Safety Measures Taken in High-Gradient Accelerating-Structure Test Facility at KEK

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KEK / Accelerator Laboratory

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Contents

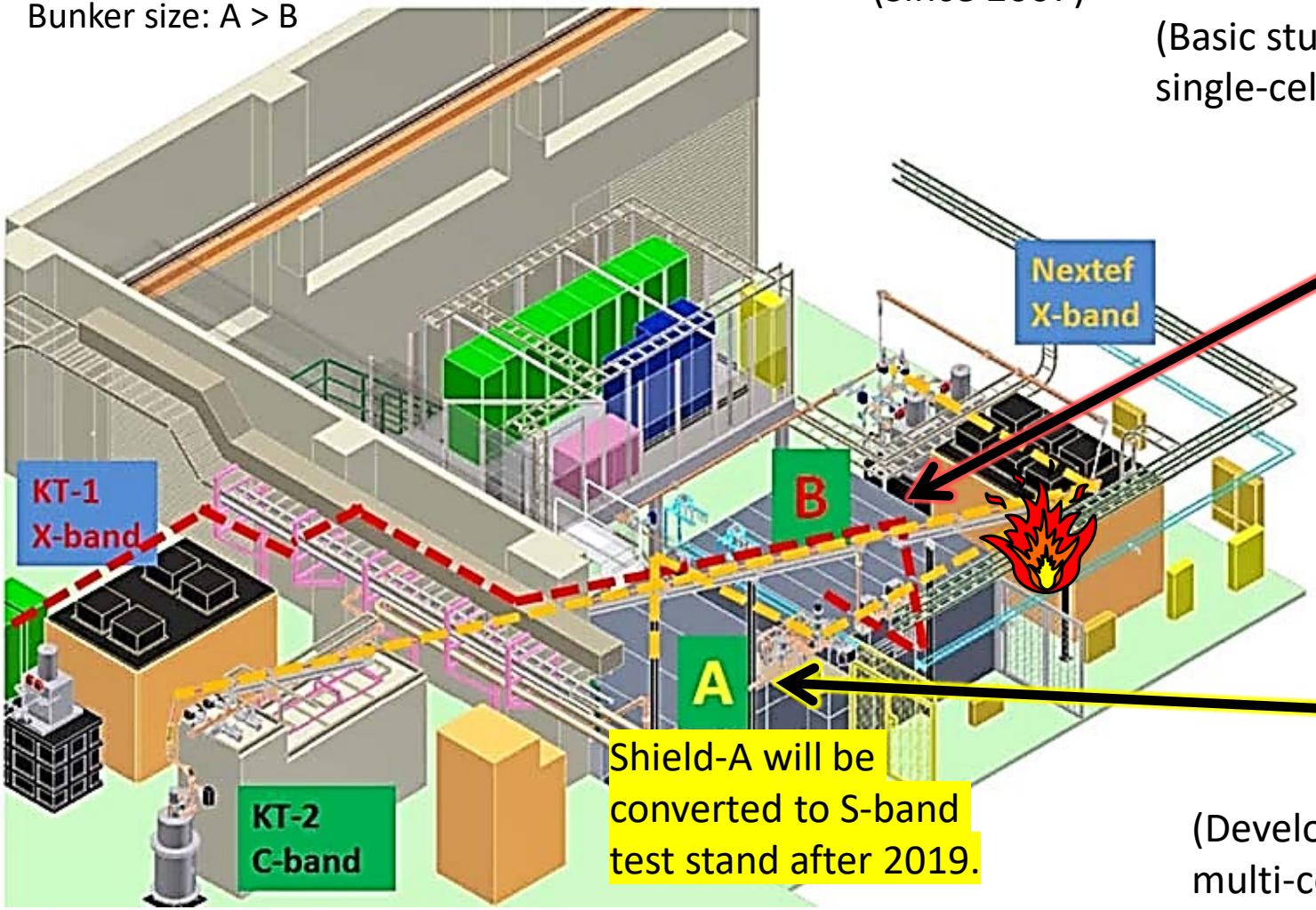
- Serious fire in 2019
- Recovery
- Safety measures against fire
- Future safety management

Nextef: New X-band Test Facility (11.4 GHz)

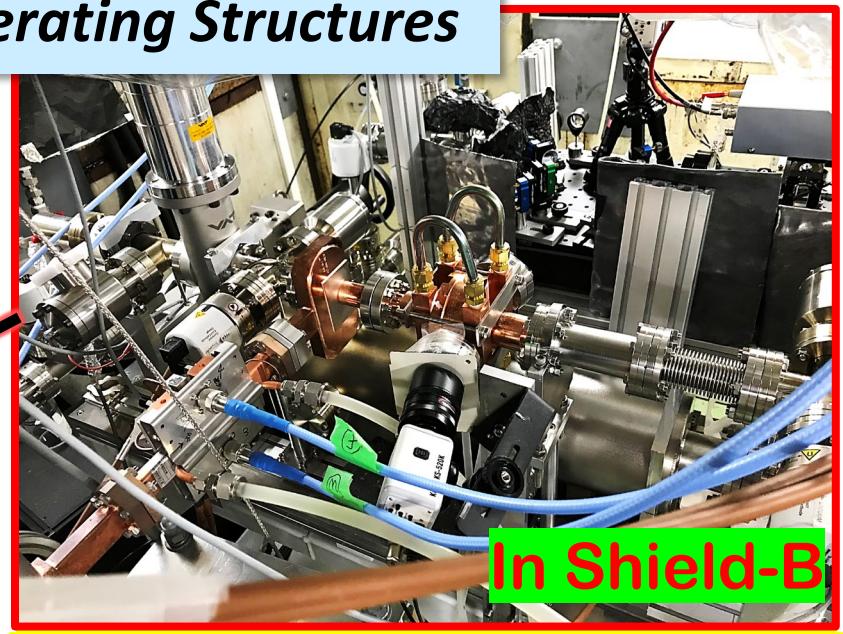
for testing Normal-Conducting High-Gradient Accelerating Structures

(Since 2007)

Bunker size: A > B

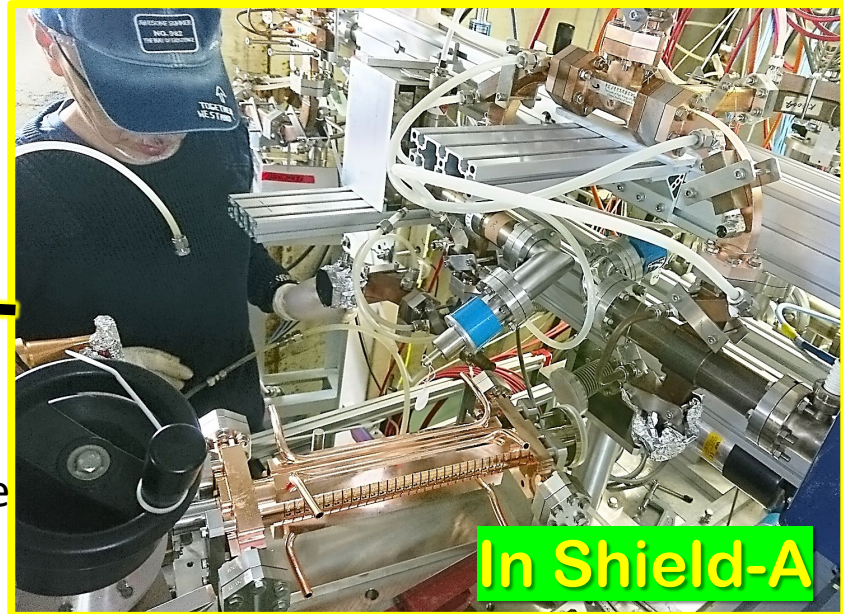


(Basic study using single-cell structures)

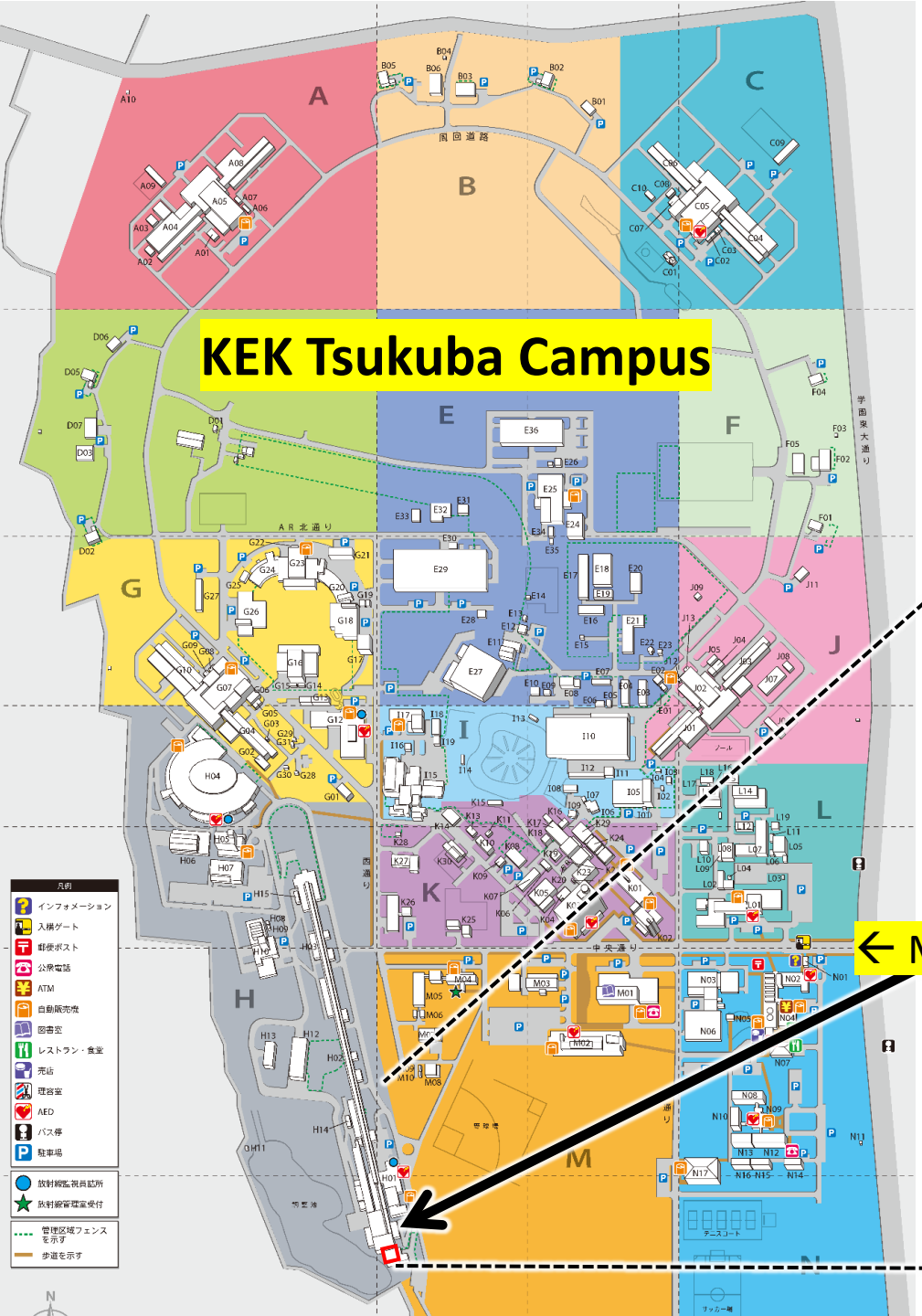


Shield-A will be converted to S-band test stand after 2019.

(Development of multi-cell prototype structures)



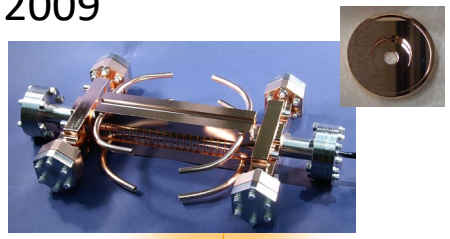
Operation time: ~4,000 hours / year


KEK Tsukuba Campus
A
B
C
D
E
F
G
H
I
J
K
L
M
N
Where
is
Nextef ?
← Main gate
e+
e-
e-
Injector Linac
← J-Arc
Google

X-band Prototype Structures Tested at Nextef1 / Shield-A

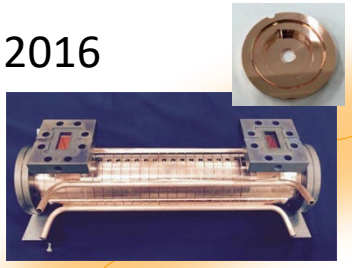
T18 → Quad → TD18 → T24 → TD24 → TD24R05 → TD24R05 → T24THU → TD24R05 → Deflector → TD24R05 → TD26CC → DCS → T24-K1 (terminated by the fire)

2009



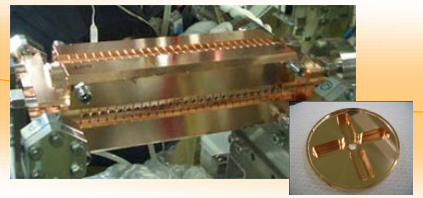
T18_Disk_#2

2016



Deflector (SINAP)

2015

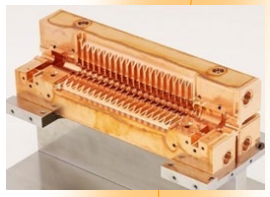


TD24R05_K1

2014-2015

T24THU_#1 (Tsinghua)

2009

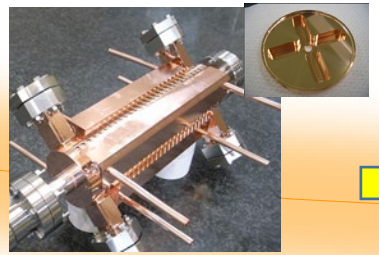


TD18_Quad

2016-2017

TD24R05_K2

2018

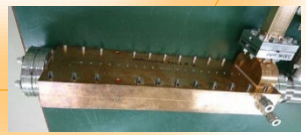


TD26CC_K1

2019

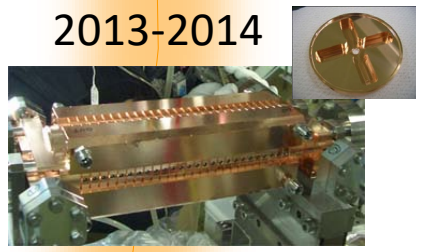
T24-K1

2018



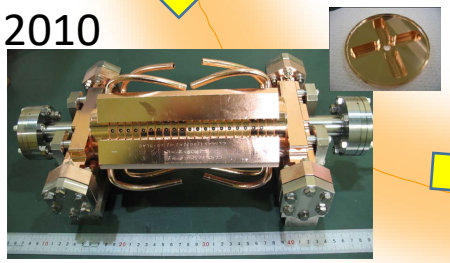
SLAC-DCS

2013-2014



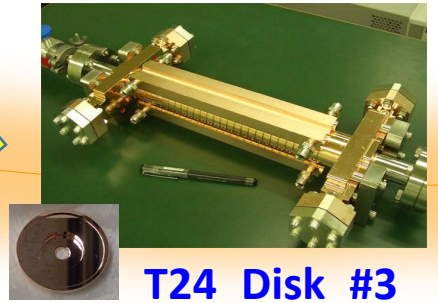
TD24R05_#4

2010



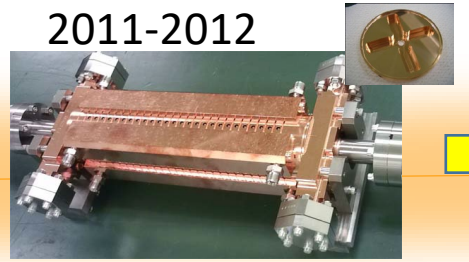
TD18_Disk_#2

2011



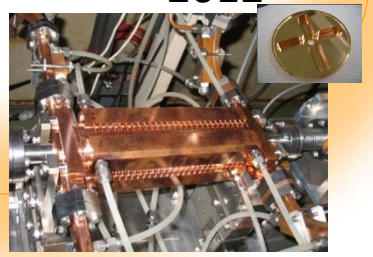
T24_Disk_#3

2011-2012



TD24_Disk_#4

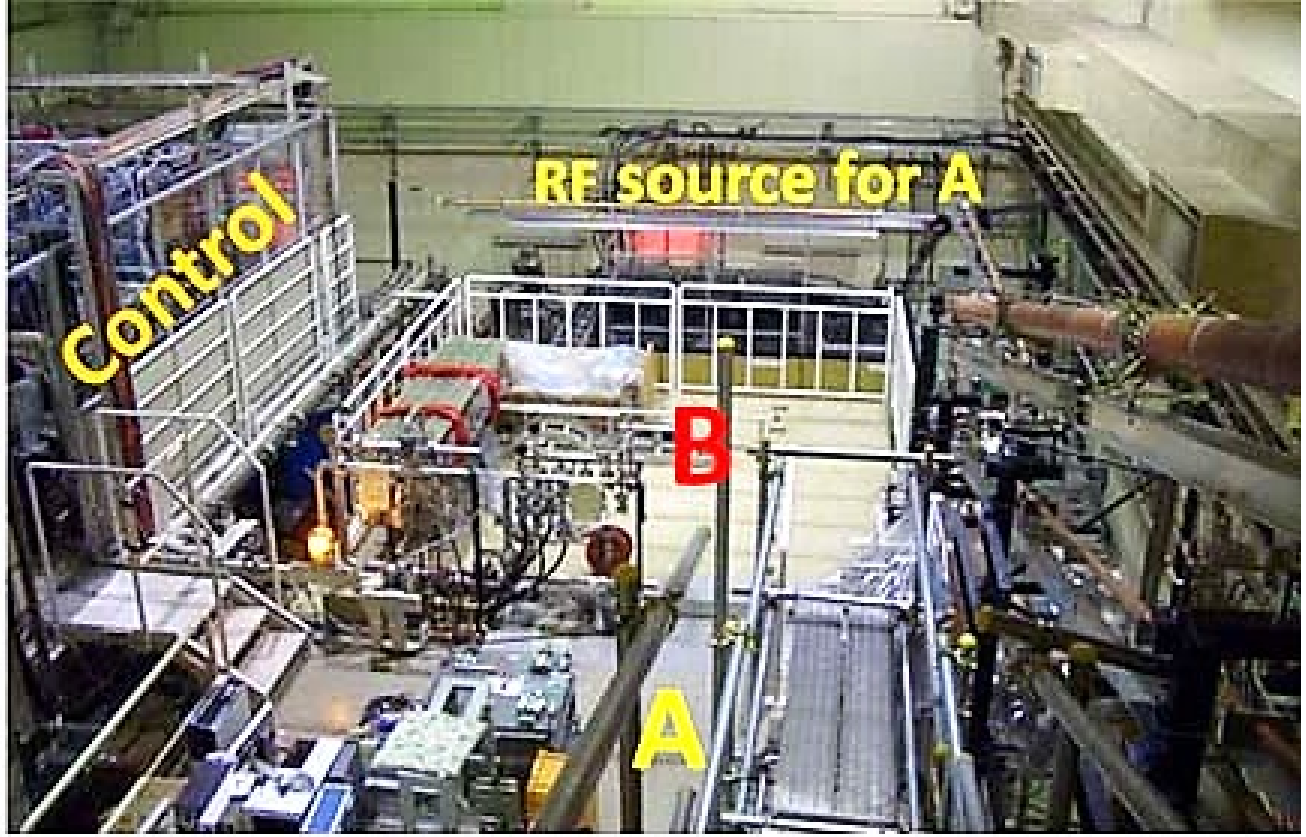
2012



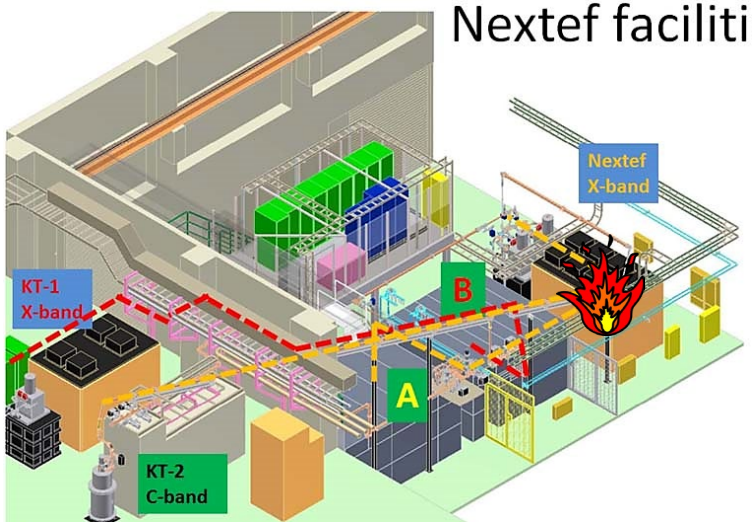
TD24R05_#2

Before the fire

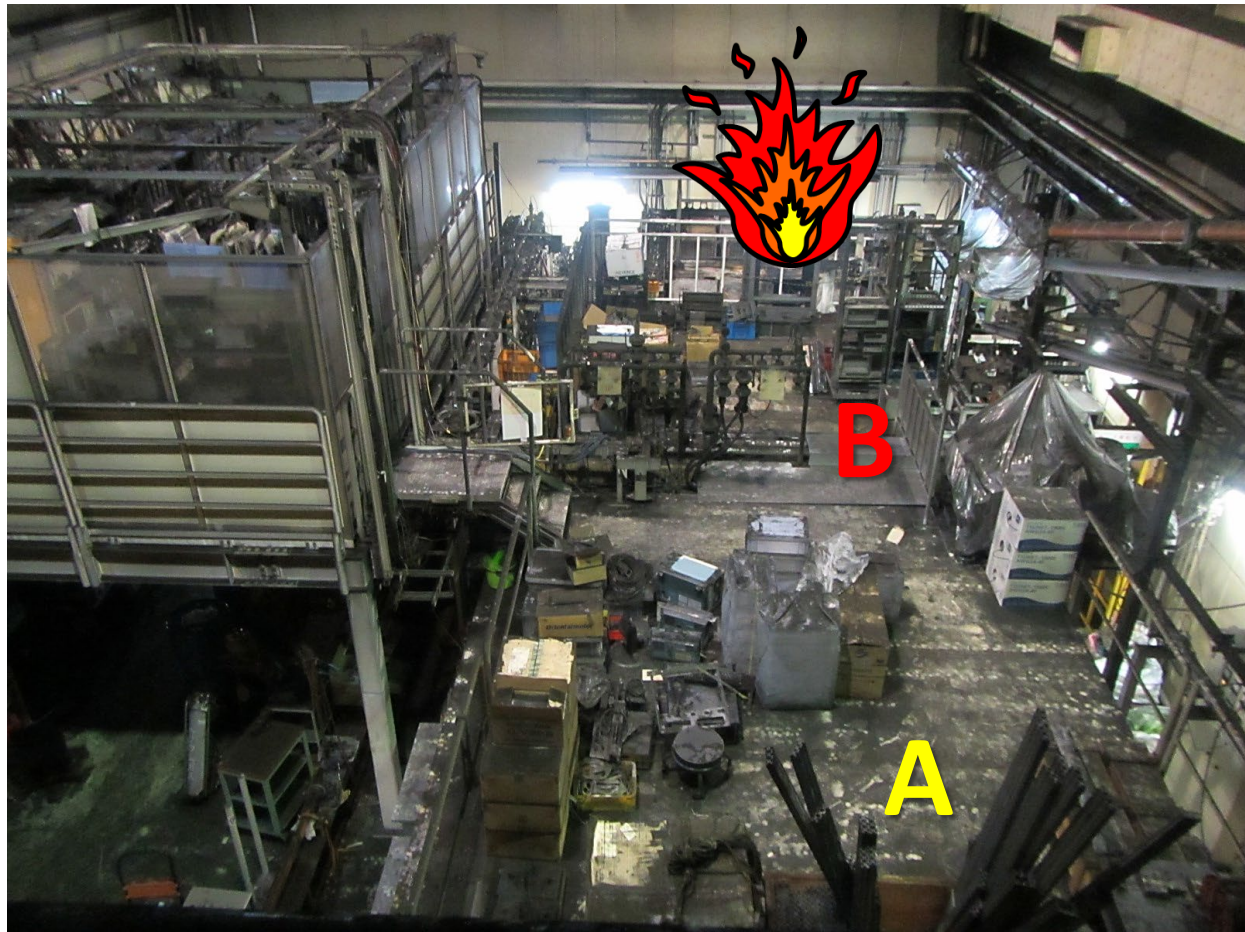
Fire on April 3rd, 2019



Nextef facilities

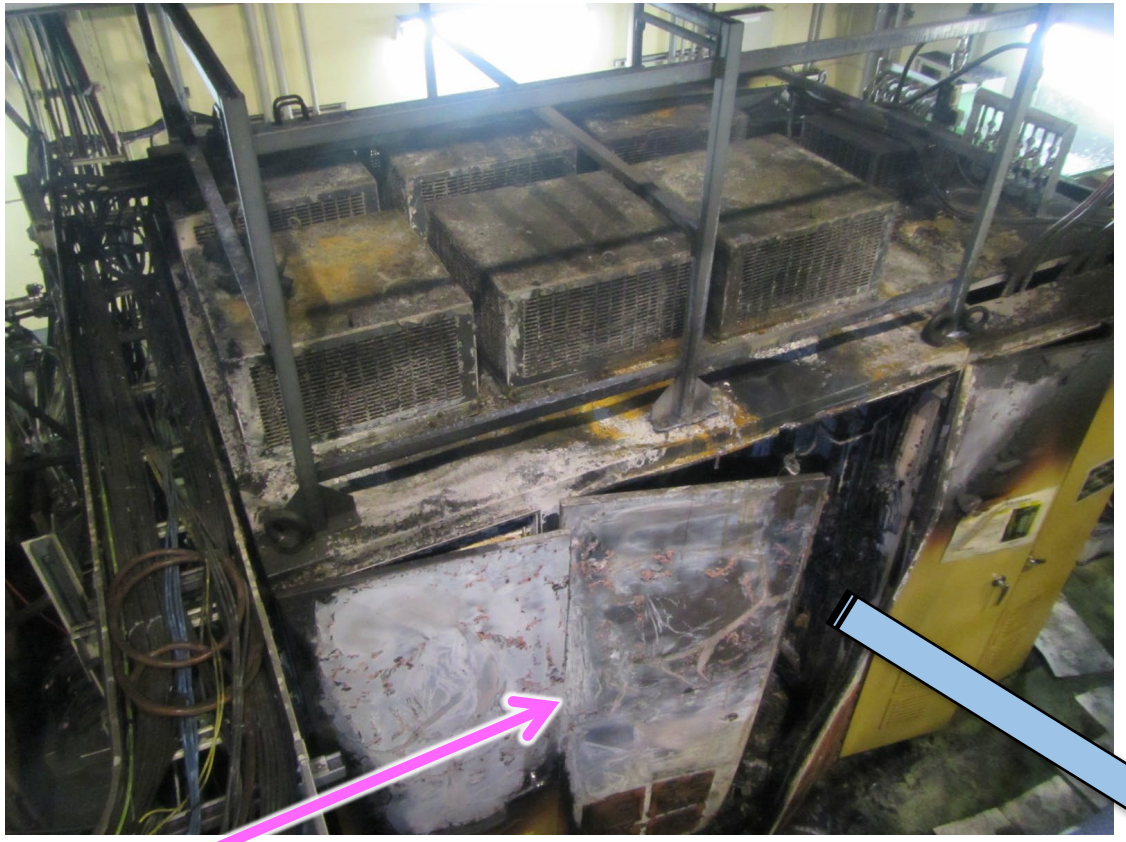


After the fire



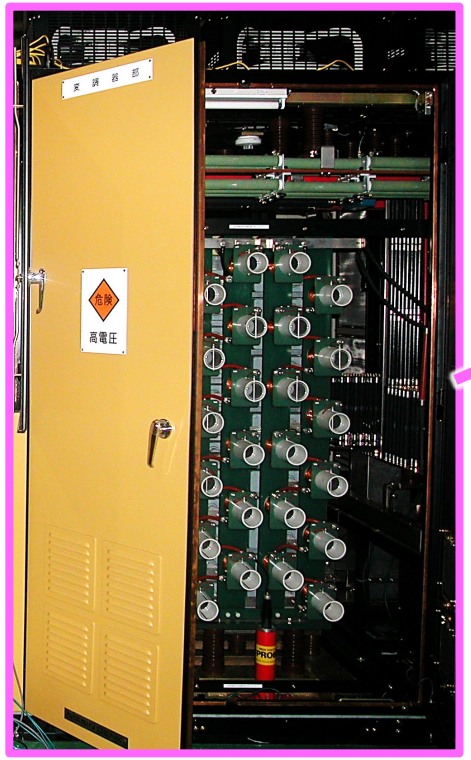
A lot of soot spatially spreaded to the injector linac building
➔ To remove the soot around Nextef, it took over a year.

Burnt modulator



All the plastic-case capacitors meltdown

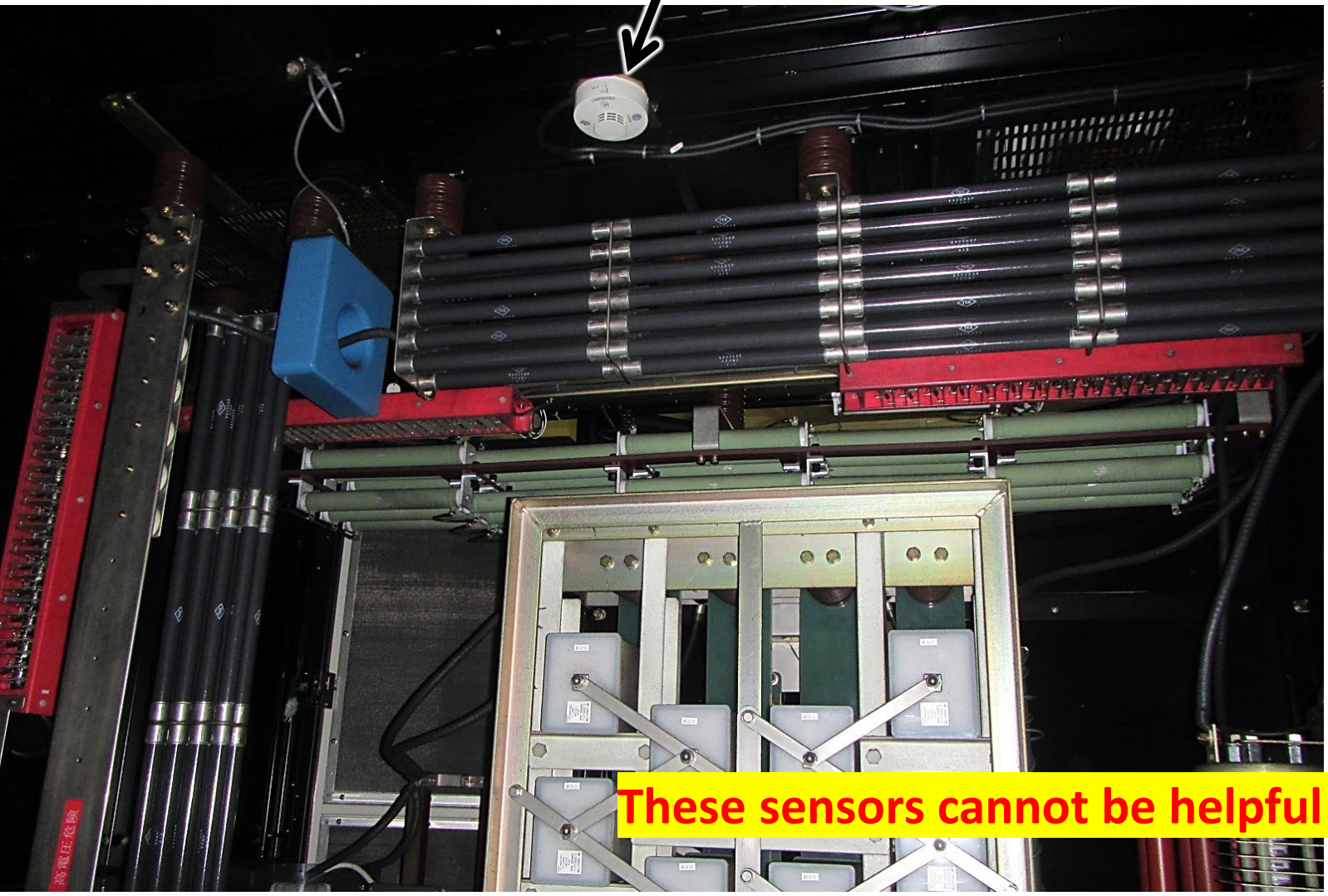
Photo before the fire



Smoke/Temperature sensors in the cubicle of the X-band modulator

Smoke sensor

located at the center of the ceiling



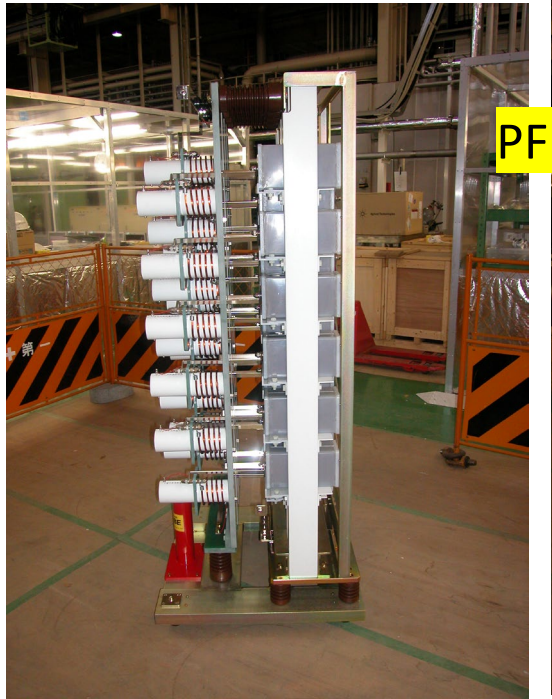
Temperature sensor (Threshold: 40 degC)

located at the edge of the ceiling

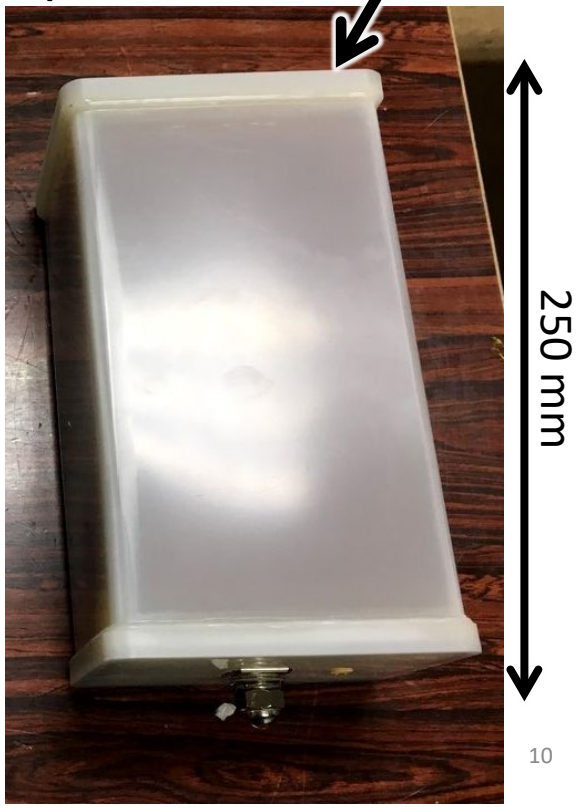
These sensors cannot be helpful for fire prevention.

What is the cause of the fire?

- No deterioration of the modulator performance observed
- The most likely cause is puncture of the plastic-case capacitors (although there is no direct evidence).
  - Fire occurred at other facilities using modulators with plastic-case capacitors.
  - At Nextef, such puncture occurred twice.



PFN



Negative impacts

- All the accelerators in KEK stopped on April 3rd, 2019
  - It took three weeks to recover the injector linac to re-inject e-/e+ to the main rings of SuperKEKB
- All the staff of the injector linac group had to clean it up around the building over a year.
- Heavy additional paper works needed
- Long time lost
  - One year for the special cleaning of the experimental hall
  - One year for recovery of the experimental facility (electricity, cooling, cabling, etc.)
  - One year for recovery of the X-band high-power source
  - One year for recovery of the control system and high-power conditioning

  } **We lost four years!**

  - Last week, we disconnected the waveguide from the dummy load, and connected it to the X-band test cavity.

Main safety measures

■Hardware

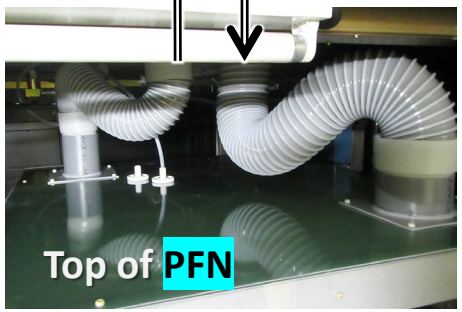
- Plastic → metal capacitors with a lower field
- Fire extinguisher installed in the modulator

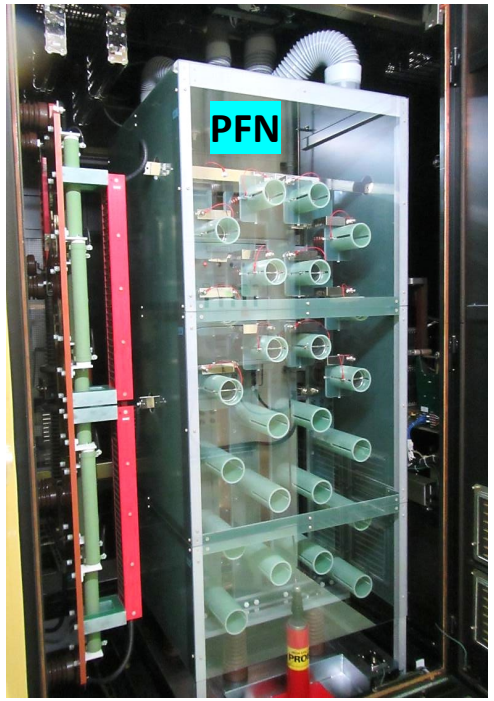
■Software

- No remote HV ON
- Video monitoring

Fire extinguisher installed

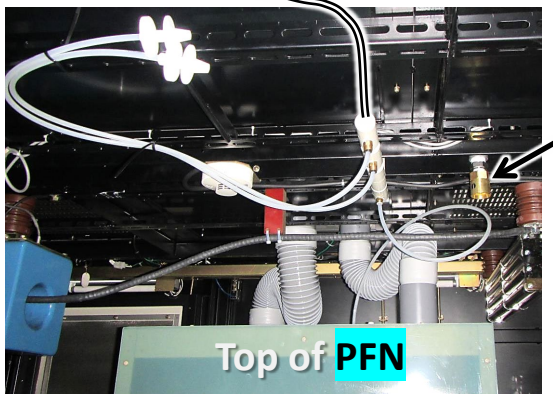
Air cooler





PFN cover to make the smoke-detection sensitivity higher

Based on what we learnt from SLAC



Nozzle

Extinguishant (CO_2+N_2+Ar)

(Intake)

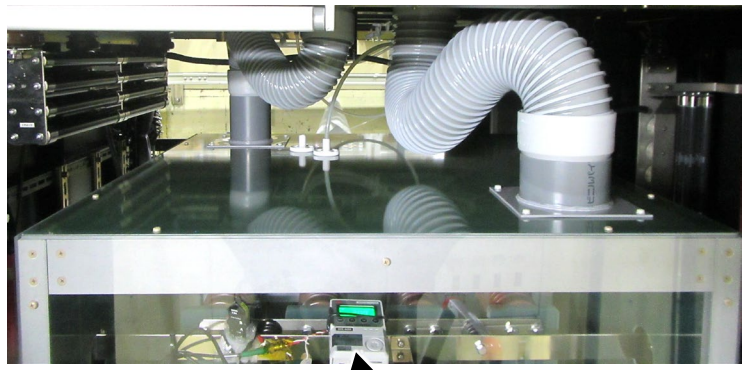
High-sensitivity smoke detector (VESDA)

Smoke density:

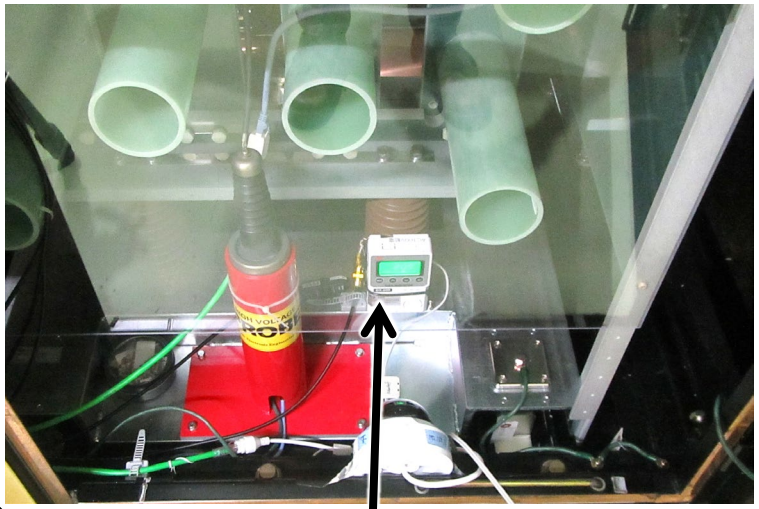
> 0.1 %/m ➔ HV OFF

> 2.0 %/m ➔ LV OFF, Start fire exting.

Measurement of the O2 level inside the modulator during/after the fire extinguishing gas injection (Aug. 25, 2022)



O2 monitor at the FPN top



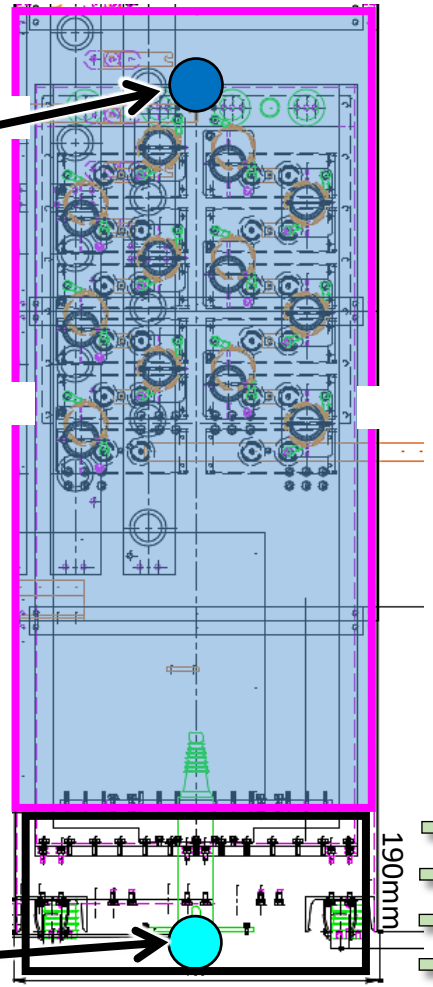
PFN cover

O2 monitor at the FPN bottom

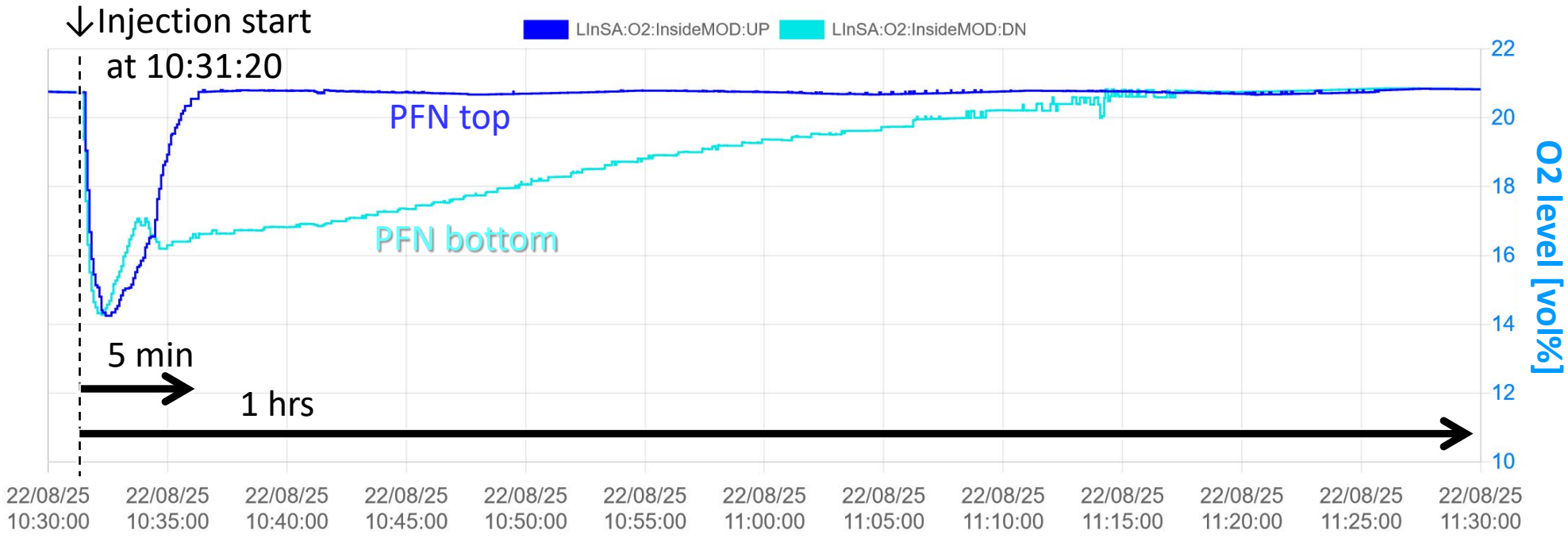
Nozzle for fire extinguishing gas injection

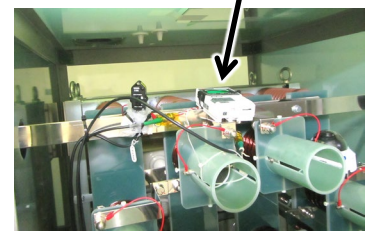
Small hole and HV line

PFN cover →

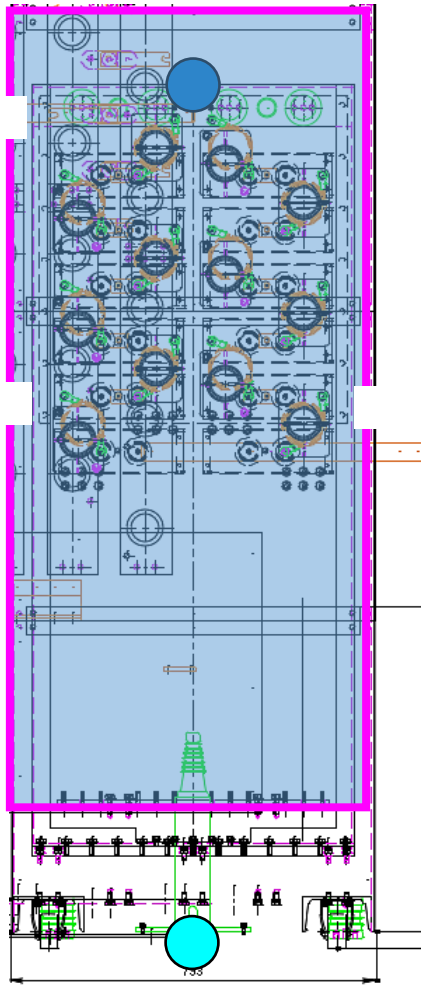


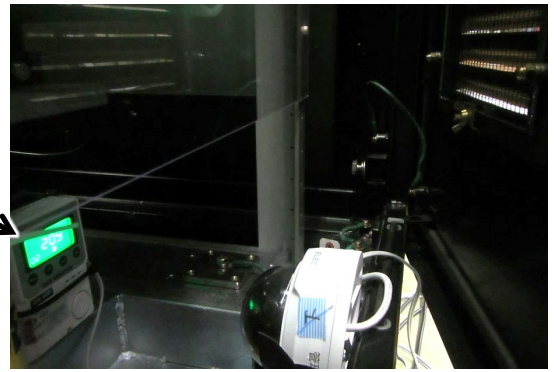
Measurement of the O2 level inside the modulator during/after the fire extinguishing gas injection (Aug. 25, 2022)





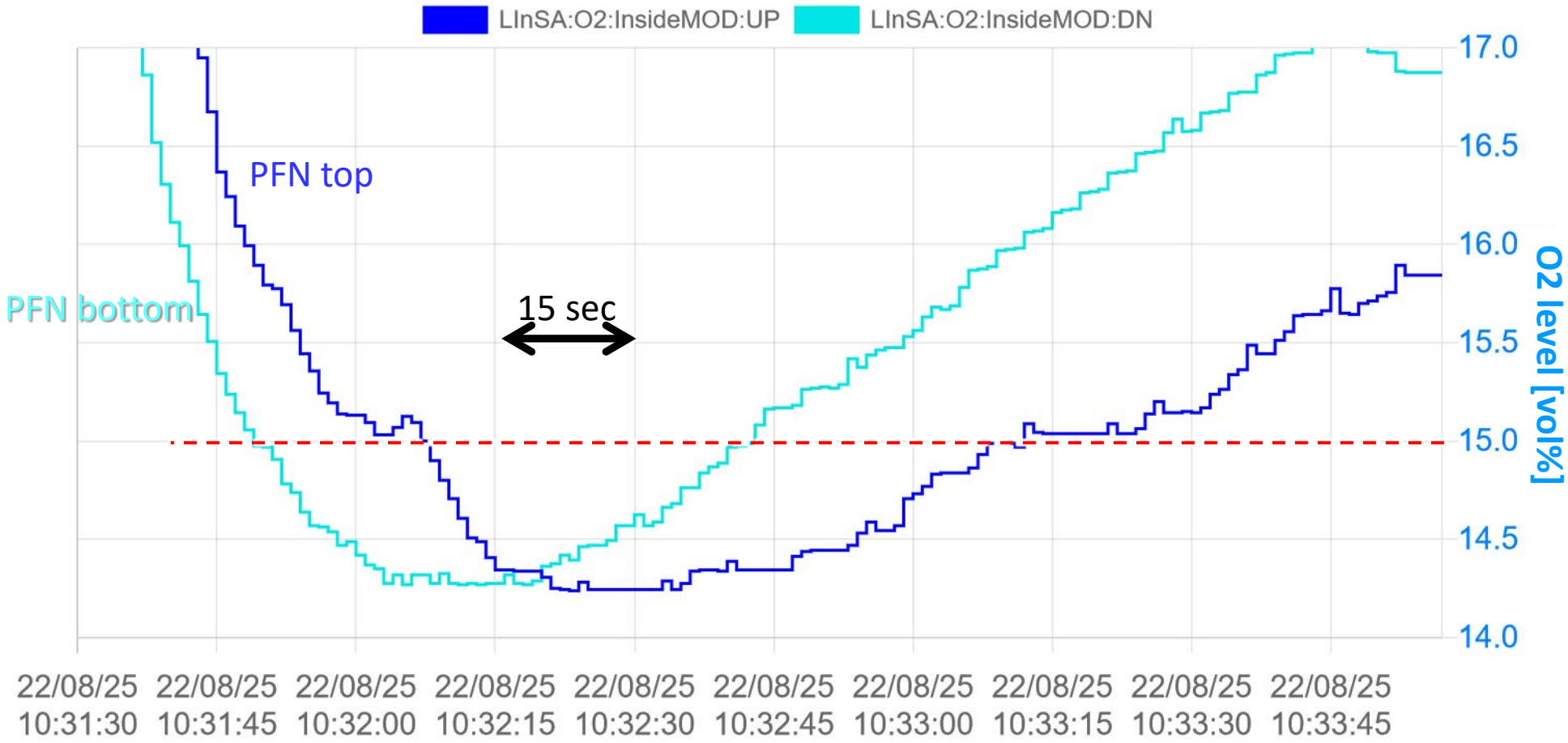
PFN

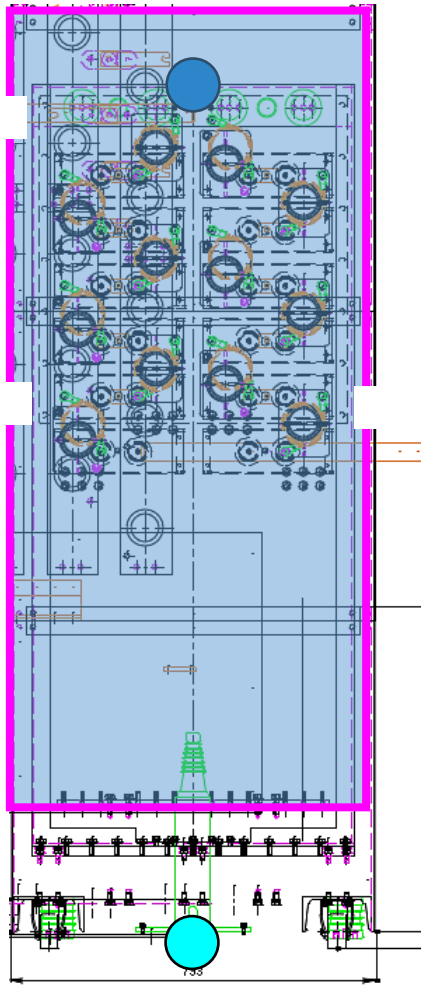




- ✓ **O2 level dropped to 14.3vol% (15vol% is the threshold for fire to persist.)**
- ✓ **After 1 hour, the O2 levels returned to normal (20.9vol%)**

Measurement of the O2 level inside the modulator during/after the fire extinguishing gas injection (Aug. 25, 2022)



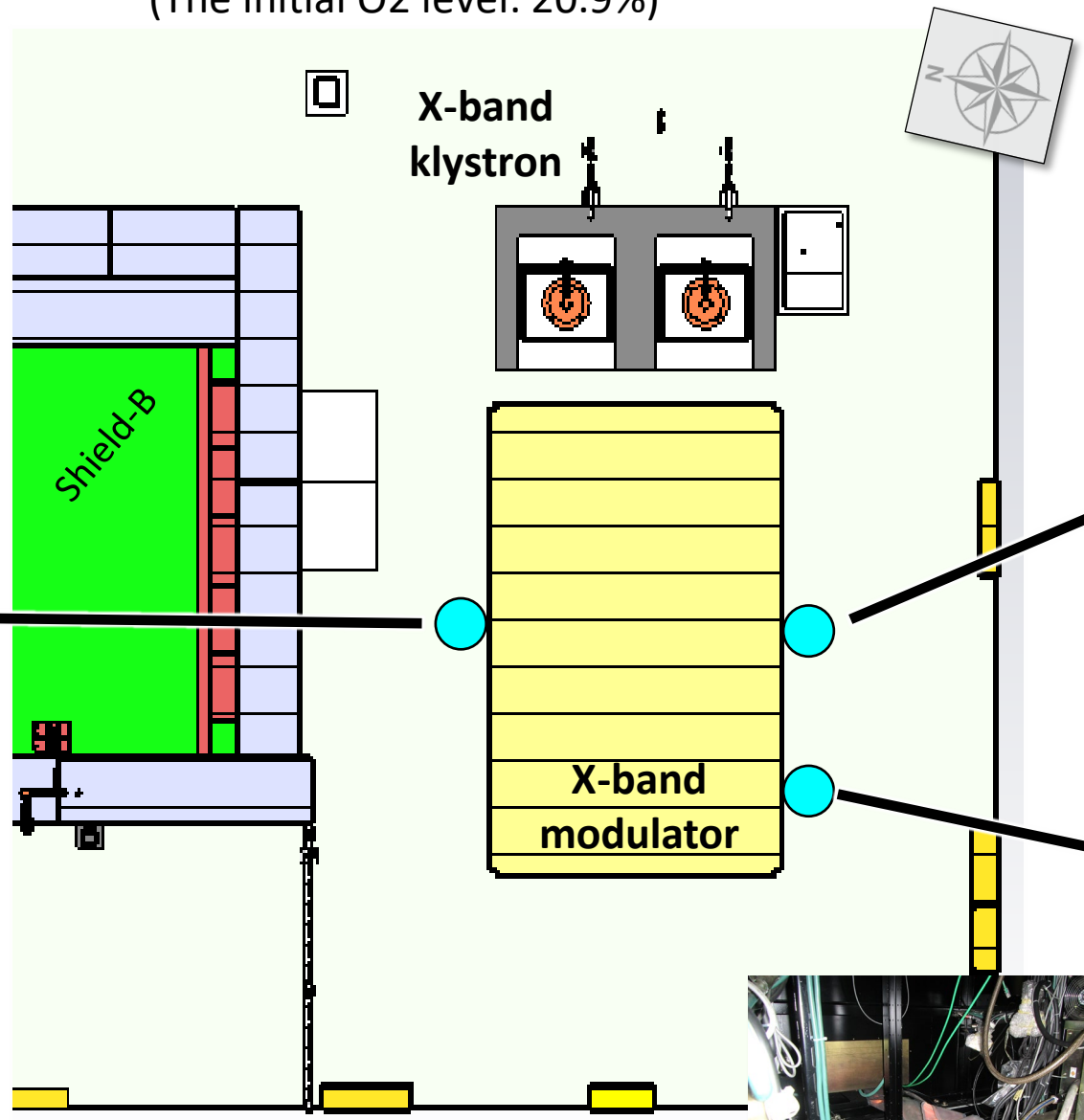


Time during the O2 level below 15vol%

- At the PFN top : 63 sec
- At the PFN bottom : 53 sec

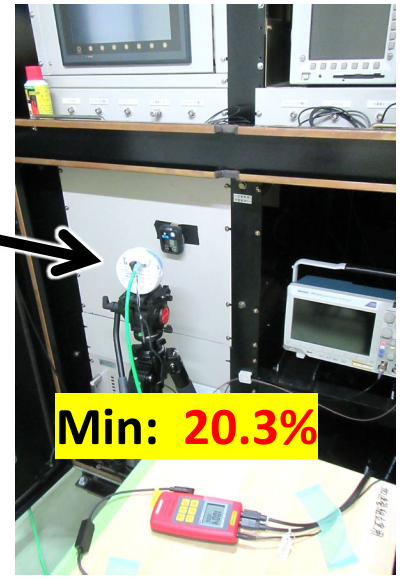
No change in the O2 level outside the modular @ at a height of 1 meter above the floor.

(The initial O2 level: 20.9%)



Min 20.9%

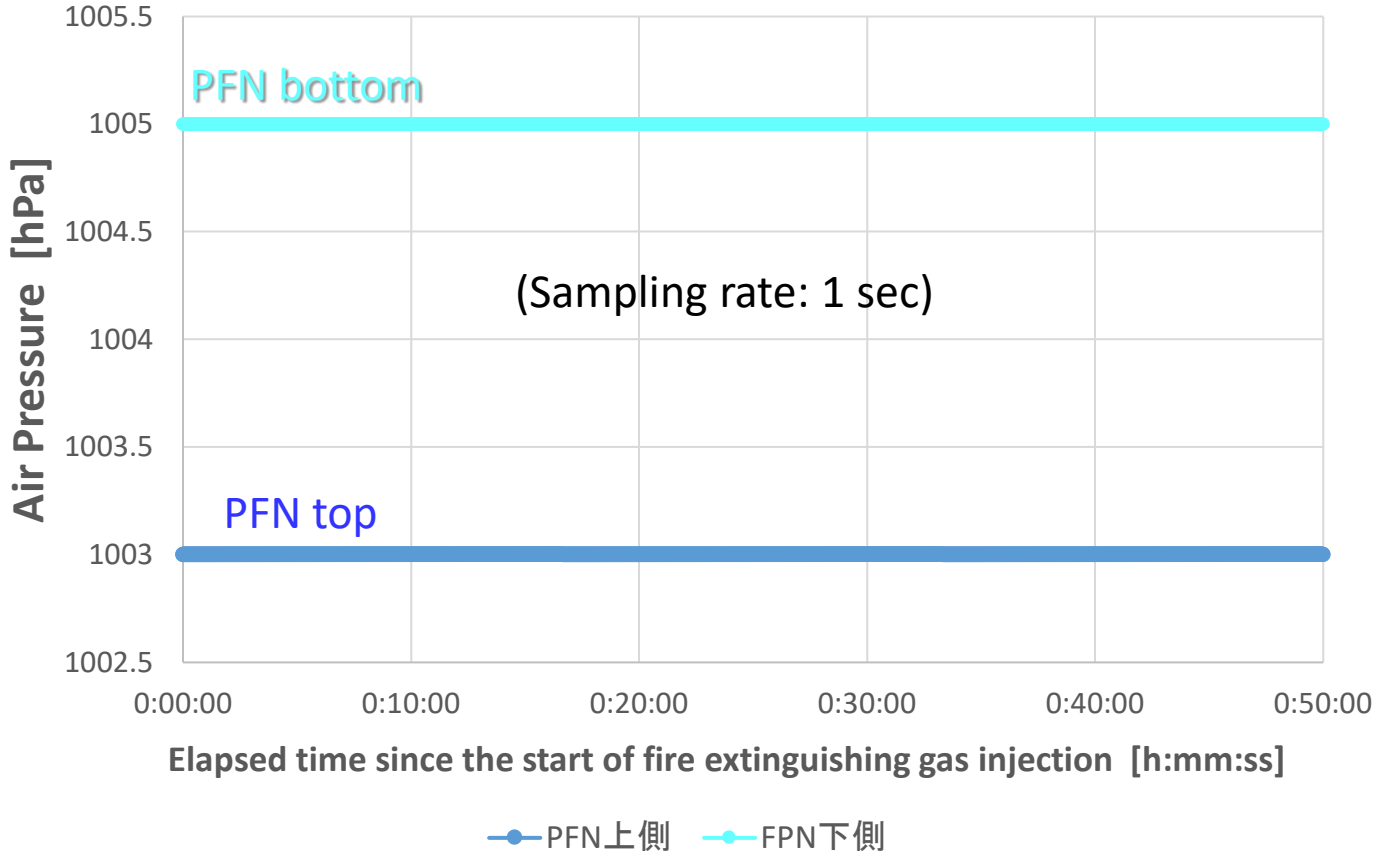
Min 20.8%



Min: 20.3%

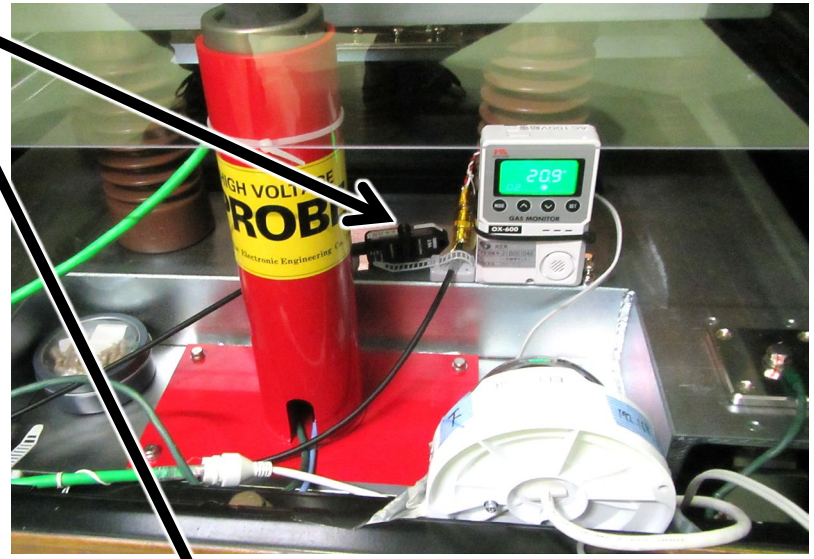
O2 levels outside the modulator cubicles are safe!

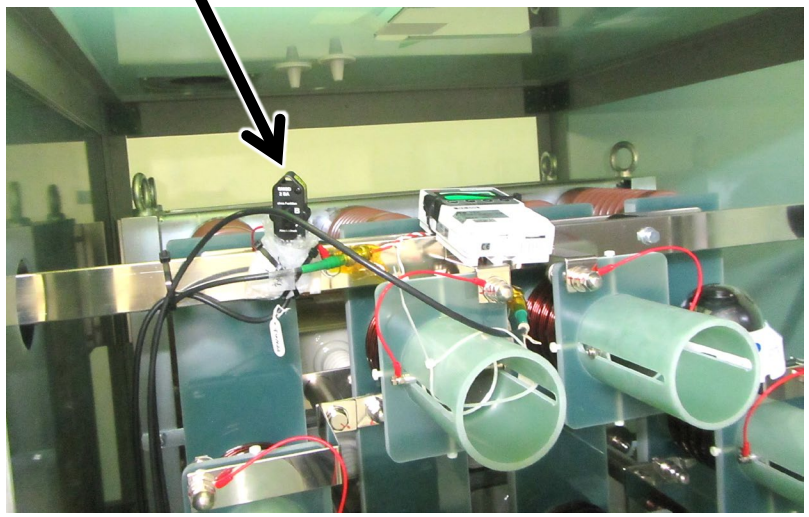
No change in gas pressure inside the modulator during/after the fire extinguishing gas injection



Pressure monitors

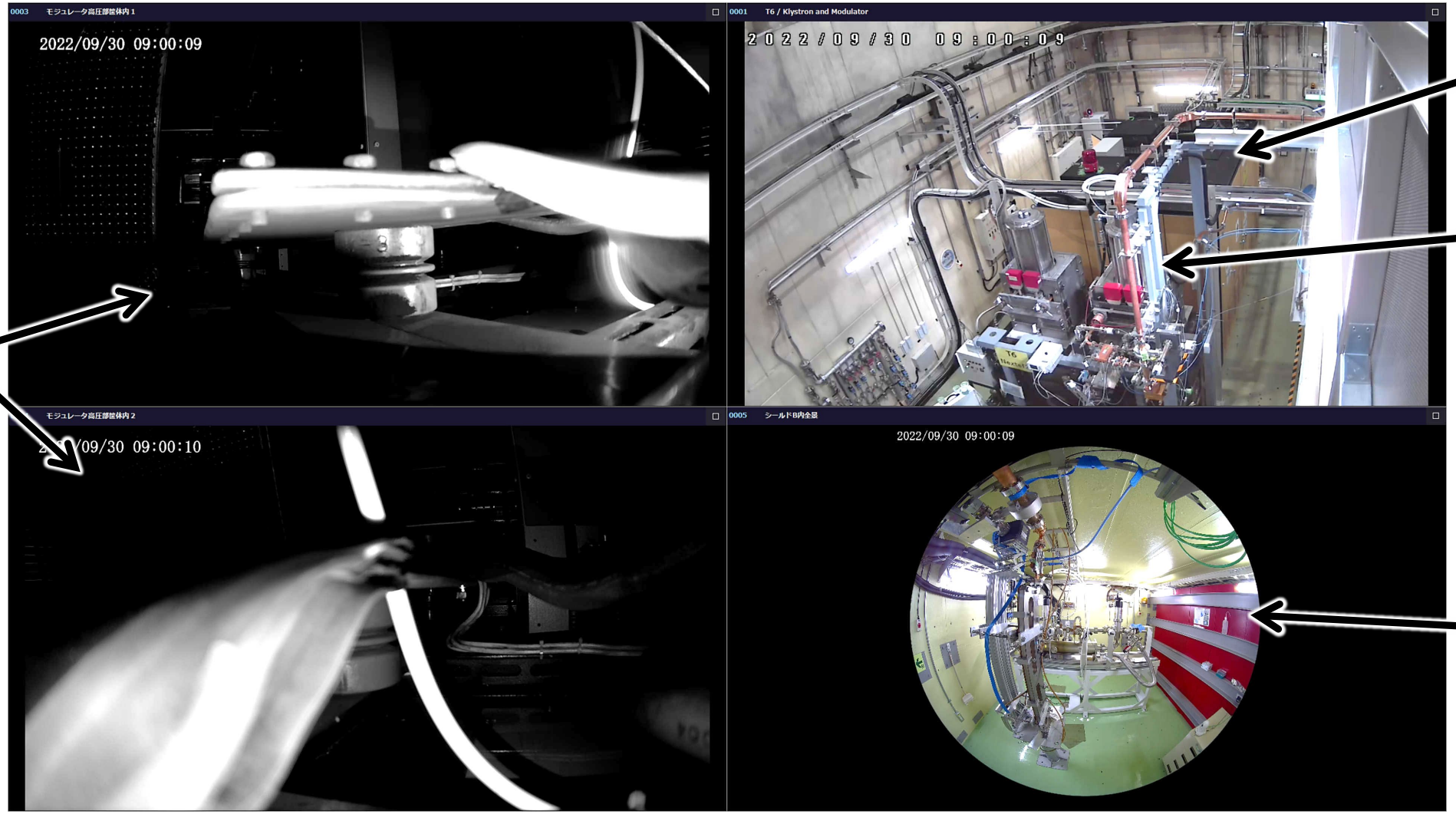
At the PFN top





At PFN bottom

Video monitoring at Nextef2



Modulator

Klystron

Inside the modulator (HV part)

Test area Inside the radiation-shield bunker (Shield-B)

Not only the outer appearance, but also the inside of the modulator being visually monitored

Listening to ultrasonic sounds from corona discharge

During operation with Es=36kV

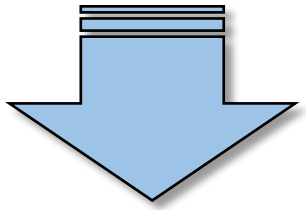
Ultrasonic leak detector made by SONOTEC Co., Ltd. (sensitive to ~40kHz)

To be incorporated in our regular inspection

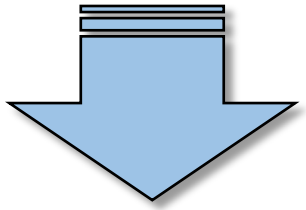
What we learned and future safety

- This experience with the fire has increased our safety awareness.
- For long-term projects, related persons and technologies are to be replaced.
- Long safety period makes our safety awareness weaker.
- Human (& money?) resources decreasing
- Future high-energy accelerator facilities are to be larger and more complicated

  ➔ Greater chance of an accident somewhere



Ensuring a high level of safety under such circumstances is considered to be beyond human ability.



“Smart Safety” based on modern technologies

Smart Safety

E.g. Project conducted by METI of Japan:
https://www.meti.go.jp/english/policy/safety_security/industrial_safety/index.html#smart

The idea is that safety and productivity can be improved simultaneously using modern technologies such as IoT, big data, and AI.

< Inputs >

- ✓ Currents/voltages
- ✓ Temperatures/humidities
- ✓ Smells
- ✓ Videos
- ✓ Ultrasonic sounds
- ✓ Microwaves
- ✓ Work/technical/failure reports
- ✓ All information available on the Internet
- ✓ Etc.

< Outputs >

- Pointing out dangerous points, areas, or rules
- Reviewing/proposing safety rules
- Stop dangerous operations?
- Etc.

Safety Management System for Future Large Accelerator Facilities?

Acknowledgment

- We are grateful to
  - Craig Burkhart
  - Keith Jobe
  - Tony Beukers

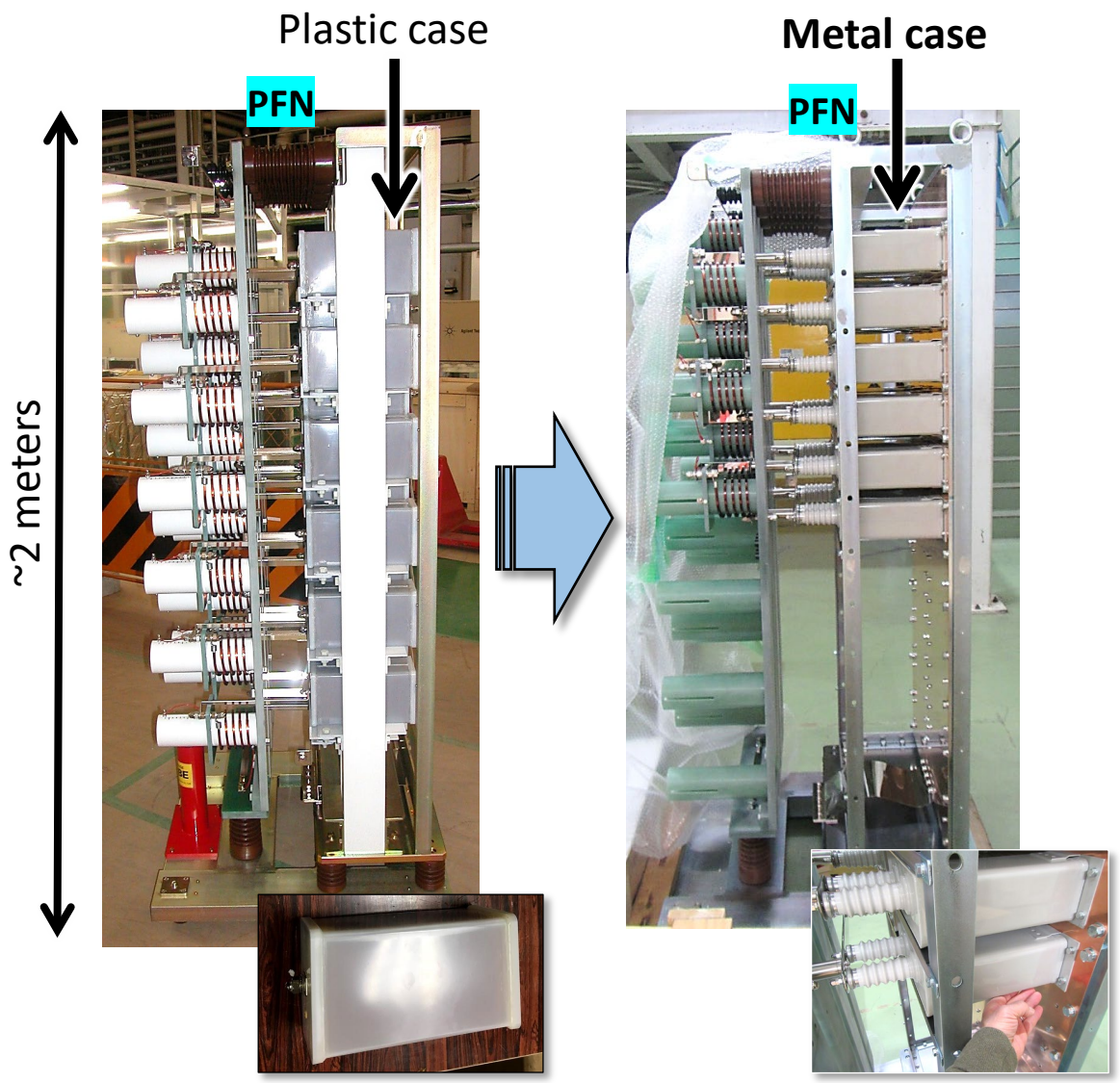
  for showing us the X-band modulators with fire extinguisher at NLCTA, and explaining safety matters at SLAC (Jan. 2020).

Thank you for your attention!

Backup slides

Capacitors replaced

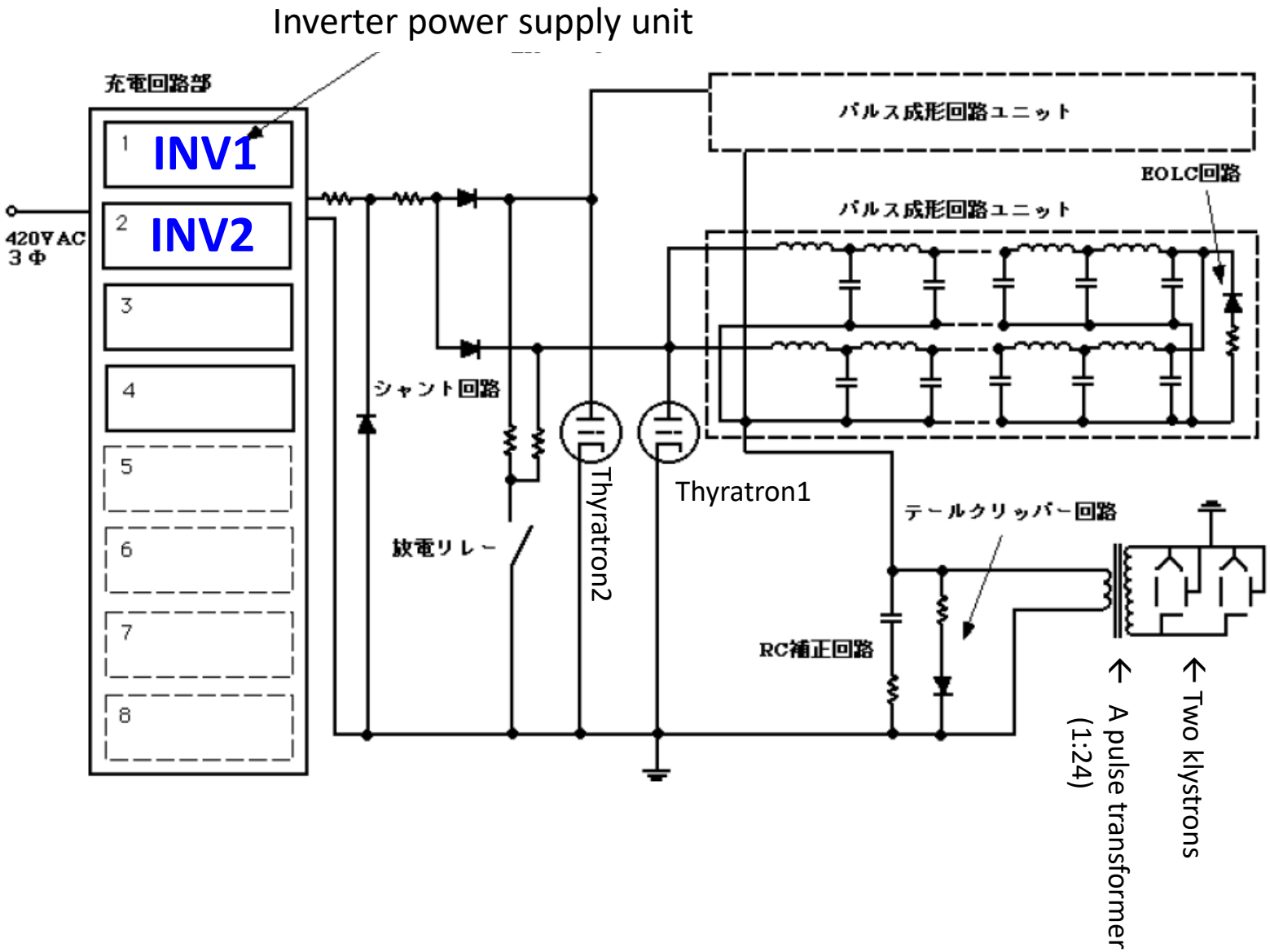
(PFN: Pulse Forming Network)



52.8 V/μm ➔ 49.8 V/μm @ 38 kV

Nextef modulator configuration at Nextef1

(PFN: Pulse Forming Network)



← PFN2 with 24 capacitors
(12 capacitors used)

← PFN1 with 24 capacitors
(12 capacitors used)

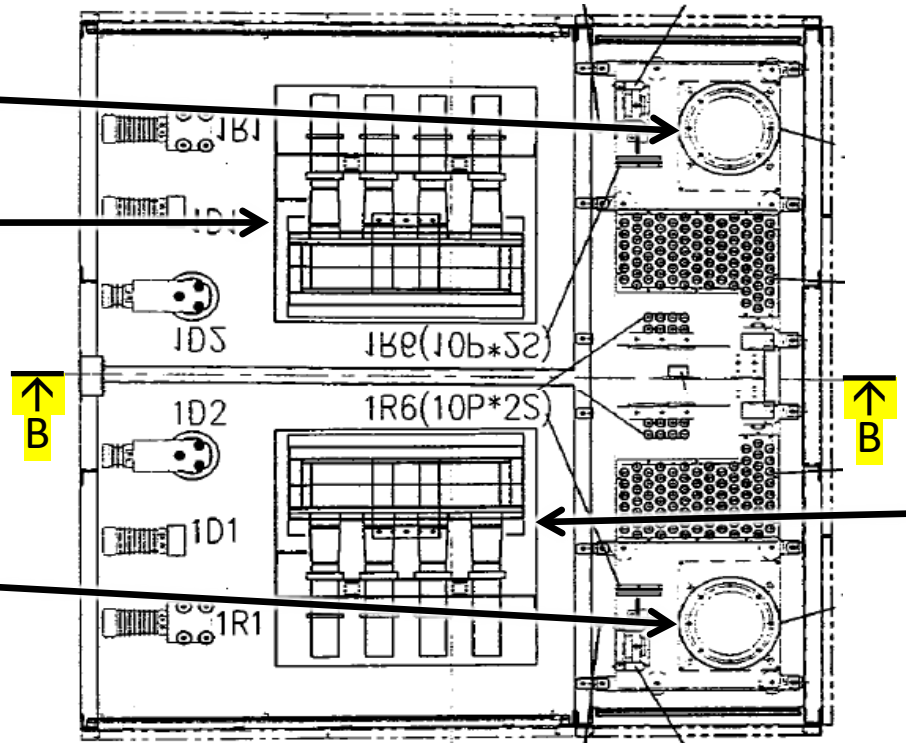
Modulator Drawing

(PFN: Pulse Forming Network)

Thyratron for PFN2

PFN2

Thyratron for PFN1

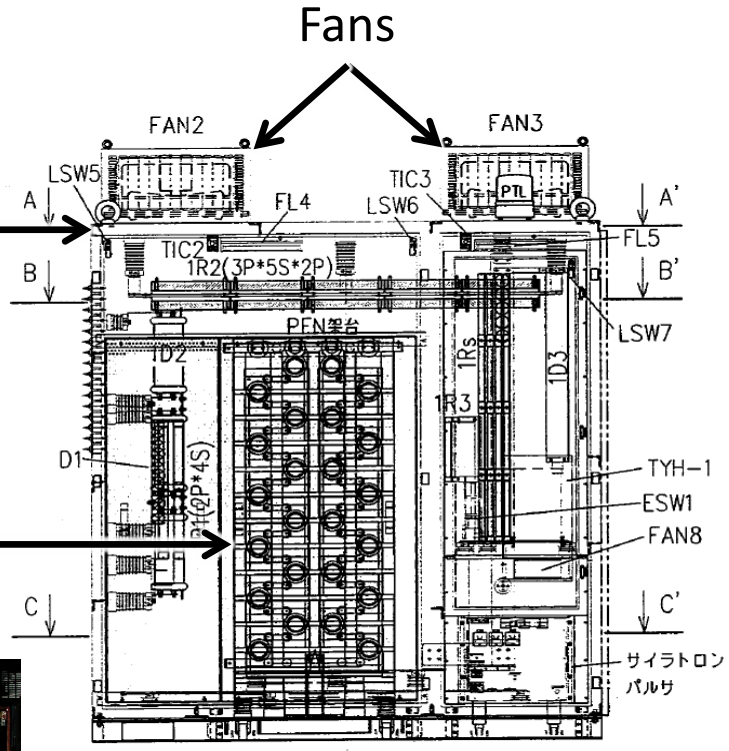


Top view (excluding the ceiling)

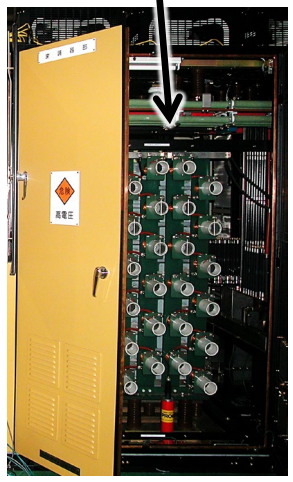
Fans

Ceiling

PFN1



B-B cross-section



Made by NISSIN
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