T2K Radioactivity in the Exhaust Air

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Radiation Monitors

- **Exhaust air monitor (gamma):** 3 pairs (S/BG)
  - NaI (TI) 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 (TI) 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

Exhaust monitor

- 2 cells (A/B) for signal / B.G.
- 10L (3atm), 50mm thick Pb
- 3in x 3in NaI

Environment monitor

NU3 also has the monitors

Area monitor

- BLU302
- BLU312
- YEL302
- YEL301
- Exhaust chimney stack
- 10atm 1inch φ x 10inch He-3 Prop. Counter

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

Ver. 1.1 [Nov.09]
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.
- 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

- Water circulation system for downstream half of DV and BD [B1]
- Air circulation system for BD / MuPit [B1+4.5]
The drain port connecting to dump pit was closed by a flange with thinner pipe.
Smoke Test

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)

- 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
NU3 exhaust monitor signal becomes much smaller.

TS exhaust becomes 0.05Bq/cc with 2 hours of beam operation.
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

- Service pit / storage area covered with concrete blocks.

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

The job was much much much much harder.
Ishida et al.
J-PARC/KEK

Ex.Monitor Measurements

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 / 30 days ➔ 0.5m x 10 = 5mBq/cc acceptable.
TS air tightening (Feb.15-22)

Need to do after every summer maintenance!

We now learn how to sense tiny air leak by hand!

Smoke tester

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

Horn Power Cables
Two square openings

Two Signal Cable trays

apply neg. pressure to 1F: -100Pa

Not only by smoke, but also by smell of smoke, we can find leak...
1.0 → 0.5 mBq/cc (20 kW, factor 2 reduction)

→ 0.5~0.8 mBq/cc (27 kW)
We doubted leak in the ducts to vent undergr. rooms.
Add air-tightened MVDs (bought for NU3..)
- Later replaced to bigger ones / install the small ones to NU3
During ventilation, sheets swollen by the air, leaking through the sealed block floor.
Signal (A-B) highly reduced (but not perfect)

0.07 ± 0.09 mBq/cc (40kW)
Air under the cover

N-14 (n, 2n) N-13 (9.97 m)
O-16 (n, p) N-16 (7.3 s)
Ar40(n,γ)Ar41 (1.83hrs)
K40 (1460keV)

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

- TS/NU3 underg rooms separated by the dumpers
- 2010Jun: 0.1~0.15mBq/cc @ ~50kW
We have introduced the second layer of sheets to shield floor.

- ~0.3mBq/cc for 145kW: $\Rightarrow$ hit 0.5mBq/cc limit with 240kW beam
- 1 month average for Jan.: 0.14mBq/cc $\Rightarrow$ 1/28~2/28: 0.32mBq/cc
Use TS 1F volume as a reservoir of irradiated air to decay.

Idea by Oyama-san

13,000 m³/h

Total 13,000 m³/h

Airflow in the room / Total

Now

Ratio (exh. radiation)

10%

Airflow in the room / Total

Now

• ^41Ar x 0.29  ^11C x 0.14  ^13N x 0.12  ^15O x 0.10

• ^41Ar x 2.9  ^11C x 1.4  ^13N x 1.2  ^15O x 1.0

T_{1/2}:

^41Ar: 110 min
^11C: 20 min
^13N: 10 min
^15O: 2 min
Design

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

Bypass line

90~0%

10~100%

TS 1F
- Duct: 600x1,000 → 4D=4m straight section needed for VAV/CAV.
- Flow control was carefully tuned on February.
Tuning for Air Flow Control
(Feb., 2012)

VAV opening ratio (%)

IF In
IF Out
Bypass
Control
Negative pressure

13,000 m³/h

Total

Bypass

Bypass 0%

0 m³/h

100%
0.4m(127kW) → 0.13mBq/cc(140-150kW) with 90% bypass

March beam: 145/ 0.13 x 0.5 = 558kW acceptable

April beam: 176/ 0.16 x 0.5 = 550kW acceptable
• The radiation level in the 1F w bypass
  • 50 mBq/cc ⇒ (70+/-5)mBq/cc [w/o beam: 35 mBq/cc]
  • Still low compared to regulation [<500 mBq/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
  • ~0.1 mBq/cc for 190 kW

* Photo taken on Nov.2, 2012
Radiation in exhaust air of TS was being the bottleneck of our beam power

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

Acceptable beam is being improved by 2 order, now ~ 1MW
Backups
Regulations on Radiation

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
Blocks should be sealed and covered after every summer maintenance!

Air-tightened door upgraded

- **2010Jun**: $0.1\sim0.15\text{mBq/cc}$ @ $\sim50\text{kW}$ →
- **2010Nov.~Dec**: $0.28\text{mBq/cc}$ @ $105\text{kW}$ → $0.36\text{mBq/cc}$ @ $115\text{kW}$

*Signal levels of A/B were reduced, but not for B-A...*
Smoke test on Jan. 13, fix some leaks at cable penetration holes.

- 0.5 mBq/cc when the additional shields were removed (105 kW)
- \( \rightarrow 0.4 \text{ mBq/cc with shields (105 kW), } 0.4 \text{ mBq/cc for 125 kW} \)