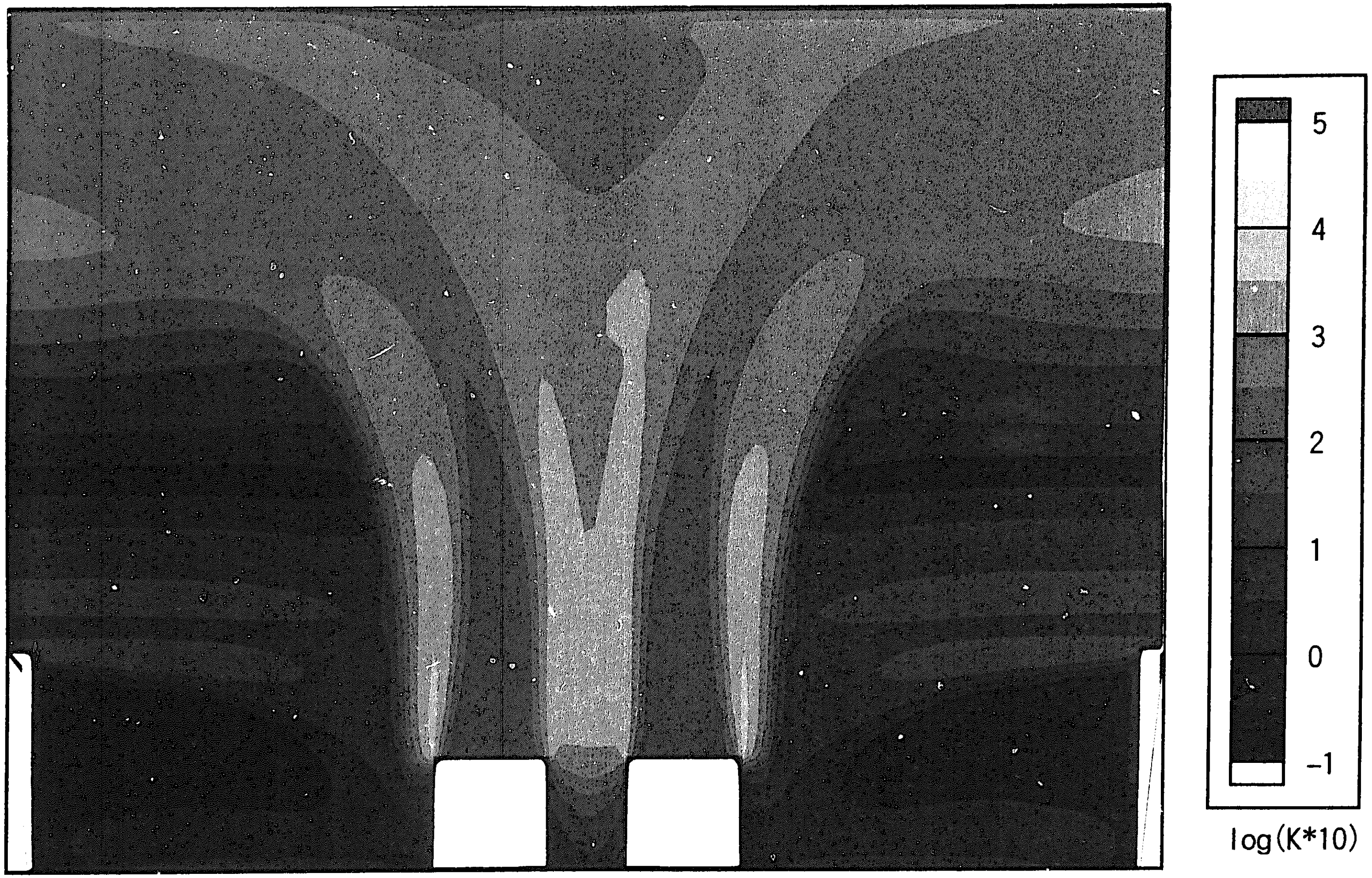


Fig.4-12 CO2: turbulent kinetic energy (K)

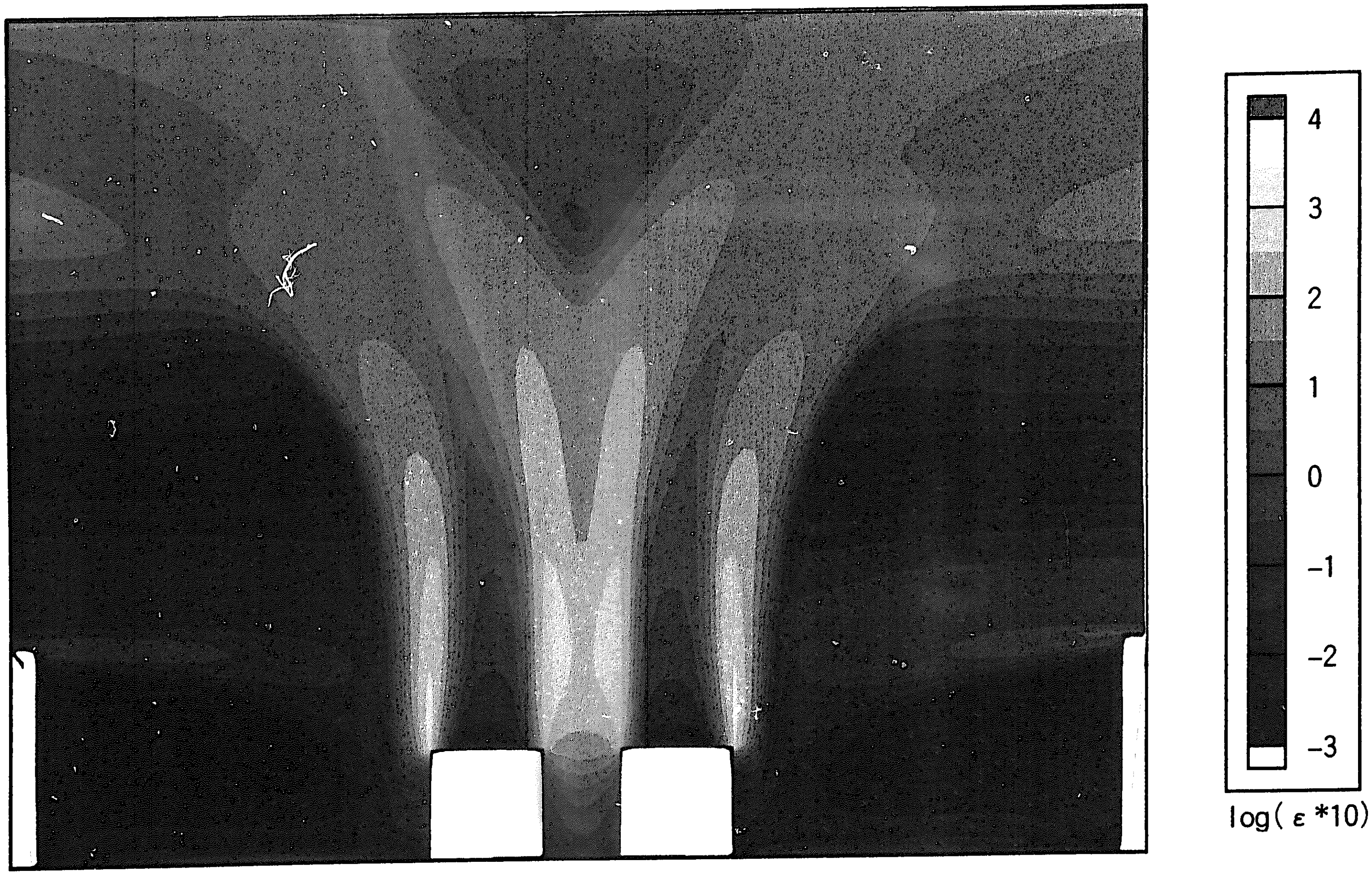


Fig.4-13 H20: dissipation rate of K (ε)

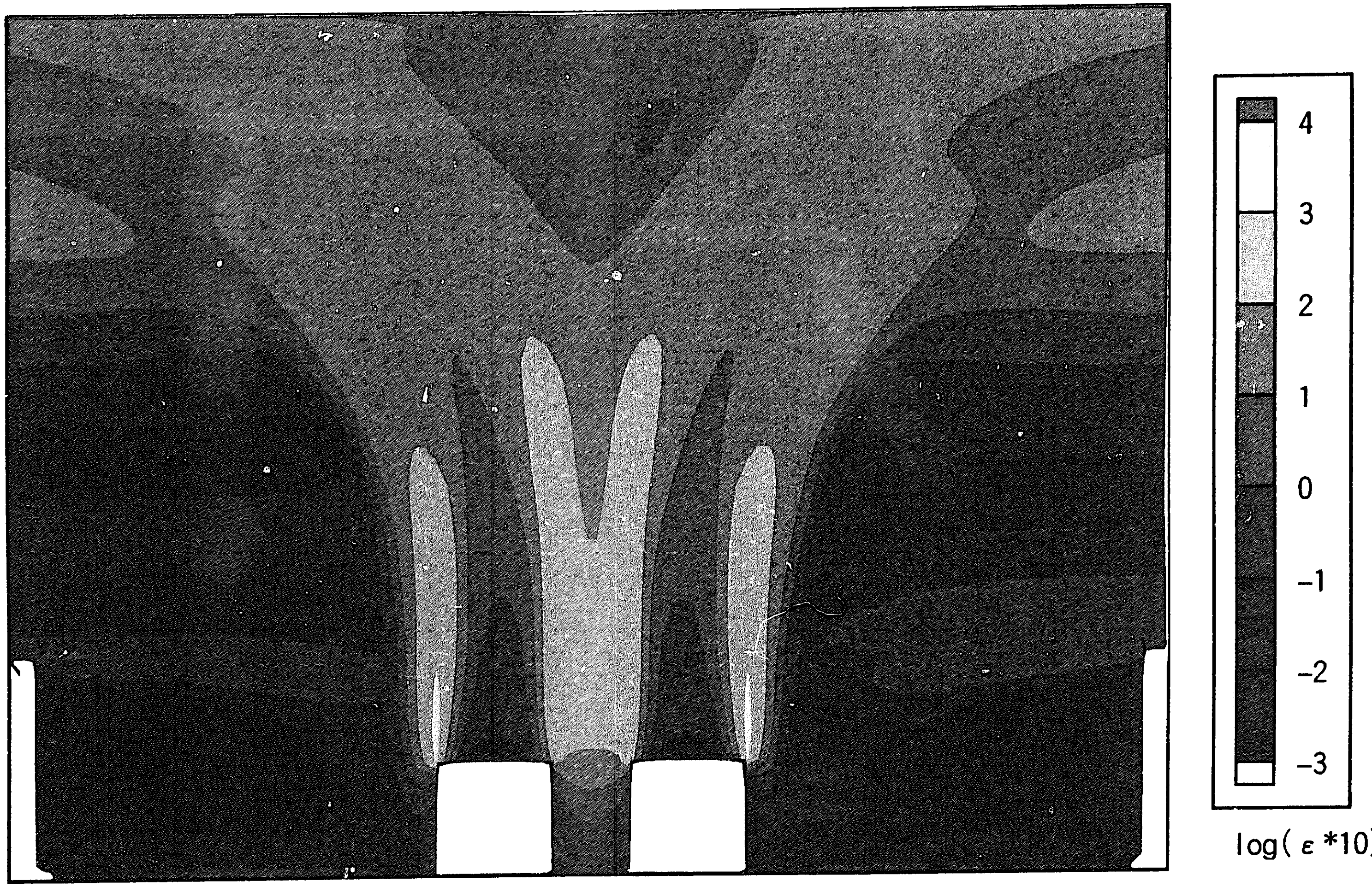


Fig. 4-14 Na: dissipation rate of K (ε)

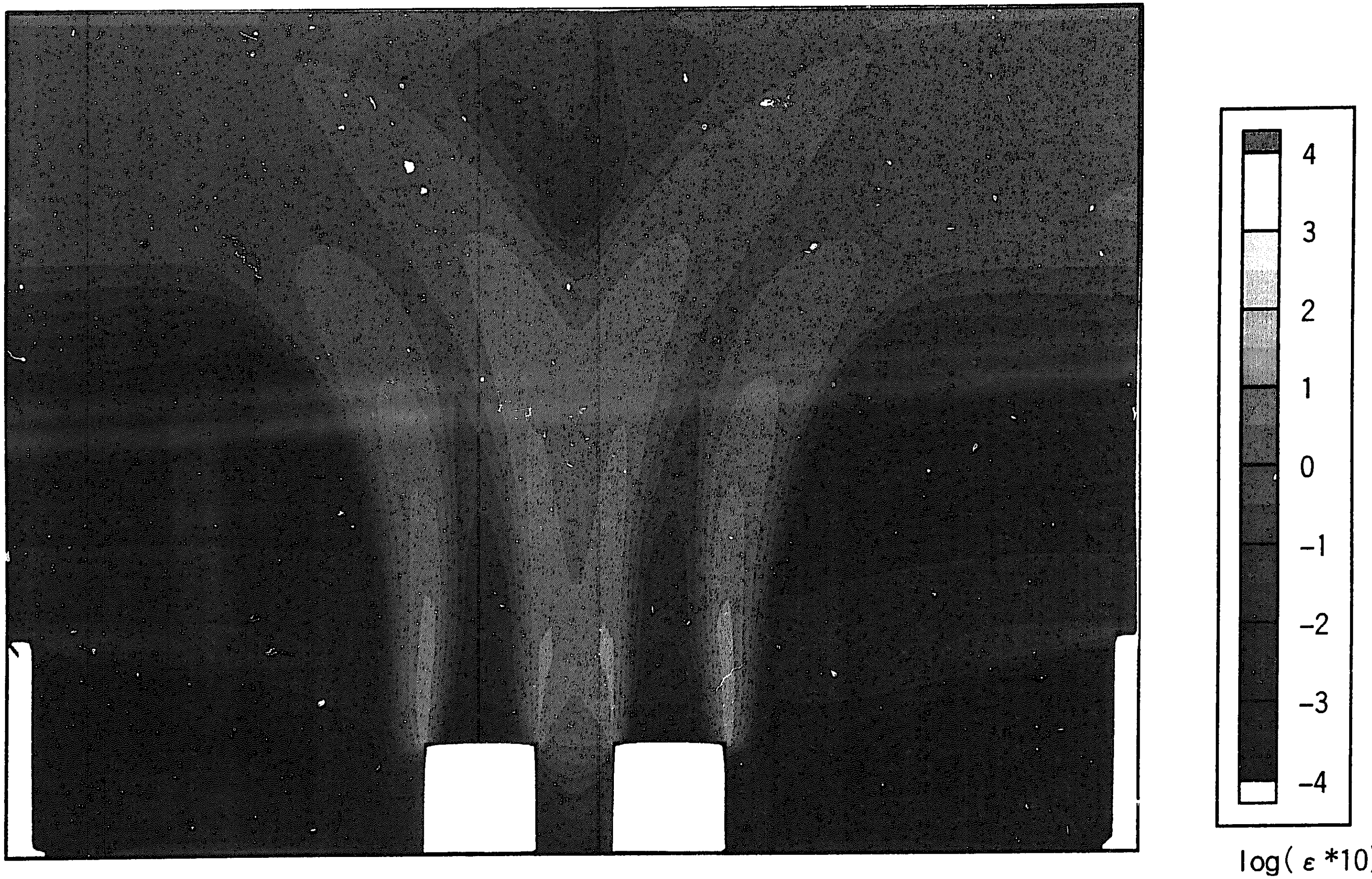


Fig.4-15 Pb: dissipation rate of K (ε)

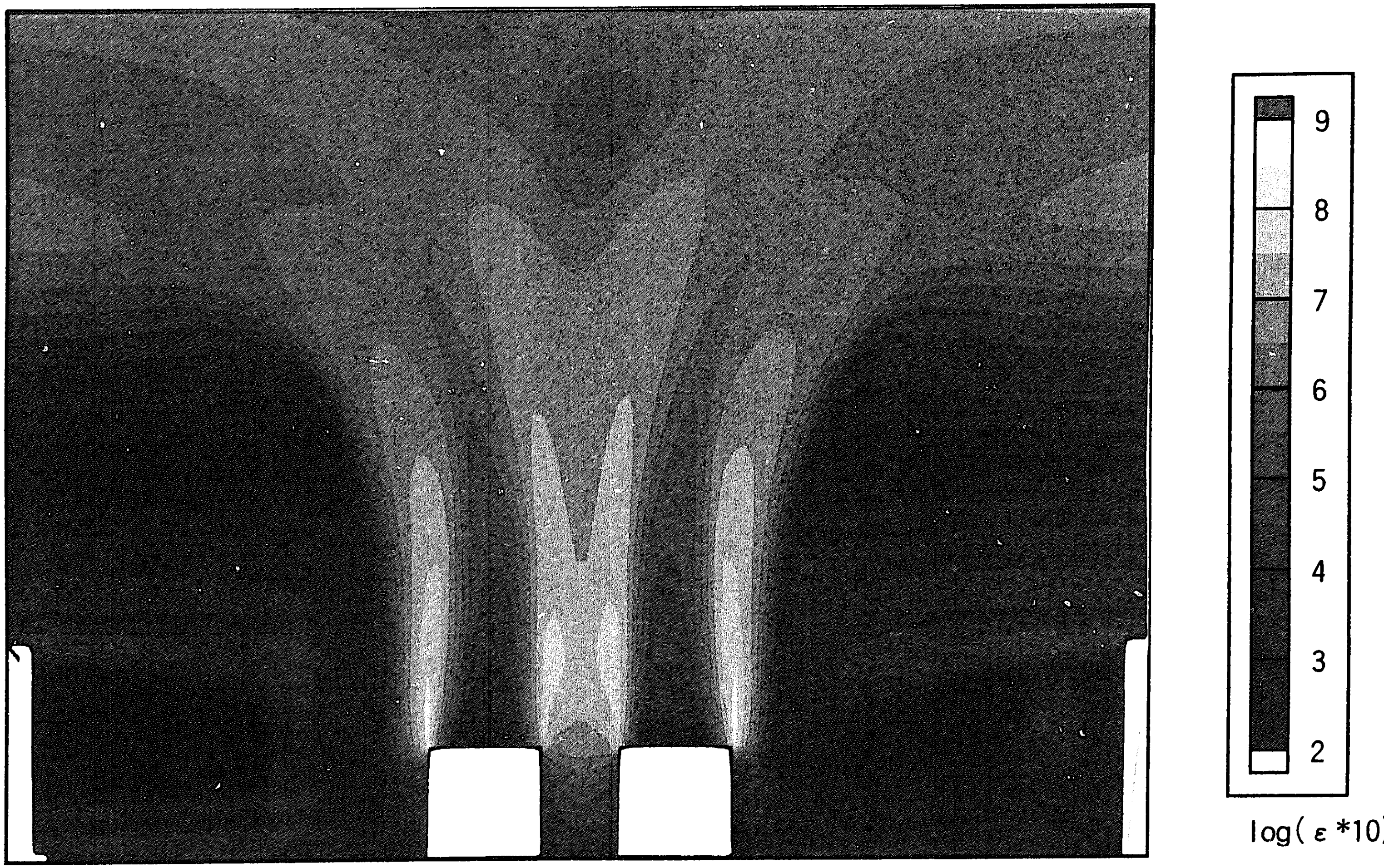


Fig.4-16 C02: dissipation rate of K (ε)

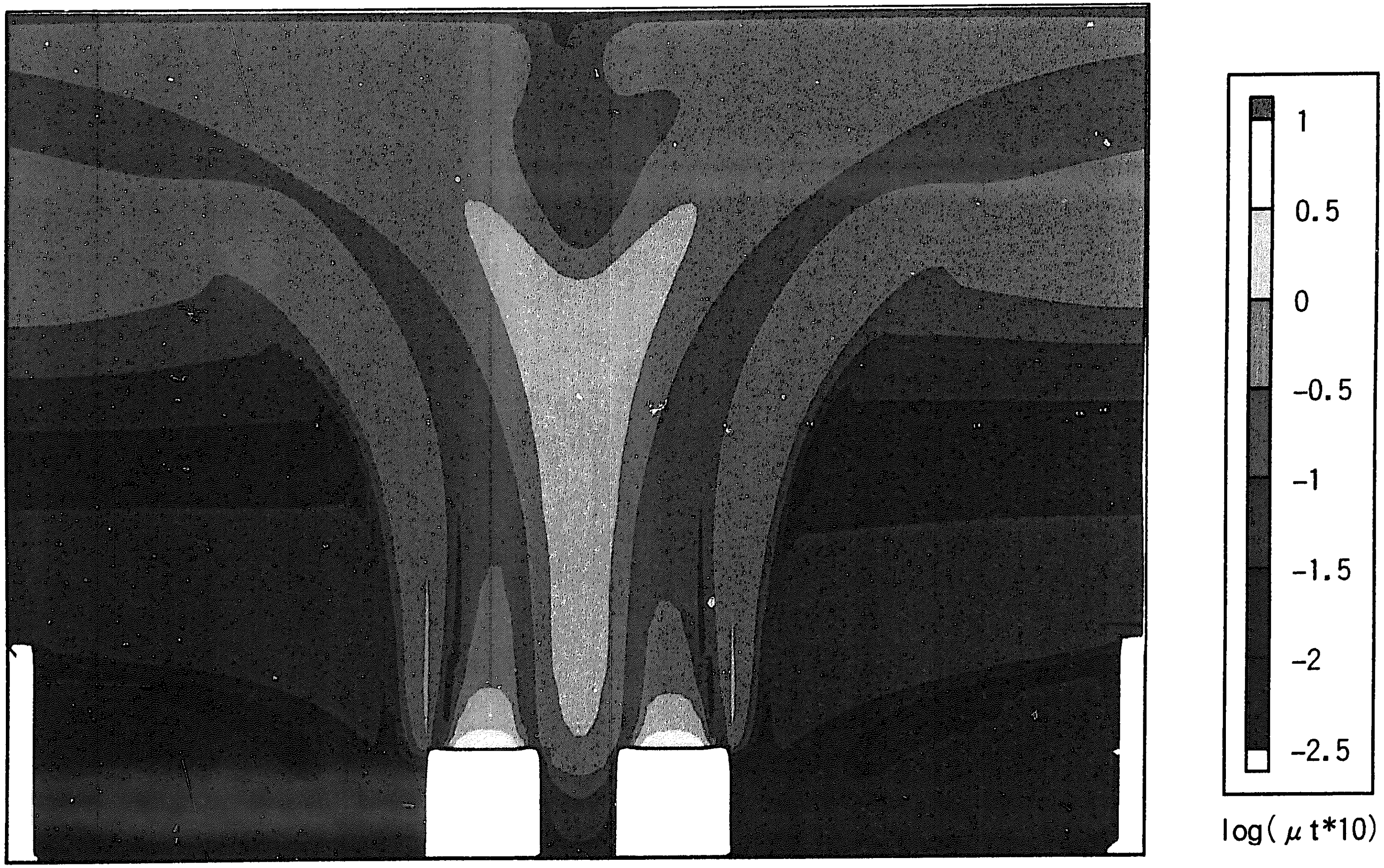


Fig.4-17 H20: turbulent viscosity (μt)

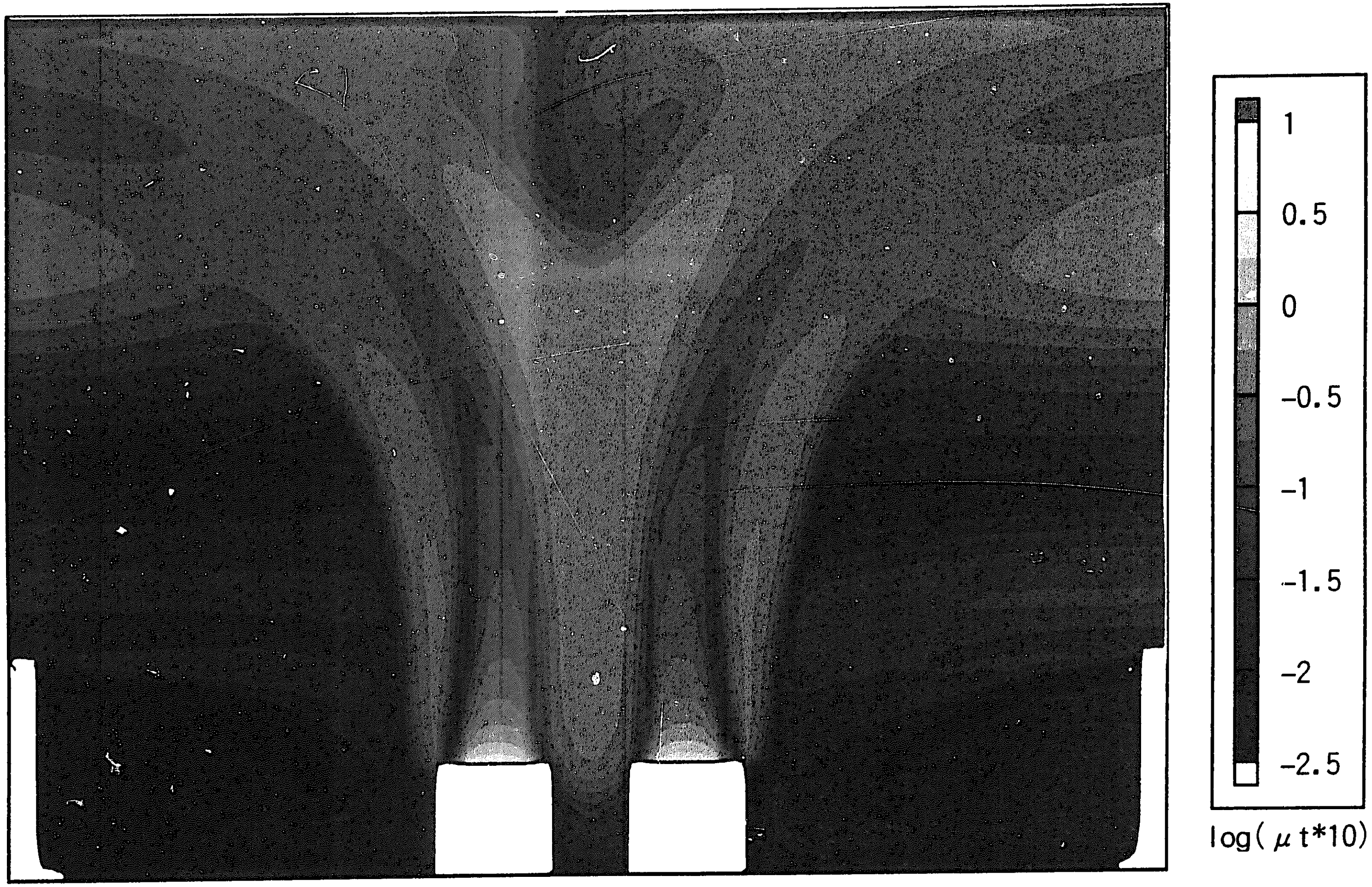


Fig.4-18 Na: turbulent viscosity (μt)

Fig.4-19 Pb: turbulent viscosity (μt)

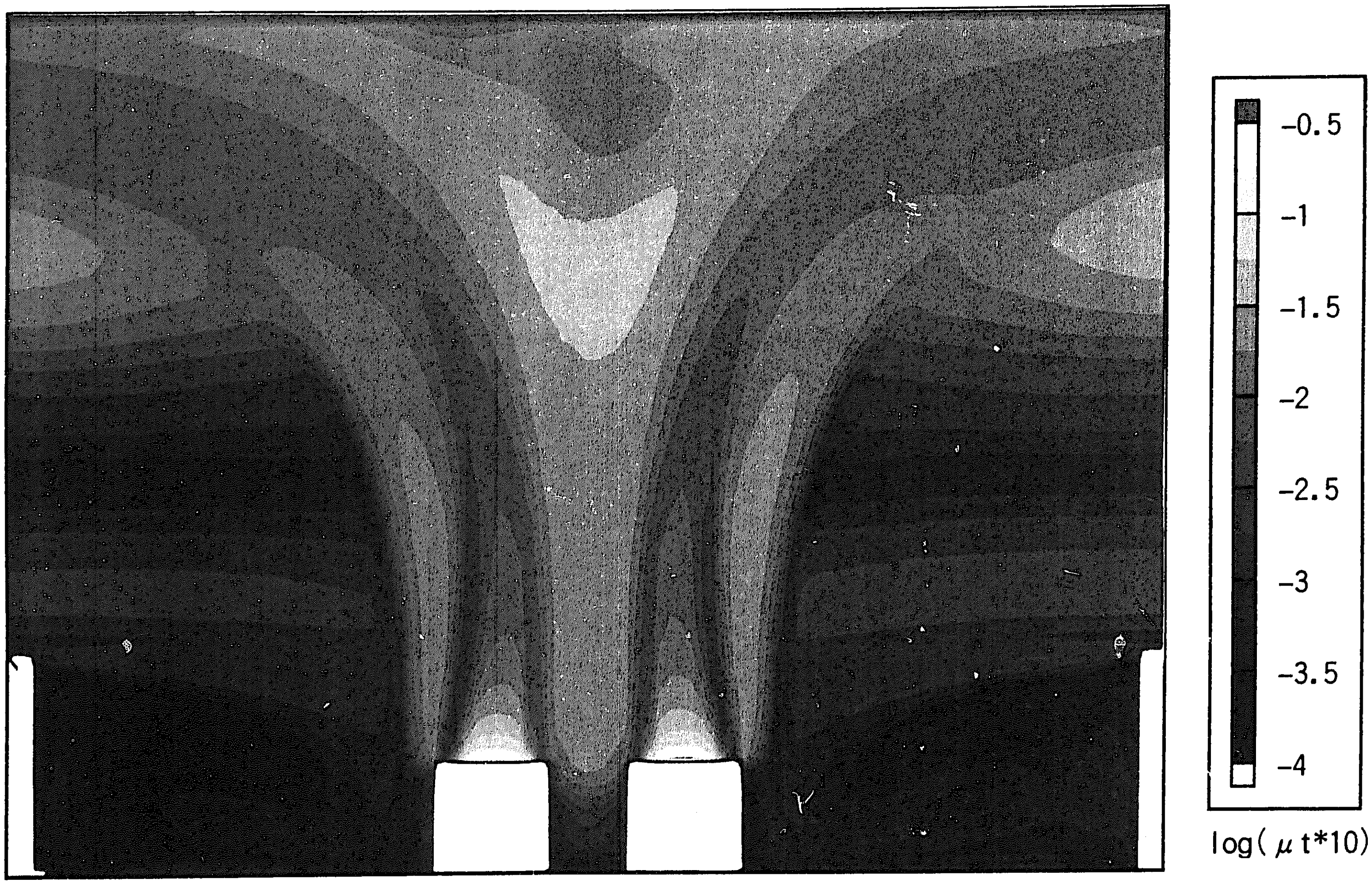


Fig.4-20 CO2: turbulent viscosity (μt)

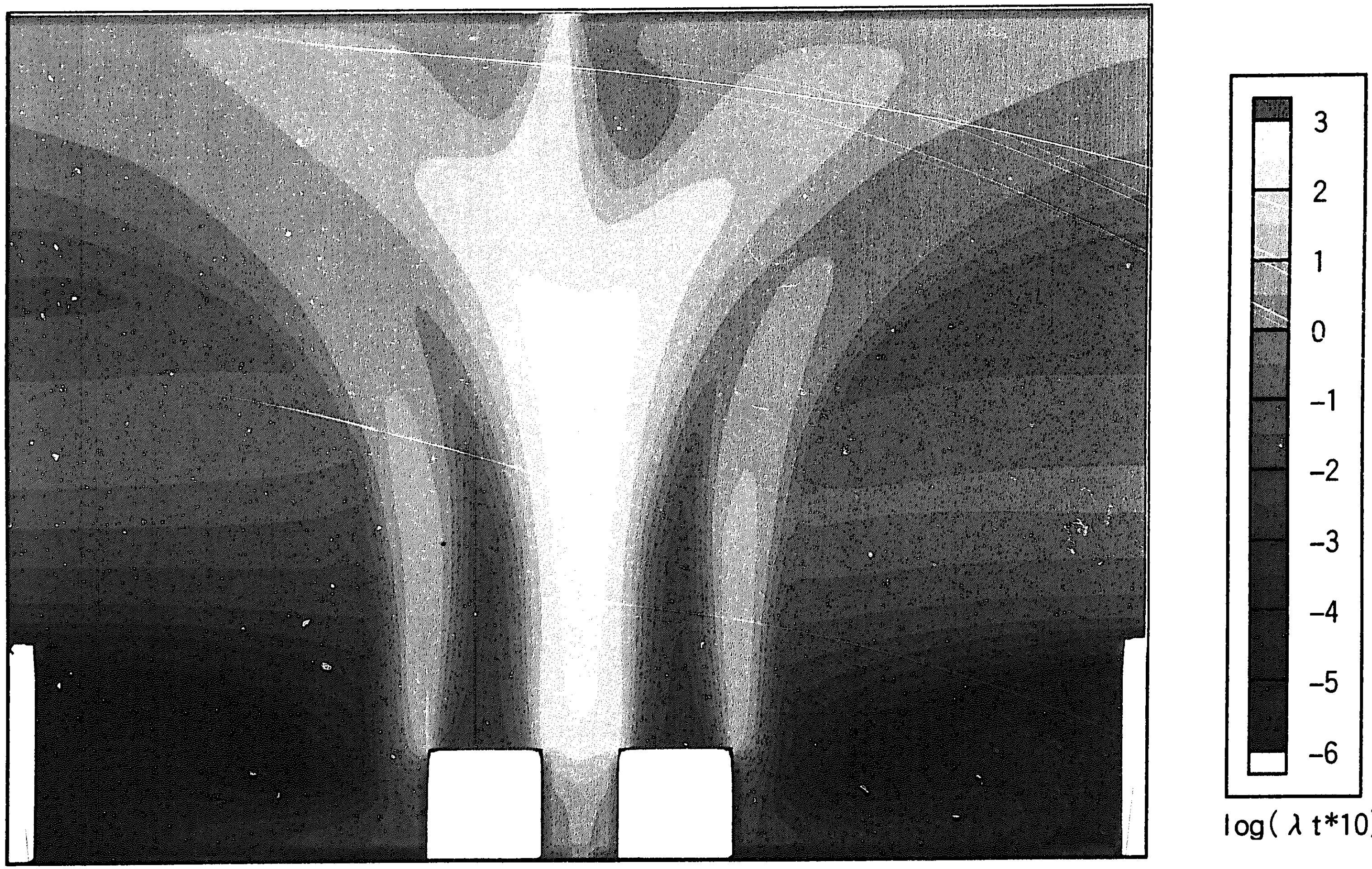


Fig.4-21 H2O: turbulent conductivity (λ t)

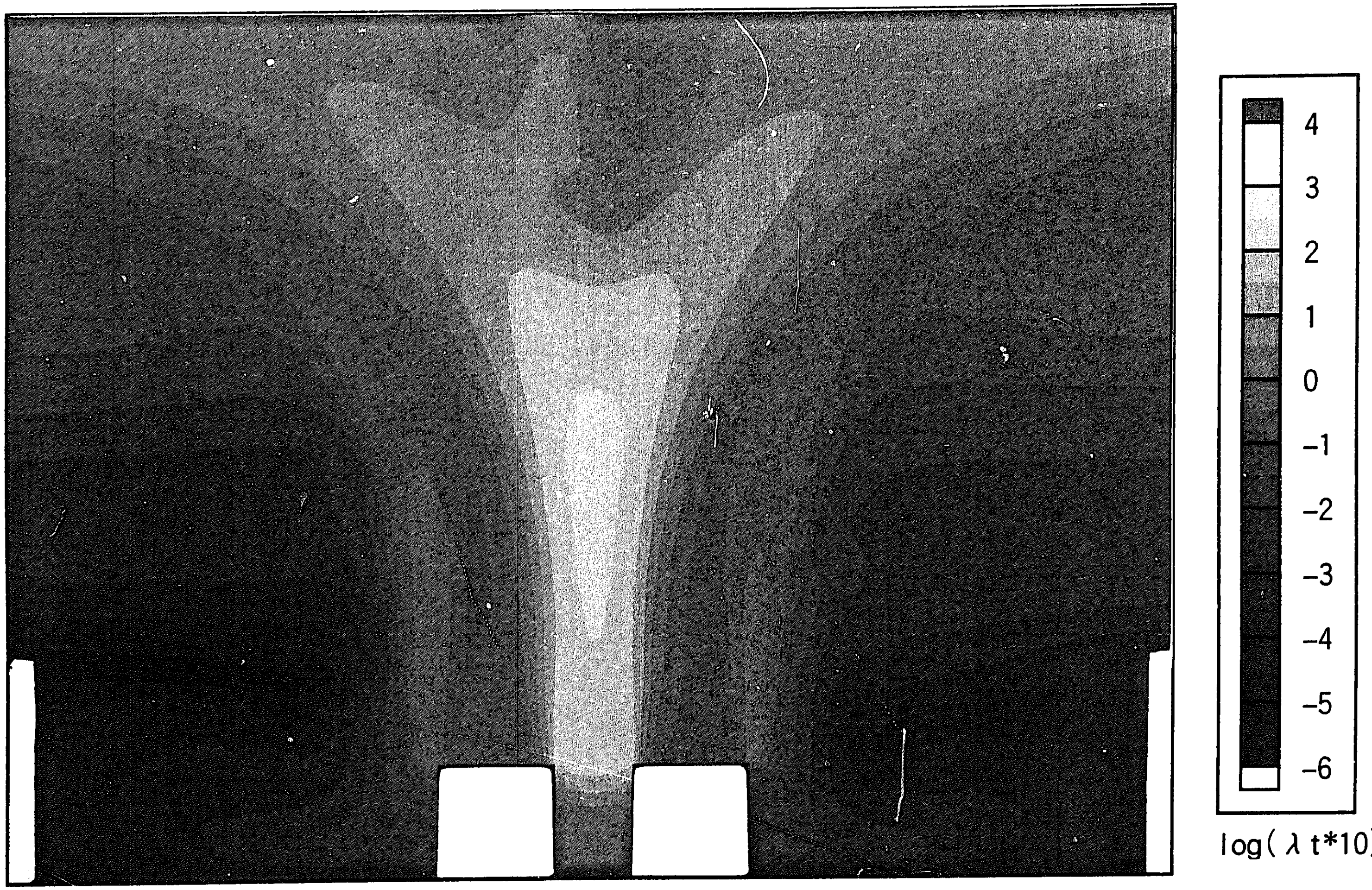


Fig.4-22 Na: turbulent conductivity (λ t)

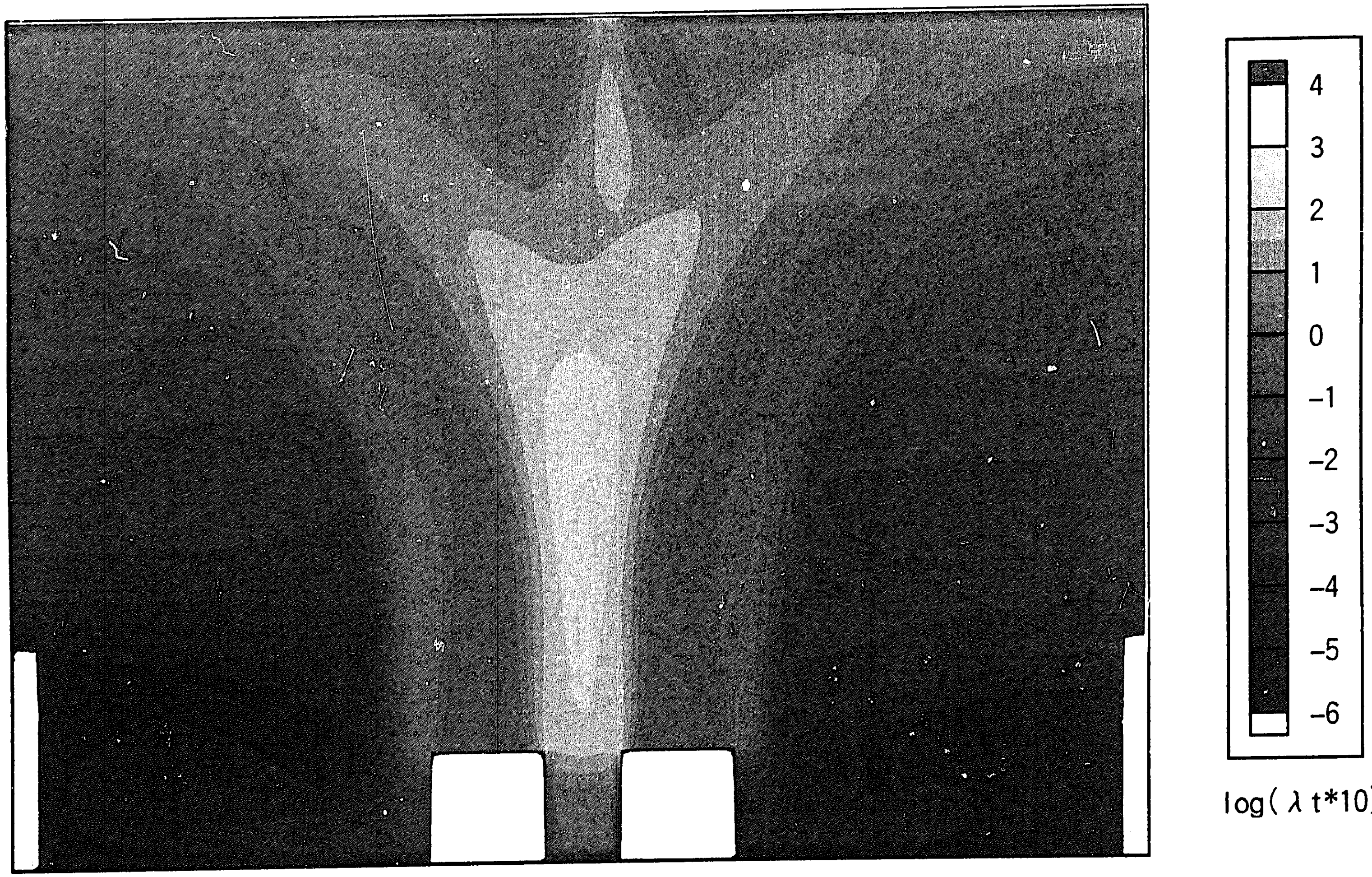


Fig.4-23 Pb: turbulent conductivity (λt)

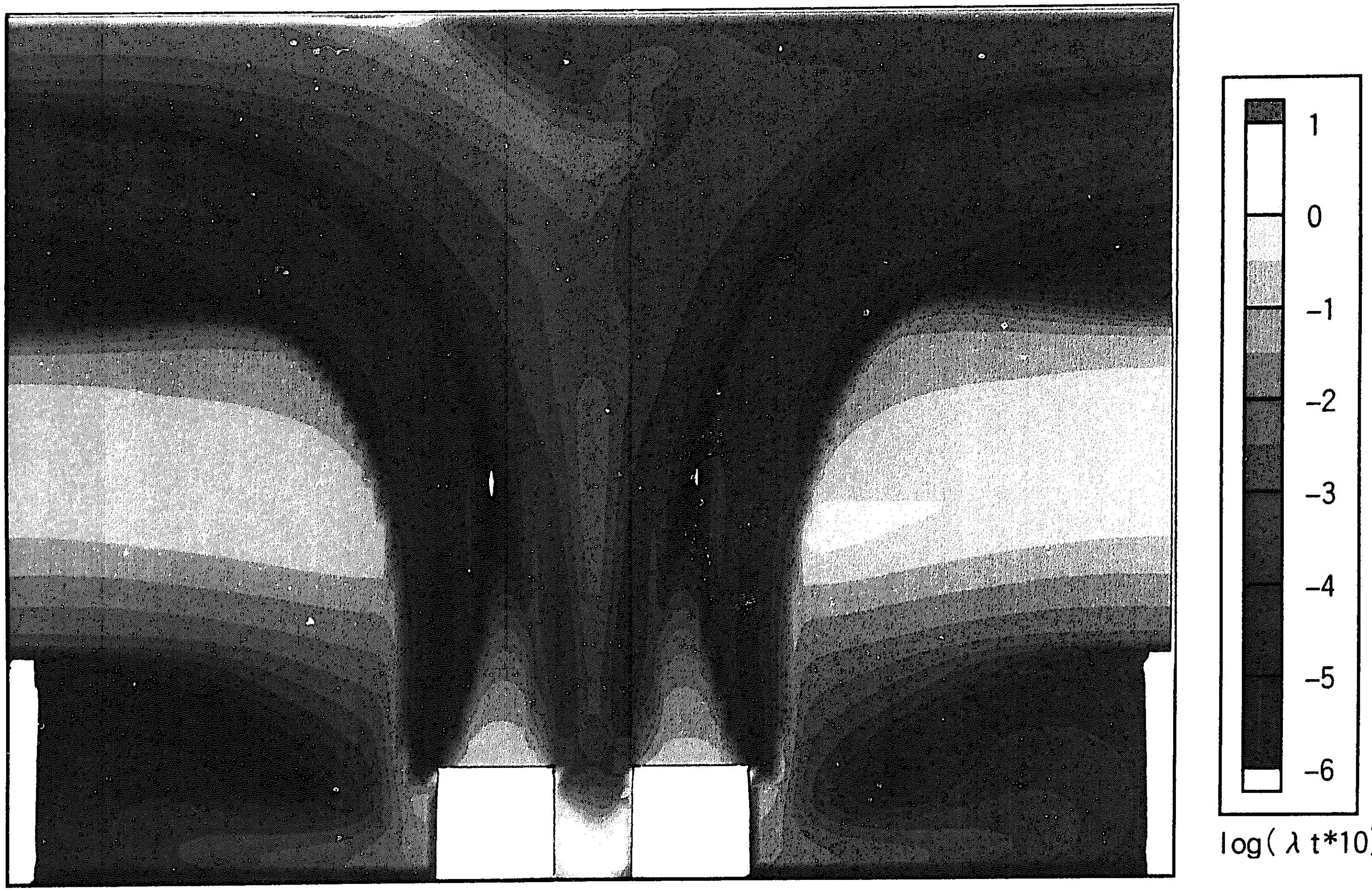


Fig.4-24 CO2: turbulent conductivity (λ t)

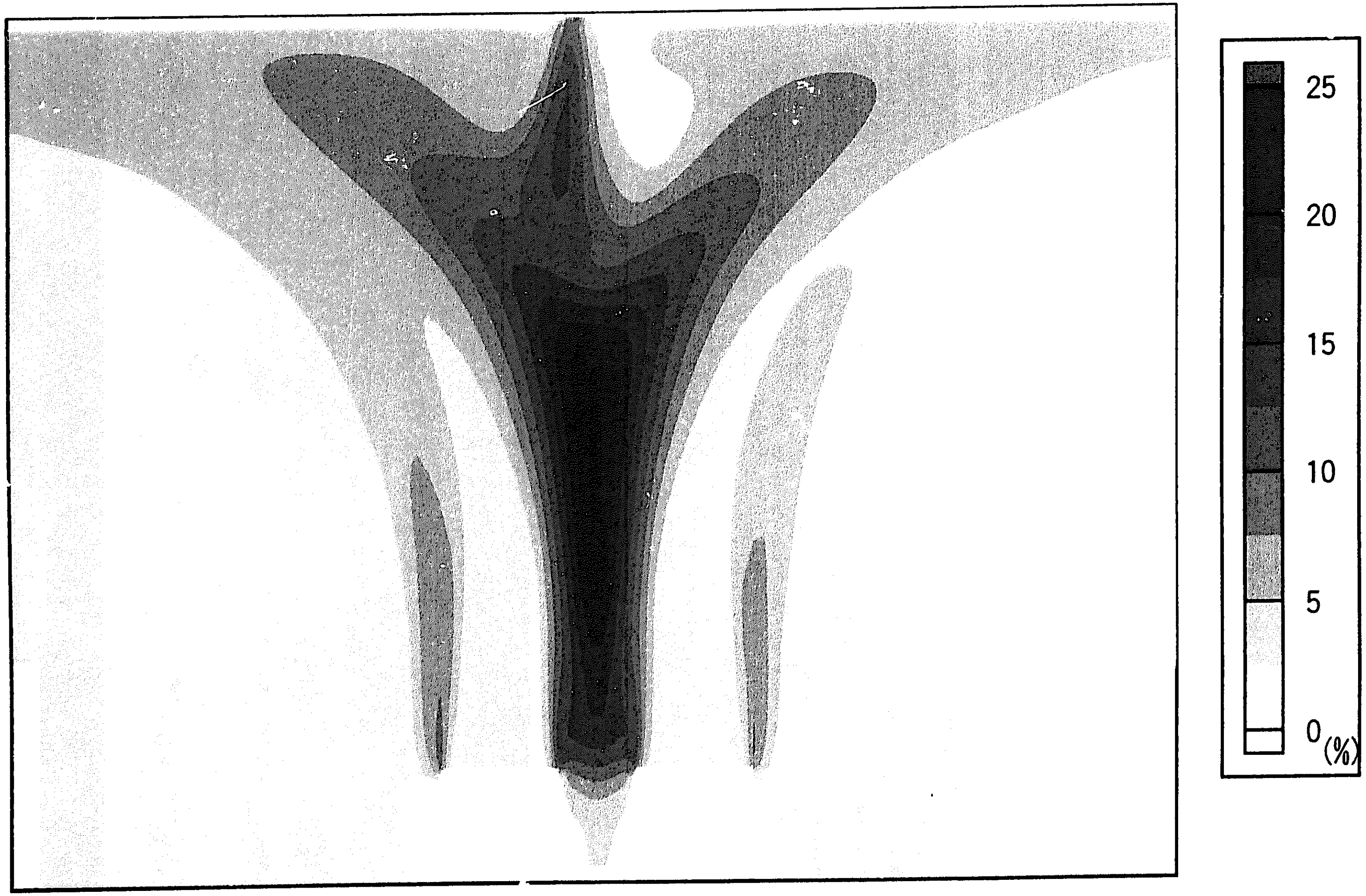


Fig.4-25 H20: normalized temperature fluctuation

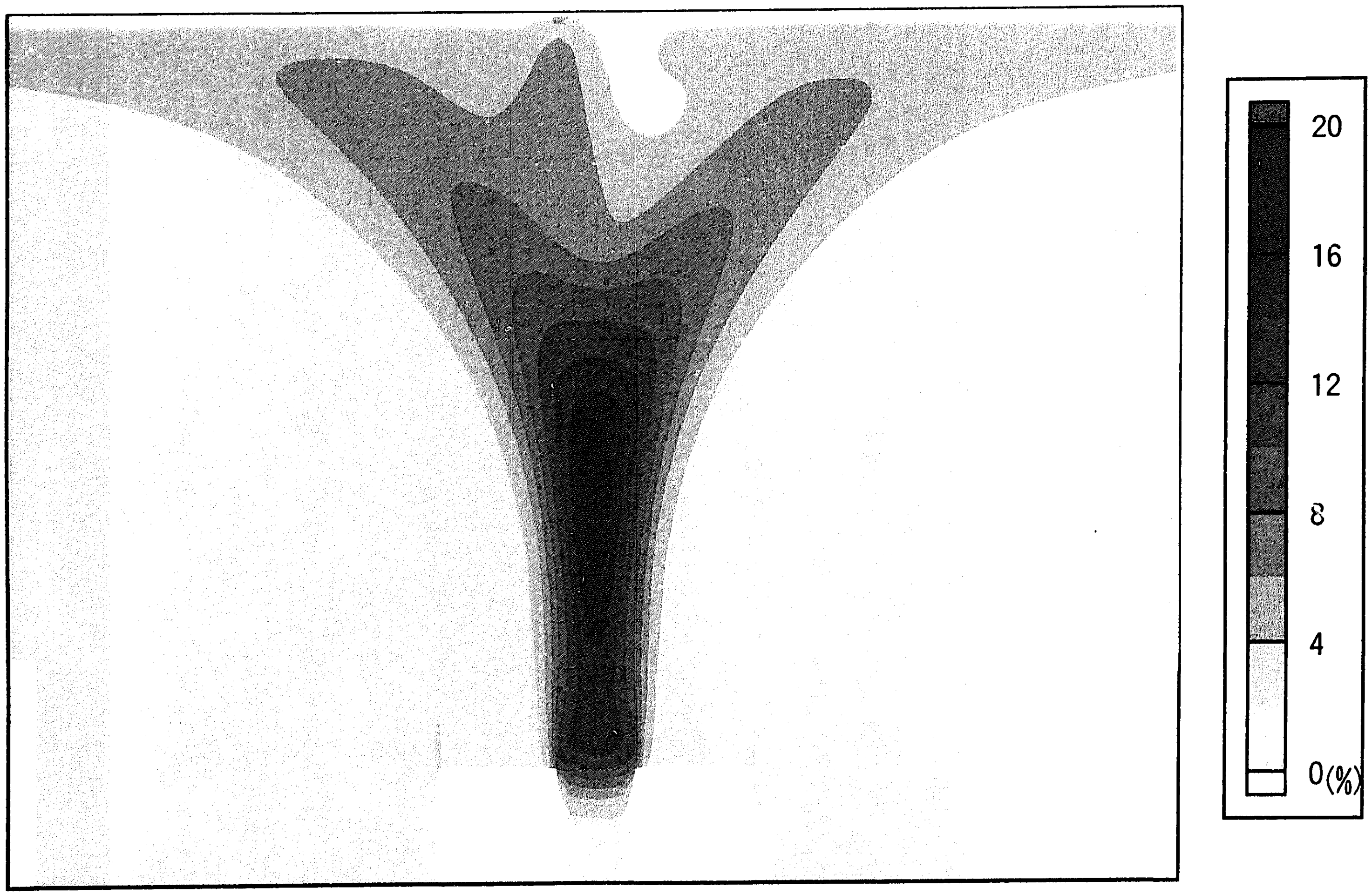


Fig.4-26 Na: normalized temperature fluctuation

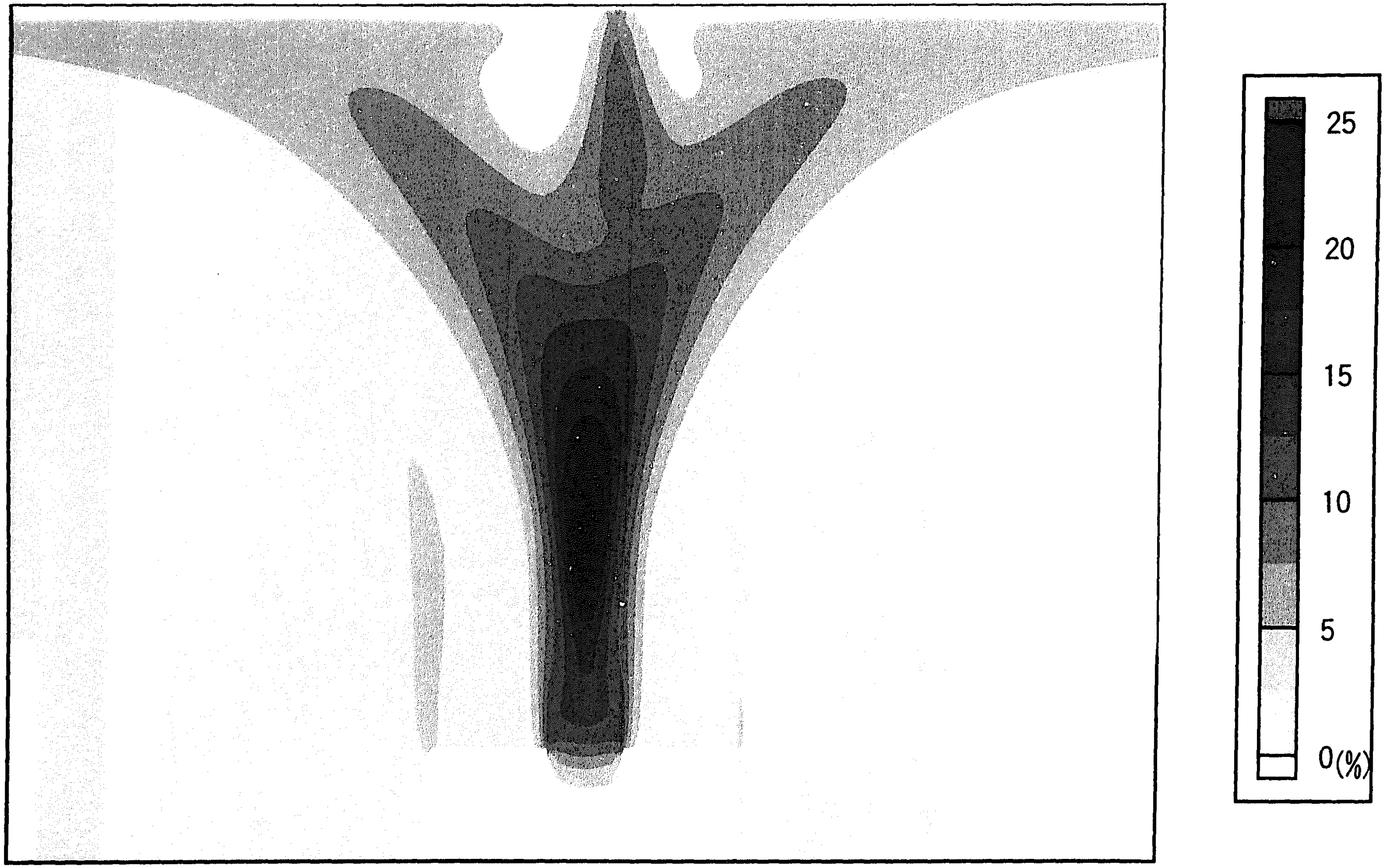


Fig.4-27 Pb: normalized temperature fluctuation

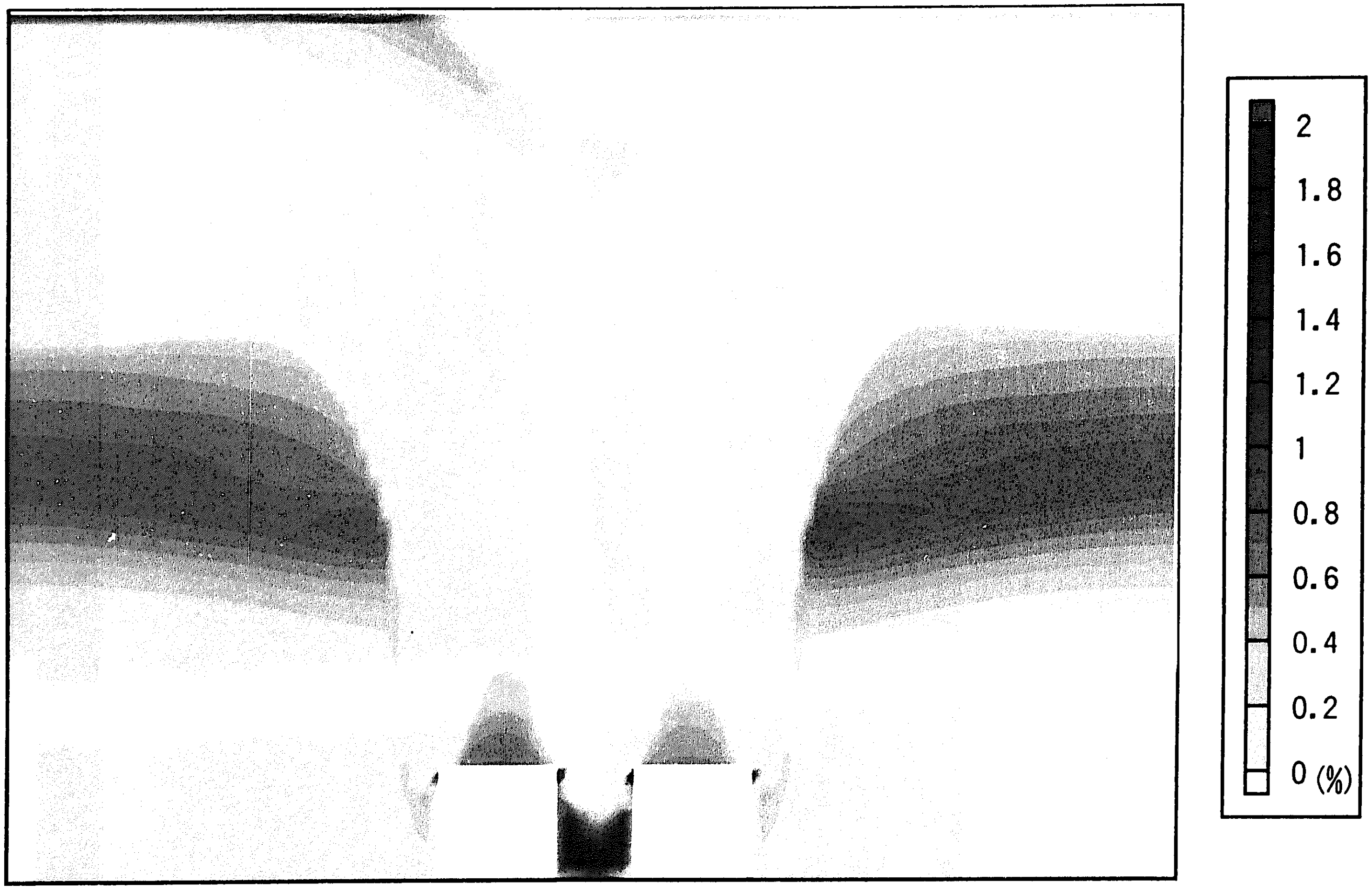


Fig.4-28 C02: normalized temperature fluctuation

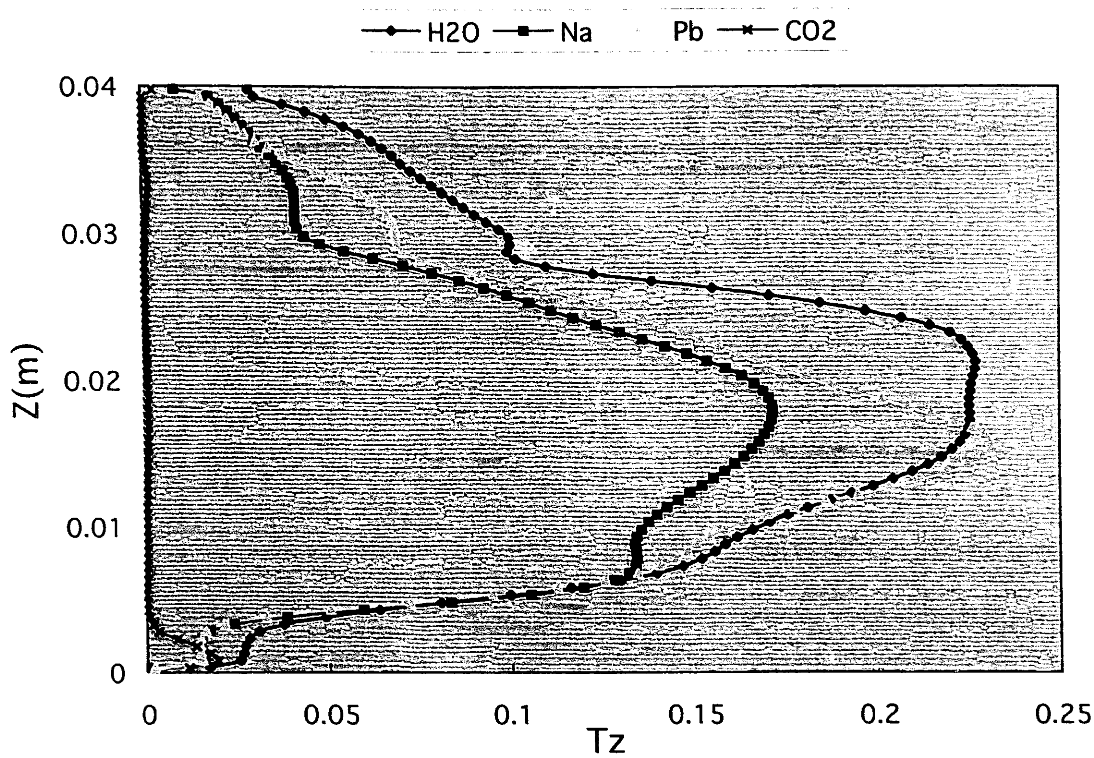


Fig.4-29 normalized temperature fluctuation
at the interface between hot and cold flows

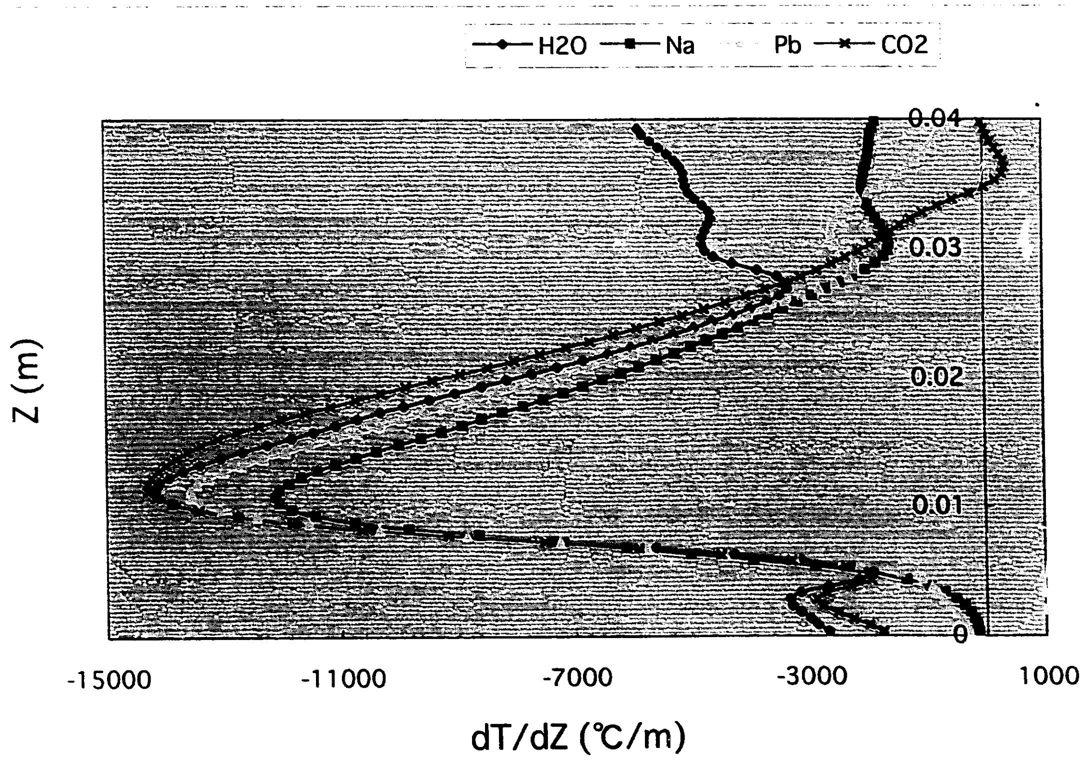


Fig.4-30 temperature gradient at the interface
between hot and cold flows

Appendices

I. Input Data for Thermal Stratification Analysis

```
**************************************************************
* THERMAL STRATIFICATION ANALYSIS WITH AQUA CODE(CASE11)      *
* WORKING FLUID :WATER(H2O)                                   *
* PREPARED BY YANG ZUMAO(1999.10.29)                          *
**************************************************************
 &GEOM
  IGEOM =  0, IFRES = 1, NL1 =10000,NM1 =5000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =100, JMAX =  1, KMAX = 40,
  NSURF = 7,
  ITURKE = 40, IFPCG = 5,
  DX =100*0.01,
  DY =  1*0.01,
  DZ =  40*0.005,
  XNORML = 2*1.0,-1.0, 0., 0., 0., 0.,
  YNORML = 2*0.0, 0.0, 0., 0., 1.,-1.,
  ZNORML = 2*0.0, 0.0, 1.,-1., 0., 0.,
 &END
REG -1.0       1   1   1   1   1  20   1  INLET
REG -1.0       1   1   1   1  21  40   2  INLET
REG -1.0     100 100   1   1   1  40   3  OUTLET
REG -1.0       1 100   1   1   1   1   4  BOTTOM
REG -1.0       1 100   1   1  40  40   5  TOP
REG -1.0       1 100   1   1   1  40   6  NEAR
REG -1.0       1 100   1   1   1  40   7  FAR
END
 &DATA
  NTMAX = 99999,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT = 1.0,1.0,
  NTHCON = -1, TREST = 060.0, IT = 1,1,
  KFLOW = 2*1, -2, 1,-3, -3, -3,
  KTEMP = 2*1, 400, 400, 400, 400, 400,
  VELOC(1) = 0.117,
  VELOC(2) = 0.033,
  TEMP0 =  58.00,
  TEMP(1)= 42.00,
  TEMP(2)= 58.00,
  GRAVZ = -9.802,
  NTPRNT = -9999,
  NTHPR = 012001, 032001, 052001,142001,212001,202001,322001
 &END
 &TURB
```

```
  HYDIN = 1.0E+10,
 &END
END
UL  0.020       1 100   1   1   1  40 INITIALIZE VEL.
END


****************************************************************
* THERMAL STRATIFICATION ANALYSIS WITH AQUA CODE(CASE12)       *
* WORKING FLUID:LIQUID SODIUM(NA)                              *
* PREPARED BY YANG ZUMAO(1999.10.29)                           *
****************************************************************
 &GEOM
  IGEOM =  0, IFRES = 1, NL1 =10000,NM1 =5000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =100, JMAX =  1, KMAX = 40,
  NSURF = 7,
  ITURKE = 40, IFPCG = 5,
  DX =100*0.01,
  DY =  1*0.01,
  DZ =  40*0.005,
  XNORML = 2*1.0,-1.0, 0., 0., 0., 0.,
  YNORML = 2*0.0, 0.0, 0., 0., 1.,-1.,
  ZNORML = 2*0.0, 0.0, 1.,-1., 0., 0.,
 &END
REG -1.0       1   1   1   1   1  20   1  INLET
REG -1.0       1   1   1   1  21  40   2  INLET
REG -1.0     100 100   1   1   1  40   3  OUTLET
REG -1.0       1 100   1   1   1   1   4  BOTTOM
REG -1.0       1 100   1   1  40  40   5  TOP
REG -1.0       1 100   1   1   1  40   6  NEAR
REG -1.0       1 100   1   1   1  40   7  FAR
END
 &DATA
  NTMAX = 99999,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT = 1.0,1.0,
  NTHCON = -1, TREST = 060.0, IT = 1,1,
  KFLOW = 2*1, -2, 1,-3, -3, -3,
  KTEMP = 2*1, 400, 400, 400, 400, 400,
  VELOC(1) = 0.117,
  VELOC(2) = 0.033,
  TEMP0 =  472.63,
  TEMP(1)= 447.37,
  TEMP(2)= 472.63,
  GRAVZ = -9.802,
  NTPRNT = -9999,
  NTHPR = 012001, 032001, 052001,142001,212001,202001,322001
```

```
 &END
 &TURB
   HYDIN = 1.0E+10,
 &END
END
UL  0.020        1 100   1   1   1  40 INITIALIZE VEL.
END


*******************************************************
* THERMAL STRATIFICATION ANALYSIS WITH AQUA CODE(CASE13)      *
* WORKING FLUID : LIQUID LEAD(PB)                             *
* PREPARED BY YANG ZUMAO(1999.10.29)                          *
*******************************************************
 &GEOM
  IGEOM =  0, IFRES = 1, NL1 =10000,NM1 =5000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =100, JMAX =  1, KMAX = 40,
  NSURF = 7,
  ITURKE = 40, IFPCG = 5,
  DX =100*0.01,
  DY =  1*0.01,
  DZ =  40*0.005,
  XNORML = 2*1.0,-1.0, 0., 0., 0., 0.,
  YNORML = 2*0.0, 0.0, 0., 0., 1.,-1.,
  ZNORML = 2*0.0, 0.0, 1.,-1., 0., 0.,
 &END
REG -1.0        1   1   1   1   1  20   1  INLET
REG -1.0        1   1   1   1  21  40   2  INLET
REG -1.0      100 100   1   1   1  40   3  OUTLET
REG -1.0        1 100   1   1   1   1   4  BOTTOM
REG -1.0        1 100   1   1  40  40   5  TOP
REG -1.0        1 100   1   1   1  40   6  NEAR
REG -1.0        1 100   1   1   1  40   7  FAR
END
 &DATA
  NTMAX = 99999,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT = 1.0,1.0,
  NTHCON = -1, TREST = 060.0, IT = 1,1,
  KFLOW = 2*1, -2, 1,-3, -3, -3,
  KTEMP = 2*1, 400, 400, 400, 400, 400,
  VELOC(1) = 0.117,
  VELOC(2) = 0.033,
  TEMP0 =  492.63,
  TEMP(1)= 467.37,
  TEMP(2)= 492.63,
```

```
  IFPROP= 1,
  FC0H= 4.3704E+04,
  FC1H= 1.60E+02,
  FC0RO= 1.09782E+04,
  FC1RO= -1.178,
  FC0K= 17.46658,
  FC1K= -3.9585E-03,
  FC0MU= 3.8253E-03,
  FC1MU= -3.91E-06,
  GRAVZ = -9.802,
  NTPRNT = -9999,
  NTHPR = 012001, 032001, 052001,142001,212001,202001,322001
 &END
 &TURB
   HYDIN = 1.0E+10,
 &END
END
UL  0.020       1 100   1   1   1  40 INITIALIZE VEL.
END


***********************************************************
* THERMAL STRATIFICATION ANALYSIS WITH AQUA CODE(CASE14)    *
* WORKING FLUID : CARBON DIOXIDE(CO2)                       *
* PREPARED BY YANG ZUMAO(1999.10.29)                        *
***********************************************************
 &GEOM
  IGEOM =  0, IFRES = 1, NL1 =10000,NM1 =5000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =100, JMAX =  1, KMAX = 40,
  NSURF = 7,
  ITURKE = 40, IFPCG = 5,
  DX =100*0.01,
  DY =  1*0.01,
  DZ =  40*0.005,
  XNORML = 2*1.0,-1.0, 0., 0., 0., 0.,
  YNORML = 2*0.0, 0.0, 0., 0., 1.,-1.,
  ZNORML = 2*0.0, 0.0, 1.,-1., 0., 0.,
 &END
REG -1.0        1   1   1   1   1  20   1  INLET
REG -1.0        1   1   1   1  21  40   2  INLET
REG -1.0      100 100   1   1   1  40   3  OUTLET
REG -1.0        1 100   1   1   1   1   4  BOTTOM
REG -1.0        1 100   1   1  40  40   5  TOP
REG -1.0        1 100   1   1   1  40   6  NEAR
REG -1.0        1 100   1   1   1  40   7  FAR
```

```
END
 &DATA
  NTMAX = 99999,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT = 1.0,1.0,
  NTHCON = -1, TREST = 060.0, IT = 1,1,
  KFLOW = 2*1, -2, 1,-3, -3, -3,
  KTEMP = 2*1, 400, 400, 400, 400, 400,
  VELOC(1) = 0.117,
  VELOC(2) = 0.033,
  TEMP0 =  392.39,
  TEMP(1)= 387.62,
  TEMP(2)= 392.39,
  IFPROP= 1,
  FC0H= 167465.718,
  FC1H= 1449.828,
  FC0RO= 1.2685,
  FC1RO= -1.2045E-03,
  FC0K= 2.073E-02,
  FC1K= 7.221E-05,
  FC0MU= 1.8089E-05,
  FC1MU= 3.007E-08,
  GRAVZ = -9.802,
  NTPRNT = -9999,
  NTHPR = 012001, 032001, 052001, 142001,212001,202001,322001
 &END
 &TURB
   HYDIN = 1.0E+10,
 &END
END
UL  0.020       1 100   1   1   1  40 INITIALIZE VEL.
END


*************************************************************
* THERMAL STRATIFICATION ANALYSIS WITH AQUA CODE(CASE21)      *
* WORKING FLUID : WATER(H2O)                                  *
* PREPARED BY YANG ZUMAO(1999.10.29)                          *
*************************************************************
&GEOM
  IGEOM =  0, IFRES = 1, NL1 =10000,NM1 =5000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =100, JMAX =  1, KMAX = 40,
  NSURF = 7,
  ITURKE = 40, IFPCG = 5,
  DX =100*0.01,
  DY =  1*0.01,
```

```
  DZ =  40*0.005,
  XNORML = 2*1.0,-1.0, 0., 0., 0., 0.,
  YNORML = 2*0.0, 0.0, 0., 0., 1.,-1.,
  ZNORML = 2*0.0, 0.0, 1.,-1., 0., 0.,
 &END
REG -1.0        1   1   1   1   1  20   1  INLET
REG -1.0        1   1   1   1  21  40   2  INLET
REG -1.0      100 100   1   1   1  40   3  OUTLET
REG -1.0        1 100   1   1   1   1   4  BOTTOM
REG -1.0        1 100   1   1  40  40   5  TOP
REG -1.0        1 100   1   1   1  40   6  NEAR
REG -1.0        1 100   1   1   1  40   7  FAR
END
 &DATA
  NIMAX = 99999,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT = 1.0,1.0,
  NTHCON = -1, TREST = 060.0, IT = 1,1,
  KFLOW = 2*1, -2, 1,-3, -3, -3,
  KTEMP = 2*1, 400, 400, 400, 400, 400,
  VELOC(1) = 0.127,
  VELOC(2) = 0.033,
  TEMP0 =  60.00,
  TEMP(1)= 40.00,
  TEMP(2)= 60.00,
  GRAVZ = -9.802,
  NTPRNT = -9999,
  NTHPR = 012001, 032001, 052001,142001,212001,202001,322001
 &END
 &TURB
   HYDIN = 1.0E+10,
 &END
END
UL  0.020       1 100   1   1   1  40 INITIALIZE VEL.
END


*************************************************************
* THERMAL STRATIFICATION ANALYSIS WITH AQUA CODE(CASE22)     *
* WORKING FLUID : LIQUID SODIUM(NA)                          *
* PREPARED BY YANG ZUMAO(1999.10.29)                         *
*************************************************************
&GEOM
  IGEOM =  0, IFRES = 1, NL1 =10000,NM1 =5000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =100, JMAX =  1, KMAX = 40,
  NSURF = 7,
```

```
  ITURKE = 40, IFPCG = 5,
  DX =100*0.01,
  DY =  1*0.01,
  DZ =  40*0.005,
  XNORML = 2*1.0,-1.0, 0., 0., 0., 0.,
  YNORML = 2*0.0, 0.0, 0., 0., 1.,-1.,
  ZNORML = 2*0.0, 0.0, 1.,-1., 0., 0.,
 &END
REG -1.0        1   1   1   1   1  20   1  INLET
REG -1.0        1   1   1   1  21  40   2  INLET
REG -1.0      100 100   1   1   1  40   3  OUTLET
REG -1.0        1 100   1   1   1   1   4  BOTTOM
REG -1.0        1 100   1   1  40  40   5  TOP
REG -1.0        1 100   1   1   1  40   6  NEAR
REG -1.0        1 100   1   1   1  40   7  FAR
END
 &DATA
  NTMAX = 99999,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT = 1.0,1.0,
  NTHCON = -1, TREST = 060.0, IT = 1,1,
  KFLOW = 2*1, -2, 1, -3, -3, -3,
  KTEMP = 2*1, 400, 400, 400, 400, 400,
  VELOC(1) = 0.108,
  VELOC(2) = 0.033,
  TEMP0 =  470.00,
  TEMP(1)= 450.00,
  TEMP(2)= 470.00,
  GRAVZ = -9.802,
  NTPRNT = -9999,
  NTHPR = 012001, 032001, 052001,142001,212001,202001,322001
 &END
 &TURB
   HYDIN = 1.0E+10,
 &END
END
UL  0.020       1 100   1   1   1  40 INITIALIZE VEL.
END


*************************************************************
* THERMAL STRATIFICATION ANALYSIS WITH AQUA CODE(CASE23)    *
* WORKING FLUID : LIQUID LEAD(PB)                           *
* PREPARED BY YANG ZUMAO(1999.10.29)                        *
*************************************************************
&GEOM
  IGEOM =  0, IFRES = 1, NL1 =10000,NM1 =5000,
```

```
  ISYMCH = 3, IFITEN = 3,
  IMAX =100, JMAX =  1, KMAX = 40,
  NSURF = 7,
  ITURKE = 40, IFPCG = 5,
  DX =100*0.01,
  DY =  1*0.01,
  DZ =  40*0.005,
  XNORML = 2*1.0,-1.0, 0., 0., 0., 0.,
  YNORML = 2*0.0, 0.0, 0., 0., 1.,-1.,
  ZNORML = 2*0.0, 0.0, 1.,-1., 0., 0.,
 &END
REG -1.0        1   1   1   1   1  20   1  INLET
REG -1.0        1   1   1   1  21  40   2  INLET
REG -1.0      100 100   1   1   1  40   3  OUTLET
REG -1.0        1 100   1   1   1   1   4  BOTTOM
REG -1.0        1 100   1   1  40  40   5  TOP
REG -1.0        1 100   1   1   1  40   6  NEAR
REG -1.0        1 100   1   1   1  40   7  FAR
END
 &DATA
  NTMAX = 99999,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT = 1.0,1.0,
  NTHCON = -1, TREST = 060.0, IT = 1,1,
  KFLOW = 2*1, -2, 1,-3, -3, -3,
  KTEMP = 2*1, 400, 400, 400, 400, 400,
  VELOC(1) = 0.108,
  VELOC(2) = 0.033,
  TEMP0 =  490.00,
  TEMP(1)= 470.00,
  TEMP(2)= 490.00,
  IFPROP= 1,
  FC0H= 4.3704E+04,
  FC1H= 1.60E+02,
  FC0RO= 1.09782E+04,
  FC1RO= -1.178,
  FC0K= 17.46658,
  FC1K= -3.9585E-03,
  FC0MU= 3.8253E-03,
  FC1MU= -3.91E-06,
  GRAVZ = -9.802,
  NTPRNT = -9999,
  NTHPR = 012001, 032001, 052001,142001,212001,202001,322001
 &END
 &TURB
   HYDIN = 1.0E+10,
 &END
```

```
END
UL  0.020        1 100   1   1   1  40 INITIALIZE VEL.
END


*************************************************************
* THERMAL STRATIFICATION ANALYSIS WITH AQUA CODE(CASE24)     *
* WORKING FLUID :CARBON DIOXIDE(CO2)                         *
* PREPARED BY YANG ZUMAO(1999.10.29)                         *
*************************************************************
&GEOM
  IGEOM =  0, IFRES = 1, NL1 =10000,NM1 =5000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =100, JMAX =  1, KMAX = 40,
  NSURF = 7,
  ITURKE = 40, IFPCG = 5,
  DX =100*0.01,
  DY =  1*0.01,
  DZ =  40*0.005,
  XNORML = 2*1.0,-1.0, 0., 0., 0., 0.,
  YNORML = 2*0.0, 0.0, 0., 0., 1.,-1.,
  ZNORML = 2*0.0, 0.0, 1.,-1., 0., 0.,
 &END
REG -1.0         1   1   1   1   1  20   1  INLET
REG -1.0         1   1   1   1  21  40   2  INLET
REG -1.0       100 100   1   1   1  40   3  OUTLET
REG -1.0         1 100   1   1   1   1   4  BOTTOM
REG -1.0         1 100   1   1  40  40   5  TOP
REG -1.0         1 100   1   1   1  40   6  NEAR
REG -1.0         1 100   1   1   1  40   7  FAR
END
 &DATA
  NTMAX = 99999,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT = 1.0,1.0,
  NTHCON = -1, TREST = 060.0, IT = 1,1,
  KFLOW = 2*1, -2, 1,-3, -3, -3,
  KTEMP = 2*1, 400, 400, 400, 400, 400,
  VELOC(1) = 0.205,
  VELOC(2) = 0.033,
  TEMP0 =  400.00,
  TEMP(1)= 380.00,
  TEMP(2)= 400.00,
  IFPROP= 1,
  FC0H= 167465.718,
  FC1H= 1449.828,
  FC0RO= 1.2685,
```

```
  FC1RO= -1.2045E-3,
  FC0K= 2.073E-02,
  FC1K= 7.221E-05,
  FC0MU= 1.8089E-05,
  FC1MU= 3.007E-08,
  GRAVZ = -9.802,
  NTPRNT = -9999,
  NTHPR = 012001, 032001, 052001,142001,212001,202001,322001
 &END
 &TURB
   HYDIN = 1.0E+10,
 &END
END
UL  0.020        1 100   1   1   1  40 INITIALIZE VEL.
END
```

II. Input Data for Thermal Striping Analysis

```
************************************************************
* THERMAL STRIPING ANALYSIS WITH AQUA CODE                 *
* WORKING FLUID :WATER(H2O)                                *
* PREPARED BY YANG ZUMAO (2000.1.6)                        *
************************************************************
 &GEOM
  IGEOM =  0, IFRES = 1, NL1 =20000,NM1 =30000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =108, JMAX =  3, KMAX = 80,
  NSURF =10,
  ITURKE = 40, IFPCG = 5,
  DX =108*0.0005,
  DY =  3*0.0005,
  DZ = 80*0.0005,
  XNORML =  1.,-1., 0., 0., 0., 0., 2*0.,1.,-1.,
  YNORML =  0., 0., 1.,-1., 0., 0., 2*0.,0., 0.,
  ZNORML =  0., 0., 0., 0., 1.,-1., 2*1.,0., 0.,
 &END
REG -1.0       3   3   1   3   1  20   1  +X WALL
REG -1.0      51  51   1   3   1  10   1
REG -1.0      69  69   1   3   1  10   1
REG -1.0     106 106   1   3   1  20   2  -X WALL
REG -1.0      40  40   1   3   1  10   2
REG -1.0      58  58   1   3   1  10   2
REG -1.0       1 108   1   1  21  80   3  +Y WALL
REG -1.0       3 106   1   1  11  20   3
REG -1.0       3  40   1   1   1  10   3
REG -1.0      51  58   1   1   1  10   3
REG -1.0      69 106   1   1   1  10   3
REG -1.0       1 108   3   3  21  80   4  -Y WALL
REG -1.0       3 106   3   3  11  20   4
REG -1.0       3  40   3   3   1  10   4
REG -1.0      51  58   3   3   1  10   4
REG -1.0       1   2   1   3  21  21   5  +Z WALL
REG -1.0       3  40   1   3   1   1   5
REG -1.0      51  58   1   3   1   1   5
REG -1.0      69 106   1   3   1   1   5
REG -1.0     107 108   1   3  21  21   5
REG -1.0       1 108   1   3  80  80   6  -Z WALL
REG -1.0      41  50   1   3  11  11   7  +Z  HOT INLET
REG -1.0      59  68   1   3  11  11   8  +Z COLD INLET
REG -1.0       1   1   1   3  21  80   9  +X OULET
REG -1.0     108 108   1   3  21  80  10  -X OUTLET
END
```

```
&DATA
 NTMAX = 5000,
 IDTIME = 0, ISTATE = 0, IFENER = 1, DT =  1.0 ,  1.0,
 NTHCON = -1, IT = 1, 1,  ITMAXP=99,
 KFLOW = 2*1, -3, 3*1, 2*1, 2*-5,
 KTEMP = 6*400, 2*1, 2*400,
 VELOC(7) = 2*2.85,
 TEMP0 = 50.,
 TEMP(7)= 70.,30.,
 GRAVZ = -9.807,
 NTPRNT = -9999,
 NTPLOT = -9999,
 NTHPR = 142002, 212002, 202002,322002
 &END
 &TURB
  HYDIN = 1.0E+10,
  KEITER=1, ITKBUG=0,
 &END
END
END


*************************************************************
* THERMAL STRIPING ANALYSIS WITH AQUA CODE                  *
* WORKING FLUID :LIQUID SODIUM(NA)                          *
* PREPARED BY YANG ZUMAO (2000.1.6)                         *
*************************************************************
&GEOM
  IGEOM =  0, IFRES = 1, NL1 =20000,NM1 =30000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =108, JMAX =  3, KMAX = 80,
  NSURF =10,
  ITURKE = 40, IFPCG = 5,
  DX =108*0.0005,
  DY =  3*0.0005,
  DZ = 80*0.0005,
  XNORML =  1.,-1., 0., 0., 0., 0., 2*0.,1.,-1.,
  YNORML =  0., 0., 1.,-1., 0., 0., 2*0.,0., 0.,
  ZNORML =  0., 0., 0., 0., 1.,-1., 2*1.,0., 0.,
 &END
REG -1.0        3   3   1   3   1  20   1  +X WALL
REG -1.0       51  51   1   3   1  10   1
REG -1.0       69  69   1   3   1  10   1
REG -1.0      106 106   1   3   1  20   2  -X WALL
REG -1.0       40  40   1   3   1  10   2
REG -1.0       58  58   1   3   1  10   2
REG -1.0        1 108   1   1  21  80   3  +Y WALL
```

```
REG -1.0        3 106   1   1  11  20   3
REG -1.0        3  40   1   1   1  10   3
REG -1.0       51  58   1   1   1  10   3
REG -1.0       69 106   1   1   1  10   3
REG -1.0        1 108   3   3  21  80   4  -Y WALL
REG -1.0        3 106   3   3  11  20   4
REG -1.0        3  40   3   3   1  10   4
REG -1.0       51  58   3   3   1  10   4
REG -1.0        1   2   1   3  21  21   5  +Z WALL
REG -1.0        3  40   1   3   1   1   5
REG -1.0       51  58   1   3   1   1   5
REG -1.0       69 106   1   3   1   1   5
REG -1.0      107 108   1   3  21  21   5
REG -1.0        1 108   1   3  80  80   6  -Z WALL
REG -1.0       41  50   1   3  11  11   7  +Z  HOT INLET
REG -1.0       59  68   1   3  11  11   8  +Z COLD INLET
REG -1.0        1   1   1   3  21  80   9  +X OULET
REG -1.0      108 108   1   3  21  80  10  -X OUTLET
END
 &DATA
  NTMAX = 5000,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT =  1.0 ,  1.0,
  NTHCON = -1, IT = 1, 1,  ITMAXP=99,
  KFLOW = 2*1, -3, 3*1, 2*1, 2*-5,
  KTEMP = 6*400, 2*1, 2*400,
  VELOC(7) = 2*2.,
  TEMP0 = 300.,
  TEMP(7)= 320.,280.,
  GRAVZ = -9.807,
  NTPRNT = -9999,
  NTPLOT = -9999,
  NTHPR = 142002, 212002, 202002,322002
 &END
 &TURB
   HYDIN = 1.0E+10,
   KEITER=1, ITKBUG=0,
 &END
END
END


*****************************************************************
* THERMAL STRIPING ANALYSIS WITH AQUA CODE                      *
* WORKING FLUID :LIQUID LEAD(PB)                                *
* PREPARED BY YANG ZUMAO (2000.1.6)                             *
*****************************************************************
&GEOM
```

```
 IGEOM =  0, IFRES = 1, NL1 =20000,NM1 =30000,
 ISYMCH = 3, IFITEN = 3,
 IMAX =108, JMAX =  3, KMAX = 80,
 NSURF =10,
 ITURKE = 40, IFPCG = 5,
 DX =108*0.0005,
 DY =  3*0.0005,
 DZ = 80*0.0005,
 XNORML =  1.,-1., 0., 0., 0., 0., 2*0.,1.,-1.,
 YNORML =  0., 0., 1.,-1., 0., 0., 2*0.,0., 0.,
 ZNORML =  0., 0., 0., 0., 1.,-1., 2*1.,0., 0.,
&END
REG -1.0       3   3   1   3   1  20   1  +X WALL
REG -1.0      51  51   1   3   1  10   1
REG -1.0      69  69   1   3   1  10   1
REG -1.0     106 106   1   3   1  20   2  -X WALL
REG -1.0      40  40   1   3   1  10   2
REG -1.0      58  58   1   3   1  10   2
REG -1.0       1 108   1   1  21  80   3  +Y WALL
REG -1.0       3 106   1   1  11  20   3
REG -1.0       3  40   1   1   1  10   3
REG -1.0      51  58   1   1   1  10   3
REG -1.0      69 106   1   1   1  10   3
REG -1.0       1 108   3   3  21  80   4  -Y WALL
REG -1.0       3 106   3   3  11  20   4
REG -1.0       3  40   3   3   1  10   4
REG -1.0      51  58   3   3   1  10   4
REG -1.0       1   2   1   3  21  21   5  +Z WALL
REG -1.0       3  40   1   3   1   1   5
REG -1.0      51  58   1   3   1   1   5
REG -1.0      69 106   1   3   1   1   5
REG -1.0     107 108   1   3  21  21   5
REG -1.0       1 108   1   3  80  80   6  -Z WALL
REG -1.0      41  50   1   3  11  11   7  +Z  HOT INLET
REG -1.0      59  68   1   3  11  11   8  +Z COLD INLET
REG -1.0       1   1   1   3  21  80   9  +X OULET
REG -1.0     108 108   1   3  21  80  10  -X OUTLET
END
 &DATA
  NTMAX = 5000,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT =  1.0 ,  1.0,
  NTHCON = -1, IT = 1, 1,  ITMAXP=99,
  KFLOW = 2*1, -3, 3*1, 2*1, 2*-5,
  KTEMP = 6*400, 2*1, 2*400,
  VELOC(7) = 2*1.14,
  TEMP0 = 380.,
```

```
 TEMP(7)= 400.,360.,
 IFPROP = 1,
 FC0H = 4.3704E+04
 FC1H = 1.60E+02
 FC0RO = 1.09782E+04,
 FC1RO = -1.178,
 FC0K = 18.1,
 FC1K = -5.385E-03
 FC0MU = 4.31E-03
 FC1MU = -5.03E-06
 GRAVZ = -9.807,
 NTPRNT = -9999,
 NTPLOT = -9999,
 NTHPR = 142002, 212002, 202002,322002
&END
&TURB
  HYDIN = 1.0E+10,
  KEITER=1, ITKBUG=0,
&END
END
END


*************************************************************
* THERMAL STRIPING ANALYSIS WITH AQUA CODE                  *
* WORKING FLUID :CARBON DIOXIDE(CO2)                        *
* PREPARED BY YANG ZUMAO (2000.1.6)                         *
*************************************************************
&GEOM
  IGEOM =  0, IFRES = 1, NL1 =20000,NM1 =30000,
  ISYMCH = 3, IFITEN = 3,
  IMAX =108, JMAX =  3, KMAX = 80,
  NSURF =10,
  ITURKE = 40, IFPCG = 5,
  DX =108*0.0005,
  DY =  3*0.0005,
  DZ = 80*0.0005,
  XNORML =  1.,-1., 0., 0., 0., 0., 2*0.,1.,-1.,
  YNORML =  0., 0., 1.,-1., 0., 0., 2*0.,0., 0.,
  ZNORML =  0., 0., 0., 0., 1.,-1., 2*1.,0., 0.,
 &END
REG -1.0        3   3   1   3   1  20   1  +X WALL
REG -1.0       51  51   1   3   1  10   1
REG -1.0       69  69   1   3   1  10   1
REG -1.0      106 106   1   3   1  20   2  -X WALL
REG -1.0       40  40   1   3   1  10   2
REG -1.0       58  58   1   3   1  10   2
```

```
REG -1.0       1 108   1   1  21  80   3  +Y WALL
REG -1.0       3 106   1   1  11  20   3
REG -1.0       3  40   1   1   1  10   3
REG -1.0      51  58   1   1   1  10   3
REG -1.0      69 106   1   1   1  10   3
REG -1.0       1 108   3   3  21  80   4  -Y WALL
REG -1.0       3 106   3   3  11  20   4
REG -1.0       3  40   3   3   1  10   4
REG -1.0      51  58   3   3   1  10   4
REG -1.0       1   2   1   3  21  21   5  +Z WALL
REG -1.0       3  40   1   3   1   1   5
REG -1.0      51  58   1   3   1   1   5
REG -1.0      69 106   1   3   1   1   5
REG -1.0     107 108   1   3  21  21   5
REG -1.0       1 108   1   3  80  80   6  -Z WALL
REG -1.0      41  50   1   3  11  11   7  +Z  HOT INLET
REG -1.0      59  68   1   3  11  11   8  +Z COLD INLET
REG -1.0       1   1   1   3  21  80   9  +X OULET
REG -1.0     108 108   1   3  21  80  10  -X OUTLET
END
 &DATA
  NTMAX = 5000,
  IDTIME = 0, ISTATE = 0, IFENER = 1, DT =  1.0 ,  1.0,
  NTHCON = -1, IT = 1, 1,  ITMAXP=99,
  KFLOW = 2*1, -3, 3*1, 2*1, 2*-5,
  KTEMP = 6*400, 2*1, 2*400,
  VELOC(7) = 2*125.,
  TEMP0 = 240.,
  TEMP(7)= 260.,220.,
  IFPROP = 1,
  FC0H = 2.16E+05,
  FC1H = 1286.289,
  FC0RO = 1.52,
  FC1RO = -2.013E-03,
  FC0K = 2.073E-02,
  FC1K = 7.221E-05,
  FC0MU = 1.8089E-05,
  FC1MU = 3.007E-08,
  GRAVZ = -9.807,
  NTPRNT = -9999,
  NTPLOT = -9999,
  NTHPR = 142002, 212002, 202002,322002
 &END
 &TURB
   HYDIN = 1.0E+10,
   KEITER=1, ITKBUG=0,
```