2.4

Overview of the Risk Assessment for Chiller

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Today’s Outlines

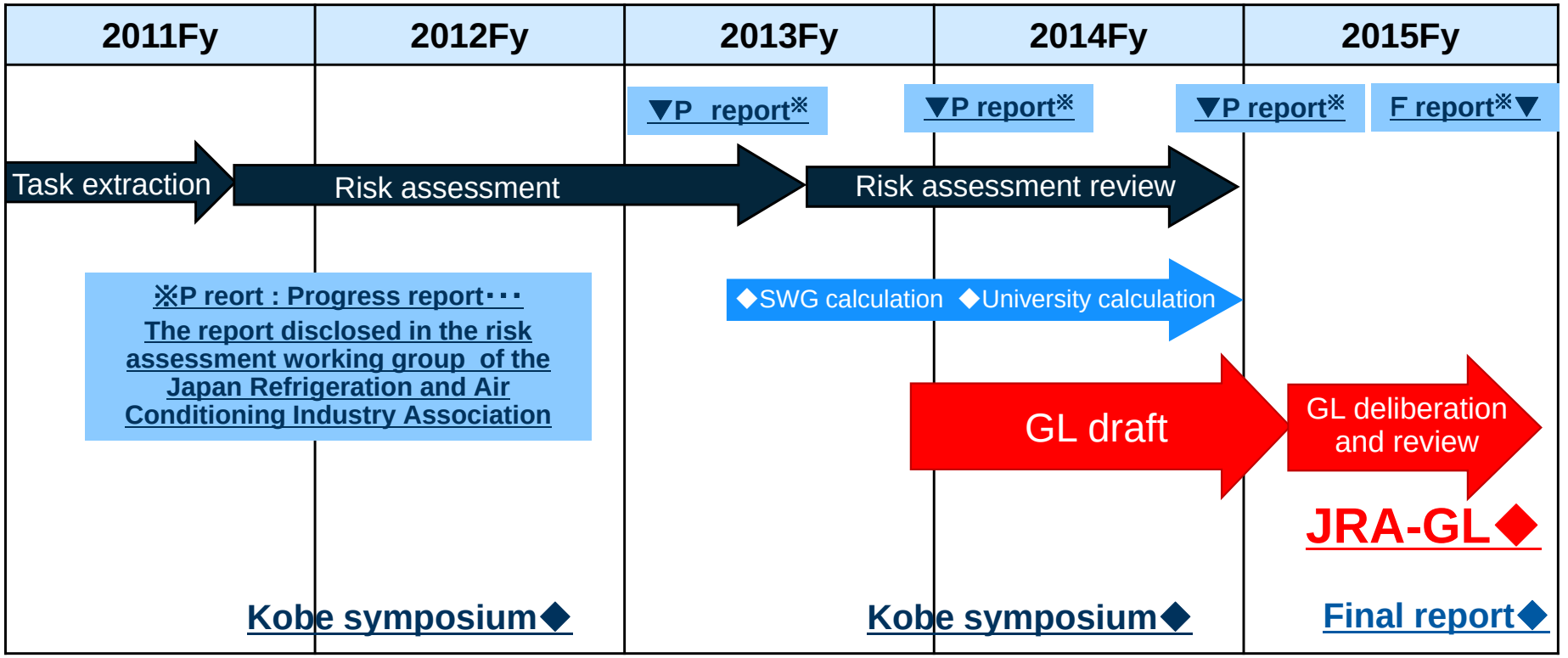
- Schedule

- Regal system in Japan
- Risk assessment detail
- Countermeasure
- GL

- Conclusions

1. Risk assessment process chart of chiller SWG

- The working group , which consists of professional chiller engineers, in Japan Refrigeration and Air Conditioning Industry Assosication (JRAIA) started in 2011.
- Risk assessments(RAs) were executed until last year and the guideline(GL) draft was created at the end of 2014, which is now being deliberated to be issued as the guideline during this fiscal year.



2. Risk assessment and legal system

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Industrial Safety and Health Law

【Order for Enforcement】
A workplace employing a certain number of workers shall appoint a General Safety and Health Manager.
【Enforcement Regulations】
The General Safety and Health Manager shall perform risk assessments.

The Building Standards Act

High Pressure Gas Safety Act

Refrigeration Safety Regulations

Article 7.14 Electrical Equipment refers to explosion preventive performance・・

KHK0302-3(2012)

Standards of Refrigeration and Air-Conditioning Equipment Facilities〔Fasilities with Flammable Gases（including mildly-flammable Gases）〕

JRA -GL15

Guideline of design construction for ensuring safety against refrigerant leakage form chillers using mildly-flammable refrigerants

EN1127-1(2011)

Explosive atmospheres – Explosion prevention and protection

IEC60079s(2011)

Explosive atmospheres – Equipment ;General requirement

JIS60079s
Electric Machinery and Instruments Used in Explosive Atmospheres General Requirements is the 2007 version of IEC.
＞Outdoor natural ventilation＝Zone2
＞forced ventilation with preliminary and warning devices.
＋normally, explosive atmospheres are not formed.
＝Zone2NE(not dangerous）

ISO5149

Refrigeration system and heat pumps – safety and environmental requirements

3. Target products

	Water-cooled chillers	Air-cooled heat pumps
Type	Modular Chillers Screw chillers Centrifugal	Modular Chillers Screw chillers
Cooling capacity	7.5kW - 17,500kW	
Installation location	machine room	outdoor
Standard specifications for risk assessments		
Cooling capacity	Approx. 180kW	Approx. 90kW
Refrigerant charge amount	23.4kg	11.7kg（per 1 system ）
Dimensions	1.28W × 1.28D × 1.28H [m]	1.00W × 3.00D × 2.30H [m]

Water-cooled chillers

Mayekawa

Kobe Steel

Mitsubishi Heavy Industries

Ebara Refrigeration Equipment And Systems

Air-cooled heat pumps

Mitsubishi Electric

Toshiba-Carrier

Hitachi Appliacnes

4. Acceptable probability of harm

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Table.4 Probability of occurrence of hazards per a chiller a year

		Probability of occurrence of harm		Industrial-level product adoption	
		consumer goods	industrial level product (cases /units per year)		Number of accidents
5	Frequent	10^{-3}	10^{-1}	$(1.0X10^{-1})$	once a year per 10 units
4	Probable	10^{-4}	10^{-2}	$(1.0X10^{-2})$	once a year per 100 units
3	Probable	10^{-5}	10^{-3}	$(1.1X10^{-3})$	134 times a year
2	Remote	10^{-6}	10^{-4}	$(1.1X10^{-4})$	14 times a yea
1	Improbable	10^{-7}	10^{-5}	$(7.5X10^{-6})$	once or twice a year
0	**Incredible**	10^{-8}	10^{-6}	$(7.5x10^{-7})$	**once or twice every ten years**

5. Definition of life stages

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Table 5 Work content and sales of chiller in each life stage

Life Stage	Target	Work content	Ratio of Number		Number of sale	LS ratio
			AC	WC		
Logistics	Supplier	Transpotation and storage in warehouse	Total		9,687	0.0517
Installation	Operator	Carrying in・Installation・Storage・Trial operation	7	3	9,687	0.0517
Usage		During use and halt	7	3	134,000	0.7145
Repair		During pipe connection, pipe disconnection, refrigerant discharge, leak detection	Total		22,637	0.1207
		During refrigerant recovery, refrigerant charge, and inspection and repair				
Overhaul		During disassembly, refrigerant recovery After recovery container is stored, during assembly	Total		1,838	0.0098
Disposal	Supplier	During refrigerant recovery,after recovery container is stored, disassembly, carrying out	Total		9,687	0.0517

6. FTA and calculation method of probability (1)

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◆ **Basic FTA** was configured to align the probability of refrigerant leakage and probability of existence of ignition sources in 6 Life Stages (LS)（Figure.5）.

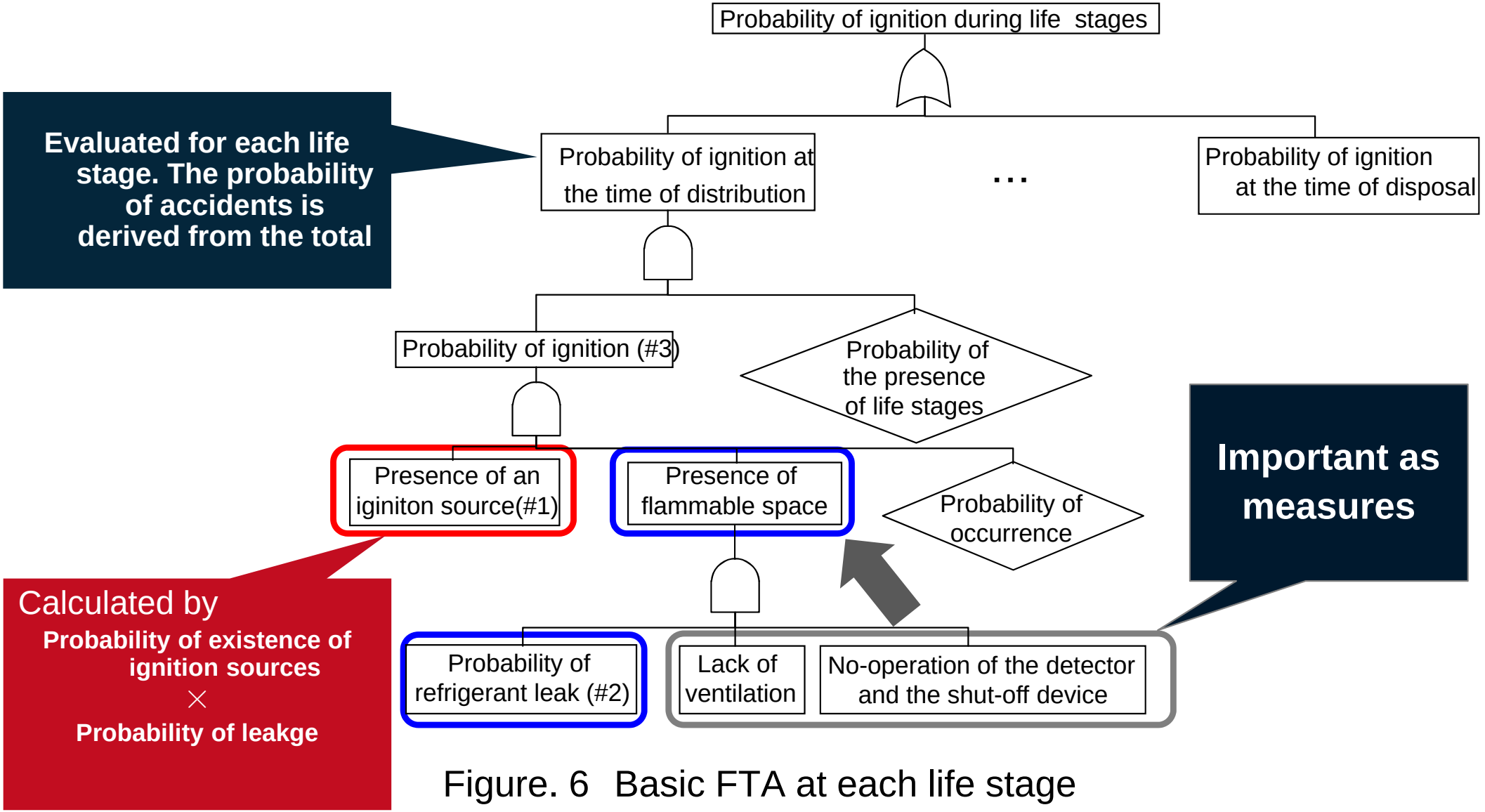

Figure. 6 Basic FTA at each life stage

7. FTA and calculation method of probability (2)

- In order to detect all the probable ignition sources, FTA common to all life stages was configured for calculating the probability of the existence of ignition sources and prbability of leakage.

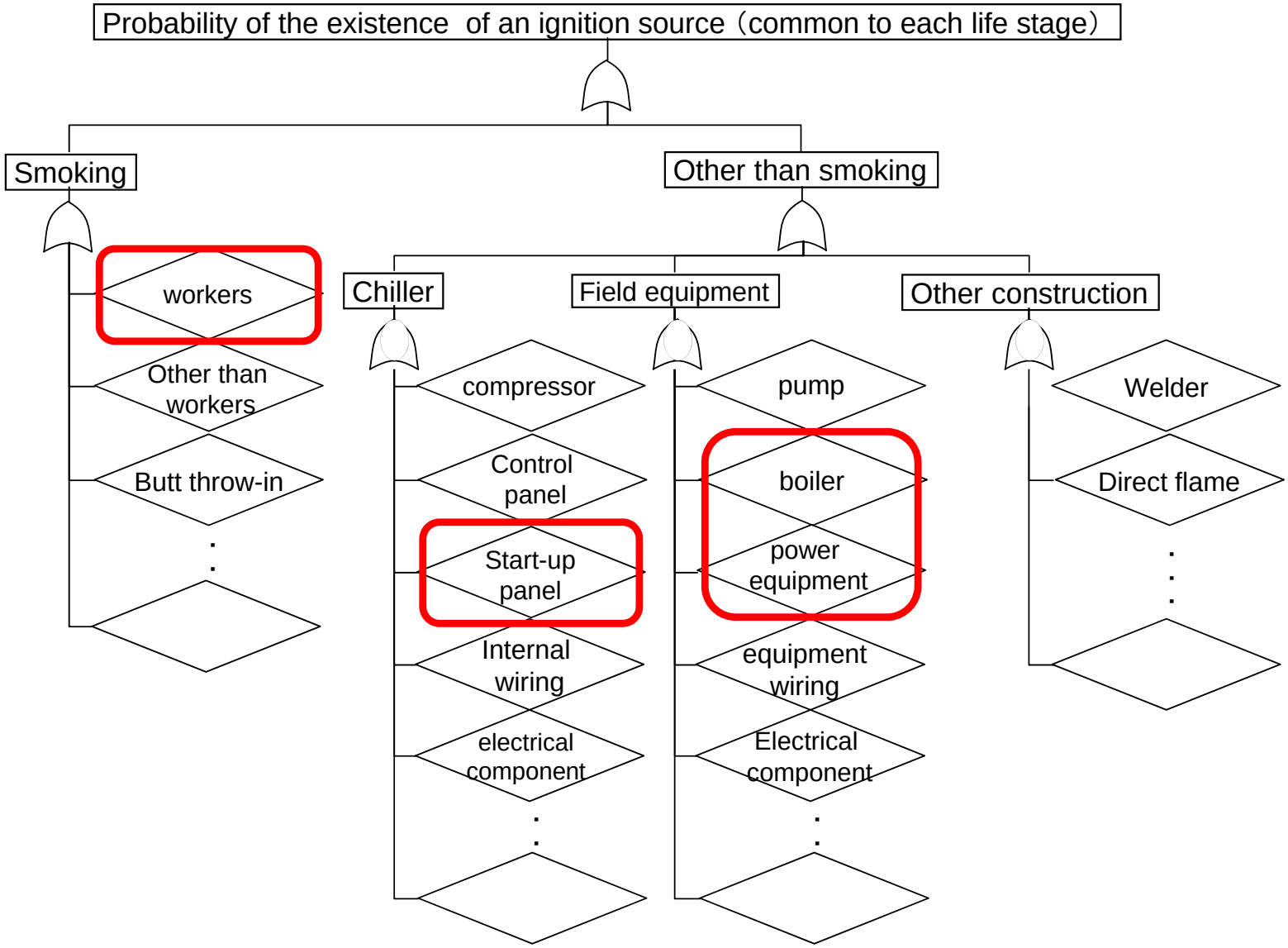

Figure 7 Common FTA for probability of the existence of igniton sources

8. Frequency of refrigerant leakage accidents

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We estimated the record with the actual accident data RA members submitted

①The total shipment volume of water-cooled (W/C) chillers, air-cooled (A/C) chillers, and turbo chillers are derived from the annual shipment volume of chiller SWG companies.

②Annual proportional rates against the summarized data of this study were derived from annual shipment volume provided by JRAIA.

③Total numbers of leakage cases were determined by adding each company's number of WC, AC, and turbo chiller leakage cases .

④Total number of leakage cases was estimated by the proportional rate of each chiller SWG company.

⑤Frequency of leakage was determined by deviding estimated total number by the volume of METI stock units（130 K units）.（The ratio of WC/AC chillers was assumed to be 3：7.）

Table 8 Frequency of leakage occurrence for each leakage rate from fiscal 2004 to 2011.

2004-2011	Frequency of leakage（cases/units･year）			
	W/C chiller	A/C HP	Centrifugal	Total
burst leak	5.83×10^{-6}	1.35×10^{-5}	0	**1.07×10^{-5}**
rapid leak	1.07×10^{-4}	1.87×10^{-4}	0	**1.56×10^{-4}**
slow leak	1.64×10^{-3}	2.21×10^{-3}	7.09×10^{-3}	2.27×10^{-3}

9. Machine room model（Image）

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◆ Overview of the chiller machine room

(1) Probable **Ignition sources** are a boiler with **a burner** (only the surface temperature should be considered) , a hot and chilled water generator, starter panels, power panels, and electrical components（**breakers and solenoid switches)** in the operation panels of chillers and pumps

(2) **Building Standard Act** indicates the **values of（oxygen consumption, heat removal, oxygen concentration）**corresponding to **ventilation** and actual circumstances.

(3)Exhaust from the burning appliances such as the boiler and the absorption chiller by direct boiling is discharged outside through **independent duct.**

(4)Exhaust air **is not discharged to other rooms** and does not affect outdoor air exhaust and air intake into other buildings.

(5)Ventilation is **2 air-changes /h ×2 lines** , totaling 4 air-changes /h（ISO5149）

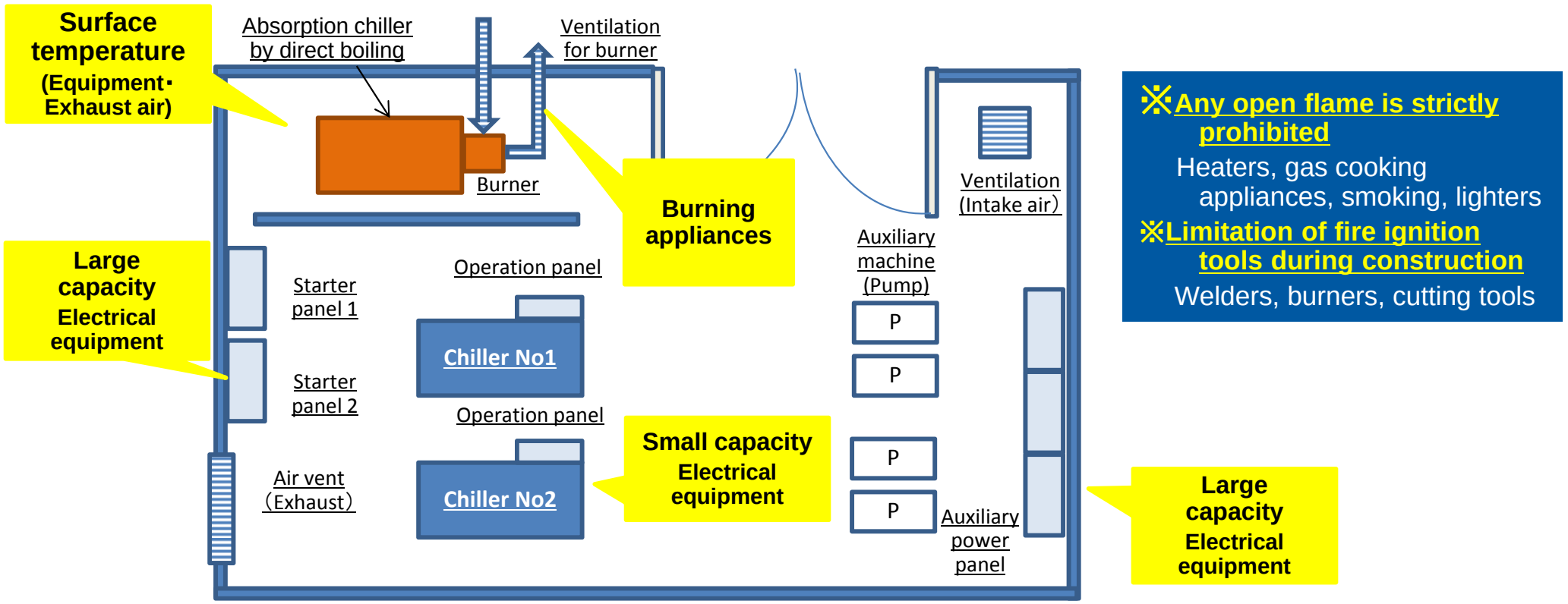
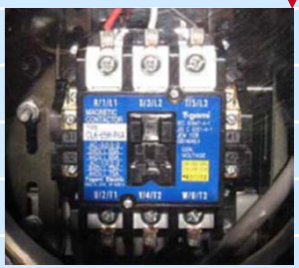


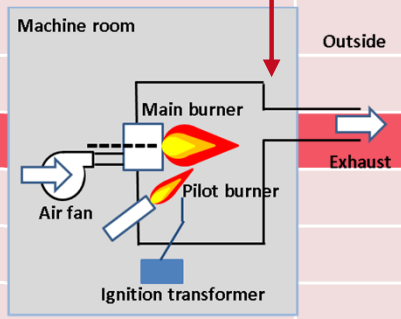
Figure.9 Machine room image

10. Ignition sources（igniton assessment）

Table 10 Ignition sources in the machine room

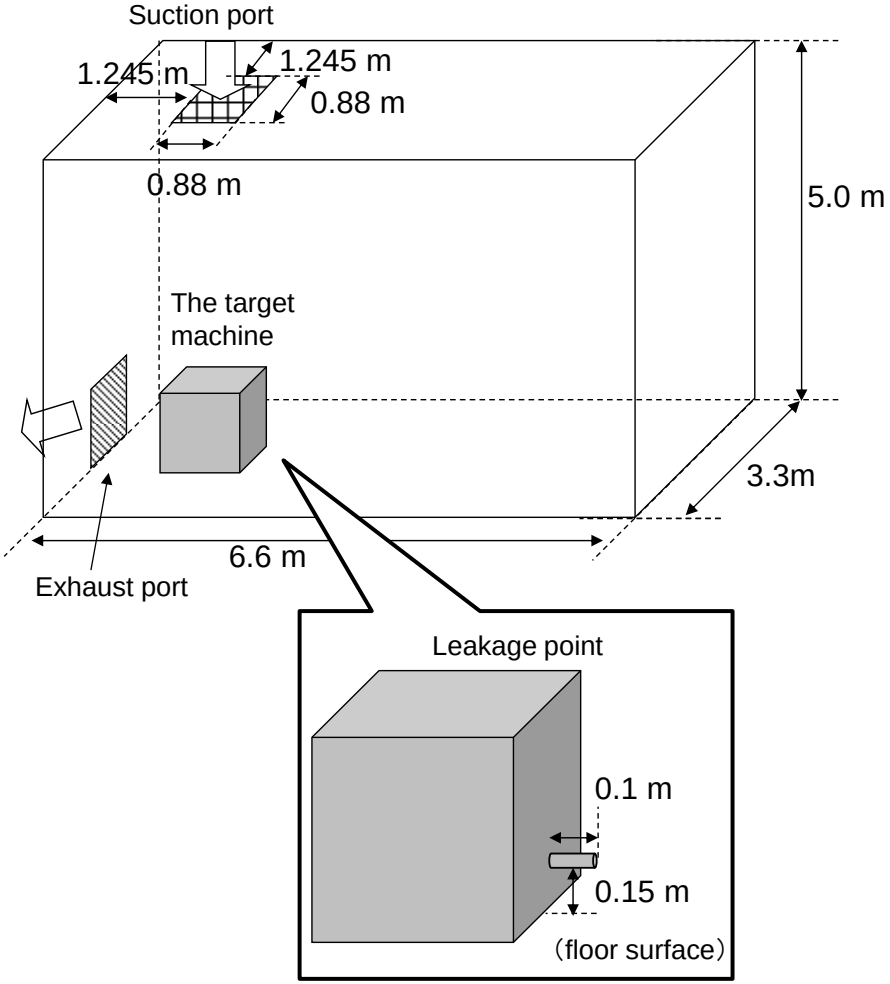
Category		Ignition soruce	Ignition	Remarks	Usage
Sparks	Electrical parts	Home appliance and a small-sized electrical product	No	5kVA or below	No
		Electrical part inside equipment	Yes	Solenoid switch with 5kVA or above	1.61x01-3
		AC power source	No	Equivalent to quenching distance	No
		Lightening switch	No	Equivalent to quenching distance	No
	Work tools	Metal sparks（fork of a forklift）	Yes	―	No
		Electrical power tool	No	Small capacity	No
		Refrigerant recovery apparatus	No	Small capacity	No
	Smoking supplies	Match	No		No
		Oil lighter	No		No
	Human body	Static electricity emitted from a human body	No	Minimum ignition energy or less	No
Open flame	Smoking supplies	Match	Yes	Ignition=open fire	4.72x10-9
		Oil lighter	Yes	Open fire once ignited	1.18x10-6
		Electric lighter	No	Lighter not ignited	
	Burning appliance	Electric radiant heater	Yes	Prohibited to use	3.30x10-6
		Electric fan heater	No	Prohibited to use	No
		Gas water heater	Yes	Prohibited to use	No
		Gas boiler（burner ）	No	No timing of ignition	No
		Ventilation duct, boiler surface	No	140℃ or below	No
		Gas cooking appliance	Yes	Prohibited to use	No
	Work tool	Burner for brazing	No	High in gas velocity	No





11. Machine room model（installation layout）

- A room with **the height of 5m and the floor area with the horizontal and longitudinal length ratio of 1:2** was assumed, in which a chiller was installed on one half of the floor area and auxiliaries were installed on the other half.
- As the maintenance space, the clearance of at least 1.2m in front of the control panel and 1.0m from other surface was assumed.
- The leakage point was assumed to be located at the height of 0.15m from the floor and the shape of the leakage point was cylindrical nozzle of 0.10m length.



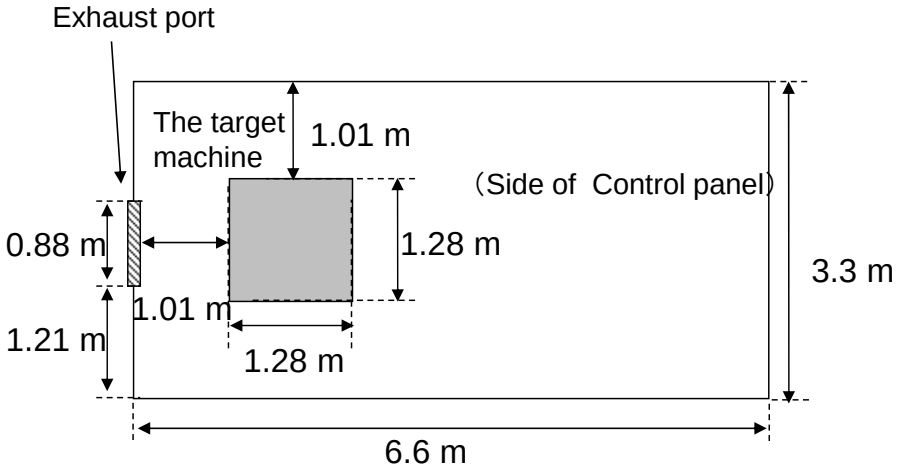


Figure 11 Machine room layout

◆ Standard specifications for risk assessment

The specification for the volume zone of each manufacture was considered as the standard specifications.

Water-cooled chiller

cooling capacity ：**Approx. 180kW**

Refrigerant charge amount ：**23.4kg**

Chiller dimension ：1.28W × 1.28D × 1.28H [m]

12. CFD Analysis result of machine room

Table 12　Unsteady state analysis result(machine room）

			Air changes [1/h]	0	2	4
Machine room volume [m³]	Refrigerant	Case of leak	Leakage rate [kg/h]	Time dependent volume [m³min]		
109	R32	Burst leak	75	0.011	0.008	0.006
		Rapid leak	10	2481	0.0004	0.0007
	R1234ze (E)	Burst leak	54	0.027	0.017	0.015
		Rapid leak	7.3	**3129**	0.001	0.0009

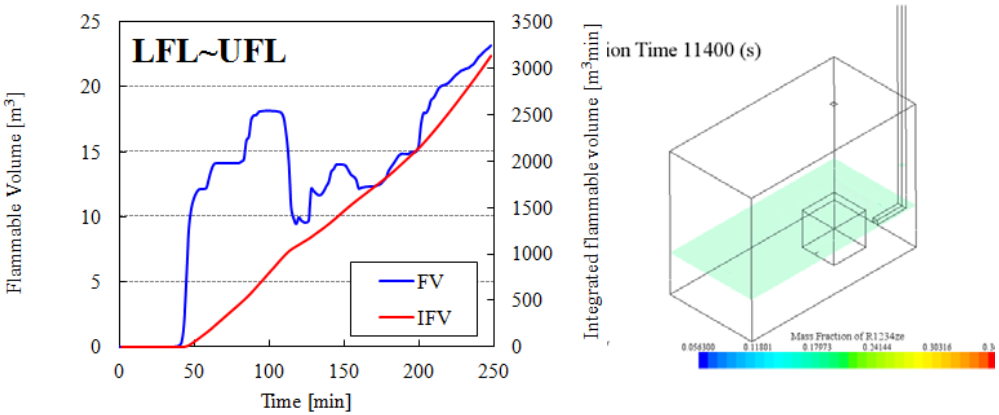


Figure 12.1　Analysis result of concentration and time dependent volume

（R1234ze(E)wet, air change:0 times, rapid leak）

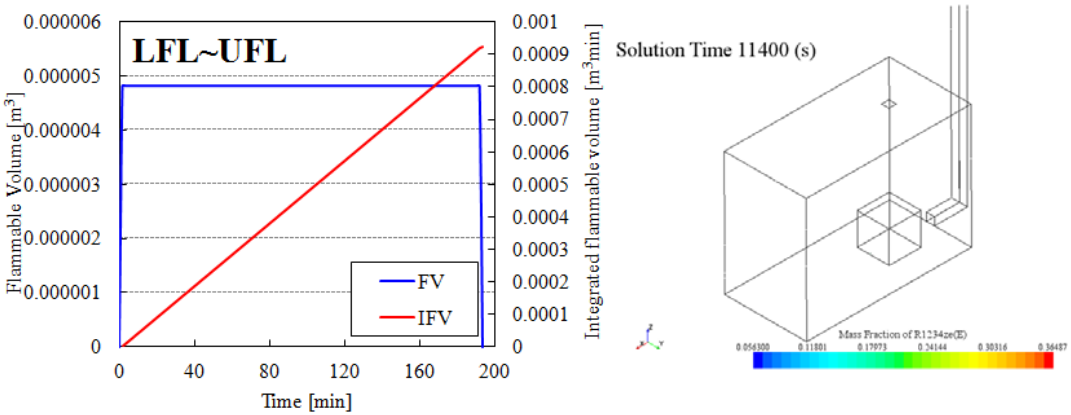


Figure 12.2　Analysis result of concentration and time dependent volume

（R1234ze(E)wet, air changes:4 times, rapid leak）

13. Air-cooled Heat Pump Model for CFD

- **An air-cooled HP** installed outdoors and lacking walls on all four sides has low chance of **forming a flammable space** compared to water-cooled chiller installed in the machine room. Based on the soundproofing installation procedure described by the manufacturer, the analysis model including four walls, two plain walls and two with an aperture of 25%, where flammable space is most possibly formed, are assumed.
- The following two refrigerant leakage points were assumed.（Figure.13.2）

Leakage point **①Leakage from the air heat exchanger of the outdoor unit**

・In the center of the front surface of the unit and at the height of 0.15m from the heat exchanger on the floor.

・Slow leak：I.D of 1mm Rapid leak：I. D. of 4mm Burst leak：I.D. Of 8mm（The diameter of the nozzle shall be the length at which the refrigerant leaks at the velocity of sound）・Leakage direction：horizontal

Leakage point **②Leakage from the unit inside the bottom panel of the outdoor unit**

・The apertures of 2m×10mm in the middle of the both side bottom panels with the longitudinal length of 3m were assumed.

・The bottom panel other than those regions were assumed hermetic. ・Leakage direction：horizontal

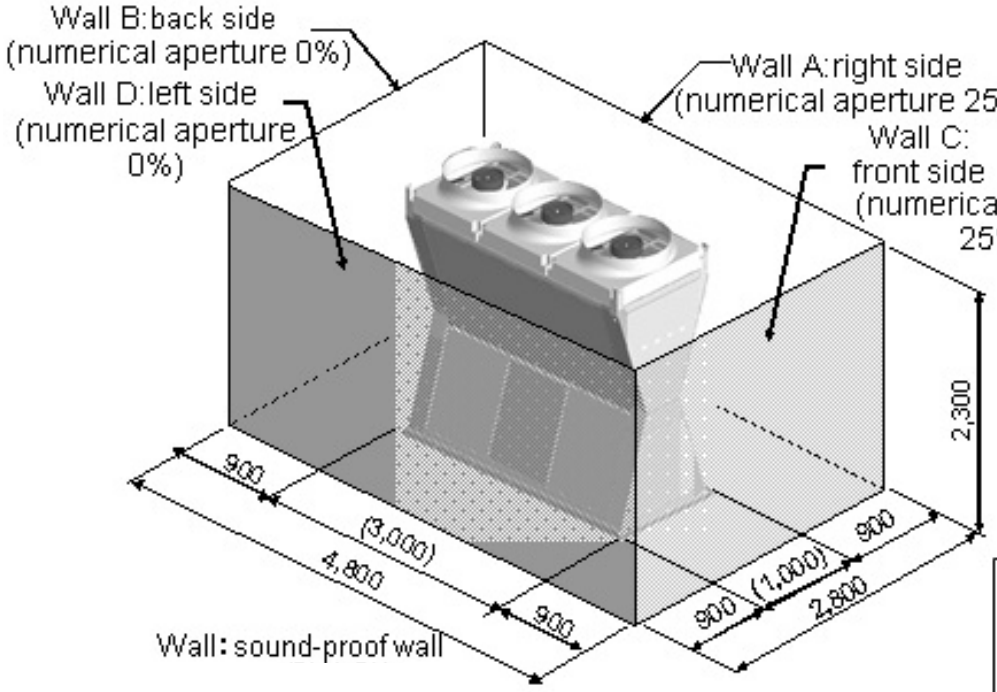


Figure 13.1 Air-cooled HP analysis model（wall aperture）

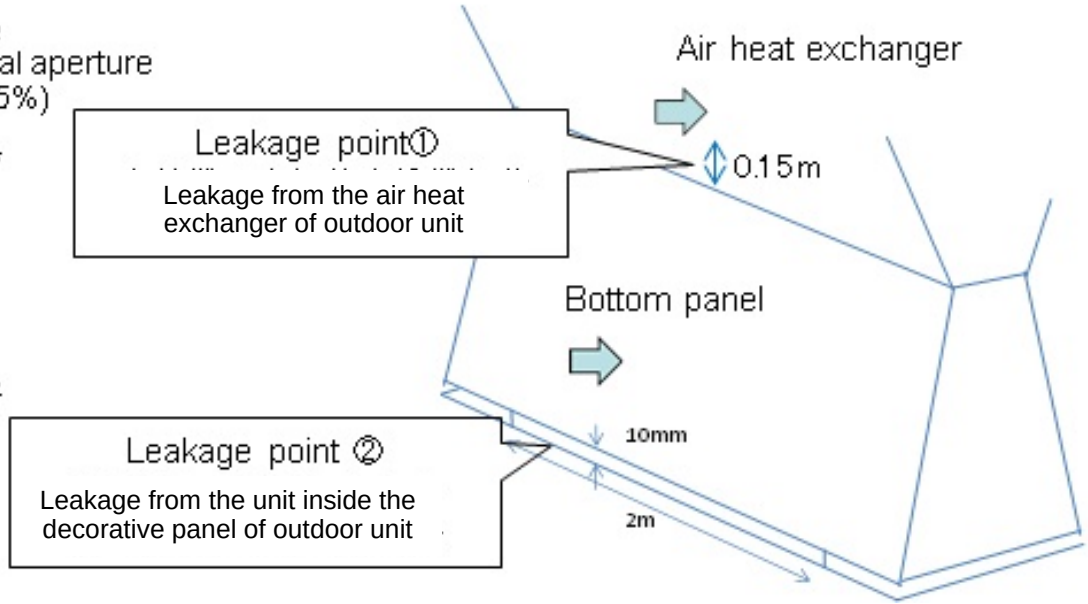


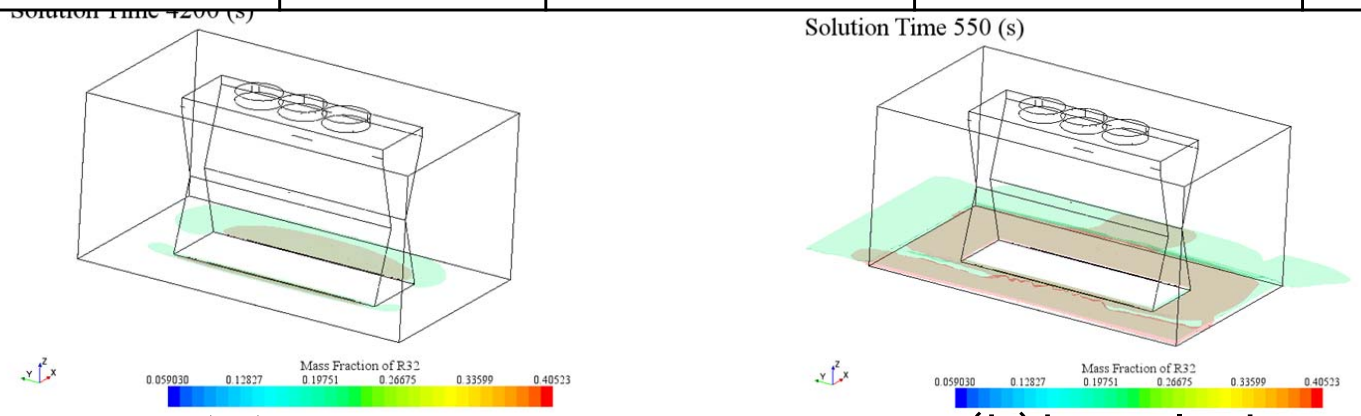
Figure13.2 Air-cooled HP analysis model（leakage point）

14. CFD Analysis result of Air cooled HP

- **In case of leakage from air heat exchanger, the flammable space is very small and** negligible.
- Meanwhile, in case of leakage from the aperture of the bottom panel , **the refrigerant accumulates in the lower region of the unit forming flammable space.**

Table 14 Unsteady state analysis result（Wind velocity 0m/s）

Unit horse power [Hp]	Leakage point	Refrigerant	Case of leak	Leakage velocity [kg/h]	Time dependent volume [m³min]
30	Air heat exchanger	R32	Rapid leak	10	0.0002
		R1234ze(E)	Rapid leak	7.3	0.0003
	Unit decorative panel lower part	R32	Rapid leak	10	3.732
			Burst leak	75	4.242
		R1234ze(E)	Rapid leak	7.3	3.989
			Burst leak	54	5.685



（a）rapid leak　　（b）burst leak

Figure 14 Concentration isosurface in case of leakage from the bottom aperture of the decorative panel（R32, wind velocity:0m/s）

15. Probability of accidental fire

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- Integrated value of the probability of ignition is calculated both for with and without ventilation.
- With ventilation, the highest probability of ignition is 10^{-12}. Therefore, it was evaluated as **"Incredible".**

Risk assessment result

Probability of ignition (times/year・units)

Life stage	Without ventilation※		With ventilation	
Ignition during logistics	4.28×10^{-6}	–	1.51×10^{-13}	–
Ignition during installation and commissioning	4.67×10^{-6}	1.32×10^{-4}	2.40×10^{-12}	3.90×10^{-12}
Ignition during usage	6.19×10^{-5}		4.97×10^{-13}	
Ignition during repair	6.52×10^{-5}		1.00×10^{-12}	
Ignition during disposal	1.72×10^{-5}	–	9.23×10^{-12}	–

Probability of occurrence

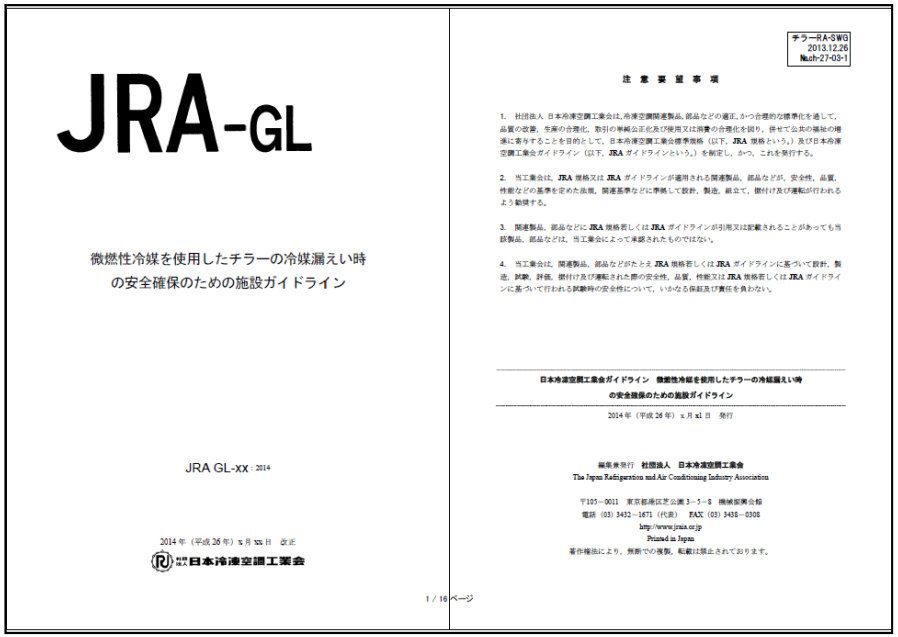
※On the assumption that the probability of flammable space is 1.（Ignition occurrs when there is an ignition source.）

Guideline basic policy

- **Since mechanical ventilation essentially guarantees safety, it is important to establish mechanical ventilation standards and mechanical ventilation installation check procedures.**

16. Measures and guidelne

1. Installation of **mechanical ventialtion**
   :2 air-changes/h × 2 lines
   with backup to guarantee ventilation effectiveness .
   Air intake from the above and exhaust from the bottom.
   Controllable from outside the machine room
2. Installation of **refrigerant leakage detection and warning device**
   Operation with independent power source such as UPS, installed in the place where refrigerant could accumulate.


JRA-GL

微燃性冷媒を使用したチラーの冷媒漏えい時の安全確保のための施設ガイドライン

JRA GL-xx : 2014

2014年（平成26年）x月xx日　改正

日本冷凍空調工業会

チラーRA-SWG
2013.12.26
No.h-27-03-1

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2014年（平成26年）x月x1日　発行

編集兼発行　社団法人　日本冷凍空調工業会
The Japan Refrigeration and Air Conditioning Industry Association

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3. Chiller **start interlock**
   Chiller will not start when **mechanical ventilation** fails or stops.
4. **Inspection**
   Compulsory inspections of **mechanical ventilation and refrigerant leakage detector** at appropriate frequency.
5. **Strict prohibition of open flame**
   Strict prohibition of smoking, open flame（cooking appliance and heaters）, hot water generator.

The results of Risk assessment for chillers,

- the probability of accidental fire and burn using the flammable refrigerant is 3.9×10^{-12} with appropriate measures.
  It is smaller than once every hundred years.

- 2-Independent mechanical ventilation lines will be required on the GL as most important countermeasure to prevent accident in the machine room

- We are going to develop JRA-GL and general overview of RA in 2015fy.

Thank you for your attention.