T2K Radioactivity in the Exhaust Air

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J-PARC / KEK

[CONTENTS]

1. Exhaust monitor signal & improvements for air-tightness
2. Ventilation system trouble by neutrons
3. Bypass line installation and operation
4. Summary

Radiation Monitors

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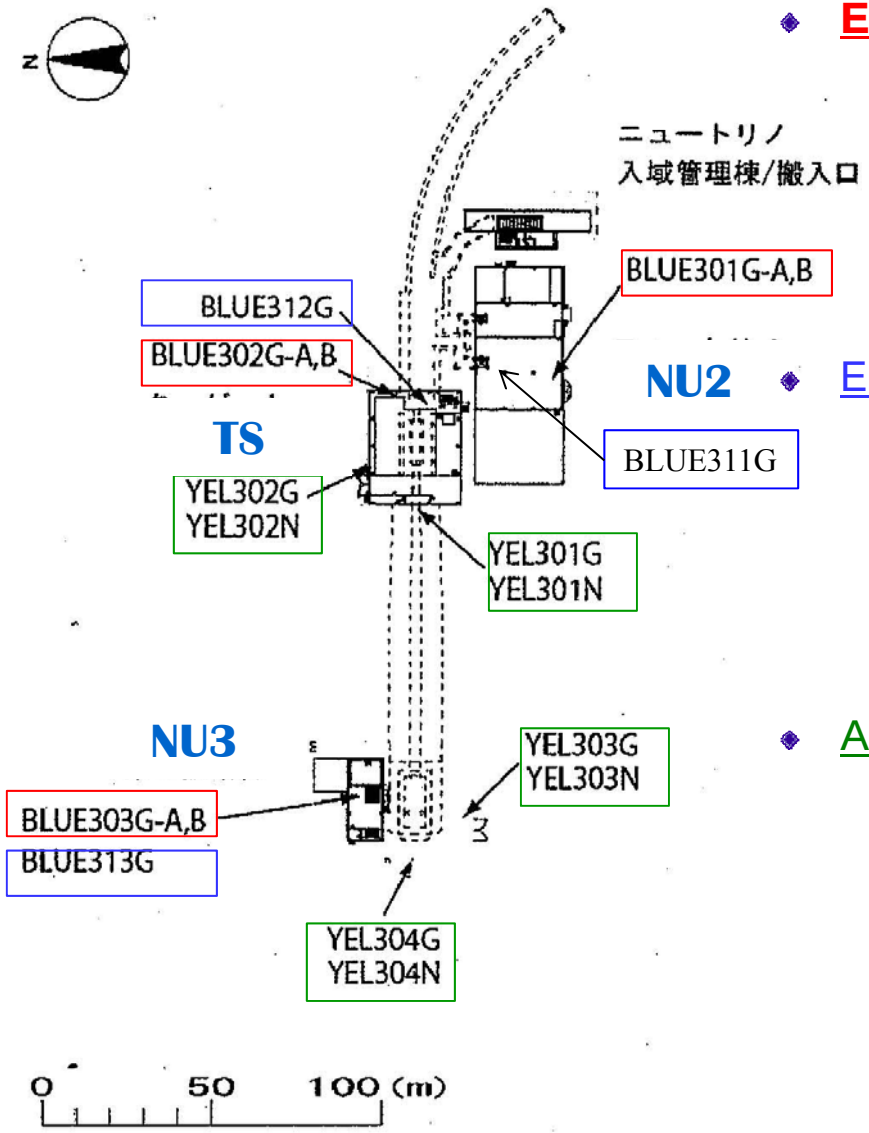

- **Exhaust air monitor** (gamma): 3 pairs(S/BG)
  - NaI (Tl) scintillation counter
  - Level of exhaust at upstream of the exhaust chimney stack.
  - Should be no signal during beam
  - < 0.5 mBq/cc for 3 month average
- Environment air monitor (gamma): 3
  - NaI (Tl) Scintillation counter
  - level of environment at pits/machine rooms at TS / NU3
  - Entry prohibited with signal > 10mBq/cc
  - NU2 exhaust is also monitored.
- Area monitor (gamma/n): 4 pairs
  - Ionization chamber / ^{3}He counter
  - Near the boarders of rad. controlled area
  - Gamma: < 0.3uSv/h [alert 0.8uSv/h]
  - Neutron: < 0.01uSv/h [alert 0.5uSv/h]
  - Integration over every 1 hour is used for PPS: limit: 0.5uSv/h x 1hr.

Radiation monitors at TS

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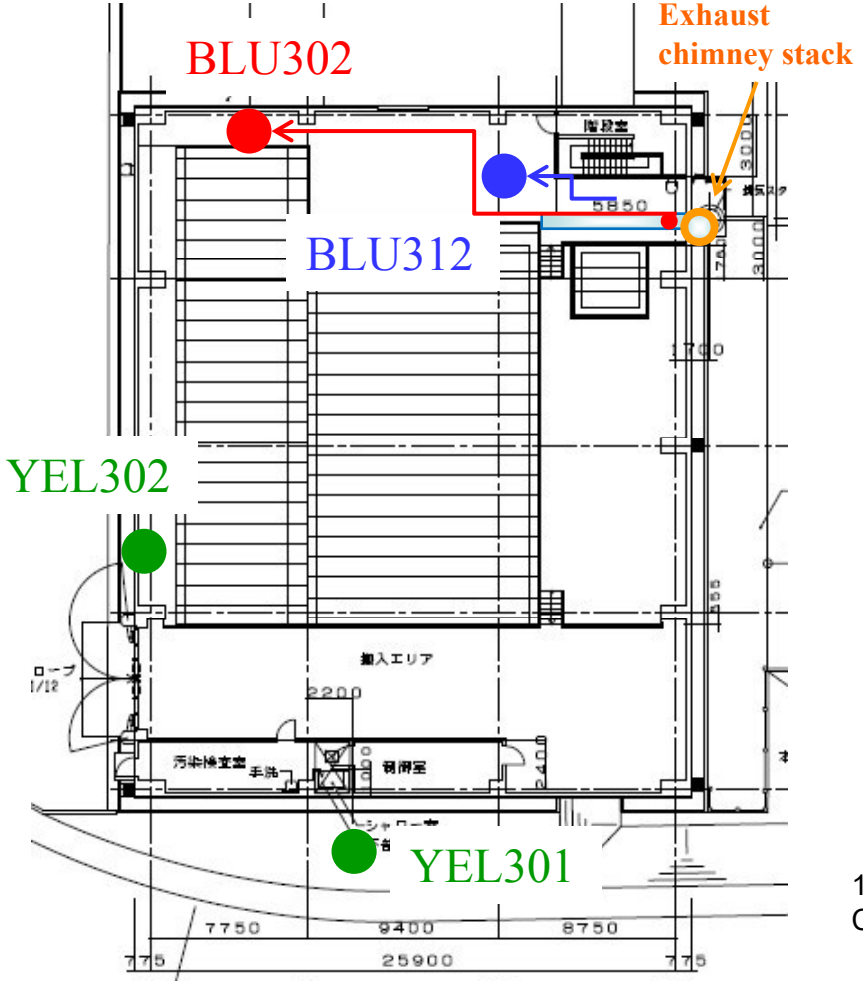
Exhaust monitor

10L（3atm）, 50mm thick Pb
3inφx3in NaI

Environment monitor

41L（1atm）
30mm thick Pb
2inchφx2inch NaI



Area monitor

10atm 1inchφ × 10inch He-3 Prop. Counter

NU3 also has the monitors

Exhaust monitor signal (Dec.24, 2009)

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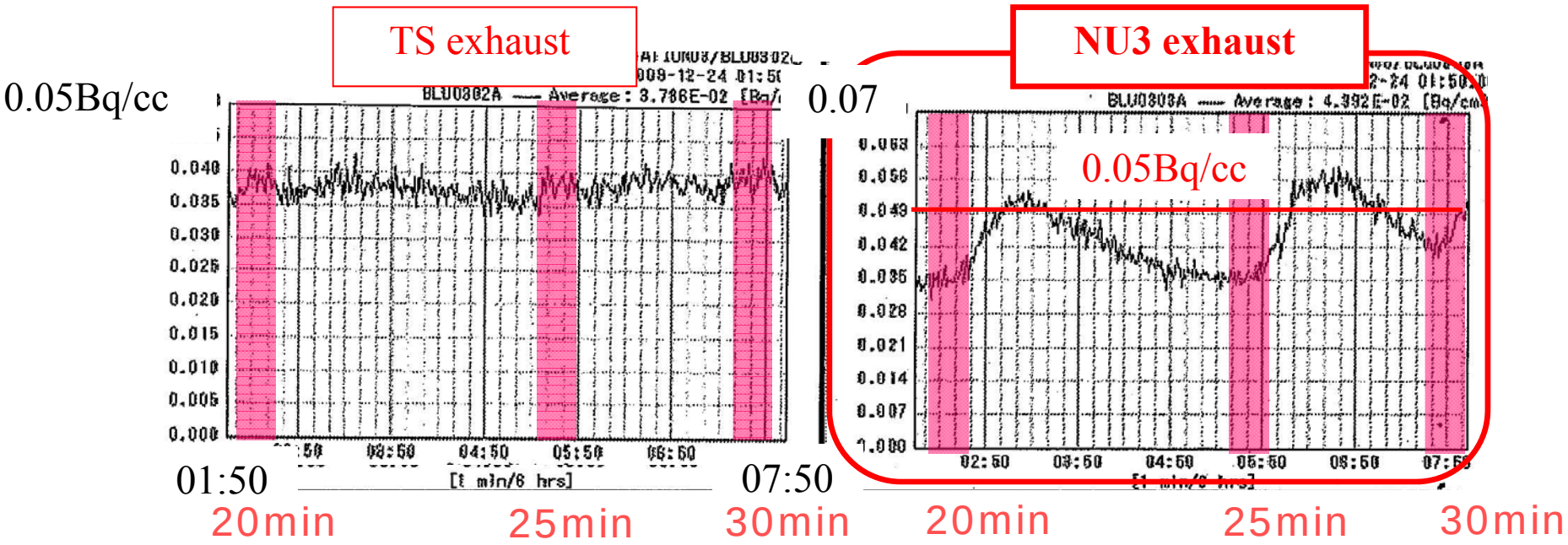

- MR R#28: The first continuous (20kW) beam
- NU3 exhaust signal: Alert level= 0.05Bq/cc(Raw data) ⇔ Observed 0.06 Bq/cc
  - **Beam operation was limited within only ~30min due to the radiation in the exhaust air.**

Flow chart of NU3 Air Conditioning (Beam Operation Mode)

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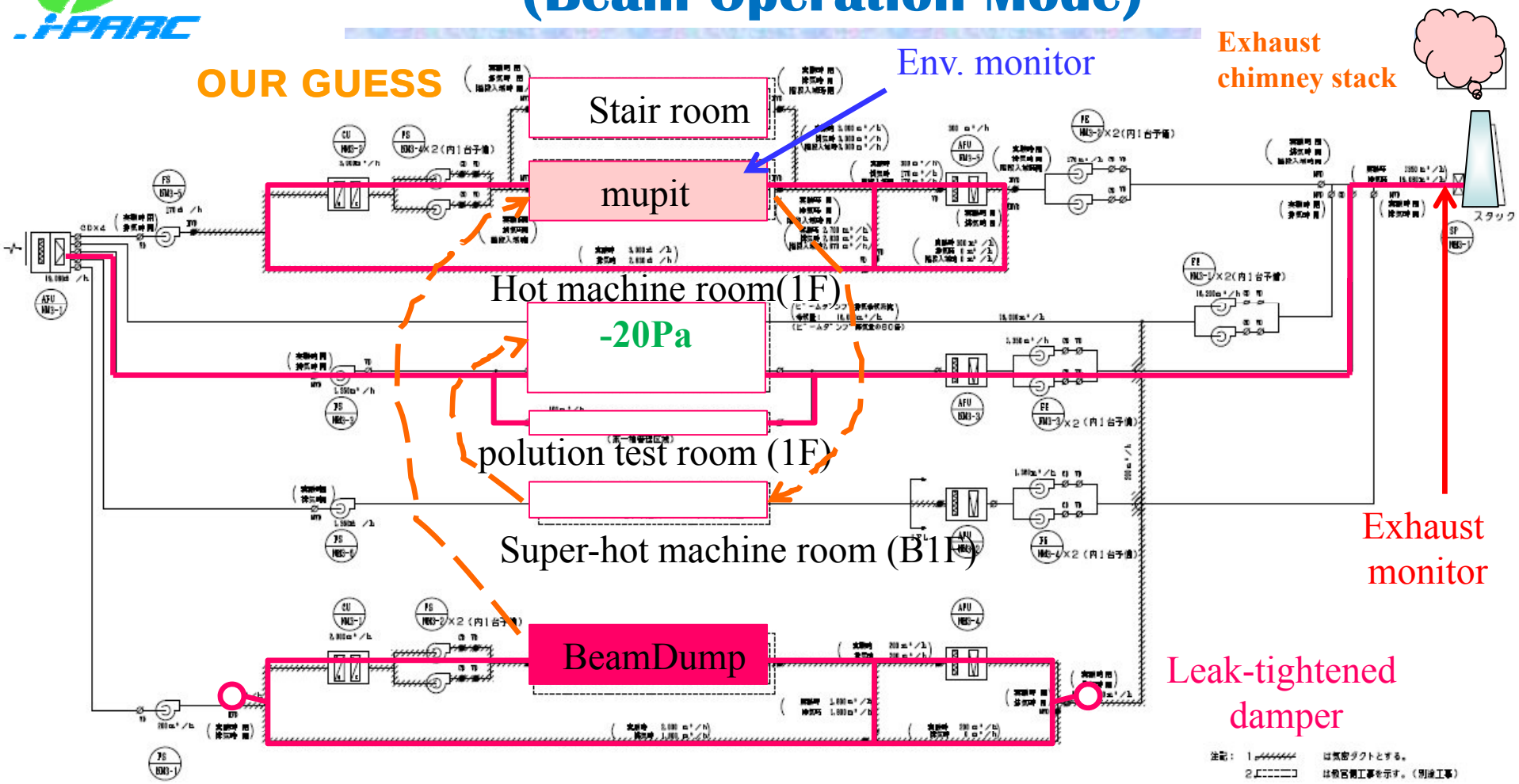

- If air tightness of the pits / rooms are bad, irradiated air in BD can go to the hot machine room
- We started to investigate air flow / air tightness of pits / rooms

NU3: Neutrino Utility Building #3
Beam Dump Pit /μPit

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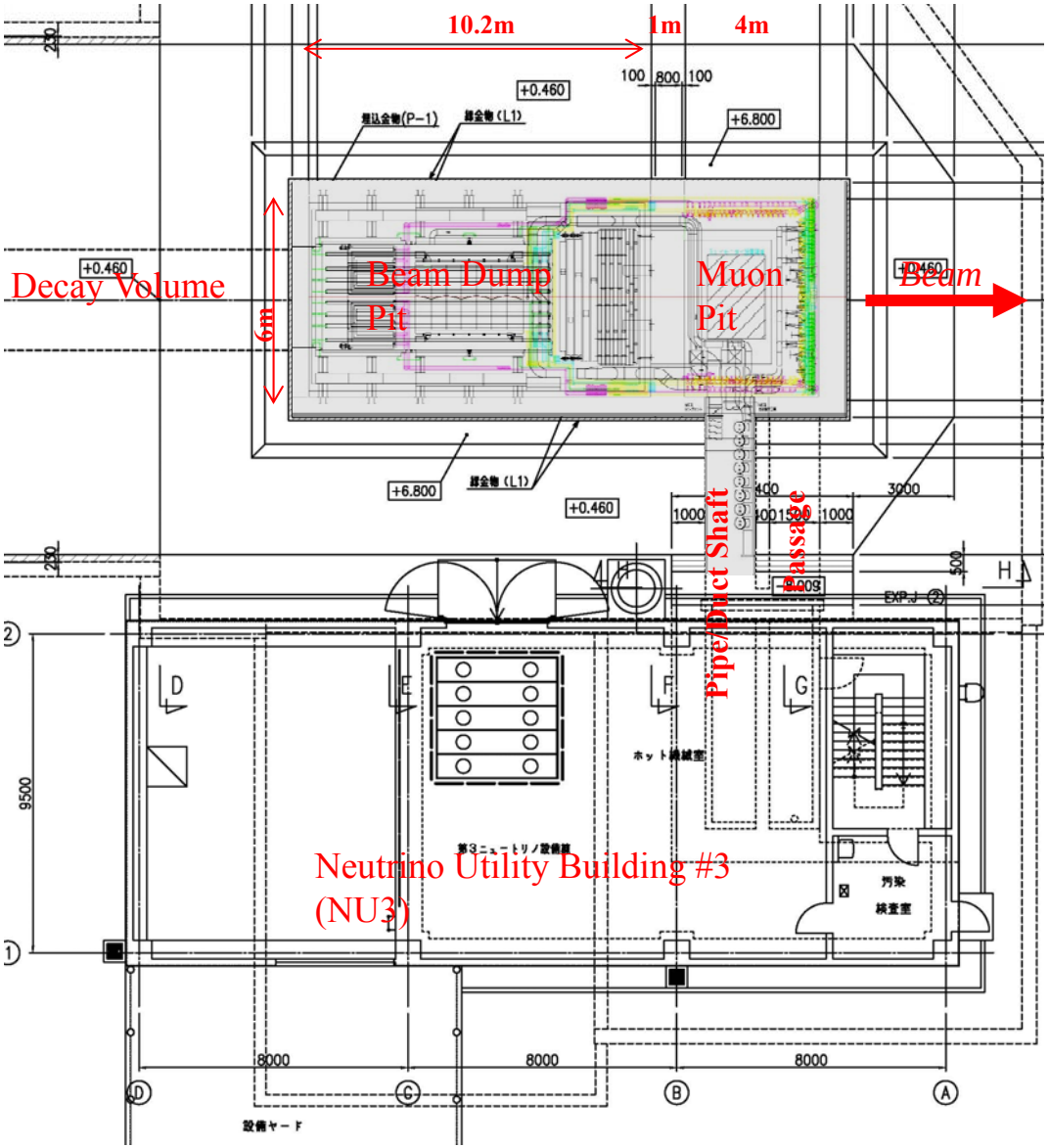

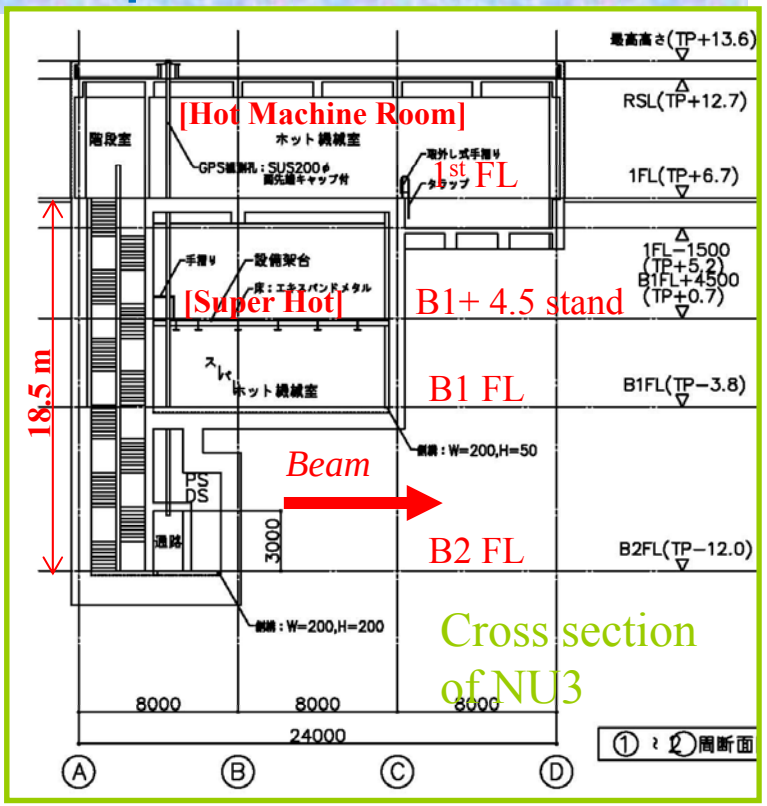

- Water circulation system for downstream half of DV and BD [B1]
- Air circulation system for BD / MuPit [B1+4.5]

Drain water pit at muon pit

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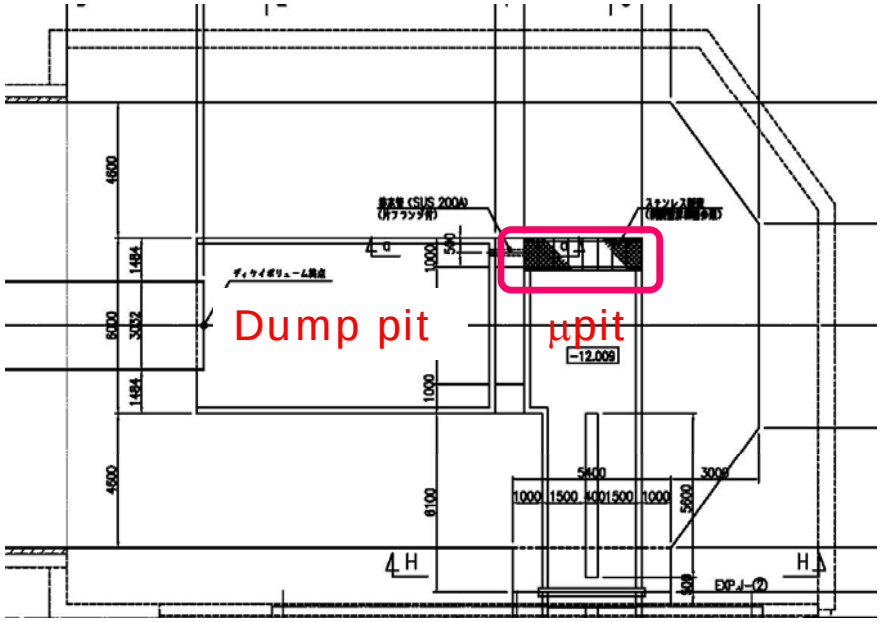

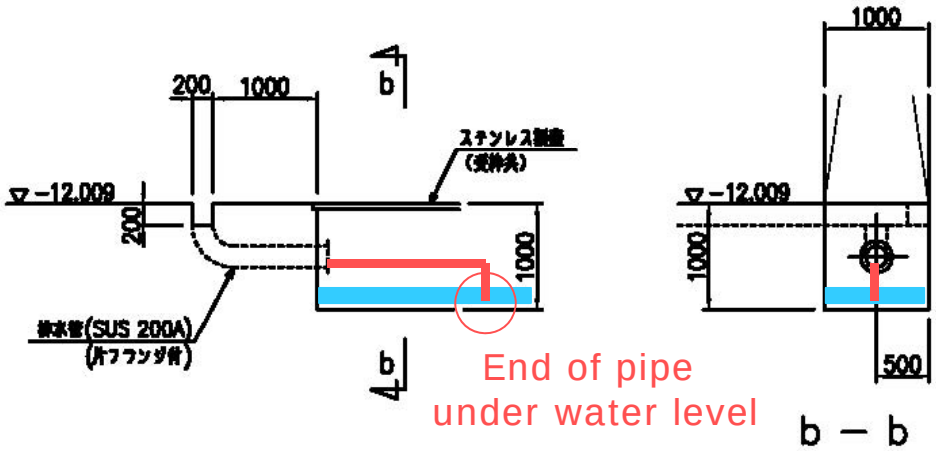

- The drain port connecting to dump pit was closed by a flange with thinner pipe.

Smoke Test

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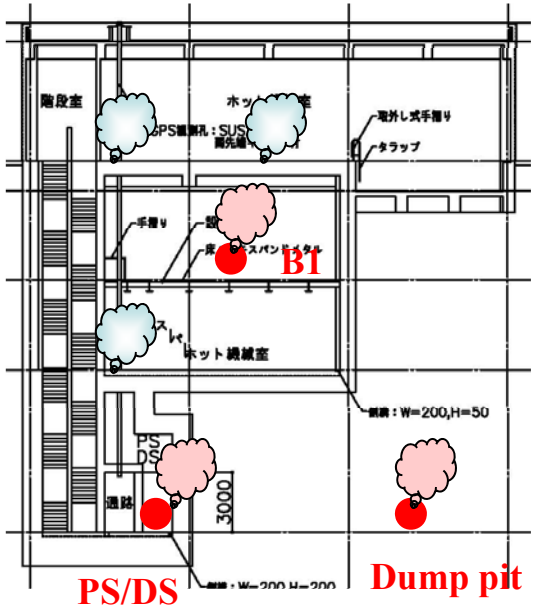
- Test with a smoke machine, normally used for theater plays !



- B2 PS/DS ⇒ smoke around heat-retention of square-ducts / penetration of cable bundles
- B1 ⇒ around service hatch / penetration of cable bundles

Air tightening (NU3)

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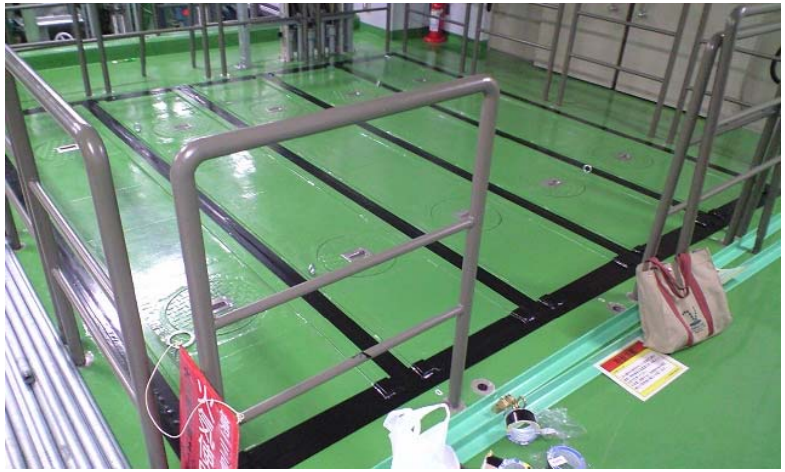

- Remove insulation around ducts → seal with thin iron plates and caulking
- Liquid silicone glue for the cable penetrations
- Seal edges of concrete blocks at the delivery entrance to downstairs
- Doors sealed with tape, repeat smoke tests to find remaining leaks

Jan. 23-24（MR Run#29）

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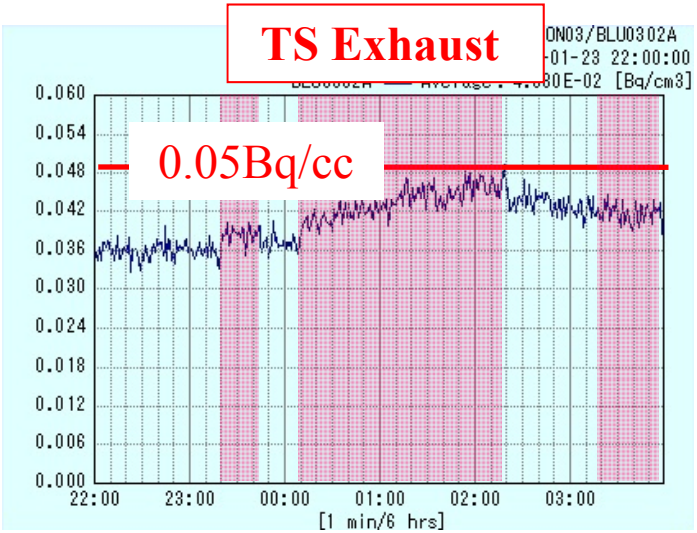

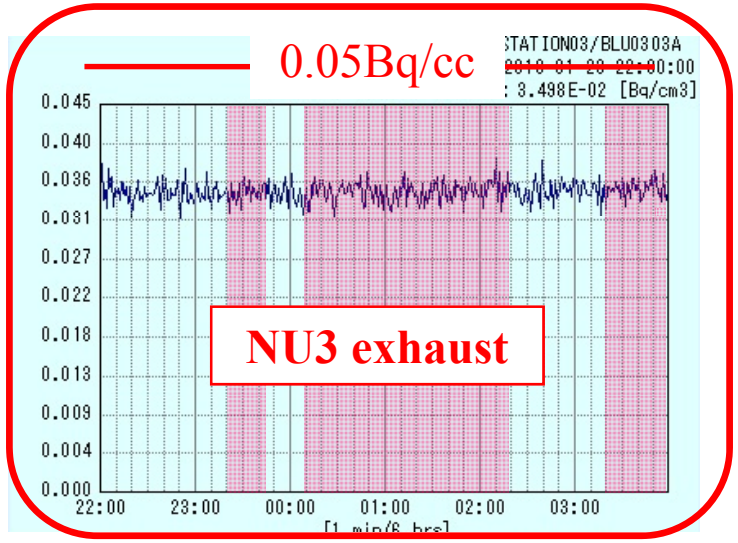

- NU3 exhaust monitor signal becomes much smaller
- TS exhaust becomes 0.05Bq/cc with 2 hours of beam operation

Flow of the Irradiated Air at NU3 (beam commissioning mode)

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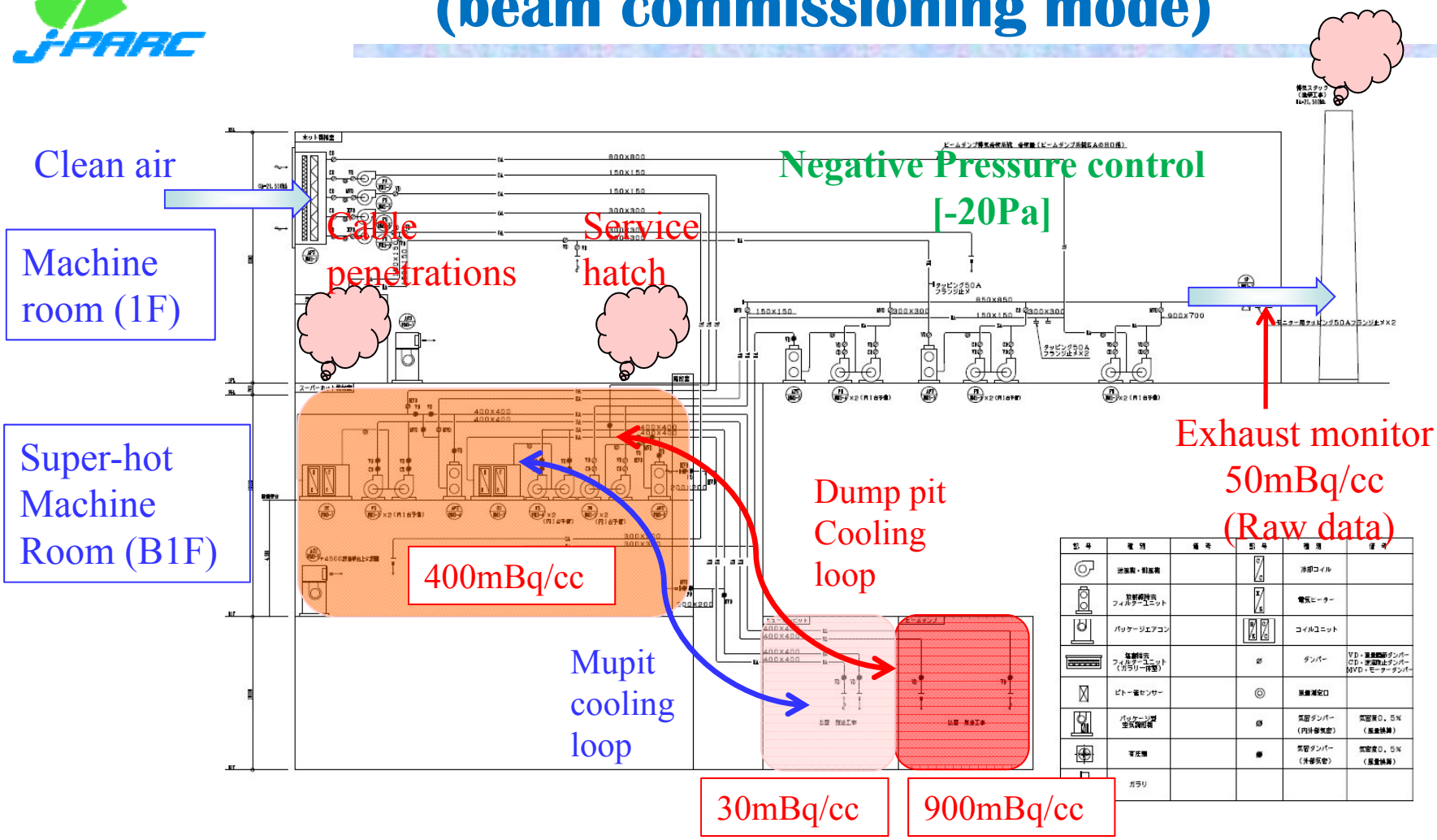

- Environment air monitor suggests that irradiated air was leaked into super-hot machine room from (air-tightened) dump pit cooling loop.
- The air is going into 1F through service hatch and cable penetrations

Flow of the Irradiated Air at TS

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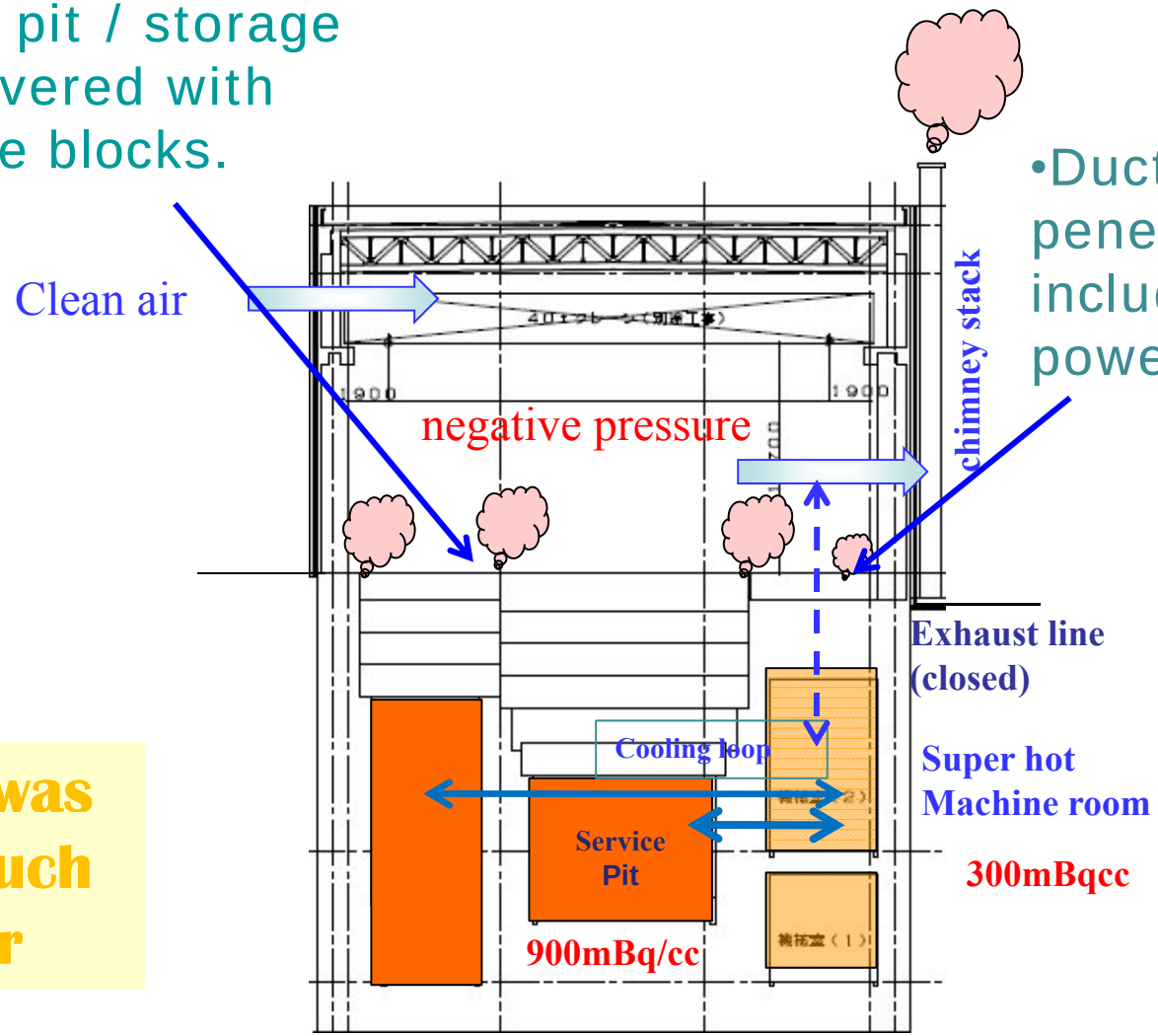
- Service pit / storage area covered with concrete blocks.



•Duct /pipe/ cable penetrations, including horn power cables.

The job was much much harder

Ex.Monitor Measurements

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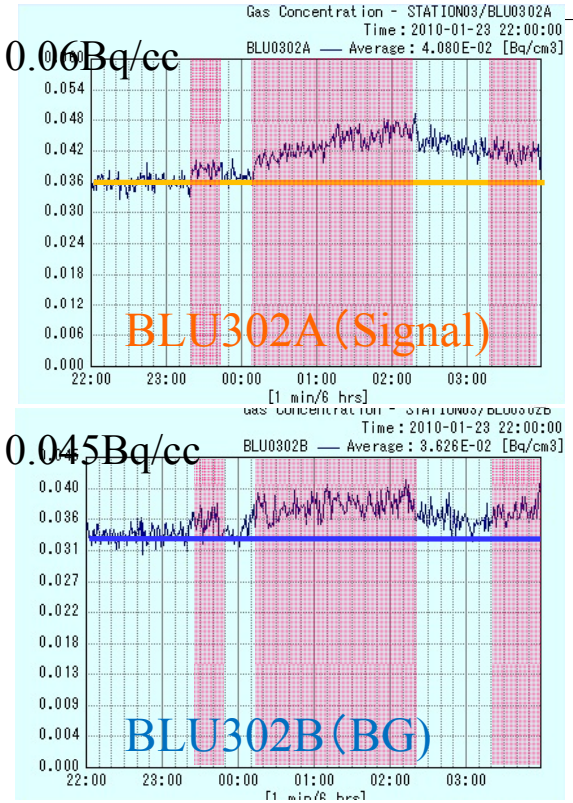

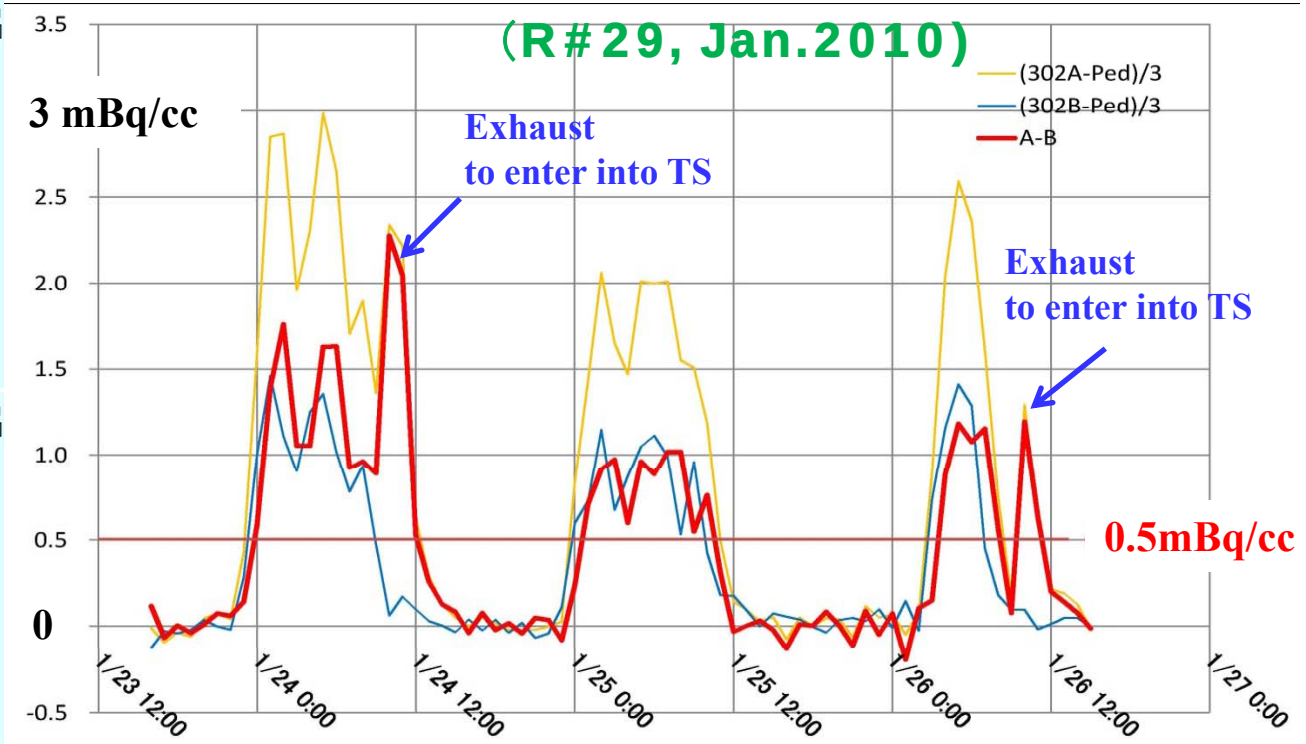

- Both A(cell with 3 atm. exhaust air) and B(closed, BG cell) have signal
  - Gamma ray from 1F environment (outside of the cell) air is observed as common signal.
- Radiation level in Exhaust = [{A – Pedestal} - {B – Pedestal}] / 3 (atm.)
  - **1mBq/cc~1.5mBq/cc** ←→ law limit < 0.5mBq/cc [3-month average]
  - January: 3 days operation / 30days → 0.5m x 10 = 5mBq/cc acceptable.

TS air tightening（Feb.15-22）

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Smoke tester

- Stop air flow coming out between concrete blocks by backup material and caulking

Cable penetration

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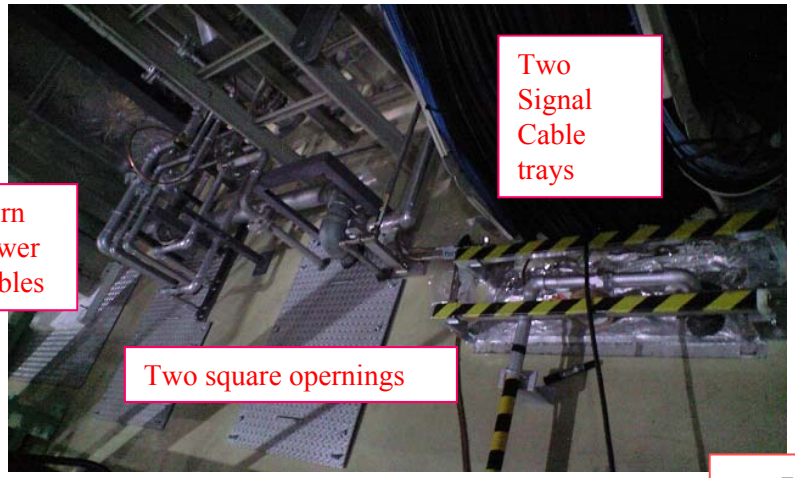
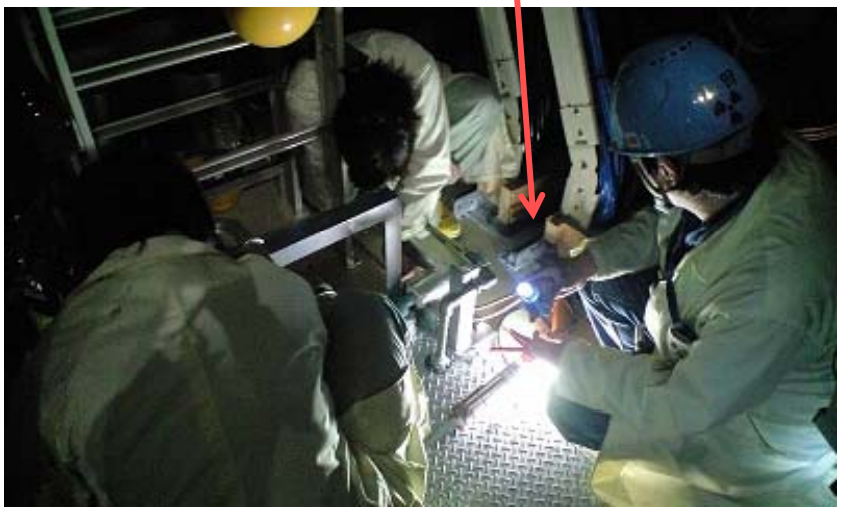


apply neg.pressure to 1F: -100Pa

Not only by smoke, but also by smell of smoke, we can find leak…



R#29 Jan.30~Feb.6 → R#30 Feb.22~Mar.1

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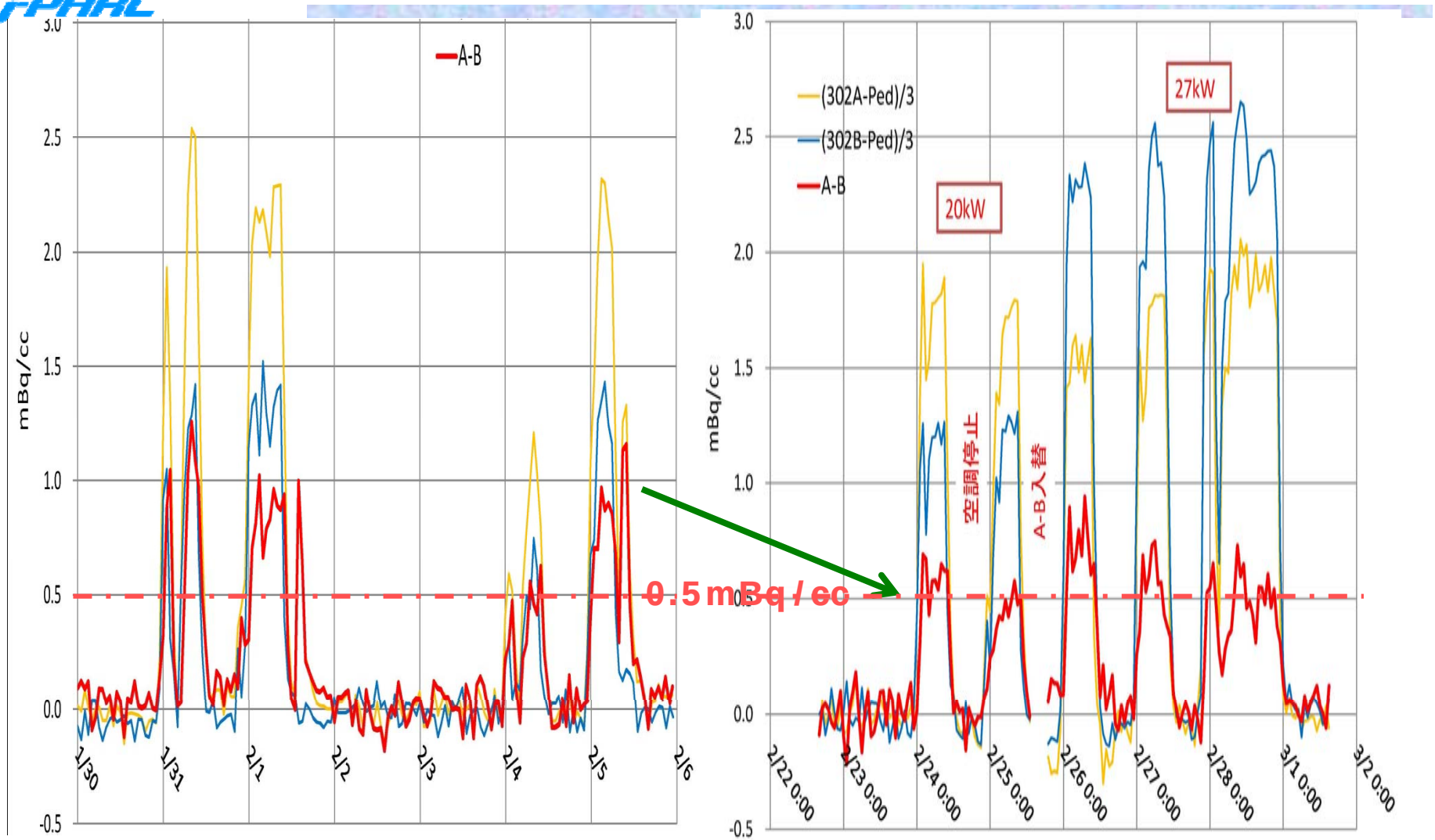
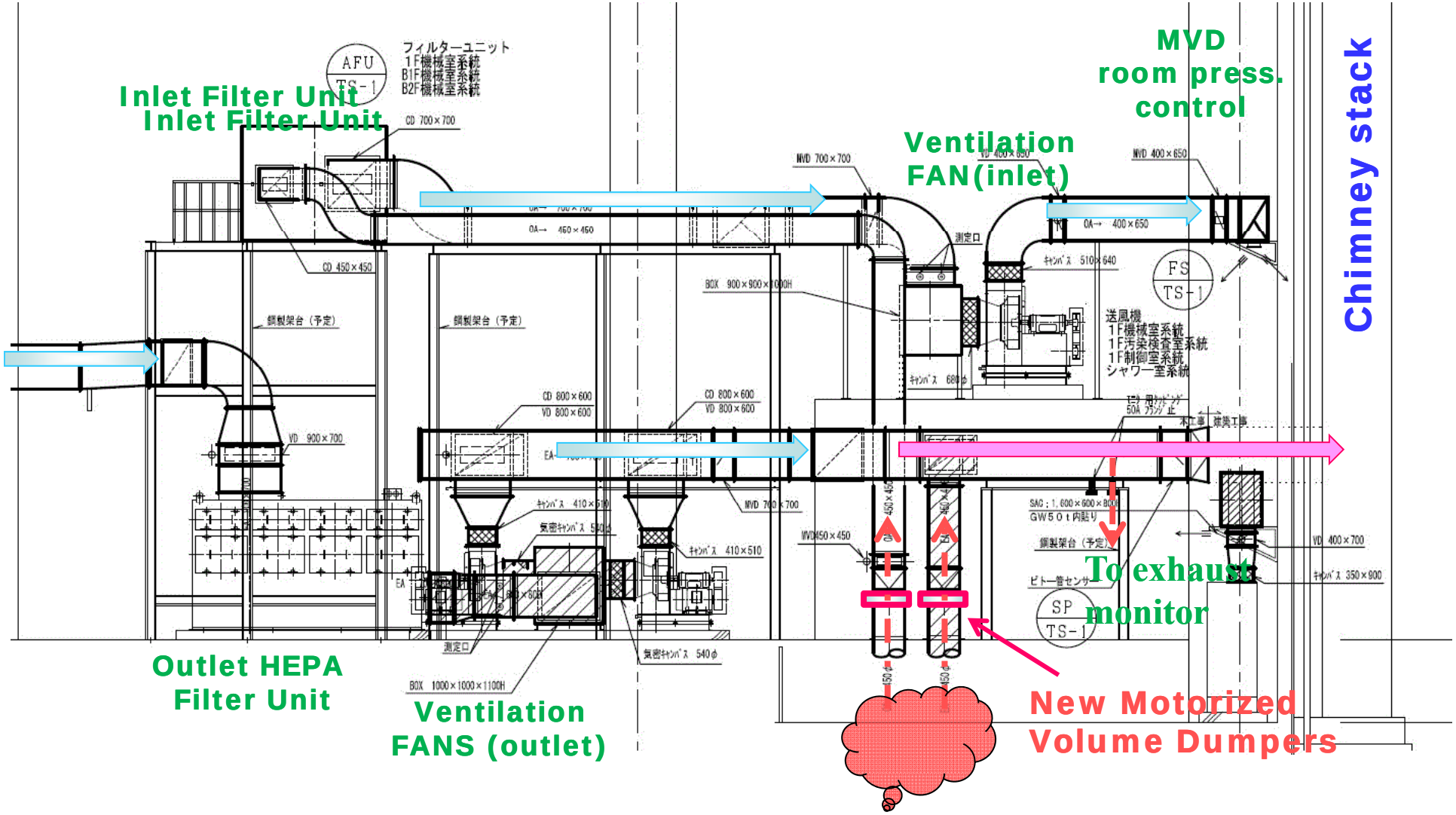


- 1.0 →0.5mBq/cc (20kW, factor 2 reduction)
- → 0.5~0.8mBq/cc (27kW)

Add MVDs in the Underg. Vent Line (Mar.30~Apr.2,2010)



- We doubted leak in the ducts to vent undergr. rooms

Install MVD Mar.30~Apr.2

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- Add air-tightened MVDs (bought for NU3..)
  - Later replaced to bigger ones / install the small ones to NU3

Cover Shield Block Surface

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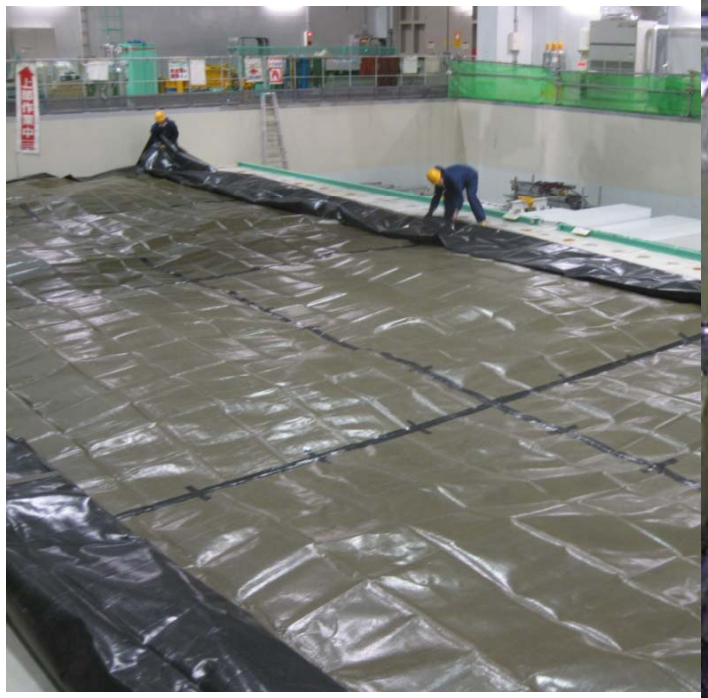

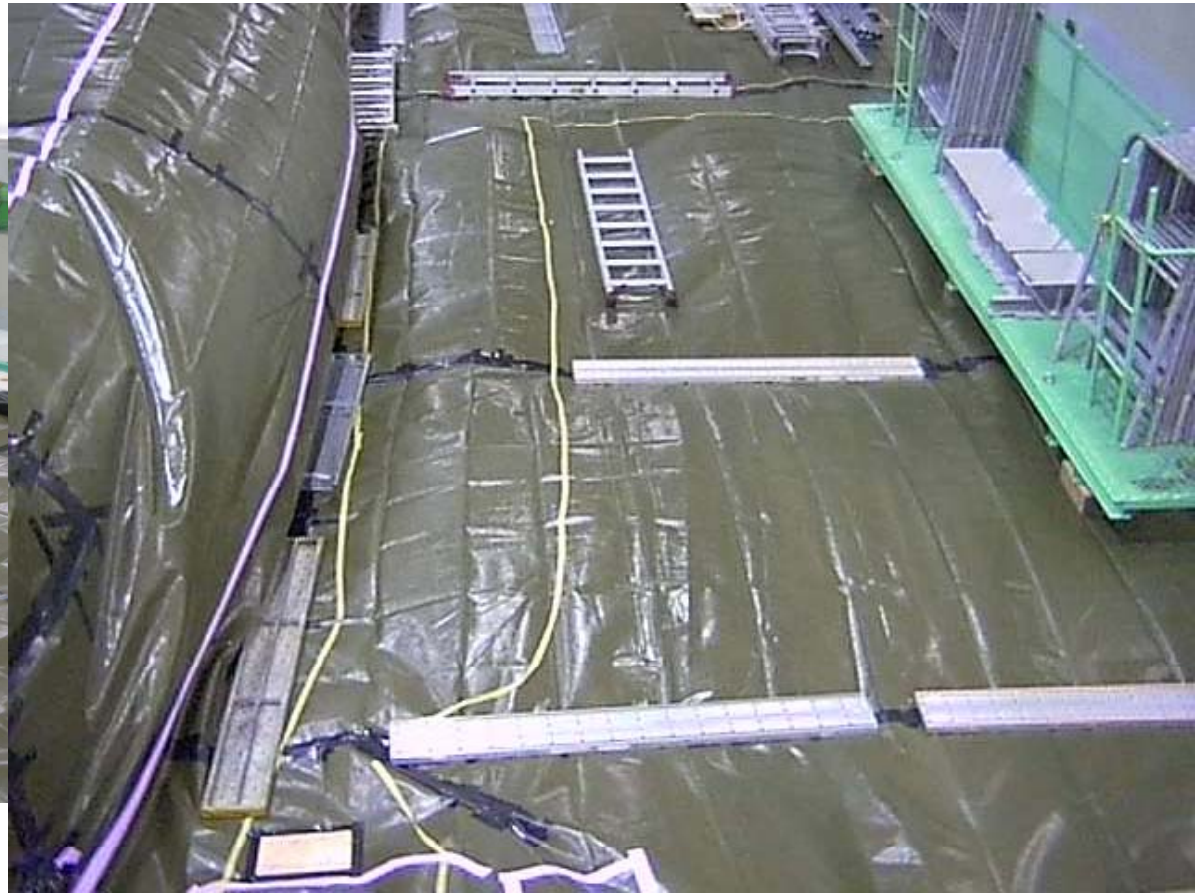

- During ventilation, sheets swollen by the air, leaking through the sealed block floor..

Mar.19-25(R#31)→Apr.14-21 (R#32)

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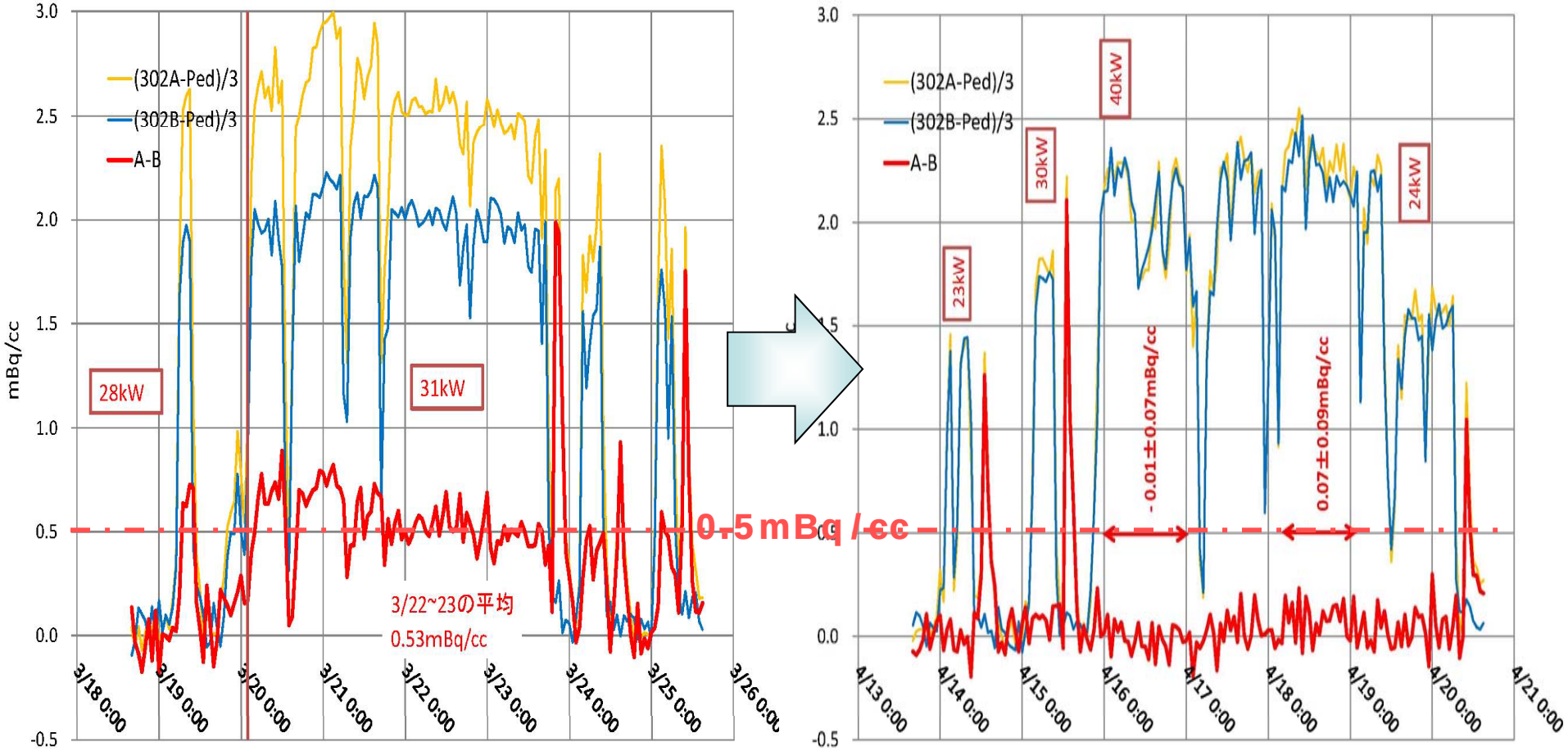

- Signal (A-B) highly reduced (but not perfect)
- 0.07 +- 0.09mBq/cc (40kW)

Air under the cover

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- Radiation level under the cover: ~ 90mBq/cc

Sudden Stop of TS Ventilation System [Apr.20-21, 2010]

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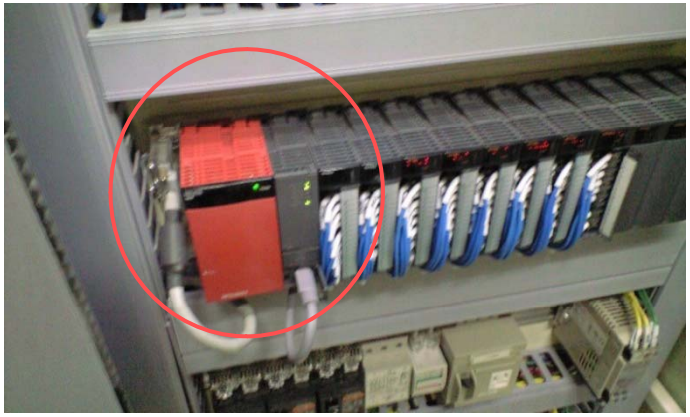

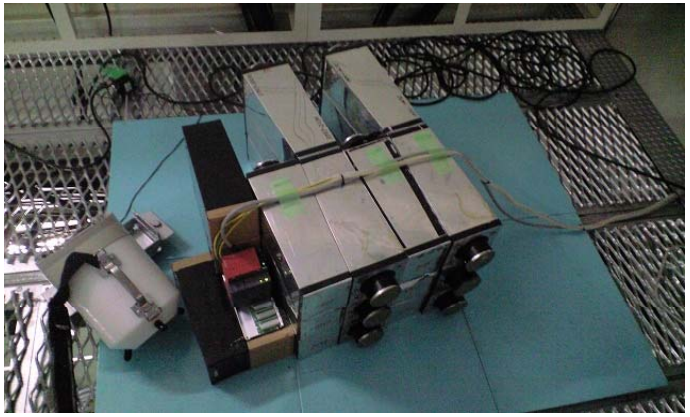

- The control panel was located in B1F machine room, since limitation of 1F floor space. Later we noticed it was around the level of target..
- "Single event upset" on a CPU unit of the PLC by beam-induced fast neutrons.
- As temporary fix during Run-1, extract / relocate the CPU unit by 10m to area with less neutrons, then covered with LG blocks.
- Whole control panels of air-conditioning/cooling water at TS moved to the ground floor in 2009, summer.

Install MVDs (Jun.2~4, 2010)

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TS

NU3

- TS/NU3 underg rooms separated by the dumpers
- **2010Jun: 0.1~0.15mBq/cc @ ~50kW**

2011 Feb.~Mar.

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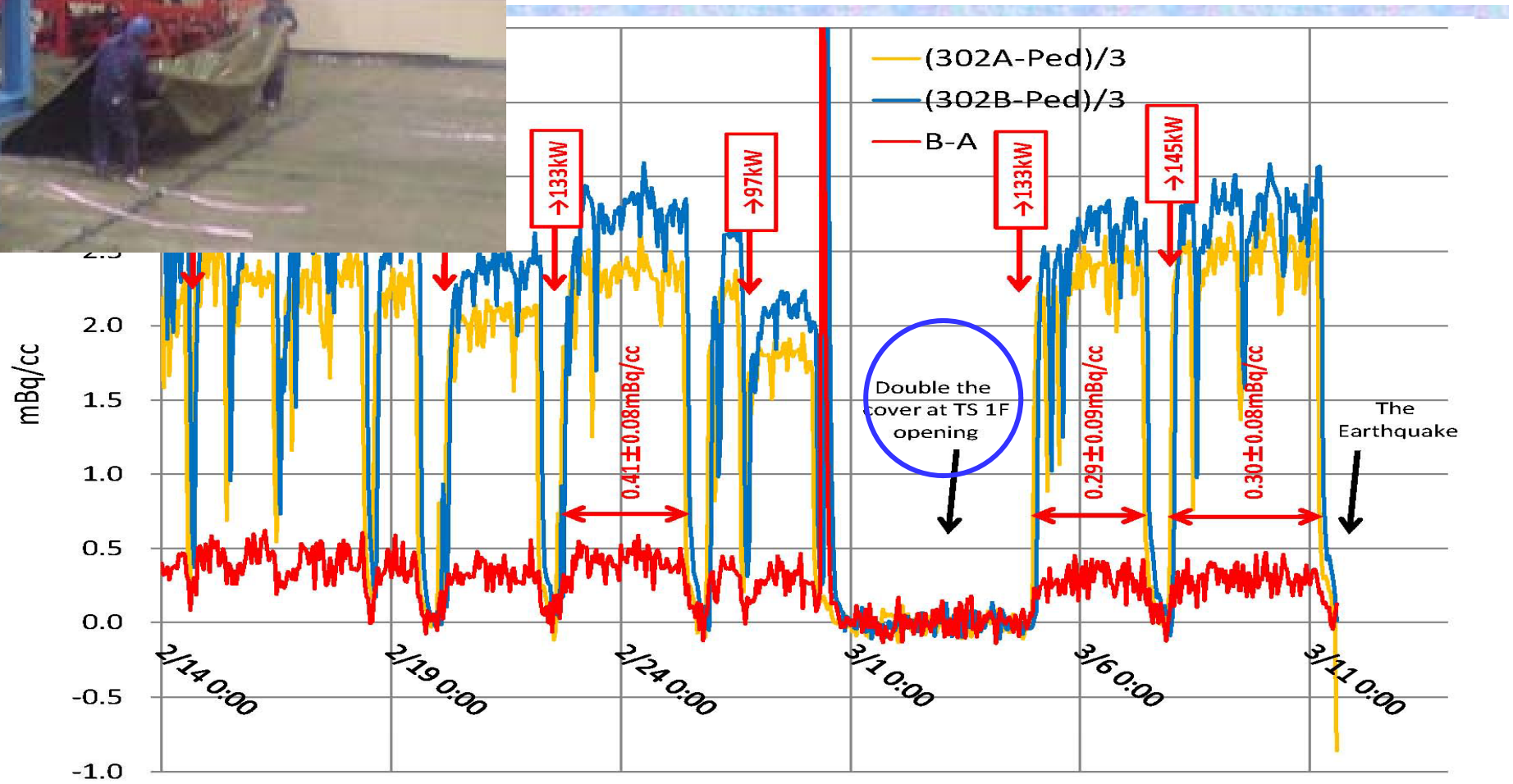

- We have introduced the second layer of sheets to shield floor.
- ~0.3mBq/cc for 145kW : ⇒ hit 0.5mBq/cc limit with 240kW beam
- 1 month average for Jan.:0.14mBq/cc ⇒ 1/28~2/28: 0.32mBq/cc

Bypass line: Idea & Expectation

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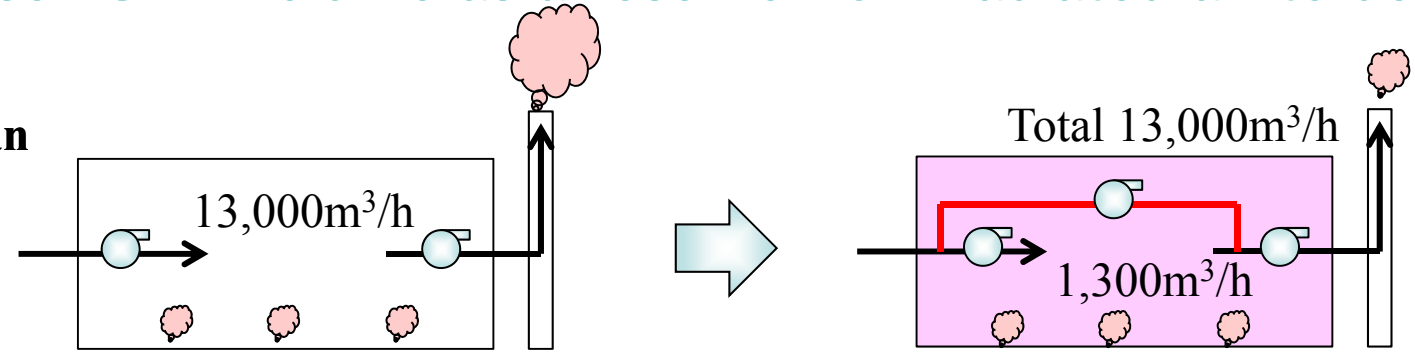
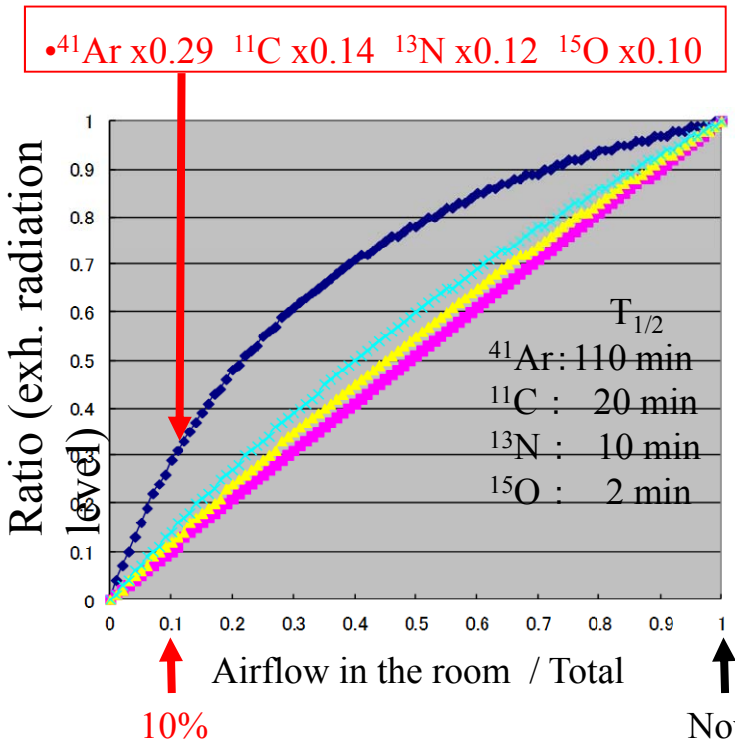
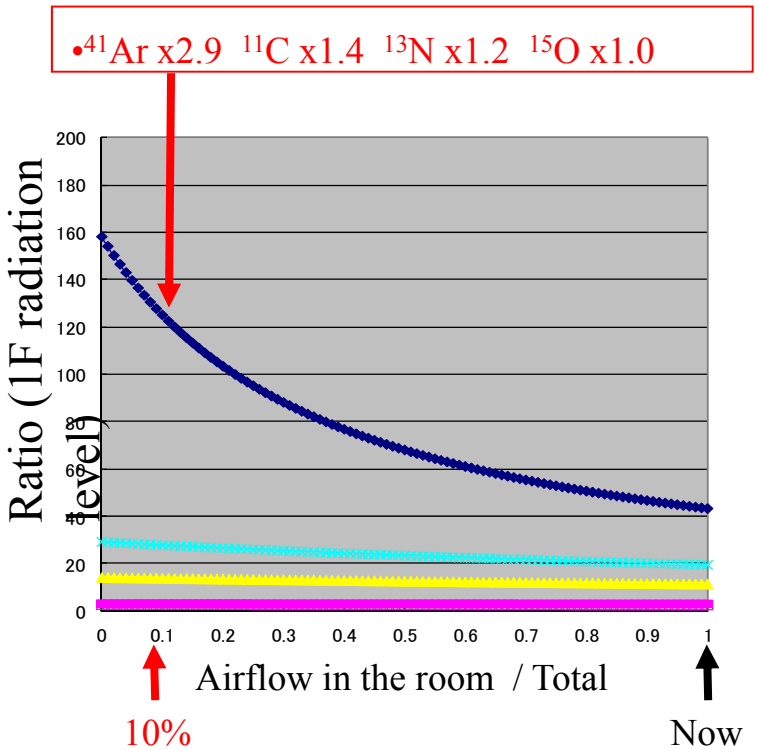
- Use TS 1F volume as a reservoir of irradiated air to decay.

Idea by Oyama-san







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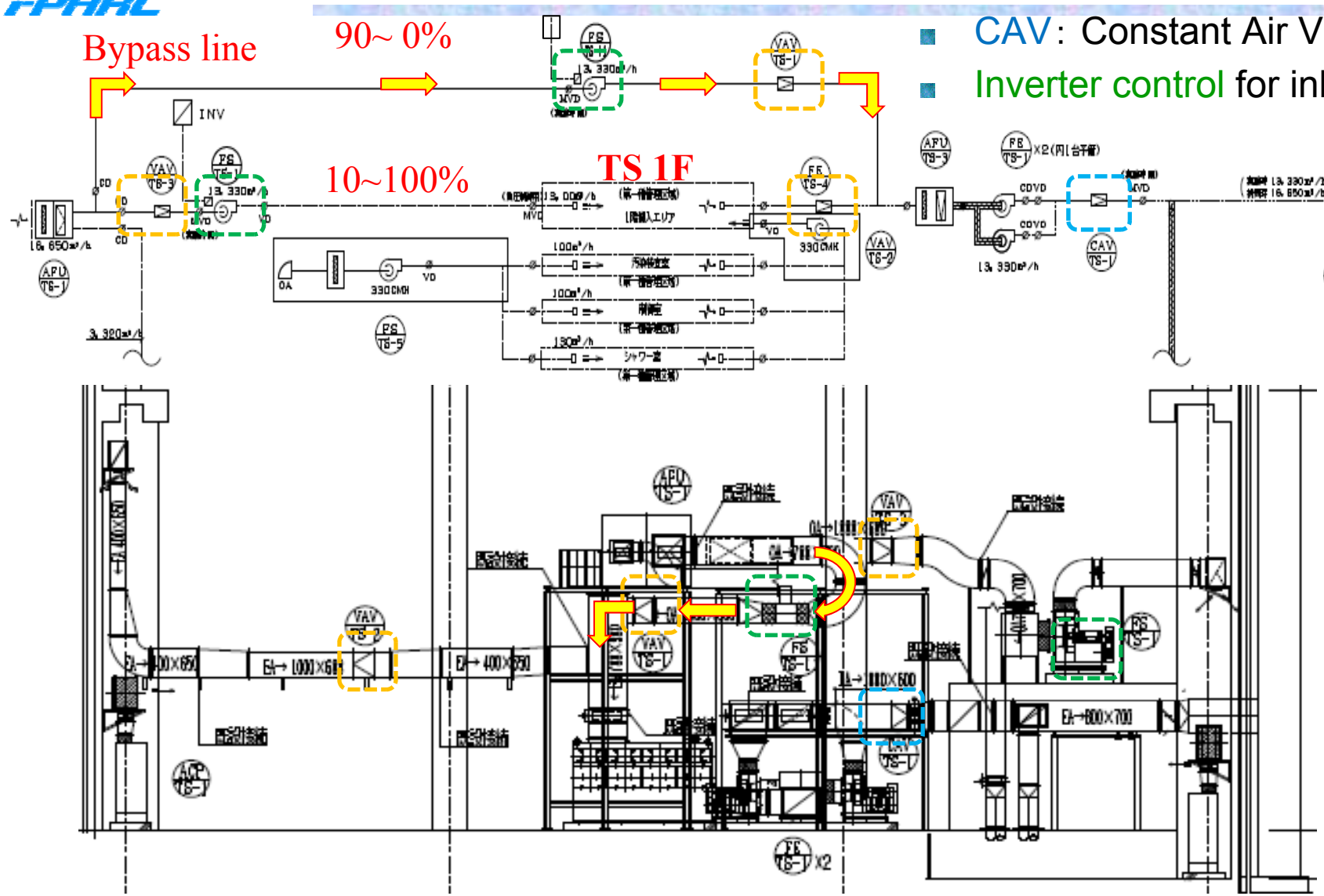
Design

- VAV : Variable Air Volume
- CAV : Constant Air Volume
- Inverter control for inlet fans



Construction Dec.2011-Jan.2012

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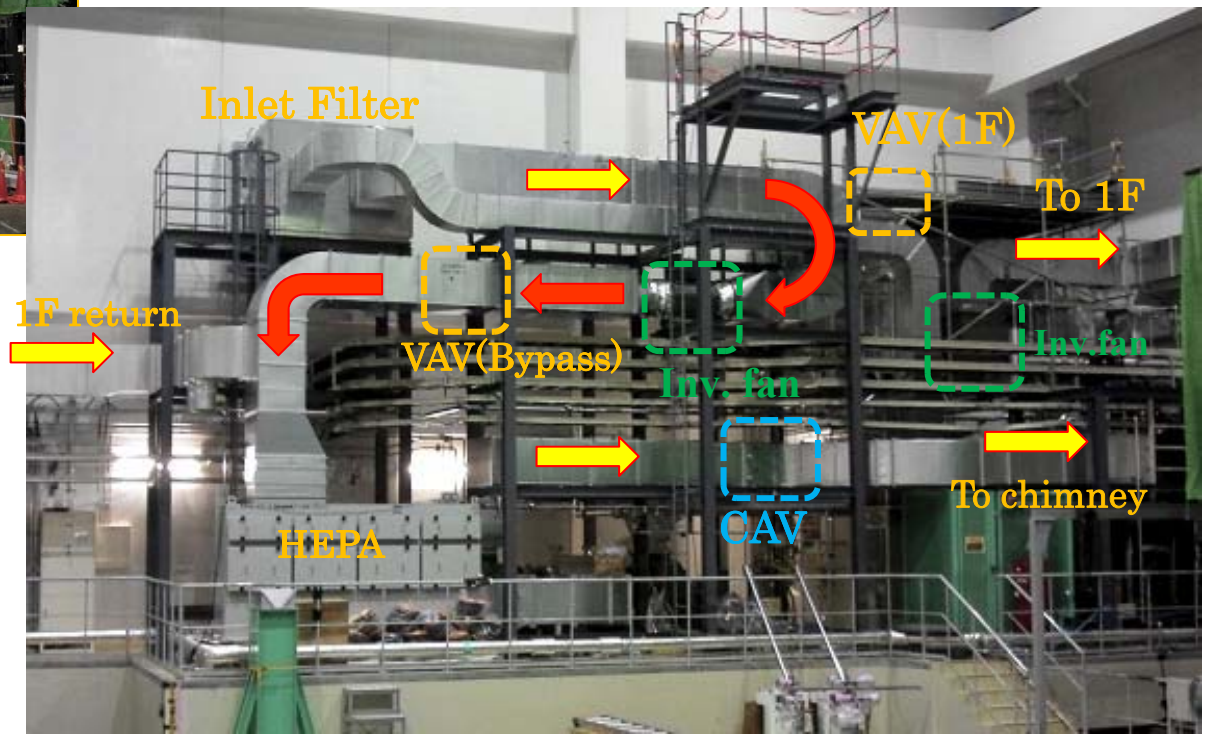

- Duct: 600x1,000 → 4D=4m straight section needed fro VAV/CAV.
- Works completed on Jan.13, 2012. Bypass flow set to zero for Jan. beam.
- Flow control was carefully tuned on February.

Tuning for Air Flow Control (Feb., 2012)

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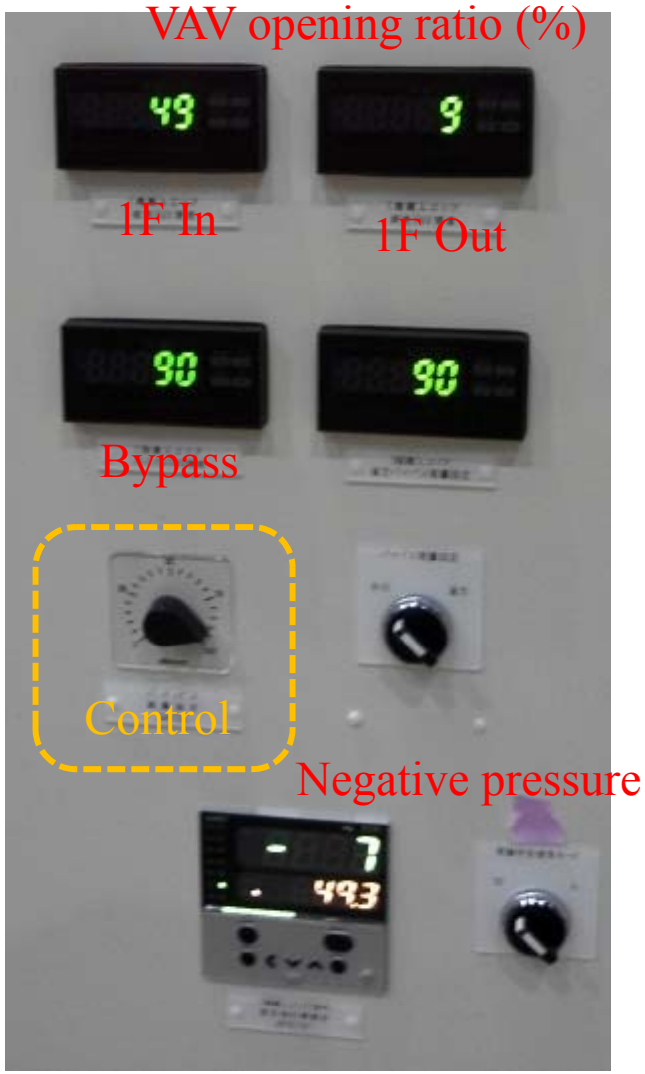

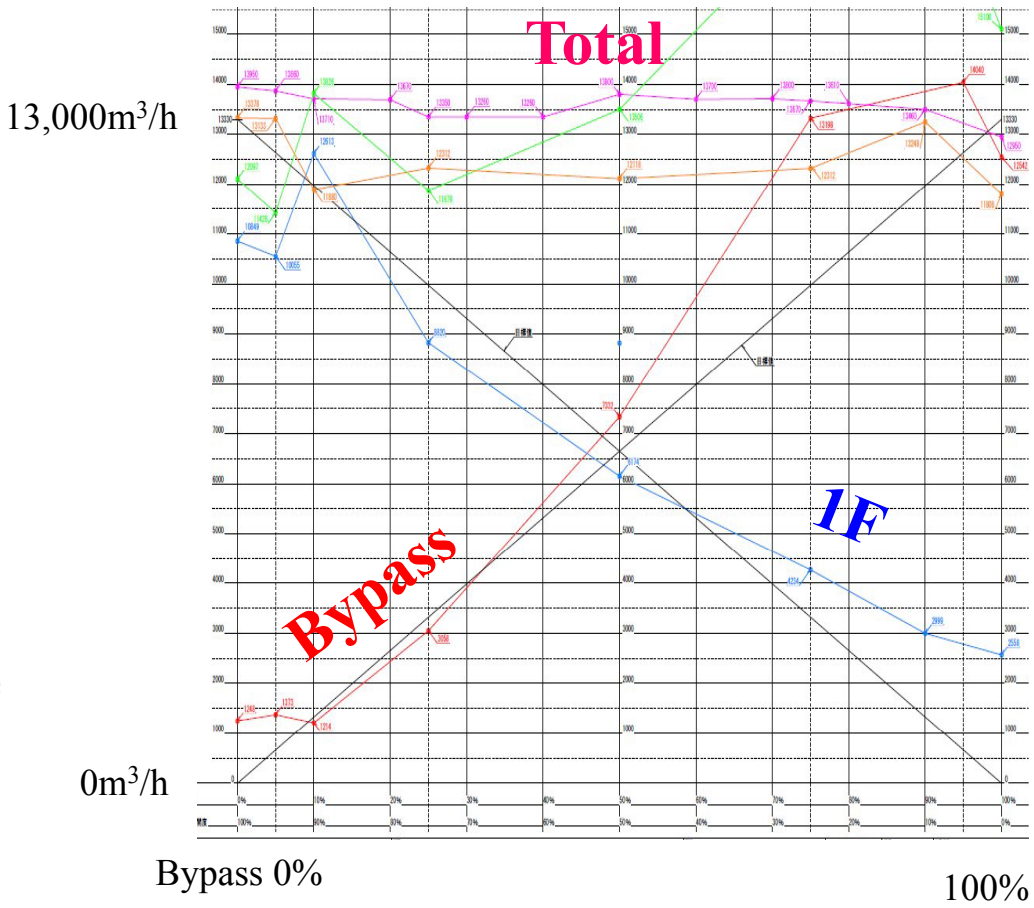

Mar.~Apr. 2012

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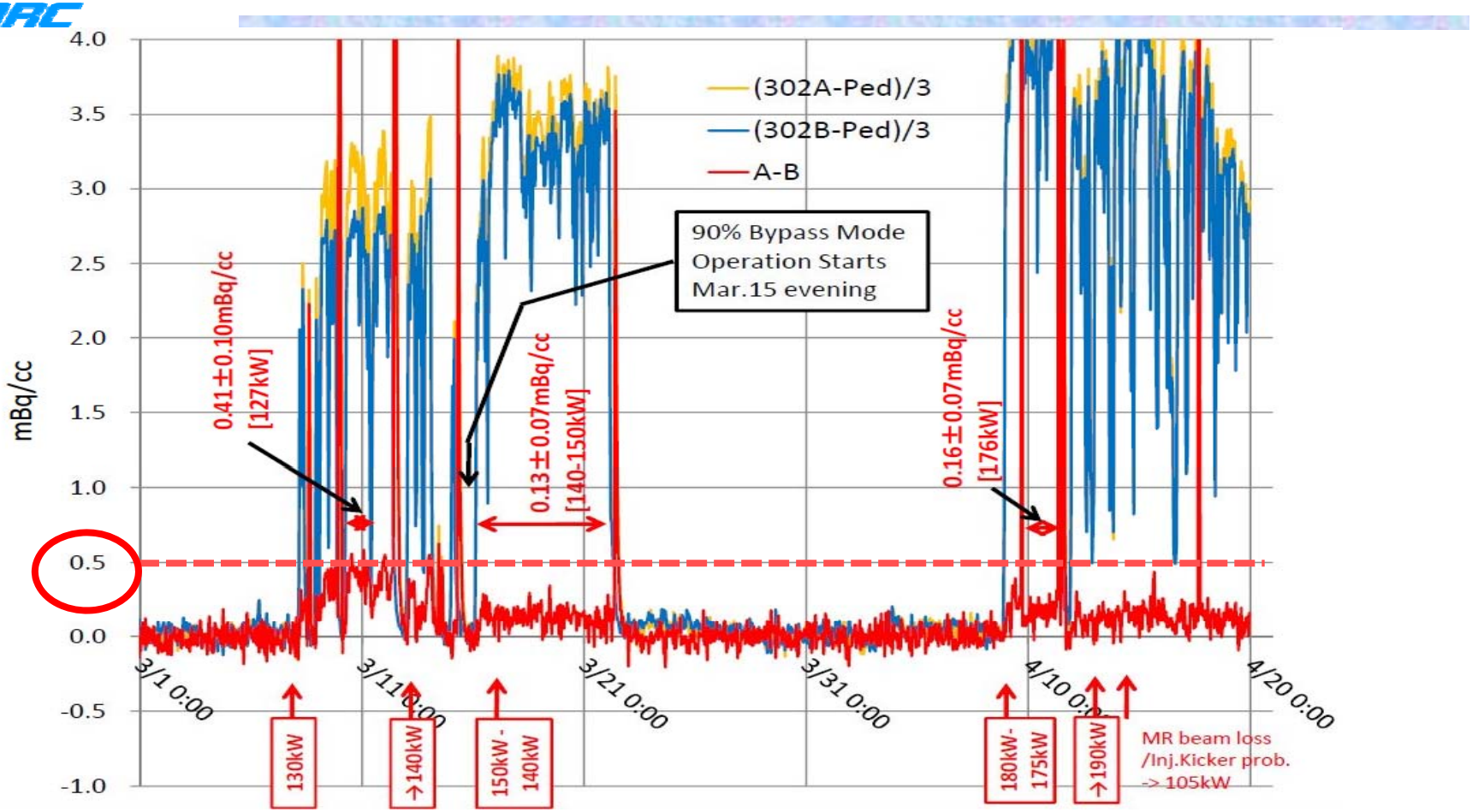

- 0.4m(127kW)→0.13mBq/cc(140-150kW) with 90% bypass
- March beam: 145/ 0.13 x0.5=558kW acceptable
- April beam: 176/ 0.16 x0.5=550kW acceptable

Balloon Sheet Installation (Apr.2012)

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- The radiation level in the 1F w bypass
  - 50mBq/cc ⇒ (70+-5)mBq/cc [w/o beam: 35mBq/cc]
  - Still low compared to regulation [<500mBq/cc]

- Improve shield cover: Continuous 2-layer sheets for balloon was installed in Apr.2012 during beam.
- Radiation level after installation
  - reduced by factor ~2
  - ~0.1mBq/cc for 190kW

* Photo taken on Nov.2, 2012

Summary

Radiation in exhaust air of TS was being the bottleneck of our beam power

	Observed	Acceptable <0.5m
2010 Jan.-Feb.	1.5mBq/cc (20kW)	~7kW
* Air tightening for floor blocks, seal cable penetration holes, & smoke tests		
2010 Feb.-Mar.	0.5(20)→0.8(27kW)	~17kW
* Add MVDs for ducts to underground rooms / cover block floor by water-proof sheets		
2010 Jun.	0.1~0.15(50kW)	170kW
* Add blocks to gaps at shield floor, upgrade of air-tightened doors		
2010 Nov.~2011 Feb.	0.28(105)→0.4(125kW)	160kW
* Add second layer of sheets		
2011 Mar.	0.3(145kW)	240kW
* Install bypass line to 1F vent line		
2012 Mar.~Apr.	0.13(145)→0.16(176kW)	550kW
* Balloon sheet installation		
2012 May.~Jun.	→ 0.1mBq/cc(190kW)	950kW

Acceptable beam is being improved by 2 order, now ~ 1MW

Backups

Regulations on Radiation

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Radiation level, ( ) = J-PARC design rule

- Boundary of radiation control area: <0.5μSv/h (<0.25μSv/h)
- Accessible area for radiation worker: <25μSv/h (<12.5μSv/h)
- (Boundary between building and underground soil: <5mSv/h)

Radioactivity in disposed water

- ^{3}H: <60 Bq/cm^{3}
- ^{7}Be: <30 Bq/cm^{3}
- ^{22}Na: <0.3 Bq/cm^{3}

Radioactivity in exhausted air through a stack

- ^{3}H: <5 mBq/cm^{3} in three months average
- ^{41}Ar: <0.5 mBq/cm^{3} in three months average

Additional Concrete Shields (2010 Summer)

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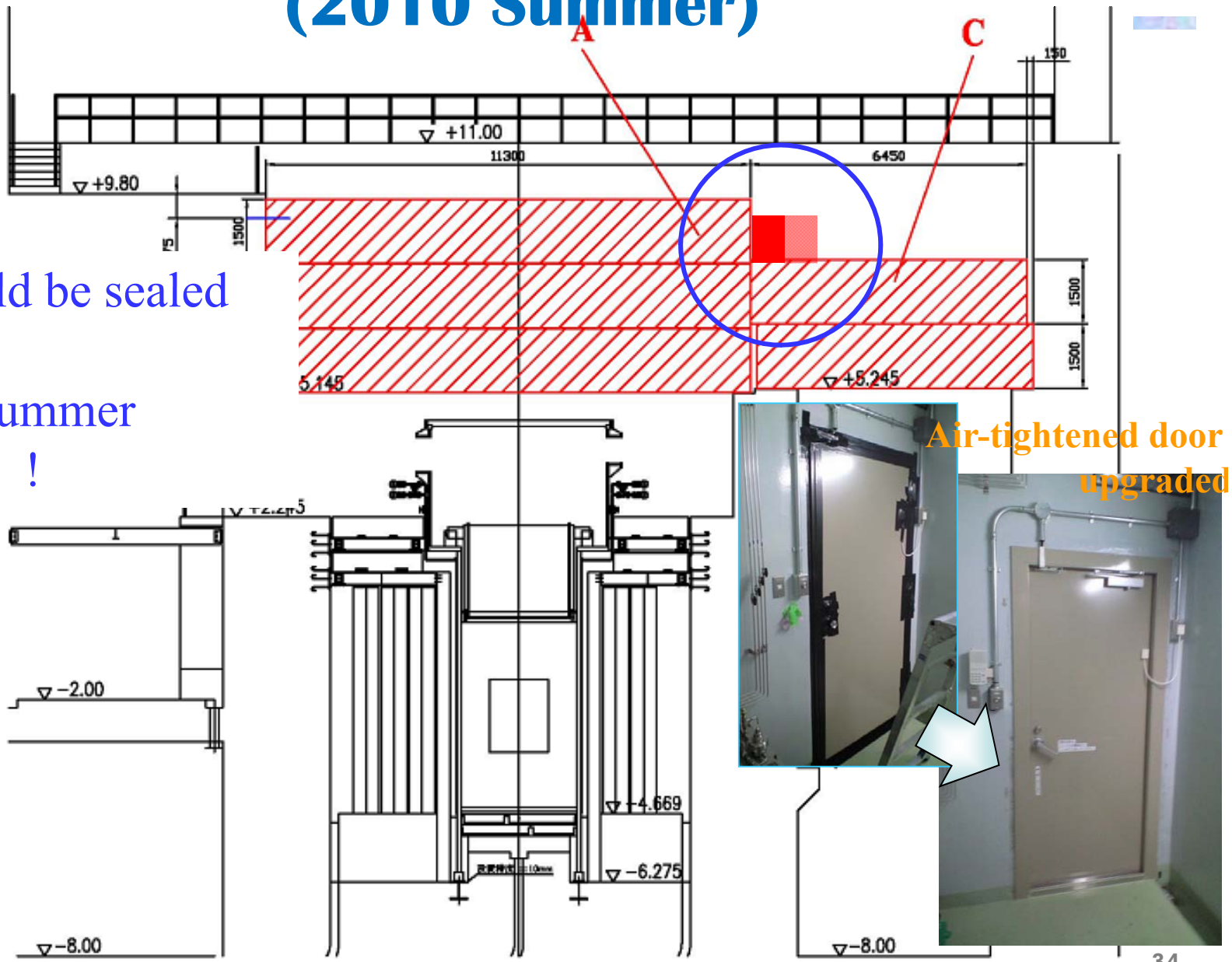
Blocks should be sealed and covered after every summer maintenance !



2010 Jun.→2010 Nov.~Dec.

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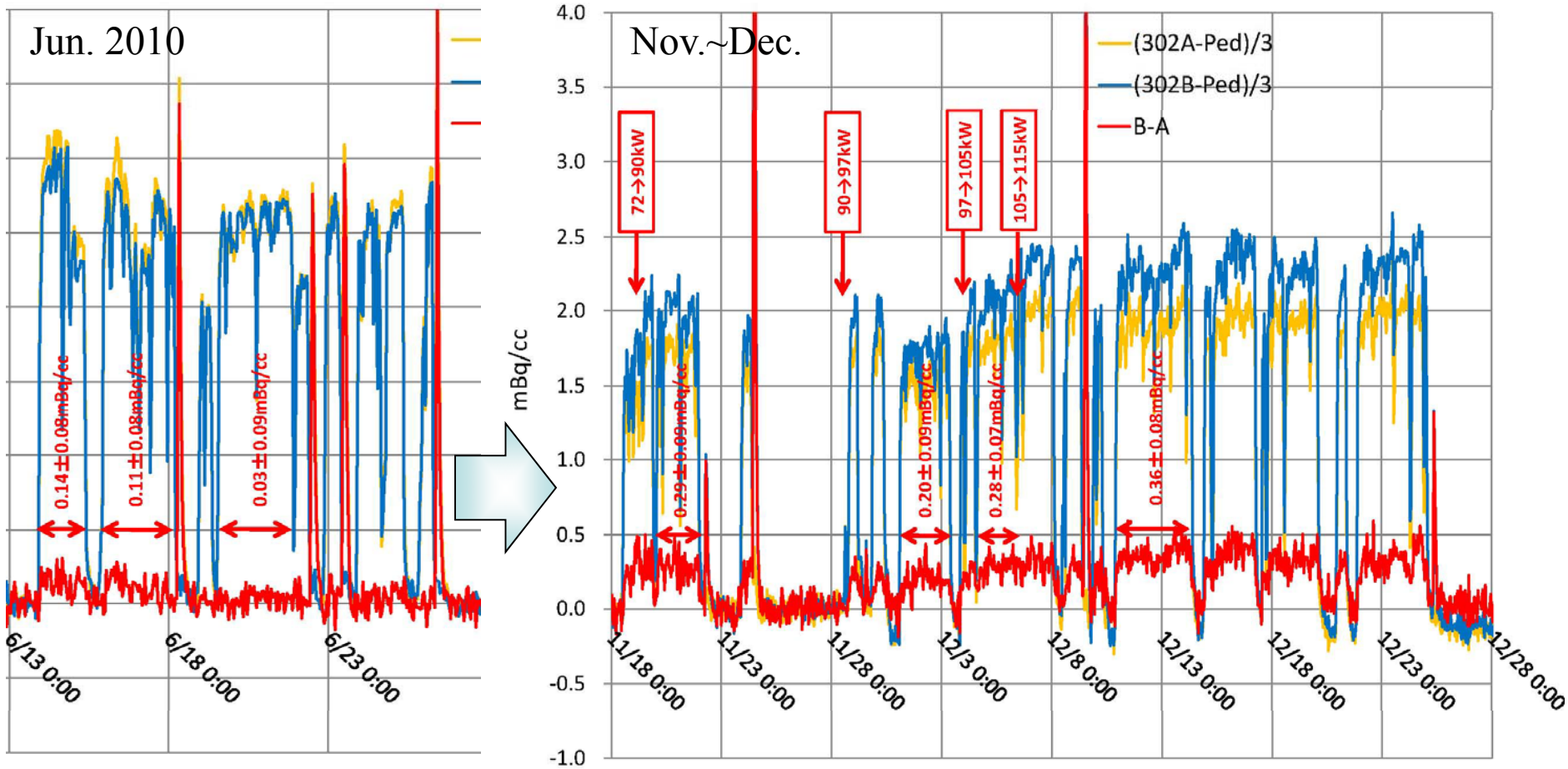
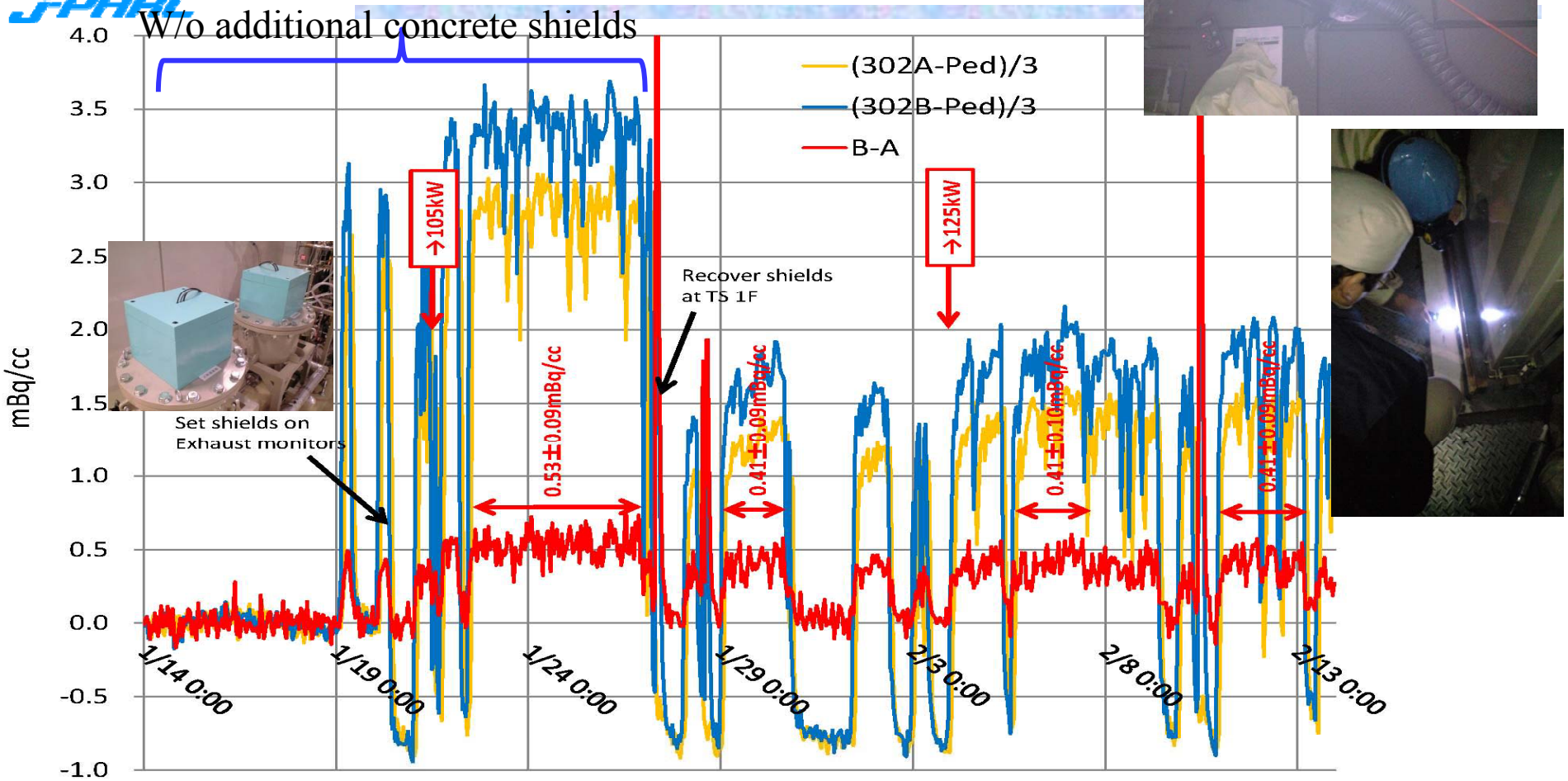


- 2010Jun: 0.1~0.15mBq/cc @ ~50kW →
- 2010Nov.~Dec: 0.28mBq/cc @105kW → 0.36mBq/cc@115kW
  - Signal levels of A/B were reduced, but not for B-A…

2011 Jan.~Feb.



- Smoke test on Jan.13, fix some leaks at cable penetration holes.
- 0.5mBq/cc when the additional shields were removed (105kW)
  → 0.4mBq/cc with shields(105kW), 0.4mBq/cc for 125kW