Fire at Nextef

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For Nextef team

The 23rd KEKB Accelerator Review Committee Meeting

2019-07-09

Missions of Nextef (New X-band Test Facility)

- X-band high-gradient accelerating structure collaborative development under agreement between CERN and KEK (ICA-JP-0103)

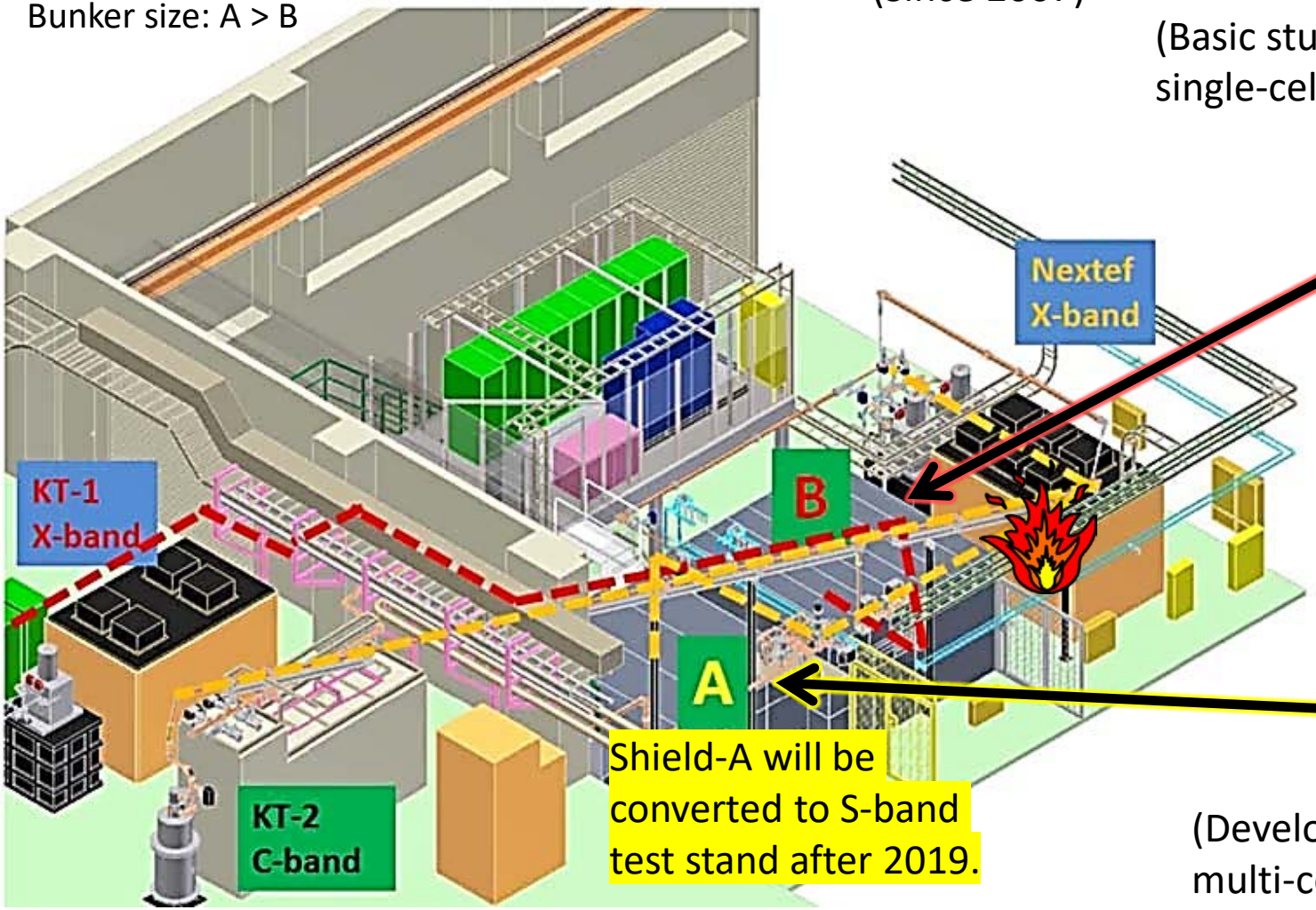
- Development of efficient and cost-effective high-gradient normal conducting accelerating structures as a US-Japan cooperative program (mainly with SLAC)

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

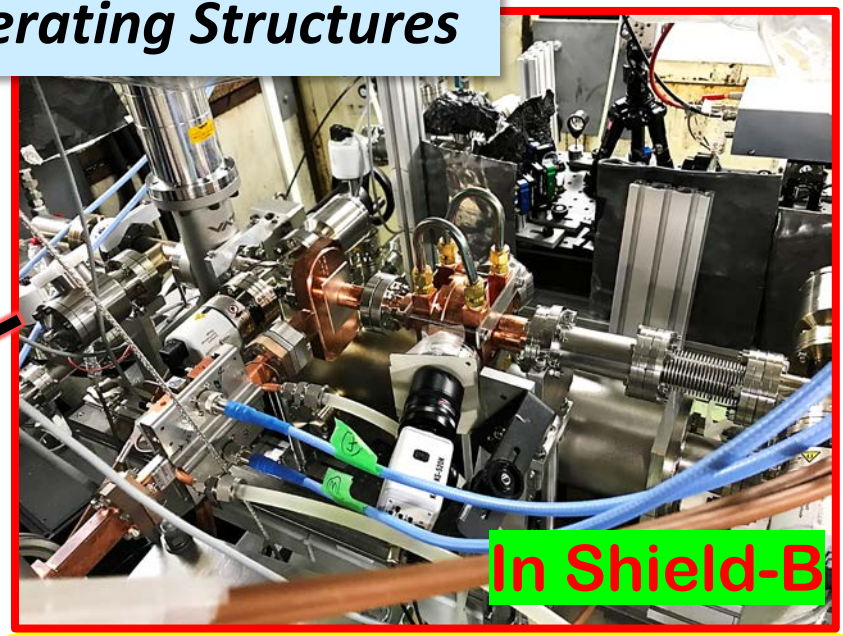
for testing Normal-Conducting High-Gradient Accelerating Structures

(Since 2007)

Bunker size: A > B



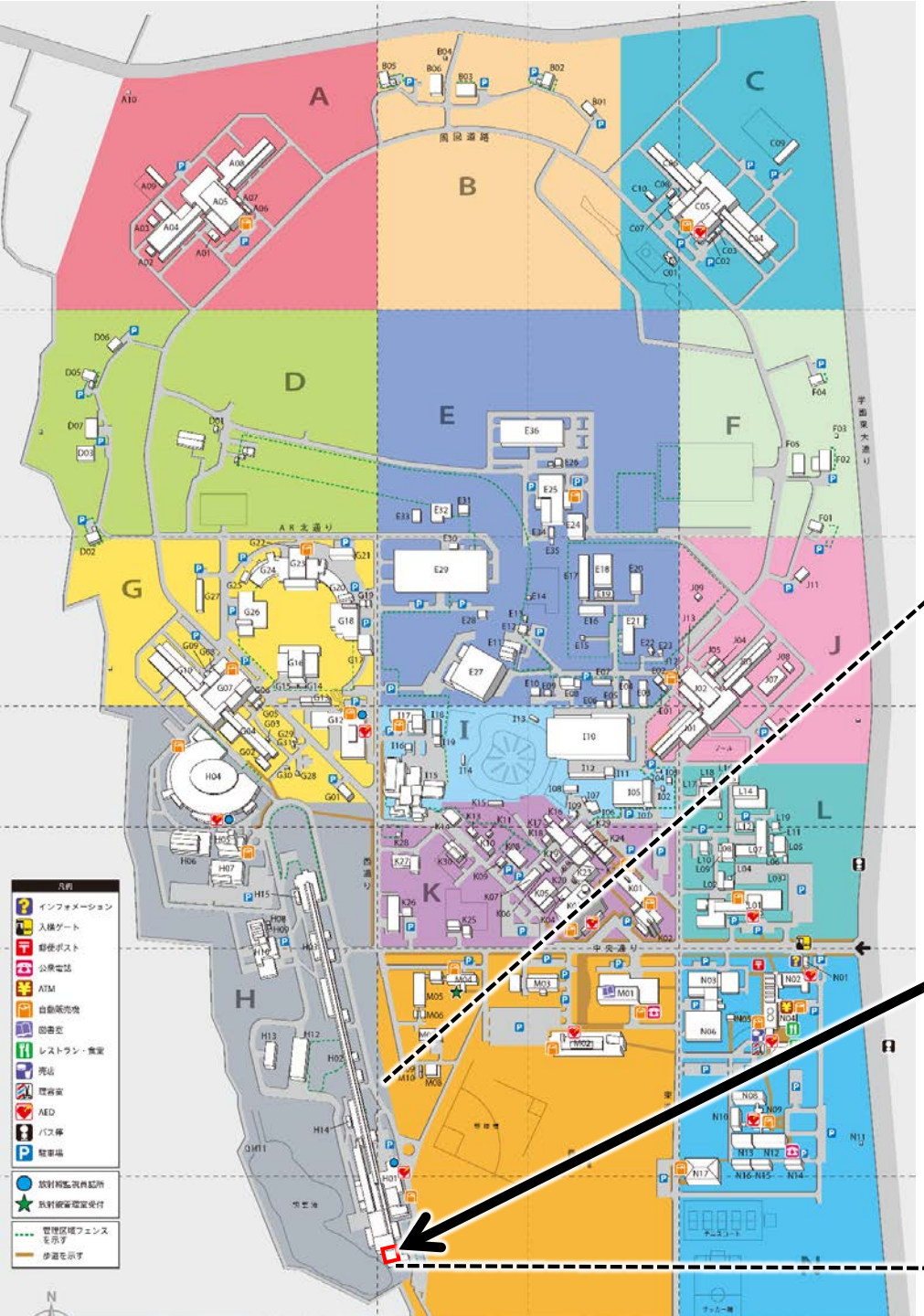
(Basic study using single-cell structures)



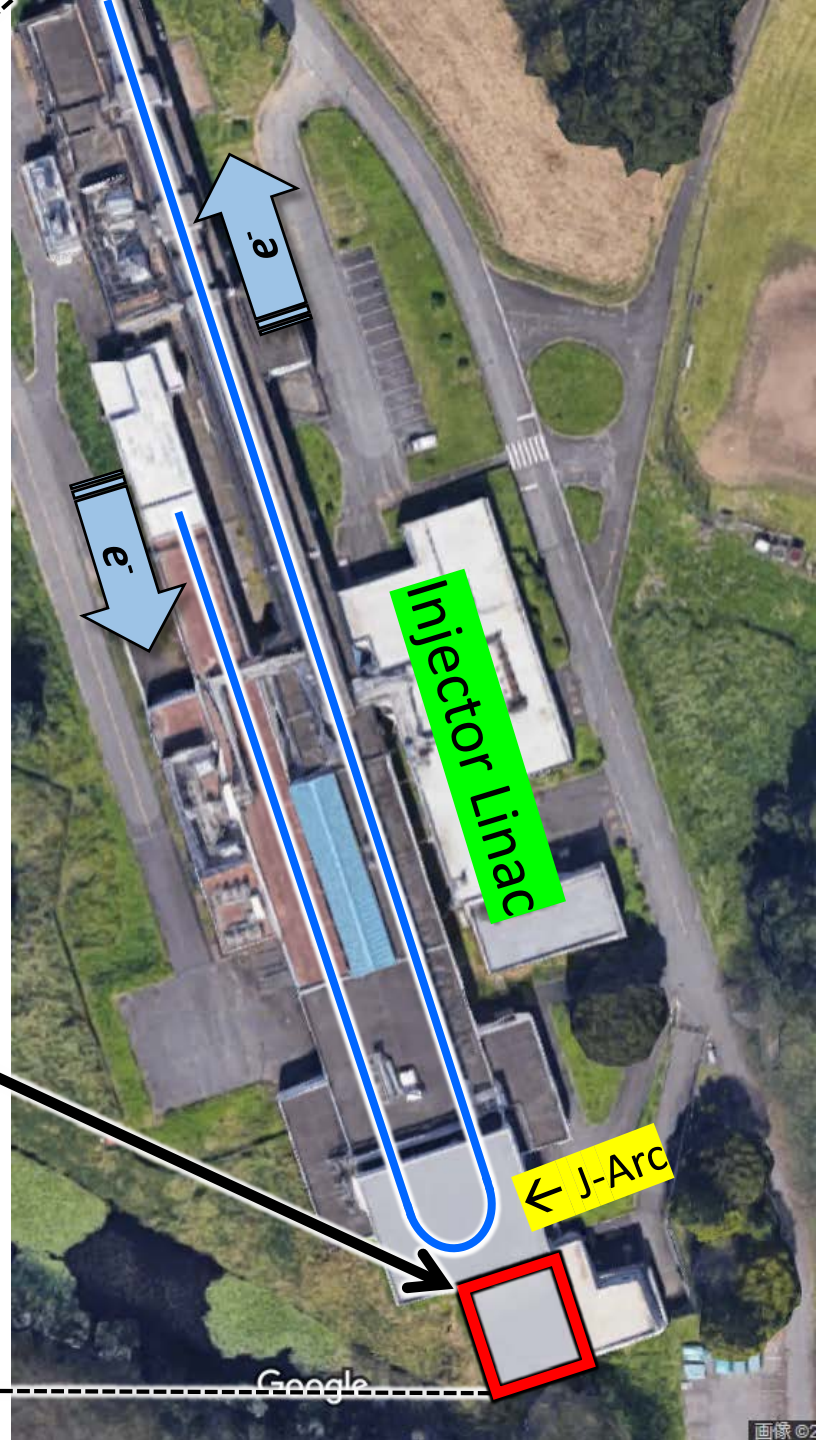
Shield-A will be converted to S-band test stand after 2019.

(Development of multi-cell prototype structures)

Operation time: ~4,000 hours / year



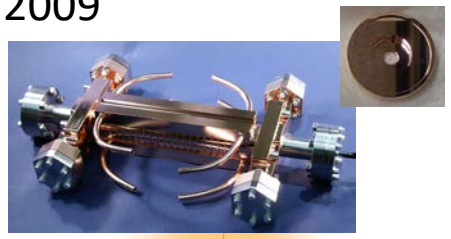
Where is Nextef ?



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

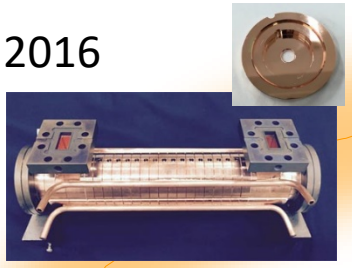
T18 → Quad → TD18 → T24 → TD24 → TD24R05 → TD24R05 → T24THU → TD24R05 → Deflector → TD24R05 → TD26CC → DCS → T24-K1 (terminated by the fire)

2009



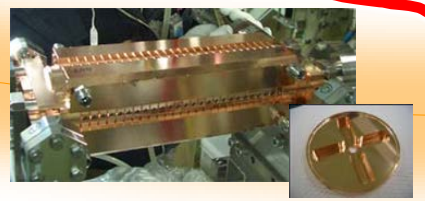
T18_Disk_#2

2016



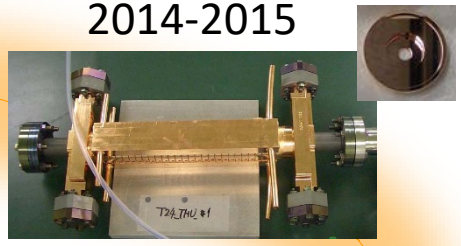
Deflector (SINAP)

2015



TD24R05_K1

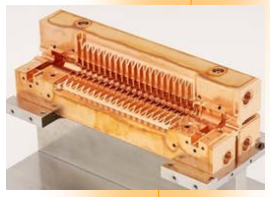
2014-2015



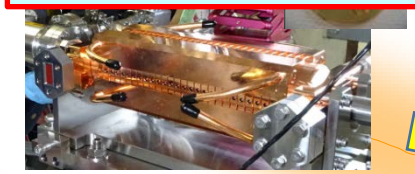
T24THU_#1 (Tsinghua)

- ✓ KEK-made
- ✓ Meet the CLIC specification (< 3 x 10^{-7} breakdowns/pulse/m) for E_{acc} = 100 MV/m

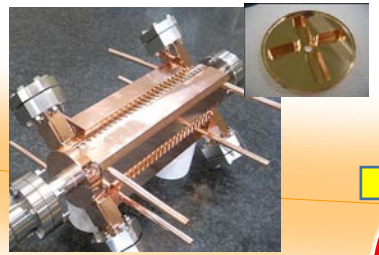
2009



TD18_Quad

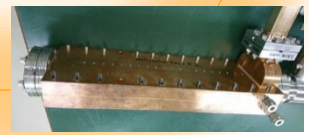


TD24R05_K2



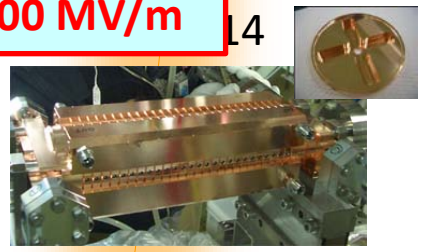
TD26CC_K1

2018



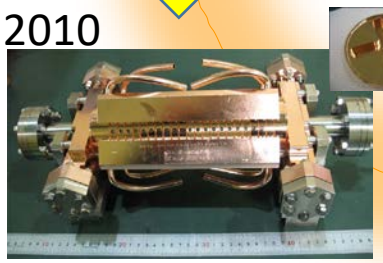
SLAC-DCS

14



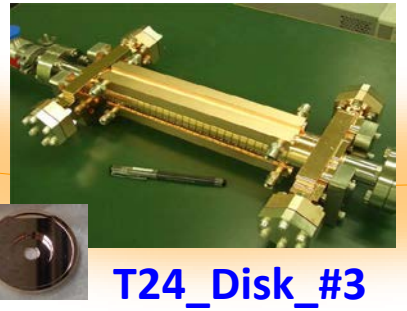
TD24R05_#4

2010



TD18_Disk_#2

2011

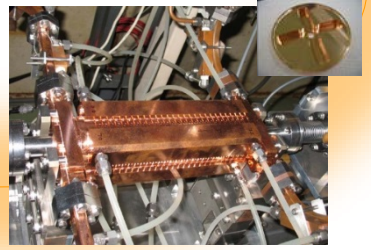


T24_Disk_#3

2011-2012

TD24_Disk_#4

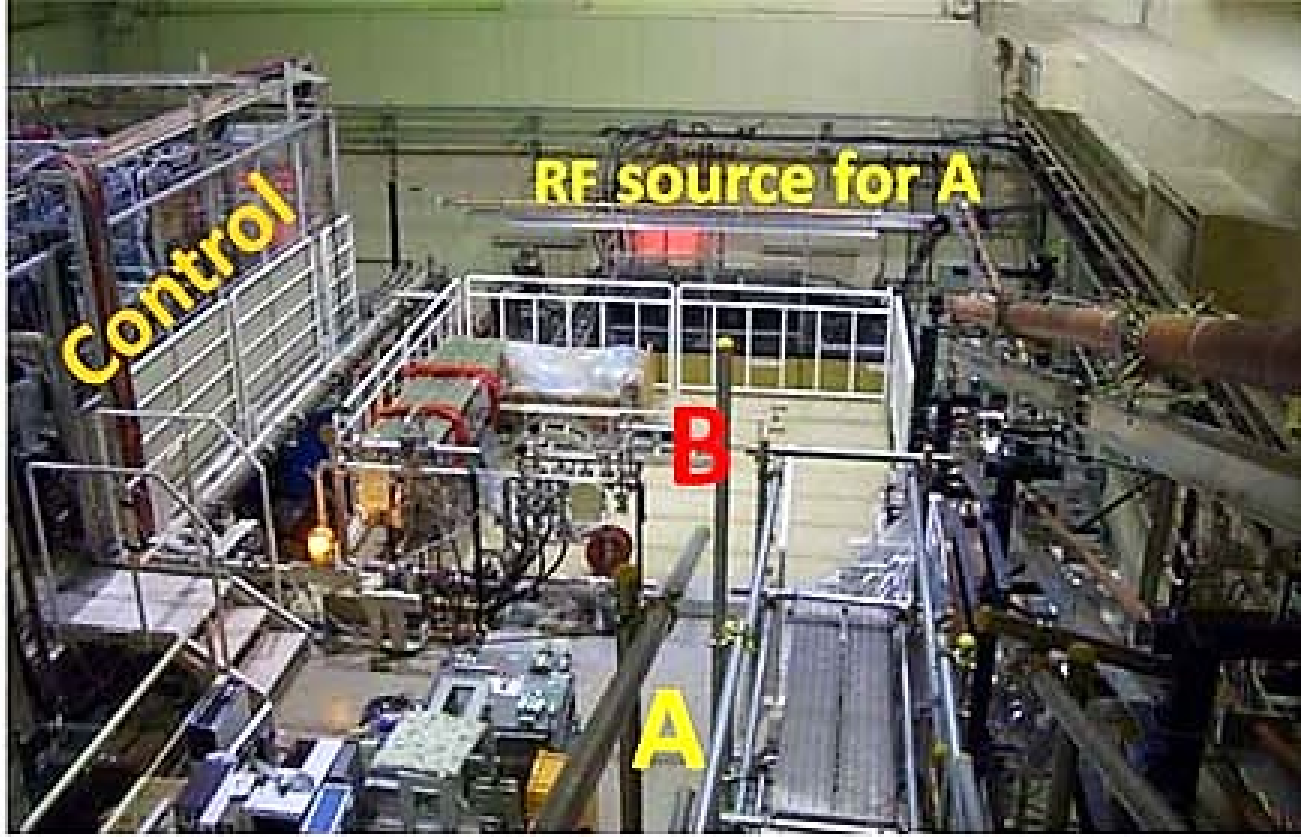
2012



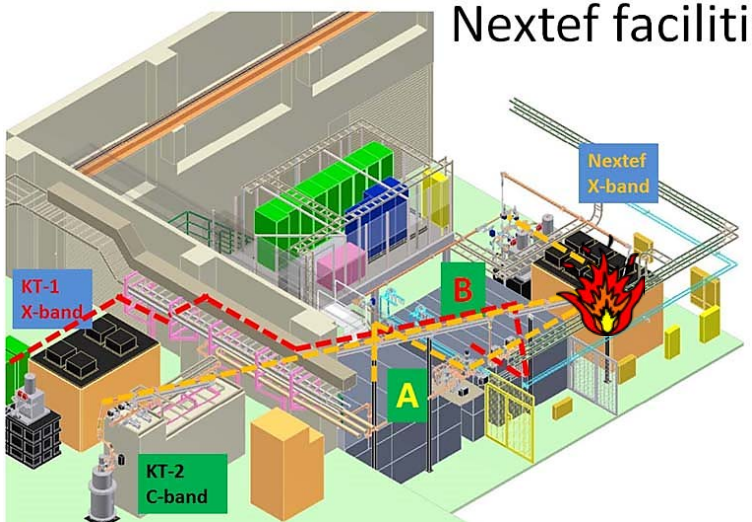
TD24R05_#2

Fire on April 3rd, 2019

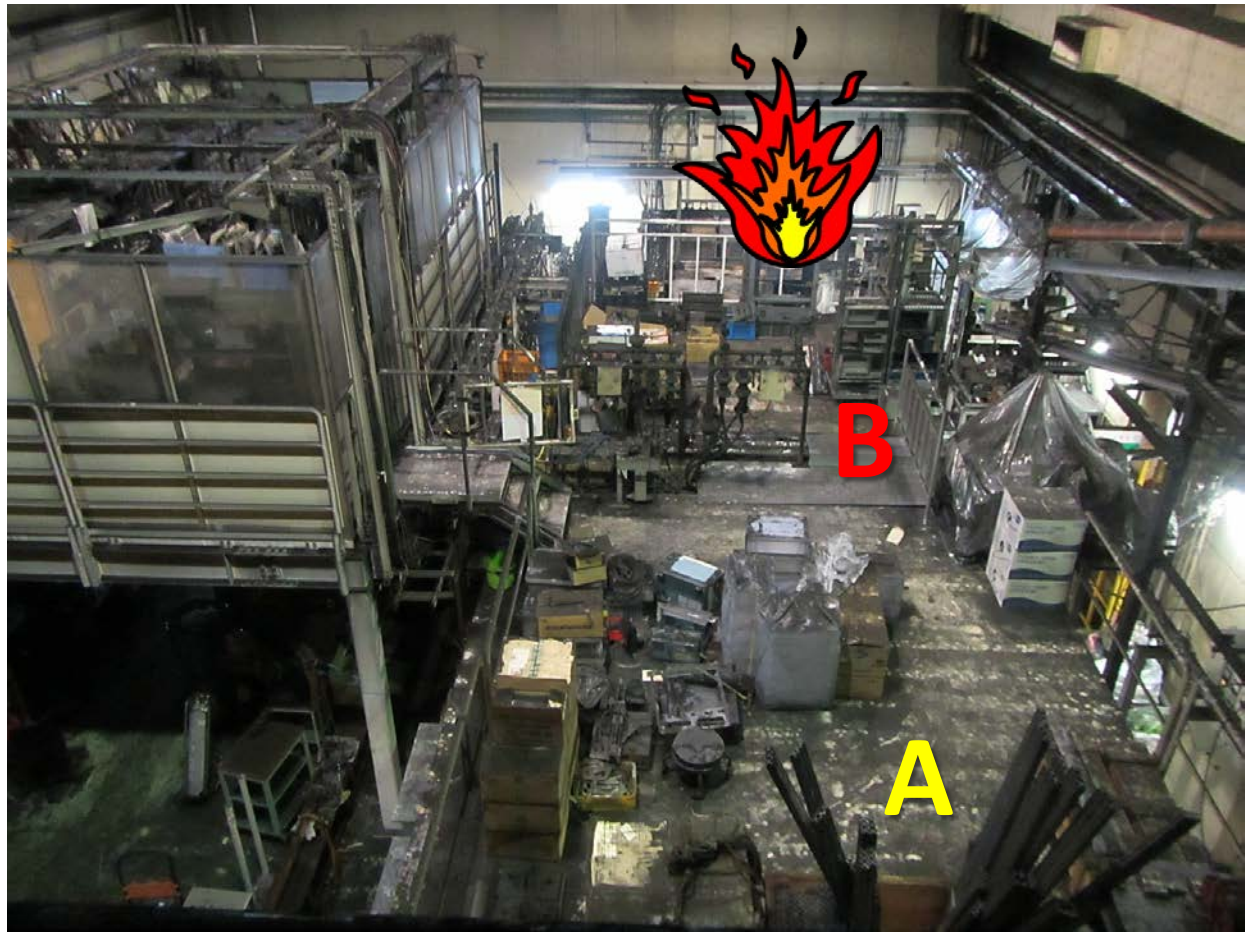
Before the fire



Nextef facilities

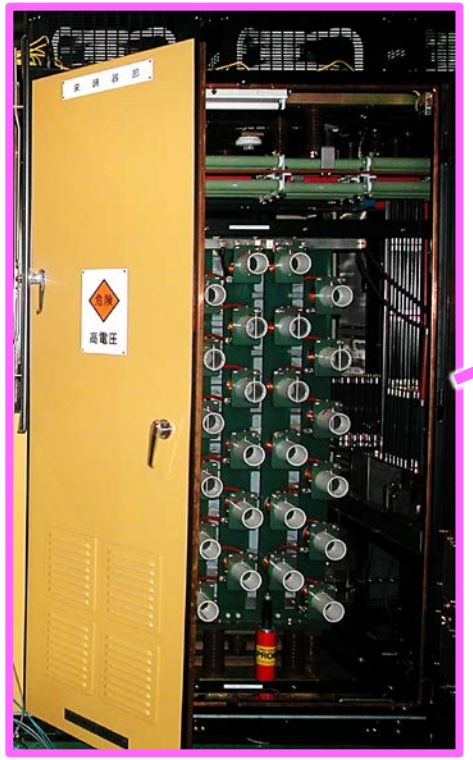


After the fire



Burnt modulator

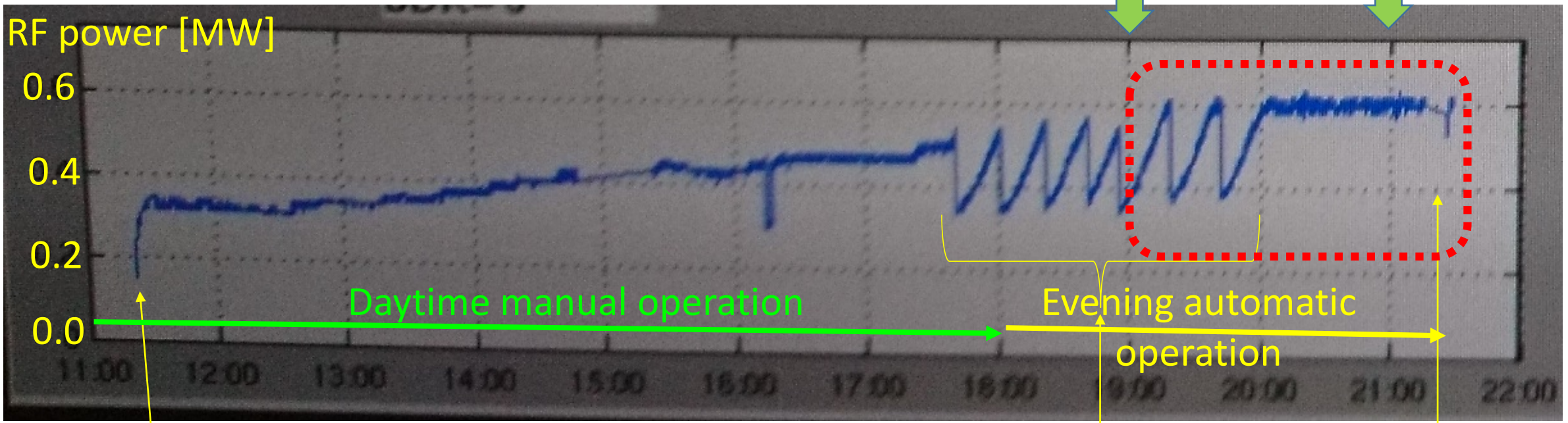
Photo before the fire



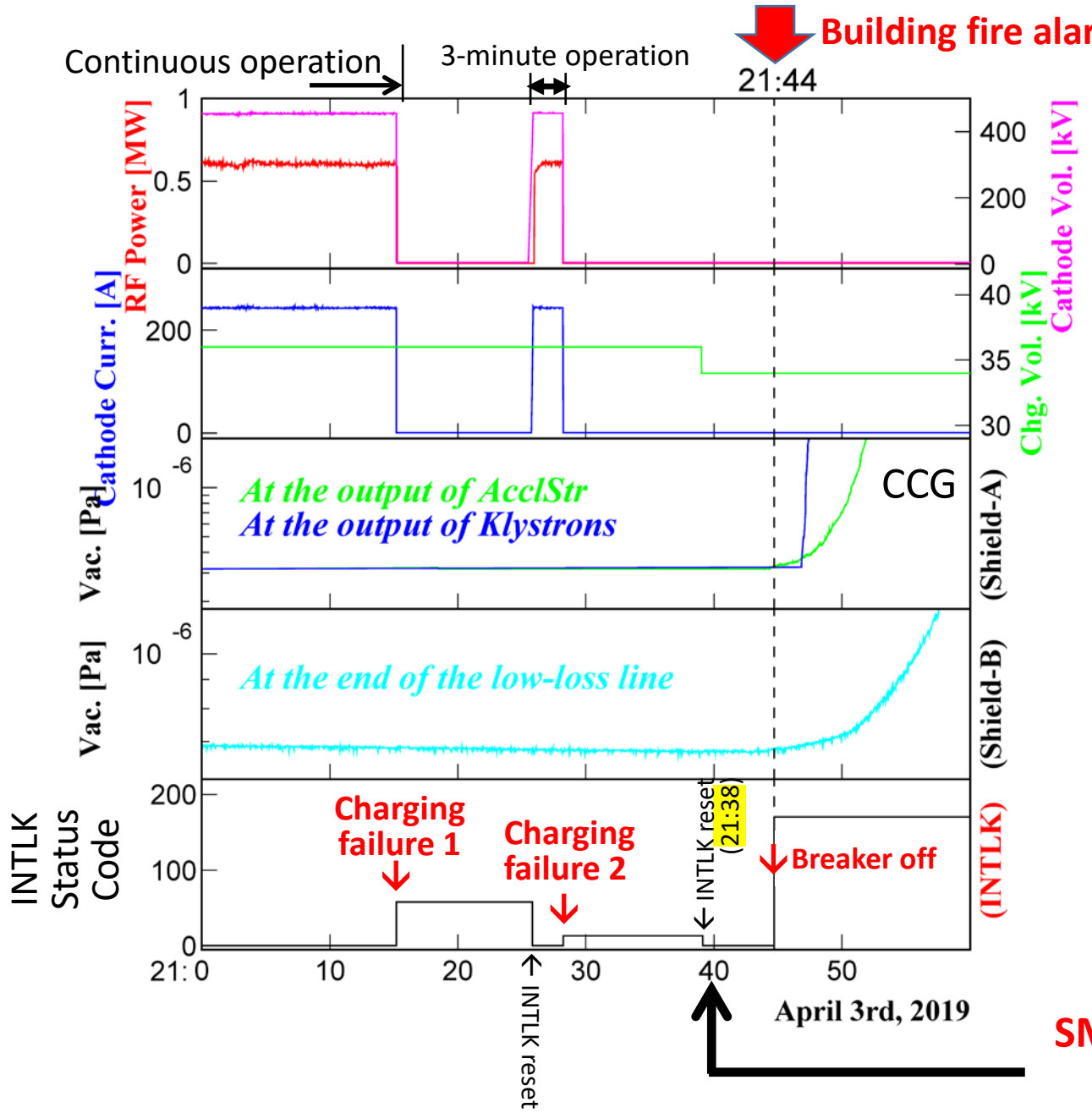
Operation History in April 3rd, 2019

Continuous Operation Started for High-Power Testing of a Newly Installed Accelerating Structure

(Final target RF power of this test: ~40 MW)



Just before the fire, History of the operation and INTLK messages



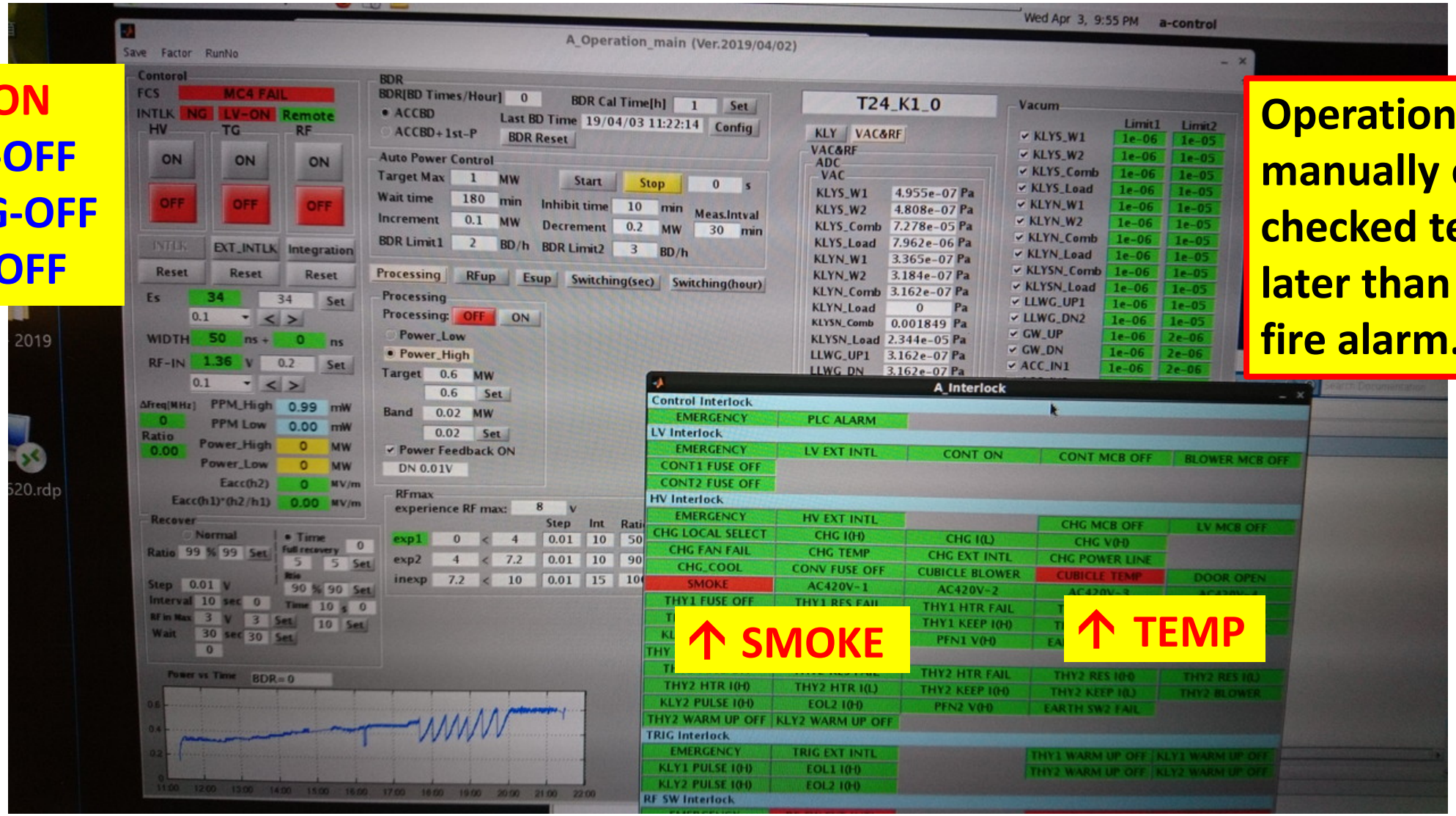
No particular until 21:38
(nobody in the site of Nextef)

SMOKE and **CUBICLE TEMP** activated
(for the first time)

Operation Panel with the final INTLK messages

At 21:55 on April 3rd, 2019

LV-ON
HV-OFF
TRG-OFF
RF-OFF

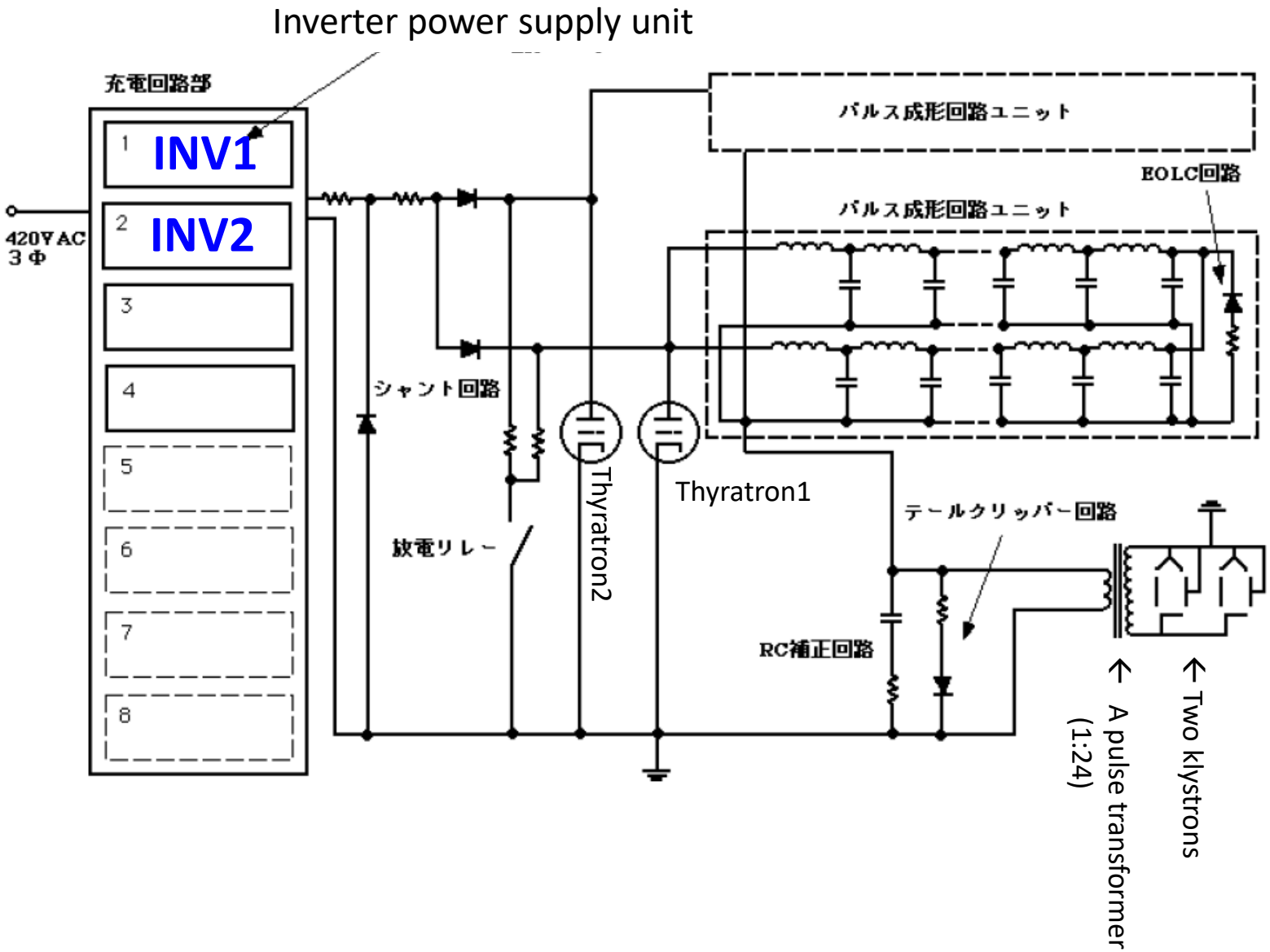


Operation panel manually opened and checked ten minutes later than the building fire alarm.

X-band Modulator

Nextef modulator configuration

(PFN: Pulse Forming Network)

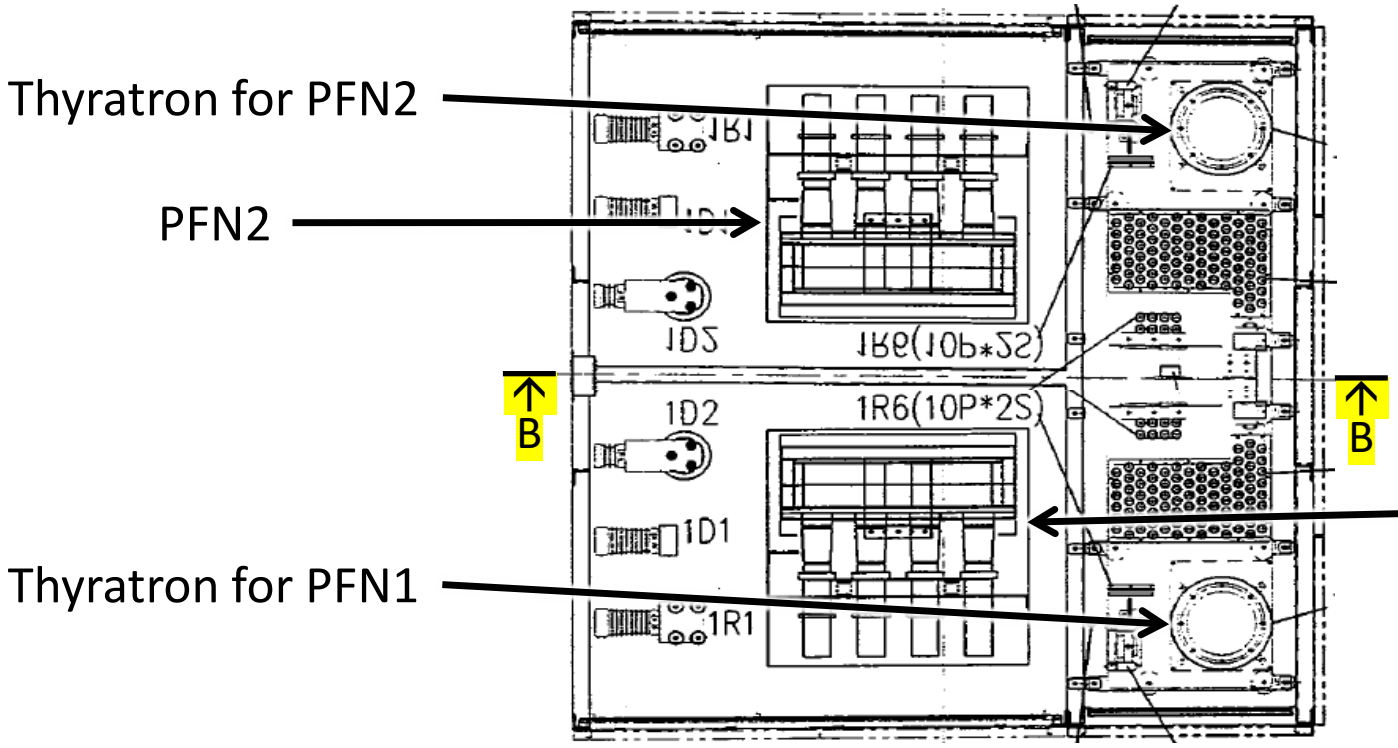


← PFN2 with 24 capacitors
(12 capacitors used)

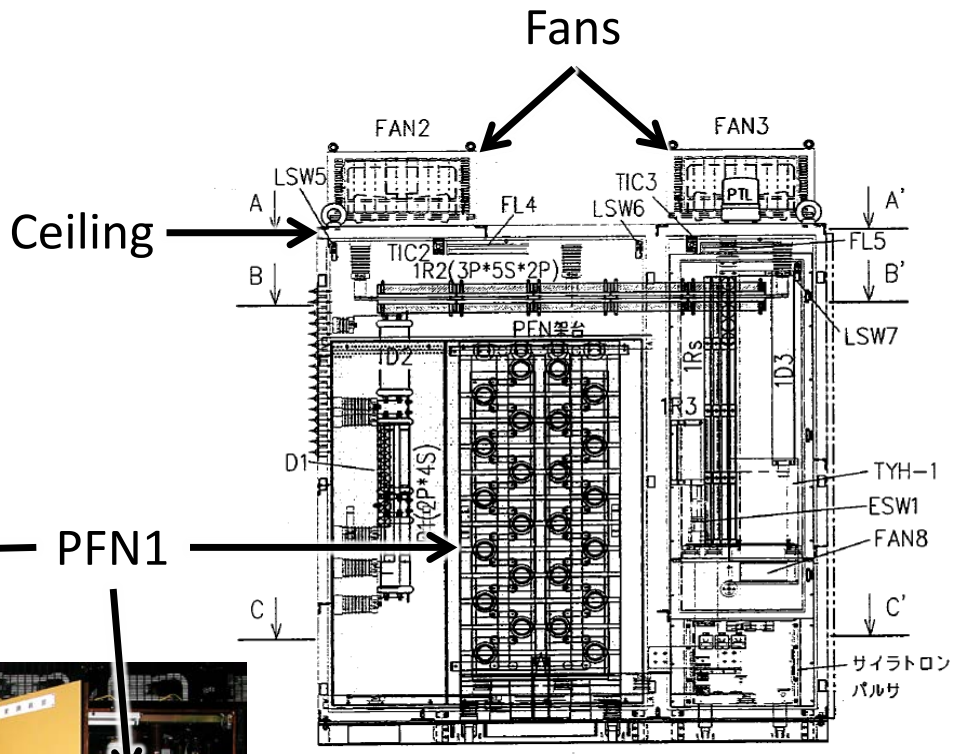
← PFN1 with 24 capacitors
(12 capacitors used)

Modulator Drawing

(PFN: Pulse Forming Network)



Top view (excluding the ceiling)



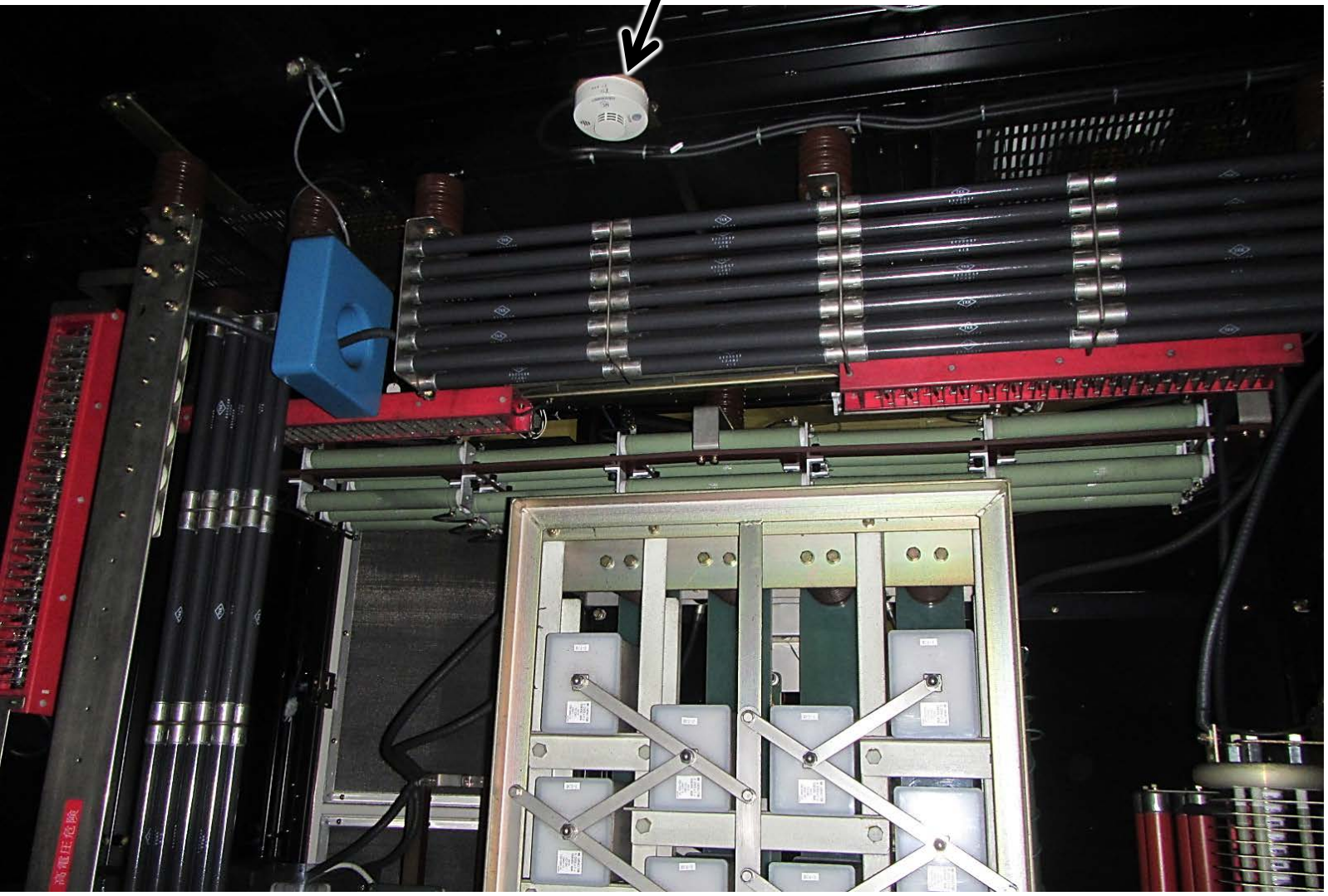
B-B cross-section

Made by NISSIN
(NKD-06900)

INTLK sensors in the cubicle of the X-band modulator

Smoke sensor

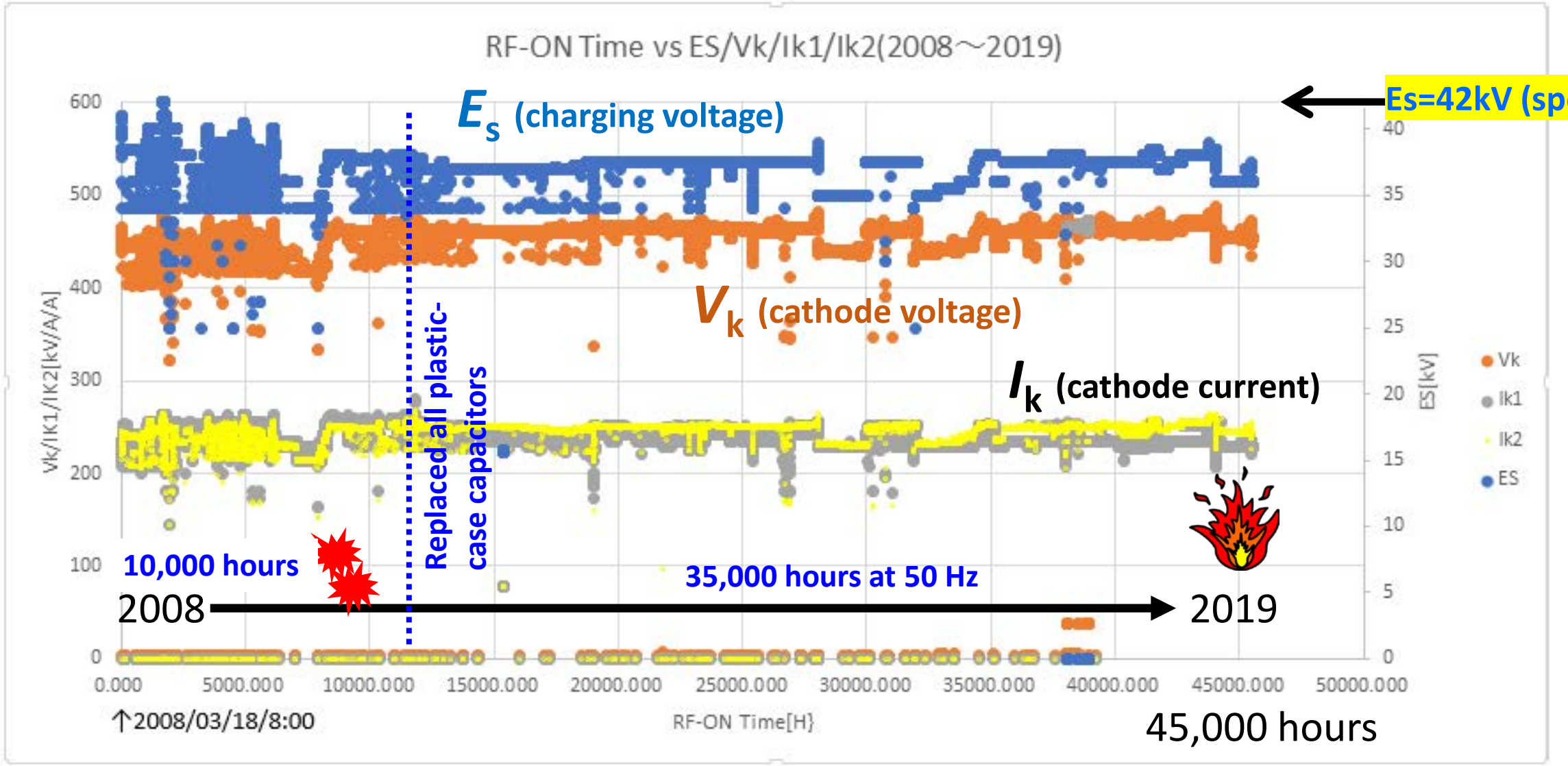
located at the center of the ceiling



Temperature sensor (Threshold: 40 degC)

located at the edge of the ceiling

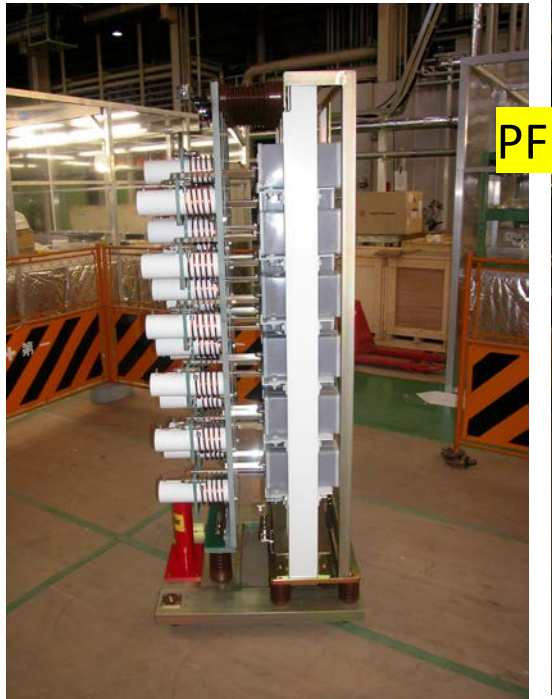
Long-term operation of the modulator



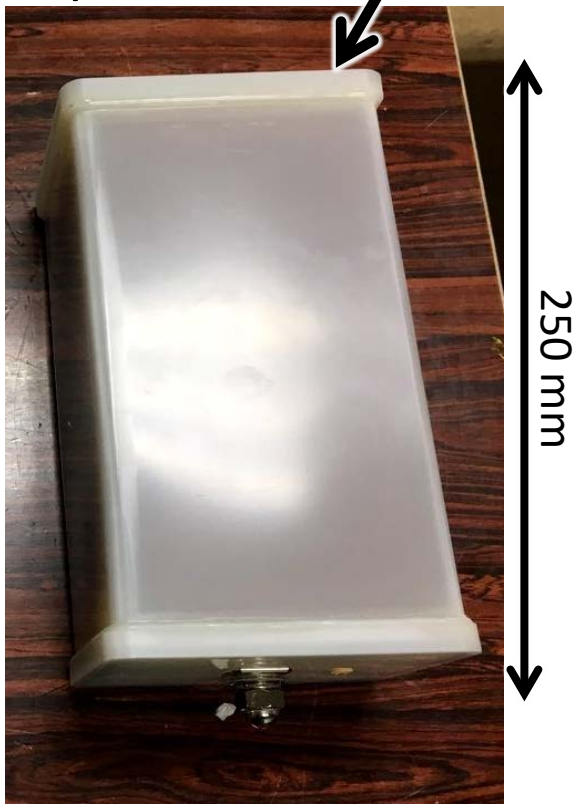
The Nextef modulator had been operated below the spec.

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



Puncture of plastic-case capacitors in the Nextef modulator

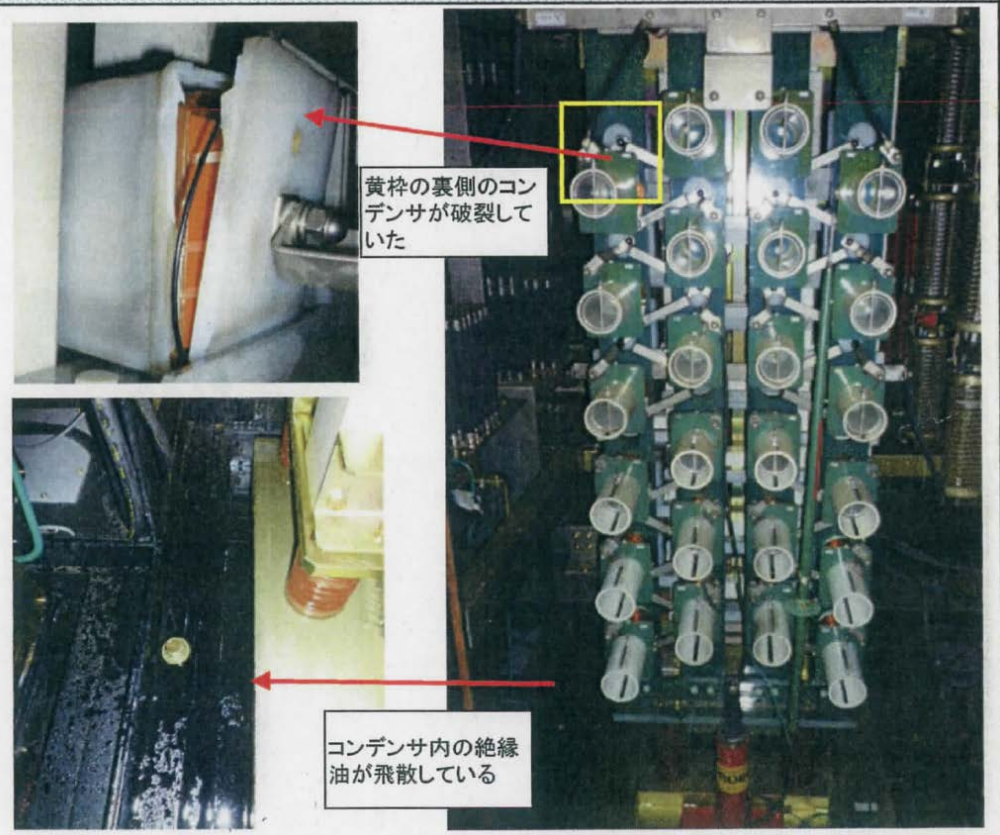
2010-02-21

＃２（北）PFN 最上段のコンデンサー不良

処置内容

2/21 時点
手の届く範囲で飛び散った絶縁油の拭き取りを実施。

画像 1



破裂したコンデンサと絶縁油飛散の状況

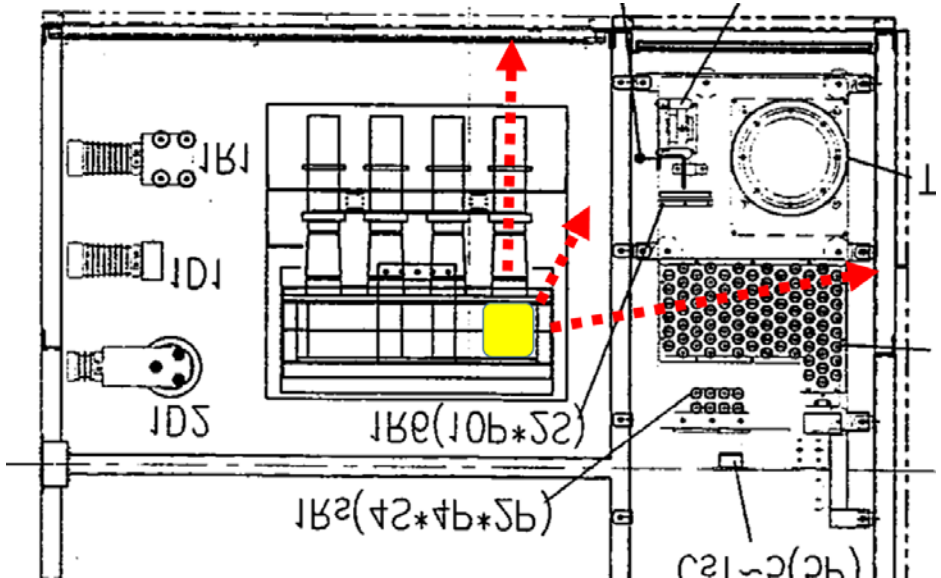
TR0116_100221_KL_T6 北側PFNのコンデンサ破裂した件.xls

PFN の東側壁

PFN の北側ドア

Oil splash

No fire

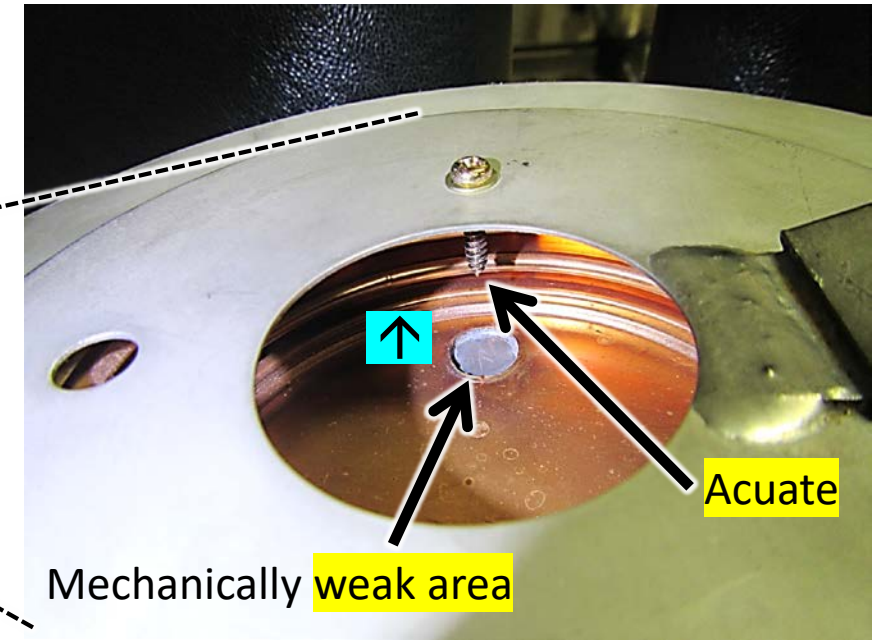


Parameters of the capacitors

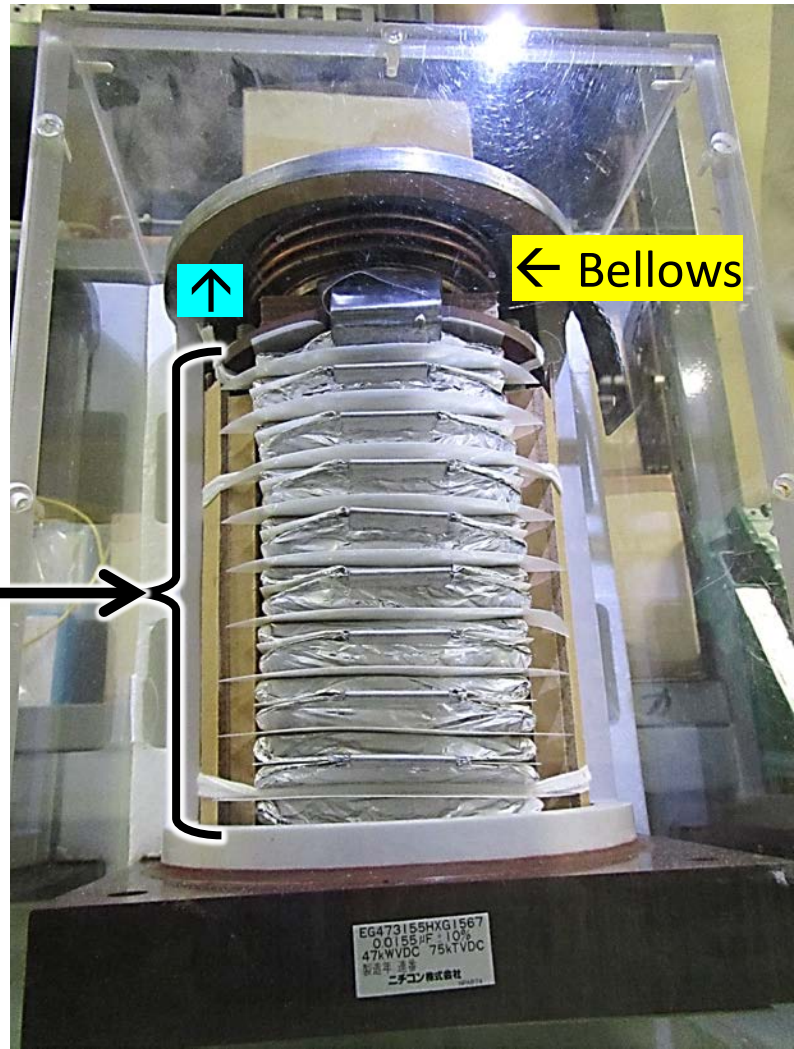
Safety-oriented

Item		Unit	Nextef (PFN2)	ATF (after improvements(*))	Injector Linac (S-band)
Case	Size	mm	110 x 140 x 250	150 x 130 x 380	∅162 x 260
	Volume	cm^3	3850	7410	5359
	Material		**Plastic**	**Plastic**	**Ceramics**
	Puncture protection		**None**	**None**	**Equipped**
Material of electrode			Al	Al	Al
Material of dielectric			Polypropylene	Polypropylene	Polypropylene + low-density paper
Type of insulating oil			Plant oil (flash point: 230 degC)	Plant oil (flash point: 230 degC)	Synthetic oil (flash point: 148 degC)
Weight		kgf	4.7	~10	10.0
Capacitance		nF	30.5	46	15.5
Charging voltage in op.		kV	38	44	43
# of elements			20 to 22	25	21
Electrode gap		μm	36	36	47
Potential gradient in op.		V/μm	**52.8**	**48.9**	**43.6**
Repetition rate in op.		Hz	50	3	50
Lifetime	Design	hour	$3.9x10^5$	$1.0x10^5$	$1.5x10^5$
	Estimate	hour	—	—	**$2.8x10^{15}$**
Time to failure		hour	~35,000	> 10,000 (No failure)	> 150,000 (No failure)

Puncture protection mechanism in the capacitors for Injector Linac



(Cut model)



Comparison

Ceramic-case capacitor at Injector Linac

Plastic-case capacitor at Nextef

Safe

250 mm

in capacitance

Price : ~3,000 USD ~500 USD

Cost-effective

(*) Significant improvements made for plastic-case capacitors used at ATF

- The winding method to form a capacitor from films was improved to reduce the appearance of wrinkles and make the electrode gap uniform.
- The potential gradient in operation was reduced to make the lifetime longer.
  - 75 ➔ 48.9 V/μm
  - lifetime ∝ (potential gradient)^n (n >> 1)
- The fabrication process was improved to suppress foreign matter inclusion into the insulting oil.
  - Foreign matter inclusion was observed in the previous versions of plastic-case capacitors.
  - Foreign matter inclusion is known to induce partial discharge.
- Various sizes were reviewed and re-optimized.
- etc.

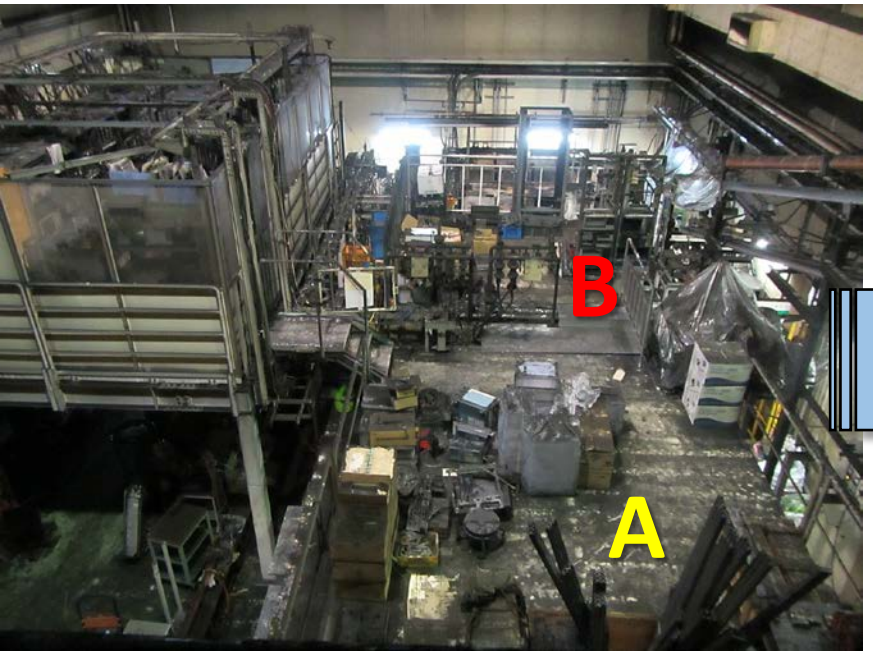
(In the Nextef modulator, we used the previous versions of plastic-case capacitors fabricated before the abovementioned improvements were made.)

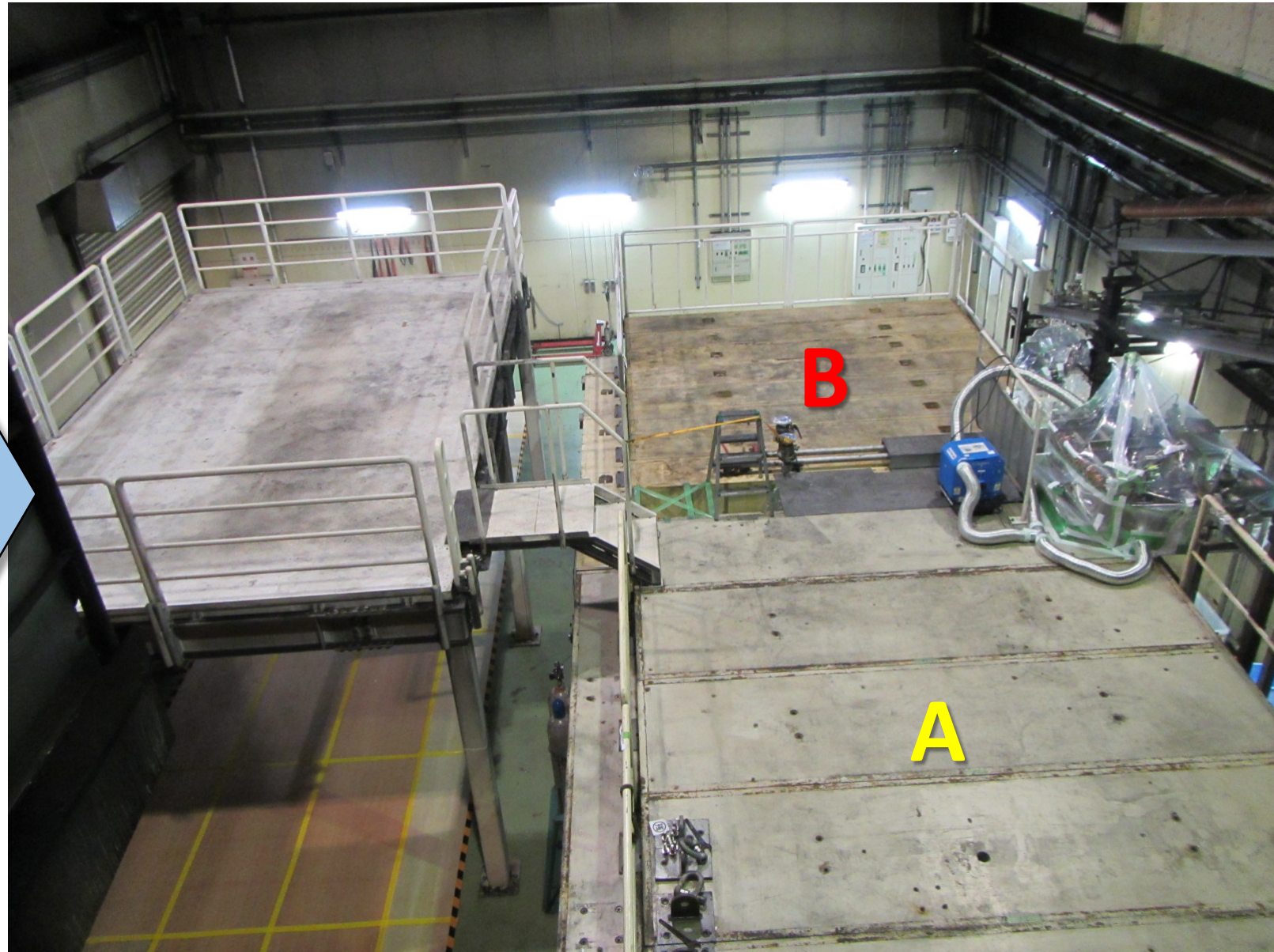
Recovery

All the devices, equipments and instruments have been removed for cleaning the experimental hall.

(Taken at the end of Jun., 2019)

(Taken in April., 2019)





Nextef system improvements under consideration

1. No plastic case, use metallic or ceramic case for capacitors.
2. Reduce potential gradient in capacitors
3. Routine check of capacitors on size, capacitance, loss tangent, etc.
4. Install monitoring the modulator by TV cameras
5. The smoke detection in the cubicle of the modulator should be integrated in the fire alarm system of the building.
6. If smoke is detected, stop cooling fans attached on the modulator ceiling.
7. Fire extinguisher should be installed inside the modulator, and activated automatically.
8. Location and sensitivity of smoke sensors should be optimized.
9. Temperature sensors inside the modulator should be optimized.

Nextef recovery protocol proposal after modulator-related INTLK activation

1. Check INTLK messages, recorded pulse shapes, and videos recorded by TV cameras
2. Input check marks to make sure all of the above items are checked
3. Temporally reset by physical switch located near the modulator
   - Remote reset is then impossible(**).
   - By this temporal reset, we can resume the operation, and proceed to the next step.
4. Confirm normal operation
   - Locally check the situation by seeing the operation for half or a minute in a close distance from the modulator
   - Then we can push the main reset button
   - Unless this main reset button is pushed within a defined period (e.g. 60 s), HV is forced to be OFF.

(**) At ATF, remote reset of modulator-related INTLK has been impossible from the beginning.

Summary

- Nextef is a high-gradient test facility for normal-conducting accelerating structures.
  - Operated since 2008, basically 24-hours, ~4,000 hours/year
  - Achieves enough performance of X-band prototype structures to meet the CLIC specification.
- Fire in the modulator on April 3rd, 2019
  - Severe damage to only Nextef but also Injector Linac
  - The most likely cause is puncture of the plastic-case capacitors.
  - Recovery process underway
  - More safe capacitors will be used for the next Nextef modulator.
    - Routine check of capacitors on size, capacitance, loss tangent, etc.
  - Nextef control system will be reconstructed in a safety-oriented manner.
  - Monitoring and INTLK will be stepped up.