

Safety research of A2L/A3 refrigerants and risk assessment in Japan

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Trade-off relationship between GWP and flammability

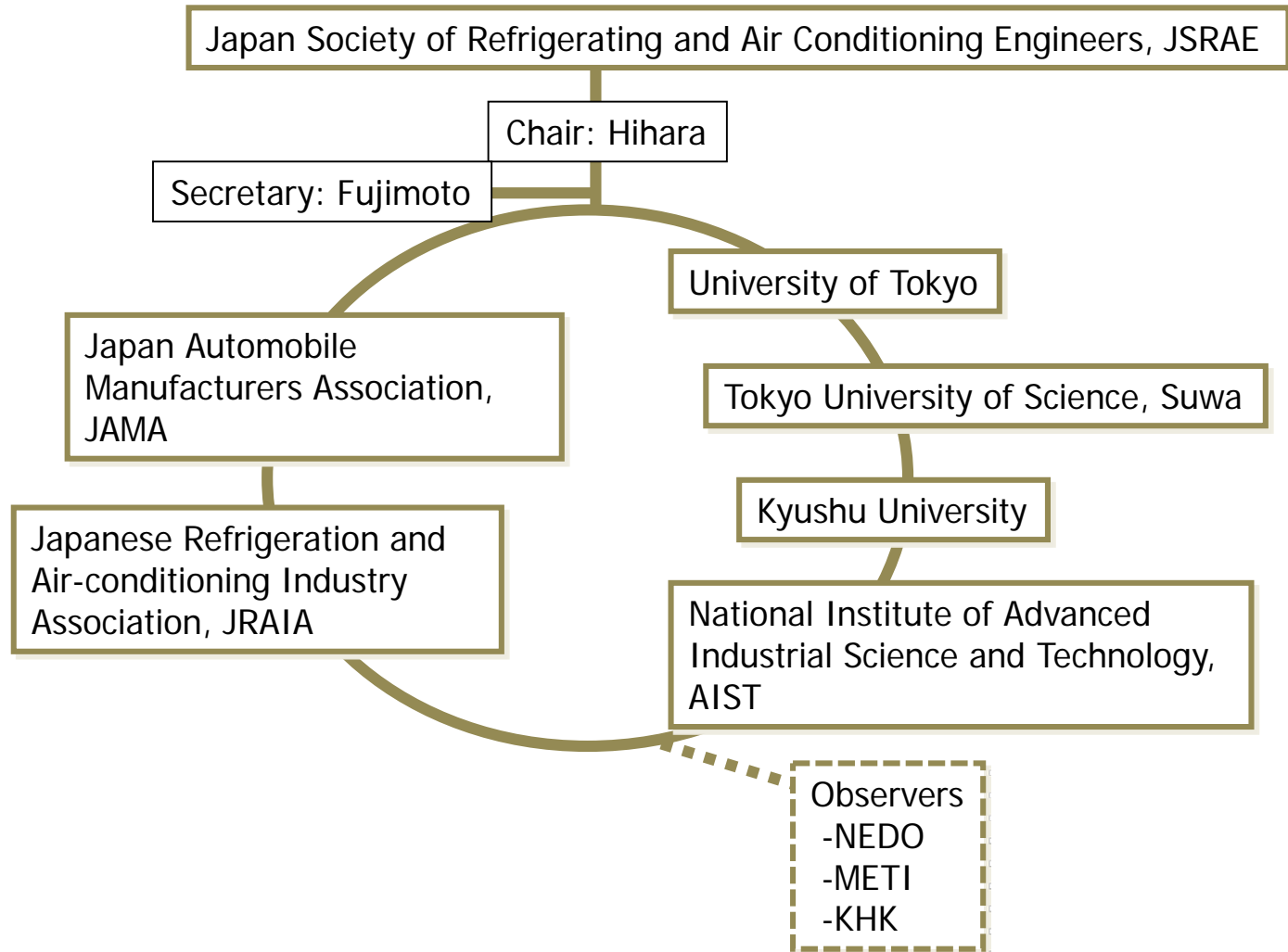
- To reduce the emission of greenhouse gases including HFCs from refrigerating and air-conditioning equipment, a change in refrigerants from HFCs to lower GWP refrigerants is one of the key issues.
- R1234yf, R32, and R290 have much lower GWPs than R410A. R410A is nonflammable, but R1234yf, R32, and R290 are flammable. Because the burning velocities of R1234yf and R32 are smaller than 10 cm/s, flammability of R1234yf and R32 is mild and it is categorized under the A2L class of the ASHRAE.

Refrigerant	R410A	R32	R1234yf	R717	R290
Boiling temperature, °C	-51.4	-51.7	-29.4	-33.3	-42.1
Critical temperature, °C	71.3	78.1	94.7	132.4	96.7
GWP (100 years)	2088	675	4	<1	<3
Burning velocity (cm/s)	-	6.7	1.5	7.2	38.7
LFL [vol %]	-	13.3	6.2	15	1.8
UFL [vol %]	-	29.3	12.3	28	9.5
Minimum ignition energy (mJ)	-	15	500	21	0.246
Flammability	1	2L	2L	2L	3

Research committee on risk assessment of A2L/A3 refrigerants in JSRAE

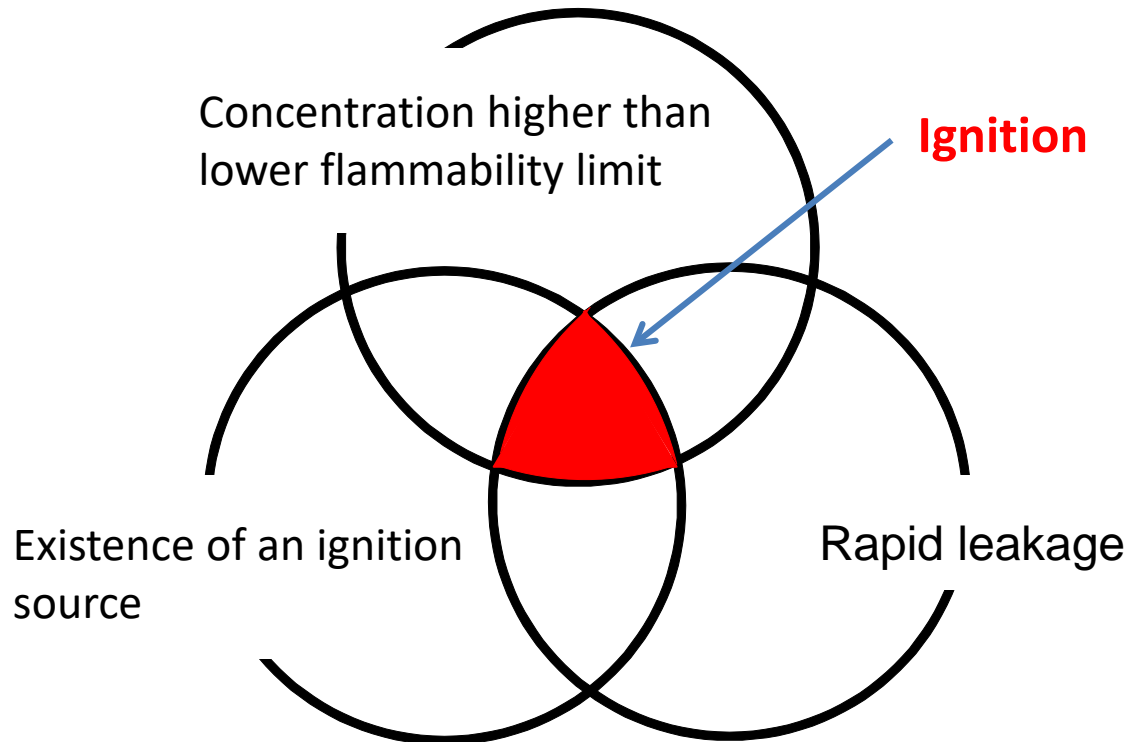
- For promoting the use of low-GWP refrigerants, relaxation of the legal regulation of mildly flammable refrigerants is necessary. Before relaxing regulations, risk assessment of flammable refrigerants should be carried out, and reasonable guidelines for safe design and safe use of refrigerating and air-conditioning equipment with flammable refrigerants should be formulated.
- A project sponsored by the New Energy and Industrial Technology Development Organization (NEDO) on the performance and safety of new refrigerants started in 2011. The Japanese Refrigeration and Air Conditioning Industry Association (JRAIA) also started the risk assessment of flammable refrigerants. To exchange knowledge of safety issues and risk assessments among researchers and manufacturers, a research committee was established by the Japan Society of Refrigerating and Air Conditioning Engineers (JSRAE).

Organization of the research committee for safety of A2L/A3 refrigerants



Methodology of Risk Assessment

$$[\text{Probability of fire accident}] = [\text{Rapid leakage}] \times [\text{High concentration of refrigerant}] \times [\text{Ignition source}]$$



Numerical simulation of diffusion of refrigerant leaking in a room

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Purpose

Flammable refrigerants leakage = Risk of fire accident

Risk = Flammable gas volume,
presence time,
and existence probability of ignition source



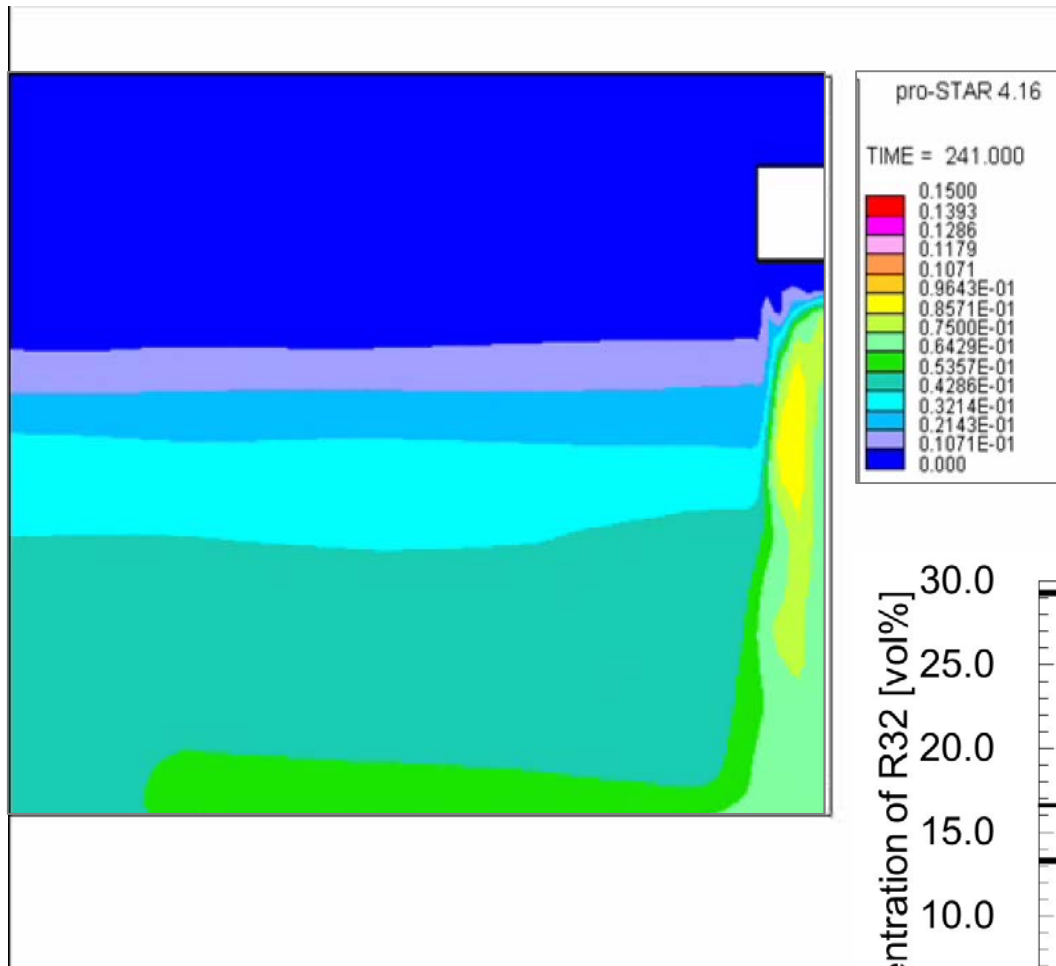
Flammable gas volume and presence time etc...
are numerically analyzed when a refrigerant leaked
into a living space

- Target refrigerants
 - R32, R1234yf, R1234ze, R290
- Target equipments
 - RAC. for home, VRV, Chiller
- Located
 - Indoor, Outdoor, Machine room

Leakage scenarios for split air conditioners

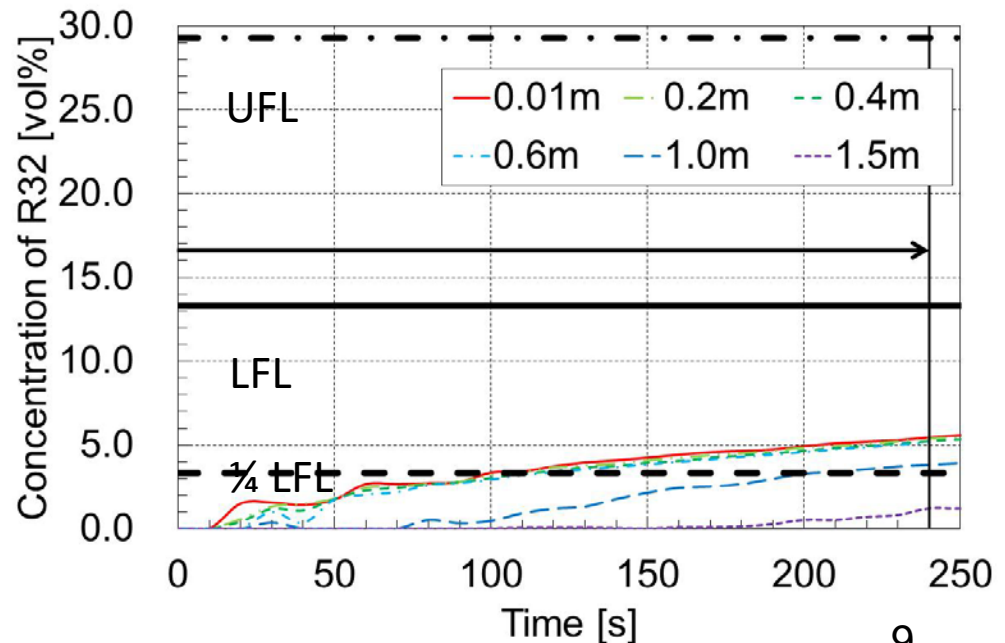
Position of leakage	No.	Refrigerant	Amount [g]	Flow rate [g/min]	Ventilation
Wall-mounted indoor unit	1	R32	1000	250	None
	2	R1234yf	1400	350	
	3	R32	1000	125	None
	4	R1234yf	1400	175	
	5	R32	1000	1000	None
	6	R1234yf	1400	1400	
	7	R290	500	125	None
	8	R290	200	50	
Floor-standing indoor unit	9	R32	1000	250	None
	10	R1234yf	1400	350	
Outdoor unit	11	R32	1000	250	0.5 m/s
	12	R1234yf	1400	350	

Result: Concentration distribution (No.1)

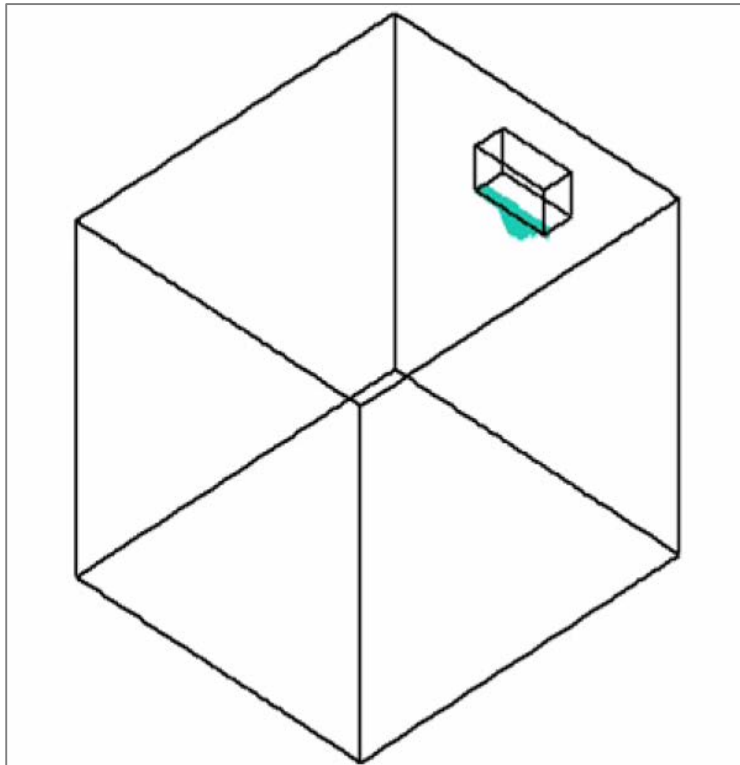


- Because the density of R32 is higher than air, R32 flows down to the floor, and is accumulated.
- The concentration was lower than the LFL on the floor.

Refrigerant: R32
 Amount: 1000 g
 Flow rate: 250 g/min



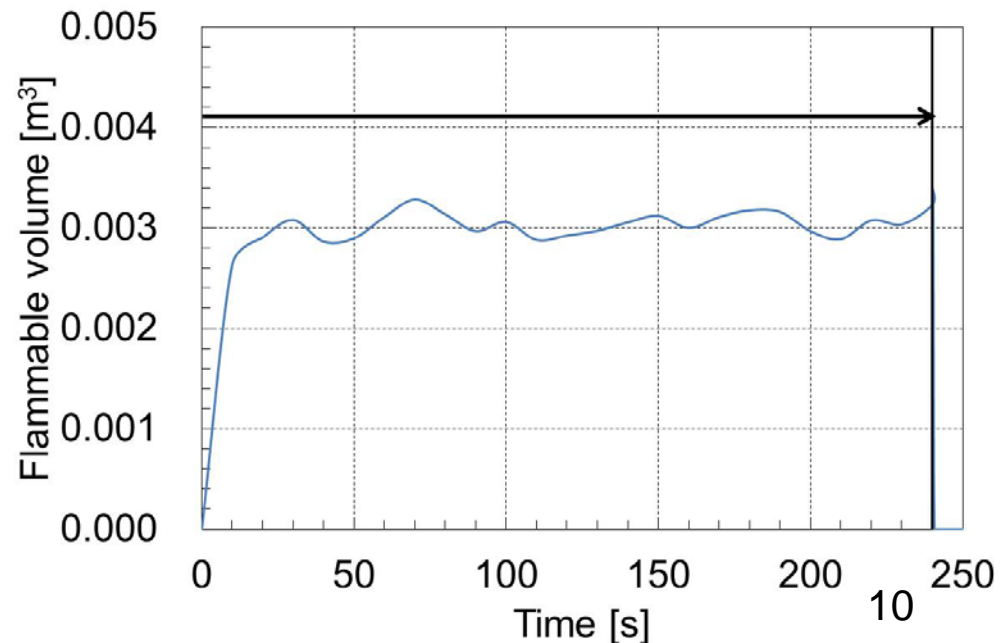
Result: Combustible gas region (No.1)



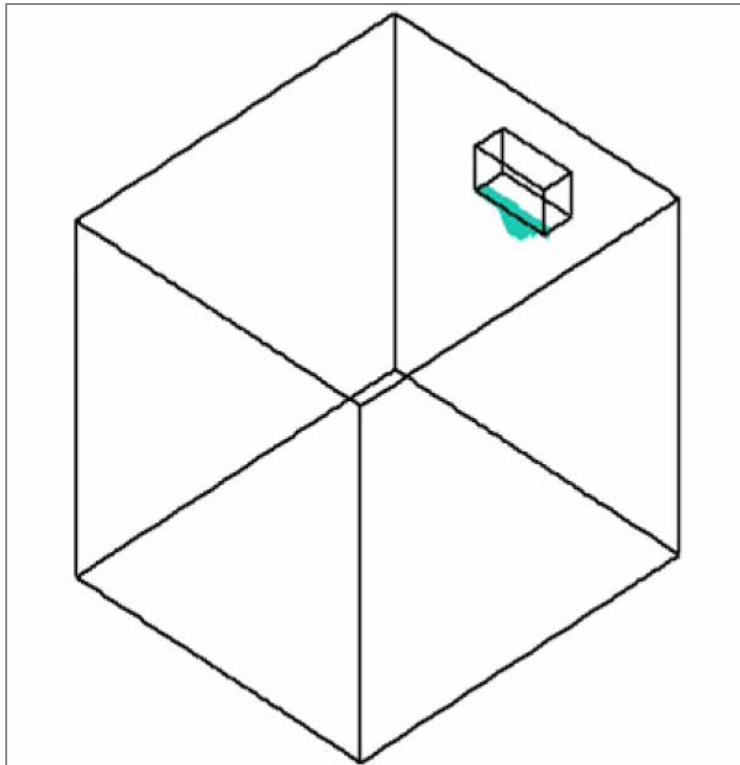
pro-STAR 4.16
TIME = 150.000

- The combustible gas region existed just below the air outlet of the indoor unit only.
- The flammable gas volume was very small.
- After leakage, the combustible gas region vanished in less than a second.

Refrigerant: R32
Amount: 1000 g
Flow rate: 250 g/min



Result: Combustible gas region (No.1)



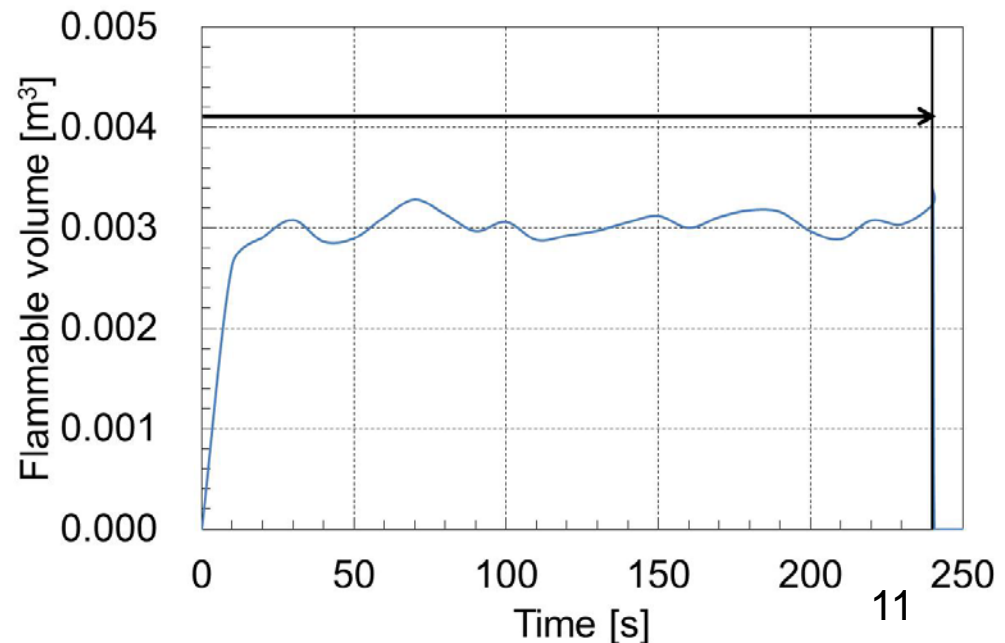
pro-STAR 4.16
TIME = 150.000

▪ The combustible gas region existed just below the air outlet of the indoor unit only.

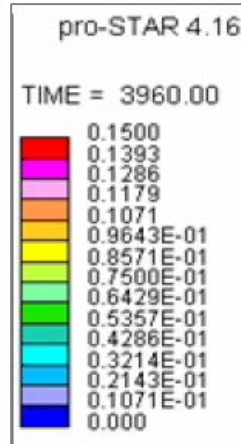
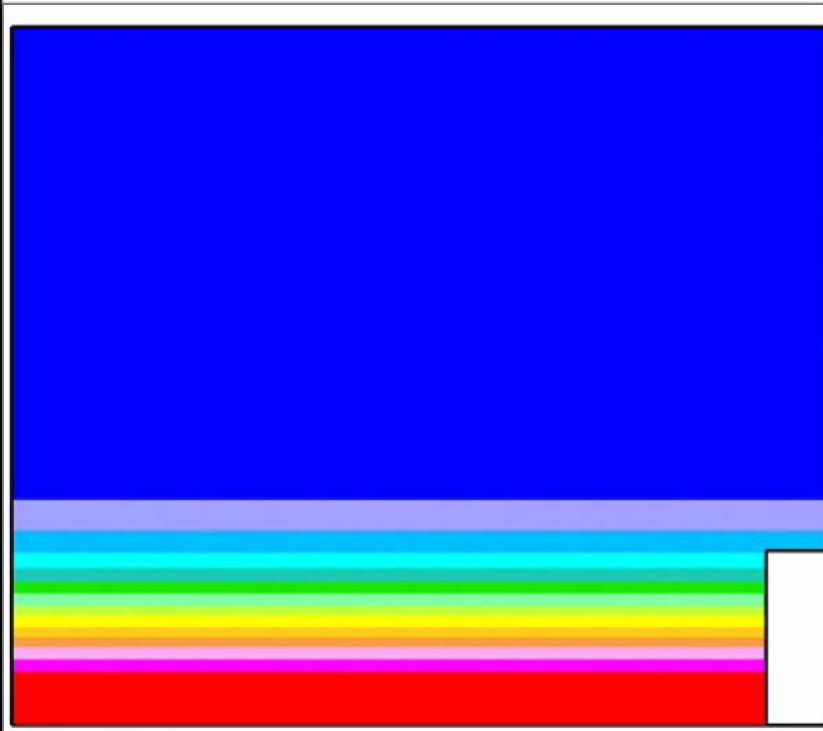
Combustion does not occur if the ignition source does not exist inside the indoor unit.

in less than a second.

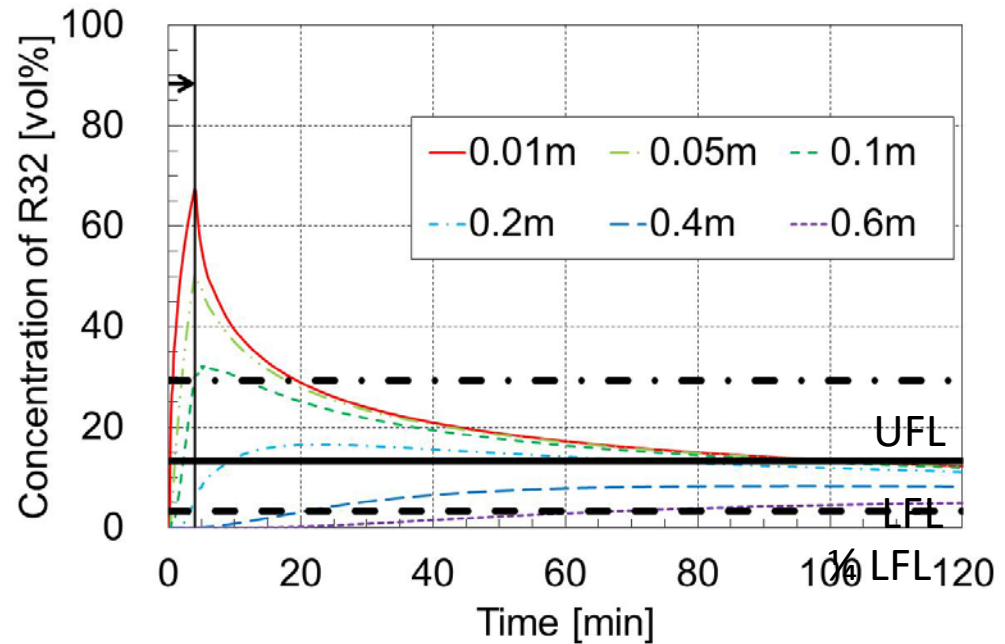
Refrigerant: R32
Amount: 1000 g
Flow rate: 250 g/min



Result : Concentration distribution (No.9)

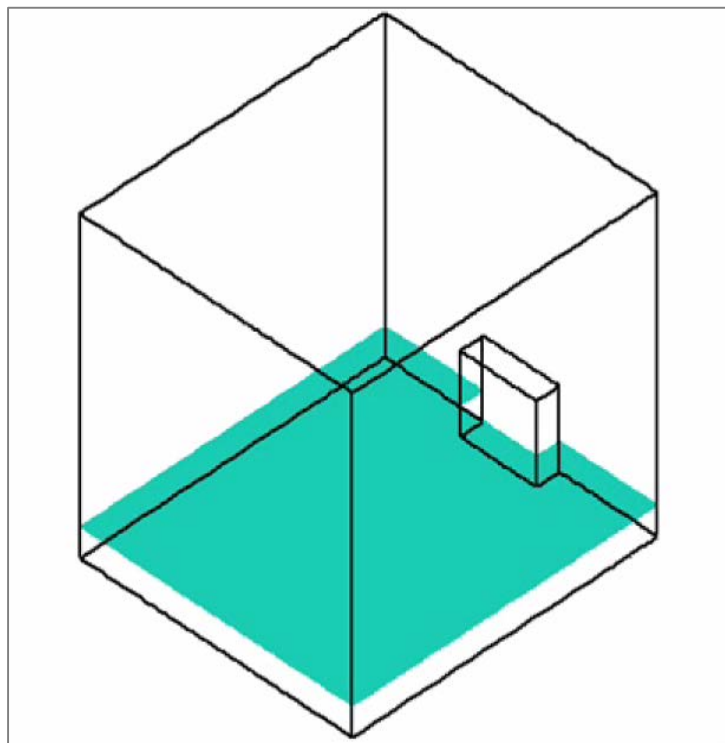


▪ There was a region where the concentration was higher than the UFL on the floor.



Refrigerant : R32
 Amount : 1000 g
 Flow rate : 250 g/min

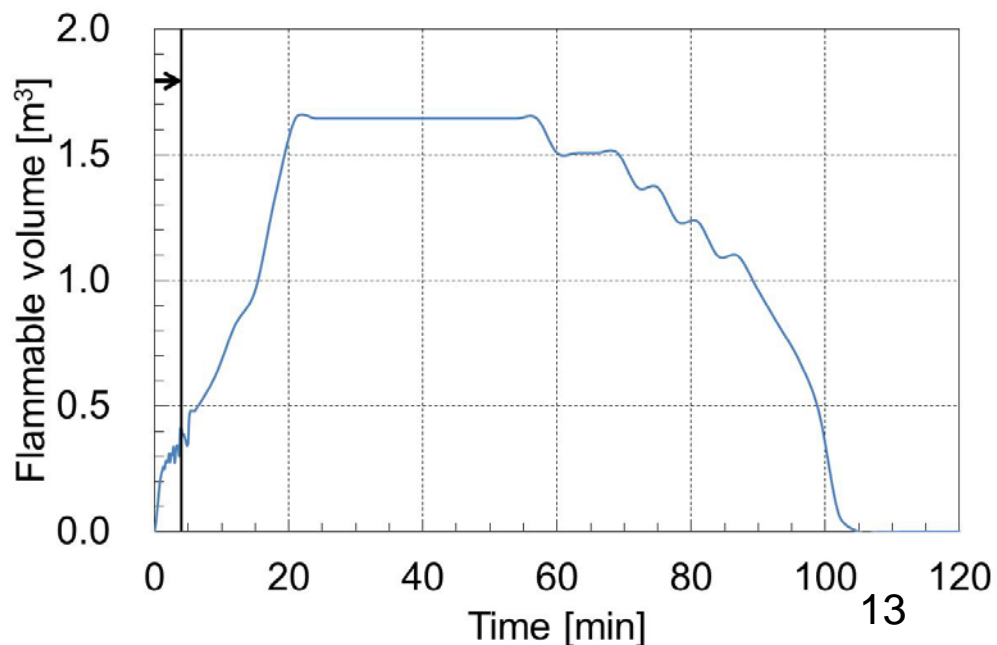
Result: Combustible gas region (No.9)



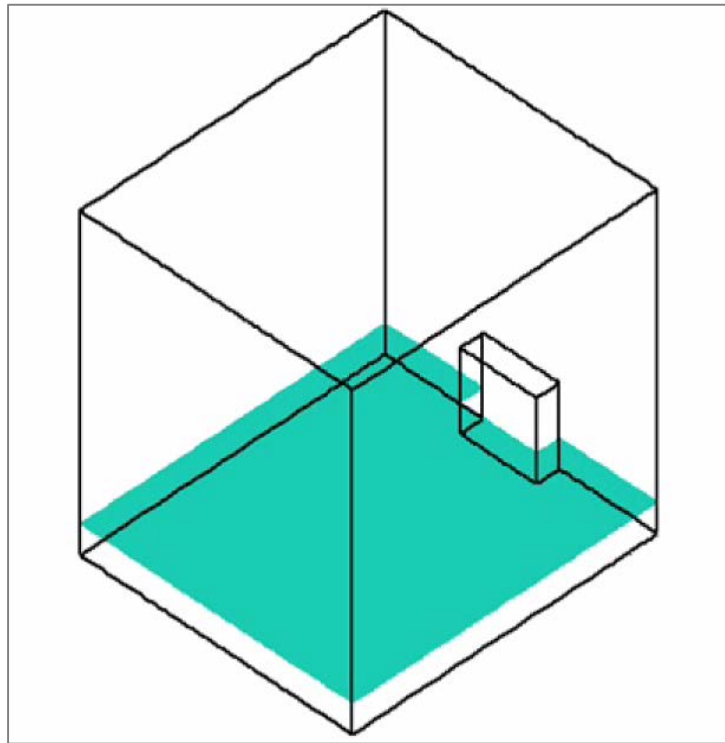
pro-STAR 4.16
TIME = 3960.00

- The mixing of the refrigerant is weak, and the refrigerant concentration in the vicinity of the floor is high.
- In this case, not only the combustible gas volume is large, but also its duration is long.

Refrigerant: R32
Amount: 1000 g
Flow rate: 250 g/min



Result: Combustible gas region (No.9)

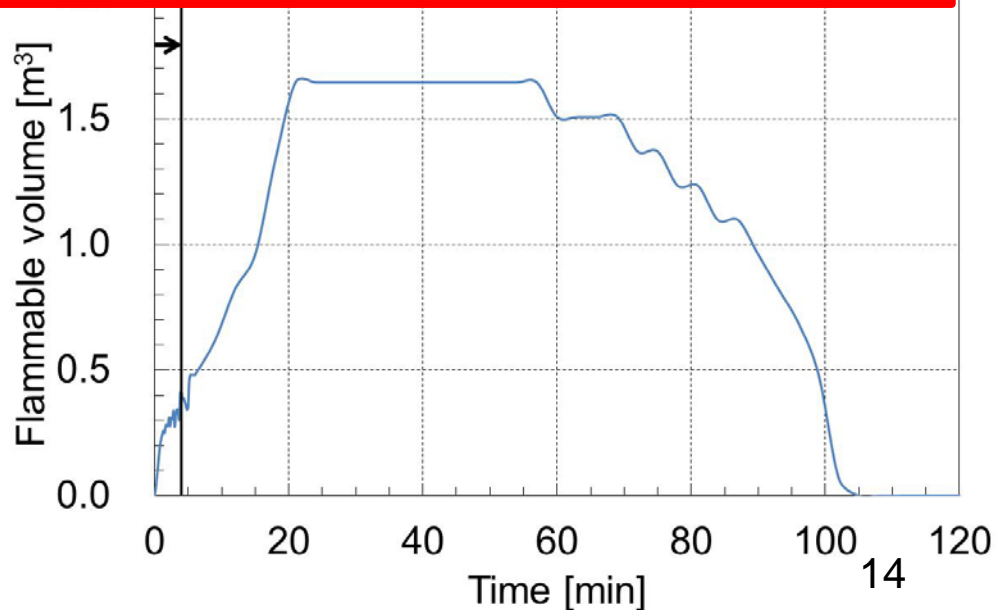


pro-STAR 4.16
TIME = 3960.00

- The mixing of the refrigerant is weak, and the refrigerant concentration in the vicinity of the floor is high.
- In this case, not only the

The leakage of flammable refrigerants from a floor-standing indoor unit has a high risk of fire.

Refrigerant: R32
Amount: 1000 g
Flow rate: 250 g/min



Flammability of 2L refrigerants

National Institute of Advanced Industrial
Science and Technology (AIST)

Research Institute for Sustainable Chemistry

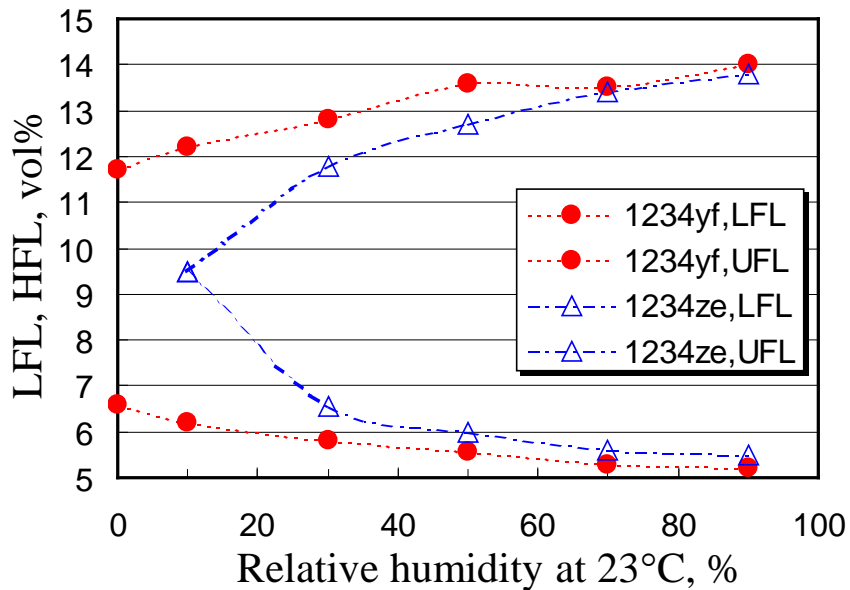
Flammability limits of non-flammable refrigerants

R-410A, R-410B, and R-134a are considered to be non-flammable. However, they become flammable under such a condition as 50%RH at 60 °C.

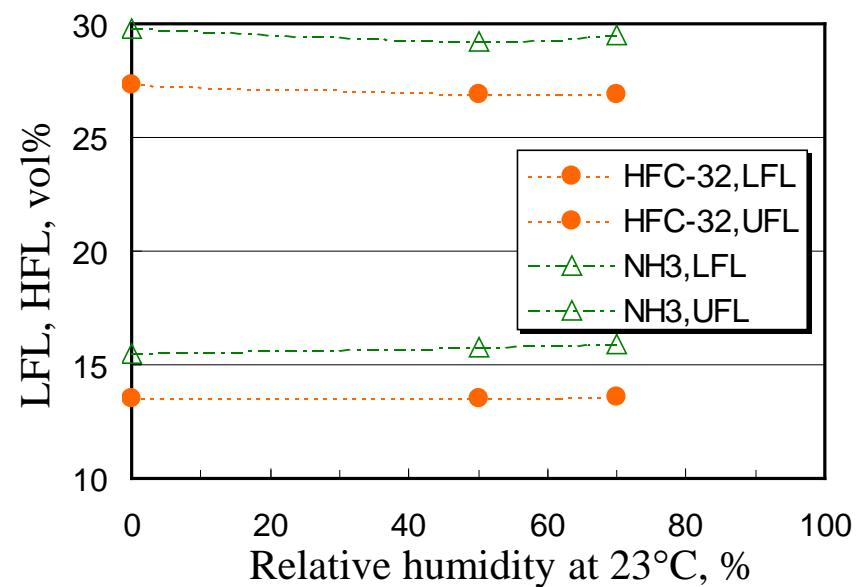
	LFL		UFL	
	vol%	±	vol%	±
R22	non-flammable			
R134a	11.5	0.3	15.9	0.4
R410A	15.6	0.2	21.8	0.4
R410B	16.3	0.3	20.9	0.4
R413A	7.16	0.15	14.3	0.5

Dependence of humidity on flammability limit

Flammability limit of R-1234yf and R-1234ze(E)

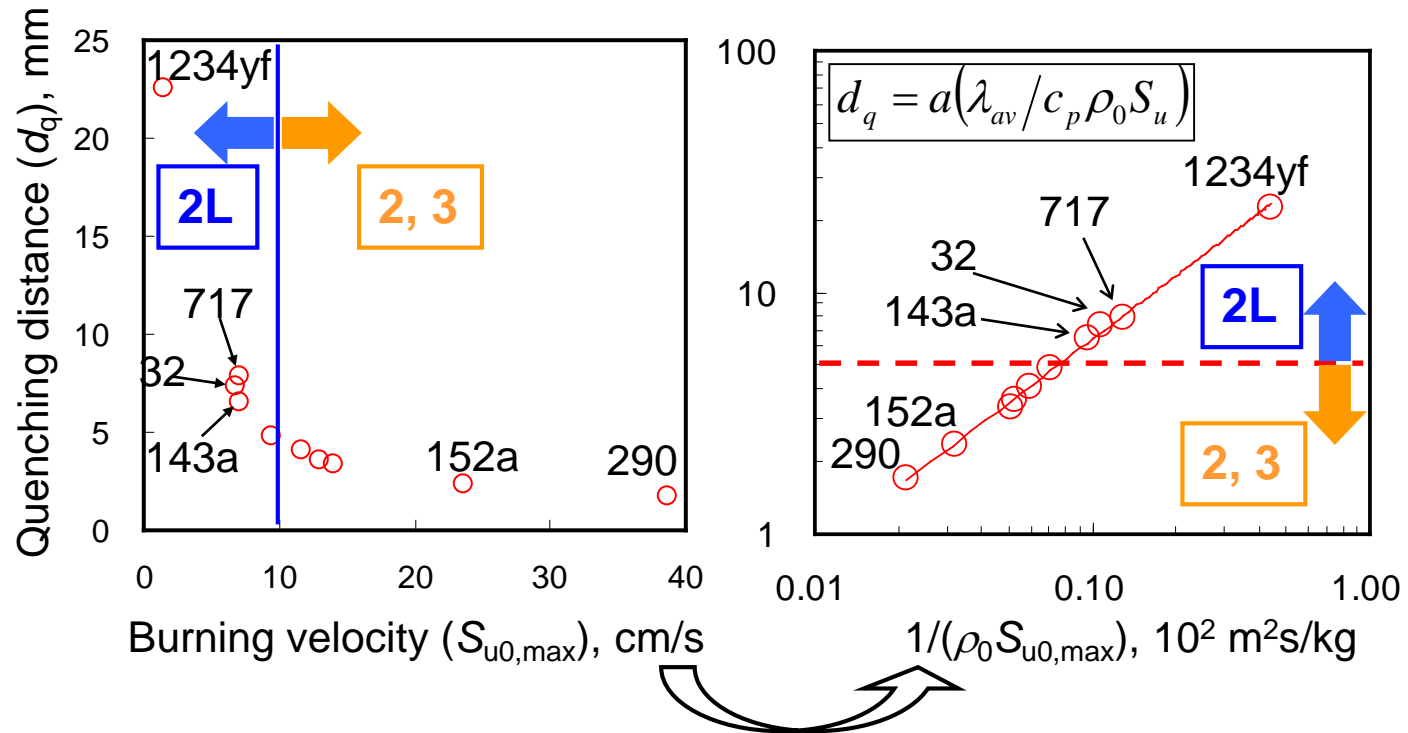
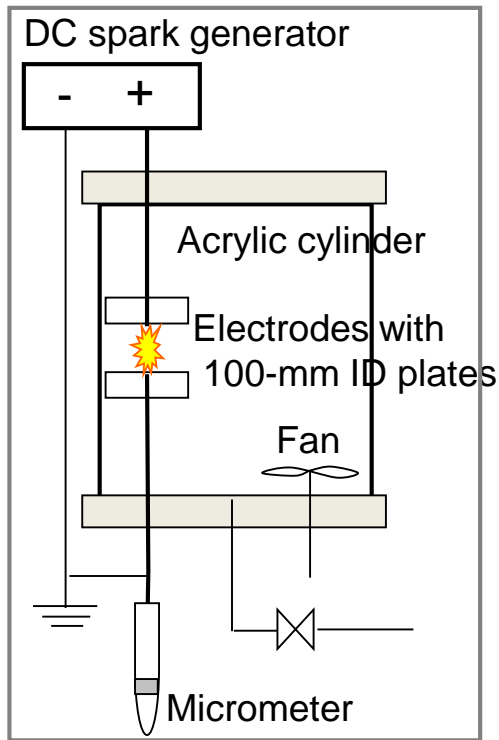


Flammability limit of R-32 and ammonia



- Flammability limits of R-1234yf and R-1234ze(E) are clearly effected by humidity. Flammable region is stretching by moisture.
- Flammability of R-32 and ammonia is not influence by humidity.

Quenching distance measurement



- ✓ The quenching distance has a strong relationship with flammability, like burning velocity.
- ✓ The quenching distances of 2L class refrigerants are larger than 5 mm..

Experimental Evaluation of Physical Hazard of A2L Refrigerant Assuming Actual Handling Situations

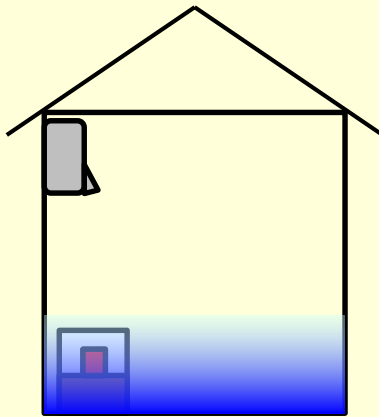
Tokyo University of Science, Suwa



Background & Objective

In the actual handling situation of air conditioning systems...

➤ Leaked refrigerant generally has a certain degree of concentration distribution.



➤ Ignition source is very various, and ignition behavior greatly affected by the turbulence and flow of the accumulated refrigerant.

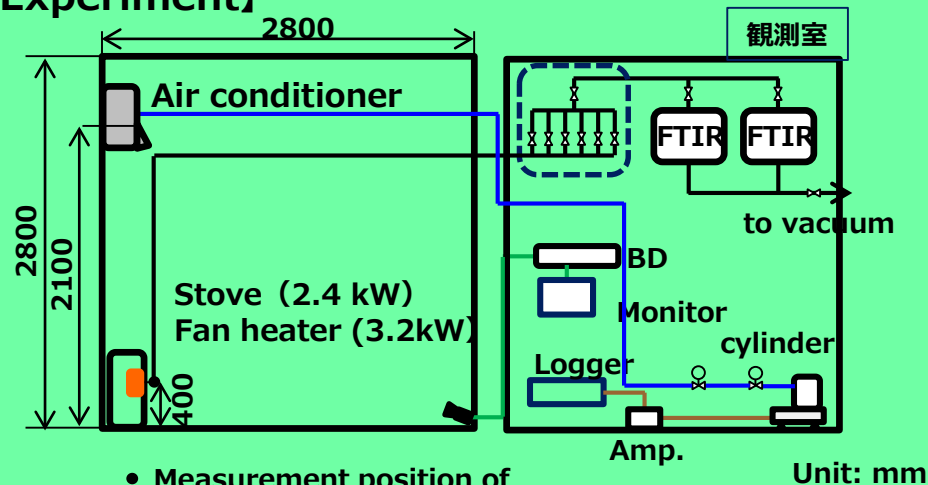


We examined physical hazard by burning of A2L refrigerant **under several conceivable accident situations** based on these fundamental combustion behaviors.

Physical Hazard evaluation assuming conceivable accident scenarios (TUSS)
Use with fossil-fuel heating appliance

Accident scenario: A wall-mount type room air conditioner containing an A2L refrigerant is simultaneously used with a fossil-fuel heating appliance inside a general living space.

[Experiment]



- Measurement position of refrigerant and HF concentration

Refrigerants : R32, R1234yf, R410A

Leak amount : 800 g

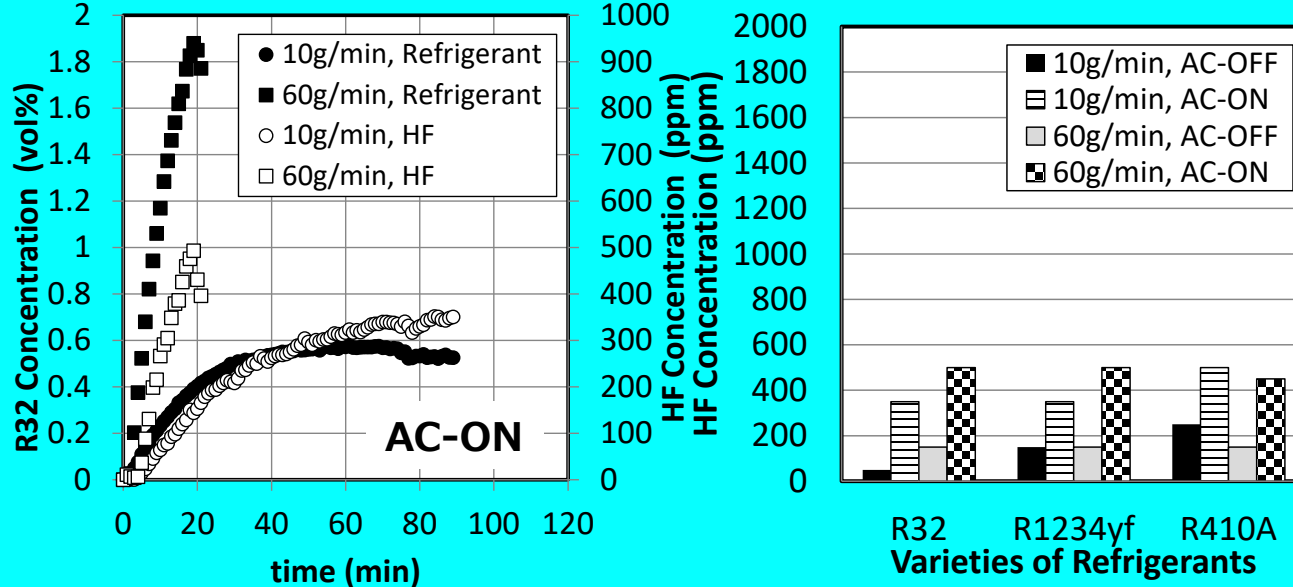
Leak rate : 10 g/min, 60 g/min

Heater : radiative stove (2.4 kW), oil fan heater (3.2 kW)



Physical Hazard evaluation assuming conceivable accident scenarios (TUSS)
Use with fossil-fuel heating appliance

【Results】 Heater: radiative stove



➤ Refrigerant concentration (<2 vol%) was much lower than LFL. Therefore no ignition and flame propagation to A2L refrigerants were observed.

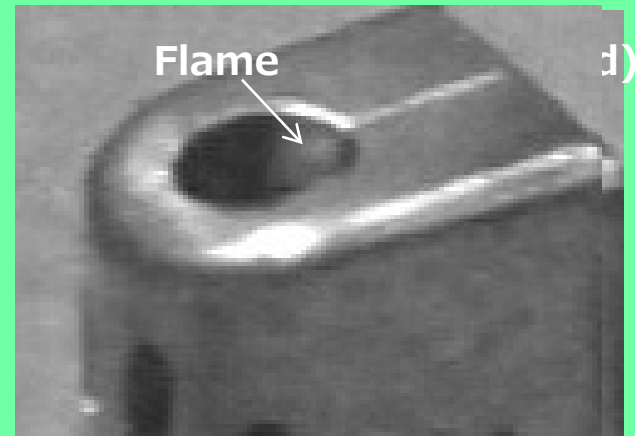
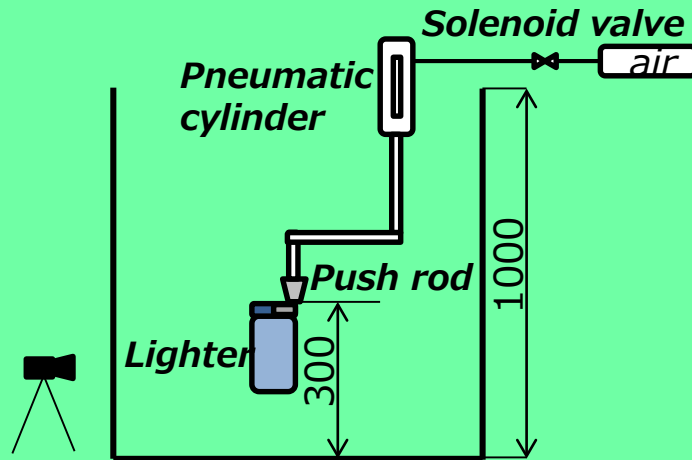
➤ Hydrogen fluoride which is generated due to the combustion or thermal decomposition was confirmed. The concentration of generated HF is more than 3 ppm which is the permissible value, even R410A.

Physical Hazard evaluation assuming conceivable accident scenarios (TUSS)
Ignition & flame propagation by a lighter

Accident Scenario: A service operative uses a portable lighter to smoke in a space in which an A2L refrigerant has leaked and accumulated.

Type 1: piezo gas lighter

[Experiment] Refrigerant: R1234yf, R1234ze(E), R32



It was predicted that the concentration of n-butane/A2L refrigerants/air mixture is **within the flammable range when the concentration of A2L refrigerants close to a gas lighter is less than LFL.**

Conclusion

1. From 2011 to 2015, the Research Committee conducted safety research and risk assessment of A2L refrigerants. A new guideline of mildly flammable refrigerants for refrigerating and air conditioning equipment was drafted in 2016.
2. New safety rules and regulations came into effect in 2016. R32, R1234yf and R1234ze(E) can be used as inactive gases for refrigerating and air conditioning equipment.
3. The Research Committee started to conduct the safety research and risk assessment of A3 refrigerants from 2016.
4. The final report on risk assessment of mildly flammable refrigerants can be freely downloaded from the following website.

http://www.jsrae.or.jp/jsrae/committee/binensei/risk_eng.html



Thank you for your attention!