2.3

Overview of the Risk Assessment for VRF System

JRAIA, VRF Risk Assessment SWG

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- **Features for VRF with mildly flammable refrigerants**
- **Targets and schedule**
- **1st step Establishment of method for risk assessments**
- **2nd step Risk assessment results and proposal of safety measures**
- **3rd step Proposal of technical standards which can achieve both of safety and environments**

*) R32 among mildly flammable refrigerants is investigated in this risk assessments.

Features of VRF systems and A2L refrigerants

Features of VRF system compared with single split	Risk
➢ Large amount of refrigerant charge that can all leak into just one room	↗ up
➢ Numerous joints connecting refrigerant circuit or parts of valves, vessels and sensors	
➢ Strict check of refrigerant sealing and leaks	↘ down
➢ Highly skilled personnel for installation, repair and maintenance	
➢ A variety of system configuration, mode free type, water cooled or ice storage type, etc.	Risk should be specified
➢ Wide range capacity of outdoor and indoor units	

+

Features of A2L refrigerants compared with A2, A3	Risk
➢ Lower size of flammable space because of larger LFL	↘ down
➢ Type of ignition source is limited because of larger MIE	

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Risk is allowable ? Safety measures ?

LFL : Lower Flammable Limit
MIE : Minimum Ignition Energy

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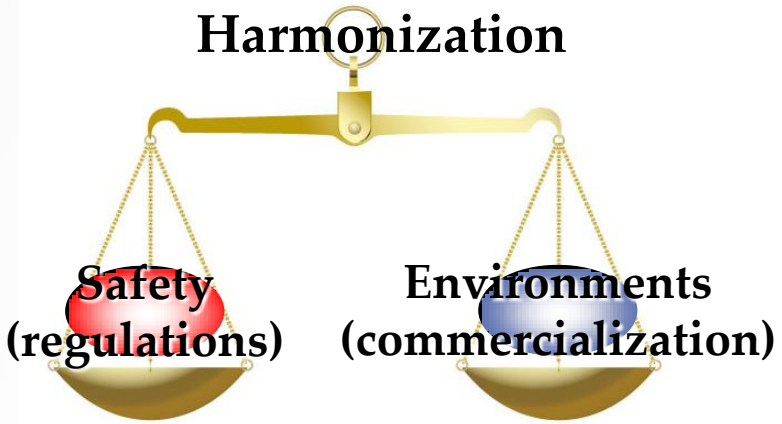
Objectives

Step	Objectives	Schedule
1st	• Establishment of method for risk assessments	′11/4 ～′12/7
2nd	• Proposal of safety measures based on the assessment results	′12/8 ～′14/9
3rd	• Proposal of technical standards which can achieve both of safety and environments	′14/10 ～′16/3



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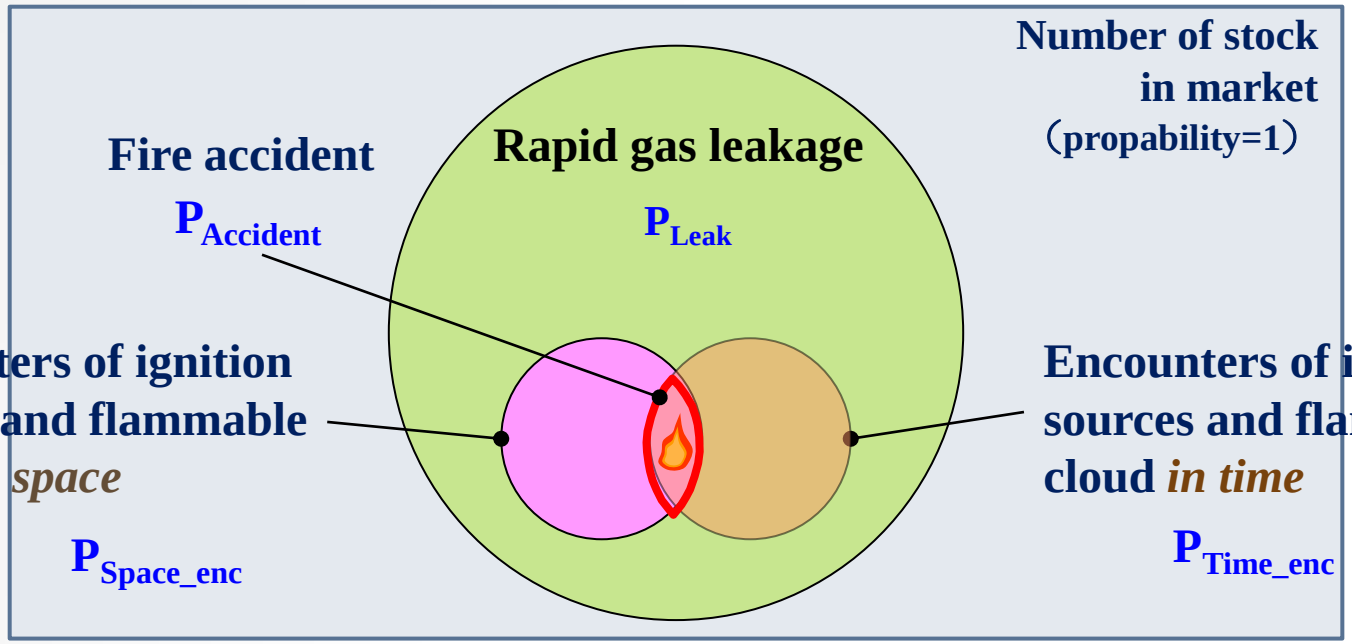
Probability of fire accidents

$$P_{Accident} = P_{Leak} \times P_{Space\_enc.} \times P_{Time\_enc.}$$

$P_{Accident}$	:	Probability of fire accident	[times/(unit・year)]
P_{Leak}	:	Probability of rapid gas leakage	[times/(unit・year)]
$P_{Space\_Enc.}$	:	Probability in space of encounters of ignition sources and flammable cloud	[-]
P_{Time_Enc}	:	Probability in time of encounters of ignition sources and flammable cloud	[-]

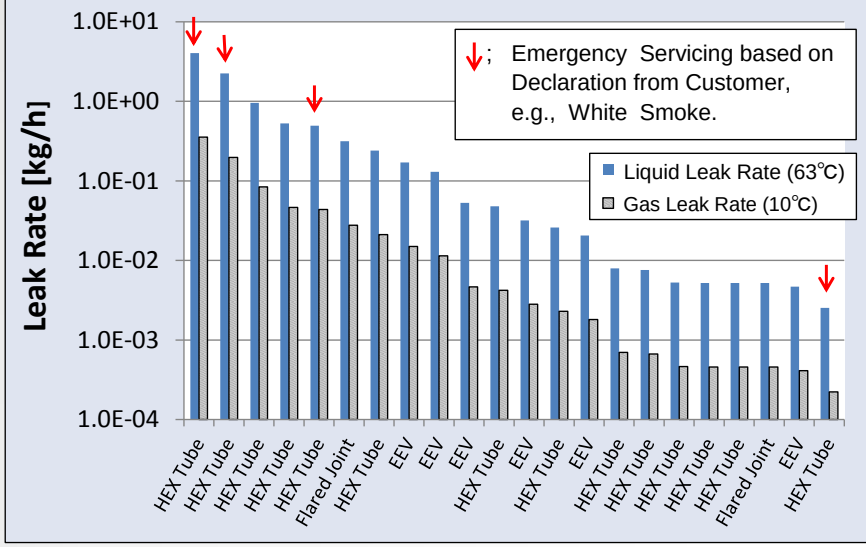


Probabilities of gas leaks

Probability of gas leaks classified by leak rates

		Total	Slow Leak ～1 [kg/h]	Rapid Leak ～10 [kg/h]	Burst Leak ～75 [kg/h]
Indoor Unit	Probability of Leak [ppm]	350	345	5	0
Outdoor Unit	Probability of Leak [ppm]	7600	6126	1338	137

Measurements of leak rate



Investigation of numbers of rapid leak

Servicing data of manufacturer B, 2010

	White Smoke	Smelled Burning	Holes in Pipe	Nrp
Indoor Unit	0	1	0	1
Outdoor Unit	1	3	3	7

Ignition Sources

Y : Ignited N : not ignited

		Ignition Source	R32	R290 (ref.)
Spark (in flammable cloud)	Electric Parts	Appliance (cause of fire)	Y	Y
		Parts in Unit	N	Y
		Power Outlet, 100V	N	Y
		Light Switch	N	Y
	Smoking Equipment	Match	Y	Y
		Oil Lighter	Y : being evaluated	Y
		Electric Gas Lighter	N	Y
	Work Tool	Metal Spark (forklift)	Y	Y
		Electric Tool	N	Y
		Recovery Machine	N	Y
	Body	Static Electricity	N	Y
Open Flame (contact with flammable cloud)	Smoking Equipment	Match	Y	Y
		Oil or Gas Lighter	Y	Y
	Combustion Equipment	Heater	Y	Y
		Water Heater	Y	Y
		Boiler	Y	Y
		Cooker	Y	Y
	Work Tool	Gas Burner	Y	Y

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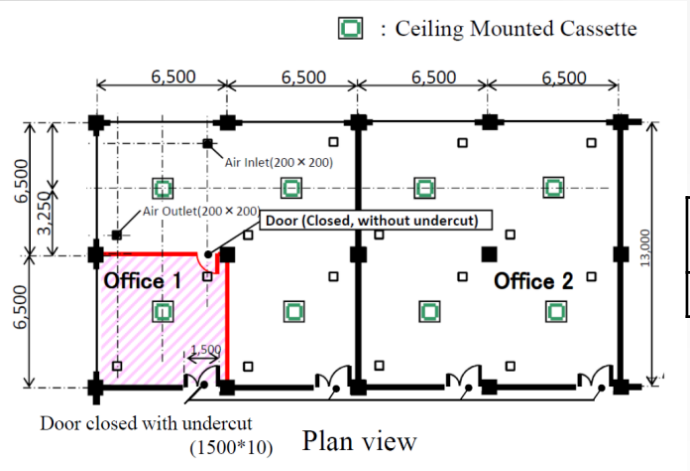
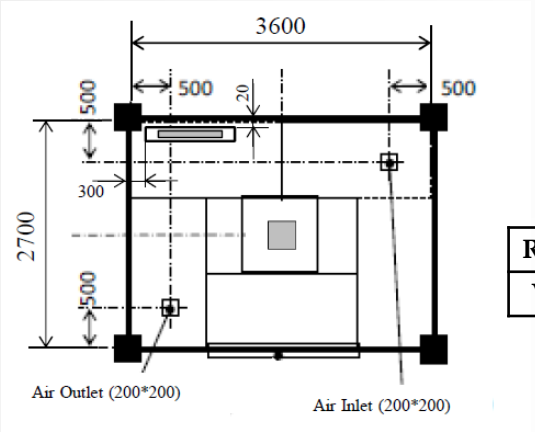
Models of indoor installations

1) Meeting room in office (Ceiling cassette type)



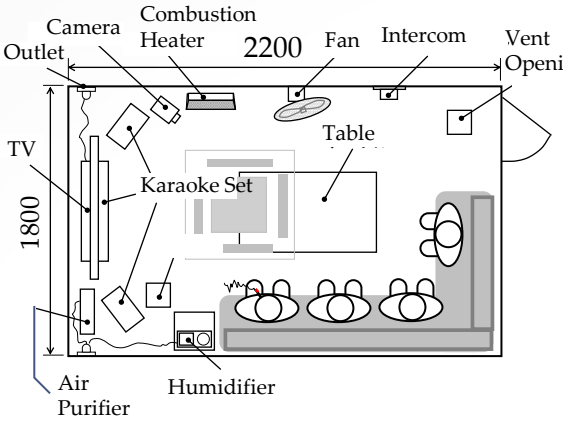
R32 [kg]	26.3 to 88.1
V [m³]	110

2) Restaurant (Floor type)



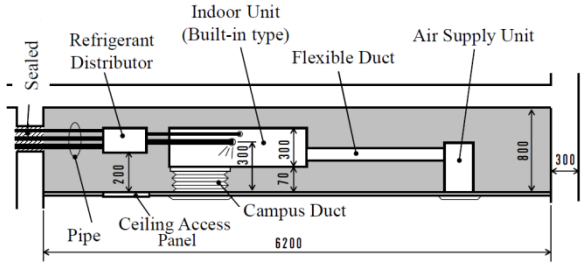
R32 [kg]	52.8
V [m³]	24.3

3) Karaoke (Ceiling cassette type)



R32 [kg]	88.1
V [m³]	9.5

4) Ceiling space (Ceiling duct type)



R32 [kg]	88.1
V [m³]	32.5

Probability of fire accident during indoor operation

In each installation cases

[time/(unit・year)]

Not allowable | Allowable

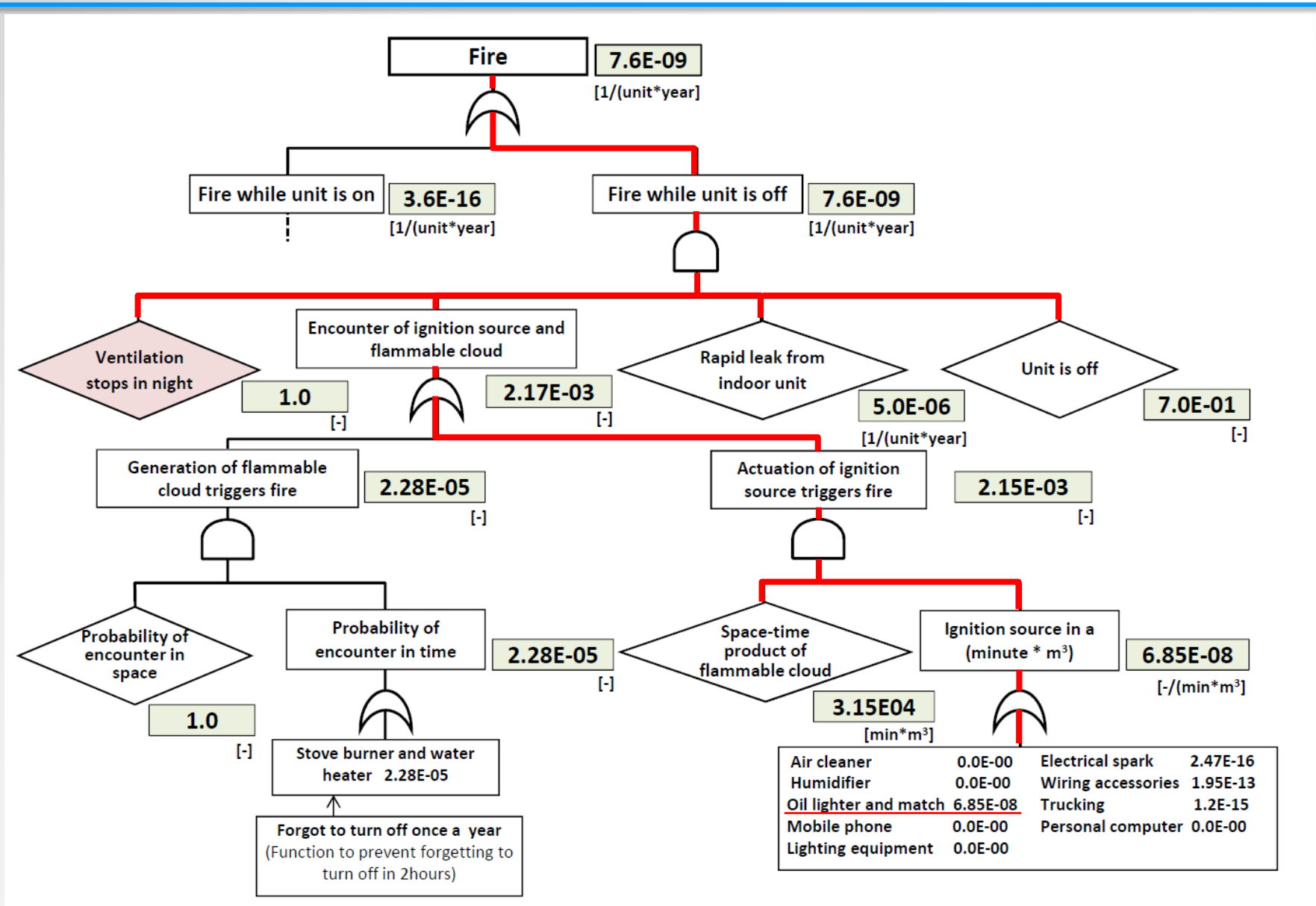
Installation case					Fire accident probability A		
					Without measures		With measures
Site		Type	Constituent ratio P	Allowable probability	No vent.	Vented *1)	
Indoor	Office	Ceiling	$3.8*10^{-1}$	$1.0*10^{-9}$	$7.6*10^{-9}$* 2)	$3.5*10^{-12}$	$3.5*10^{-12}$
	Karaoke	Ceiling	$2.1*10^{-3}$		$1.8*10^{-7}$	$4.4*10^{-11}$	0.0
	Restaurant	Floored	$2.0*10^{-2}$		$3.8*10^{-7}$	$5.4*10^{-9}$ *3)	$2.6*10^{-10}$ *4)
	Hair salon	Ceiling	$1.6*10^{-3}$		$1.3*10^{-9}$	$1.2*10^{-10}$	$6.8*10^{-12}$
	BBQ restaurant	Ceiling	$7.8*10^{-4}$		$2.8*10^{-9}$	$4.4*10^{-10}$	$1.5*10^{-11}$
	Ceiling Space In office	Duct	$3.8*10^{-1}$		$3.0*10^{-10}$	-	-

Total in market

Total＝Σ(P＊A)	$4.0*10^{-1}$	$1.0*10^{-9}$	$1.1*10^{-8}$	$1.1*10^{-10}$	$6.6*10^{-12}$

*1) Indoor ventilation according to Japanese building code
*2) Ventilation turned off 18:00 to 09:00
*3) Supply and exhaust on the ceiling surface
*4) Mechanical ventilation with a vent opening near the floor

FTA of Indoor Operation (Office, ventilation turns off at night)



Indoor safety measures by refrigerant charge ratio

Step 1 Calculation of R, refrigerant charge ratio

$$R\ [kg/m3] = \frac{M\ [kg]}{V\ [m^3]}$$

R : Refrigerant charge ratio [kg/m3]
M : Total charge amount [kg]
V : Room volume [m3]
= Floor Area [m2] * Ceiling height [m]

Step 2 Safety measurements corresponding to R

→ R values and number of measure are under consideration

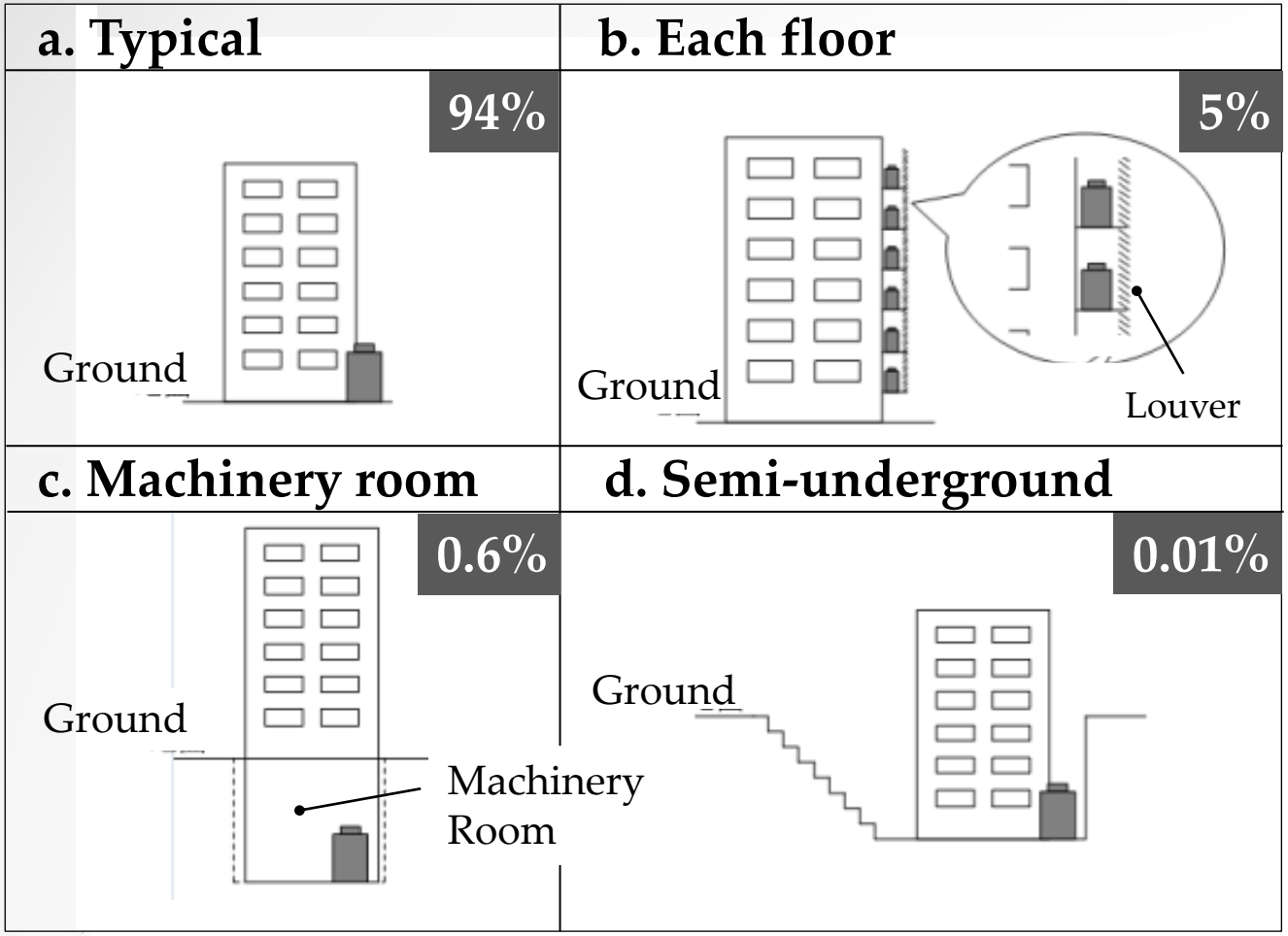
	R [kg/m3]			
	QLUV		QLMV	QLAV
	No Ventilation	Ventilation through gap	Additional ventilation	One more measure
Except ones on the lowest floor	None		1	2
The lowest underground floor *)	None	1	2	System redesigned

*) No effect of ventilation through gap

Step 3 Select safety measures among the following

1. Leak detection + Ventilation（interlocked with indoor unit）
2. Leak detection + Refrigerant shut off valve
（ interlocked with indoor unit if the valve is not placed in indoor unit)
3. Leak detection + Warning alarm
（ interlocked with indoor unit if the alarm is not placed in indoor unit)

Outdoor Installation Models



- **Charge amount : 26.3～max. 150kg**

Constituent ratios

Probability of fire accident during outdoor operation

In each installation cases

[time/(unit • year)]

Not allowable	Allowable

Installation case				Fire accident probability A		
				Without measures		With measures
Site		Constituent ratio P	Allowable probability	No vent	Vented *1)	
Out-door	Open space	$9.4*10^{-1}$	$4.0*10^{-9}$	$1.9*10^{-11}$	-	-
	Each floor	$5.0*10^{-2}$		$3.0*10^{-9}$	-	-
	Semi-underground	$1.0*10^{-4}$		$1.1*10^{-7}$	-	$2.5*10^{-13}$
	Machinery room	$6.0*10^{-3}$		$6.1*10^{-8}$	-	$3.2*10^{-9}$

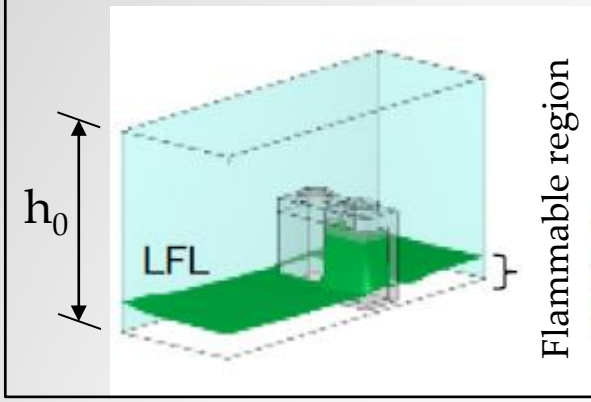
Total in market

Total＝Σ(P ∗ A)	1.0	$4.0*10^{-9}$	$5.4*10^{-10}$	-	$1.9*10^{-11}$

*1) Indoor ventilation according to Japanese building code

Safety measures for semi-underground

No ventilation

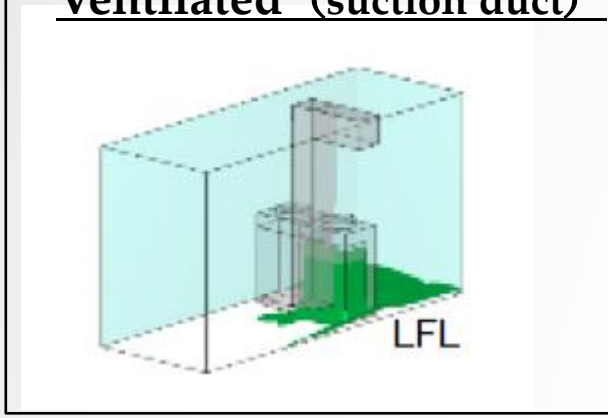


Safety measures are necessary under the following

$$M/V \div LFL \geqq -0.3 \times h_0 + 1.3$$

M	:	Charge amount	[kg]
V	:	Volume of semi-underground space	[m^3]
LFL	:	Lower flammable limit	[kg/m^3]
h_0	:	Depth of semi-underground space	[m]

Ventilated (suction duct)



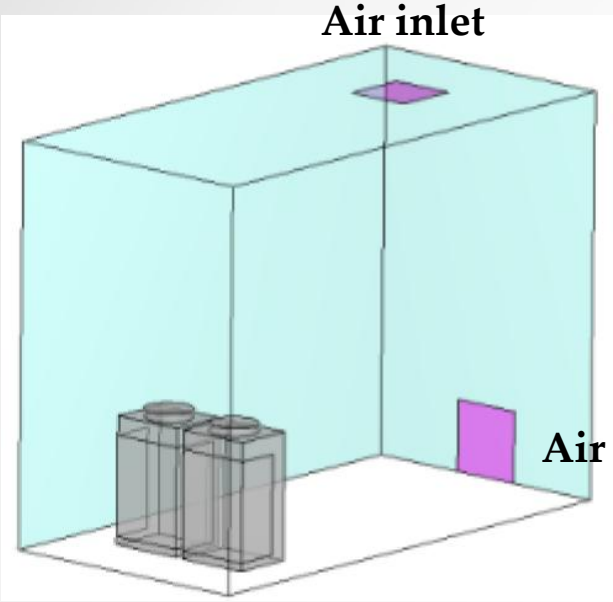
Select safety measure from the following

1. Installation of suction duct and leak detector
2. Ventilation with outdoor fan after detection of gas leak

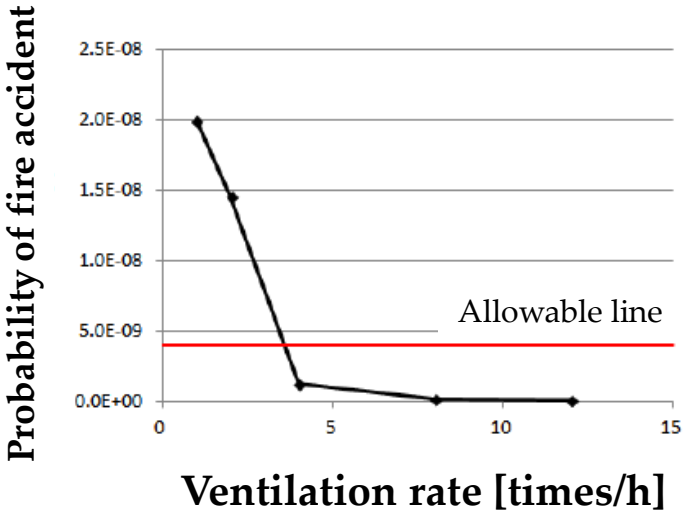
Safety measures for machinery room

Continuous mechanical ventilation, 2 times/h * 2 series
(Volume ≥ 95m3, Height ≥ 5m)

Installation case



Probability of fire accident and ventilation rate



- Size 3.3*6.6*5.0m = 109m^3 (size change evaluated)
- Leak rate = 75[kg/h], Charge amount = 150[kg]
- Failure rate = 0.025 [%/series] * 2 [series]

- Boiler and smoking tools as ignition sources

Probability of fire accident during each working

In each installation cases

[time/(unit • year)]

Not allowable | Allowable

Installation case					Fire accident probability A					
					Installation		Repairing		Disposal	
			Constitu-ent ratio P	Allowable probability	Without meas.	With meas.	Without meas.	With meas.	Without meas.	With meas.
In-door	Office	Ceiling	$3.8*10^{-1}$	$1.0*10^{-8}$	$1.9*10^{-9}$	-	$8.7*10^{-11}$	$8.8*10^{-12}$	$2.9*10^{-14}$	$2.9*10^{-15}$
	Restaurant	Floored	$2.0*10^{-2}$		$1.9*10^{-9}$	-	$1.2*10^{-8}$	$3.9*10^{-11}$	$3.4*10^{-12}$	$3.4*10^{-13}$
	Karaoke	Ceiling	$2.1*10^{-3}$		-	-	-	—	-	—
Out-door	Open space	-	$9.4*10^{-1}$		$1.9*10^{-9}$	-	$1.4*10^{-9}$	$1.4*10^{-10}$	$2.4*10^{-10}$	$3.2*10^{-11}$
	Each floor	-	$5.0*10^{-2}$		$1.9*10^{-9}$	-	$3.1*10^{-9}$	$3.1*10^{-9}$	$1.0*10^{-9}$	$1.4*10^{-10}$
	Semi-underground	-	$1.0*10^{-4}$		$1.1*10^{-8}$	$1.9*10^{-9}$	$3.6*10^{-7}$	$2.1*10^{-9}$	$3.3*10^{-8}$	$4.8*10^{-10}$
	Machinery room	-	$6.0*10^{-3}$		$1.1*10^{-8}$	$2.1*10^{-9}$	$8.6*10^{-7}$	$5.4*10^{-9}$	$2.2*10^{-8}$	$3.3*10^{-10}$

Total in market

			Without meas.	With meas.
Indoor total＝Σ(P＊A)	$4.0*10^{-1}$	$1.0*10^{-8}$	$1.0*10^{-9}$	$4.1*10^{-12}$
Outdoor total＝Σ(P＊A)	1.0	$1.0*10^{-8}$	$9.0*10^{-9}$	$3.7*10^{-10}$

Safety aspects for service personnel

1. Leak check where gas to be accumulated easily
2. How to avoid harm of ignition of gas-burner
3. Education for service people about A2L refrigerants
4. Description of cautions on service manuals

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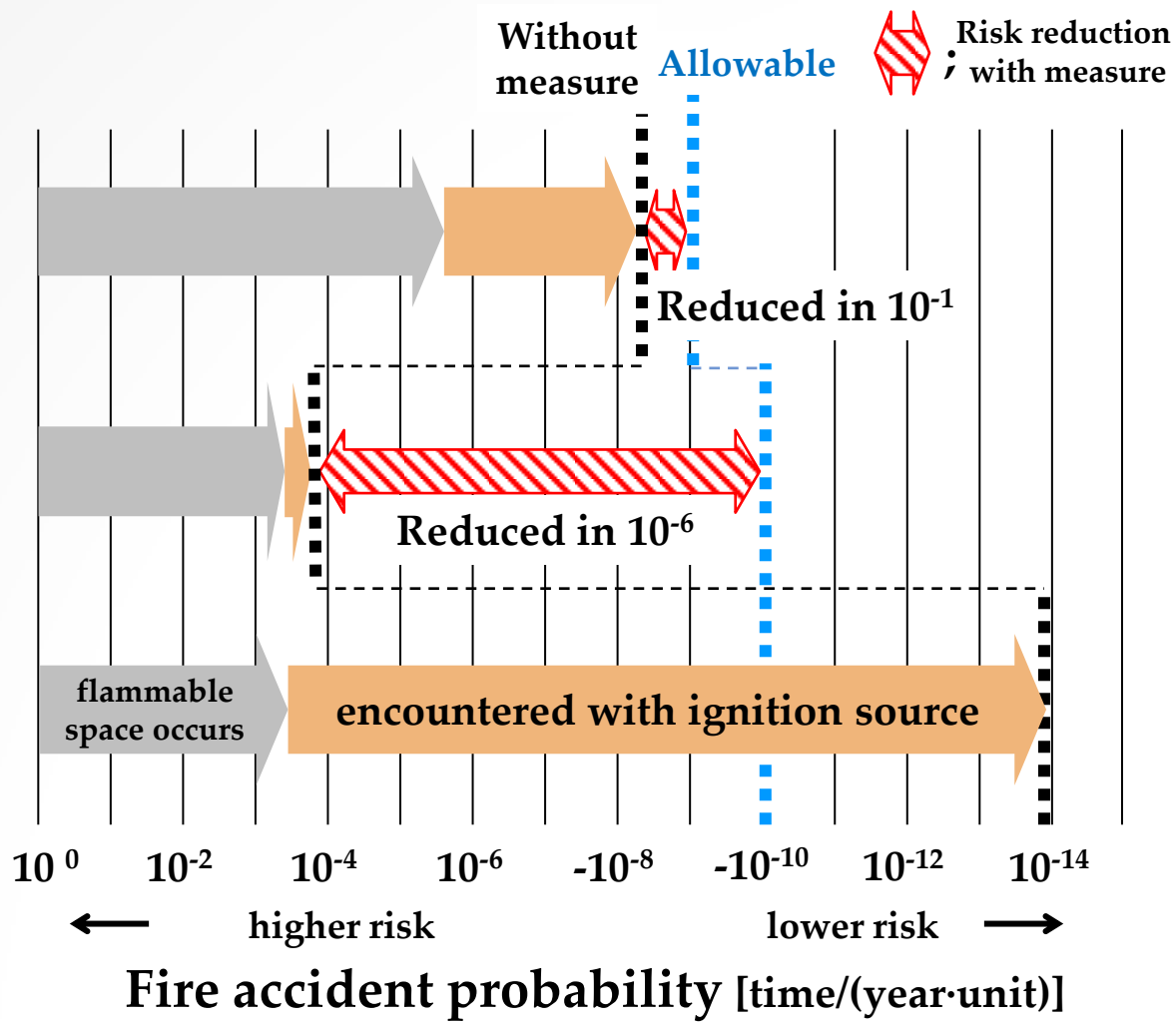
Impact on Fire accident probability

Strength of flammability and charge amount have large impact

Product	Ref.	Charge in drop-in[*1)] [kg]	Site · Vent.
VRF [*2)] (10^7 units)	R32	88.1	Office (40.3m²) · Turn off at night
Room air-con. [*3)] (10^8units)	R290[*4)]	0.5	ditto
	R32	1.0	Room (7m²) · None

*1) Drop-in to R410A model
R32 : 10[kg/h], R290 : 7.5[kg/h]
*2) Ceiling mounted
*3) Wall mounted, single
*4) Yao et al, 2000, JRAIA Kobe Symposium.
Leak rate of R290 is same as R32.



Features of regulations and standards

Appropriate regulations and standards balanced to strength of risks

Products		Flamma -bility	Charge in drop-in*1) [kg]	Risk reduction rate necessary for safety	Standard and Regulation for safety
VRF *2)	R32	mild	88.1	10^{-1}	**Industry standards** (semi-official facility standards are desirable)
Room air-con.*3)	R290*4)	strong	0.5	10^{-6}	**Legal regulations ?**
	R32	mild	1.0	-	**Voluntary installation manual**

*1) Drop-in to R410A model, R32 : 10[kg/h], R290 : 7.5[kg/h]
*2) Ceiling mounted
*3) Wall mounted, single
*4) Yao et al, 2000, JRAIA Kobe Symposium., Leak rate of R290 is same as R32.

Summary

1. **Risk assessment is performed for VRF with R32, probability of fire accidents are clarified.**

2. **Safety measurements are proposed which can reduce fire risks lower than allowable level, even under severe installation cases for VRF with R32.**

3. **Safety for VRF with R32 should be guaranteed with industry standard and semi-official facility standard (ex. KHK standards for facility).**

*) KHK : High Pressure Gas Safety Inst. of Japan

Thank you for your attention.