Operational Status of the J-PARC Neutrino Secondary Beam-line

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On behalf of the Neutrino Experimental Facility Group, J-PARC KEK

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- Conventional horn-focused beam-line, designed/constructed for T2K (Tokai-to-Kamioka) long base-line neutrino oscillation experiment & for its future upgrade
  - Superconducting Combined Function Magnets (SCFM) at the primary proton beam-line
  - First application of off-axis configuration, angle adjustable between 2~2.5^{o}
  - Design intensity =750kW

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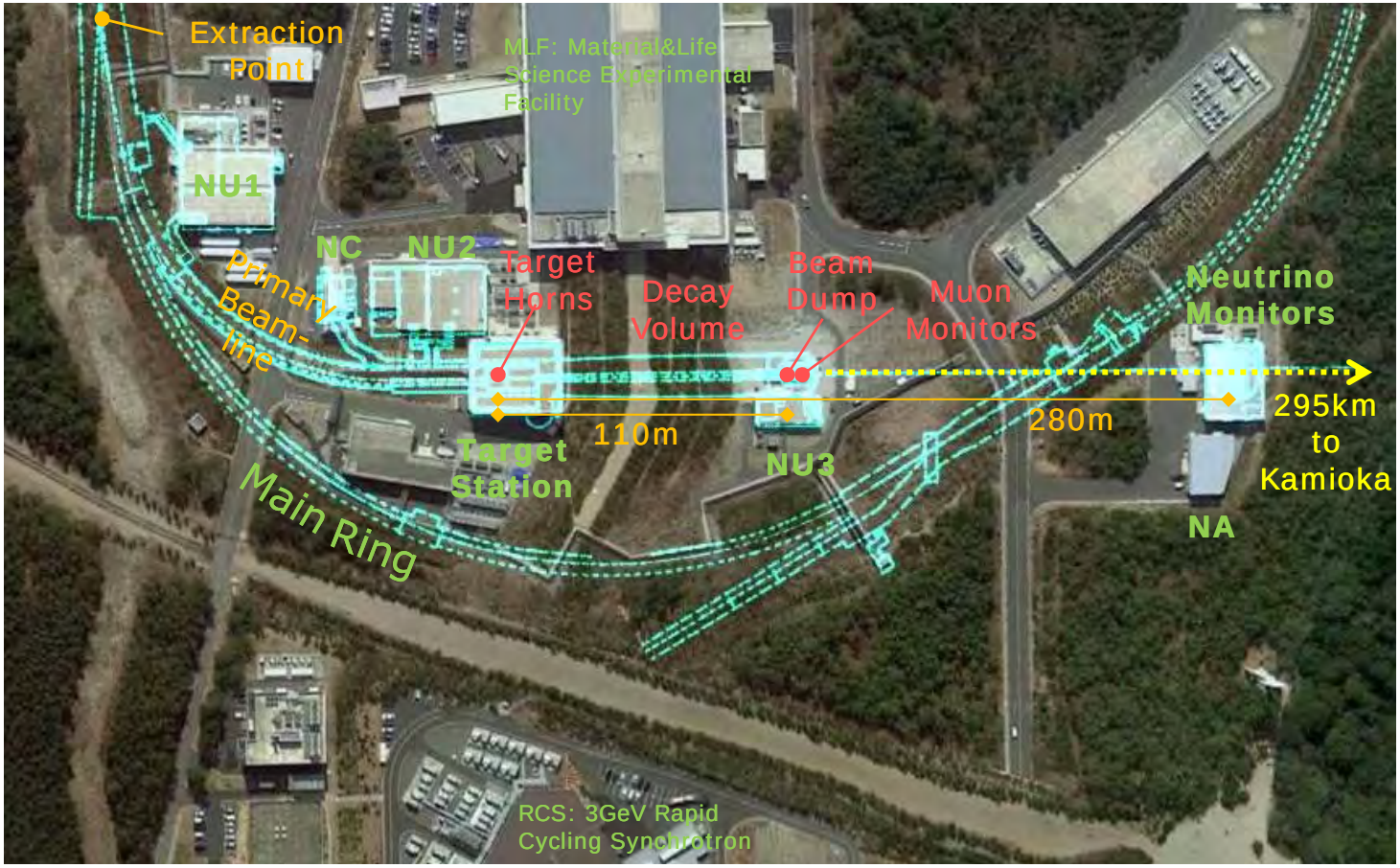

Secondary Beam-line

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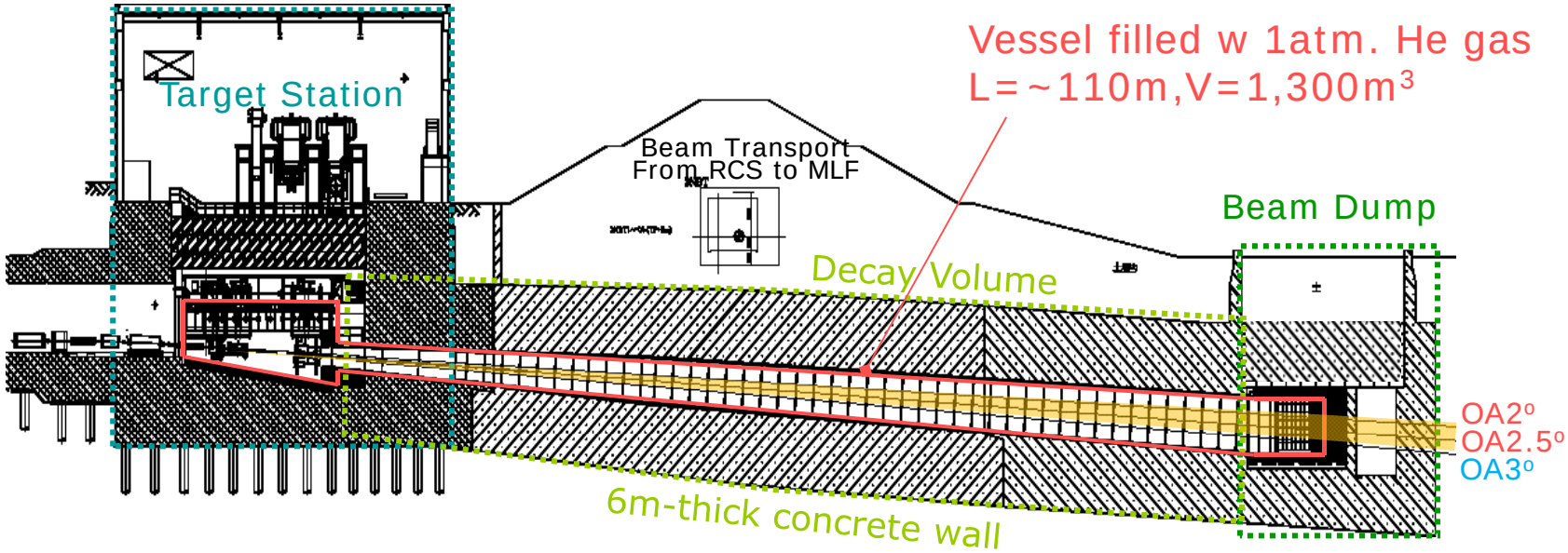

- Target Station(TS), Decay Volume(DV), & Beam Dump(BD)
  - TS: He-cooled graphite target, 3 magnetic horns, remote maintenance
  - DV: 94m-long tunnel with rectangular cross section
  - BD: hadron absorber made of large graphite blocks, surrounding iron shields
- All the apparatus are enclosed in a gigantic vacuum/helium vessel, made of carbon steel plates.
  - He atmosphere prevents nitrogen oxide (NO_x) production / oxidization of apparatus.
- Iron plates of the vessel are cooled by water circuits.
  - Maintenance is not possible after beam operation due to irradiation.
  - Radiation shielding / cooling capacity were designed to accept up to ~4MW beam (w/o safety margin) .

Target Station (TS)

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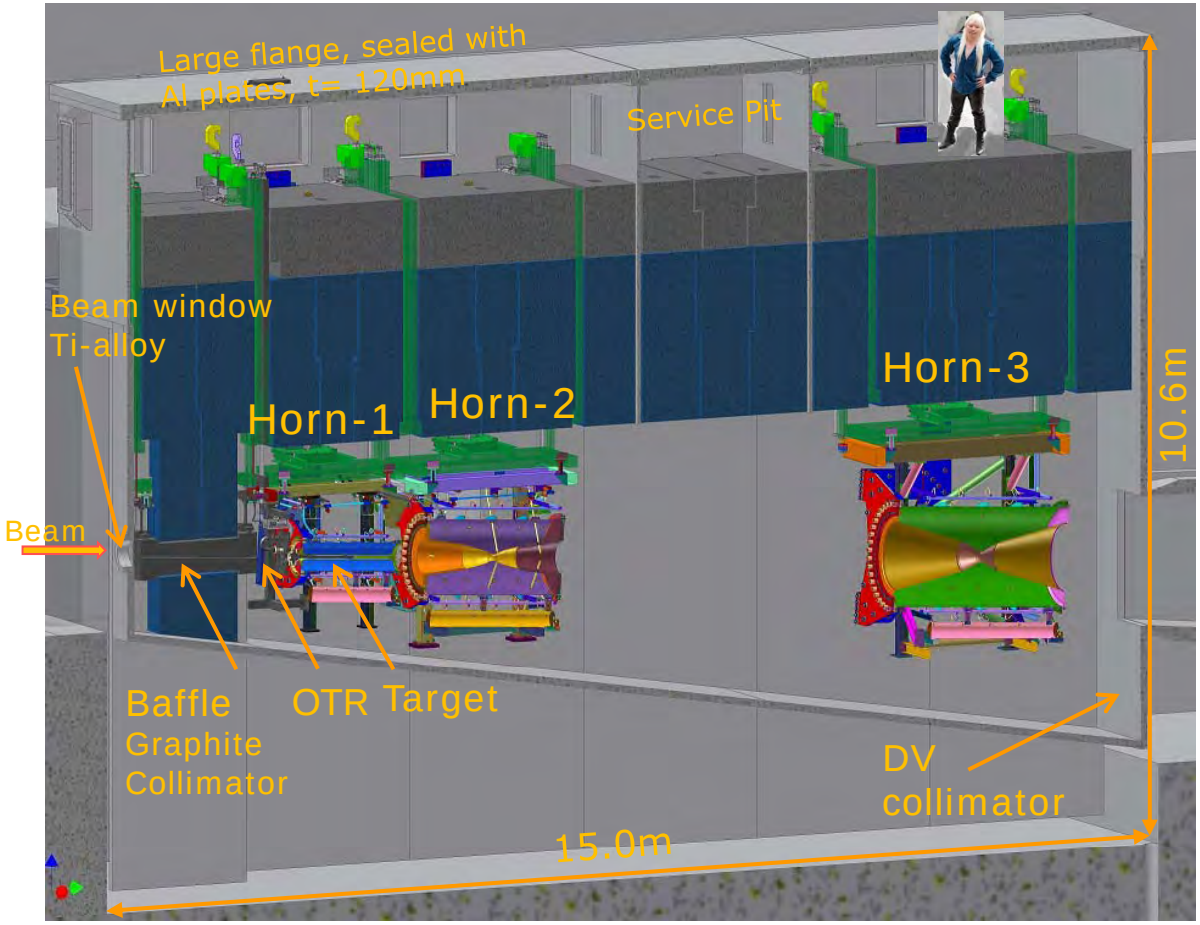
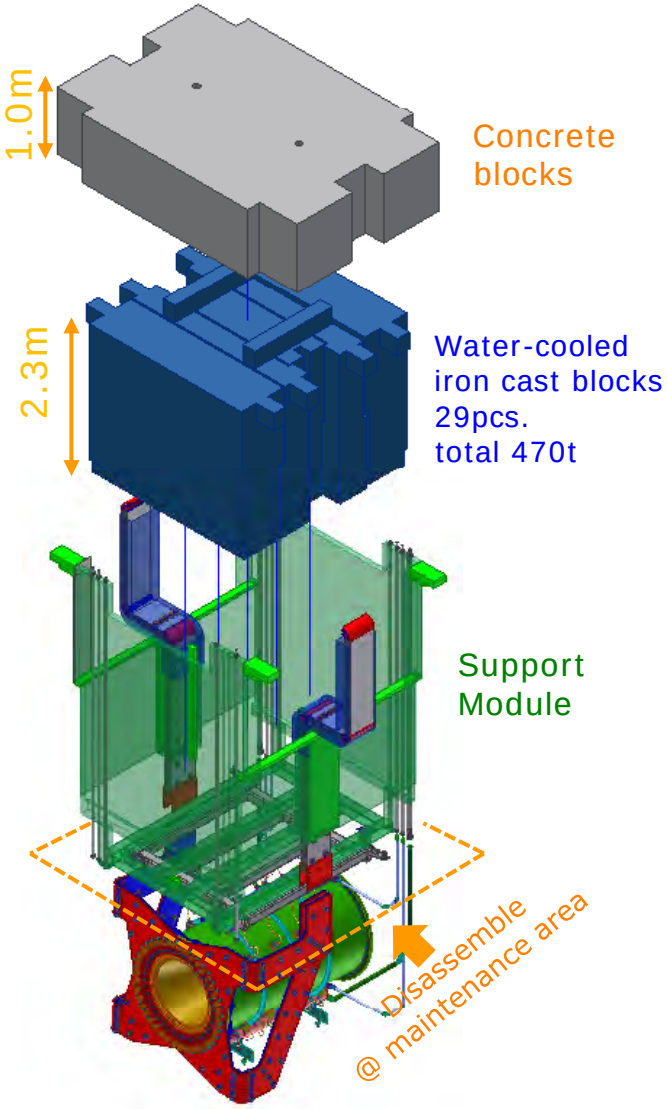
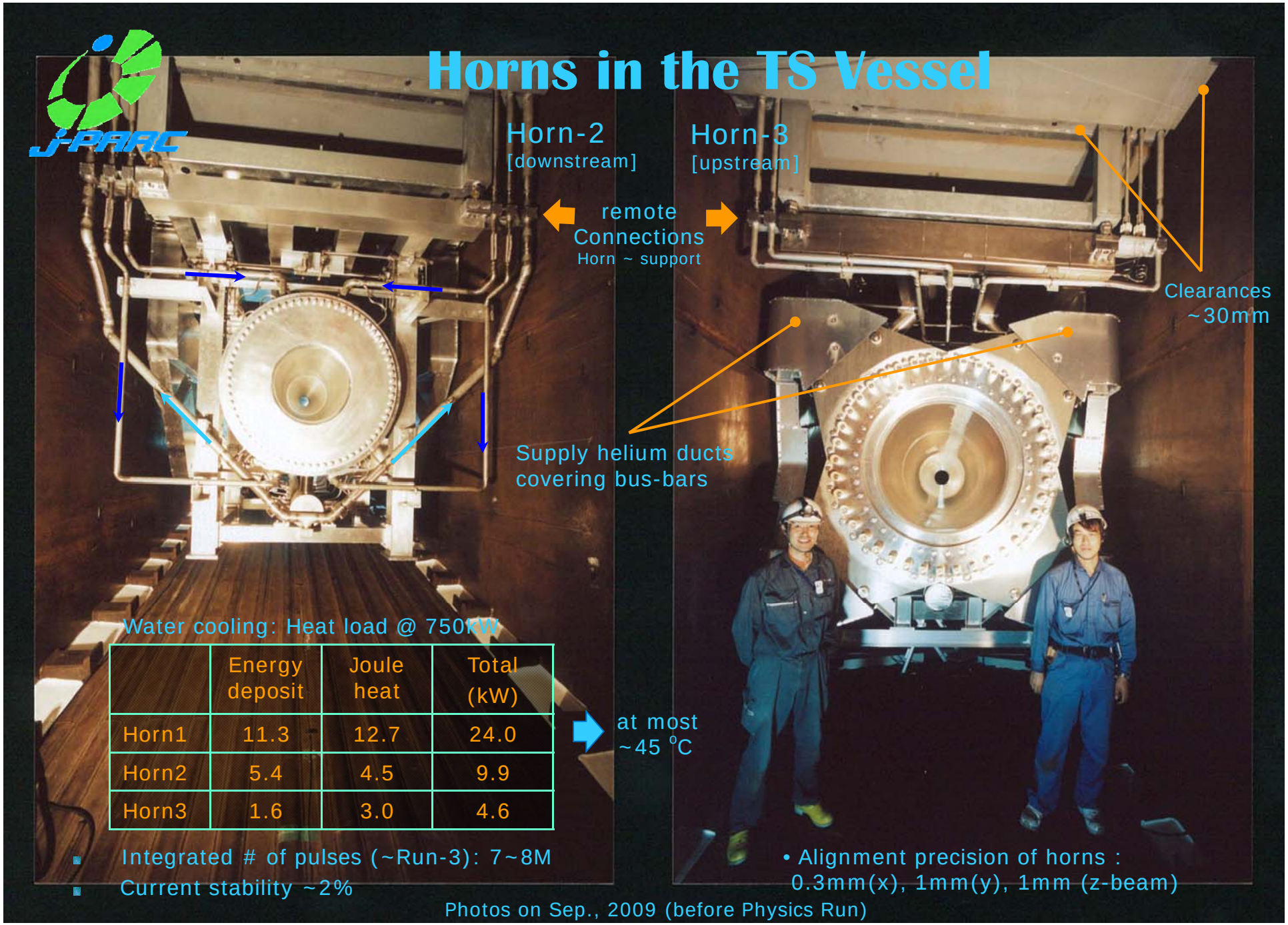




- Horns / a baffle are supported from the wall of vessel by support modules.
- Apparatus on the beam-line are highly irradiated after beam. Remote maintenance is key issue.

Horns in the TS Vessel



Water cooling: Heat load @ 750kW

	Energy deposit	Joule heat	Total (kW)
Horn1	11.3	12.7	24.0
Horn2	5.4	4.5	9.9
Horn3	1.6	3.0	4.6

at most ~45 °C

- Integrated # of pulses (~Run-3): 7~8M
- Current stability ~2%

- Alignment precision of horns : 0.3mm(x), 1mm(y), 1mm (z-beam)

Photos on Sep., 2009 (before Physics Run)

T2K Target

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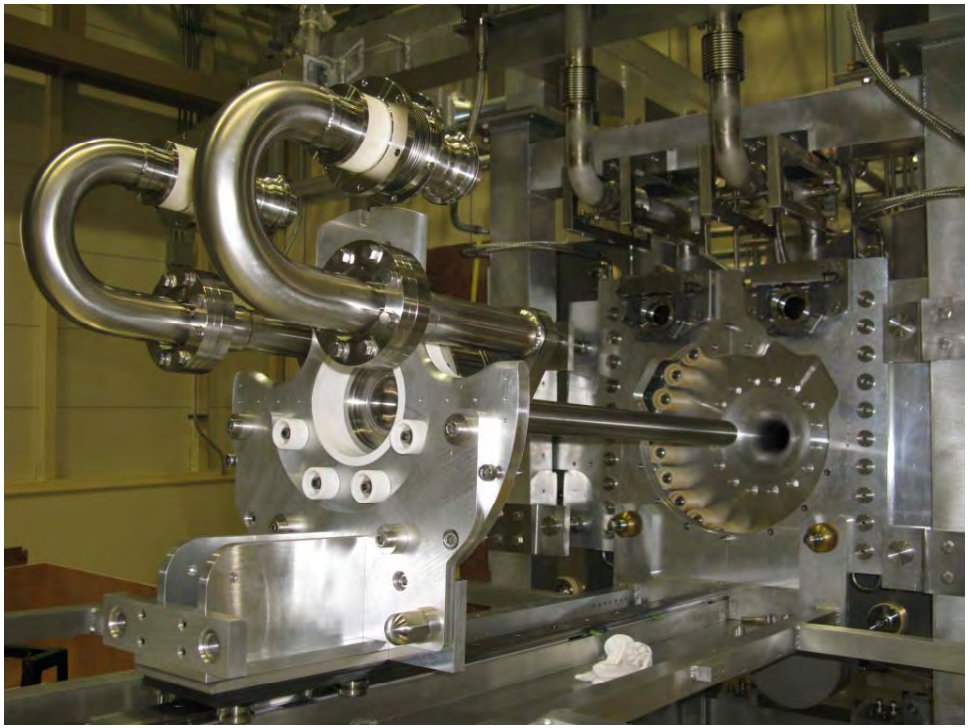

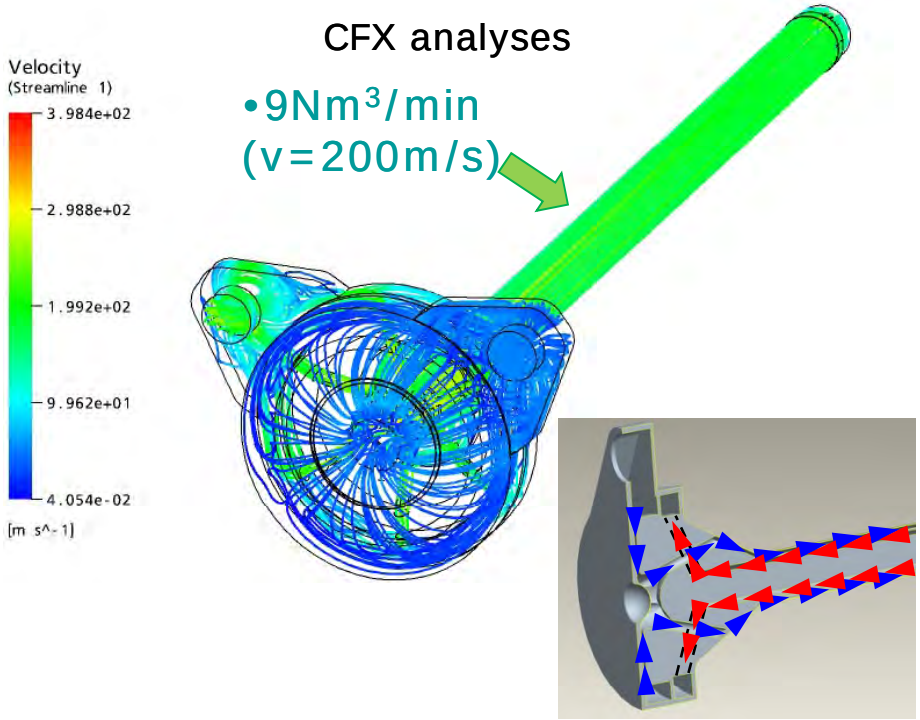

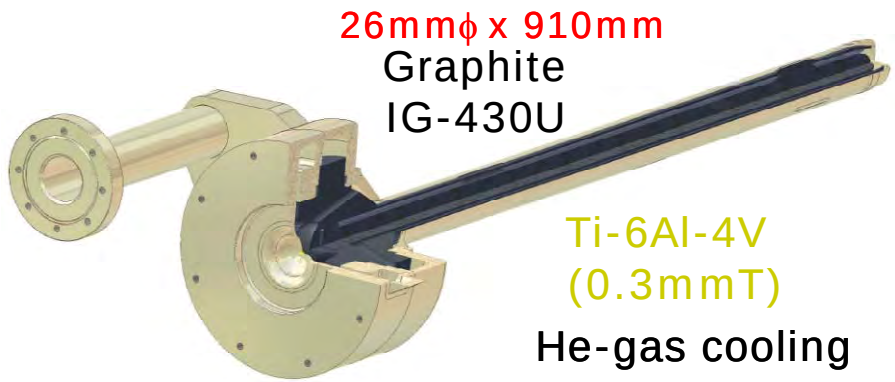

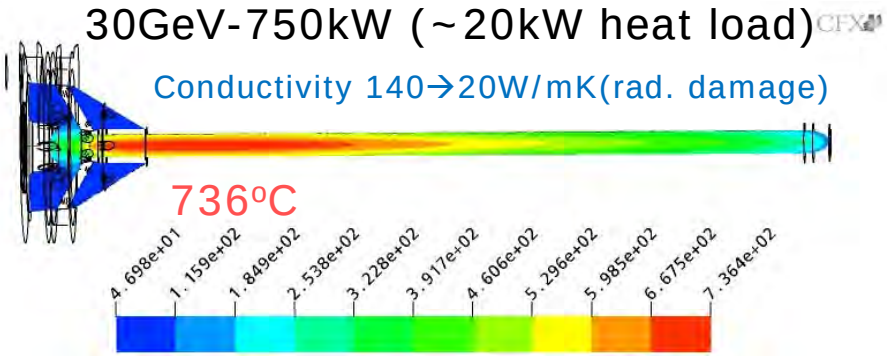

ΔT~200K ~7MPa (cf. Tensile 37MPa→15MPa)

Delivered POT to Neutrino Facility (MR Fast Extraction)

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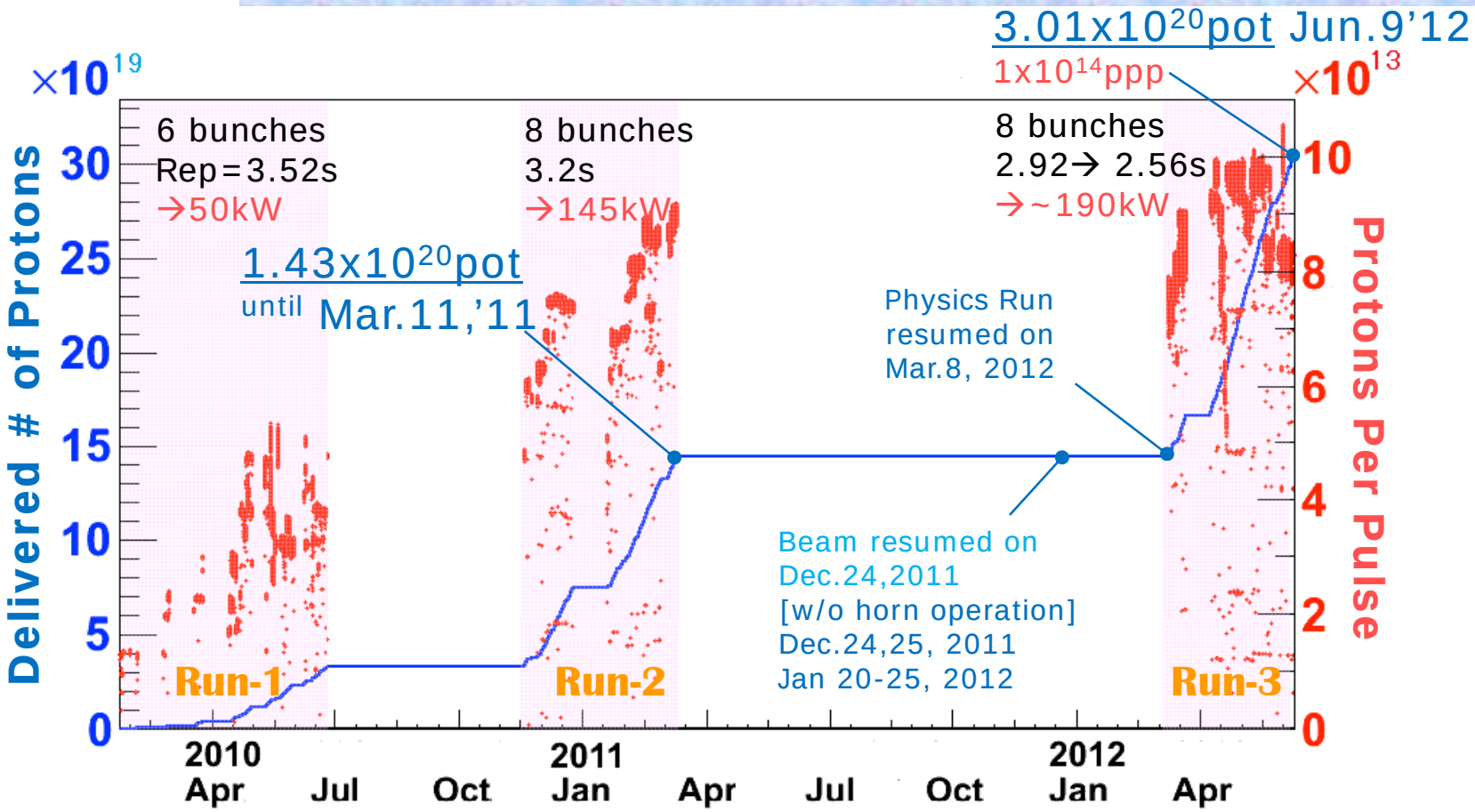

- After earthquake(3/11,2011), beam operation resumed in the same year (Dec.24, 2011) and physics run resumed within one year(Mar.8, 2012).
- Stable operation at ~190kW achieved, 1×10^{14}ppp (1.26×10^{13}x8b), rep rate=2.56s
- Bottleneck: MR injection loss / ion source current / radioactivity in exhaust of MR facility building

Target Cooling (Run-1)

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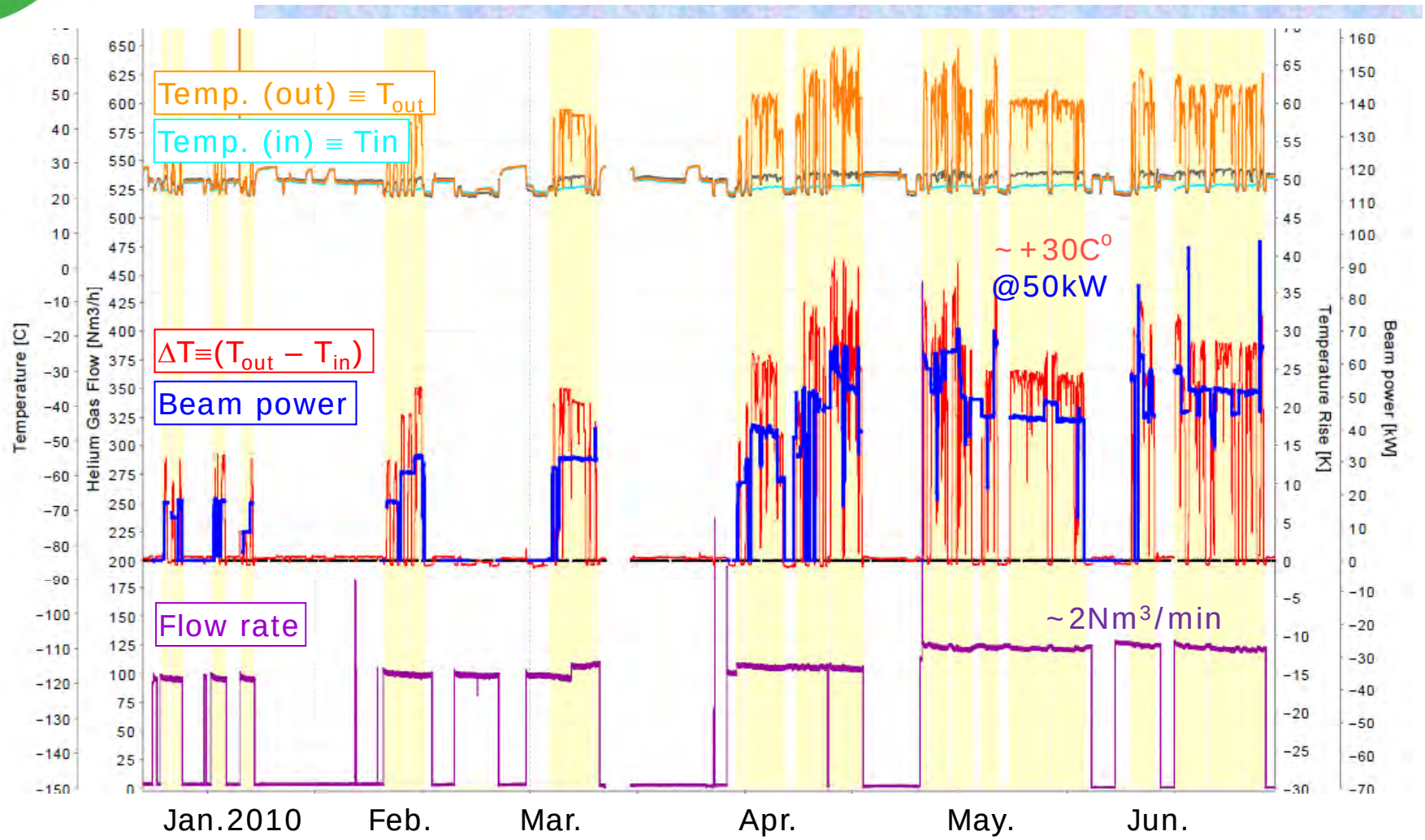

- Temperature raise of He gas shows the direct correlation w/ beam power.
- Up to now (~Run-3) 1st target and He cooling system runs w/o troubles.
  - For 190kW: Flow rate: 3.7~3.8m³/min, DT=+55C°

Beam-line Operation & Chief Events (1)

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- Beam commissioning / installations in 2009
  - 1st beam on Apr.-May: Horn-1 only. Vessel filled with air.
  - Installation of horn-2&3 in summer shutdown.
  - He vessel commissioning in Oct.
  - 2nd Beam on Nov.~Dec [20kW]
- Run-1: Jan.~Jun. 2010 [20→50kW]
  - Radiation in exhaust at NU3/TS restricted our beam power.
- 2010 summer shutdown
  - Relocation of underground control panels of air ventilation / water circulation at TS to avoid attack of fast neutrons to PLCs
  - Upgrade horn power supply: 3 horns connected in series
- Run-2: Nov. 2010 ~ [70→100→145kW]
- Earthquake (Mar.11, 2011)
  - Damages around the facility buildings due to subsidence, but few major troubles for visible apparatus.

Beam-line Operation & Chief Events (2)

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- Recovery / maintenance works (Mar.~Dec. 2011)
  - The first operation of remote maintenance of irradiated Horn-3
  - Visual inspection of DV/BD
  - Realignment of horns in the vessel
  - New horn power supply damaged during test operation (Dec.22, 2011)
- First beam after Eq. (Dec.24,2011), but w/o horn operation
  - Rapid re-installation of old horn PS
  - Upgrade of TS air ventilation to reduce radiation in the exhaust.
- Run-3: Mar.8~Jun.9 2012 [→~190kW]

- 2012 summer shutdown (now)
  - Recovery works continuing: repair expansion joint at the muon pit
  - Repair broken horn PS to revive 2 PS operation
  - Production of spare Horn-2&3, horn support modules and casks

Radiation in Exhaust Air (1)

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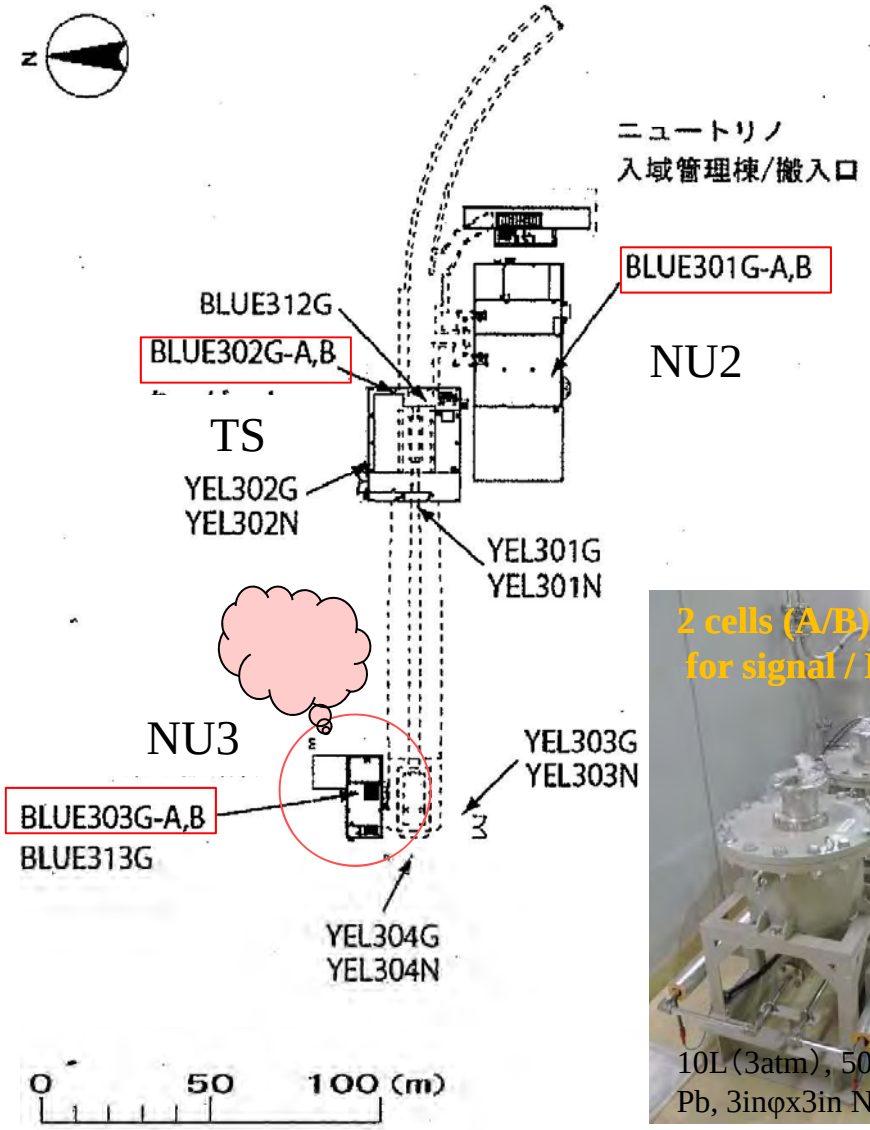
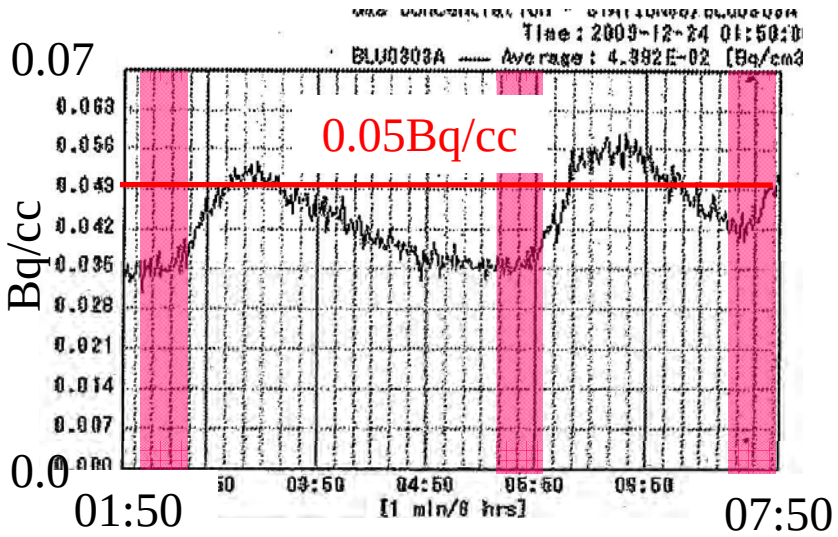


- Monitor radiation level of exhaust at upstream of the chimney stack
  - A pair (Signal/BG) of NaI (TI)
  - < 0.5 mBq/cc [3 month average]
- 1st continuous (20kW) beam (Dec.24,'09)
  - NU3 exhaust: 60m Bq/cc (raw data) :
  - ~8mBq/cc after correction.
- Beam operation limited within 30min.



Radiation in Exhaust Air (2)

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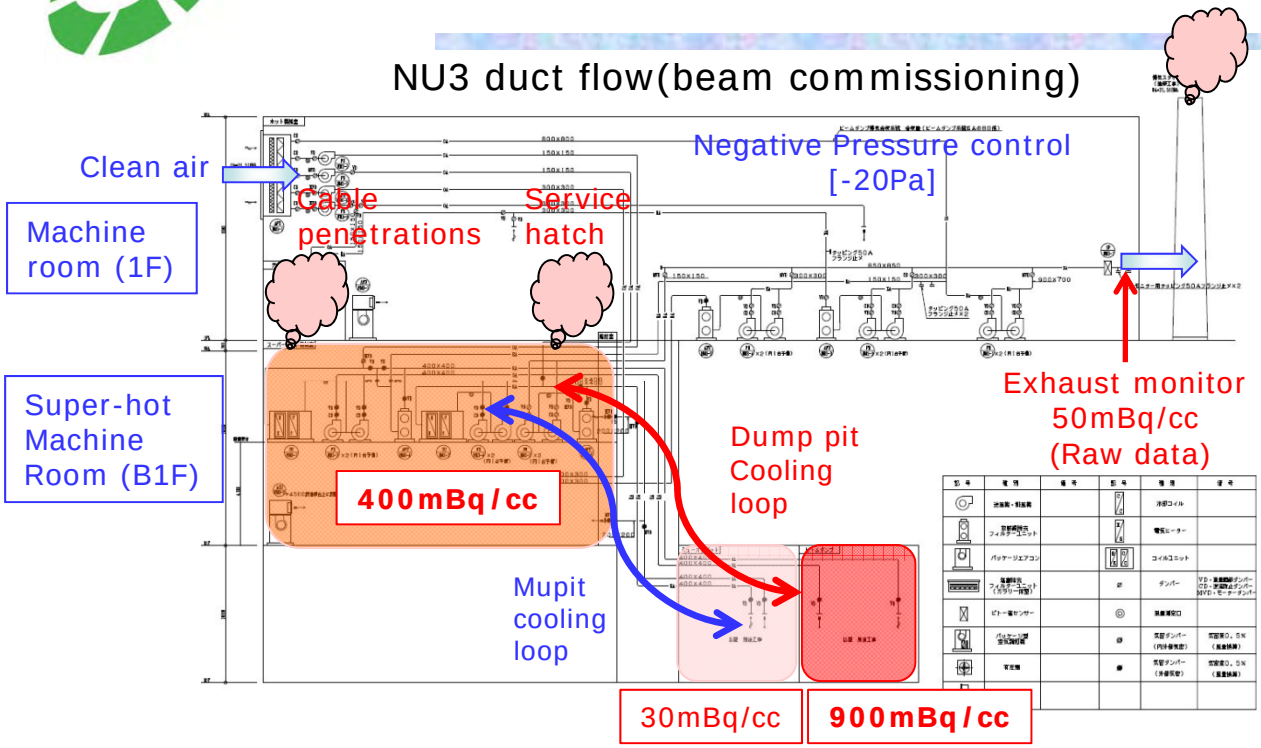
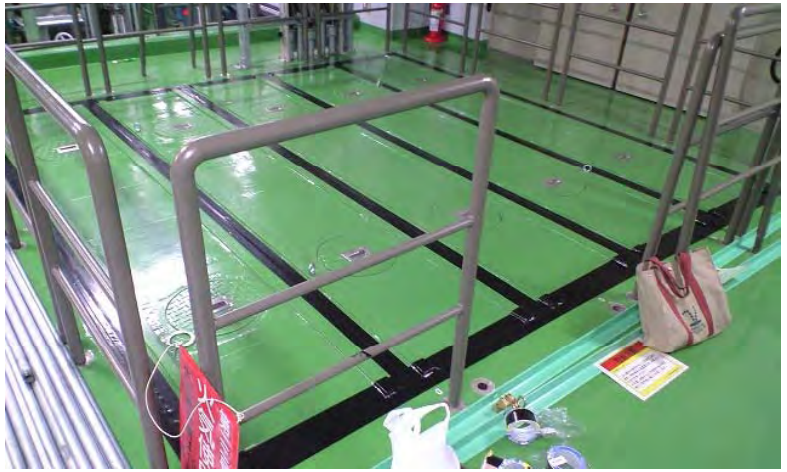
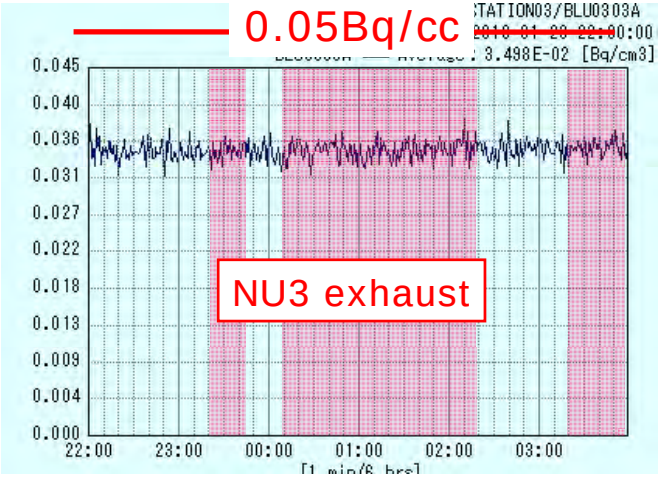
NU3 duct flow(beam commissioning)



- Irradiated air was leaked into B1F super-hot machine room from (air-tightened) dump pit cooling ducts
- The air is going into 1F through service hatch and cable penetration



Jan. 23~24, 2010



Radiation in Exhaust Air (3)

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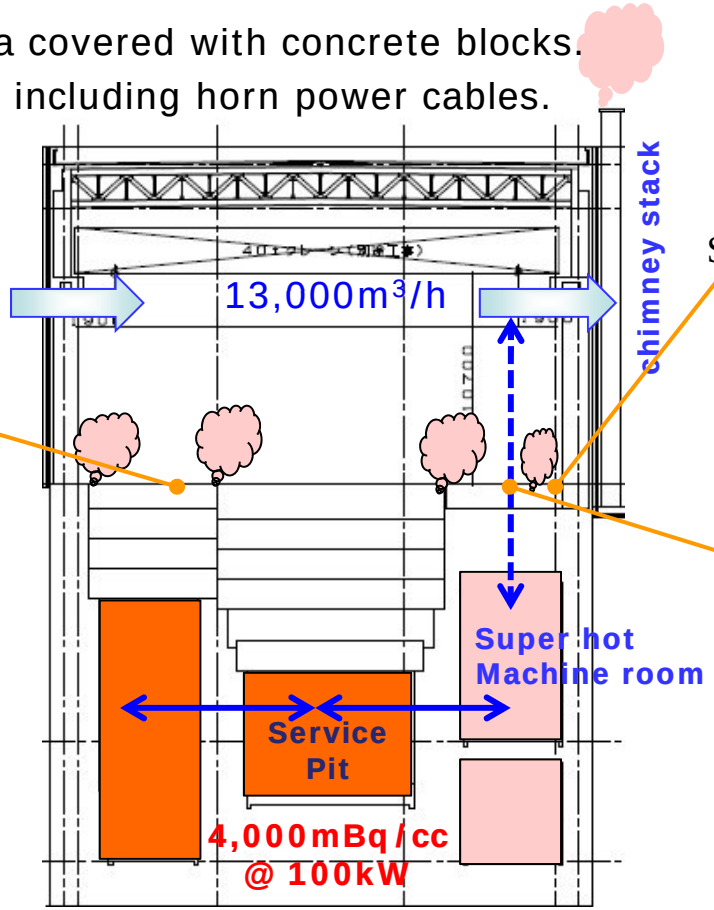
- The job was much harder for TS
  - Service pit / storage area covered with concrete blocks.
  - More cable penetrations, including horn power cables.

Put backup material and caulking cover block surface by air-tight sheet



Silicon to cable holes/smoke tests

Doubled air-tightened dampers for exhaust lines

- 0.3mBq/cc at 150kW (Run-2) → 0.1mBq/cc at 190kW (Run-3)
  - Bypass duct line (to use 1F as a reservoir of irradiated air) installed to ventilation system
  - Improvement for the shield cover: Continuous 2-layer sheets, used for balloon
  - Acceptable beam power (< 0.5mBq/cc): 250kW → ~1MW

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

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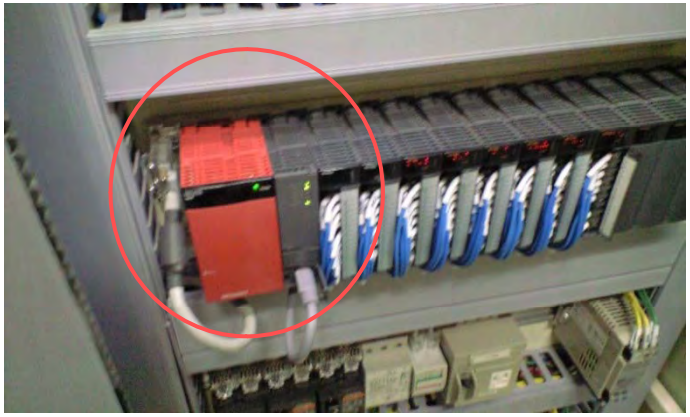

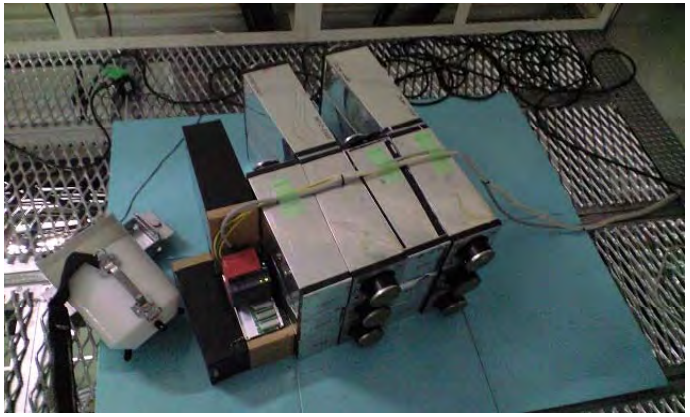

- The control panel was in B1F machine room at around the level of target. "Single event upset" on a CPU unit of the PLC by beam-induced fast neutrons.
- As temporary fix during Run-1, extract / relocate the CPU unit by 10m to area with less neutrons, then covered with LG blocks.
- Whole control panels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

Remote Maintenance of Horn-3 (1) [Summer, 2011]

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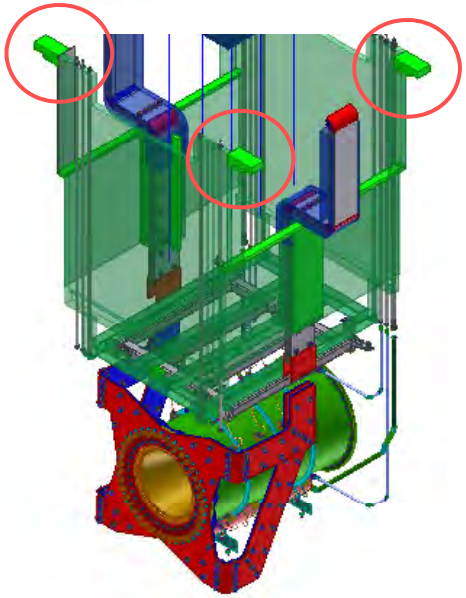
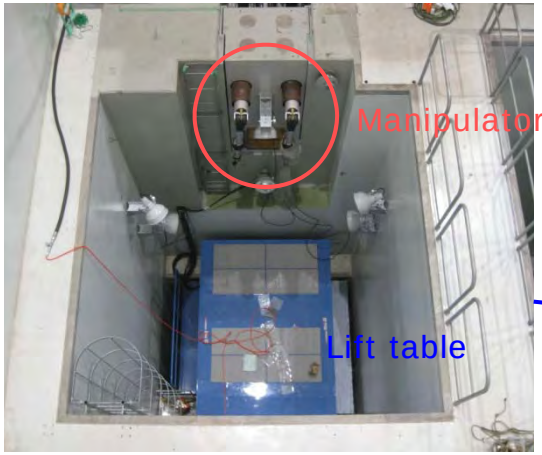
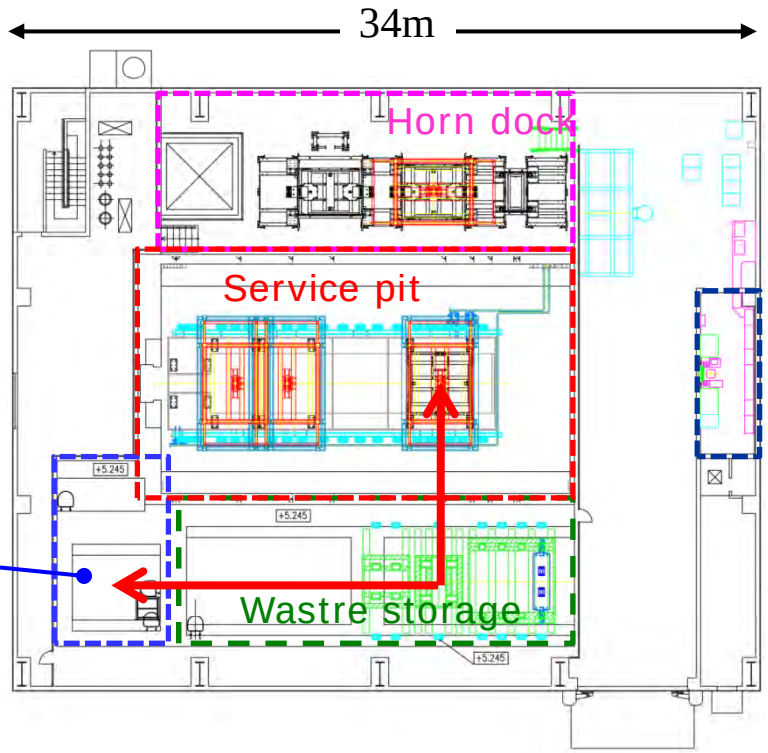


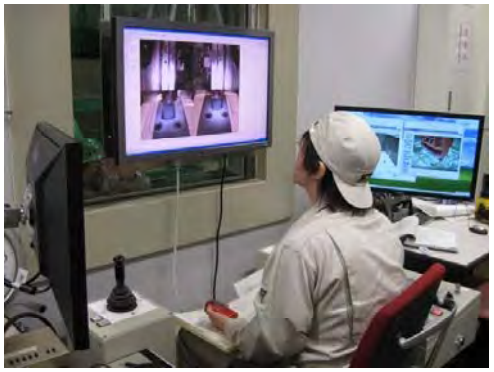
- Support bases at the top of horns broken due to earthquake, and horn moved.
- Possibly horns in the vessel hit the wall, and may have some damages.
- To inspect / survey horn and support module, we took out Horn-3 from the vessel to maintenance area

Maintenance area





Control room



Every process managed remotely at control room

Remote Maintenance of Horn-3 (2)

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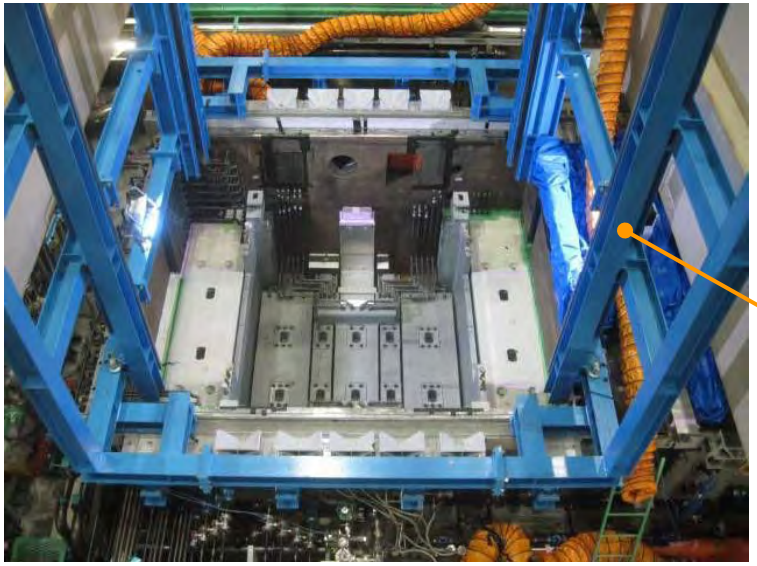

Remote Maintenance of Horn-3 (3)

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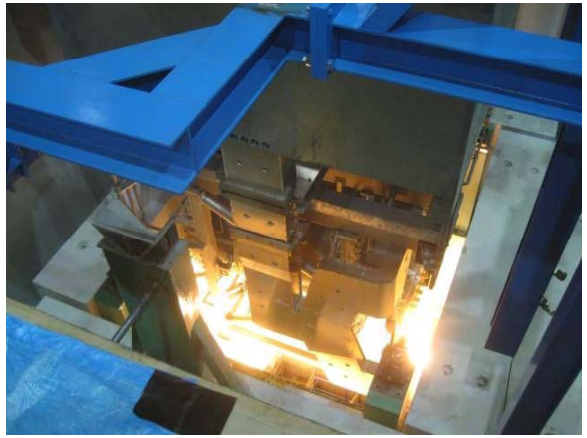
To maintenance area



- **Positioning accuracy**
  - By crane : < 2 cm
  - With guide : a few mm
  - cf. clearance ~30 mm

- Scheme worked very nicely.
  - Only a few hours to move Horn-3 from vessel to maintenance area.
- Radiation level outside of TS became several x 10uSv/h at most (Horn: ~10mSv/h)
  - Need to add shields, redefine radiation controlled area at TS
- Horn stacked on the way back to vessel, due to interference with DV collimator support at downstream
  - Need better control for tilt of horn (by using counter weight etc.)

Visual Inspection of DV/BD (1) [Summer, 2011]

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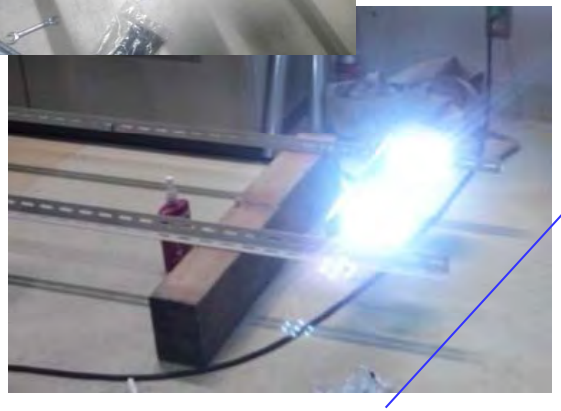
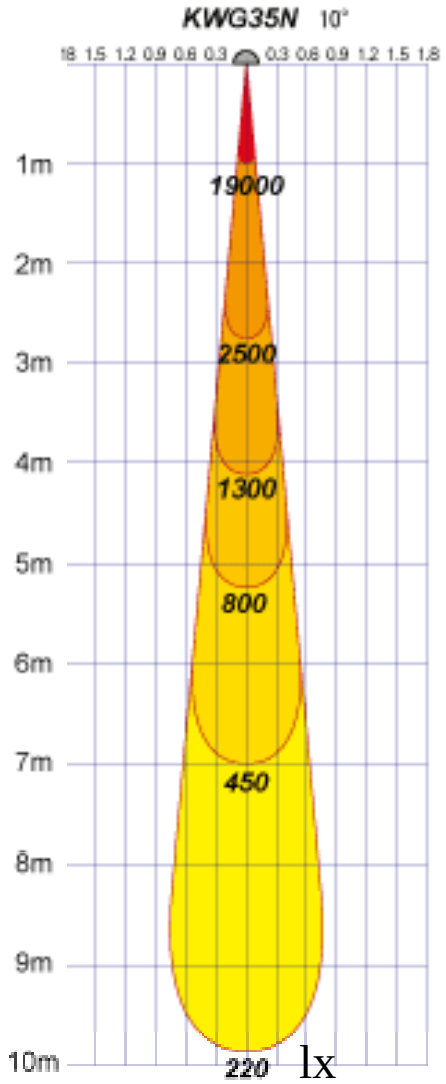
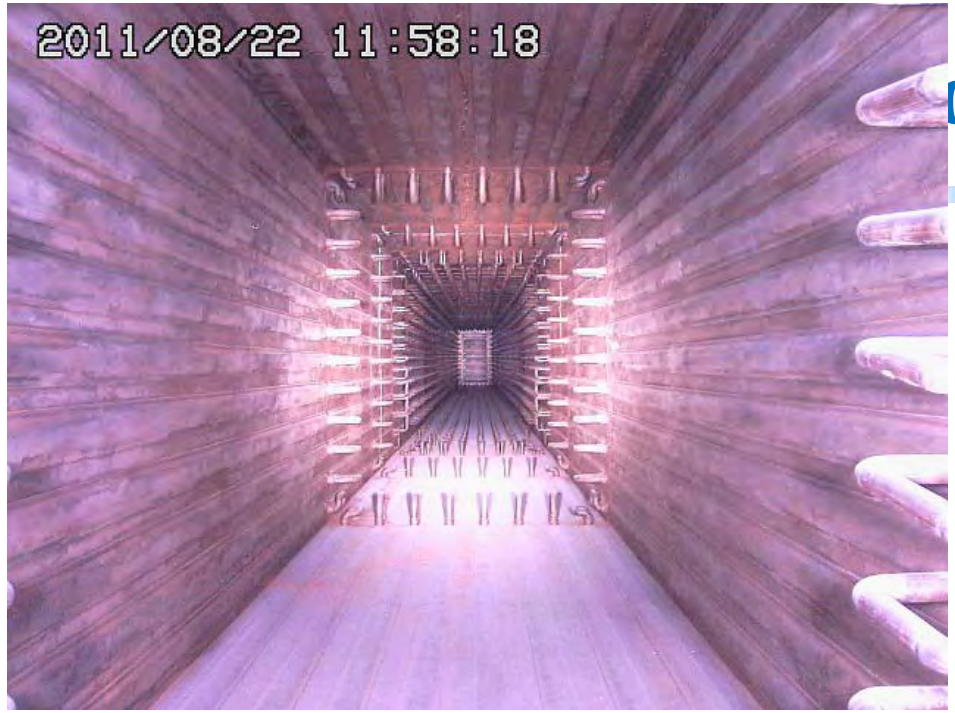




MOS sensor, min.illuminance=0.5lx
X36 (18x2EX) optical zoom

36W LED, 3,600lm
illuminating angle10deg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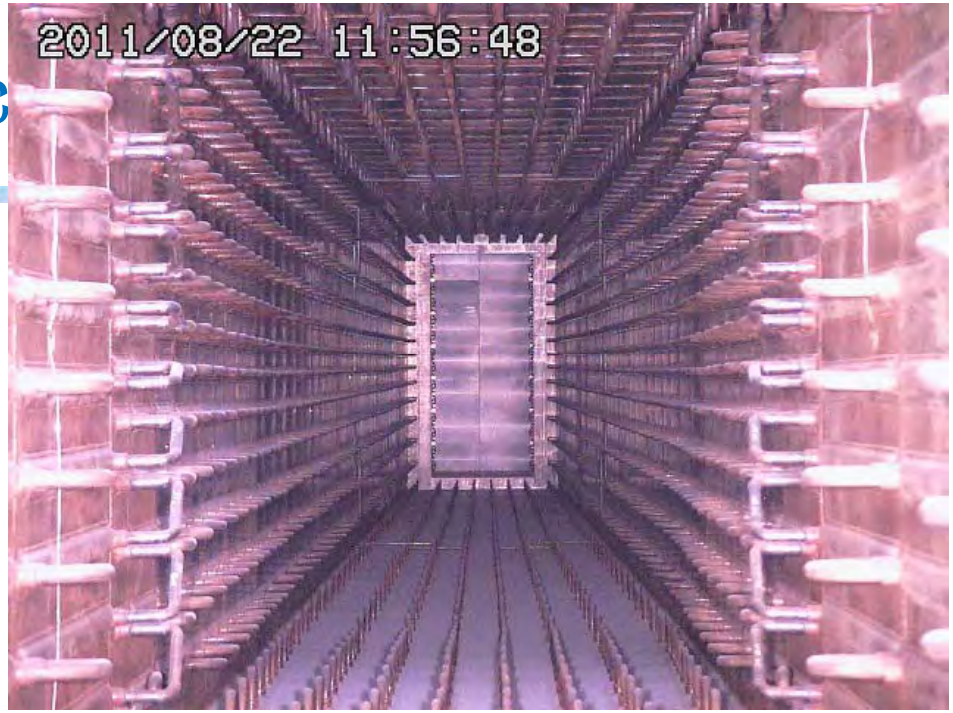
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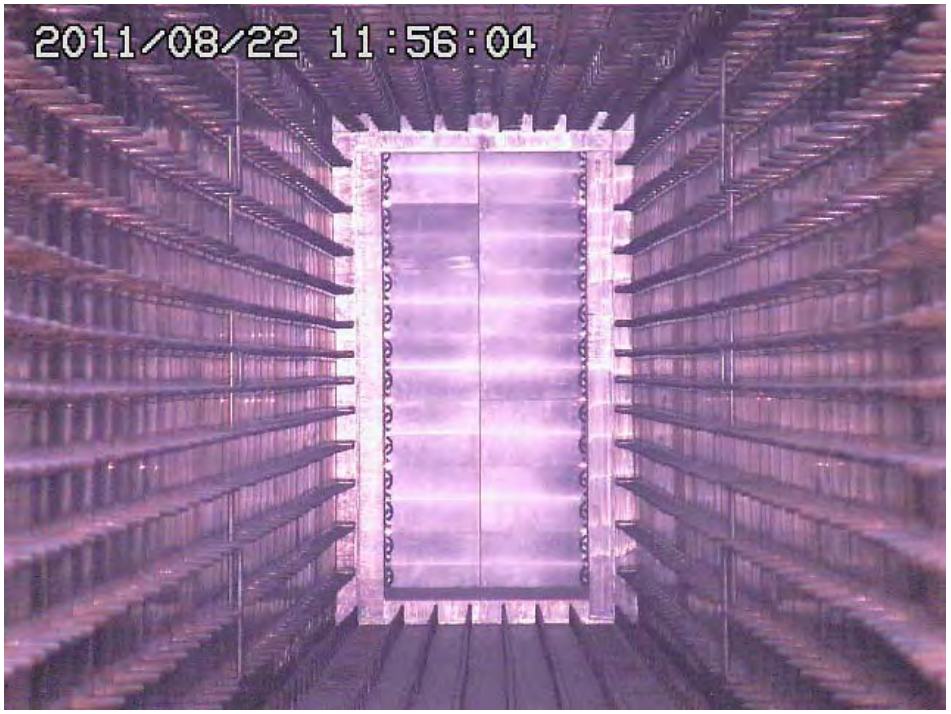
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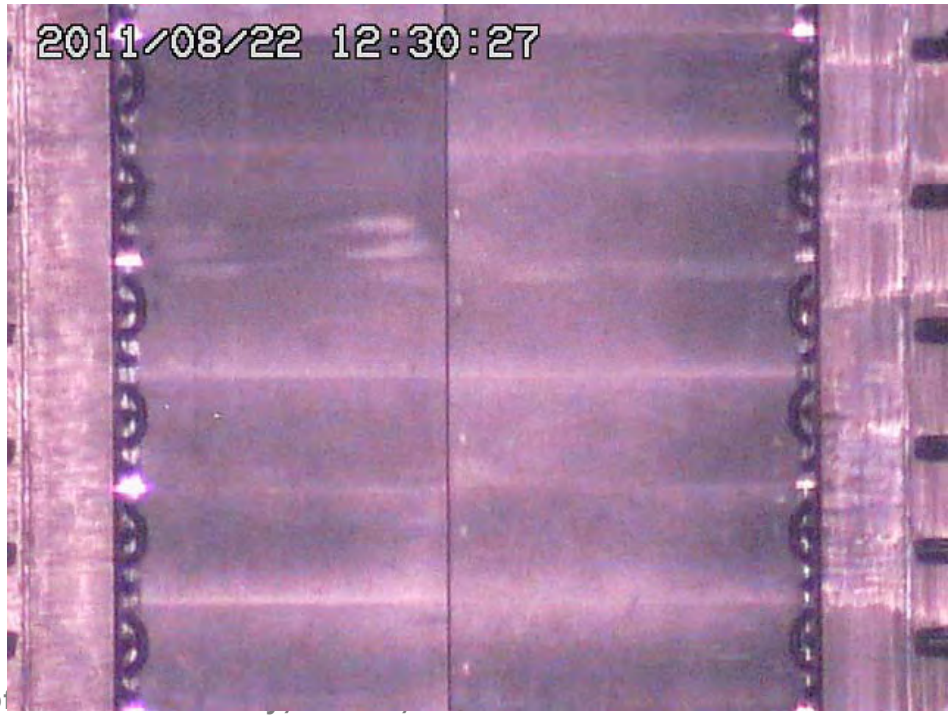
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Horn Alignment in TS Vessel [Summer, 2011]

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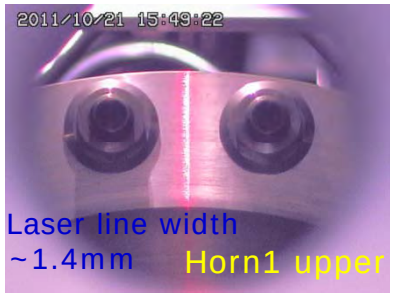
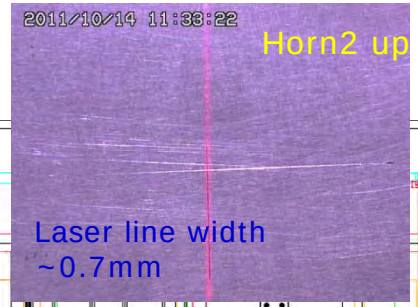
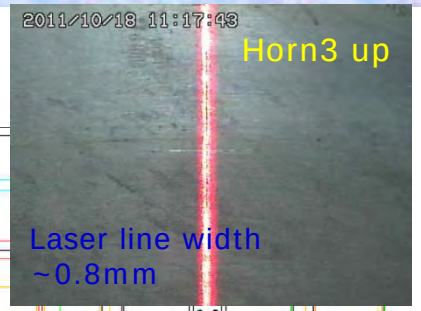
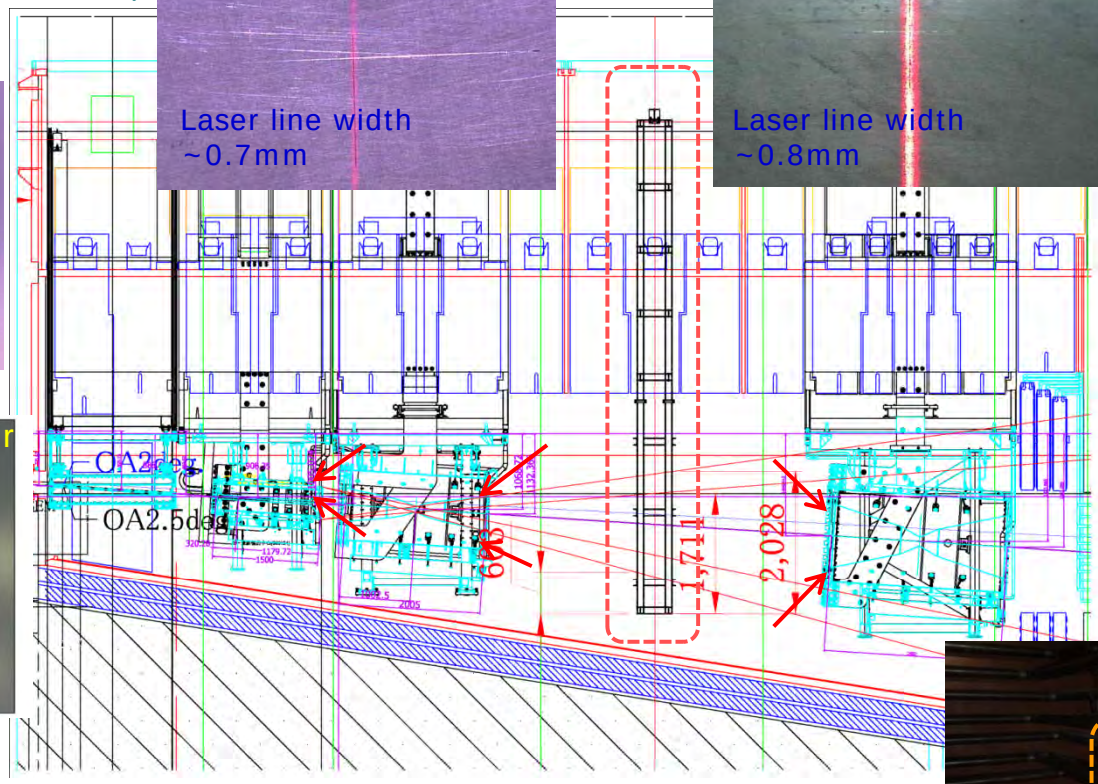
compare
laser line (module center)
to scribe line (horn center)

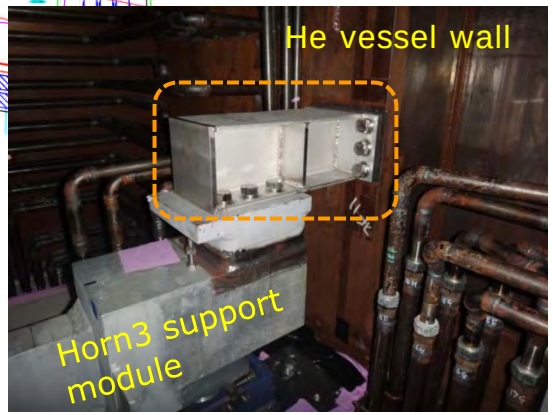








Alignment tool
3 Web cameras +
1 laser leveling tool



- Relative position btw. horn and support module was correct within survey precision (~1mm)
  - No significant deformation due to earthquake
- After the alignment works, Horn support modules were fastened rigidly to the He vessel wall.

Major Failure of Horn Power Supply [Dec.22, 2011]

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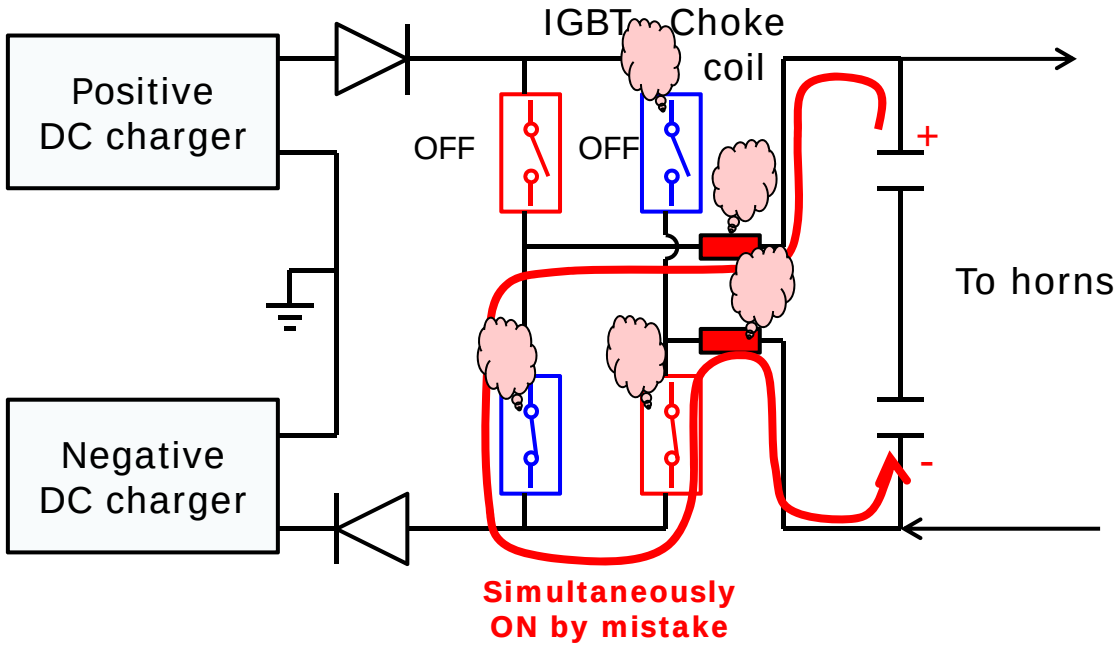

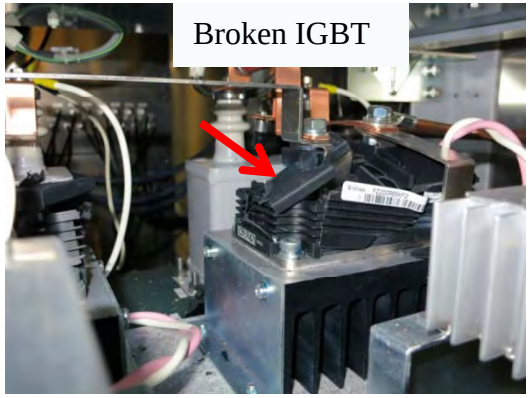

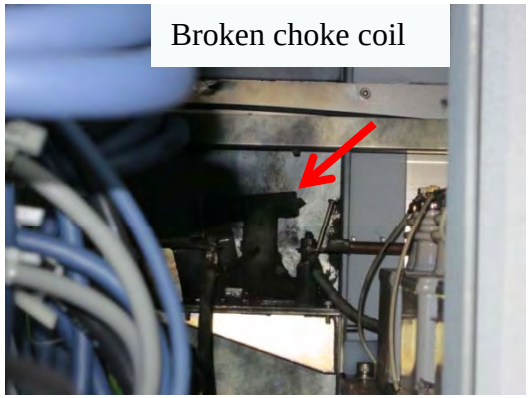

- It is very likely that IGBT(Insulated Gate Bipolar Transistor) switches unnecessarily turned ON during current discharge due to some noises.
- We forced to postpone Run-3 for reinstalling old PS
- The broken PS is now under repair with various countermeasures:
  - Noise-tolerant control system
  - Enhancement of monitoring IGBT voltage
  - Add rapid fuses for protection of capacitors

New Strip Line Layout [Summer, 2012]

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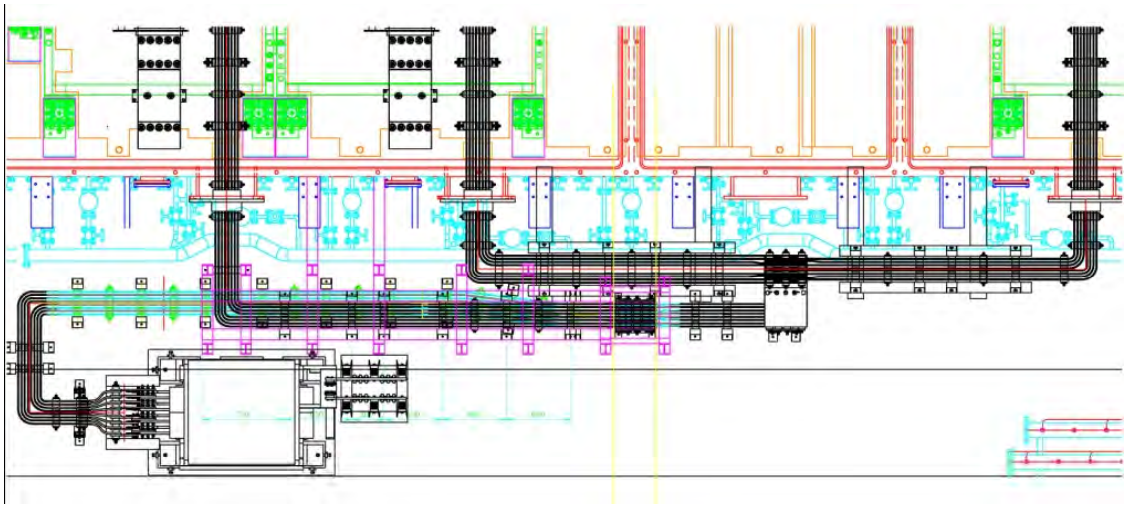
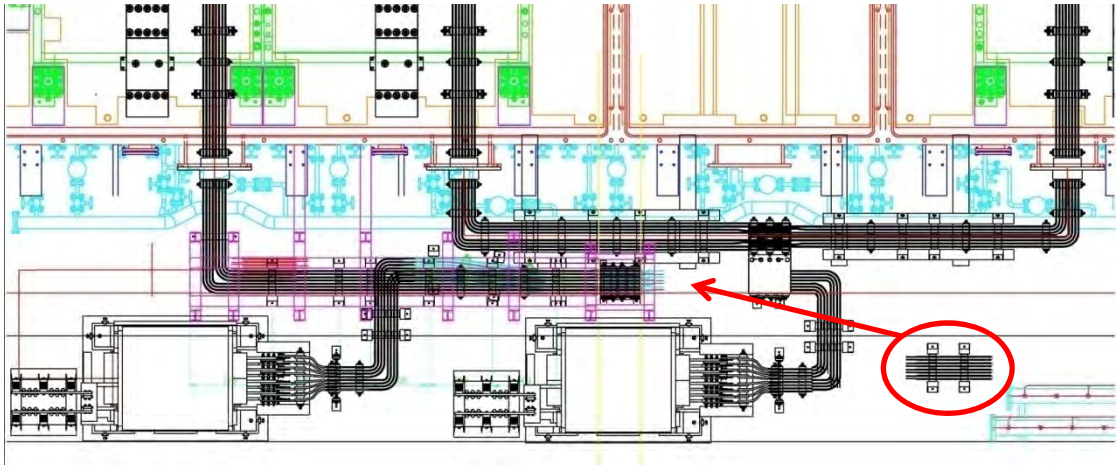
Present 1 PS configuration



Configuration to allow easy switch of 2PS/1PS operations



- 3 horn operation with 1PS require higher charging voltage and thus causes higher risk in operation.
- We decided to go back to 2 PS operation, one for 1st horn, another for 2nd and 3rd horns (as Run-1)
- Newly proposed strip line layout allows us to switch easily two configurations

Upgrade for Radioactive Water Disposal

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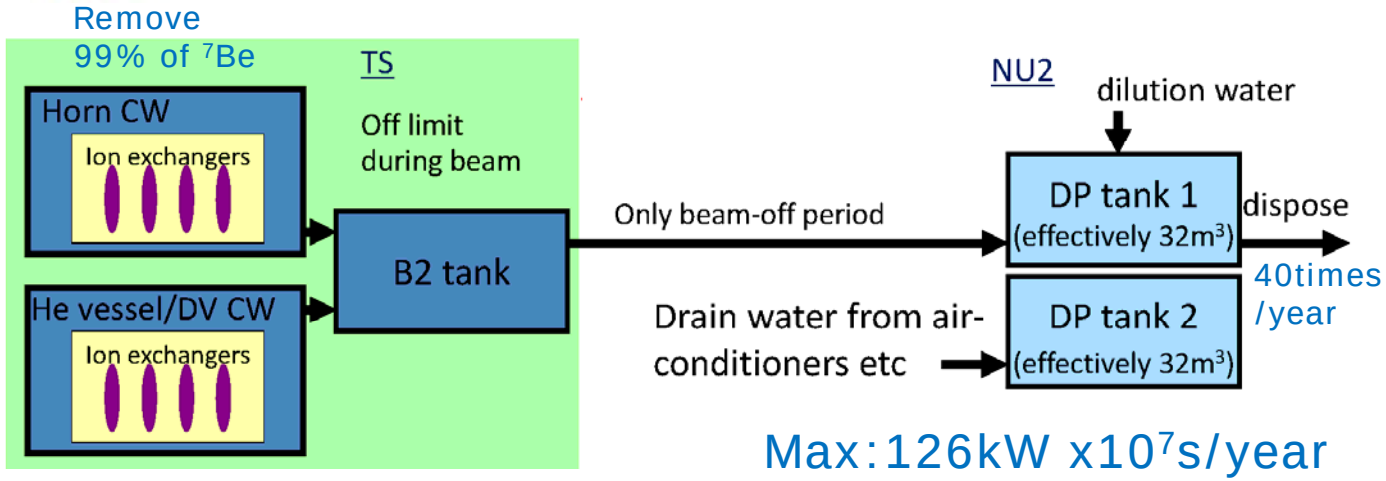
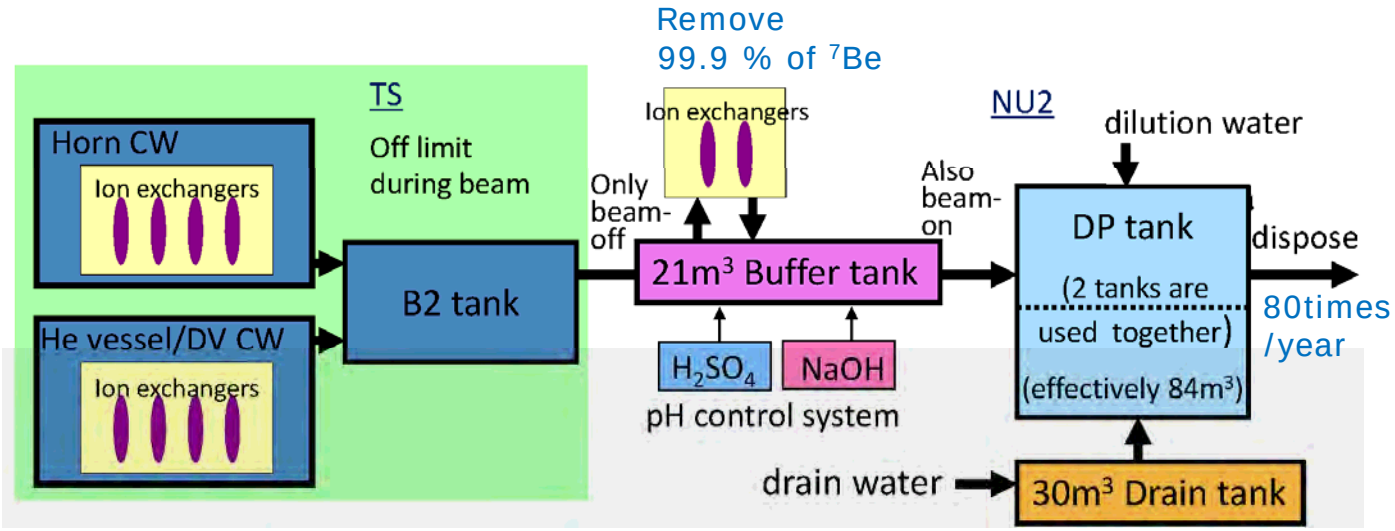


- ^{3}H in disposed water must be <42Bq/cc
- For Run-2, 27GBq of ^{3}H produced.
  - 22dilution/disposal x 32m^3 DP tank were performed.



- Upgrade allows 80 x 84m^3 in a year.
- ^{7}Be in disposed water must be <1.2GBq/year
  - 0.52GBq for Run-2 with 99% reduction.
  - 99.9% required for 750kW.

Upgrade ready in Jan.2012. Max: 590kW x10^{7}s/year

Summary

- Operational experiences of the secondary beam-line at J-PARC neutrino facility were overviewed.
  - After earthquake, we resumed beam operation in the year, and physics run resumed within one year (Mar.8, 2012).
  - We have achieved to accept ~190kW continuous beam.
- Major events in 2011:
  - Remote maintenance of horn-3
  - Visual inspection of DV/BD
  - Realignment of horns after earthquake within required precision
  - Horn power supply failure (recovery in 2012)
- Radioactive waste:
  - It is always the bottleneck of high-power facilities.
  - Exhaust air : recent upgrade on TS ventilation allows to accept ~1MW beam
  - Water disposal : recent upgrade on NU2 tank system allows to accept ~600kWx10^7sec/y

Prospect

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- The two PS operation of horns may allow to enhance horn current from 250kA to nominal 320kA (increase flux at peak by 10%), and also allow operation with higher rep-rate.
- We will be ready for Run-4 in 2012 fall, and try to accept beam as much us possible until scheduled long shutdown in summer 2013 for LINAC upgrade
  - Improve significance of appearance to ~5σ w O(10^{21}) pot

NBI: Neutrino Beam Instrumentation Work Shop

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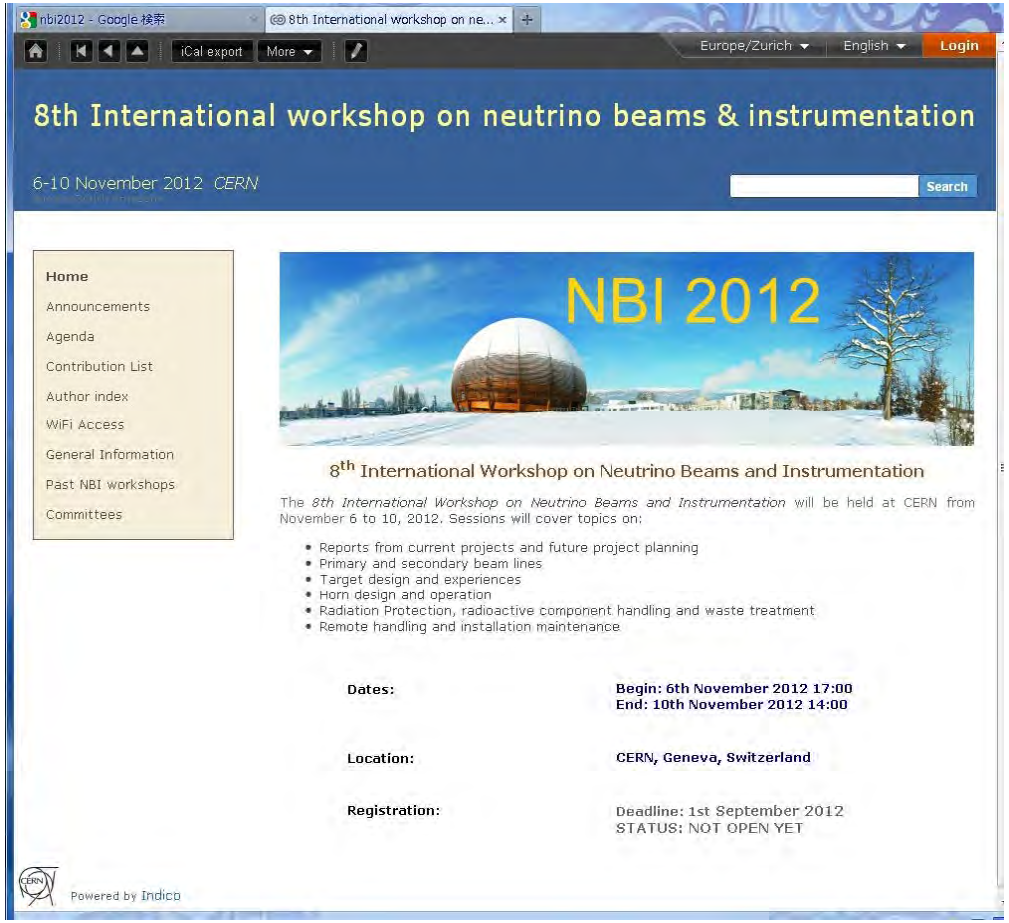

- Series of WS, initiated at KEK on 1999, and opened in one-a few year bases at CERN/FNAL/KEK
- Valuable opportunities to meet CNGS/NuMI/T2K beam-line experts together and share their experiences.
- 8th one will be held at CERN from November 6 to 10, 2012.
- Sessions will cover topics on:
  - Reports from current projects and future project planning
  - Primary and secondary beam lines
  - Target design and experiences
  - Horn design and operation
  - Radiation Protection, radioactive component handling and waste treatment
  - Remote handling and installation maintenance

Backups

MR Power Improvement Scenario

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	Achieved	Next Step	Target
Power(MW):	0.2	0.30	0.75
Energy(GeV)	30	30	30
Rep Cycle(sec)	2.56	2.4	1.28
No. of Bunch	8	8	8
Particle/Bunch	1.26×10^{13}	1.9×10^{13}	2.5×10^{13}
Particle/Ring	1.0×10^{14}	1.5×10^{14}	2×10^{14}
LINAC(MeV)	181	400	400
RCS	h=2	h=2	h=2

* Summer 2012:
upgrade of RF collimator
MR Inj.loss limit (450W→)2kW
Beam power: 0.2~0.3MW

Combination of
High rep. rate
and
High beam density
RF higher harmonic

Front end upgrade: Ion source (30mA→40mA), RFQ & LINAC 400MeV to avoid severe space charge effect at RCS injection

* LINAC upgrade
in summer 2013 (~0.4MW)

For increasing repetition rate, RF and magnet power supply improvement is necessary.
→ R&D has been started.

* High grad RF and MR PS
~5 years from now

Managing the beam loss is necessary to keep the maintenance scenario.
→ Dedicated collimator system to localize beam loss is necessary.

Recovery from the earthquake damages

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- Out-door units of TS package air-conditioners

- Subsidence around beam-dump pit / NU3

The Gigantic Helium Vessel

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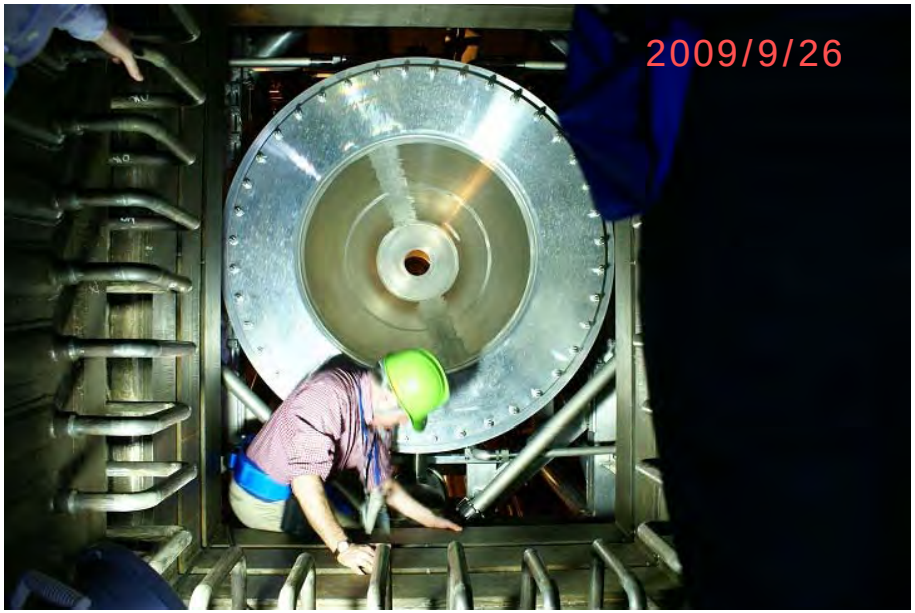
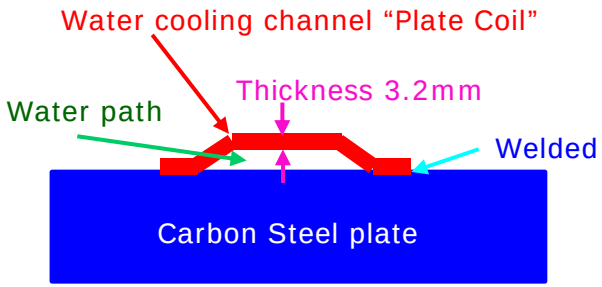
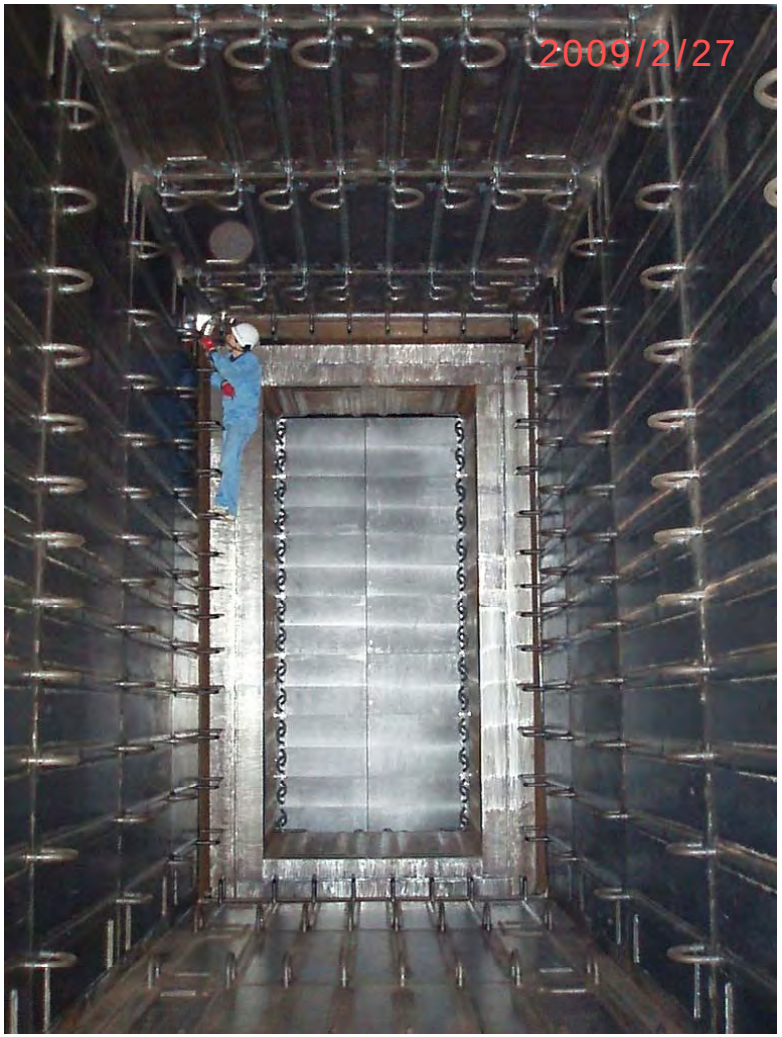
Cross section of DV is 1.4m x 1.7m at entrance





3.0mx5.1m at the most downstream end.



Target Remote Replacement

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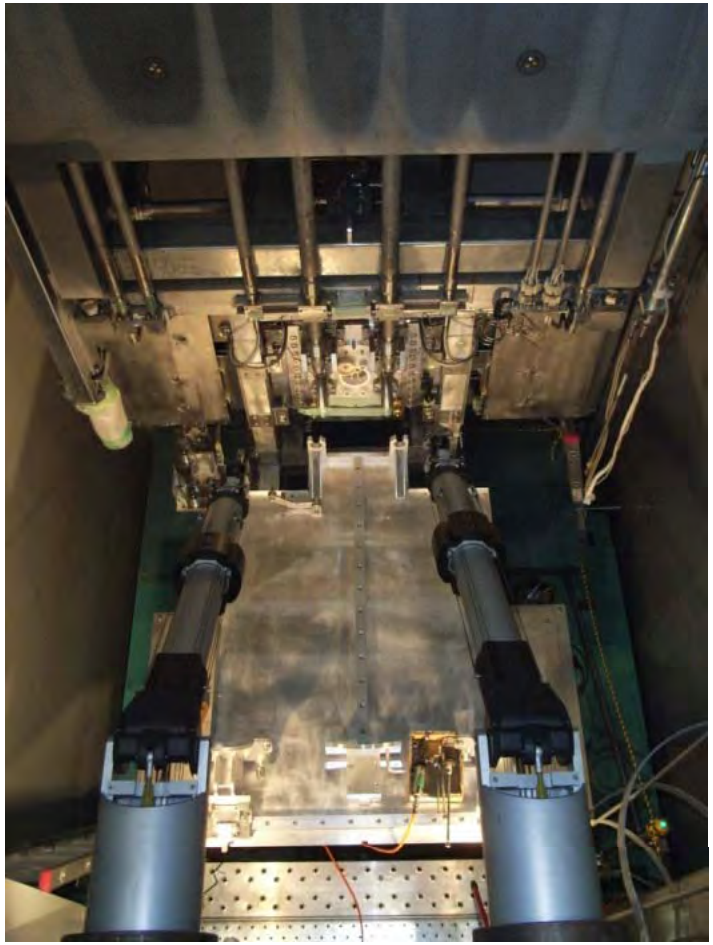

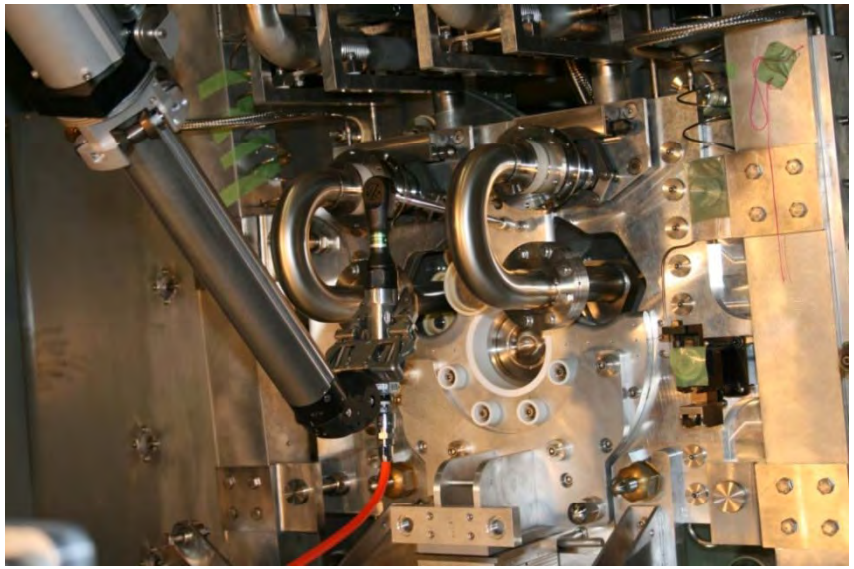

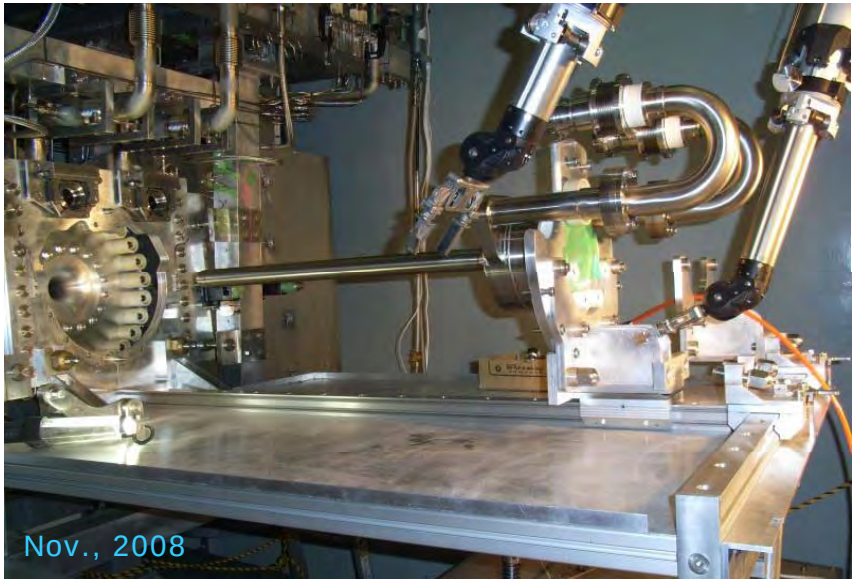

- Remote maintenance area at TS
- R&D on-going by RAL-KEK-TRIUMF

Horn Power Supply Upgrade

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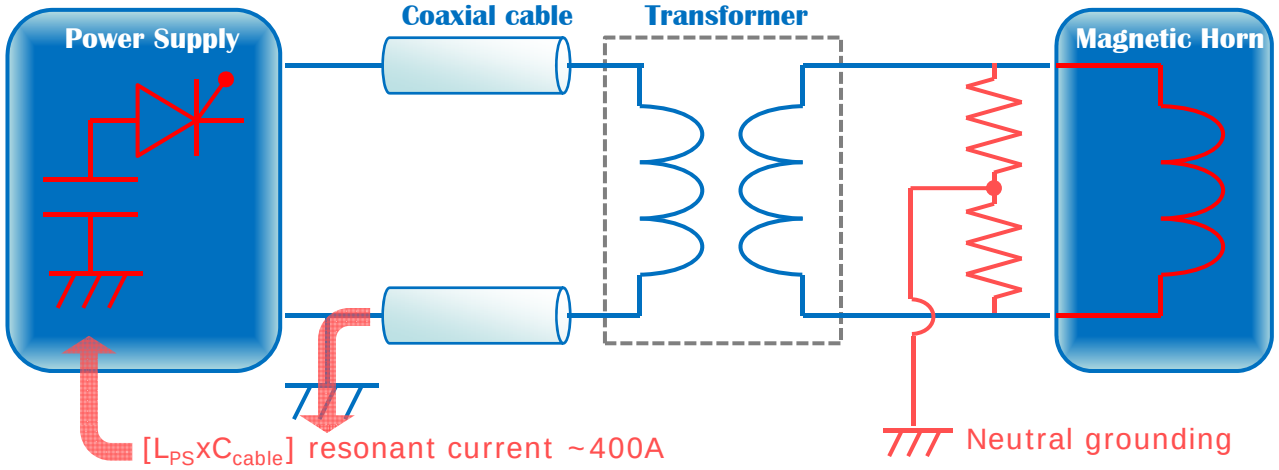
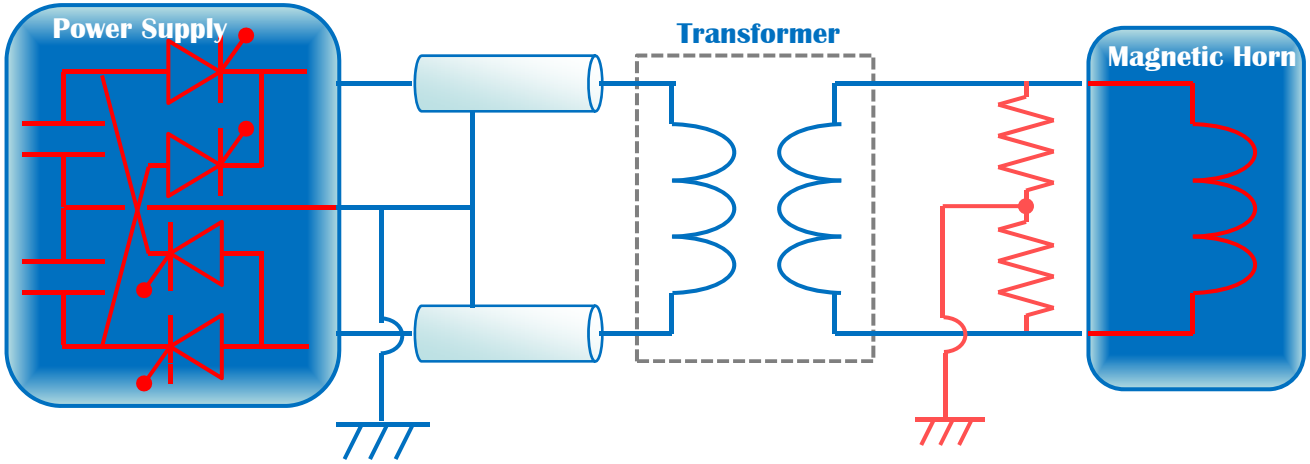
- Old power supply (Run-1)



- Very old (more than 15years)
- Potential noise problem
  - ✓400A rapid noise flow into earth lines and causes false operation of control unit.
- No energy recovery mechanism
  - ✓Waste all the energies of capacitors in every cycle.

- New power supply (Run-2)



[Design]
- Symmetric circuit
- Noise clean
  - ✓Minimize any noise
- Energy recovery mechanism
  - ✓ To recycle more than 80% energy
- 1.9 sec repetition rate
- 3 horns with 1 power supply

- Up to now 60% recovery / 2.6sec operation realized.
- Stable operation during R2

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