The Fire and Explosion Simulation of Flammable Gas Release within a Semiconductor Plant

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Contents

Preface

- Semiconductor industry is not only a capital and technological intensive industry but also a highly risky industry.
- Owing to the diversity hazardous materials (SiH_4, PH_3, H_2, IPA, DCS, etc.) that been used during the process operation, a fire and explosion accident might happen if any one of these materials were released from a leaking pipe, storage tank, or machinery
- Some of the material are even poisonous to the people and environment.

Some Fire & Explosion Accident Happened in Taiwanese Semiconductor Plant

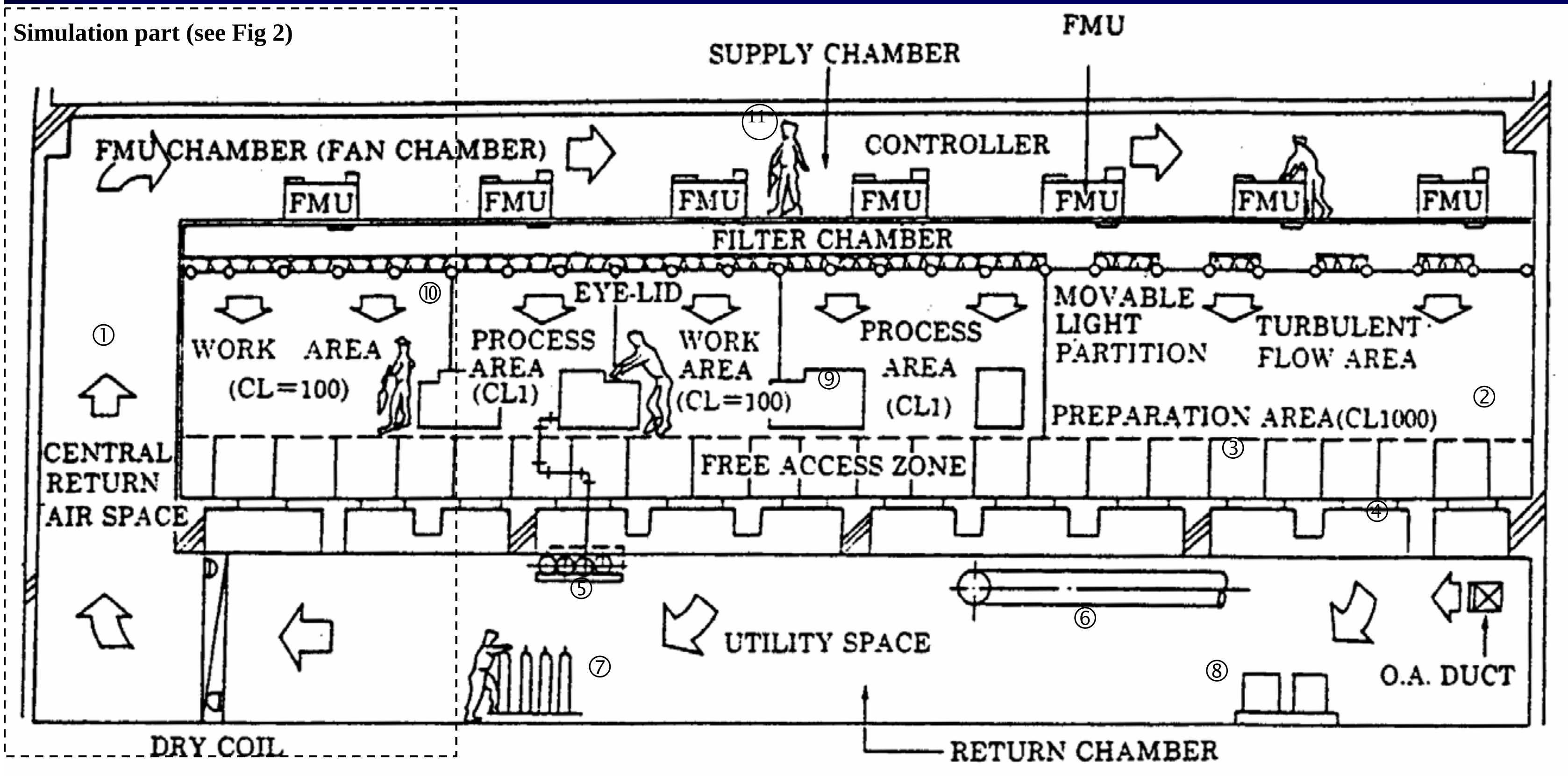
Date	Company	Cause	Total Lost (NT$)
May/01/96	Episil Tech.	H_2 residue conc. too high	~1 million
Oct/14/96	WEC Fab3	Machinery fire in 3F	6.4 billion
Apr/27/97	tsmc Fab2	ES dust collector fire	~1 million
Oct/03/97	UICC	Special gas ex. pipe leak	12.2 billion
Nov/11/97	AMP	Acid tank T abnormal	~0.3 billion
Dec/26/97	UICC	Contractor's fault	NA
Jan/09/98	UICC	Contractor's fault	NA
Jan/15/98	ITRC	Air cond. pipe exploion	~1 million
May/01/05	ASE Inc.	Boiler explosion	~12.2 billion

A fire and explosion accident of the ASE Inc. happened in Neili, Taiwan this May

Preface (cont.)

- The CFD technique has become more and more mature during recent years and has been utilized in different area such as mechanical, chemical, civil, and safety engineering.
- A properly designed CFD model can simulate possible fire and explosion scenarios in a cleanroom (C/R) and test different hazard mitigation measures at the same time.
- The simulation results can be demonstrated in a 3D dynamic form to the related personnel. These results not only can facilitate understanding of the hazard developing progress but can also be provided as the design references for preventing disasters and securing safety in a semiconductor plant.

Introduction to the Simulation Plant



① Airflow direction
② Raised floor or porous floor
③ Floor support
④ Guiding pit/hole
⑤ Liquid pipes
⑥ Gases exhaust duct
⑦ Gas bottles
⑧ Pumps
⑨ Manufacturing machinery
⑩ Separation wall
⑪ Personnel with bunny suit

Figure 1: Cross-Sectional Diagram of a Semiconductor Plant

Software Introduction

- FLACS software was employed as the physical model to calculate all kinds of fire & explosion consequences (P, J, T…)
- FLACS is a kind of CFD (computational fluid dynamics) software, it includes 3 parts:
  - CASD (computer aided scenario design)
  - flacs (flame acceleration simulator)
  - FLOWVIS (flow visualization)
- The 3D, real time simulation results can be shown in the movie files

Model Construction and Scenario Enumeration

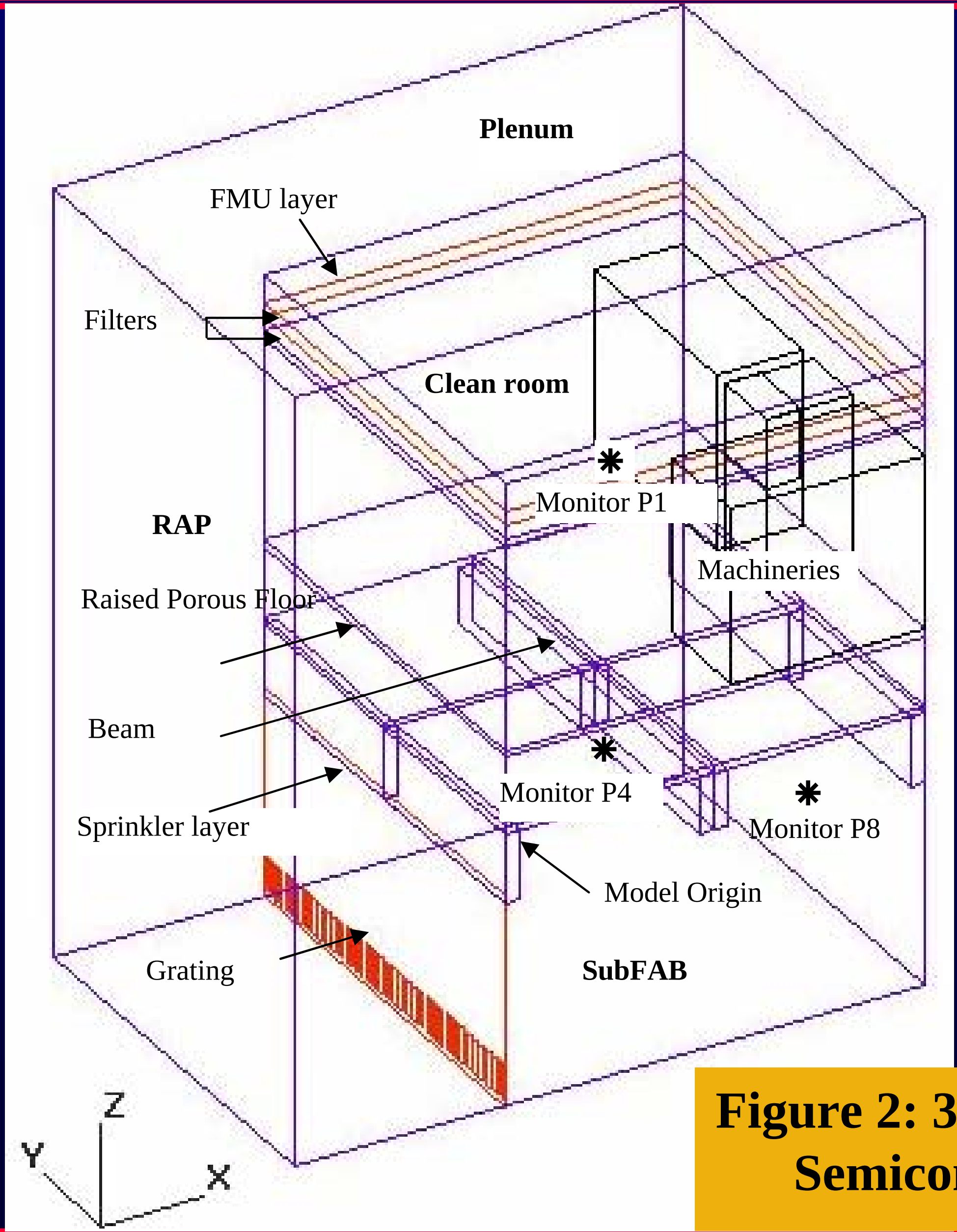


Figure 2: 3D Layout Model of a Semiconductor Plant

C/R Standard

Item	Basic conditions
Cleanliness	PROCESS AREA: CLASS < 0.1 (Particle Size 0.05 μm) SERVICE AREA: CLASS 100 (Particle Size 0.1 μm)
Temp. & Humidity	Temp.: 23 ℃ ± 5 ℃ (space distribution) Indoor cond. 23 ℃ ± 0.2℃ (time distribution) R.H.: 45 % ± 3% (time distribution)
Pressure	Pressure difference with other rooms: + 1.5 ~ 3 mmAq
Airflow	Vertical single airflow: Transecting airflow: 0.25 ~ 0.3 m/s ± 20% FILTER face airflow: 0.3 ~ 0.35 m/s ± 20%

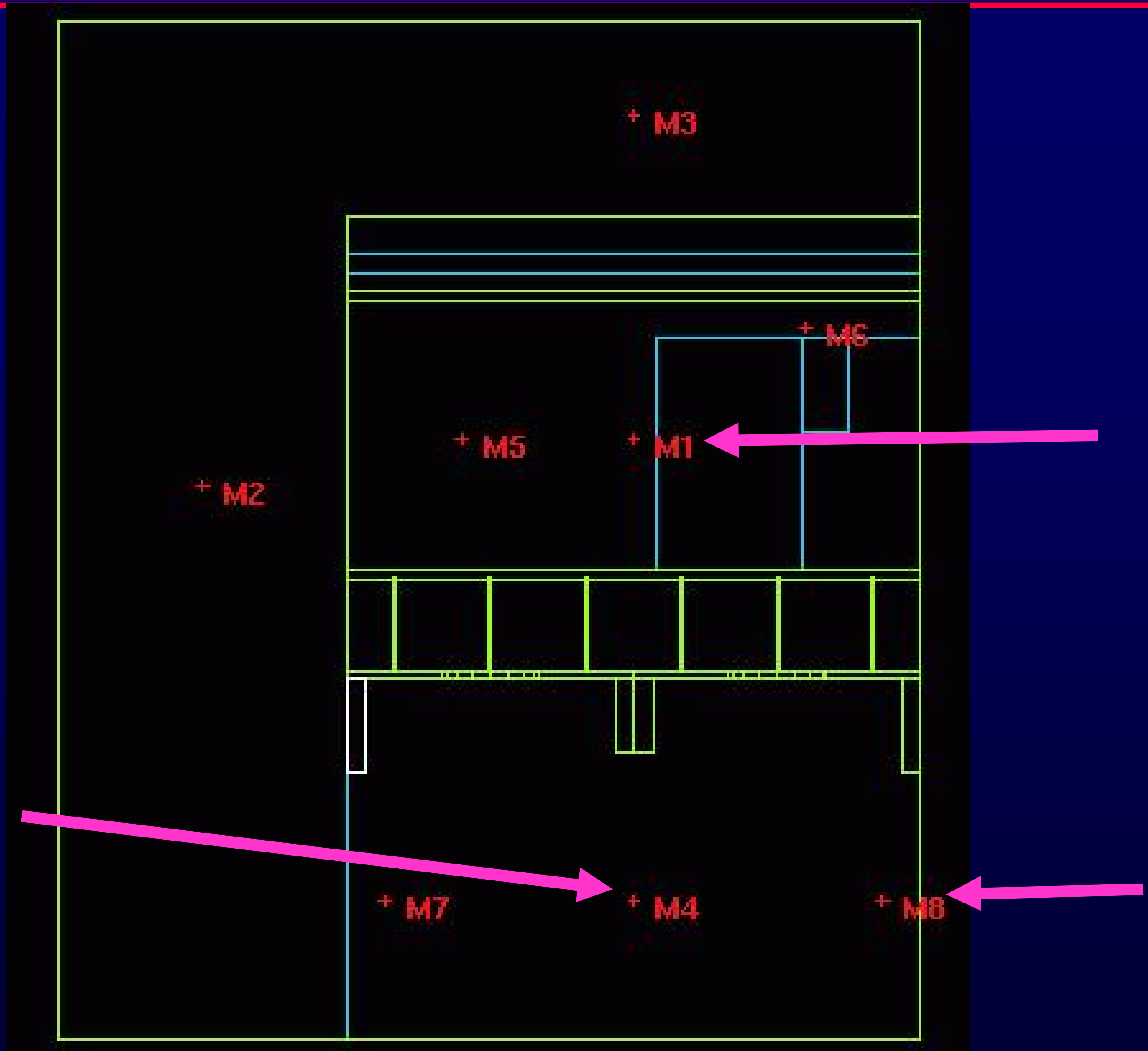
Research Methods

Parameters \ No.	1A	1B	1C	2A	2B	3A	3B	4A	4B	5A	5B	5C	6A	6B	6C
Airflow modelling[a]	**N**	**F**	**F+L**	F+L		F+L		F+L		F+L			F+L		
Gas category	N/A[d]			**C_3H_8**	**H_2**	C_3H_8		C_3H_8		C_3H_8			C_3H_8		
Leak location[b]	N/A			SubFAB		**Sub FAB**	**C/R**	Sub FAB		SubFAB			SubFAB		
Leaking rate (m/sec)	N/A			2		2		**2**	**4**	2			2		
Sprinkler's water drop diameter, μm	N/A			N/A		N/A		N/A		**700**	**1000**	**846**	846		
Mitigation facilities[c]	N/A			N/A		N/A		N/A		N/A			**S**	**P**	**S+P**

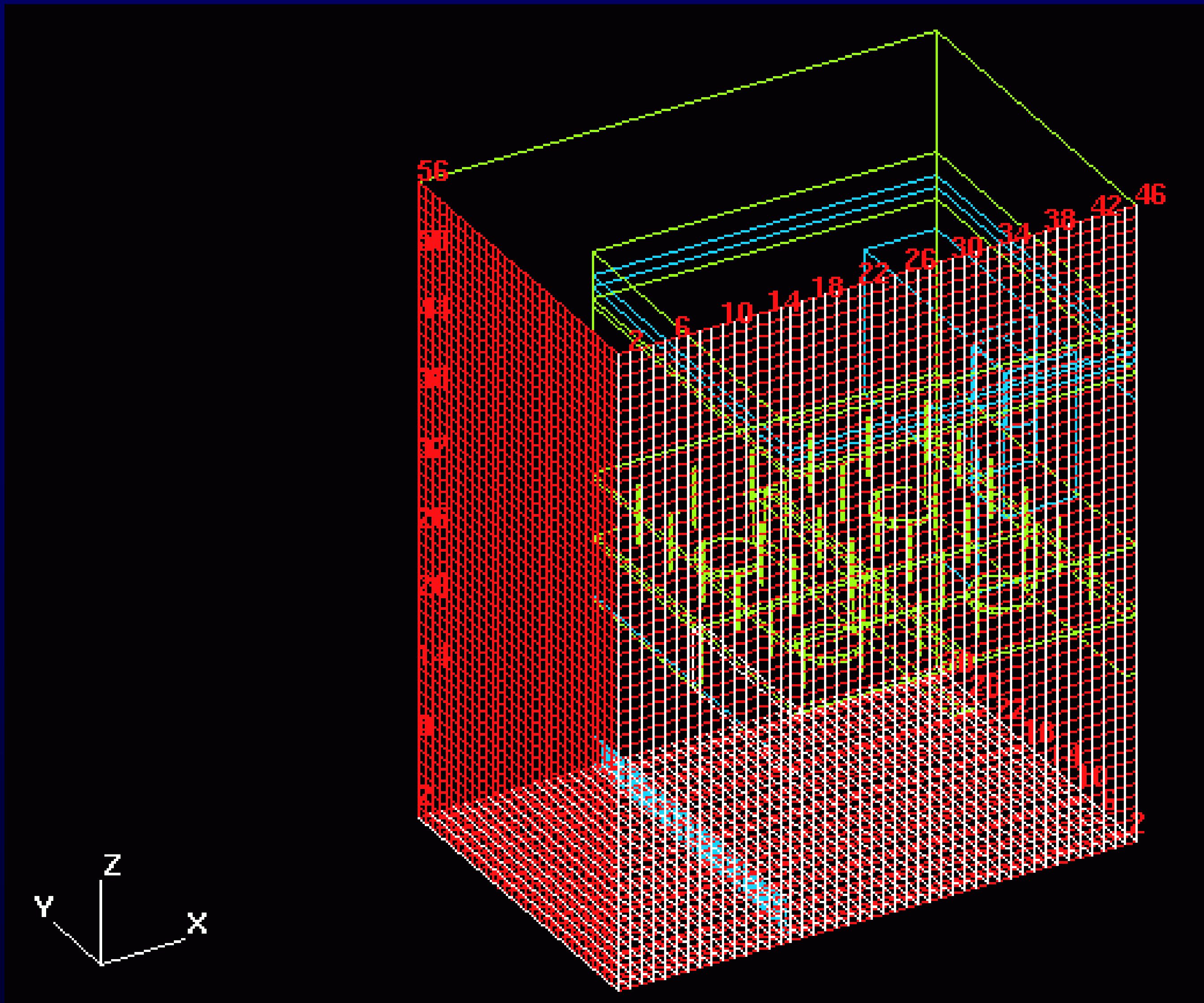
[a] N: 36 nozzles with one RAP fan; F: 25 fans; F+L: 25 fans with three porous layers.

[b] C/R: cleanroom. [c] S: sprinkler; P: pressure release panel. [d] N/A: not available

Monitors Deposition Diagram

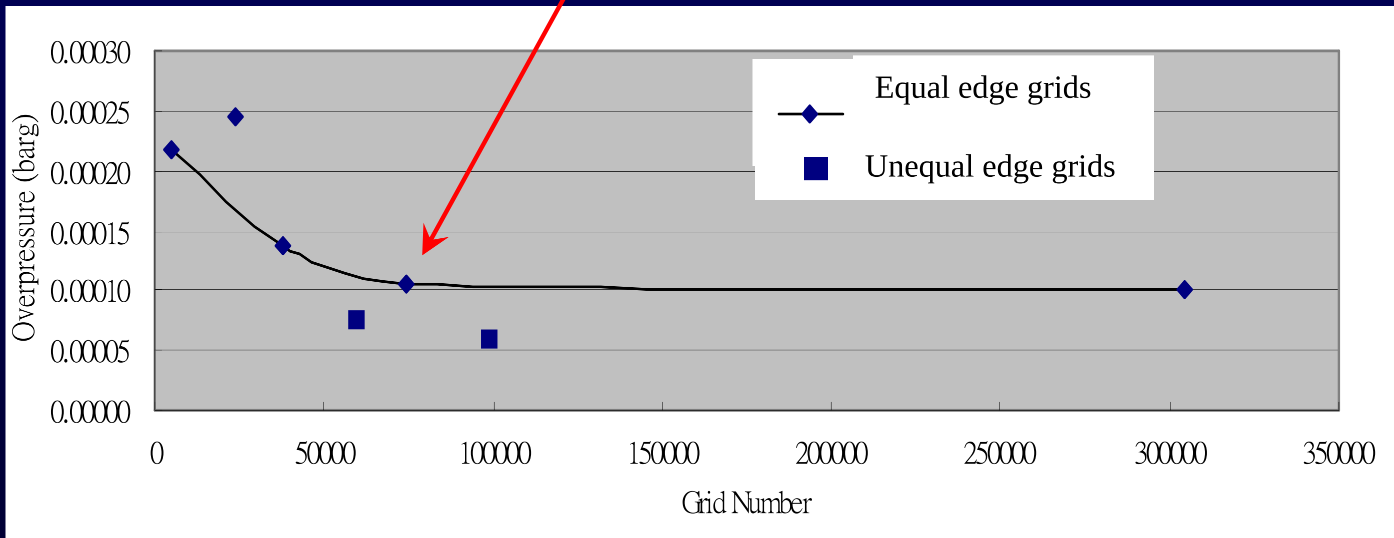


Grid Cells Deposition Diagram

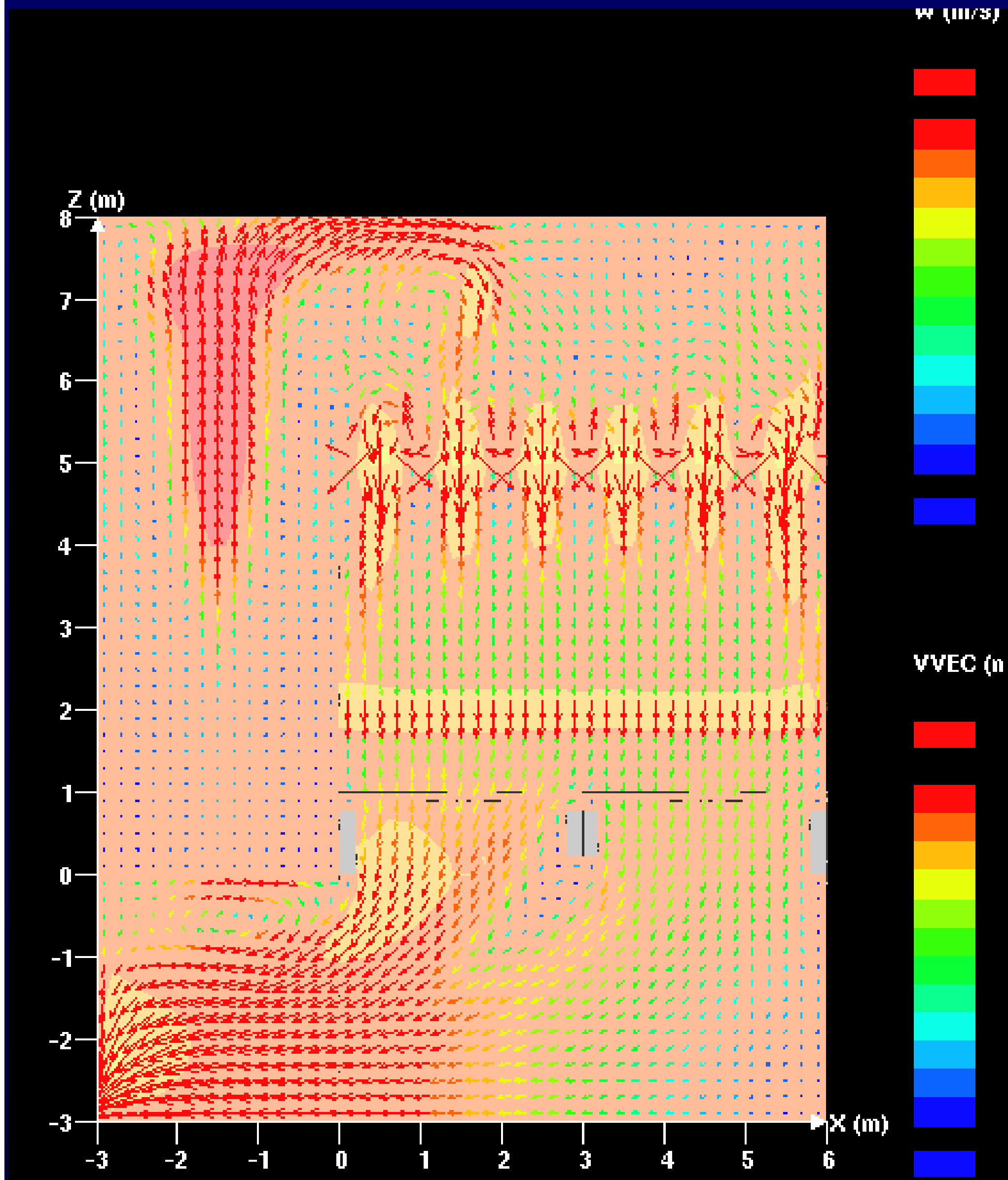


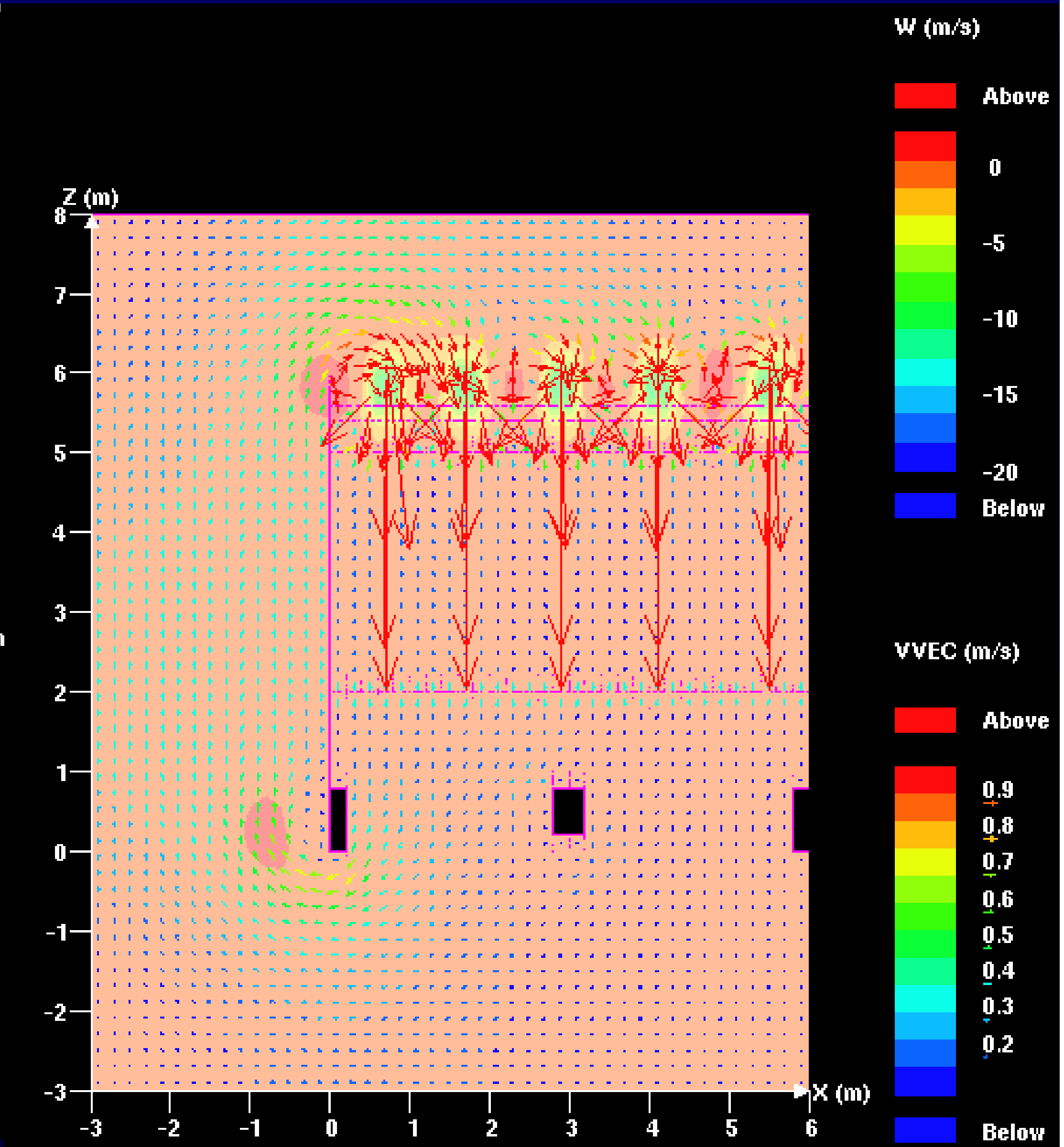
Different Modules Used for Grid Convergent Test (Simulation Time: 5 Sec)

Features \ Module code	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Grid 7
Total grid number	4,752	38,016	**74,250**	304,128	24,000	59,400	99,000
Grid number in (x, y, z) axis	(18,12,22)	(36,24,44)	**(45,30,55)**	(72,48,88)	(30,20,40)	(45,30,44)	(45,40,55)
Unit grid dimension (m) in (x, y, z) axis	(0.5,0.5,0.5)	(0.25,0.25,0.25)	**(0.2,0.2,0.2)**	(0.125,0.125 ,0.125)	(0.3,0.3,0.275)	(0.2,0.2,0.25)	0.2,0.15,0.2)
Overpressure (barg)	0.00021861	0.00013781	**0.00010587**	0.00009985	0.00024458	0.00007455	0.00005882

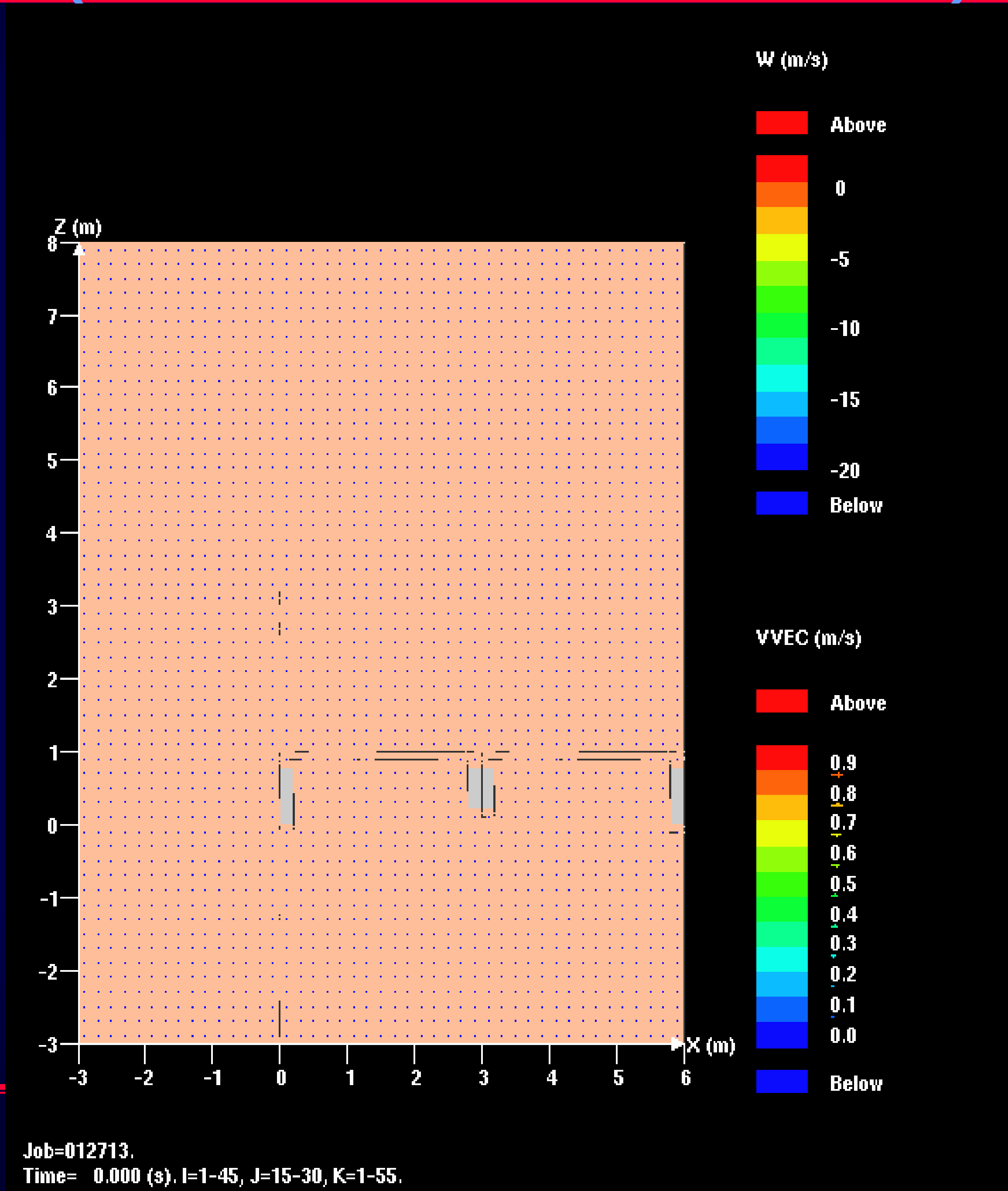


Fluid Fields of the Airflow Simulation Results (Simulation Time: 5 Sec)





Fluid Fields of the Airflow Simulation Results (Simulation Time: 60 Sec)



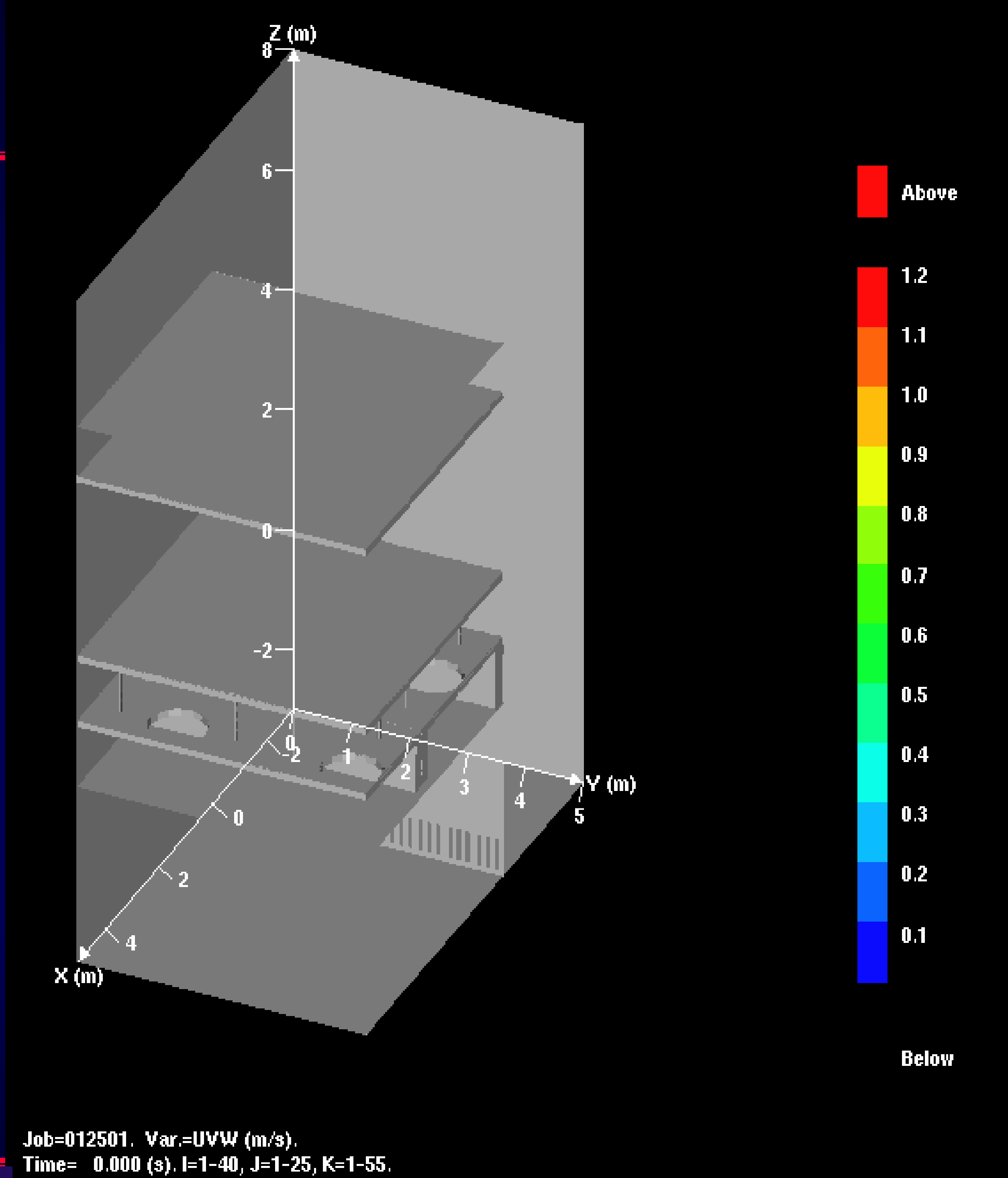


圖2 潔淨室流場模擬 (剖面)

Comparison of Hazardous Consequence Analyses under Different Conditions

Parameter \ No.	2A, 3A, 4A	2B	3B	4B	5A	5B	5C, 6A	6B	6C
Overpress. (barg)	1.40	0.24	1.06	3.00	1.52	1.54	1.46	0.20	0.22
Impulse pressure (Pa*s)	1.60×10^{6}	2.54×10^{5}	1.20×10^{6}	3.25×10^{6}	1.72×10^{6}	1.73×10^{6}	1.63×10^{6}	2.00×10^{4}	2.10×10^{4}
Temp. (K)	2294[a] 1600[b]	1802[a]	2242[a]	2353[a]	1842[b]	1852[b]	800[b]	1613[b]	600[b]

[a] Measured at monitor point M/P4.   [b] Measured at monitor point M/P8.

Comparison of Different Sprinkler Systems

No. / Parameter	2A 3A 4A	2B	3B	4B	5A	5B	5C 6A	6B	6C
Overpress. (barg)	1.40	0.24	1.06	3.00	1.52	1.54	1.46	0.20	0.22
Impulse pressure (Pa*s)	1.60×10^6	2.54×10^5	1.20×10^6	3.25×10^6	1.72×10^6	1.73×10^6	1.63×10^6	2.00×10^4	2.10×10^4
Temp. (K)	2294[a] 1600[b]	1802[a]	2242[a]	2353[a]	1842[b]	1852[b]	800[b]	1613[b]	600[b]

[a] Measured at monitor point M/P4. [b] Measured at monitor point M/P8.

Comparison of Different Mitigation Measures

Chemical: Propane

Leak place: Subfab

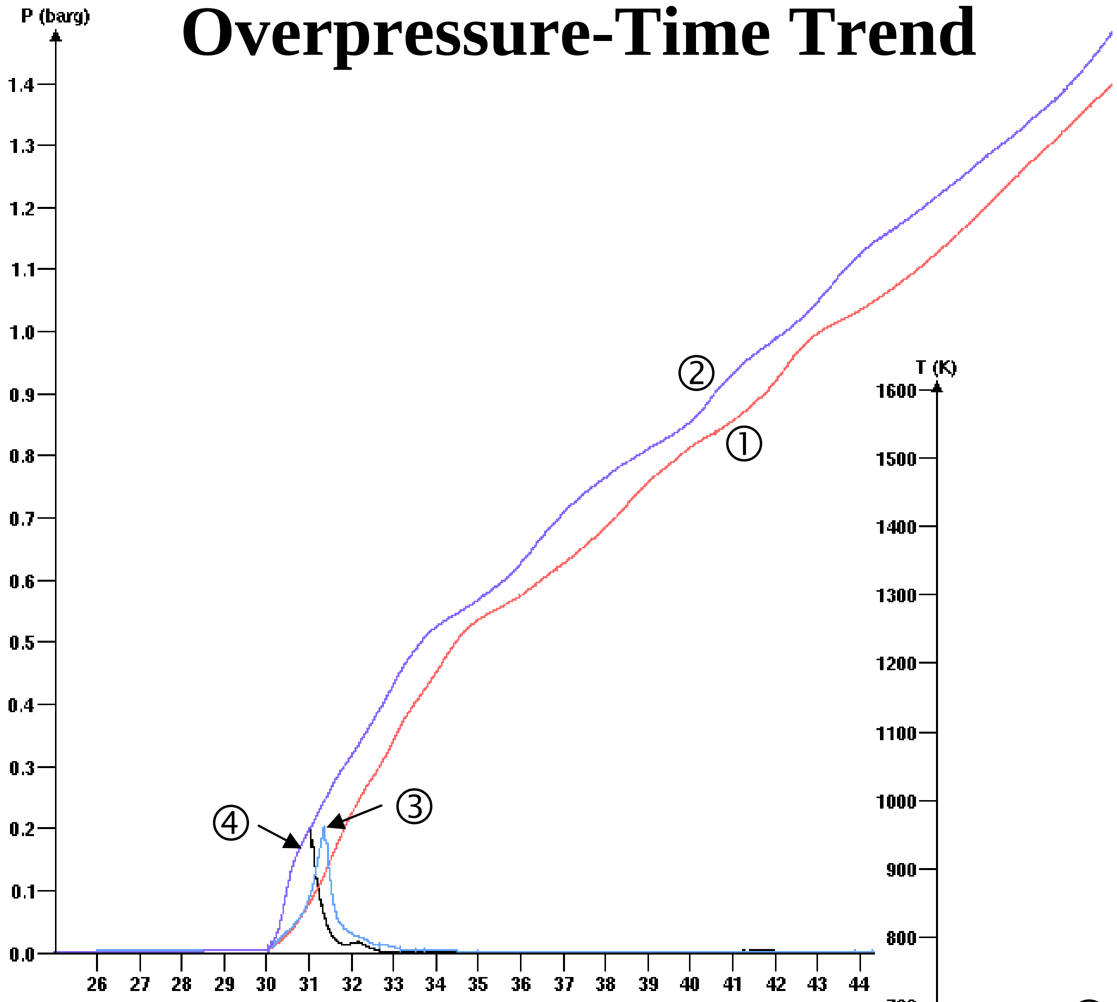
Flammable gas volume: 4 m^3

Monitor point: P4

Mitigation Measures	Overpressure (barg)	Press. Impulse (Pa*s)	Temp. (K)
None	1.40	1,600,000	1,600
Water sprinkler (846 μm)	1.46	1,630,000	800
Pressure relief panel	0.20	20,000	1,613
Water (846 μm) + Panel	0.22	21,000	600

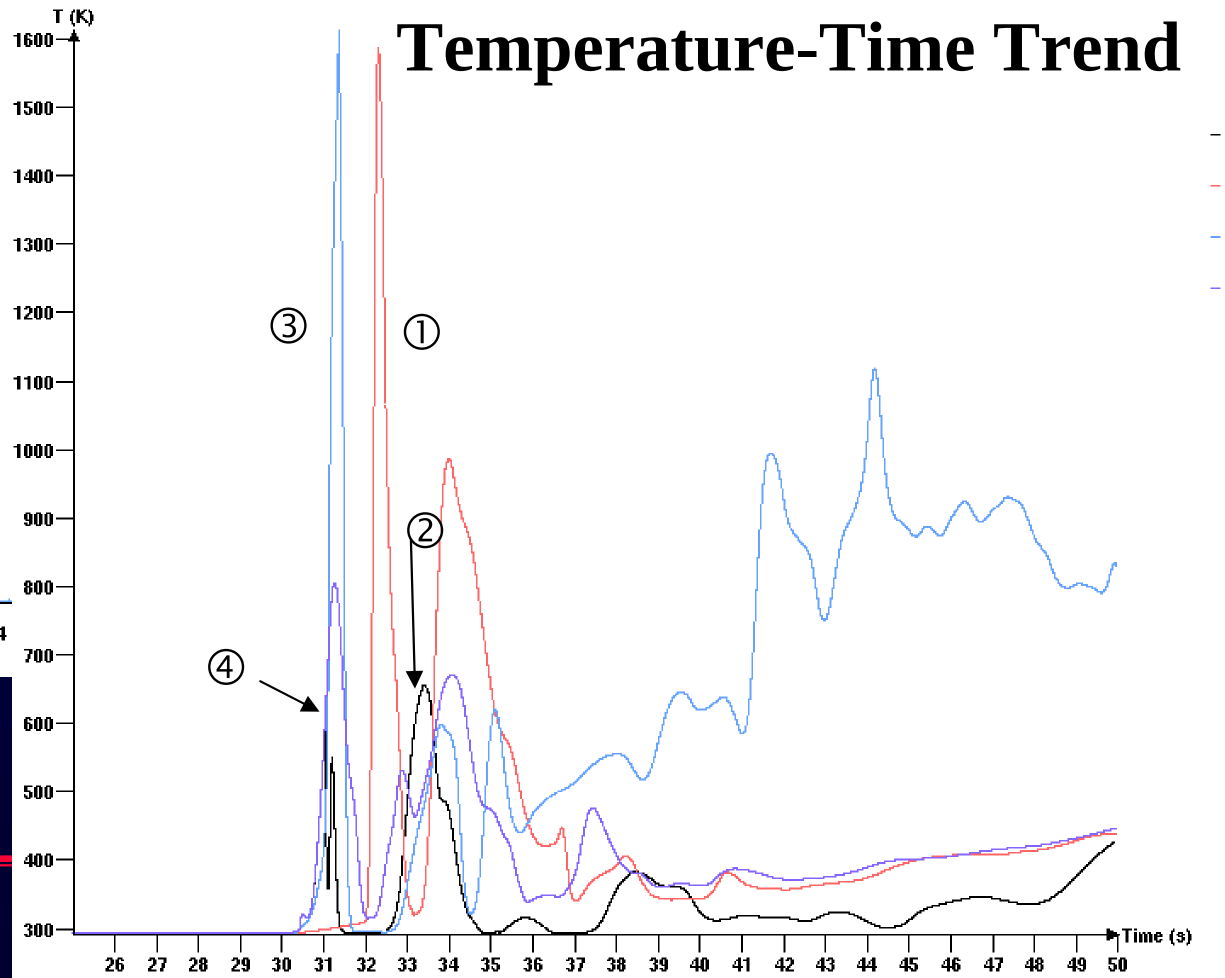
Simulation Results of Propane Fire and Explosion Accident Recorded by Monitor P8

Overpressure-Time Trend



① Without mitigation measures;
② With sprinkler (Dw=846 mm)
③ With pressure release panel
④ With sprinkler & release panel

Temperature-Time Trend



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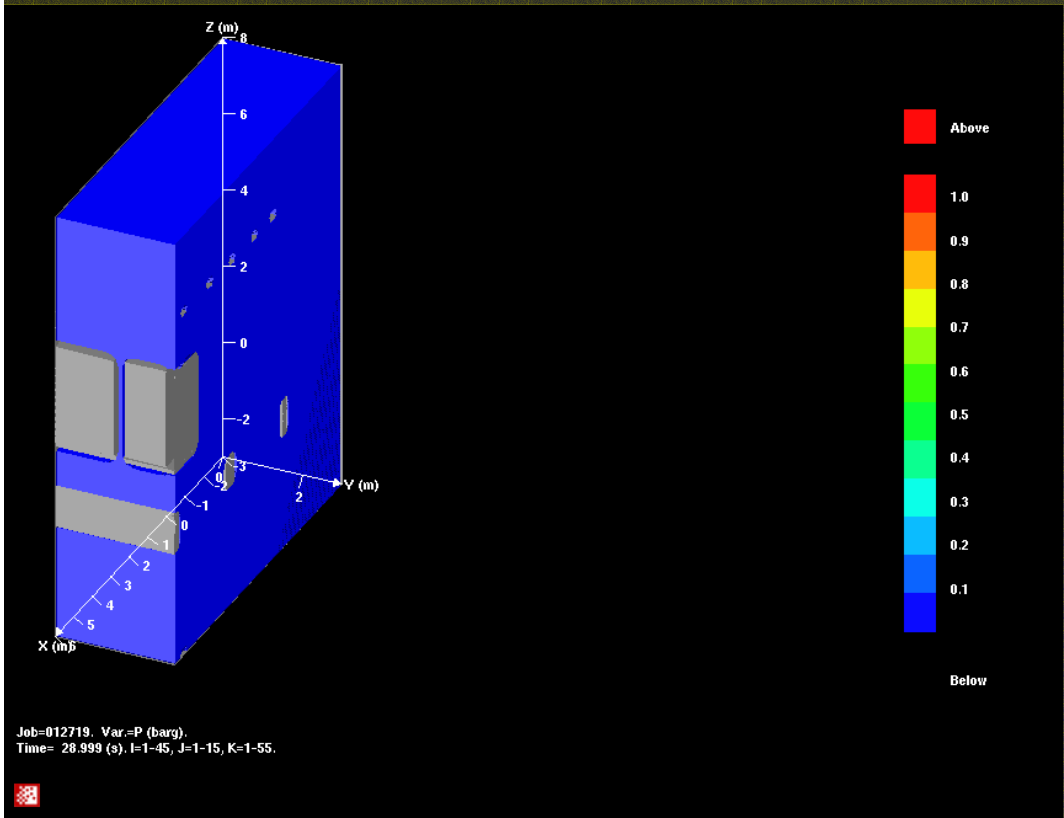
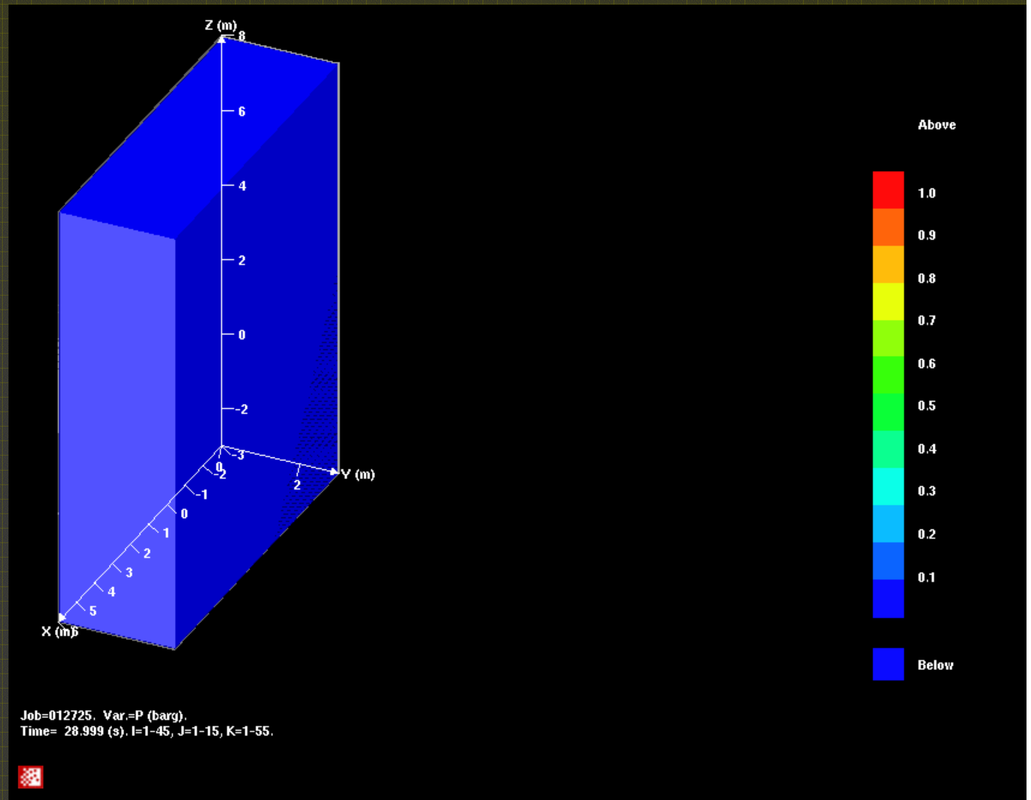
Comparison of dynamic simulation results of zero-mitigation with two-mitigation measures



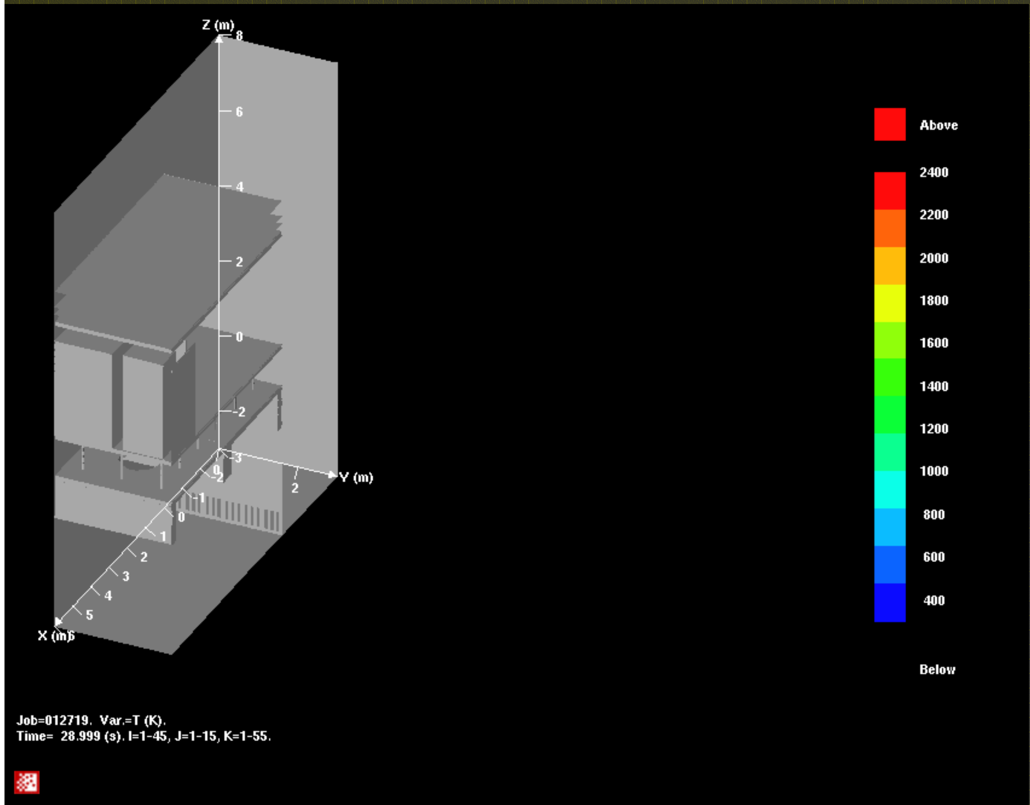


(a) No mitigation

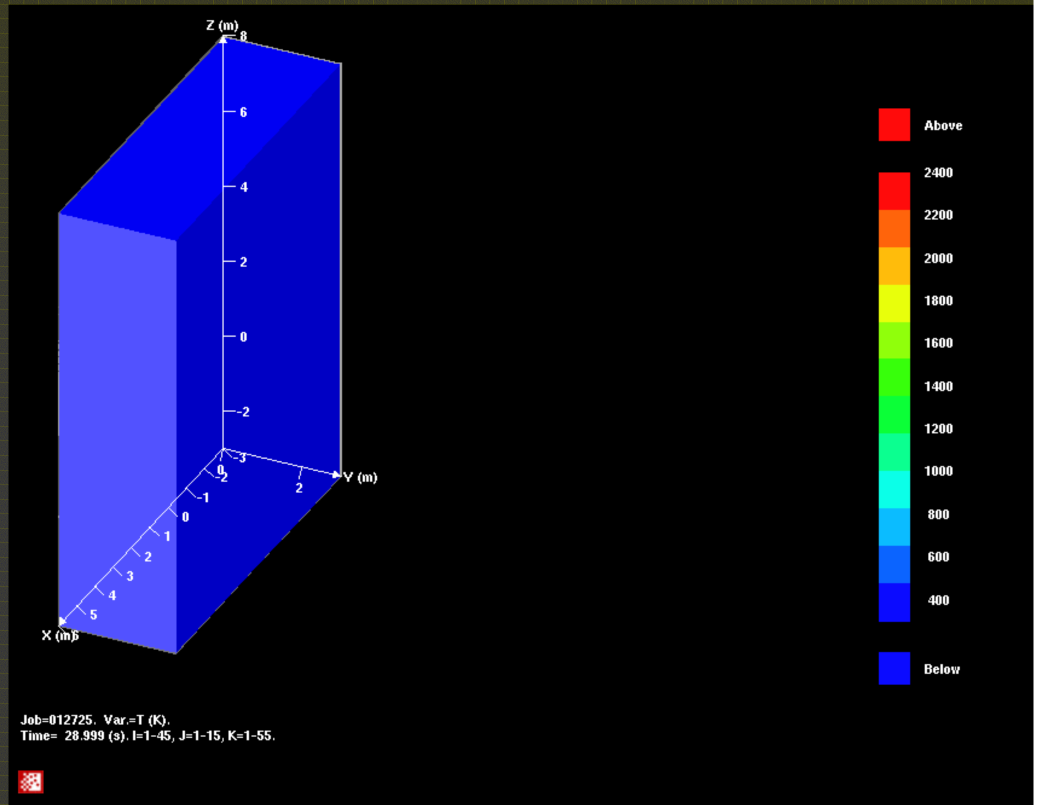
(b) Sprinkler + relief panel

3D Dynamic Overpressure Variation History (Monitor p8)

Comparison of dynamic simulation results of zero-mitigation with two-mitigation measures



(a) No mitigation



(b) Sprinkler + relief panel

3D Dynamic Temperature Variation History (Monitor p8)

Conclusions

- A CFD simulation model was built and tested to mimic the fluid field of a semiconductor manufacturing plant. Different hazard scenarios were proposed and simulated and various mitigation measures were provided to evaluate their efficiency.
- When a slowly propane leak happened and ignited in a SubFAB area, the fire and explosion results (overpressure = 1.40 barg; temperature = 1600~2294 K) could cause a permanent damage to the equipment while personnel within the area will never have enough time to escape.
- With only a proper sprinkler system installed (DW = 846 μm), the temperature could be decreased to a certain limit while the overpressure still very high. On the other hand, the overpressure will drop immediately while its temperature remains very high if only a pressure release panel is activated.

Conclusions (cont.)

- The temperature and overpressure will both reduced efficiently (overpressure = 0.22 barg; temperature = 600 K) only when different mitigation measures are integrated and implemented at the same time.
- Through the 3D dynamic demonstrations of the overpressure, pressure impulse and temperature field of different hazard scenarios and their countermeasures, the CFD simulation method can provide the related personnel a quick and easy way to gain insights into the mitigation designs for all kind of fire and explosion hazards happened in a semiconductor plant.

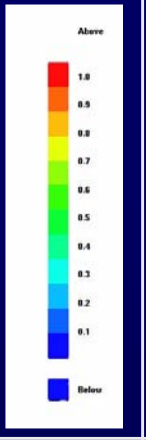
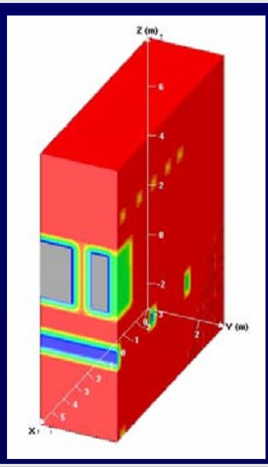
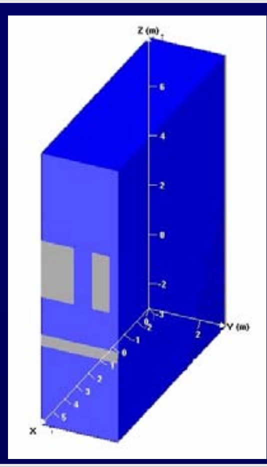
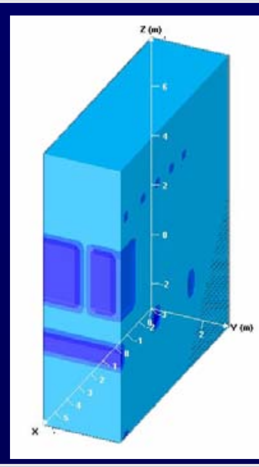
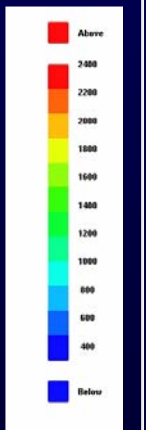
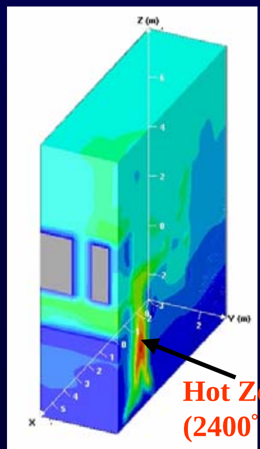
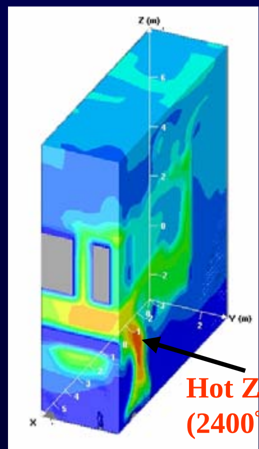
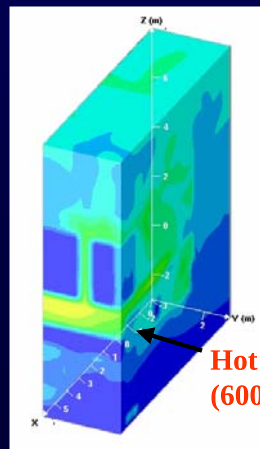
Thank you for your attention!

Acknowledgement

The authors are grateful to the National Science Council of Taiwan for financial support of this study under the project of "Development of a 3D risk analysis technique (NSC 94-2211-E-224-007-)".

CPR Lab

FAB with Different Mitigation Measures under a Propane Fire and Explosion Accident

		FAB without Any Mitigation Measures	FAB Equipped with a Pressure Release Panel	Equipped with Release Panel & Sprinkler System
P°				
		(a) 42.8 Sec after Ignition	(b) 30.8 Sec after Ignition	(c) 31.0 Sec after Ignition
T				
		(d) 31.2 Sec after Ignition	(e) 48.2 Sec after Ignition	(f) 48.9 Sec after Ignition