

# **A2L refrigerants risk assessment results and risk assessment plan for A3 refrigerant**

**July 12, 2017**

**JRAIA**

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# 1. Agenda

【1】Introduction

【2】A2L refrigerant risk assessment and the tolerable level

【3】Study for A2L refrigerant air-conditioner  
(Residential air-conditioner and  
light commercial air-conditioner)

【4】Guideline of Japan refrigeration and  
air-conditioning industry association

【5】Risk assessment plan for A3 refrigerant air-conditioner

【6】Conclusion

## 2. Agenda

【1】Introduction

【2】A2L refrigerant risk assessment and the tolerable level

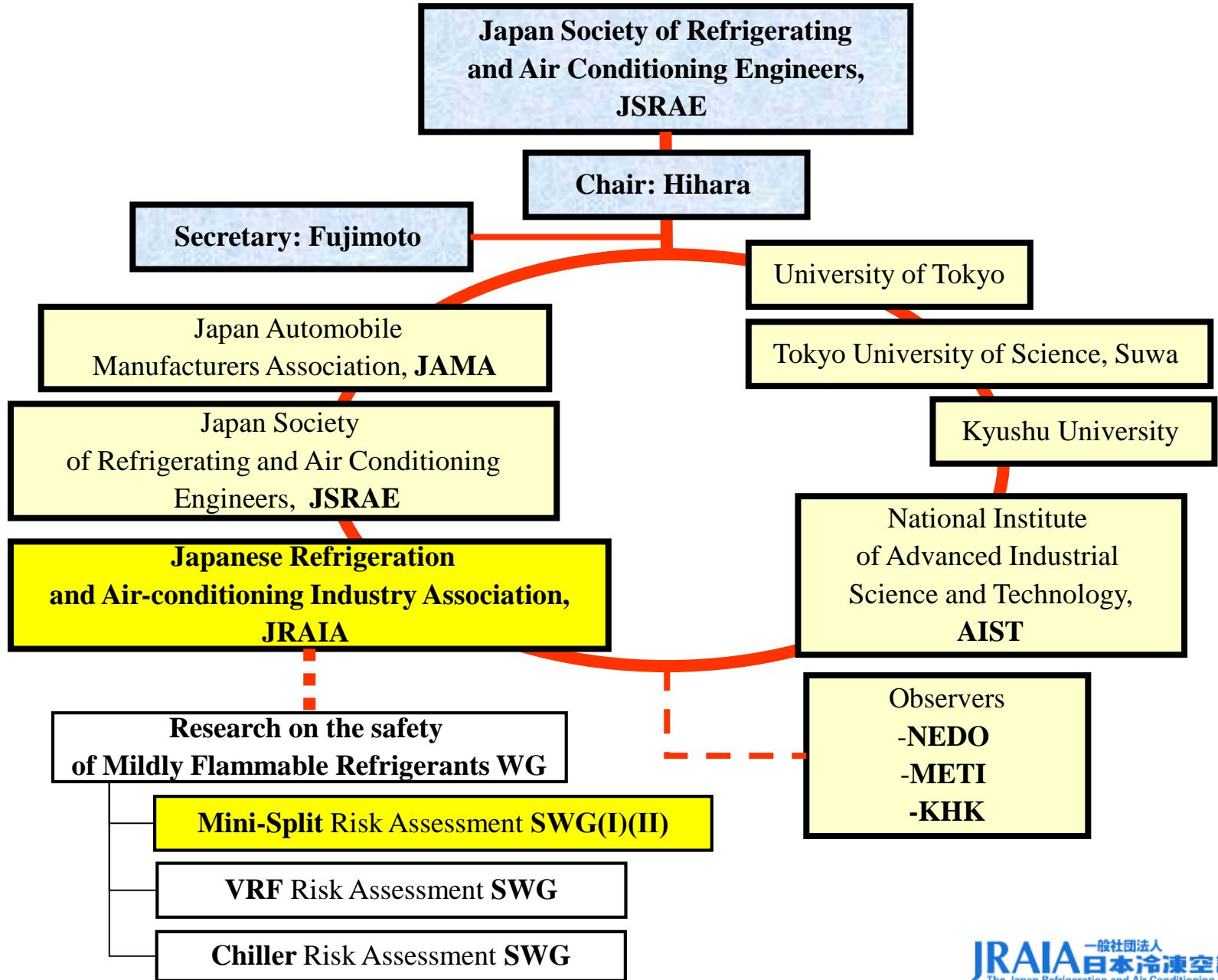
【3】Study for A2L refrigerant air-conditioner  
(Residential air-conditioner and  
light commercial air-conditioner)

【4】Guideline of Japan refrigeration and  
air-conditioning industry association

【5】Risk assessment plan for A3 refrigerant air-conditioner

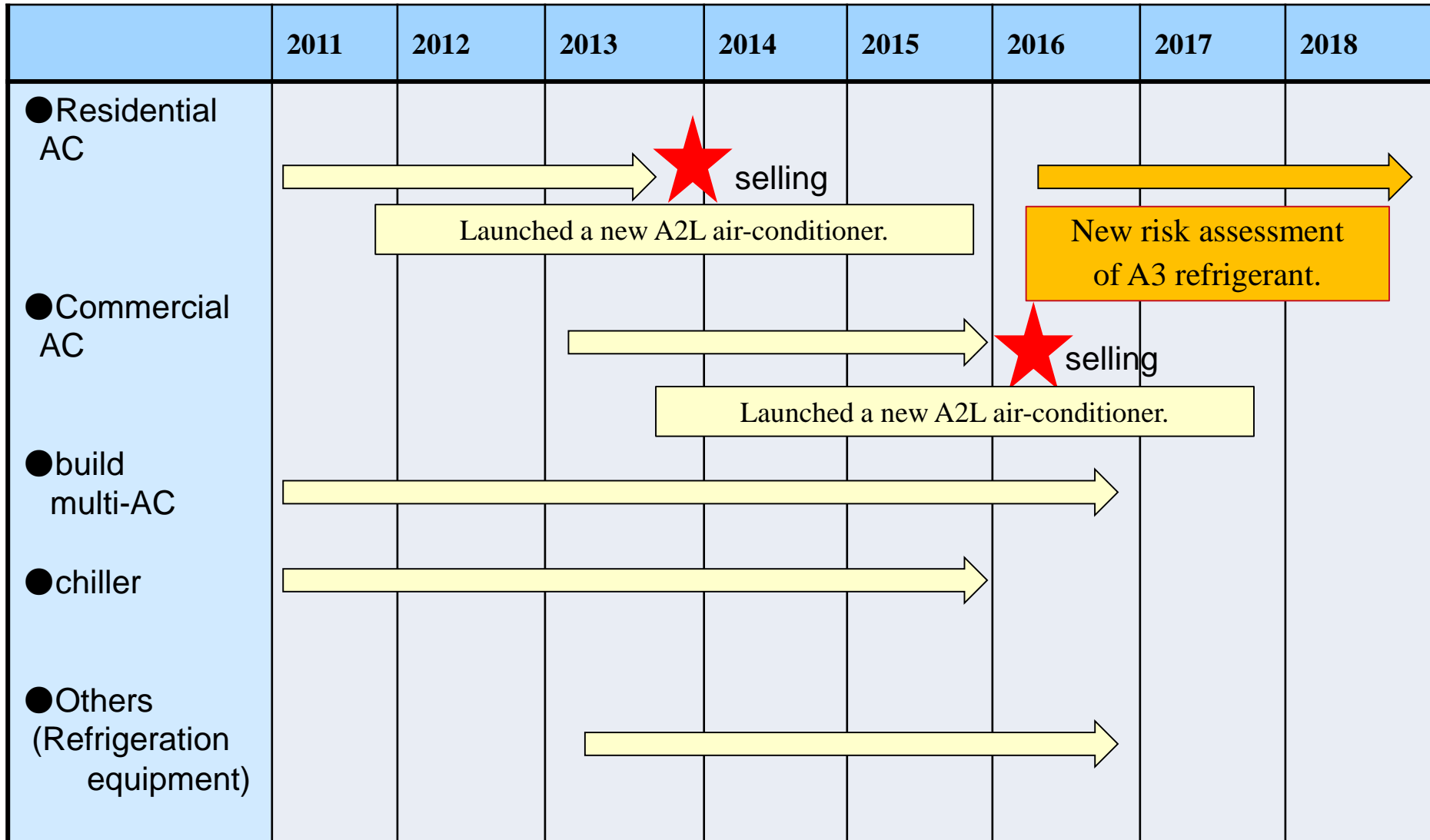
【6】Conclusion

### 3. Organization of the research committee



## 4. Schedule of Risk Assessment for AC and others

**A2L refrigerant risk assessment has difficulty and long period**



# 5. Agenda

【1】Introduction

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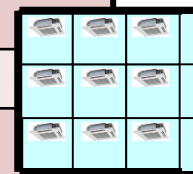
【4】Guideline of Japan refrigeration and  
air-conditioning industry association

【5】Risk assessment plan for A3 refrigerant air-conditioner

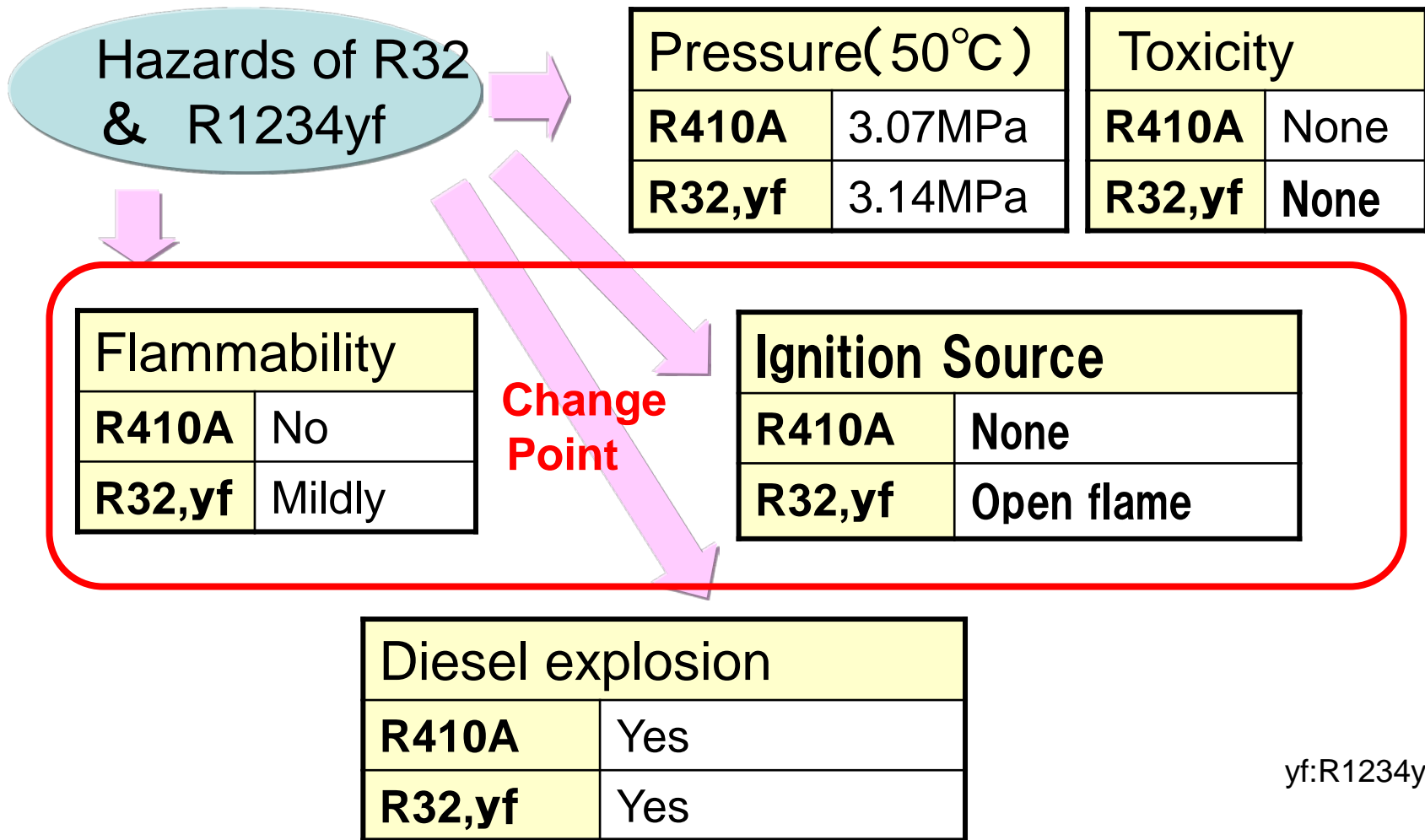
【6】Conclusion

## 6. Features of different Air-conditioners

Product	Residential AC	Commercial package AC	VRF
Cooling Capacity	2.2-8 kW	3.6-30 kW	14-168kW
Refrigerant Charge	1-4kg	2-19 kg	5-100 kg
Installation Outdoor : Indoor	1:1(-5) (Indoor: multi rooms)	1:1(-4) (Indoor: <u>single room</u> )	1-3:1-64 (Indoor : <u>multi rooms</u> )
Type of indoor unit	Wall mounted Floor mounted Ceiling cassette	Wall mounted Ceiling cassette Ducted <u>Floor mounted</u>	Wall mounted Ceiling cassette Ducted Floor mounted
Type of outdoor unit	Air-cooling	<u>Air-cooling</u> Ice-storage	Air-cooling Ice-storage Water-cooling
Indoor install location	residence	Office Kitchen/Dining room Factory Karaoke room (Tightness)	Office Kitchen/Dining room Factory Karaoke room (Tightness)
Outdoor install location	Ground Balcony	Ground Each floor <u>Semi-underground</u> <u>Narrow space</u>	Ground Each floor Semi-underground Machinery room
Storage	Bulk storage warehouse Narrow warehouse	Bulk storage warehouse Narrow warehouse	Bulk storage warehouse
Logistics	Truck Mini-van	Truck Mini-van	Truck



# 7. Hazards of R32 and R1234yf ; A2L

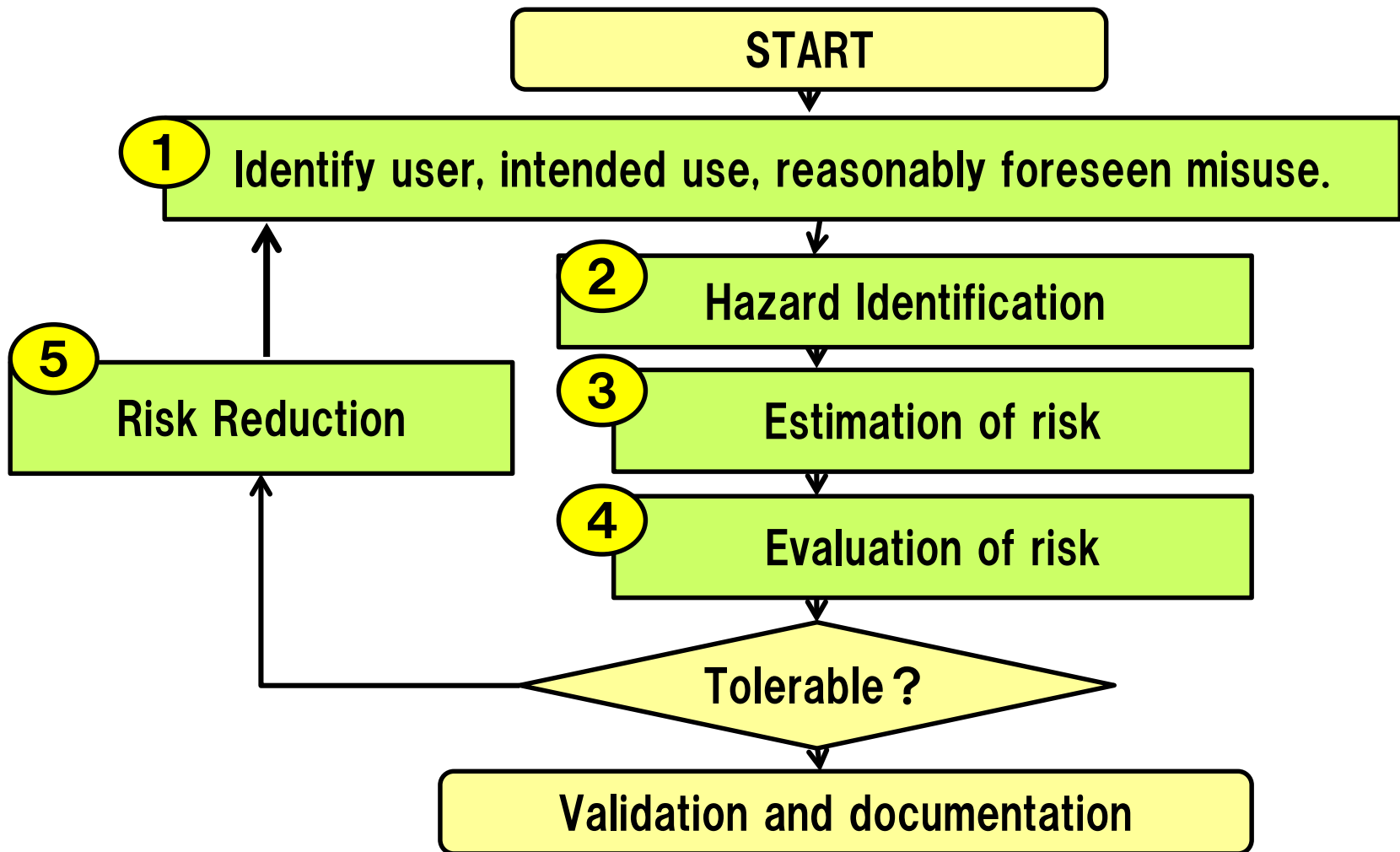


- Flammability and ignition source are studied in changing to R32 and R1234yf
- Diesel explosion and contact flame study for R32 and R1234yf are performed universities and AIST don't change the study result with R410A



## 8. Procedure of risk evaluation in ISO/IEC guide 51

JRAIA has been conducting the risk assessment in accordance with ISO/IEC guide 51.



## 9. Start : Identify the tolerable risk

### Guide 51 ;

#### ◆ Safety means ;

Freedom from risk which is not tolerable.

#### ◆ Tolerable risk ;

Accepted in a given context based on the current values of society.

### Examples of the current values in Japan

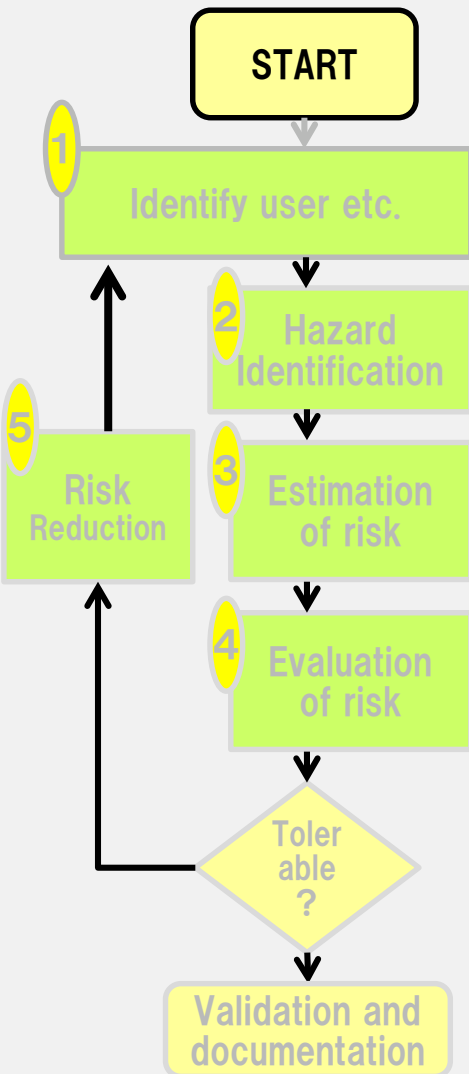
1. Chemical factory :  $10^{-5}$  [accidents/(year\*site)]

2. Car :  $10^{-7}$  [accidents/(year\*unit)]

3. Home appliance :  $10^{-8}$  [accidents/(year\*unit)]

for one million units in the market

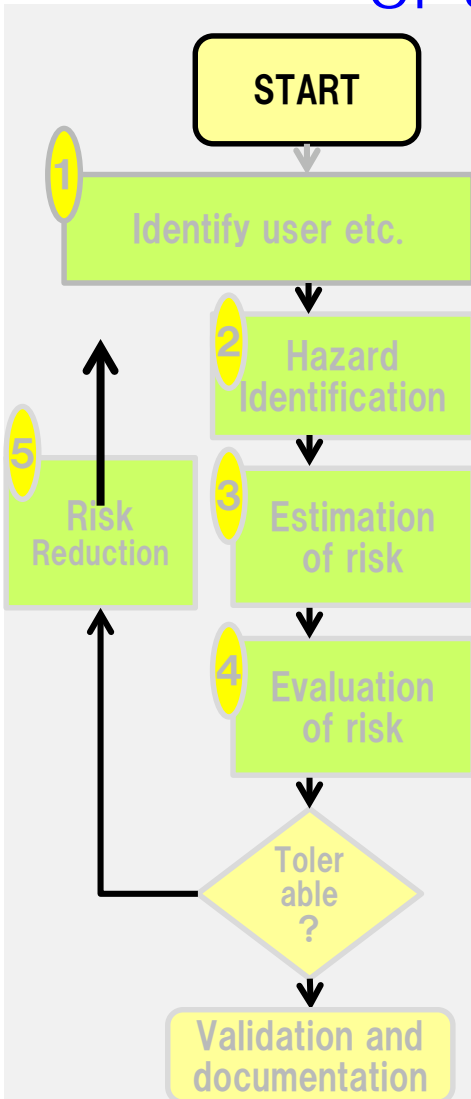
**JRAIA decided the accident less than once per century would be tolerable for use.**



# 10. Start : Identify the tolerable risk

Tolerable value is dependent on the number of units in the market for each products

The tolerable value was increased by 10 times because they are handled by trained professionals except when use.



Product/ System	No. of units in market	Tolerable value	
		Use	Install,service etc.
Residential A/C	$1 \times 10^8$	$1.0 \times 10^{-10}$	$1.0 \times 10^{-9}$
Commercial A/C	$7.8 \times 10^6$	$1.3 \times 10^{-9}$	$1.3 \times 10^{-8}$
VRF	$1 \times 10^7$	$1.0 \times 10^{-9}$	$1.0 \times 10^{-8}$
Chiller	$1.34 \times 10^5$	$7.5 \times 10^{-7}$	$7.5 \times 10^{-7}$
GHP	$4.5 \times 10^5$	$3.7 \times 10^{-9}$	$3.7 \times 10^{-8}$
Display cabinet	$4.9 \times 10^5$	$2.0 \times 10^{-8}$	$2.0 \times 10^{-7}$
Condensing unit	$1.46 \times 10^5$	$6.9 \times 10^{-8}$	$6.9 \times 10^{-7}$

The tolerable value was increased in chillers

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# 12. Probability of presence of ignition source ; A2L

## Comparison of the probability of the presence of ignition sources for air-conditioners

Ignition source [Units]		Office	Kitchen	
Spark [times/m <sup>3</sup> min]	Indoor Unit	$5.7 \times 10^{-16}$	$4.5 \times 10^{-16}$	P=installed units × accident rate/numbers on market/space volume/(365 × 24 × 60) Fire accident rate: 3 times/year (NITE), numbers on market: 88.4 mil. units
	Air Cleaner	$7.0 \times 10^{-16}$	-	Installed: 0.2 units/room, accident rate: 3.6/year, numbers on site: 17.3 mil
	Humidifier	$5.6 \times 10^{-16}$	-	Installed: 0.09 units, accident rate: 3/year, numbers on site: 8.11 mil
	Mobile	$7.6 \times 10^{-16}$	-	Installed: 8.12, accident rate: 23/17 years (LT10year), numbers: 23.9 mil.
	PC	$1.2 \times 10^{-14}$	-	Installed: 8.12, accident rate: 174/17 years (LT10year), numbers on site: 11.8 mil
	Light	$1.3 \times 10^{-15}$	$1.6 \times 10^{-15}$	Installed: 10/15, accident rate: 227/17 years (LT10year), numbers on site: 165 mil
	Tracking	$6.7 \times 10^{-16}$	$1.1 \times 10^{-15}$	Installed: 10/15, accident rate: 202/17 years (LT10year), numbers on site: 298 mil
	Refrigerator	-	$1.6 \times 10^{-14}$	Installed: 0/3, accident rate: 267/17 years (LT10year), numbers on site: 3.88 mil
	Freezer	-	$3.8 \times 10^{-15}$	Installed: 0/2, accident rate: 16/17 years (LT10year), numbers on site: 0.658 mil
	Dishwashers	-	$9.7 \times 10^{-15}$	Installed: 0/2, accident rate: 71/17 years (LT10year), numbers on site: 1.511 mil
	Phone	-	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
	TV	-	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
	Exhaust Fan	-	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
	Smoking Equipment (Match/Oil lighter)	-	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
	Ignition Equipment (Match/Oil lighter)	-	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
Open flame [-]	Combustion equipment	Water Heater	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
		Heater	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
		Kitchen Burner	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
		Gas Rice Cooker	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
		Gas Oven	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
		Coffee Siphon	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
		Gas Burner	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil
		Gas Roaster	-	Installed: 1.04, accident rate: 10/17 years (LT10year), numbers on site: 5.67 mil

- Sparks
  - Appliance (cause of fire), match, oil lighter and metal spark by forklift are ignition sources.
  - Static electricity by human body, electric gas lighter and electric parts in unit (less than 5 kVA) aren't ignition sources.
- Open flame
  - Open flame brought into the space where leaked refrigerant exists are regarded as ignition sources. Oil lighter, candle, gas burner for blazing and etc.
  - Combustion equipment like fan heater aren't ignition sources.

Ignition Source [Units]		
Spark [times/m <sup>3</sup> min]	Outdoor Unit	
	Smoking Equipment (Match/Oil lighter)	Worker
User		
Open flame [-]	Smoking	Worker
		User
	Boiler	

# 13. Risk assessment ; A2L

## ●examination of ignition source

### ●From study of R32

- ⇒Mildly flammable refrigerant in a room air-conditioner leaked in the space, but no flame propagation across the whole space
- ⇒Ignition was observed at the outlet of piezo lighter, but no flame propagation of lighter to *n*-butane/mildly flammable refrigerant mixture
- ⇒Under 3mm of clearances in case cover, mildly flammable refrigerant no flame propagation through clearances

Ignition source	R410;A1	R32;A2L
●Open flame (Blazing torch, Oil lighter, Candle)	No ignition	Rare ignition
●Electric spark	No ignition	Rare ignition
●Static electricity	No ignition	No ignition

# 14. Human error

## ● Probability of human error in Install and service stages and etc. of ACs

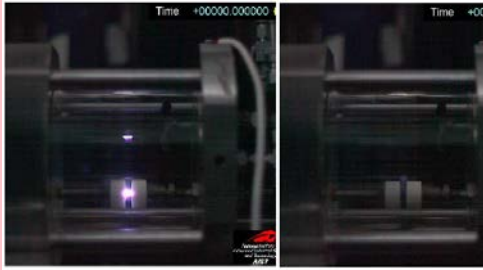
Phase	Mode of conciuosness	Physiological state	Probability
0	Unconscious, Syncope	Sleeping	1
I	Blurring	Weary, Snoozing	> 1/10
II	Normal, Relaxed	at rest, Usual working	1/100 to 1/10000
III	Normal, Clear	Active state	< 1/100000
IV	Excited	in a hurry, panic	> 1/10

## ● JRAIA adopts 1/1000

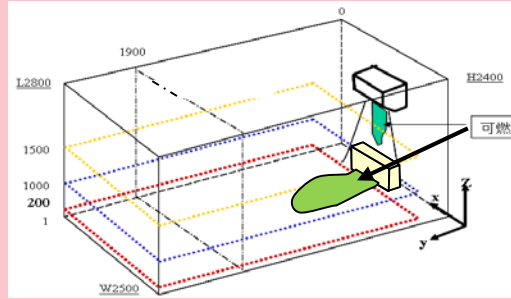
Reference : Hashimoto, K., “Human safety engineering”,  
Central Association of Work Accident Protection, (1984), pp85-97 (in Japanese)

# 15. FTA for all knowledge and experimental results

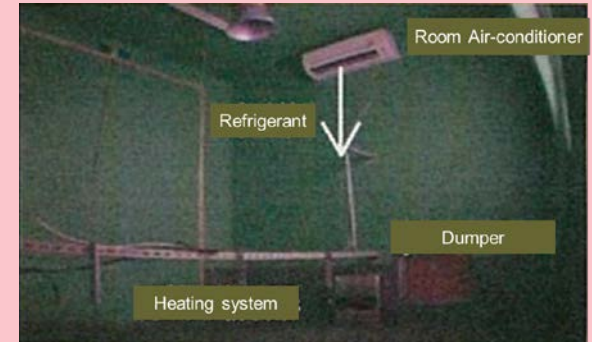
● Ignition energy & flame quenching



● Flammable gas region



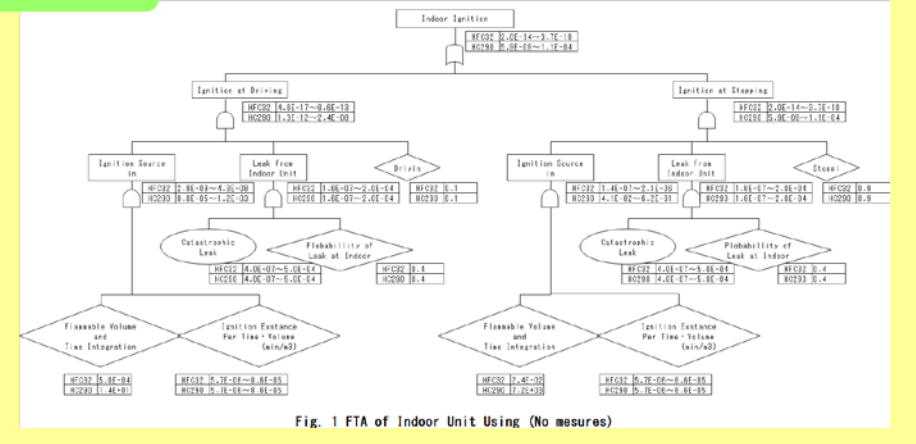
● Ignition of fossil-fuel appliance



● Human error

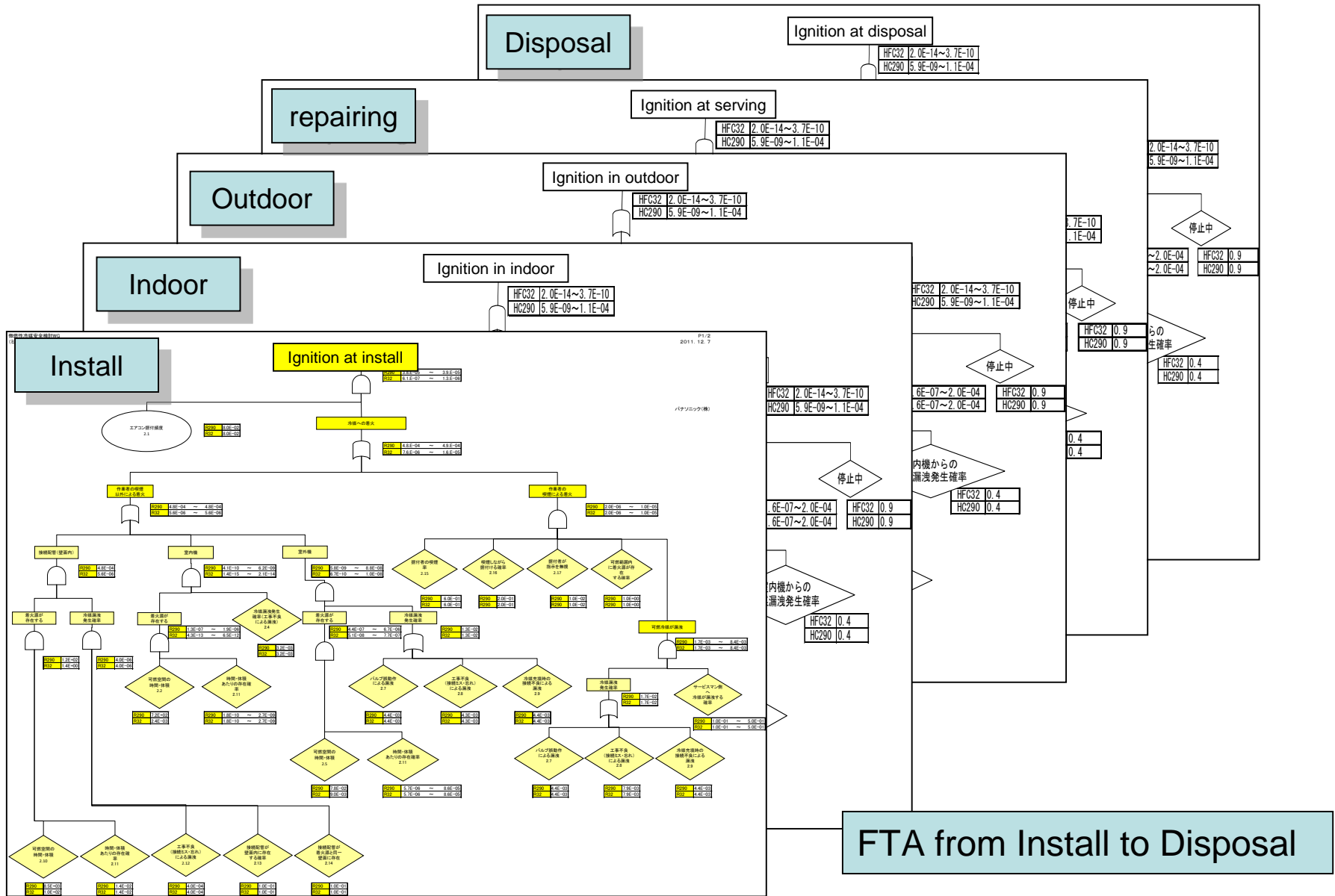
Phase	Mode of consciousness	Physiological state	Probability
0	Unconscious, Syncope	Sleeping	1
I	Blurring	Weary, Snoozing at rest, Usual working	> 1E-1
II	Normal, Relaxed	Active state	1E-2 to 1E-4
III	Normal, Clear	in a hurry, panic	< 1E-5
IV	Excited		> 1E-1

FTA





# 16. FTA of life cycle stage



FTA from Install to Disposal

## 17. Results of risk assessment ; A2L

### Wall mount type air conditioner

Risk: Ignition Probability		
	R32	R1234yf
<b>Logistic</b>	$4.1 \times 10^{-17}$	$4.5 \times 10^{-17}$
<b>Installation</b>	$2.7 \times 10^{-10}$	$3.1 \times 10^{-10}$
<b>Use (Indoor)</b>	$3.9 \times 10^{-15}$	$4.3 \times 10^{-15}$
<b>(Outdoor)</b>	$1.5 \times 10^{-10}$	$2.1 \times 10^{-10}$
<b>Service</b>	$3.2 \times 10^{-10}$	$3.6 \times 10^{-10}$
<b>Disposal</b>	$3.6 \times 10^{-11}$	$5.3 \times 10^{-11}$

- Probability of indoor use is lower than tolerable level  $10^{-10}$ .
- tolerable level  $10^{-9}$  in service, installation and others is satisfied in all stages.

- The ignition probability of R32 and R1234yf is nearly same.  
(Attention : R1234yf is extended flammable range in high humidity condition.)

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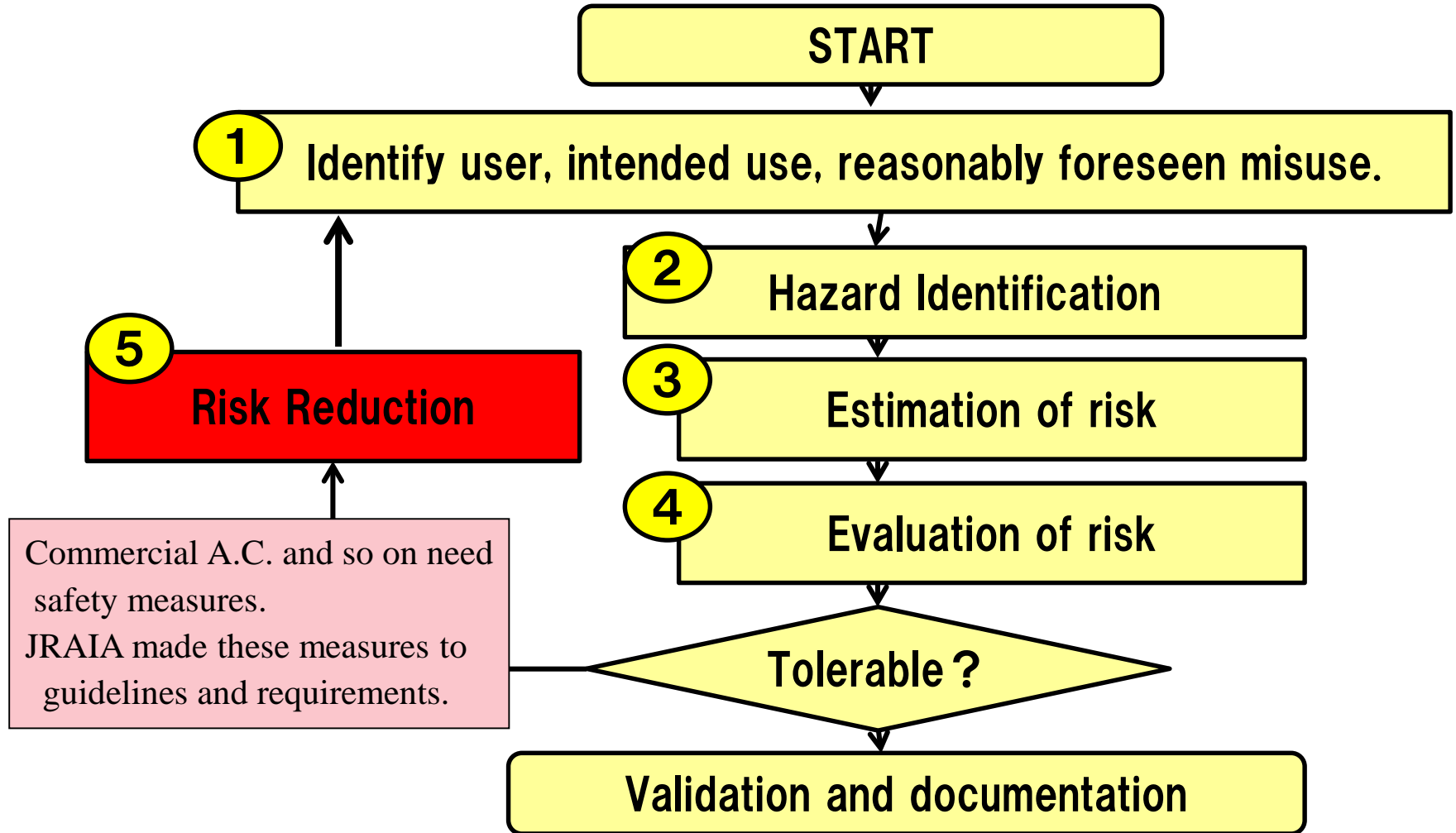
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# Procedure of risk evaluation in ISO/IEC guide51

JRAIA has been conducting the risk reduction  
by measures and regulations



## 20. The result of commercial air-conditioner risk assessment ; A2L

### The dominant risk factors and safety measures for step

Dominant risk factors		Usage stage	Installation/ Service stages	Disposal stage
Floor-mounted indoor units	Factor	Leakage gas	Leakage gas	Human error
	Item	Air circulation/ Ventilation	High concentration	Gas burner (brazing)
	Safety measures	<b>“Unit’s fan operating with a leak detector” (Min air flow: 10m<sup>3</sup>/min and minimum speed: 1.0m/s)</b>		<b>“Education for workers” and “Carrying a portable leak detector”</b>
Outdoors  Semi-underground (Depth ≥ 1.2 m)	Factor	Leakage gas	Presence of ignition sources	Human error
	Item	Air circulation/ Ventilation	Boiler	Refrigerant recovery Gas burner (brazing)
	Safety measures	<b>If refrigerant amount &gt; 1/2 x LFL x 1.2, “Unit’s fan operating with a leak detector (Air flow rate ≥ 4.0[m/s], Depth ≤ 2m and distance from discharge grille ≤ 3m), or “Mechanical ventilation”</b>		<b>“Education for workers” and “Carrying a portable leak detector”</b>
Outdoors  Narrow space	Factor	Leakage gas	Presence of ignition sources	Human error
	Item	Air circulation/ Opening	Boiler	Refrigerant recovery Gas burner (brazing)
	Safety measures	<b>“Opening of 0.6 m or more for one side”</b>		<b>“Education for workers” and “Carrying a portable leak detector”</b>

Commercial A.C. needs safety measures.

JRAIA made these measures to Guidelines and requirements.

# 21. Guideline and Requirements of JRAIA

No.	Std. GL.	Title	Application
1	JRA GL-20	Appropriate measures to prevent combustion against refrigerant gas leakage from the refrigerant charged equipment using particular inert gas	General
2	JRA 4068	Requirements of refrigerant leak detector and alarm for air conditioning and refrigeration equipment	Leak detector and alarm
3	JRA GL-15	Guideline of design construction for ensuring safety against refrigerant leakage from chiller using lower flammability(A2L) refrigerants”	Chiller 7.5kW~
4	JRA 4070	Requirements for ensuring safety against refrigerant leakage from commercial air conditioners using lower flammability(A2L) refrigerant	Commercial A.C. 3~20t
5	JRA GL-16	Guideline of design construction for ensuring safety against refrigerant leakage from commercial air conditioners using lower flammability(A2L) refrigerants	

## 22. Guideline and Requirements of JRAIA

No.	Std. GL.	Title	Application
6	JRA 4072	Requirements for ensuring safety against refrigerant leakage from commercial refrigeration equipment using lower flammability(A2L) refrigerants	commercial refrigeration equipment
7	JRA GL-18	Guideline of design construction for ensuring safety against refrigerant leakage from commercial refrigeration equipment using lower flammability(A2L) refrigerants	
8	JRA 4073	Requirements for ensuring safety against refrigerant leakage from commercial packaged air conditioner for facilities using lower flammability(A2L) refrigerants	commercial packaged A.C for facilities
9	JRA GL-19	Guideline of design construction for ensuring safety against refrigerant leakage from commercial packaged air conditioner for facilities using lower flammability(A2L) refrigerants	

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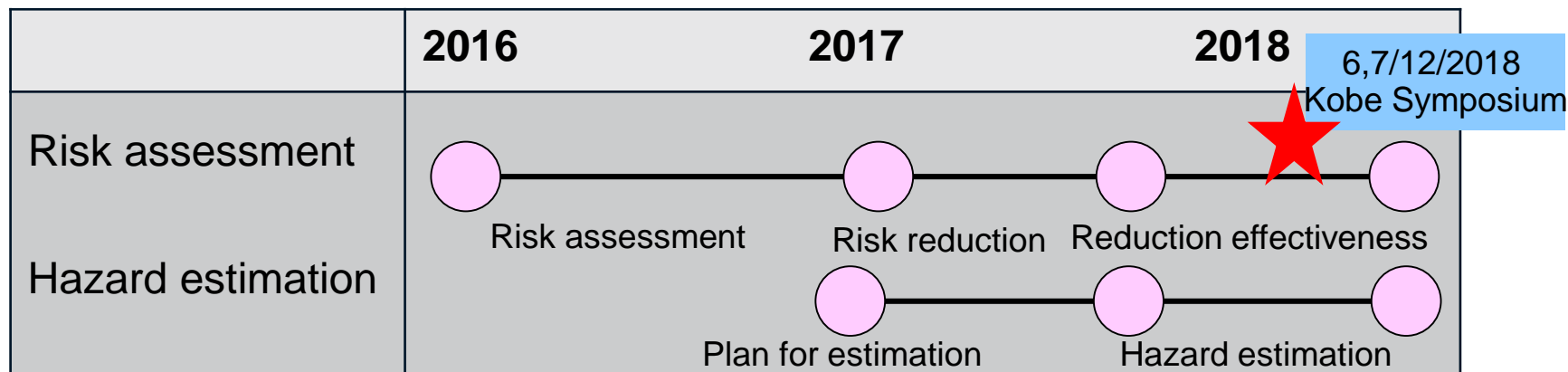
# 24. Direction and Schedule ; A3 refrigerant

## ■ Direction

- In the trend of deregulation of A3 refrigerants, JRAIA will propose air-conditioner be secured.
- Based on RAC's risk assessment method and results for A2L refrigerant , JRAIA also conducts risk assessment for A3 refrigerant and recommended measures to ensure safety from the evaluated result.
- JRAIA collaborates with universities and research institutions to compare the hazards to the refrigerant of A2L and A3 refrigerants.

## ■ Schedule

- First year ; A3 refrigerant risk assessment and countermeasure
- Second half year ; Estimation method and make plan for estimation
- Last year ; Practical estimation for risk assessment.



# 25. Probability of presence of ignition source ; A3

Ignition Source [Units]		Ground	Each Floor	Semi-Underground	Narrow Space		
Spark [times/ m <sup>3</sup> min]	Outdoor Unit	$1.4 \times 10^{-14}$	$9.5 \times 10^{-14}$	$2.5 \times 10^{-14}$	$9.1 \times 10^{-14}$	$P = 5.6/7,800,000/\text{space volume}/(365 \times 24 \times 60)$ Fire accident rate: 5.6times/year, numbers:7.8mil. units	
	Smoking Equipment (Match/Oil lighter)	Worker	$3.6 \times 10^{-10}$	$1.3 \times 10^{-9}$	$1.7 \times 10^{-9}$	$1.7 \times 10^{-9}$	[Worker] $P = \text{Smoking space rate} \times \text{service rate} \times 0.322 \times 16 / \text{space volume} / (24 \times 60) \times 0.05[\text{spark}] \times 0.01$ Smoking rate near unit: G: 0.2, EF:0.1, SU/NS: 0.5 Service rate: 0.1 Smoking rate for workers: 0.322(Japanese Male:JT) Smoking numbers for workers: 16/day (Japan) Use rate for match/oil lighter: 0.05 Rule disregarding rate during work: 0.01
		User	$5.6 \times 10^{-10}$				
Open flame [-]	Smoking	Worker	$6.0 \times 10^{-10}$				
		User	$9.3 \times 10^{-10}$				
	Boiler	$6.6 \times 10^{-4}$	$2.2 \times 10^{-4}$	$2.2 \times 10^{-4}$	$2.2 \times 10^{-4}$	$P = \text{Use rate} \times \text{Installed rate}$ Installed rate: 0.1% Use rate...Ground: 0.66(24h/day, 20days/month) Others: 0.22(8h/day, 20days/month)	

● Open flame  
 • All open flame are ignition sources  
 Oil lighter, candle etc.  
 • Open flame brought into the space where leaked refrigerant exists are regarded as ignition sources.

## 26. Ignition source ; A3

### ● Ignition source for A3 refrigerant

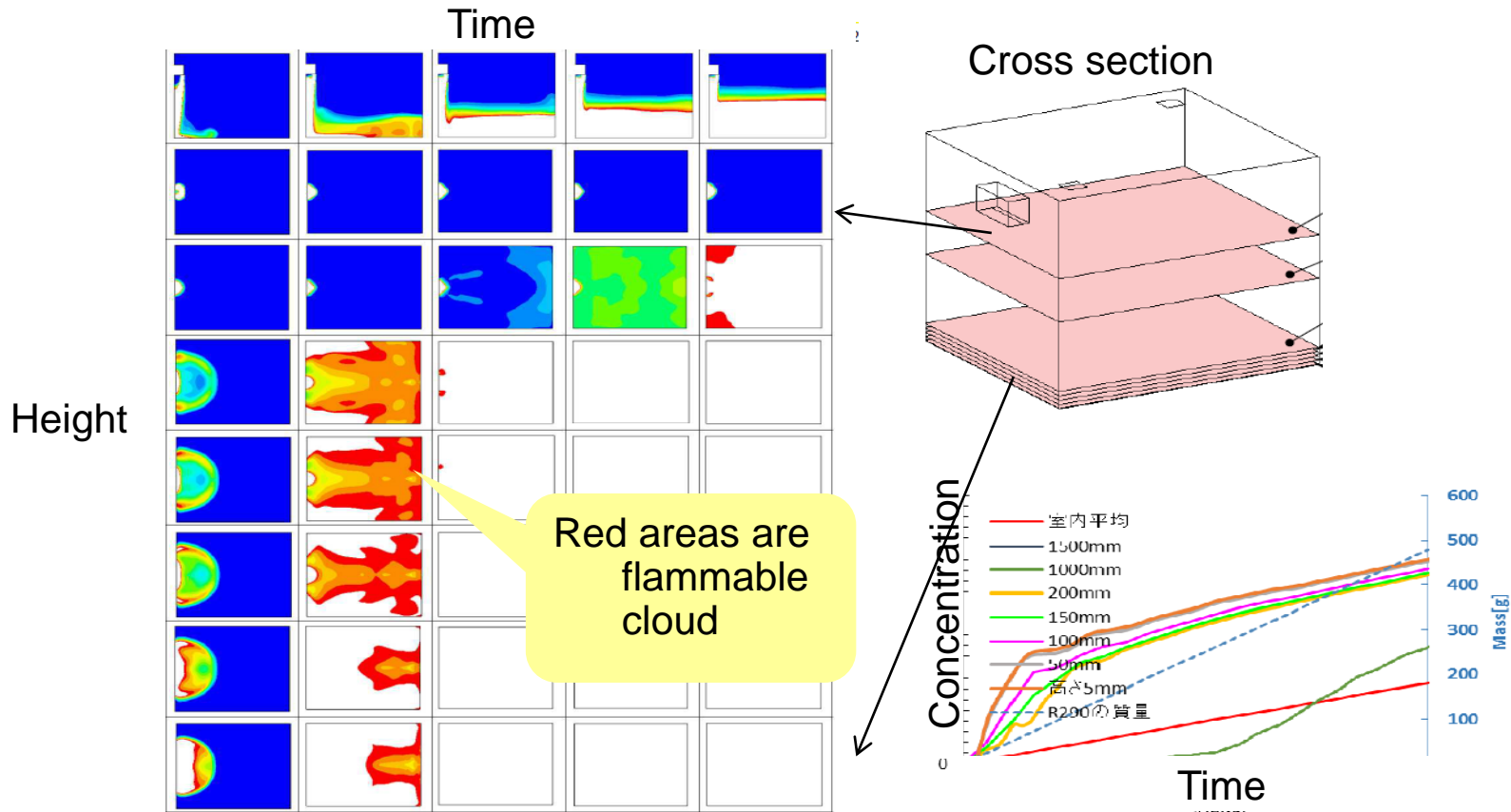
Ignition source	R410;A1	R32;A2L	R290;A3 (Propane)
● Open flame (Blazing torch, Oil lighter, Candle)	No ignition	Rare ignition	Ignition
● Electric spark	No ignition	Rare ignition	Ignition
● Static electricity	No ignition	No ignition	Occasional Ignition

# 27. Leak simulation ; A3 refrigerant

## Generation of Flammable cloud near the floor (Red area)

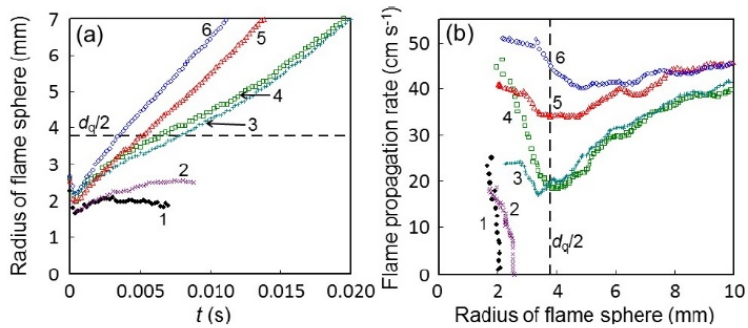
● CFD results

● Condition : refrigerant amount 500g, leakage speed 125g/min

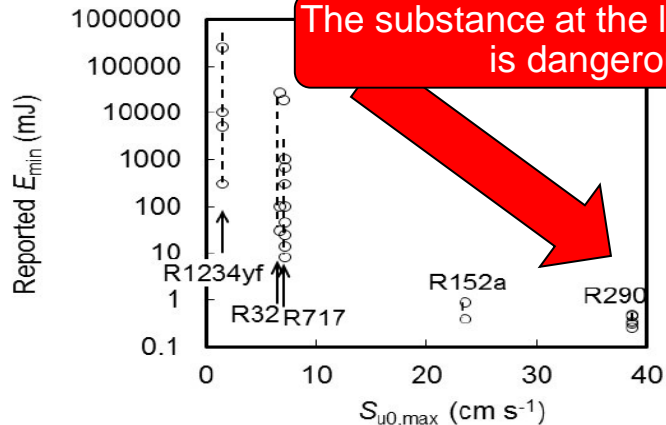


# 28. Ignition and extinction property ; A3

## 1. Ignition property



### Flame generation speed

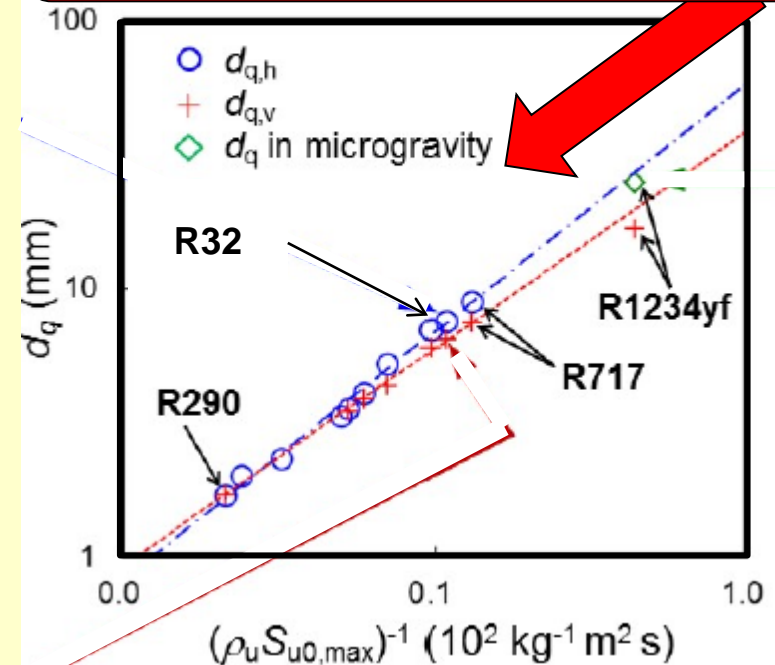


The substance at the lower right is dangerous.

### Minimum ignition energy

## 2. Quenching distance and mass burning rate

The substance at the lower left of the graph has characteristics that it easily ignites and burns violently.



### Quenching distance and mass burning rate

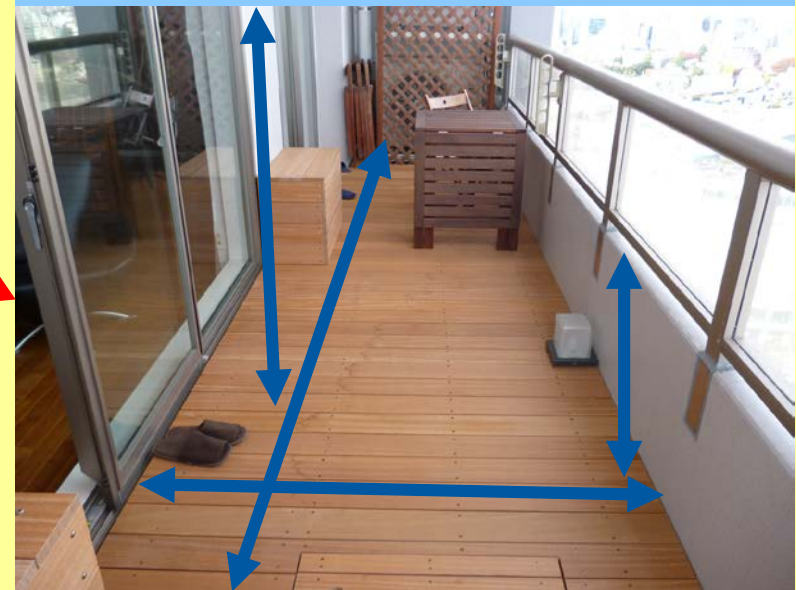
# 29. Real leakage ignition study ; A3

- Balcony is few ignition sources but A3 flammable refrigerant leaks make serious accidents

Collective apartment

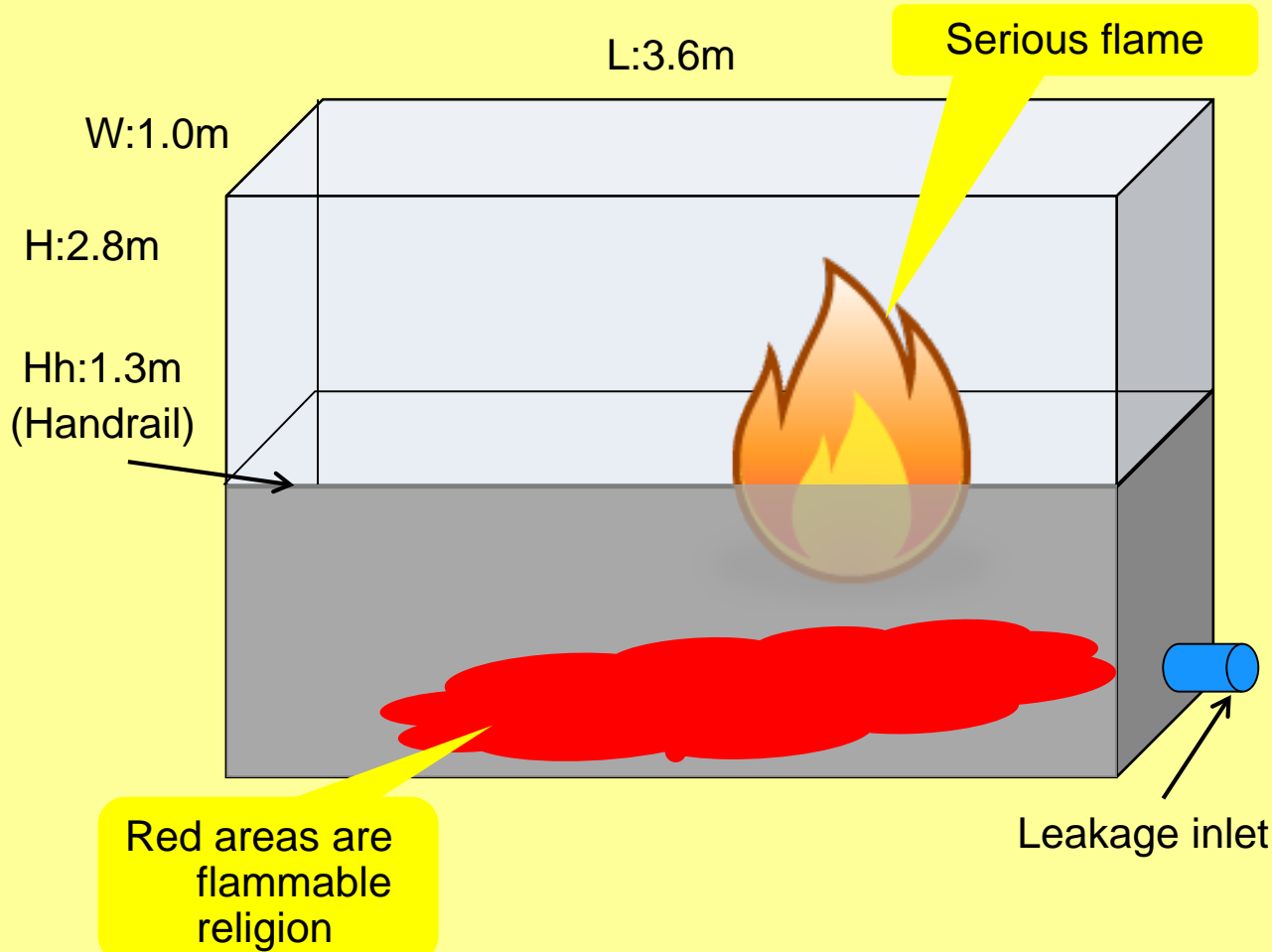


Real balcony



# 30. Real leakage ignition study ; A3

- Balcony is few ignition sources but A3 flammable refrigerant leaks make serious accidents



Real model balcony  
By Infrared camera  
High temp flame is white



# 31. RA Step for A3 refrigerant

## Establishment for safety specification of A3 refrigerant

Step	Terms
① Evaluated product	<ul style="list-style-type: none"><li>• Setting of evaluated product and usage condition</li><li>• Making the risk scenario</li><li>• Manufacturing, Transportation, Install, Use, serves, recycle</li></ul>
② Risk assessment	<ul style="list-style-type: none"><li>◎ Basic items of risk estimation<ul style="list-style-type: none"><li>• Installation case (leaky space model setting)</li><li>• Refrigerant leak rate and leak speed</li><li>• Ignition source existence probability ← Identification the ignition source</li><li>• Flammable cloud ← CFD, simplified calculation</li></ul></li></ul>
③ Measures	<ul style="list-style-type: none"><li>• Equipment measures: Air circulation and ventilation fan, shutoff valve, alarm</li><li>• Document correspondence: Instruction manual, warning display</li><li>• Regulatory compliance: regulations, industrial association manual</li></ul>
④ In market (Regulation)	<ul style="list-style-type: none"><li>• Regulatory compliance: regulations, industrial association manual</li><li>• Document correspondence: Instruction manual, warning label</li><li>• Maintenance of work procedures manual</li><li>• Improvement of working accuracy in education and training</li></ul>



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【6】Conclusion

# 33. Conclusion

RA ; Risk assessment

1. Risk assessment for A2L refrigerant
  - Completion of RA for residential air-conditioner
    - ⇒ The cumulative sales units (from 2012 to 2016) is 25 million in Japan
  - Completion of RA for commercial air-conditioner
    - ⇒ The cumulative sales units (from 2012 to 2016) is 3.5 million in Japan
  - Promotion on RA for other refrigeration products
    - Display cabinet, GHP, Condensing unite and etc.
2. Establishment of Japanese type risk assessment
3. Guideline and requirements of JRAIA for A2L
  - Apply the guideline and requirements for products in Japan
  - Reflecting on international safety standards
4. Risk assessment for A3 refrigerant
  - Promotion of appropriate FTAs based on research with industry-university collaboration.
  - Review of FTA results and planning of measures, then demonstration of its effect (At Kobe symposium in 2018)

**Thank you very much**