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Evaluation for the Effects of a Ring Plate Device to Eliminate Free Surface Gradients in Liquid Metal Fast Breeder Reactor Vessel Using Multi-Dimensional Thermohydraulics Computer Code

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Evaluation for the Effects of a Ring Plate Device to Eliminate Free Surface Gradients in Liquid Metal Fast Breeder Reactor Vessel Using Multi-Dimensional Thermohydraulics Computer Code*

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Abstract

There is a free surface at the upper plenum in a reactor vessel of LMFBR . The free surface has spatial gradient caused by the internal coolant flow . This is a disadvantageous factor to engineering from the view point of gas entrainment into coolant . To eliminate the free surface gradients , ring plates about 20 cm wide are fitted at about 1 meter under the free surface . They interfere fluid flow , and decrease the component velocity in vertical direction .

To investigate the efficiency of the ring plates , analyses with the AQUA-VOF code were carried out . For contrast , three conditions were given :

Case-1 : Without ring plates .

Case-2 : Ring plates , fitted at 1.125 m under the free surface .

Case-3 : Ring plates , fitted at 1.5 m under the free surface .

The results shown that the ring plates have a sufficiently high potential to eliminate the free surface gradients due to disperse the momentum along reactor vessel axis to radial direction . In the calculations with ring plate (Cases-2 and -3), the maximum free surface height differences and the maximum gradients of free surface were decreased to less than 15% and 64% compared with the case without ring plates , respectively .

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FIGURES

1 Introduction

In reactor vessel of a LMFBR , the free surface of coolant is a problem that intimately concerns the safety of reactor operation , because there is out of balance which momentum along the axis of reactor vessel . It cause the gradients at the free surface and has the possible to involve gas into coolant .

For restrain this phenomenon , ring plates , which are 20 cm wide , are considered to fit at the outer surface of UCS cylinder and inner surface of reactor vessel , and their levels are a little more than 1.1 m under the free surface .

The ring plates can disperse the axial momentum along reactor vessel to radial and circumferential directions , and balance the velocities of whole area , smooth the free surface . This study only discussed the dispersion in radial direction .

For convenience to discuss , three cases were calculated . Case-1 was without ring plates . Case-2 was with ring plates fitted at 1.125 m under the liquid surface . Case-3 was also with ring plates but fitted at 1.5 m under the liquid surface . The operating condition of three cases all used the last stage condition of fifth operating period of a LMFBR .

The reactor vessel structure of the LMFBR[2] show in figure 1-1 .

Main parameters of the LMFBR are as following :

Power output : 1600MWt (600MWe)

Loops : 3

Inlet temperature : 380℃

Outlet temperature : 530℃

Upper plenum gas pressure : 1.886×10^5 Pa

Primary coolant flow : 8410 kg/s

Inner diameter of reactor vessel : Φ8400

Outer diameter of UCS : Φ3000

Outer diameter of core barrel : Φ4700

Inner diameter of inlet nozzles : Φ736.6(12.7t)

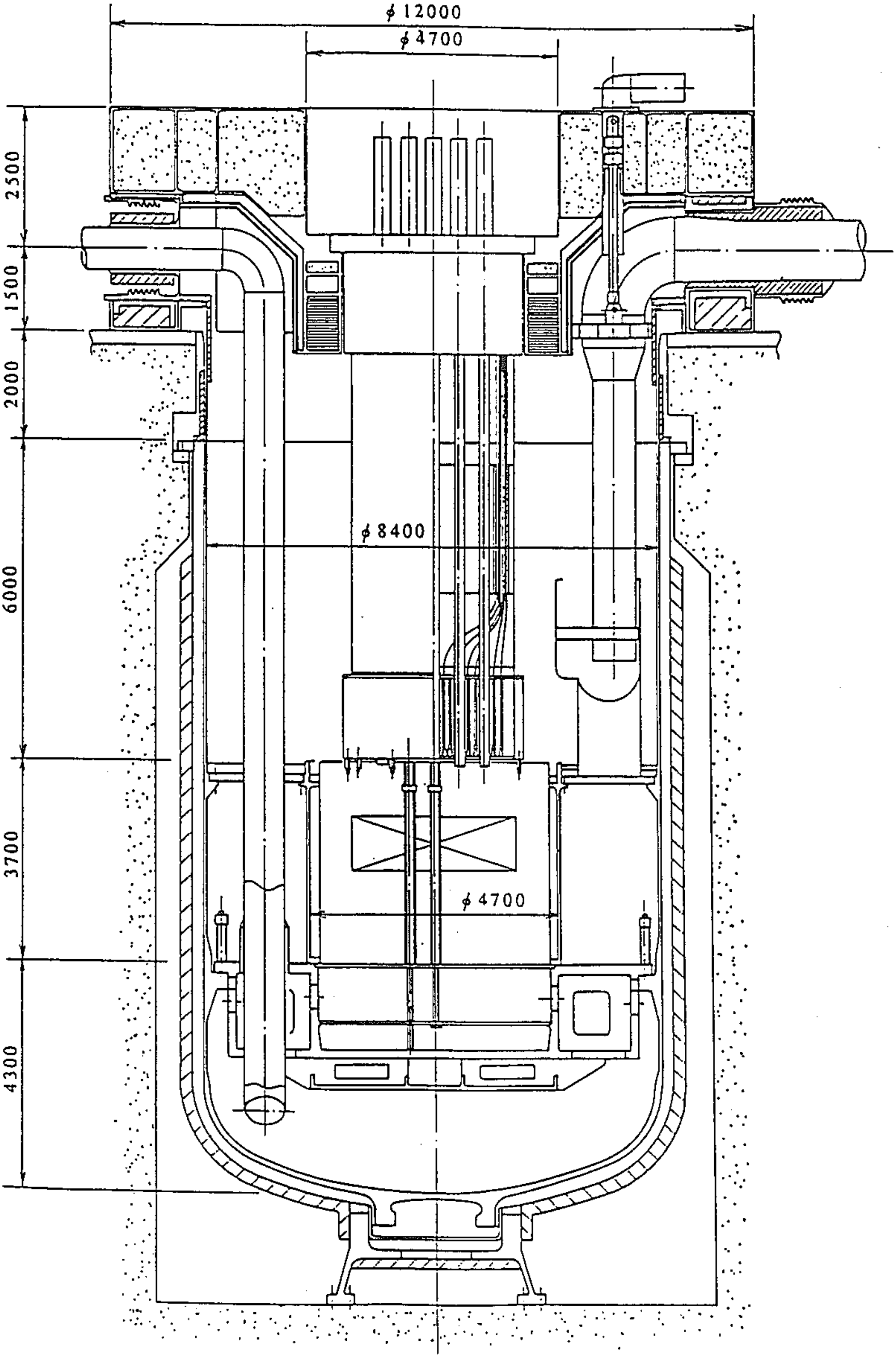

Figure 1-1 Cross sectional view of reactor vessel

Outer diameter of inlet nozzles : Φ812.8

Upper plenum high : 6000 (from top of core barrel)

Reactor core :

Inner fuel assembly : 156

Outer fuel assembly : 132

Shutdown control rod : 19

Safety control rod : 6

SUS absorber : 138

B^4C absorber : 252

2 Numerical Model

2.1 General equations

The AQUA-VOF code[2] is used for analysis thermohydraulic phenomenon with multi-dimension and arbitrary geometries in reactor and the other main components of a LMFBR . It is a time- and volume- averaged transport analysis program[3].

VOF (volume of fluid) model[1] calculates the function F(x,y,t) which is defined whose value is unity at any point occupied by fluid and zero elsewhere . When averaged over the cells of a computational mesh , the average value of F in a cell is equal to the fractional volume of the cell occupied by fluid . In particular , a unit value of F corresponds to a cell full of fluid , whereas a zero value indicates that the cell contains no fluid . Cells with F values between zero and one contain a free surface .

VOF model uses a Eulerian mesh . The cells in a rectangular shape , may have different sizes in each directions .

The time dependence of F(x,y,t) is governed by the follow equation

$$\frac{\partial F}{\partial t} + \frac{1}{r}\frac{\partial rFu}{\partial x} + \frac{\partial Fv}{\partial y} = 0 \qquad (1)$$

Where r=x when use cylindrical coordinate and r=1 when use Cartesian coordinate.

The fluid equations to be solved are the Nevier-Stokes equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - \frac{\xi u^2}{x} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + g_x + \nu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \xi\left(\frac{1}{x}\frac{\partial u}{\partial x} - \frac{u}{x^2}\right)\right] \quad (2)$$

and

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} - \frac{\xi uv}{x} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + g_y + \nu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\xi}{x}\frac{\partial v}{\partial x}\right] \quad (3)$$

Which : (u , v) is the velocities in the Cartesian coordinate directions (x , y) , or in the cylindrical coordinate directions (r , z) . The choice is according to the coordinate index ξ , which $\xi = 0$ is Cartesian coordinate using (x , y) , $\xi = 1$ is cylindrical coordinate using (r , z) . g_x , g_y is body accelerations , ν is the coefficient of kinematic viscosity , ρ is fluid density .

For a incompressible fluid , the equation (2) and (3) must be supplemented with incompressibility condition .

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\xi u}{x} = 0 \quad (4)$$

If the fluid is limited compressibility , equation (4) must be replaced with

$$\frac{1}{\rho C^2}\frac{\partial P}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\xi u}{x} = 0 \quad (5)$$

Which C is the adiabatic speed of sound in the fluid . Discrete values of the dependent variables , including the fractional volume of fluid (F) variable used in the VOF technique , are located at cell positions show in figure 2-1. The volume of fluid function F is used to identify mesh cell that contain fluid of density ρ_F. A free surface or interface cell (i , j) is defined as a cell containing a nonzero value of F and having at least one neighbouring cell (i$\pm$1 , j) or (i , j$\pm$1) that contains a zero value of F. Cell with zero F values are empty or contain another kind of fluid , in this study only one fluid , so zero F values means empty cells . Cell with non zero F values and no empty neighbours are

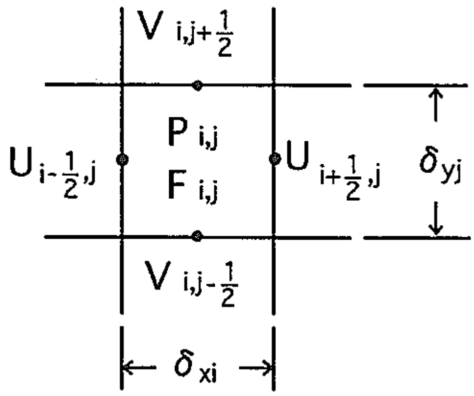

Figure 2-1 Location of variable in a typical mesh cell

treated as cells full of ρ_F fluid .

This code also has provisions for defining any cell or combination of cells in the mesh to be obstacle cells into which fluid can not flow .

2.2 The finite difference approximations

The finite difference approximations of momentum equations are given at hereafter . The notation $V_{i,j}$ means that the value of V in the i^{th} cell in the x-direction and j^{th} cell in the y-direction . Half integer subscripts refer to cell boundary locations . For example , $V_{i,j+1/2}$ refers to velocity on the boundary between the j^{th} and $j+1^{th}$ cells in the y-direction .The same as notation $U_{i,j}$, etc .

A generic form for the finite difference approximation of equation (2) and (3) is :

$$U_{i+1/2,j}^{n+1} = U_{i+1/2,j}^{n} + \delta_t\,[-(P_{i+1,j}^{n+1} - P_{i,j}^{n+1})/(\delta\rho x_{i+1/2}) + g_x - FUX - FUY + VISX] \quad (6)$$

and

$$V_{i,j+1/2}^{n+1} = V_{i,j+1/2}^{n} + \delta_t\,[-(P_{i,j+1}^{n+1} - P_{i,j}^{n+1})/(\delta\rho y_{j+1/2}) + g_y - FVX - FVY + VISY] \quad (7)$$

where

$$\delta\rho x_{i+1/2} = [\rho_F F_{i,j}\,\delta x_{i+1} + \rho_F F_{i+1,j}\,\delta x_i\,]/2$$

$$\delta\rho y_{j+1/2} = [\rho_F F_{i,j}\,\delta y_{j+1} + \rho_F F_{i,j+1}\,\delta y_j\,]/2$$

The advective and viscous acceleration terms have an obvious meaning , for example , FUX means the advective flux of U in the x-direction , etc. These terms are all evaluated using the old time level (n) values for velocities . Because the pressures at time level (n+1) are not known at the beginning of cycle . So these equations must combined with the continuity equation as following :

$$(P_{i,j}^{n+1} - P_{i,j}^{n})/(\rho C^2 \delta t) + D_{i,j}^{n+1} = 0 \quad (8)$$

where

$$D_{i,j}^{n+1} = (U_{i+1/2,j}^{n+1} - U_{i-1/2,j}^{n+1})/\delta x_i + (V_{i,j+1/2}^{n+1} - V_{i,j-1/2}^{n+1})/\delta y_j + \xi\,(U_{i+1/2,j}^{n+1} + U_{i-1/2,j}^{n+1})/(2x_j)$$

and

$$\rho = \rho_F F_{i,j}$$

3 Fundamental Free Surface Flow Problem[4)]

In this study the fundamental free surface flow problem is a two dimensional flow problem . The fluid flow channel which analyzed here is 3 m long , 0.02 m wide and 0.6 m high . It was fixed a rectangular body at the top , which is 0.2 m long , 0.02 m wide and 0.3 m high , with 0.1 m deep beneath into liquid . Here the subject which been studied is the free surface form interfered with a obstacle body .

4 In-vessel free surface problem

The liquid sodium free surface in reactor vessel of a LMFBR move about caused by internal coolant flow . It may involve gas into the coolant and cause the reactivity increase . To overcoming it , ring plates are considered to fit under the free surface . In former PNC studies , the results shown that the ring plates had high efficiency to eliminate the free surface gradients . This study use the same definition to investigate the effects of ring plates and the difference between different levels .

5 Discussion

5.1 Discuss with fundamental free surface flow problem

In this study , calculation was carried out in the Cartesian coordinate system . The mesh arrangement of flow channel show in figure 5-1 . The inlet boundary condition was constant velocity boundary . The outlet boundary condition was continued mass flow boundary dependent upon the inlet mass flow . Other boundary were treated as no-slip wall boundary .

Figure 5-2 show the velocity vector at 0.7027 s . Figure 3.5-3 show the free surface at 0.7027 s . The maximum gradient of free surface is 2.7259 , the place is between element 32 and 33 . At free surface , the maximum upward velocity is 0.714811 m/s , 0.28 m away from the body , and the maximum downward velocity is -0.930642 m/s , at inlet . Because of the obstruct of the obstacle body , at the upstream direction , about 0.22 m away from the body , the free surface increased and arrived at the highest level , about 0.55452 m . And for the liquid lashed at the body , the highest free surface moved about . There is the area where has the possible involve gas into liquid . At the downstream direction , near body , the free

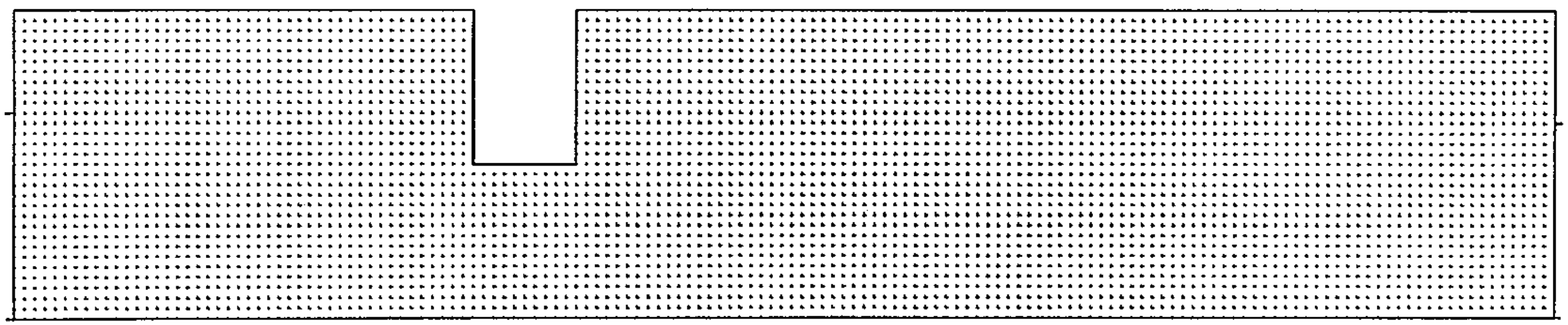

Figure 5-1 Mesh arrangement of fundamental free surface problem

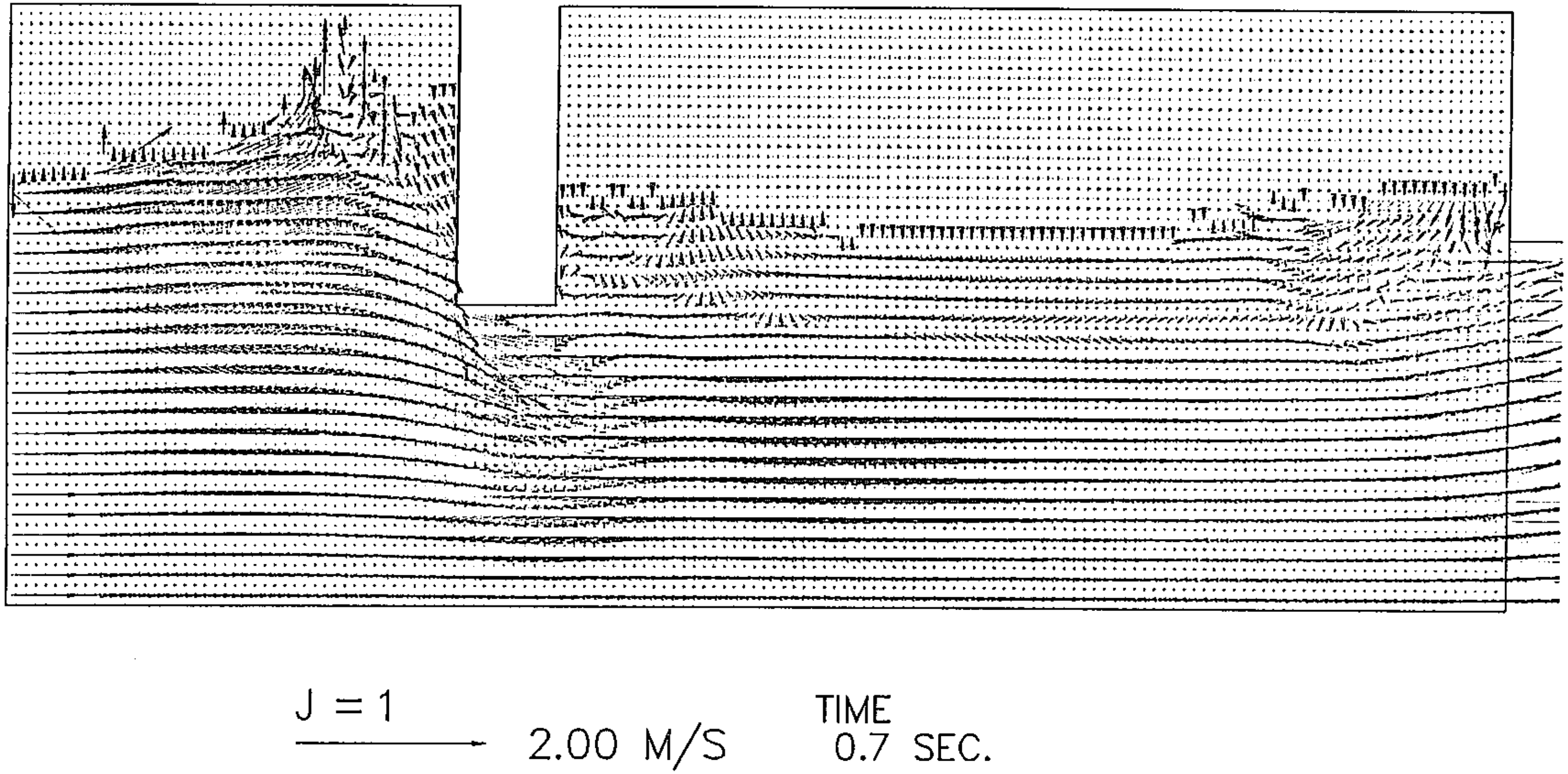

Figure 5-2 The velocity vector at 0.7027s

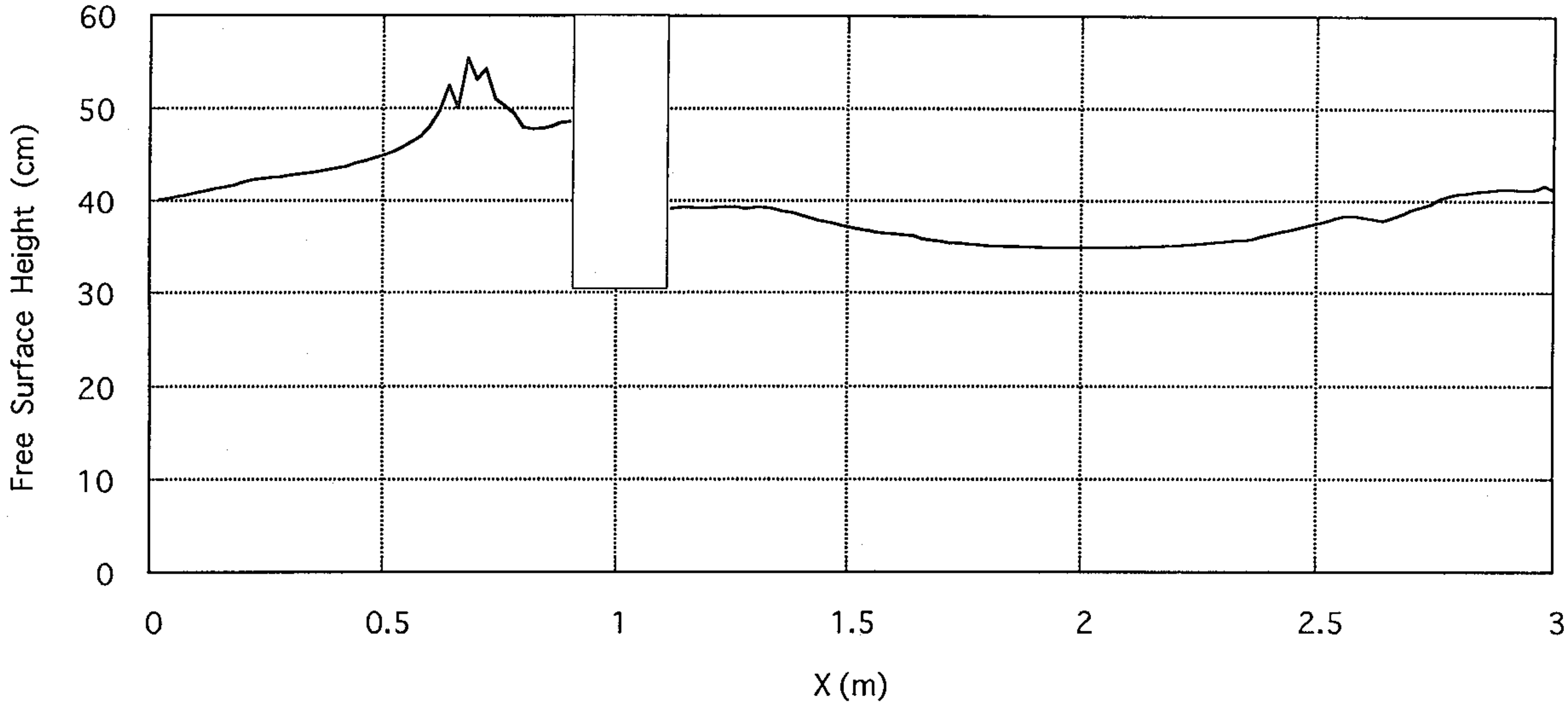

Figure 5-3 The free surface at 0.7027s

surface was at the still liquid level , about 0.9 m away from the body , the free surface was lowest , about 0.34893 m . The maximum height difference is 0.205586 m . Near the outlet , the free surface tended to still liquid surface level .

5.2 Discuss with in-vessel free surface problem

In this study , calculations were carried out with a two dimensional mesh arrangement (r-z : 29 ×44) , in a cylindrical coordinate system . The velocity along the θ direction assumed equal 0 , that means no fluid flow in this direction . Figures 5-4 , 5-5 and 5-6 show mesh arrangements of case-1 , case-2 and case-3 , respectively .

The calculational conditions show in table 5-1 . The reactor vessel center line was treated as free-slip wall , the same as top of reactor vessel . The outlet boundary condition was continued mass flow dependent upon the inlet mass flow . The others were treated as no-slip wall boundaries .

Table 5-1 calculational conditions of case-1 , case-2 , case-3

item \ case	case-1	case-2	case-3
coordination	r - θ -z	r - θ -z	r - θ -z
IMAX	29	29	29
JMAX	1	1	1
KMAX	44	44	44
ring plates level	no ring plates	1.125m under the free surface , between element 30 and 31 in z-direction	1.5m under the free surface , between element 28 and 29 in z-direction
inlet boundary condition	constant velocity boundary		
inlet average velocity (m/s)	2.0543	2.0543	2.0543
outlet boundary condition	continuative mass flow outlet boundary		
outlet average velocity (m/s)	1.0715	1.0715	1.0715
other boundary condition	no-slip wall boundary		
temperature (℃)	530	530	530
gas pressure (Pa)	1.886×10^6	1.886×10^6	1.886×10^6

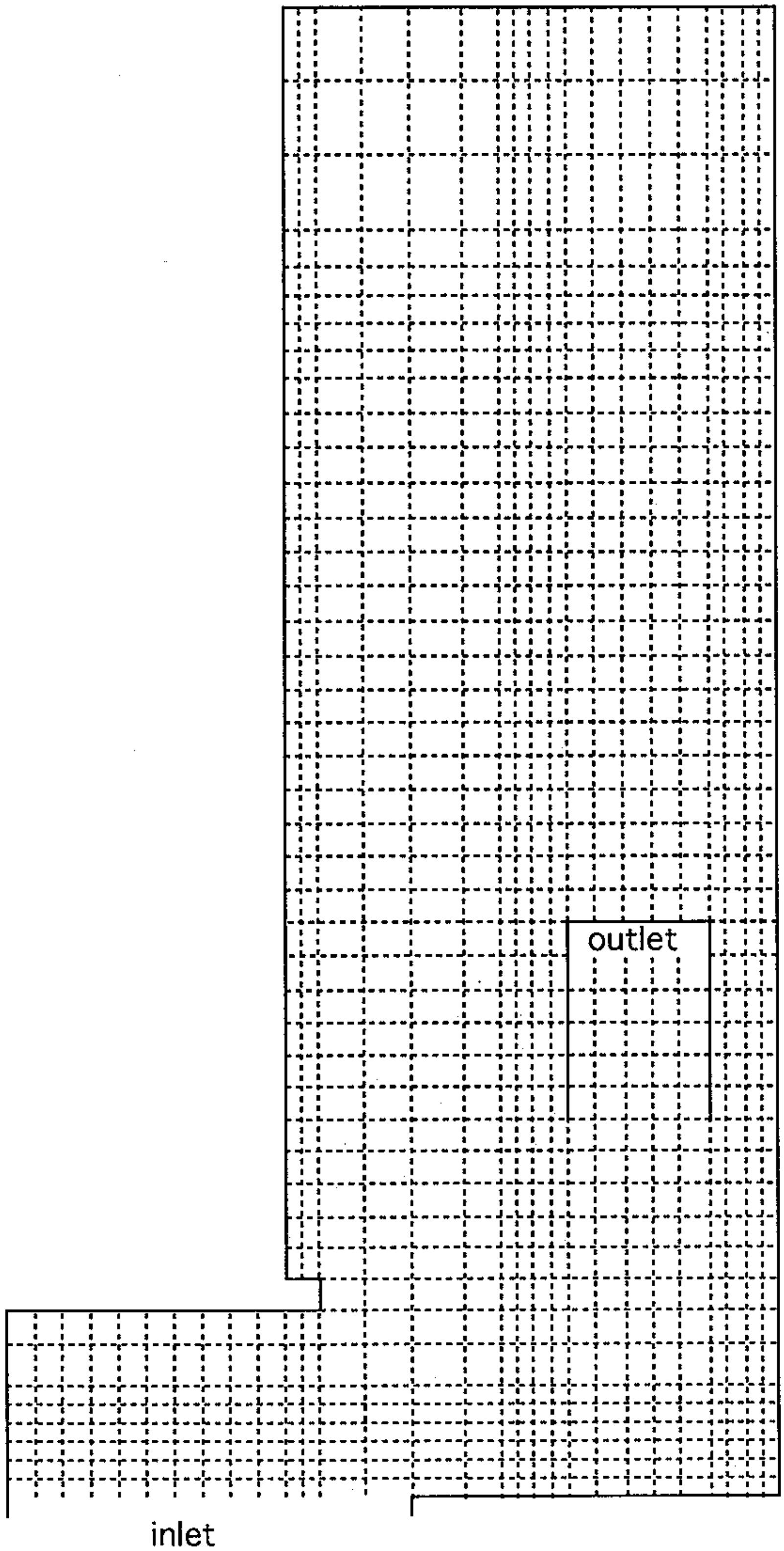

Figure 5-4 Mesh arrangement of in-vessel free surface problem (case-1)

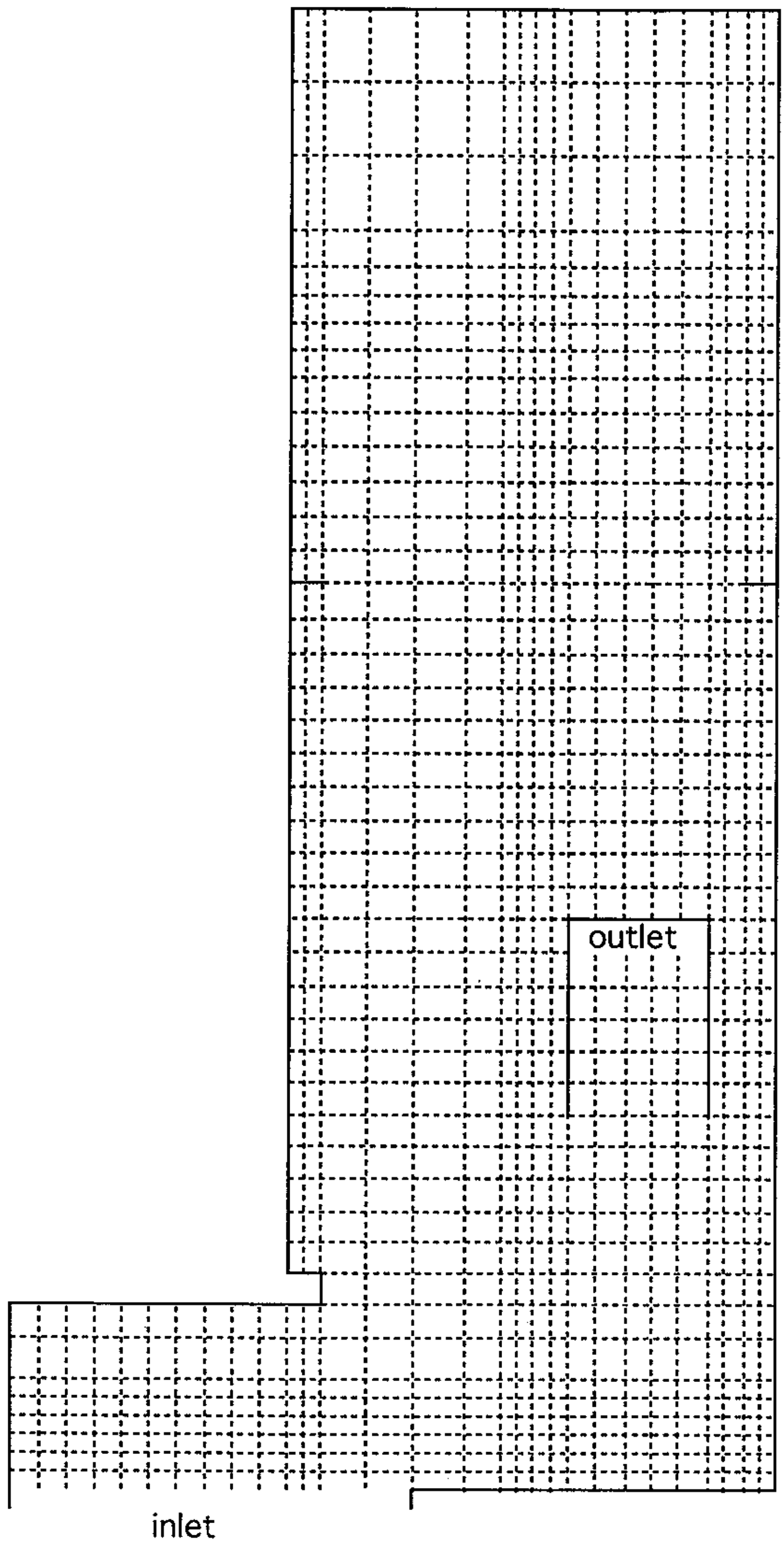

Figure 5-5 Mesh arrangement of in-vessel free surface problem (case-2)

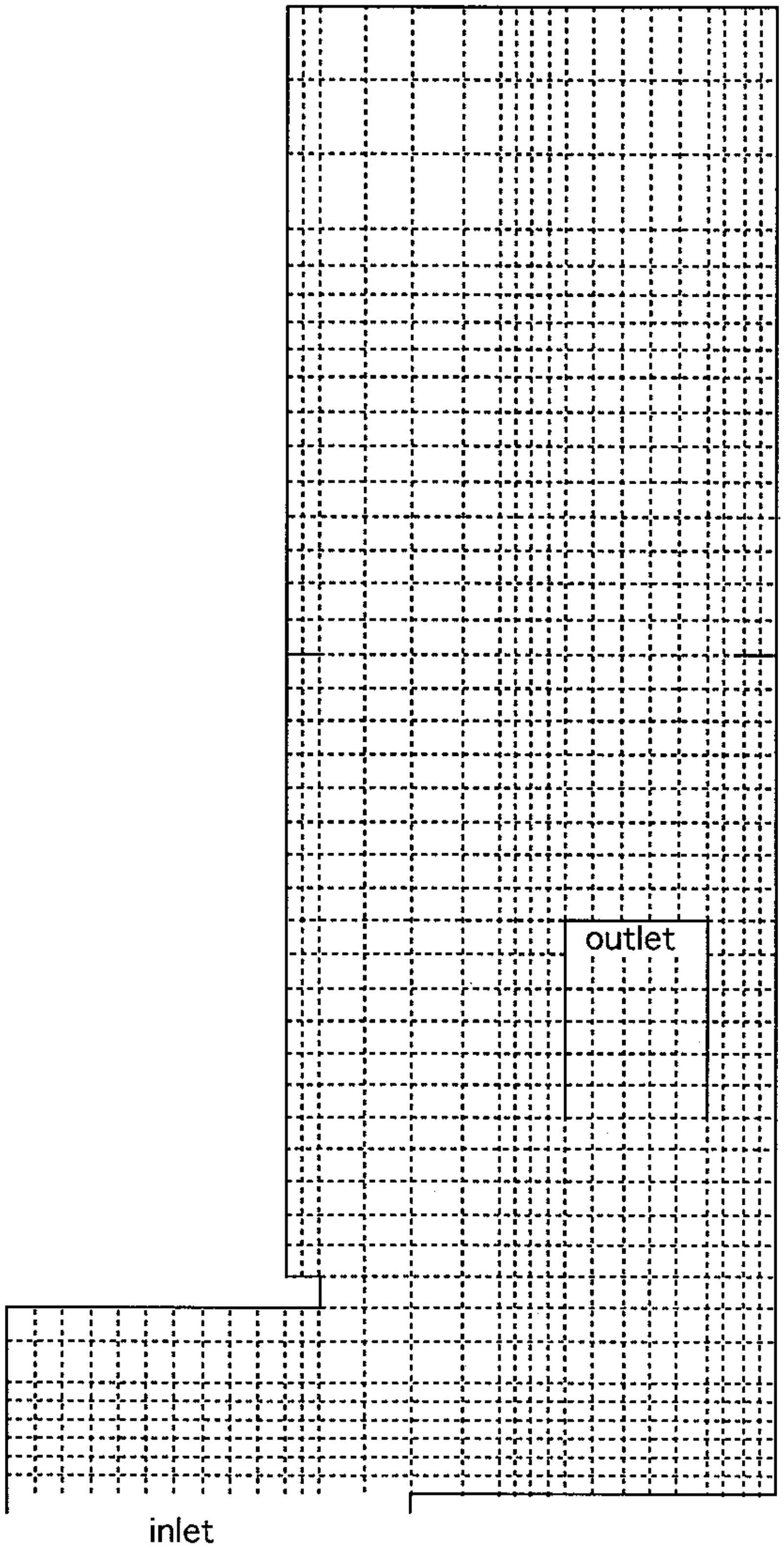

Figure 5-6 Mesh arrangement of in-vessel free surface problem (case-3)

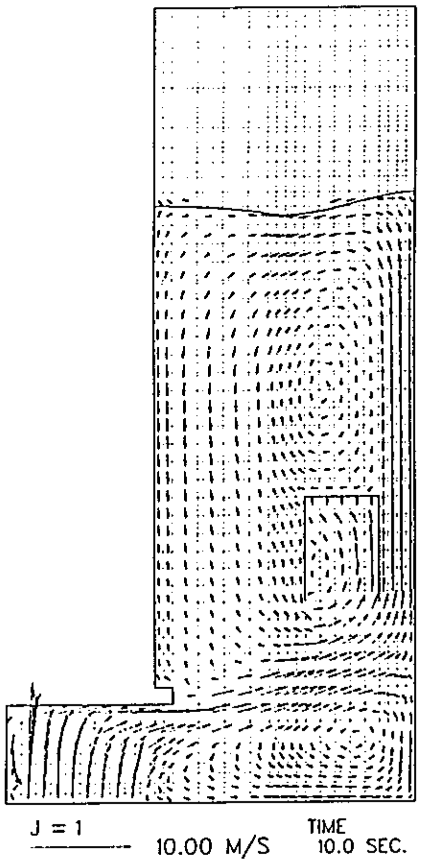

Figure 5-7 The velocity vector plot at 10s of case-1

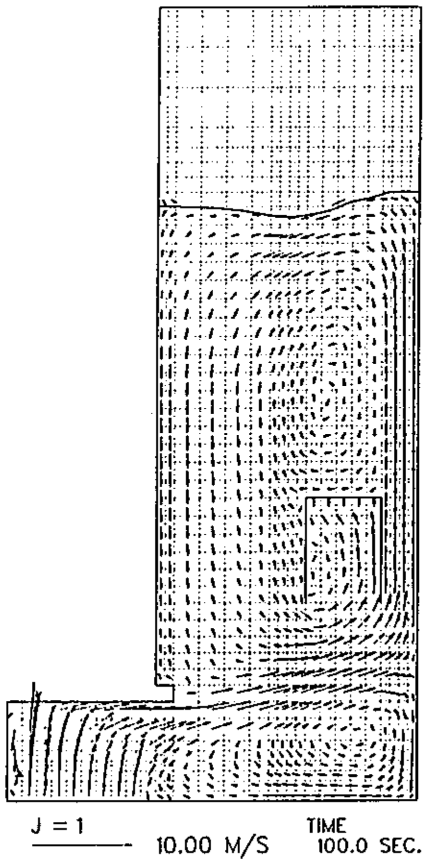

Figure 5-8 The velocity vector plot at 100s of case-1

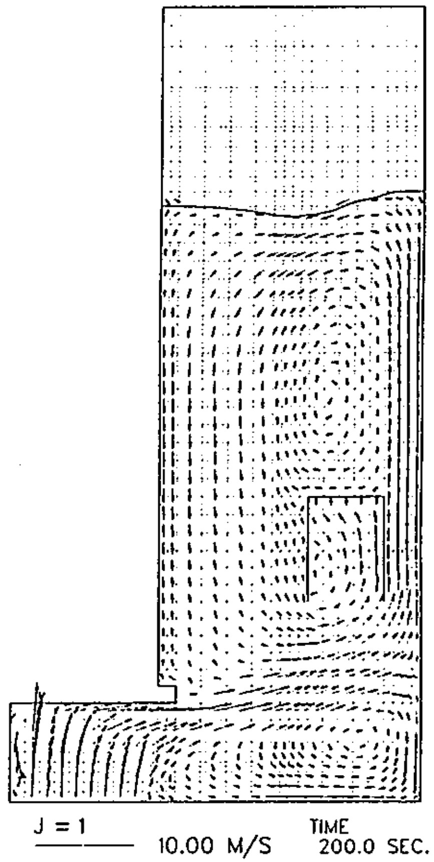

Figure 5-9 The velocity vector plot at 200s of case-1

Figures 5-7 , 5-8 , 5-9 show the velocity vector plots at 10s , 100s , 200s , respectively . Table 5-2 show the F of elements near free surface at 100s of case-1.

Table 5-2 The F of elements near free surface (case-1, 100 sec)

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0374299	0.0307874	0.0	0.0	0.0	0.0	0.0
36	1.0	1.0	0.993131	0.926354	0.803539	0.624033	0.474064
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.172058	0.434322
36	0.435686	0.454011	0.514009	0.602505	0.778191	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.703659	0.944782	1.0	1.0	1.0		
36	1.0	1.0	1.0	1.0	1.0		
35	1.0	1.0	1.0	1.0	1.0		

Table 5-3 and table .5-4 show the velocity U and W near free surface at 100s of case-1 . Table 5-5 show the F of elements near free surface at 200s of case-1 . Table 5-6 and table 5-7 show the velocity U and W near free surface at 200s of case-1 .

In case-1 , it has no ring plates fitted , the coolant flow upward along reactor reactor vessel wall without any resistance , and arrived at free surface , then turned

Table 5-3 The velocity U in x-direction near free surface (case-1, 100 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	-0.081307	-0.161232	0.0	0.0	0.0	0.0	0.0
36	-0.081307	-0.161232	-0.38580	-0.61860	-0.88501	-1.13196	-1.25097
35	-0.077262	-0.156802	-0.38580	-0.61860	-0.88501	-1.13196	-1.25097
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	-1.39949	-1.20944	-1.09872
36	-1.33565	-1.39163	-1.42464	-1.44657	-1.39949	-1.20944	-1.09872
35	-1.33565	-1.39163	-1.42464	-1.44657	-1.40948	-1.28318	-1.06880
z-direction \ x-direction	**25**	**26**	**27**	**28**	**29**		
38	0.0	0.0	0.0	0.0	0.0		
37	-0.877100	-0.722527	-0.53389	-0.289170	0.0		
36	-0.877100	-0.674795	-0.46069	-0.233092	0.0		
35	-0.806149	-0.617339	-0.41378	-0.205389	0.0		

Table 5-4 The velocity W in z-direction near free surface (case-1, 100 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.135176	0.150299	0.0	0.0	0.0	0.0	0.0
36	-0.004283	0.0059649	0.021424	0.074619	0.172126	0.283422	0.269931
35	-0.178601	-0.174450	-0.17045	-0.140469	-0.082522	-0.025145	-0.054683
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	-0.649382	-0.327228
36	0.0956080	-0.061772	-0.18433	-0.271328	-0.380592	-0.522117	-0.268250
35	-0.163370	-0.264257	-0.34019	-0.384904	-0.405472	-0.363037	-0.194527

Table 5-4 The velocity W in z-direction near free surface (case-1, 100 sec)
continue m/s

z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	-0.261843	-0.077753	0.0	0.0	0.0		
36	-0.086326	0.142181	0.282578	0.382356	0.464668		
35	0.133070	0.515230	0.690423	0.828528	0.932863		

Table 5-5 The F of elements near free surface (case-1, 200 sec)

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0429676	0.0361751	0.0	0.0	0.0	0.0	0.0
36	1.0	1.0	0.997214	0.930166	0.807050	0.627236	0.476735
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.187266	0.439699
36	0.438020	0.456008	0.515729	0.604072	0.779815	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	**25**	**26**	**27**	**28**	**29**		
38	0.0	0.0	0.0	0.0	0.0		
37	0.708315	0.948189	1.0	1.0	1.0		
36	1.0	1.0	1.0	1.0	1.0		
35	1.0	1.0	1.0	1.0	1.0		

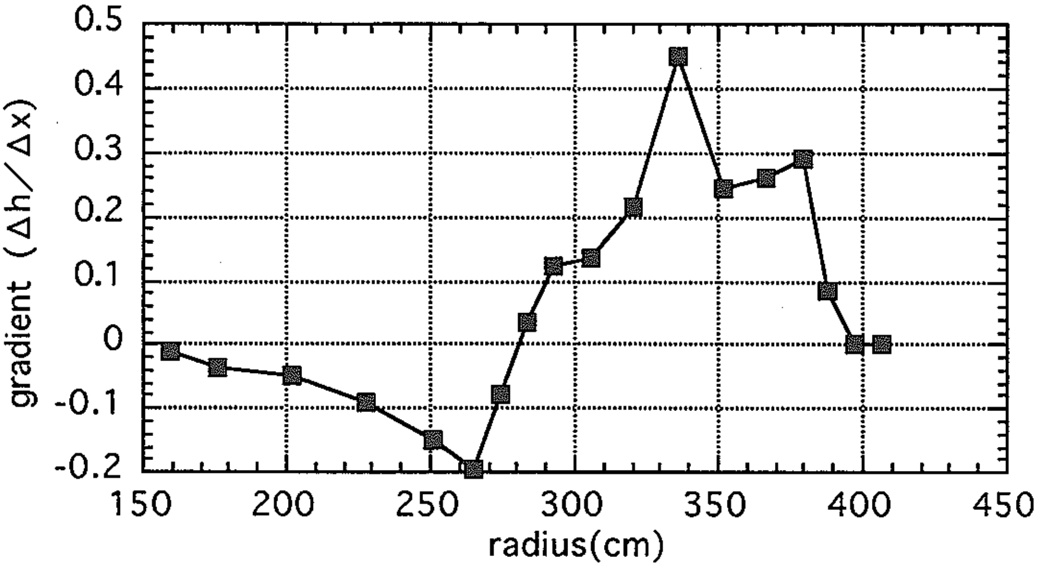

Figure 5-10 The gradient of free surface at 100s of case-1

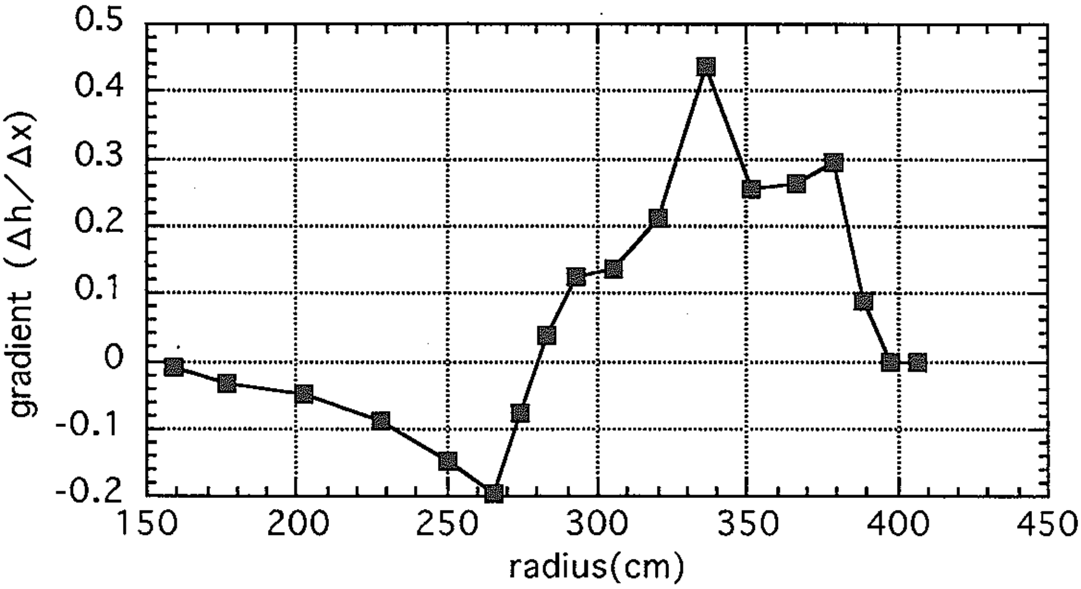

Figure 5-11 The gradient of free surface at 200s of case-1

Table 5-6 The velocity U in x-direction near free surface (case-1, 200 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	-0.081852	-0.162248	0.0	0.0	0.0	0.0	0.0
36	-0.081852	-0.162248	-0.38690	-0.619666	-0.885894	-1.13281	-1.25189
35	-0.077669	-0.157445	-0.38690	-0.619666	-0.885894	-1.13281	-1.25189
z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	-1.40338	-1.20966	-1.09908
36	-1.33667	-1.39275	-1.42578	-1.44757	-1.40338	-1.20966	-1.09908
35	-1.33667	-1.39275	-1.42578	-1.44757	-1.41002	-1.28231	-1.06810
z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	-0.877503	-0.724496	-0.53500	-0.289672	0.0		
36	-0.877503	-0.675403	-0.46118	-0.233349	0.0		
35	-0.805974	-0.617357	-0.41385	-0.205444	0.0		

Table 5-7 The velocity W in z-direction near free surface (case-1, 200 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.135318	0.150767	0.0	0.0	0.0	0.0	0.0
36	-0.005075	0.0055758	0.020772	0.074043	0.171548	0.283160	0.270103
35	-0.180567	-0.175903	-0.17127	-0.141120	-0.083049	-0.025438	-0.054702
z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	-0.659433	-0.326150
36	0.0960554	-0.061384	-0.18431	-0.271871	-0.378069	-0.528700	-0.267307
35	-0.163212	-0.264122	-0.34028	-0.385348	-0.406595	-0.365285	-0.193754

Table 5-7 The velocity W in z-direction near free surface (case-1, 200 sec)
continue m/s

z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	-0.260022	-0.072994	0.0	0.0	0.0		
36	-0.084568	0.144374	0.283912	0.383316	0.465475		
35	0.134749	0.516953	0.691979	0.829938	0.934187		

to radial direction to UCS wall , and downward . At free surface , the maximum radial velocity component is -1.44757 m/s , the maximum axial velocity component is -0.659433 m/s . Its maximum height difference of free surface is largest , about 25.537 cm . The maximum difference of velocity in z-direction at surface is 1.125 m/s . The maximum gradient of free surface is 0.4496 , see figure 3.5-11 .

Figures 5-12 , 5-13 , 5-14 show the velocity vector plots at 10s , 100s , 200s , respectively . Table 5-8 show the F of elements near free surface at 100s of case-2 .Table 5-9 and table 5-10 show the velocity U and W near free surface at

Table 5-8 The F of elements near free surface (case-2, 100 sec)

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.228190	0.206739	0.184959	0.174719	0.0	0.164141	0.177099
36	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0

z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.109002	0.0	0.0
36	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table 5-8 The F of elements near free surface (case-2, 100 sec)

continue

z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.0116074	0.033189	0.060692	0.084046		
36	1.0	1.0	1.0	1.0	1.0		
35	1.0	1.0	1.0	1.0	1.0		

Table 5-9 The velocity U in x-direction near free surface (case-2, 100 sec)
m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.116238	0.187904	0.218064	0.240876	0.225072	0.181396	0.196760
36	0.116238	0.187904	0.218064	0.240876	0.225072	0.181396	0.196760
35	0.0419086	0.0543104	0.044776	-0.060739	-0.141219	-0.147898	-0.125420
z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.315590	0.404230	0.0	0.0
36	0.201185	0.218256	0.248190	0.315590	0.404230	0.492317	0.536244
35	-0.102172	-0.075818	-0.04565	0.013823	0.094970	0.188242	0.280116
z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.489693	0.421175	0.314238	0.172502	0.0		
36	0.489693	0.421175	0.314238	0.172502	0.0		
35	0.275427	0.232047	0.164292	0.084381	0.0		

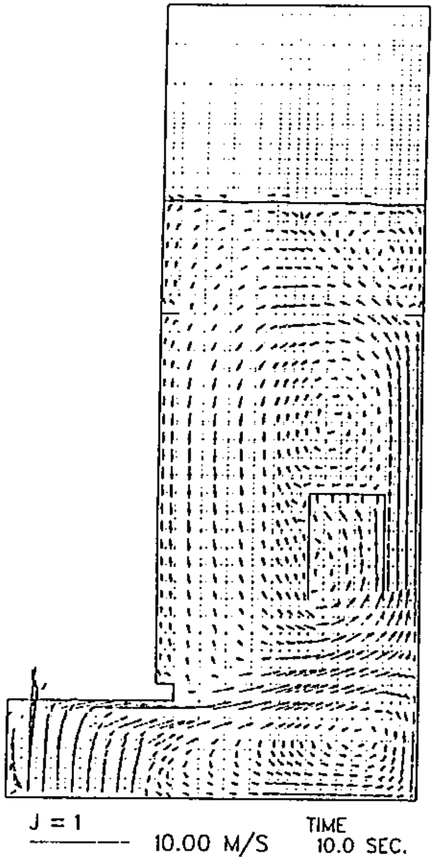

Figure 5-12 The velocity vector plot at 10s of case-2

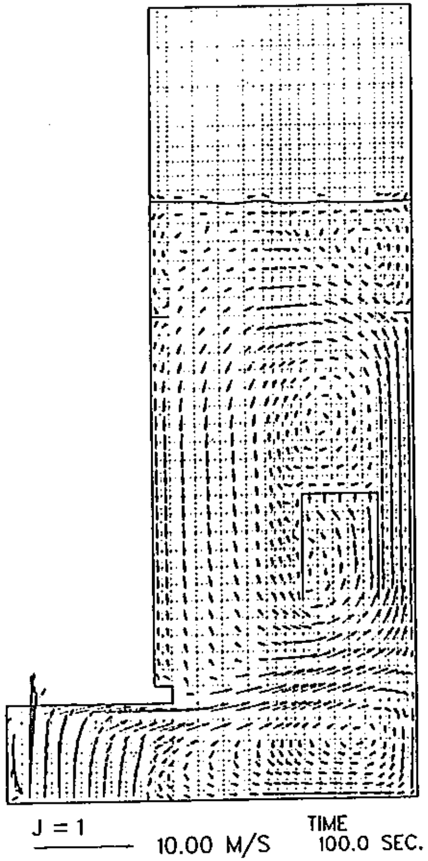

Figure 5-13 The velocity vector plot at 100s of case-2

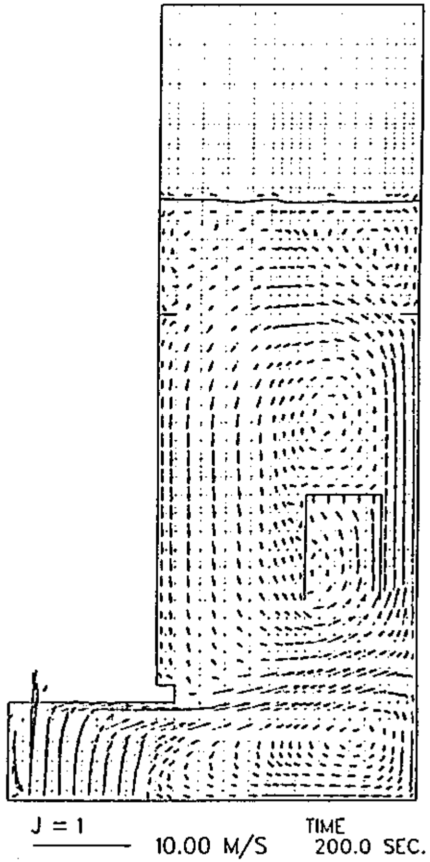

Figure 5-14 The velocity vector plot at 200s of case-2

Table 5-10 The velocity W in z-direction near free surface (case-2, 100 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	-0.153976	-0.109957	-0.030348	-0.052065	0.0	0.044699	-0.083059
36	0.045396	0.023439	0.004055	-0.022118	0.0	0.023476	-0.047571
35	0.294612	0.190184	0.047057	0.015316	0.007291	-0.003052	-0.003210
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	-0.102733	0.0	0.0
36	0.0	0.0	0.0	0.0	0.000033	0.0	0.0
35	0.022368	0.048329	0.075519	0.098960	0.128491	0.131712	0.080462
z-direction \ x-direction	**25**	**26**	**27**	**28**	**29**		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.101609	0.169109	0.221818	0.260482		
36	0.0	0.008062	0.009359	0.000555	-0.016712		
35	-0.030659	-0.108866	-0.190333	-0.276015	-0.363207		

Table 5-11 The F of elements near free surface (case-2, 200 sec)

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.227920	0.206489	0.184748	0.174577	0.0	0.164087	0.177047
36	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.109060	0.0	0.0
36	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table 5-11 The F of elements near free surface (case-2, 200 sec)
continue

z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.011746	0.033402	0.060892	0.084200		
36	1.0	1.0	1.0	1.0	1.0		
35	1.0	1.0	1.0	1.0	1.0		

Table 5-12 The velocity U in x-direction near free surface (case-2, 200 sec)
m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.116212	0.187847	0.217952	0.240701	0.224950	0.181324	0.196688
36	0.116212	0.187847	0.217952	0.240701	0.224950	0.181324	0.196688
35	0.0418977	0.0542867	0.044679	-0.060862	-0.141303	-0.147971	-0.125491
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.315554	0.404219	0.0	0.0
36	0.201128	0.218210	0.248150	0.315554	0.404219	0.492306	0.536234
35	-0.102238	-0.075880	-0.04571	0.013774	0.094930	0.188206	0.280084
z-direction \ x-direction	**25**	**26**	**27**	**28**	**29**		
38	0.0	0.0	0.0	0.0	0.0		
37	0.489682	0.421121	0.314182	0.172476	0.0		
36	0.489682	0.421121	0.314182	0.172476	0.0		
35	0.275397	0.232014	0.164264	0.084368	0.0		

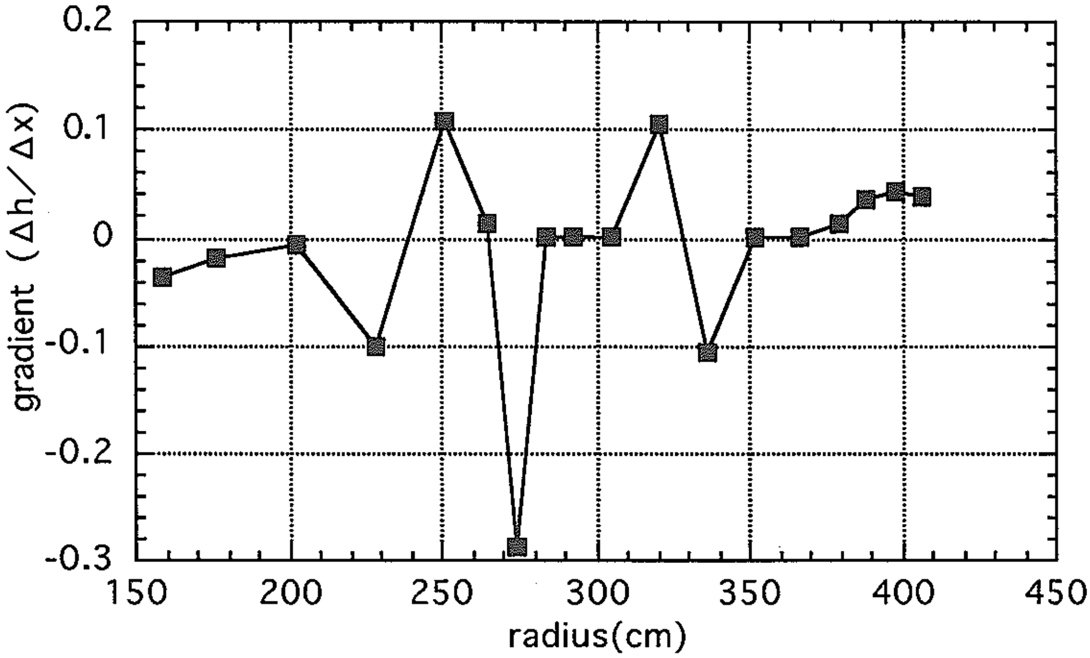

Figure 5-15 The gradient of free surface at 100s of case-2

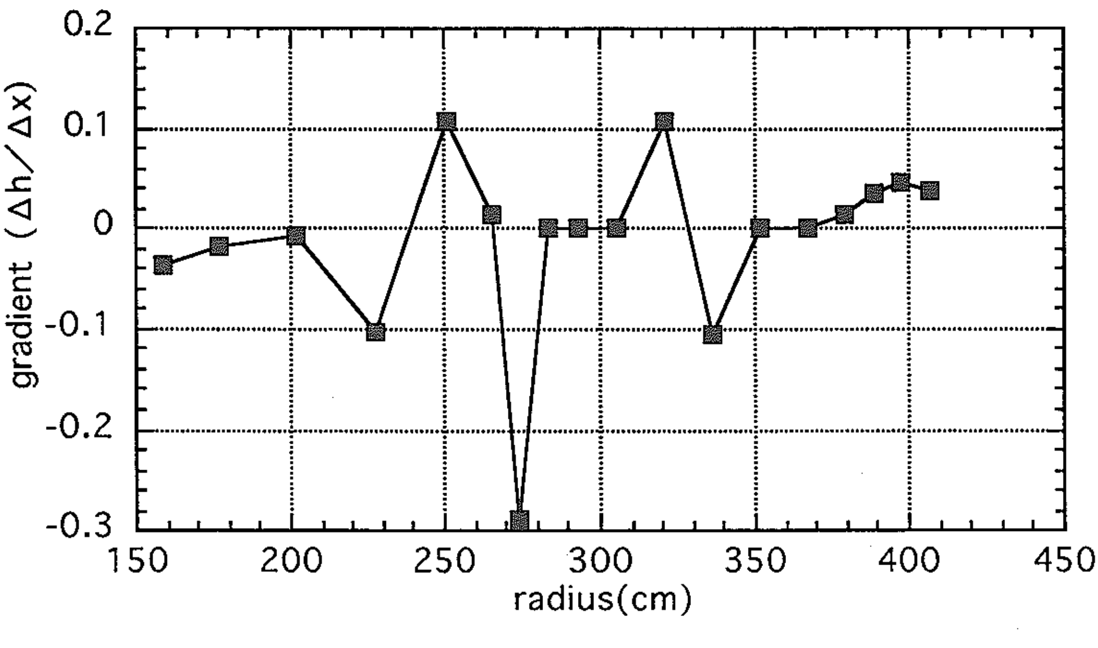

Figure 5-16 The gradient of free surface at 200s of case-2

Table 5-13 The velocity W in z-direction near free surface (case-2, 200 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	-0.153897	-0.109844	-0.030224	-0.051894	0.0	0.044662	-0.083009
36	0.045431	0.023496	0.004139	-0.021994	0.0	0.023472	-0.047525
35	0.294591	0.190172	0.047093	0.015380	0.007317	-0.003017	-0.003169
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	-0.102789	0.0	0.0
36	0.0	0.0	0.0	0.0	0.000000	0.0	0.0
35	0.022396	0.048346	0.075528	0.098963	0.128487	0.131712	0.080464
z-direction \ x-direction	**25**	**26**	**27**	**28**	**29**		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.101752	0.169066	0.221619	0.260277		
36	0.0	0.008135	0.009311	0.000404	-0.016876		
35	-0.030663	-0.108882	-0.190388	-0.276109	-0.363320		

100s of case-2 . Table 5-11 show the F of elements near free surface at 200s of case-2 . Table 5-12 and table 5-13 show the velocity U and W near free surface at 200s of case-2 .

In case-2 ,the coolant flow was interfered by ring plates , while it flow upward along reactor vessel wall . The momentum along axis of reactor vessel was dispersed to radial direction . It formed three vortexes near ring plates , but no so strong . The free surface is calm . At free surface , the maximum radial velocity component is 0.536234 m/s , the maximum axial velocity component is 0.260277 m/s . The maximum height difference of free surface is 3.423 cm . The maximum difference of velocity in z-direction at surface is 0.414 m/s , see table 5-13 . The

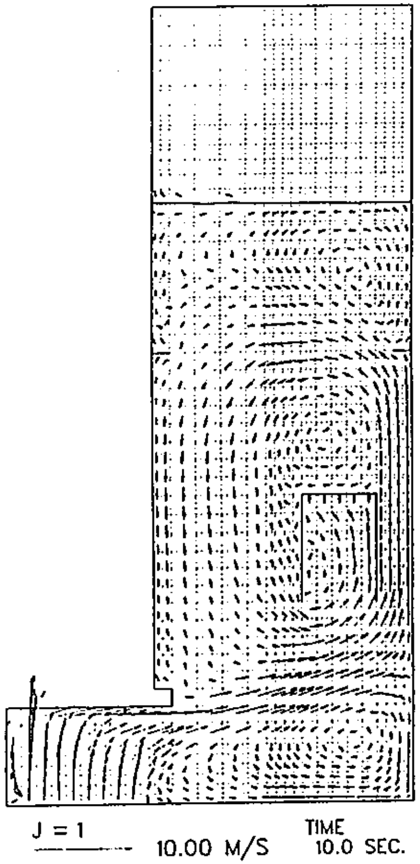

Figure 5-17 The velocity vector plot at 10s of case-3

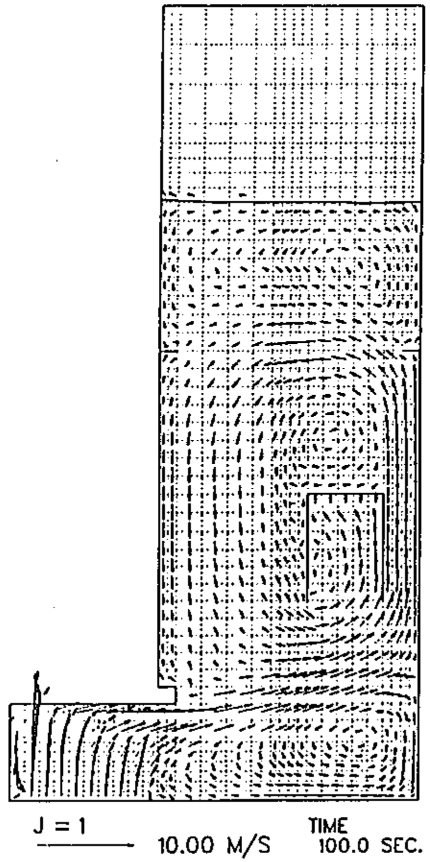

Figure 5-18 The velocity vector plot at 100s of case-3

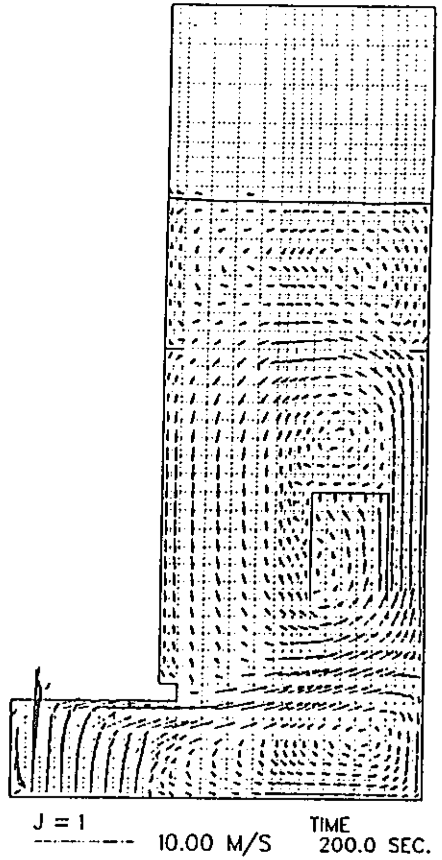

Figure 5-19 The velocity vector plot at 200s of case-3

maximum gradient of free surface level is 0.2877 , see figure 5-16 . Case-2 is the best case of all three cases .

Figures 5-17 , 5-18 , 5-19 show the velocity vector plots at 10s , 100s , 200s , respectively . Table 5-14 show the F of elements near free surface at 100s of case-3 . Table 5-15 and table 5-16 show the velocity U and W near free surface at 100s of case-3 . Table 5-17 show the F of elements near free surface at 200s of case-3 . Table 5-18 and table 5-19 show the velocity U and W near free surface at 200s of case-3 .

Table 5-14 The F of elements near free surface (case-3, 100 sec)

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.173620	0.140415	0.092293	0.0	0.023614	0.0	0.0
36	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1.0	1.0	1.0	1.0	1.0	0.993361	0.936684
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.0	0.0	0.0	0.0		
36	0.960952	0.979699	0.986172	0.989428	0.992010		
35	1.0	1.0	1.0	1.0	1.0		

Table 5-15 The velocity U in x-direction near free surface (case-3, 100 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.161869	0.279553	0.409140	0.447728	0.464276	0.0	0.0
36	0.161869	0.279553	0.409140	0.447728	0.464276	0.479763	0.490152
35	0.074109	0.120568	0.217877	0.241689	0.245621	0.258545	0.270025
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.502808	0.516417	0.529001	0.531830	0.491610	0.383841	0.326650
35	0.285132	0.302251	0.320195	0.349814	0.373224	0.383841	0.326650
z-direction \ x-direction	**25**	**26**	**27**	**28**	**29**		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.0	0.0	0.0	0.0		
36	0.242722	0.187310	0.128307	0.065581	0.0		
35	0.242722	0.187310	0.128307	0.065581	0.0		

Table 5-16 The velocity W in z-direction near free surface (case-3, 100 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	-0.229410	-0.194691	-0.125255	0.0	-0.039062	0.0	0.0
36	0.048229	0.021698	-0.021211	0.0	0.000013	0.0	0.0
35	0.395271	0.292188	0.108843	0.066977	0.048856	0.049394	0.054829
z-direction \ x-direction	**18**	**19**	**20**	**21**	**22**	**23**	**24**
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0	0.0	-0.003169	-0.022649
35	0.059094	0.060815	0.058530	0.035556	-0.019352	-0.110001	-0.073422

Table 5-16 The velocity W in z-direction near free surface (case-3, 100 sec)
continue m/s

z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.0	0.0	0.0	0.0		
36	0.012844	0.011193	0.003974	0.002125	0.001379		
35	-0.074755	-0.090866	-0.108354	-0.120778	-0.130349		

Table 5-17 The F volume of elements near free surface (case-3, 200 sec)

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.173675	0.140467	0.0923312	0.0	0.0236344	0.0	0.0
36	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1.0	1.0	1.0	1.0	1.0	0.993356	0.936673
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0
z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.0	0.0	0.0	0.0		
36	0.960937	0.979684	0.986159	0.989416	0.991998		
35	1.0	1.0	1.0	1.0	1.0		

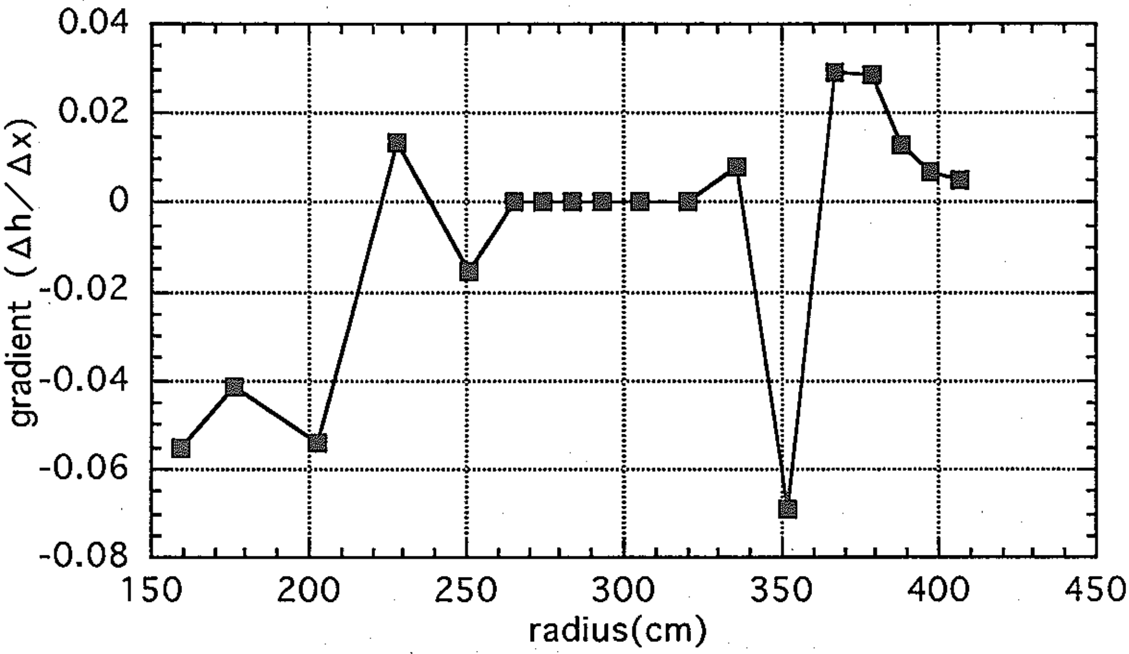

Figure 5-20 The gradient of free surface at 100s of case-3

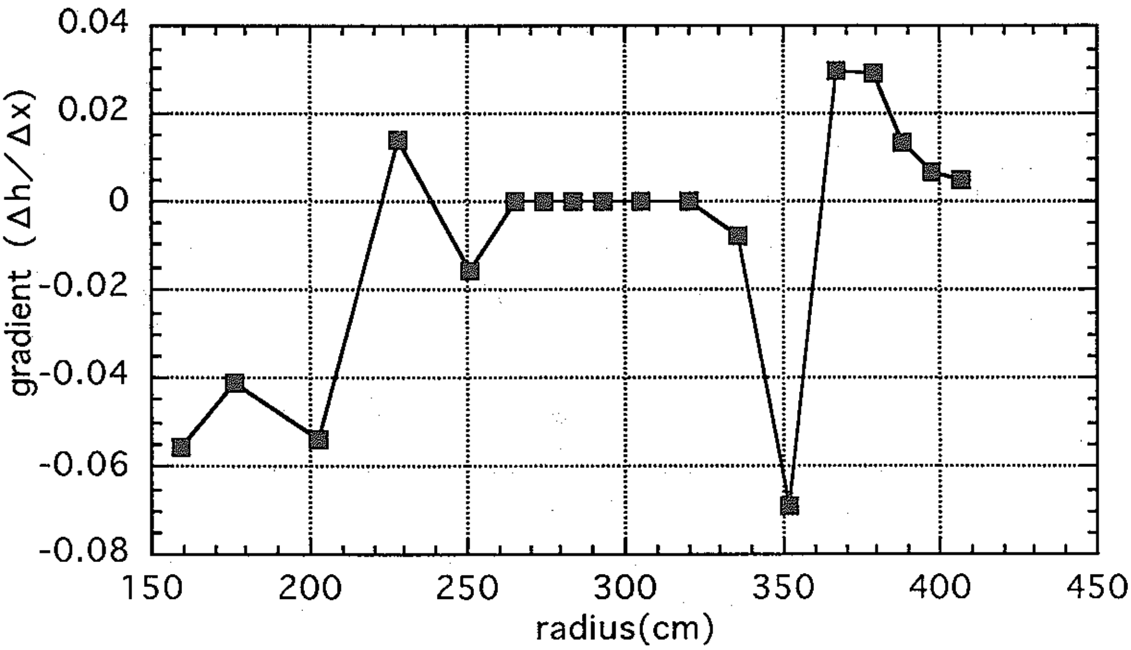

Figure 5-21 The gradient of free surface at 200s of case-3

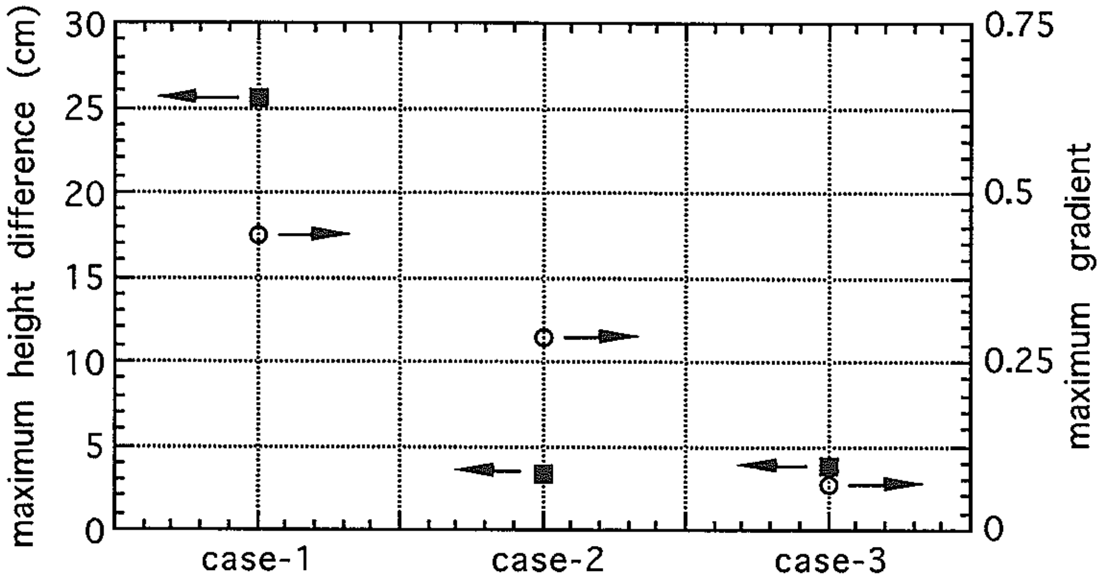

Figure 5-22 The maximum height difference and maximum gradient of free surface at 100s

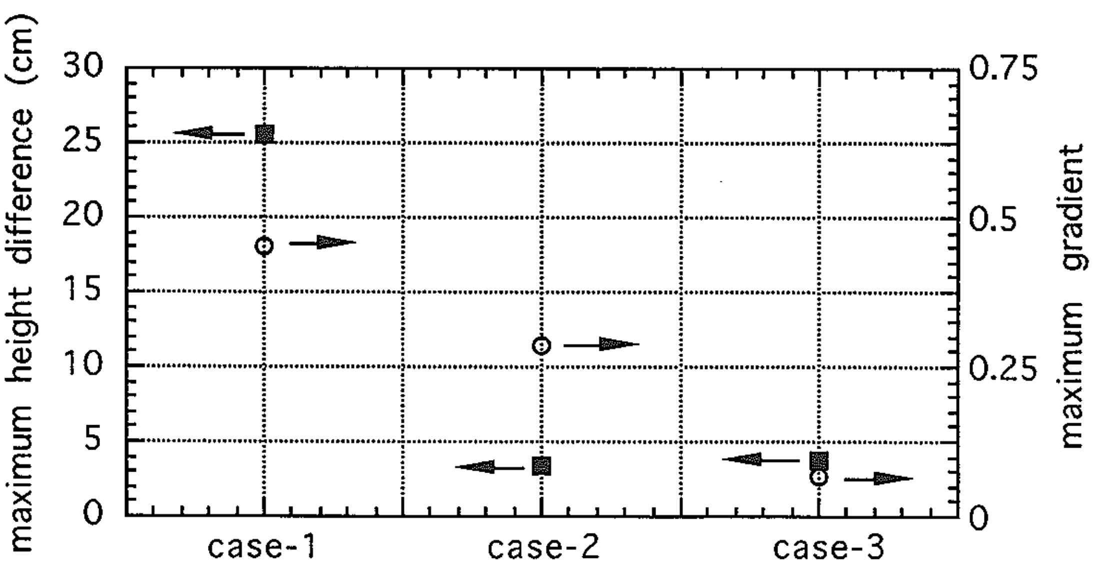

Figure 5-23 The maximum height difference and maximum gradient of free surface at 200s

Table 5-18 The velocity U in x-direction near free surface (case-3, 200 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.161866	0.279552	0.409159	0.447739	0.464294	0.0	0.0
36	0.161866	0.279552	0.409159	0.447739	0.464294	0.479778	0.490165
35	0.074110	0.120570	0.217887	0.241696	0.245629	0.258552	0.270032
z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.502820	0.516428	0.529012	0.531839	0.491618	0.383847	0.326656
35	0.285138	0.302258	0.320202	0.349820	0.373231	0.383847	0.326656
z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.0	0.0	0.0	0.0		
36	0.242727	0.187313	0.128310	0.065582	0.0		
35	0.242727	0.187313	0.128310	0.065582	0.0		

Table 5-19 The velocity W in z-direction near free surface (case-3, 200 sec)

m/s

z-direction \ x-direction	11	12	13	14	15	16	17
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	-0.229414	-0.194707	-0.125302	0.0	-0.039080	0.0	0.0
36	0.048220	0.021685	-0.021246	0.0	-0.000000	0.0	0.0
35	0.395258	0.292172	0.108825	0.066972	0.048850	0.049391	0.054827
z-direction \ x-direction	18	19	20	21	22	23	24
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0	0.0	-0.003169	-0.022647
35	0.059092	0.060814	0.058530	0.035555	-0.019353	-0.110007	-0.073420

Table 5-19 The velocity W in z-direction near free surface (case-3, 200 sec)
continue m/s

z-direction \ x-direction	25	26	27	28	29		
38	0.0	0.0	0.0	0.0	0.0		
37	0.0	0.0	0.0	0.0	0.0		
36	0.012852	0.011206	0.003990	0.002140	0.001394		
35	-0.074748	-0.090855	-0.108341	-0.120765	-0.130336		

In case-3 , the coolant flow was interfere by ring plates while it flow upward along reactor vessel wall , the same as case-2 . And axial momentum also turned to radial direction . The free surface is calm . At free surface , the maximum radial velocity component is 0.53 m/s , the maximum axial velocity component is 0.23 m/s . The maximum height difference of free surface is 3.792 cm . The maximum velocity difference in z-direction at surface is 0.296 m/s , see table 5-19 . The maximum gradient of free surface level is 0.0689 , see figure 3.5-21 . Compared with case-2 , because of the ring plates fitted lower , the coolant lashed the ring plates , it formed two stronger vortex near ring plates . And its maximum height difference has become larger . So the distance between free surface and ring plates shall not larger than case-3 .

Make a comparison between the three cases , it shows that if no ring plates were fitted , like case-1 , there were no diffusion of the momentum along the reactor axis , the flow directly arrived at the free surface , and caused the free surface oscillated . If fitted ring plates , like case-2 and case-3 , the momentum along the reactor axis were diffused in radius direction . The maximum velocity difference in z-direction at free surface is 36.8% and 26.3% of the value in case-1 , respectively , the maximum gradient of surface level is 64% and 15% of case-1 , respectively , see figures 5-22 , 5-23 .

6 Conclusions

At free surface , while have some structures immersed into the liquid , the liquid lash the structures , and cause the gradient of free surface . This phenomenon may happen in a reactor vessel of a LMFBR . To eliminate the free surface gradient in reactor vessel of a LMFBR , ring plates have a high efficiency by calculate with AQUA-VOF code . Fitted ring plates , the maximum surface level difference , velocity gradient and level gradient is less than 15% , 40% and 64% of the values without ring plates , respectively . The ring plates are better fitted at the level 1.5 m under the free surface .

ACKNOWLEDGEMENT

In the past six months , I received many kinds of support and help . First , I wish to thank my advisor Mr. T. Muramatsu , Mr. E. Matsumoto , and section manager Mr. K. Sotoh for their guidance and help of the research work . Also , I wish to thank Mr. Y. Doi , Mr. M. Iida for their help , and also due to Mr. A. Sugahara , Mr. Kawakami who have worked in the same room .

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3. T. Muramatsu, Study on Numerical Methods for Thermal Striping Phenomena, Ph. D. Thesis, Tokyo Institute of Technology (1994).
4. H.Miyata , Vortex Shedding Beneath the Free-Surface , J. Computational Mechanics , Vol. 3 , pp. 217-228 (1988) .

```
*****************************************************************
*       INPUT DATA OF FUNDAMENTAL FREE SURFACE PROBLEM          *
*                               USING AQUA-VOF CODE.            *
*                                                               *
*                                   DATE : '96.11.07 GAO MINGQING *
*****************************************************************
 &GEOM   IGEOM= 0, NL1=18000, NM1=9000, ISYMCH=3, IFITEN=3,
         IFRES= 1, IMAX=150, JMAX=1, KMAX=30, NSURF=9,
         DX=150*0.02,
         DY= 0.02,
         DZ=30*0.02,
         XNORML(1)= 2*1., 2*-1., 0., 0., 0., 0., 1.,
         YNORML(1)= 2*0.,  2*0., 1.,-1., 0., 0., 0.,
         ZNORML(1)= 2*0.,  2*0., 0., 0., 1.,-1., 0.,
         ITURKE= 0,IFPCG= 0,IFVOF=-1,
              HFREE=0.4001,
 &END
REG       -1.0   1   1   1   1   1  20   1 INLET(+X)
REG       -1.0  56  56   1   1  16  30   2 WALL(+X)
REG       -1.0 150 150   1   1   1  19   3 OUTLET(-X)
REG       -1.0 150 150   1   1  20  30   4 WALL(-X)
REG       -1.0  45  45   1   1  16  30   4 WALL(-X)
REG       -1.0   1 150   1   1   1  15   5 +Y
REG       -1.0   1  45   1   1  16  30   5
REG       -1.0  56 150   1   1  16  30   5
REG       -1.0   1 150   1   1   1  15   6 -Y
REG       -1.0   1  45   1   1  16  30   6
REG       -1.0  56 150   1   1  16  30   6
REG       -1.0   1 150   1   1   1   1   7 +Z
REG       -1.0   1  45   1   1  30  30   8 -Z
REG       -1.0  46  55   1   1  15  15   8
REG       -1.0  56 150   1   1  30  30   8
REG       -1.0   1   1   1   1  21  30   9 WALL(+X)
END
 &DATA  ISTATE=0,IFENER=0,NTHCON=-1,NTMAX=9999,ITMAXP=99,
        IDTIME=0,DT=0.001,ITIBUG=0,IDLBUG=0,IVFBUG=0,
        IZMBUG=0,IT=1,1,OMEGA=1.5,
        TREST=10.0,
        VELOC(1)=0.990,
        KFLOW=2*1,-5,5*1,1,
        KTEMP=9*400,
        TEMP0=30.,
        GRAVZ=-9.807,ZPRES0=0.,
        NTPRNT=-500,NTSMRY=1,
        NTPLOT=-100,
        NTHPR =232001,012001,032001,
        HYDIN=1.0E20,
    &END
END
END
```

```
*****************************************************************
*                                                               *
*       INPUT DATA OF IN-VESSEL FREE SURFACE PROBLEM            *
*       CASE-1                  USING AQUA-VOF CODE.            *
*                                                               *
*                                    DATE : '96.11.07 GAO MINGQING *
*****************************************************************
 &GEOM   IGEOM=-1, NL1=914, NM1=914, ISYMCH=3, IFITEN=3,
         IFRES= 1, IMAX=29, JMAX=1, KMAX=44, NSURF=18,
         DX=10*0.15,2*0.09,3*0.2575,0.1975,4*0.0923,5*0.15432,4*0.0923,
         DY= 6.283185307,
         DZ=6*0.1,0.227,10*0.173,11*0.18182,8*0.1875,4*0.15,0.2,3*0.4,
         XNORML(1)= 0., 1.,-1., 0., 0., 0., 1., 0., 0.,
                    0., 0., 0., 0., 0., 0., 0., 0., 0.,
         YNORML(1)= 0., 0., 0., 0., 0., 0., 0., 0., 0.,
                    0., 0., 0., 0., 0., 0., 0., 0., 0.,
         ZNORML(1)=-1., 0., 0., 1.,-1.,-1., 0., 1., 1.,
                    1., 1., 1., 1., 1., 1., 1., 1., 1.,
         ITURKE= 0,IFPCG= 0,IFVOF=-1,
             HFREE=6.0570302,
 &END
REG       -1.0  21  25   1   1  20  20   1 OUTLET(-Z)
REG       -1.0  13  13   1   1   9   9   2 WALL(+X)
REG       -1.0  11  11   1   1  10  44   2 *
REG       -1.0  21  21   1   1  15  20   2 OUTLET SIDE(+X)
REG       -1.0  26  26   1   1  15  20   2 *
REG       -1.0  29  29   1   1   1  44   3 WALL(-X)
REG       -1.0  20  20   1   1  15  20   3 OUTLET SIDE(-X)
REG       -1.0  25  25   1   1  15  20   3 *
REG       -1.0  11  12   1   1  10  10   4 THERMAL SHIELD(+Z)
REG       -1.0  21  25   1   1  21  21   4 OUTLET(+Z)
REG       -1.0   1  12   1   1   8   8   5 UCS BOTTOM(-Z)
REG       -1.0  11  29   1   1  44  44   6 NA SURFACE(-Z)
REG       -1.0   1   1   1   1   1   8   7 CENTER LINE(+X)
REG       -1.0  15  29   1   1   1   1   8 BOTTOM(+Z)
REG   0.015077   1   1   1   1   1   1   9 INLET(+Z)
REG   0.271426   2   2   1   1   1   1  10 *
REG   0.090643   3   3   1   1   1   1  11 *
REG   0.361908   4   4   1   1   1   1  12 *
REG   0.452391   5   5   1   1   1   1  13 *
REG   0.241279   6   6   1   1   1   1  14 *
REG   0.301597   7   7   1   1   1   1  15 *
REG   0.361913   8   8   1   1   1   1  16 *
REG   0.633355   9   9   1   1   1   1  17 *
REG   1.176207  10  14   1   1   1   1  18 REFLECTOR ETC.
END
 &DATA  IFENER=0,NTHCON=-1,NTMAX=99999,IT=1,
        IDTIME=0,DT(1)=0.001,RDTIME=0.0005,
        IFMMO=1,IFMTB=1,
        IDISP=0,NTSMRY=10,TREST=60.0,
        VELOC(9)=2.2700,TEMP(9)=530.0,
```

```
        VELOC(10)=7.4600,TEMP(10)=530.0,
        VELOC(11)=5.7329,TEMP(11)=530.0,
        VELOC(12)=7.1100,TEMP(12)=530.0,
        VELOC(13)=6.0700,TEMP(13)=530.0,
        VELOC(14)=5.7962,TEMP(14)=530.0,
        VELOC(15)=5.1579,TEMP(15)=530.0,
        VELOC(16)=6.3233,TEMP(16)=530.0,
        VELOC(17)=5.2300,TEMP(17)=530.0,
        VELOC(18)=0.2100,TEMP(18)=530.0,
        KFLOW=-5, 4*1,2*-3, 11*1,
        KTEMP= 8*400, 10*1,
        TEMP0= 530.,
        GRAVZ=-9.807,ZPRES0=6.0570202,
        PSURF=87250.,
        NTPRNT=1000,-99999,
        NTPLOT=-1000,
        NTHPR =092001,012001,032001,
        HYDIN=1.0E10
     &END
END
END
```

```
*******************************************************************
*                                                                 *
*       INPUT DATA OF IN-VESSEL FREE SURFACE PROBLEM              *
*       CASE-2                   USING AQUA-VOF CODE.             *
*                                                                 *
*                                    DATE : '96.11.07 GAO MINGQING *
*******************************************************************
 &GEOM   IGEOM=-1, NL1=914, NM1=914, ISYMCH=3, IFITEN=3,
         IFRES= 1, IMAX=29, JMAX=1, KMAX=44, NSURF=18,
         DX=10*0.15,2*0.09,3*0.2575,0.1975,4*0.0923,5*0.15432,4*0.0923,
         DY= 6.283185307,
         DZ=6*0.1,0.227,10*0.173,11*0.18182,8*0.1875,4*0.15,0.2,3*0.4,
         XNORML(1)= 0., 1.,-1., 0., 0., 0., 1., 0., 0.,
                    0., 0., 0., 0., 0., 0., 0., 0., 0.,
         YNORML(1)= 0., 0., 0., 0., 0., 0., 0., 0., 0.,
                    0., 0., 0., 0., 0., 0., 0., 0., 0.,
         ZNORML(1)=-1., 0., 0., 1.,-1.,-1., 0., 1., 1.,
                    1., 1., 1., 1., 1., 1., 1., 1., 1.,
         ITURKE= 0,IFPCG= 0,IFVOF=-1,
              HFREE=6.0570302,
 &END
REG        -1.0  21  25   1   1  20  20   1 OUTLET(-Z)
REG        -1.0  13  13   1   1   9   9   2 WALL(+X)
REG        -1.0  11  11   1   1  10  44   2 *
REG        -1.0  21  21   1   1  15  20   2 OUTLET SIDE(+X)
REG        -1.0  26  26   1   1  15  20   2 *
REG        -1.0  29  29   1   1   1  44   3 WALL(-X)
REG        -1.0  20  20   1   1  15  20   3 OUTLET SIDE(-X)
REG        -1.0  25  25   1   1  15  20   3 *
REG        -1.0  11  12   1   1  10  10   4 THERMAL SHIELD(+Z)
REG        -1.0  21  25   1   1  21  21   4 OUTLET(+Z)
REG        -1.0  11  12   1   1  31  31   4 RING PLATE(+Z)
REG        -1.0  28  29   1   1  31  31   4 *
REG        -1.0   1  12   1   1   8   8   5 UCS BOTTOM(-Z)
REG        -1.0  11  12   1   1  30  30   5 RING PLATE(-Z)
REG        -1.0  28  29   1   1  30  30   5 *
REG        -1.0  11  29   1   1  44  44   6 NA SURFACE(-Z)
REG        -1.0   1   1   1   1   1   8   7 CENTER LINE(+X)
REG        -1.0  15  29   1   1   1   1   8 BOTTOM(+Z)
REG    0.015077   1   1   1   1   1   1   9 INLET(+Z)
REG    0.271426   2   2   1   1   1   1  10 *
REG    0.090643   3   3   1   1   1   1  11 *
REG    0.361908   4   4   1   1   1   1  12 *
REG    0.452391   5   5   1   1   1   1  13 *
REG    0.241279   6   6   1   1   1   1  14 *
REG    0.301597   7   7   1   1   1   1  15 *
REG    0.361913   8   8   1   1   1   1  16 *
REG    0.633355   9   9   1   1   1   1  17 *
REG    1.176207  10  14   1   1   1   1  18 REFLECTOR ETC.
END
 &DATA  IFENER=0,NTHCON=-1,NTMAX=99999,IT=1,
```

```
        IDTIME=0,DT(1)=0.001,RDTIME=0.0003,
        IFMMO=1,IFMTB=1,
        IDISP=0,NTSMRY=10,TREST=60.0,
        VELOC(9)= 2.2700,TEMP(9)=530.0,
        VELOC(10)=7.4600,TEMP(10)=530.0,
        VELOC(11)=5.7329,TEMP(11)=530.0,
        VELOC(12)=7.1100,TEMP(12)=530.0,
        VELOC(13)=6.0700,TEMP(13)=530.0,
        VELOC(14)=5.7962,TEMP(14)=530.0,
        VELOC(15)=5.1579,TEMP(15)=530.0,
        VELOC(16)=6.3233,TEMP(16)=530.0,
        VELOC(17)=5.2300,TEMP(17)=530.0,
        VELOC(18)=0.2100,TEMP(18)=530.0,
        KFLOW=-4, 4*1,2*-3, 11*1,
        KTEMP= 8*400, 10*1,
        TEMP0= 530.,
        GRAVZ=-9.807,ZPRES0=6.0570202,
        PSURF=87250.,
        NTPRNT=1000,-99999,
        NTPLOT=-1000,
        NTHPR =092001,012001,032001,
        HYDIN=1.0E10
     &END
END
END
```

```
*****************************************************************
*                                                               *
*      INPUT DATA OF IN-VESSEL FREE SURFACE PROBLEM             *
*      CASE-3                   USING AQUA-VOF CODE.            *
*                                                               *
*                                DATE : '96.11.07 GAO MINGQING *
*****************************************************************
 &GEOM   IGEOM=-1, NL1=914, NM1=914, ISYMCH=3, IFITEN=3,
         IFRES= 1, IMAX=29, JMAX=1, KMAX=44, NSURF=18,
         DX=10*0.15,2*0.09,3*0.2575,0.1975,4*0.0923,5*0.15432,4*0.0923,
         DY= 6.283185307,
         DZ=6*0.1,0.227,10*0.173,11*0.18182,8*0.1875,4*0.15,0.2,3*0.4,
         XNORML(1)= 0., 1.,-1., 0., 0., 0., 1., 0., 0.,
                    0., 0., 0., 0., 0., 0., 0., 0., 0.,
         YNORML(1)= 0., 0., 0., 0., 0., 0., 0., 0., 0.,
                    0., 0., 0., 0., 0., 0., 0., 0., 0.,
         ZNORML(1)=-1., 0., 0., 1.,-1.,-1., 0., 1., 1.,
                    1., 1., 1., 1., 1., 1., 1., 1., 1.,
         ITURKE= 0,IFPCG= 0,IFVOF=-1,
              HFREE=6.0570302,
 &END
REG        -1.0  21  25   1   1  20  20   1 OUTLET(-Z)
REG        -1.0  13  13   1   1   9   9   2 WALL(+X)
REG        -1.0  11  11   1   1  10  44   2 *
REG        -1.0  21  21   1   1  15  20   2 OUTLET SIDE(+X)
REG        -1.0  26  26   1   1  15  20   2 *
REG        -1.0  29  29   1   1   1  44   3 WALL(-X)
REG        -1.0  20  20   1   1  15  20   3 OUTLET SIDE(-X)
REG        -1.0  25  25   1   1  15  20   3 *
REG        -1.0  11  12   1   1  10  10   4 THERMAL SHIELD(+Z)
REG        -1.0  21  25   1   1  21  21   4 OUTLET(+Z)
REG        -1.0  11  12   1   1  29  29   4 RING PLATE(+Z)
REG        -1.0  28  29   1   1  29  29   4 *
REG        -1.0   1  12   1   1   8   8   5 UCS BOTTOM(-Z)
REG        -1.0  11  12   1   1  28  28   5 RING PLATE(-Z)
REG        -1.0  28  29   1   1  28  28   5 *
REG        -1.0  11  29   1   1  44  44   6 NA SURFACE(-Z)
REG        -1.0   1   1   1   1   1   8   7 CENTER LINE(+X)
REG        -1.0  15  29   1   1   1   1   8 BOTTOM(+Z)
REG    0.015077   1   1   1   1   1   1   9 INLET(+Z)
REG    0.271426   2   2   1   1   1   1  10 *
REG    0.090643   3   3   1   1   1   1  11 *
REG    0.361908   4   4   1   1   1   1  12 *
REG    0.452391   5   5   1   1   1   1  13 *
REG    0.241279   6   6   1   1   1   1  14 *
REG    0.301597   7   7   1   1   1   1  15 *
REG    0.361913   8   8   1   1   1   1  16 *
REG    0.633355   9   9   1   1   1   1  17 *
REG    1.176207  10  14   1   1   1   1  18 REFLECTOR ETC.
END
 &DATA  IFENER=0,NTHCON=-1,NTMAX=99999,IT=1,
```

```
        IDTIME=0,DT(1)=0.001,RDTIME=0.0003,
        IFMMO=1,IFMTB=1,
        IDISP=0,NTSMRY=10,TREST=60.0,
        VELOC(9)= 2.2700,TEMP(9)=530.0,
        VELOC(10)=7.4600,TEMP(10)=530.0,
        VELOC(11)=5.7329,TEMP(11)=530.0,
        VELOC(12)=7.1100,TEMP(12)=530.0,
        VELOC(13)=6.0700,TEMP(13)=530.0,
        VELOC(14)=5.7962,TEMP(14)=530.0,
        VELOC(15)=5.1579,TEMP(15)=530.0,
        VELOC(16)=6.3233,TEMP(16)=530.0,
        VELOC(17)=5.2300,TEMP(17)=530.0,
        VELOC(18)=0.2100,TEMP(18)=530.0,
        KFLOW=-5, 4*1,2*-3, 11*1,
        KTEMP= 8*400, 10*1,
        TEMP0= 530.,
        GRAVZ=-9.807,ZPRES0=6.0570202,
        PSURF=87250.,
        NTPRNT=1000,-99999,
        NTPLOT=-1000,
        NTHPR =092001,012001,032001,
        HYDIN=1.0E10
     &END
END
END
```