Safety on J-PARC Neutrino beam line

Yoshikazu Yamada (KEK, IPNS)

Talk at EUROnu workshop on June 9, 2011

Contents

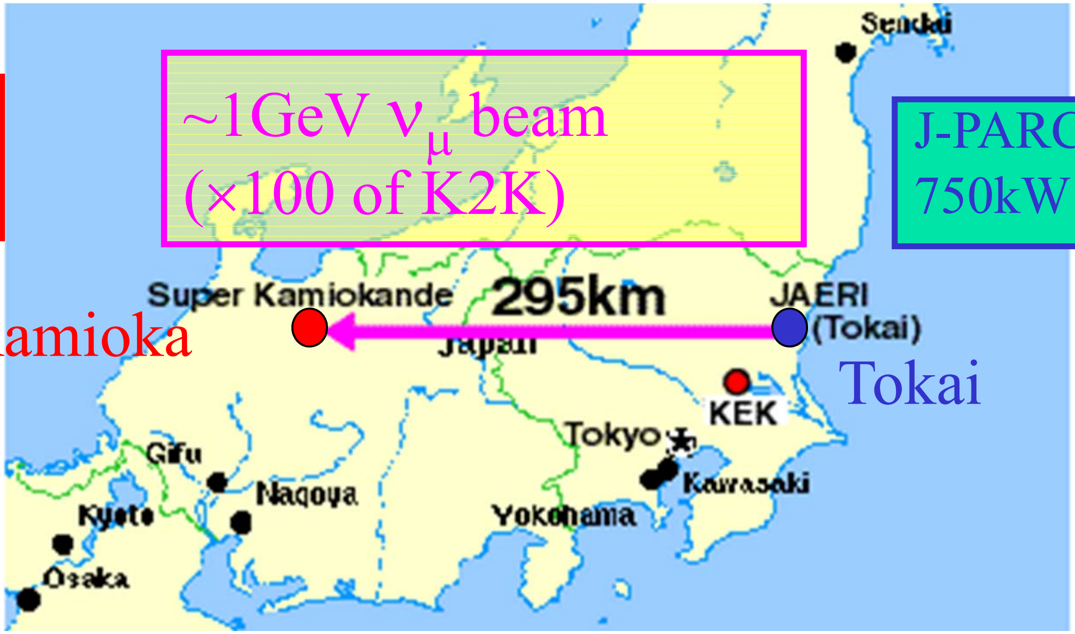
- •Introduction
- •Radiation safety
- •Primary beam line
- •Secondary beam line
- •Radioactivity in water and air
- •Summary

T2K experiment

Long baseline neutrino oscillation experiment from Tokai to Kamioka.

Super-K: 50 kton
Water Cherenkov

Phase2:
Larger detector



~1GeV ν_μ beam
(×100 of K2K)

Kamioka

Tokai

J-PARC
750kW 30GeV PS

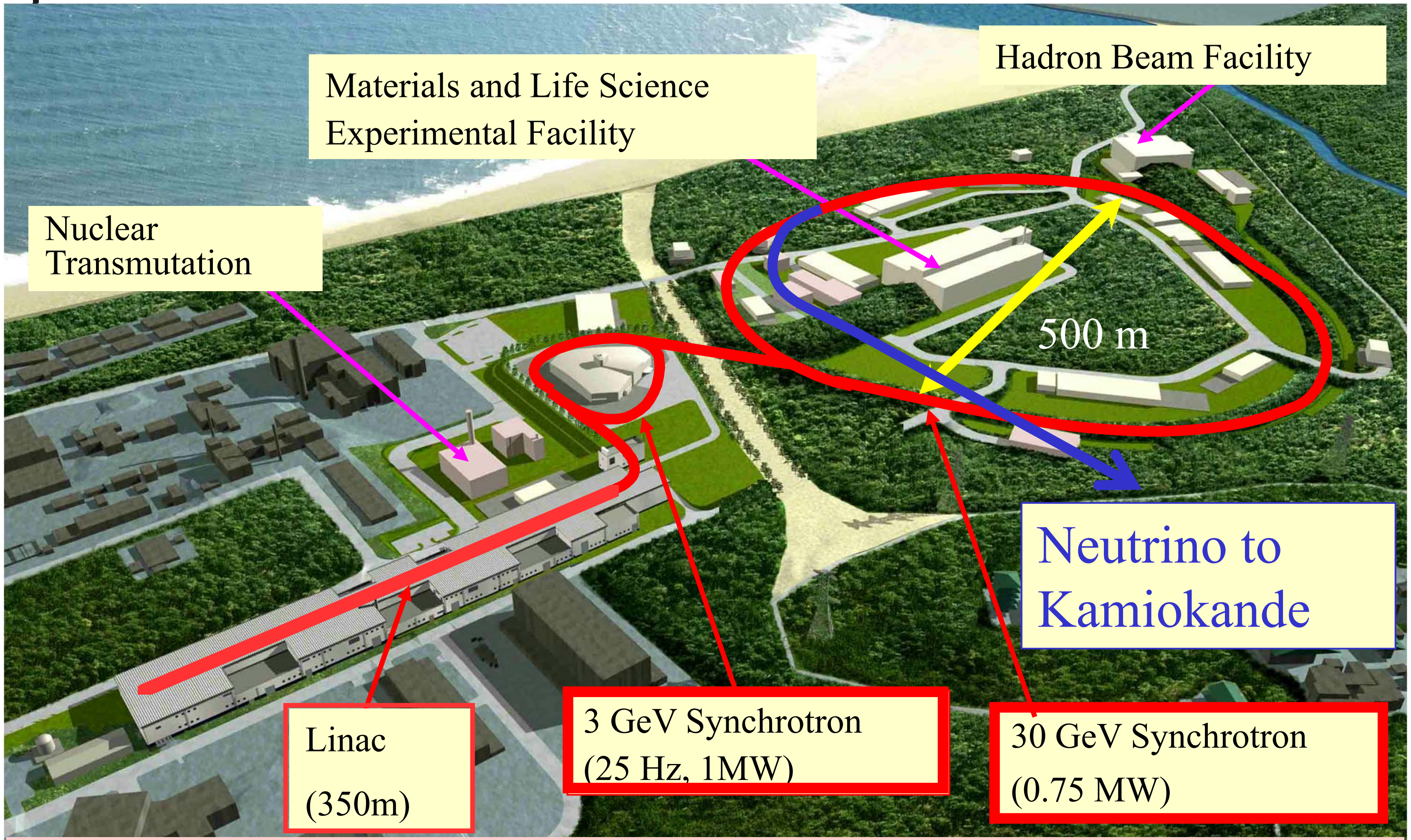
Phase2:
A few MW

Physics motivations

- ●Discovery of $\nu_\mu \to \nu_e$ appearance
- ●Precise meas. of disappearance $\nu_\mu \to \nu_x$
- ●Discovery of CP violation (Phase2)

12 countries
59 institutions
~500 collaborators

J-PARC



J-PARC = Japan Proton Accelerator Research Complex

Joint Project by KEK and JAEA(Japan Atomic Energy Agency)

J-PARC in Google

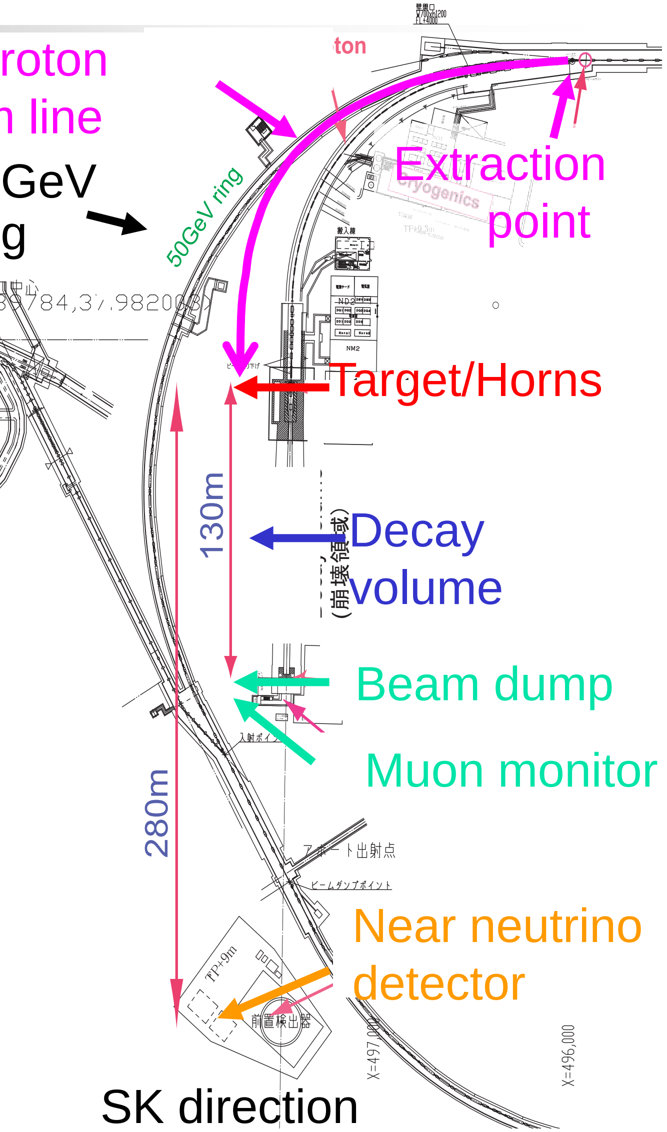
Google map
36.44918,140.604186

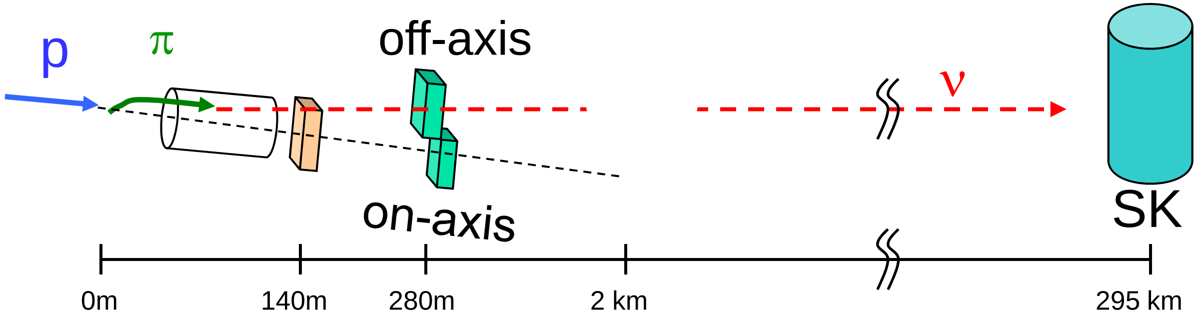
Neutrino facility

Components

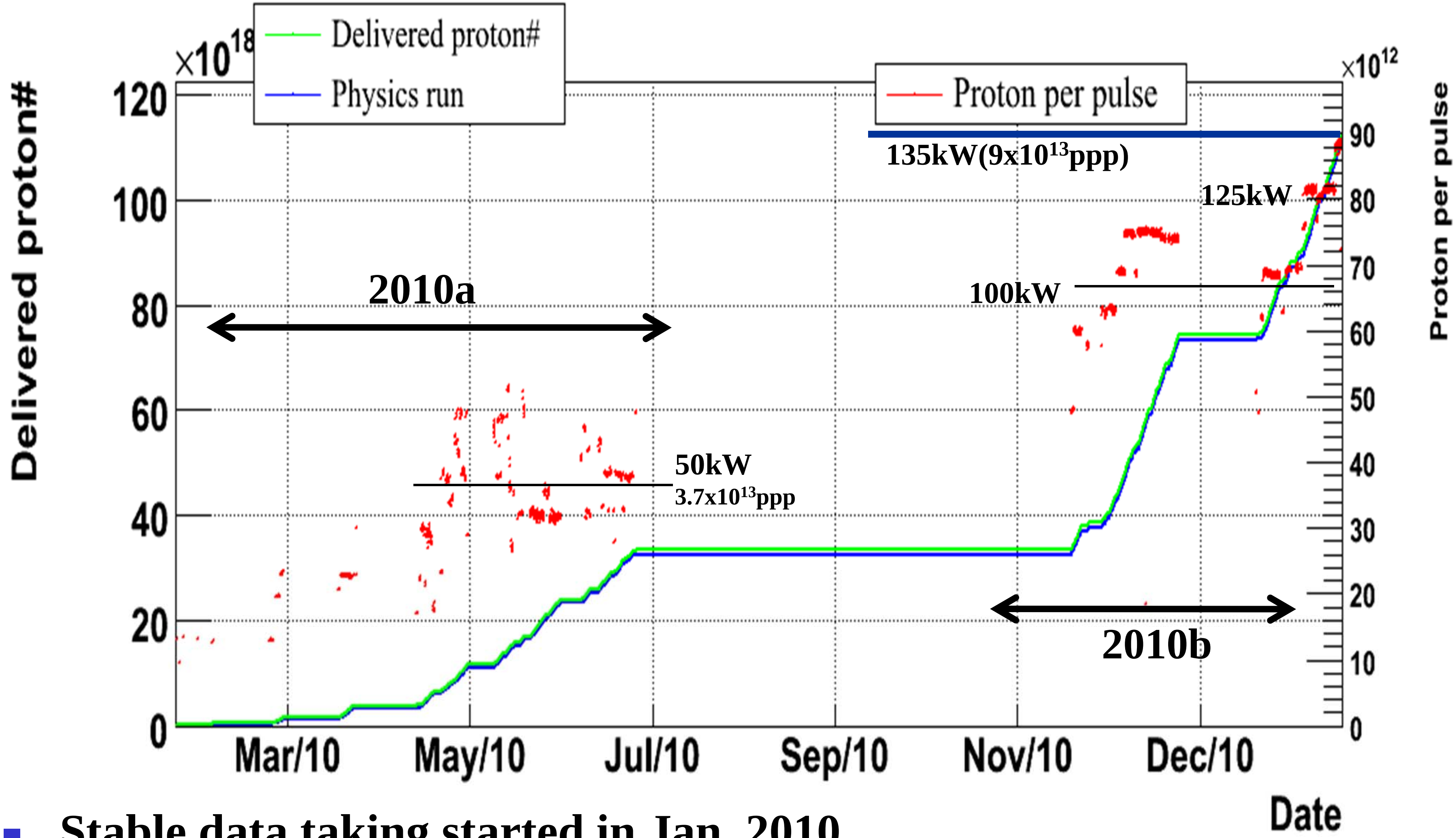
- ➢Primary proton beam line
- ➢Target/Horns
- ➢Decay volume
- ➢Beam dump
- ➢Muon monitor
- ➢Near neutrino detector (280m)

} Secondary Beam Line (Target/Horns, Decay volume, Beam dump, Muon monitor)



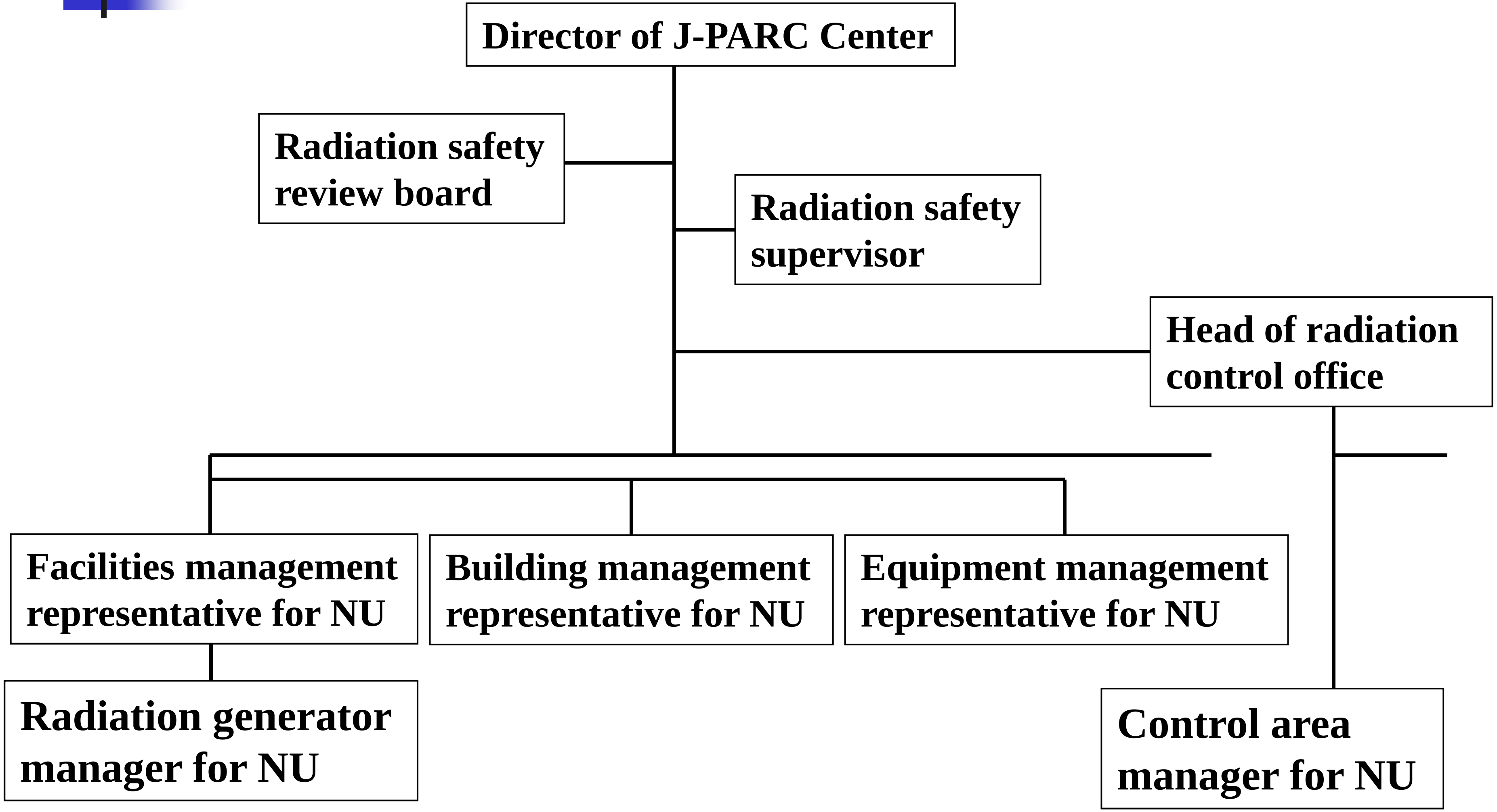


Data taking status



- Stable data taking started in Jan. 2010
- ~135kW stable operation achieved (Feb 14, 2011~)
- $1.2\mathrm{x}10^{20}$p's ($59\mathrm{kWx}10^{7}$s) delivered (Feb.21, 2011)

Organization for radiation safety



Director of J-PARC Center

Radiation safety review board

Radiation safety supervisor

Head of radiation control office

Facilities management representative for NU

Building management representative for NU

Equipment management representative for NU

Radiation generator manager for NU

Control area manager for NU

Y. Yamada
yoshikazu.yamada@kek.jp

M. Hagiwara
masayuki.hagiwara@kek.jp

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

Radiation control area

Second class radiation control area

- No radioactivity in air, in water, on surface of floor or apparatus
- Radiation level is higher than limit during beam operation
- Entrance is controlled by ID card reader
- Control rooms, electricity rooms, cryogenic machine rooms, outside yards for non-radioactive cooling water, etc.

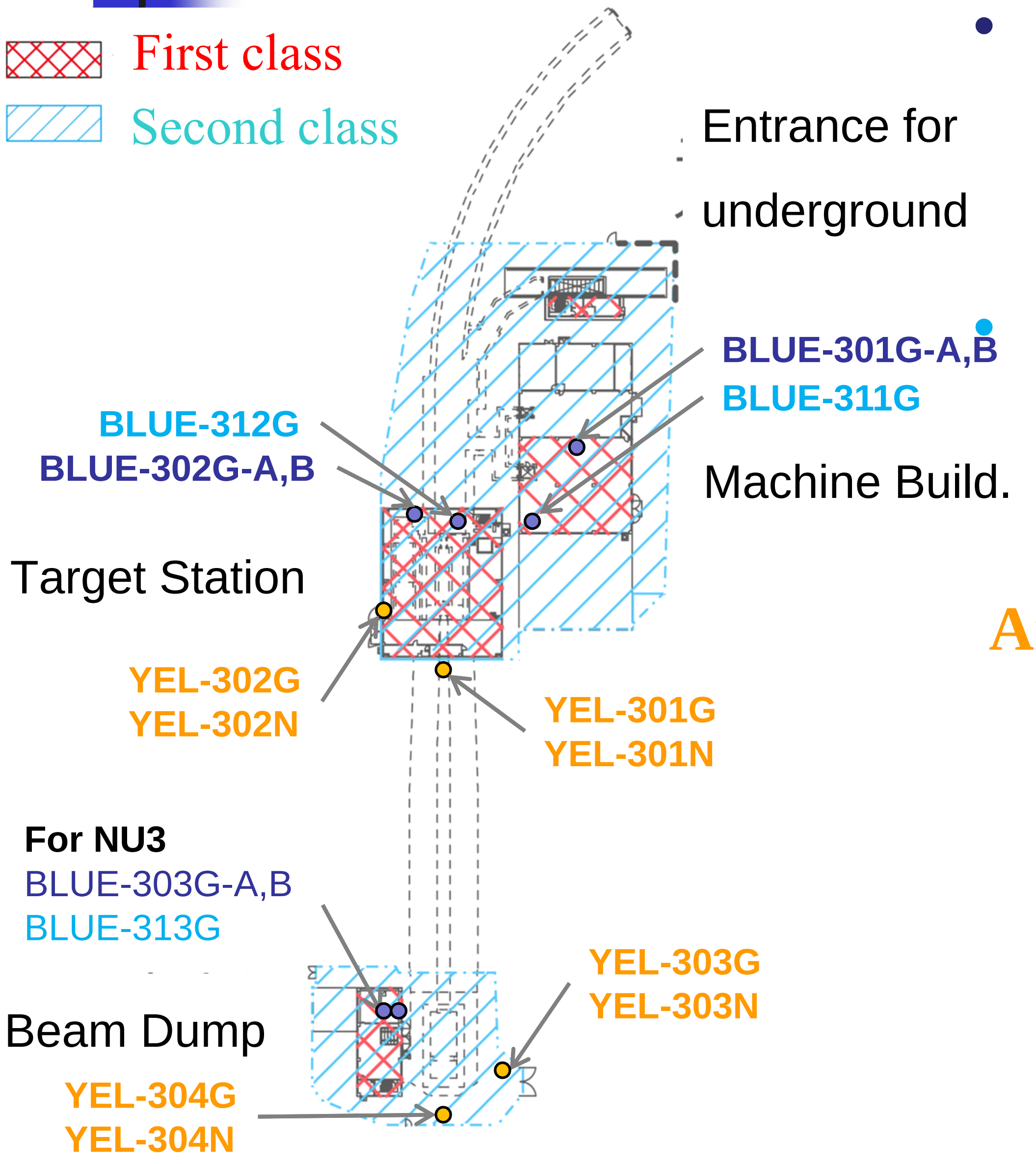
First class radiation control area

- Radioactivity in air, in water and on surface of floor or apparatus
- Radioactivity on person/article is checked by gate monitor at entrance.
- Personal dose is monitored/alarmed by Alarm Personal Dosimeter.
- Beam tunnel, Target Station, Beam Dump, Machine rooms, etc.

Interlock area (underground beam area)

- Beam is controlled by Personal Protection System (PPS)
- Entrance is controlled by personal key

Monitors for radiation control



- **Exhaust air monitor for stack**
  - (BLUE-30*G)
  - NaI(Tl) detector
  - ^{40}Ar in air < 0.5 mBq/cc
- **Air monitor for underground**
  - (BLUE-31*G)
  - NaI(Tl) detector

Area monitor for γ/n

- (YEL-*G,N)
- Gamma: Ionization chamber
- Neutron: ^{3}He proportional chamber with moderator
- outer area < 0.5 μSv/h

Personal Protection System (PPS)

Beam can be injected to NU beam line

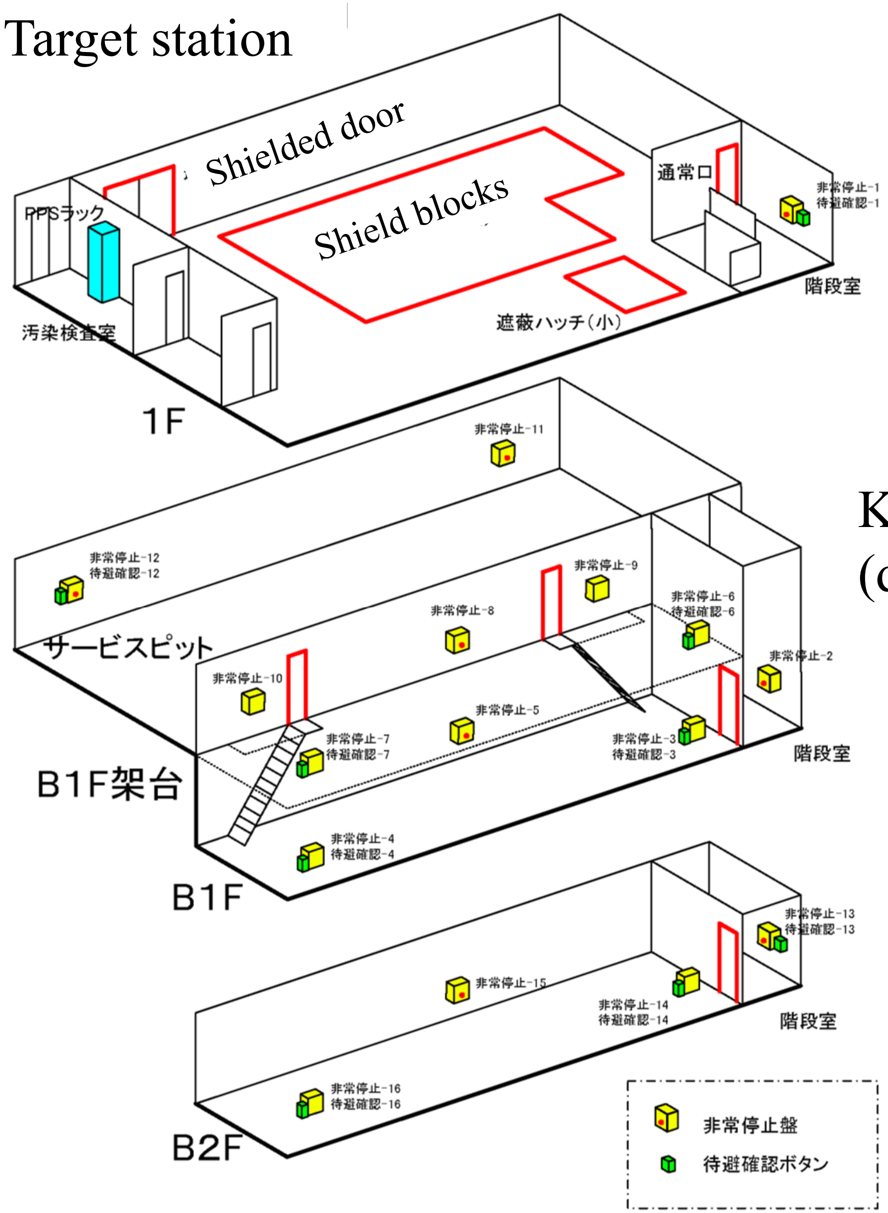
if all of following conditions is satisfied:

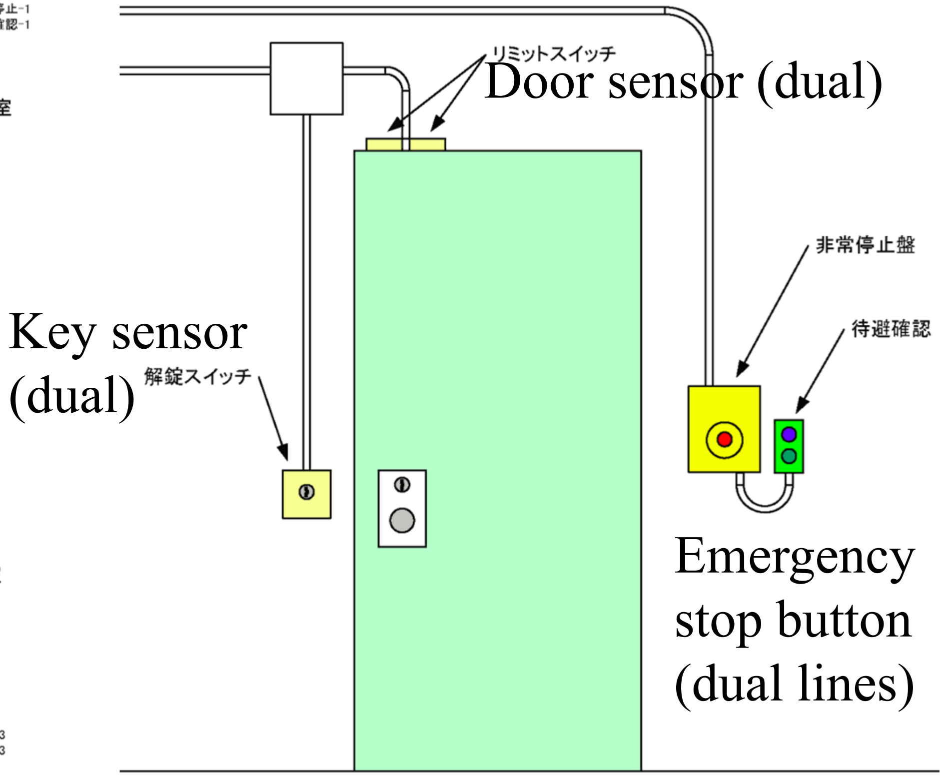
- all ventilation systems for beam area are stopped,
- all shield blocks and doors are set at closed position,
- all safety magnets are in beam operation status,
- all beam plugs are in beam operation status,
- all doors to beam area are closed,
- all personal keys of door are returned,
- all of emergency beam-stop alarm are off.

All sensors/signals are duplicated.

Personal Protection System (PPS)

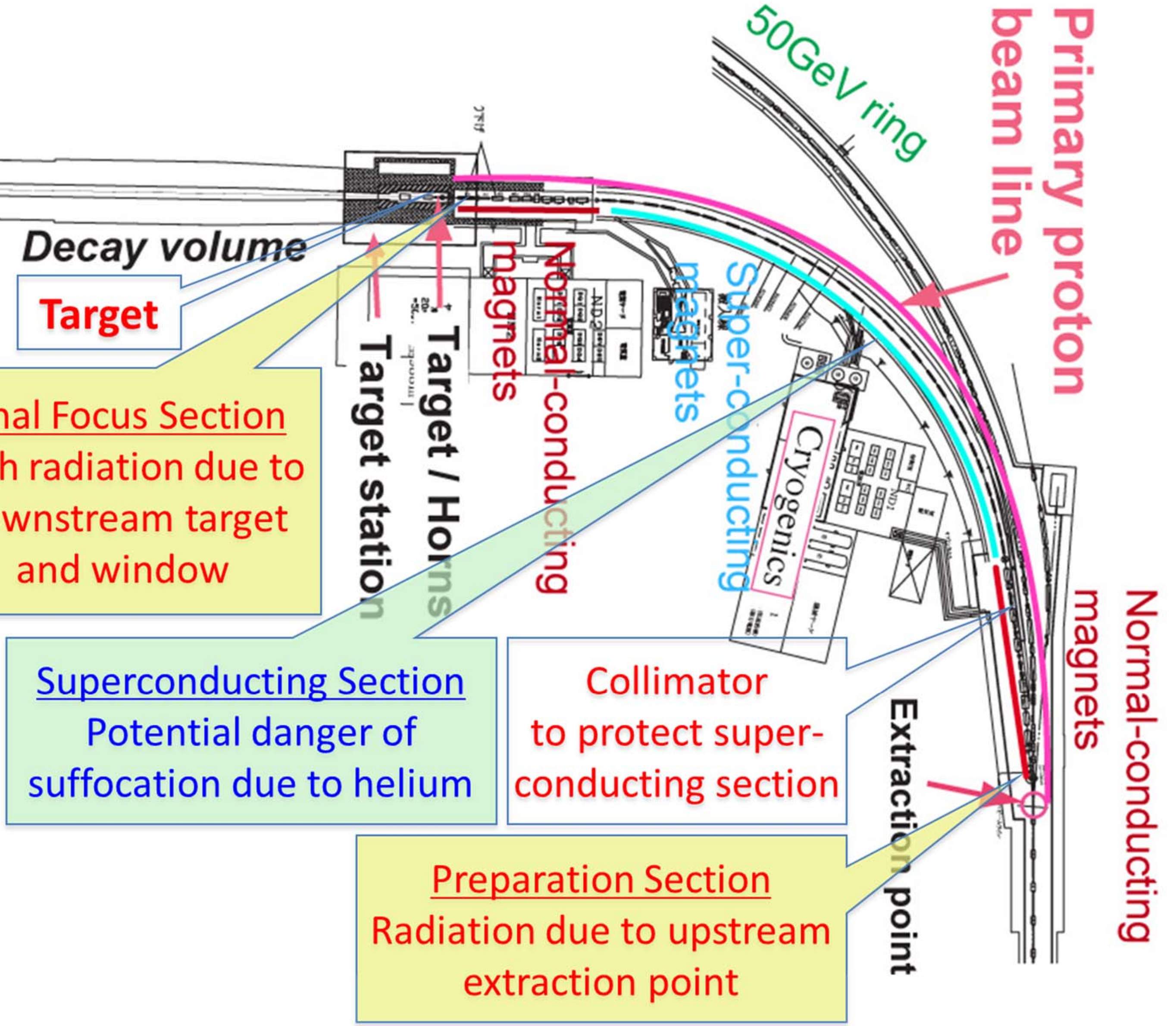
Target station





Door to the interlock area

Primary Beam Line



Final Focus Section
High radiation due to downstream target and window

Superconducting Section
Potential danger of suffocation due to helium

Collimator
to protect super-conducting section

Preparation Section
Radiation due to upstream extraction point

Protection against beam hit

If high-intensity beam directly hits beam-line equipment due to magnet trip or mis-operation, it will destroy the equipment and may results in dangerous accident.

- Catastrophic vacuum leak
- Massive quench of superconducting coils

In order to prevent such incidents,

- Beam monitors and fast beam abort
- Beam collimators

are being implemented in accordance with beam intensity increase.

Safety for superconducting magnet

i) After the CERN accident, design re-examination was done:

- electric and heat connections, mechanical anchors, etc.
- enlargement of exhaust line and relief valve done.
- externally reviewed, and verified design validity.

ii) Danger of He-gas leakage into the tunnel

- All the He gas is designed to flow back to the helium tank in case of quench. Full quench tested and confirmed.
- If helium line in the vacuum vessel breaks and vacuum vessel pressure rises higher than atmospheric pressure, helium gas flows into an exhaust line which exhaust the helium gas to the outside world (with radiation level monitored).
- If pressure is still too high even after the outside exhaust, relief valve opens to outlet the helium into the tunnel.
- Oxygen monitors and alarms distributed along the tunnel.

Semi-remote operation of flanges

Expected radio-activation at a few meter

Location	At present [μSv/h]	Eventually [μSv/h]
The most-downstream part, several meters upstream of the production target	2000	10~20 mSv/h
Upstream part close to the beam extraction point	~50	a few x100
Other normal part	several	a few x 10

Legal limit of personal exposure = 300μSv/day, 1mSv/week
--> Semi-remote flange connection/disconnection mechanism and flange mover system are (partially) installed.

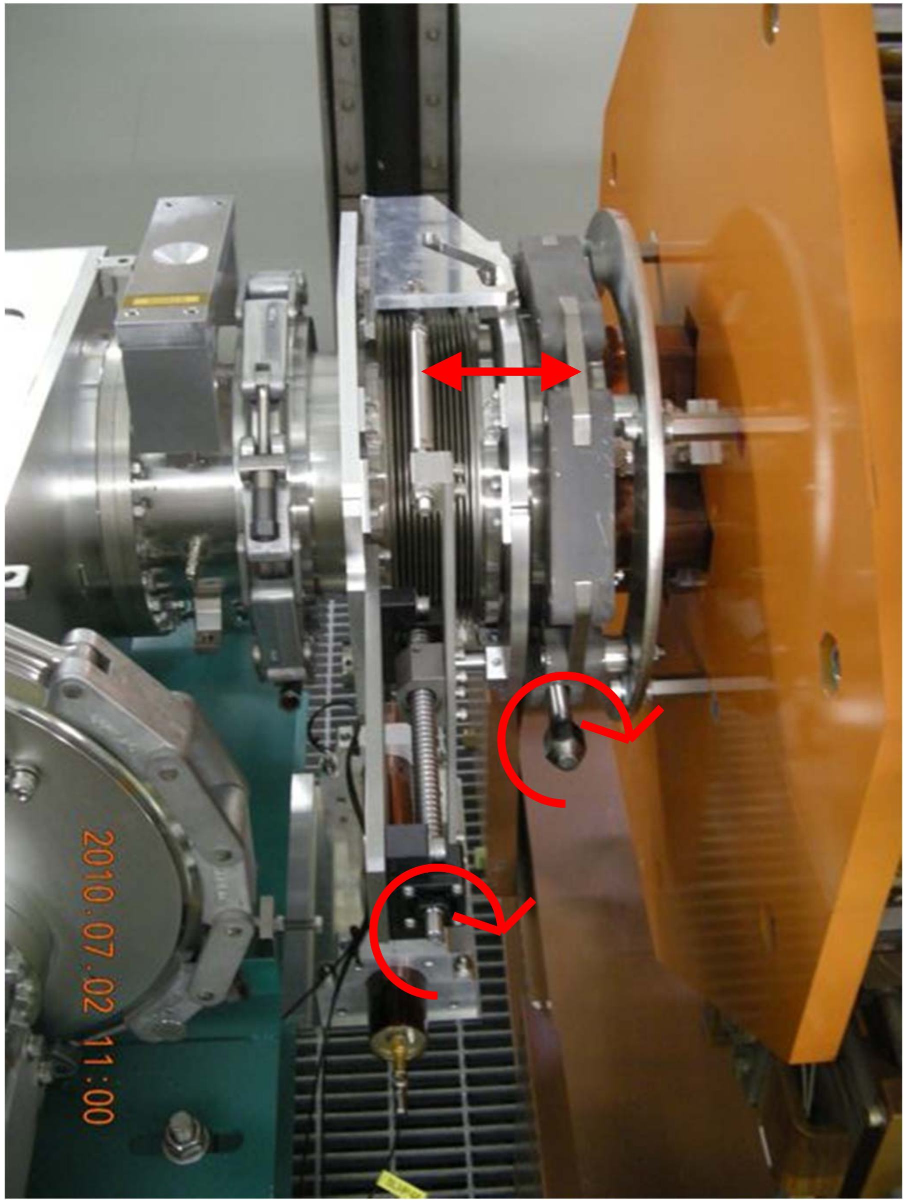
Semi-remote operation of flanges

Operation
from a few-meters distance

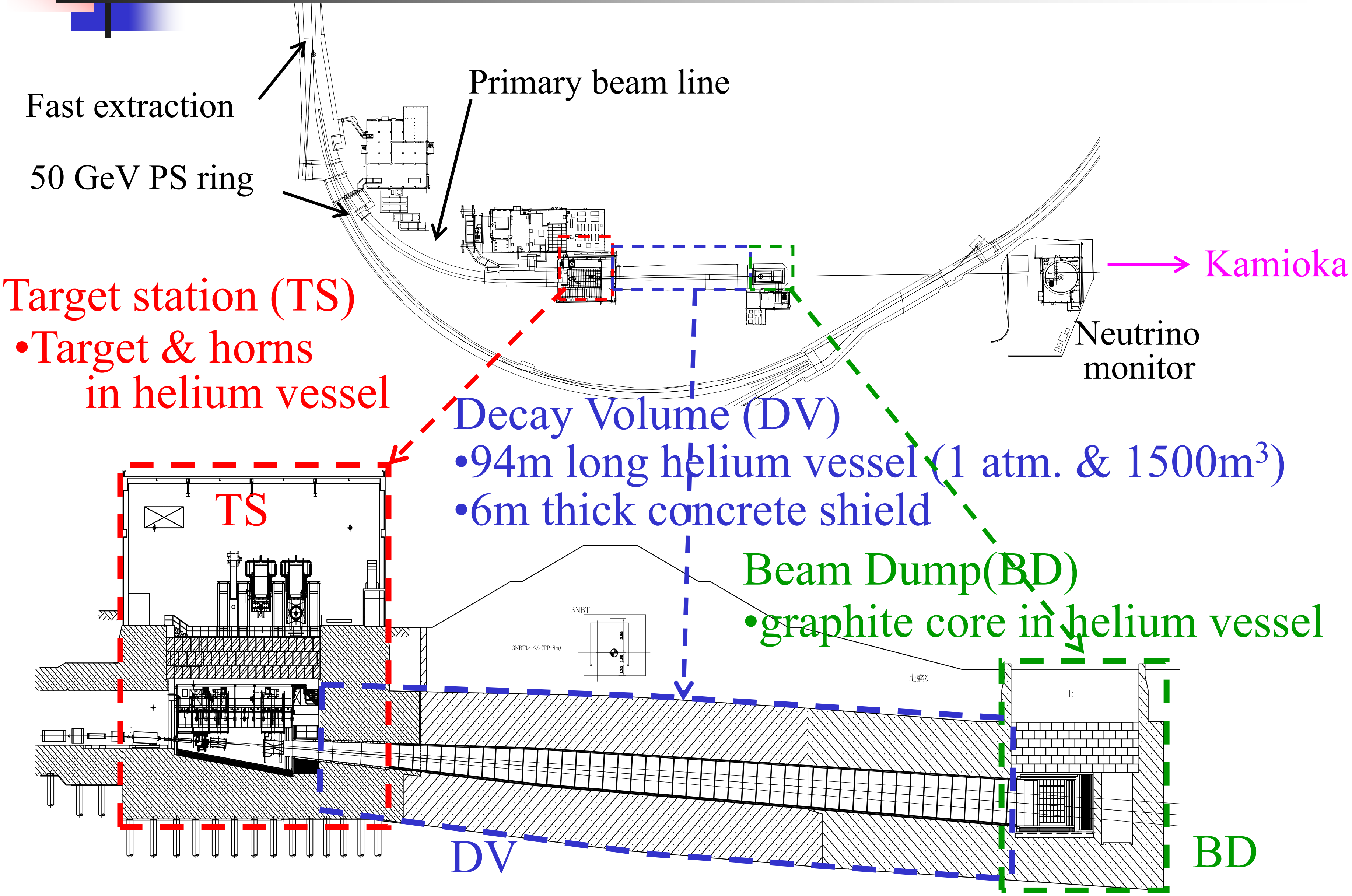
- Stay-on chain clamp releasable
  by turning a bolt from distance

- Flange moving back-and-forth
  by turning a bolt from distance

- removal/installation of gaskets
  should be done hands-on



Secondary Beam Line



Fast extraction

50 GeV PS ring

Primary beam line

Kamioka

Neutrino monitor

Target station (TS)

- Target & horns in helium vessel

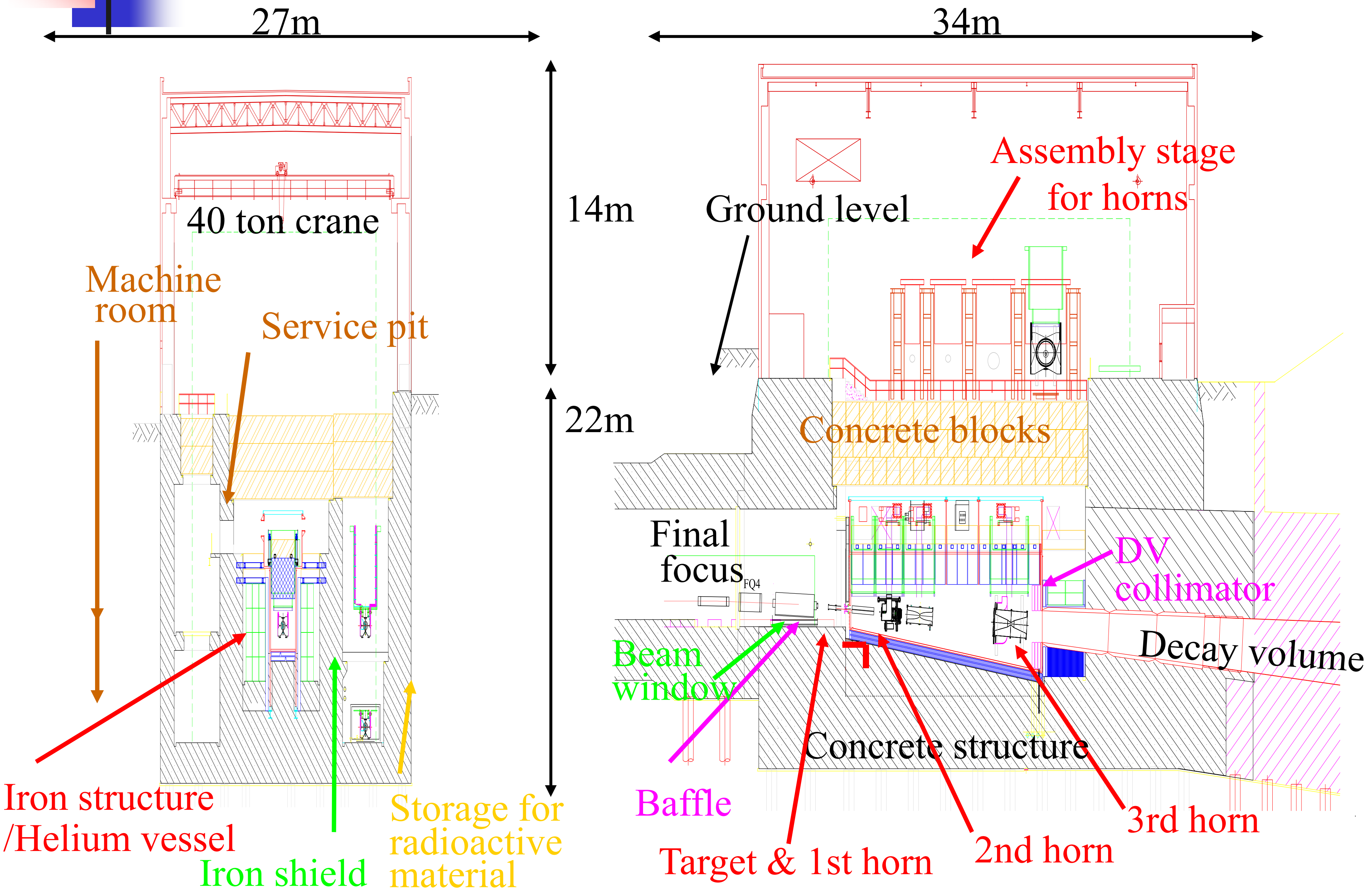
Decay Volume (DV)

- 94m long helium vessel (1 atm. & 1500m^3)
- 6m thick concrete shield

Beam Dump(BD)

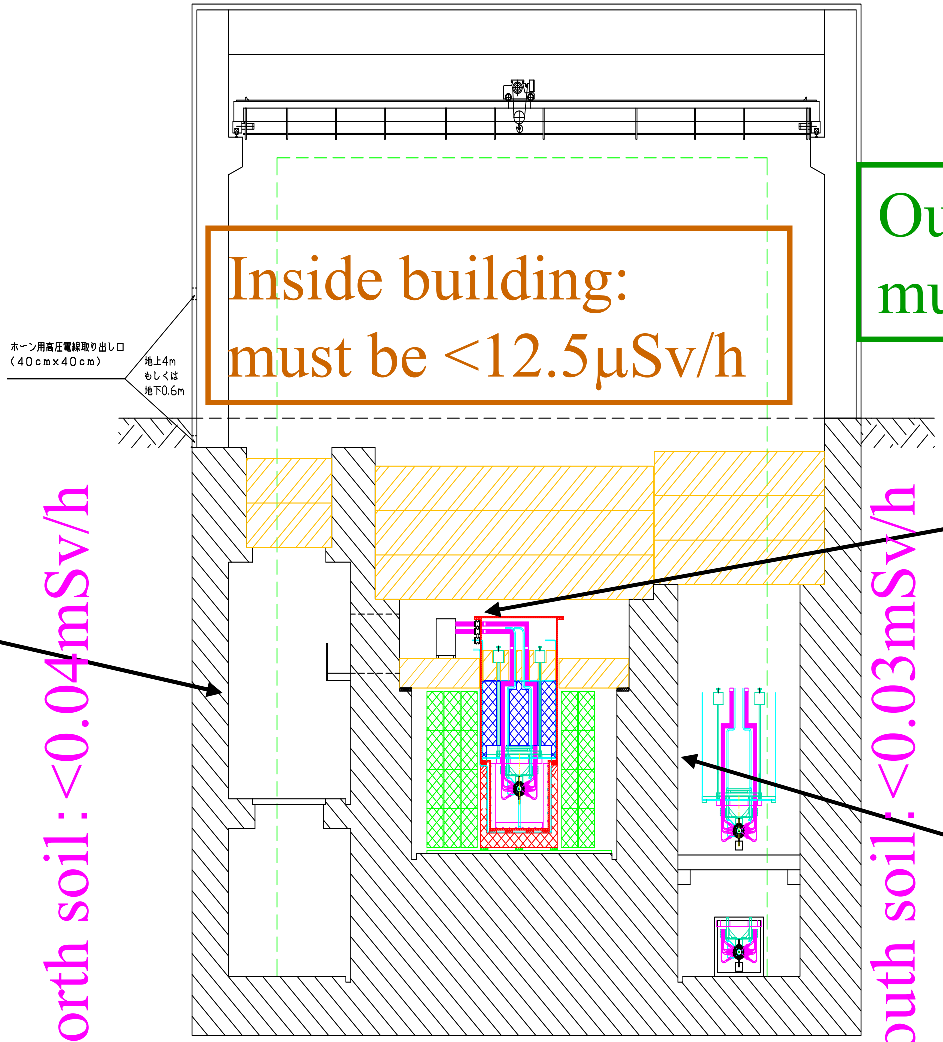
- graphite core in helium vessel

Target station (TS)



Radiation dose in beam operation

- 750kW
- Estimated by MARS



Inside building: must be <12.5μSv/h

Outside of building: must be <0.25μSv/h

Service pit: 25mSv/h

Machine room <0.35mSv/h

North soil : <0.04mSv/h

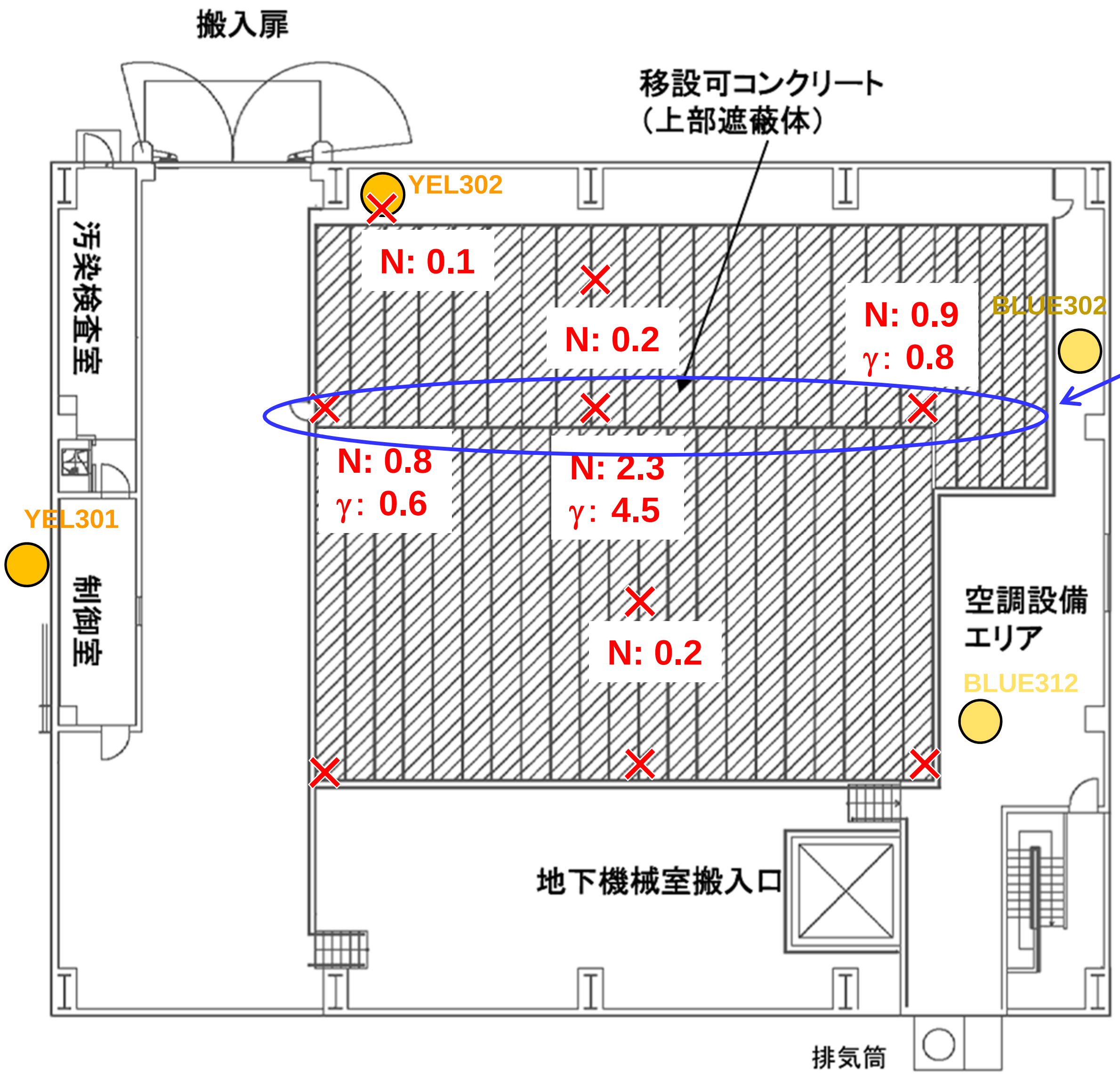
South soil : <0.03mSv/h

Storage area A few mSv/h

Bottom oil<1.6mSv/h

soil: must be <5mSv/h

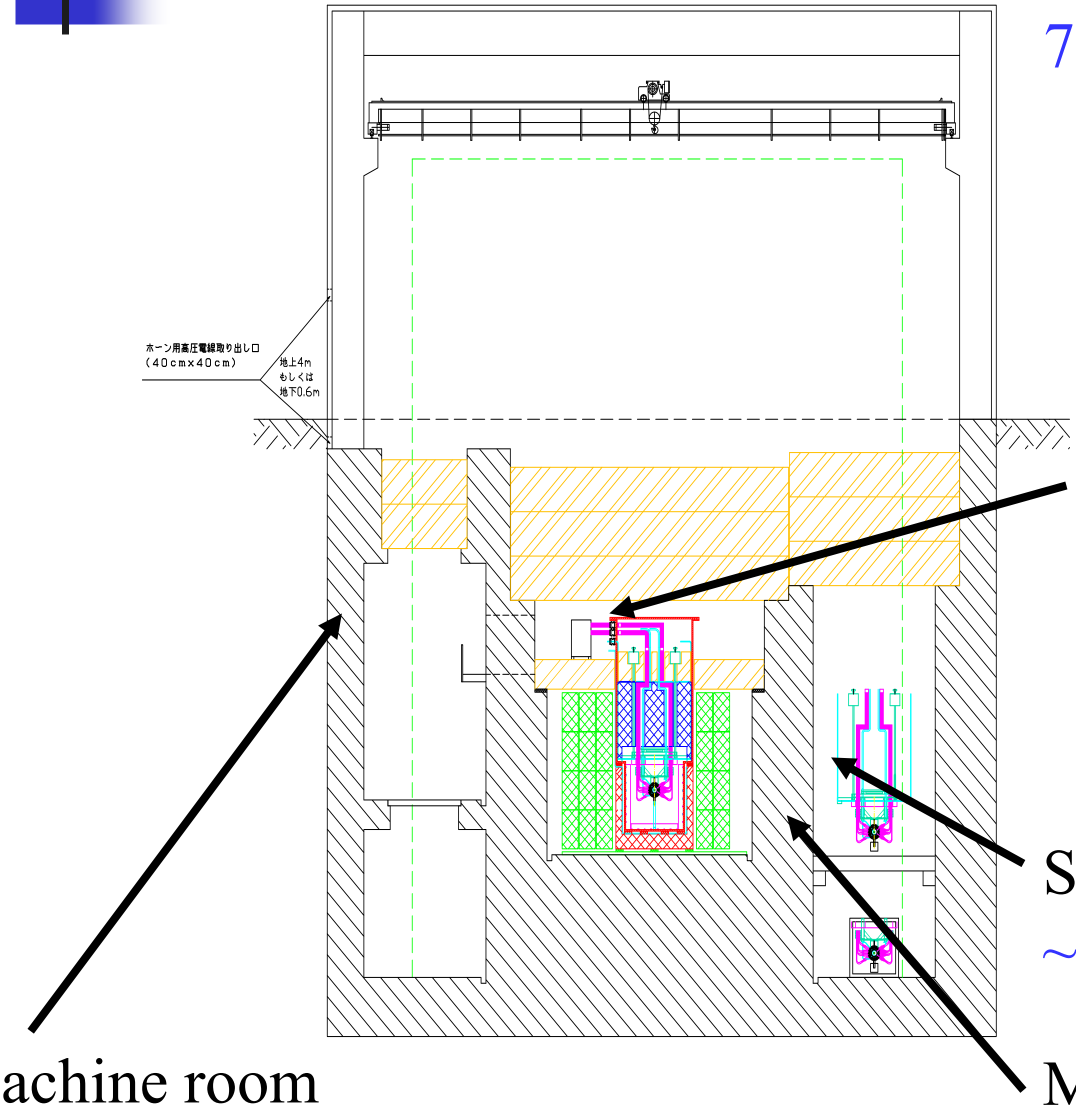
Radiation level in beam operation



- unit is μSv/h
- 50kW beam
- <12.5 @ 750kW
- Improved by additional shields (sorry for no figure)

Residual dose

750kW x 30 days operation
and
one day cooling
(by MARS)



Service pit:
~2 μSv/h
(0.2μSv/h @ 67kWx120d
& 90d cooling)

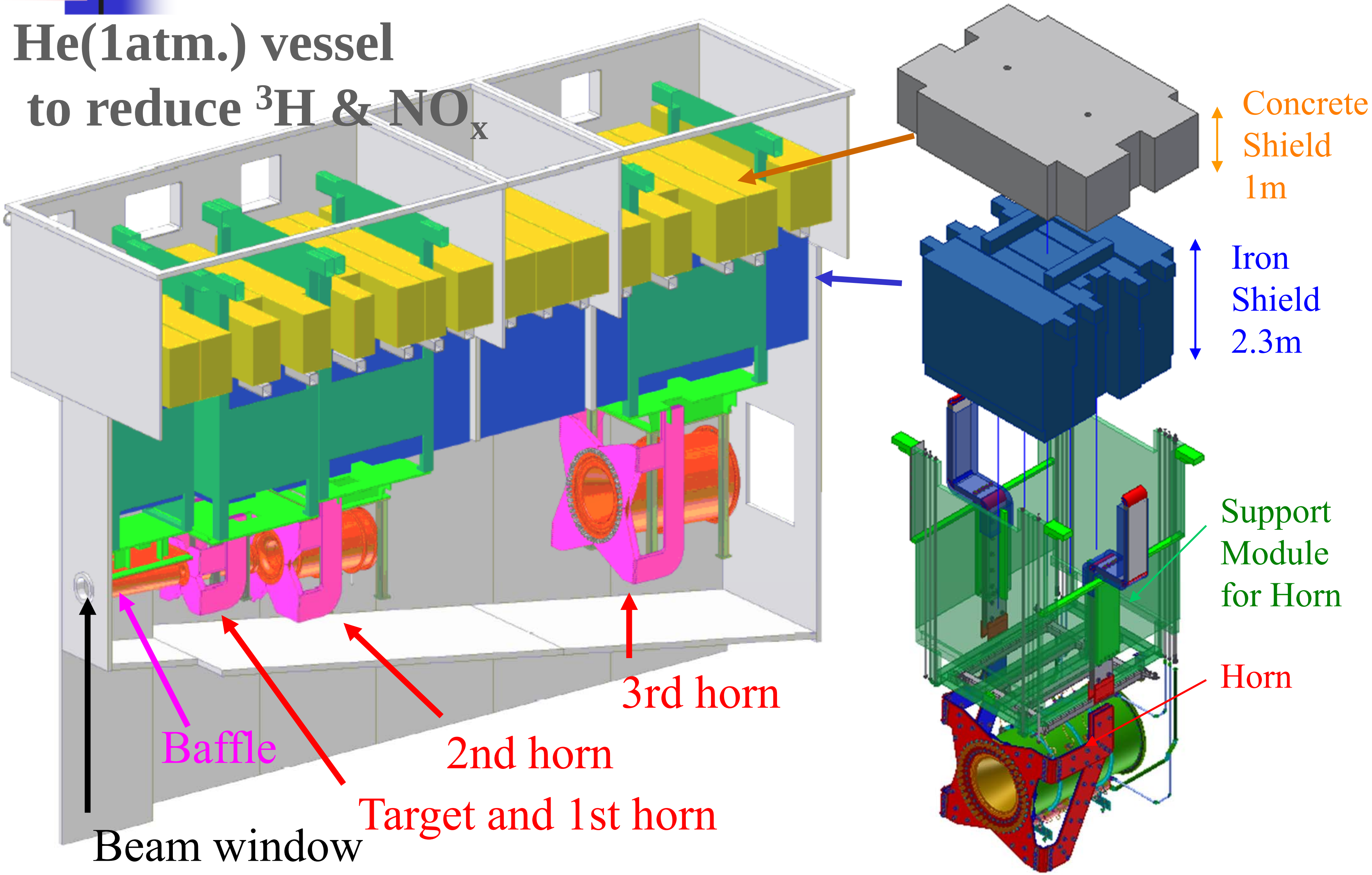
Storage area
~0.1 μSv/h

Machine room
~0.03 μSv/h

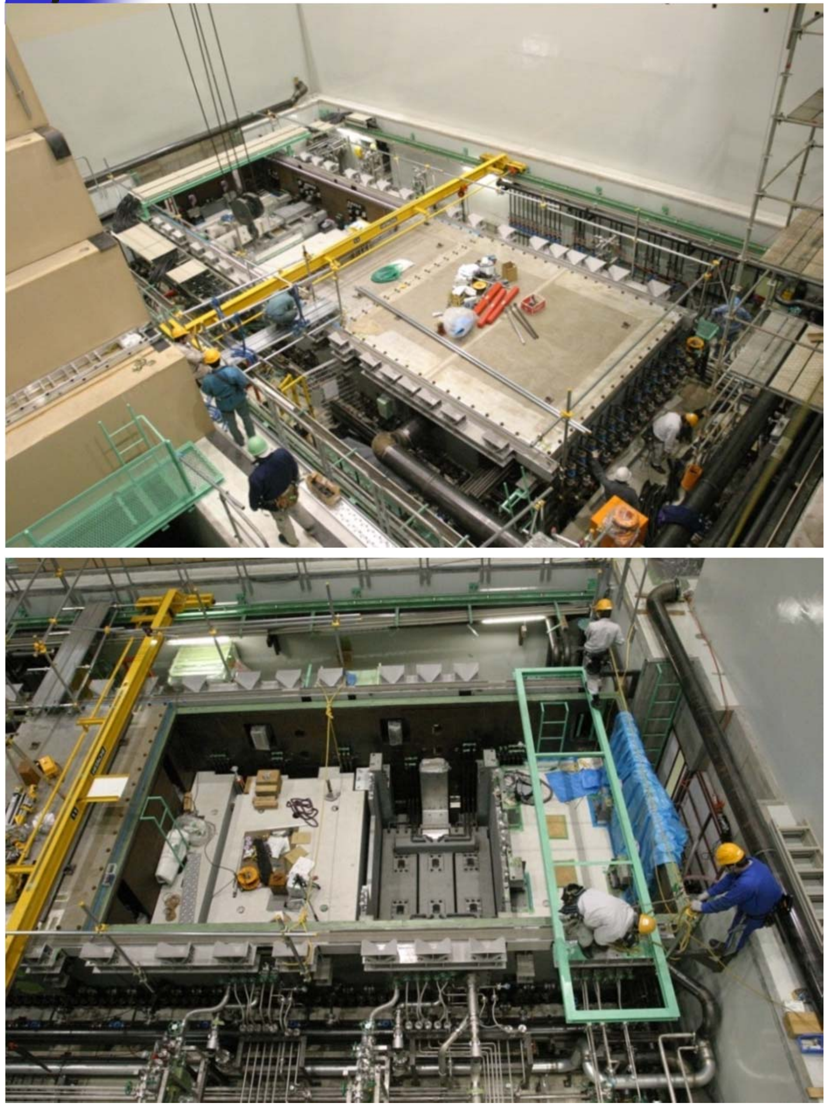
Maintenance area
~0.02 μSv/h

Target area

He(1atm.) vessel
to reduce ^{3}H & NO$_x$



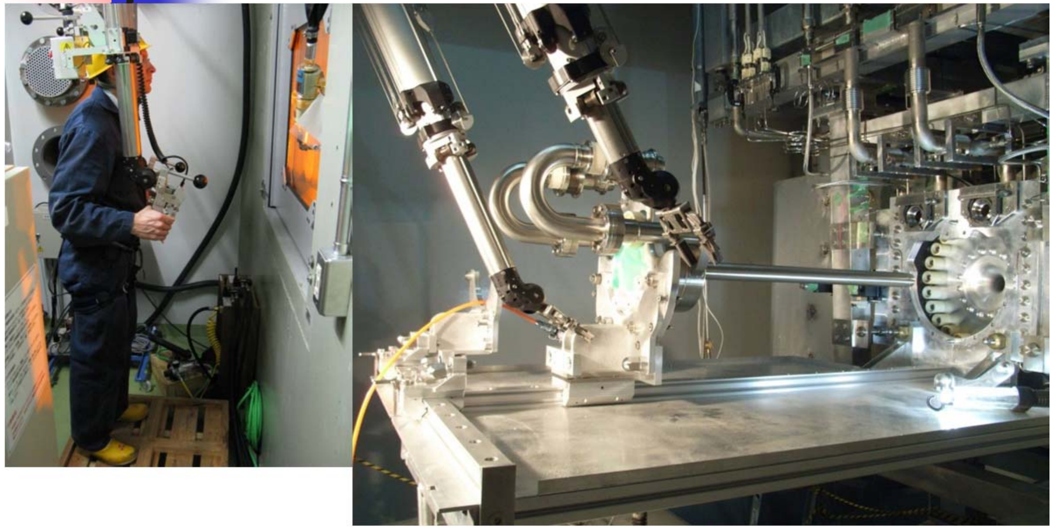
Helium vessel and 1st horn



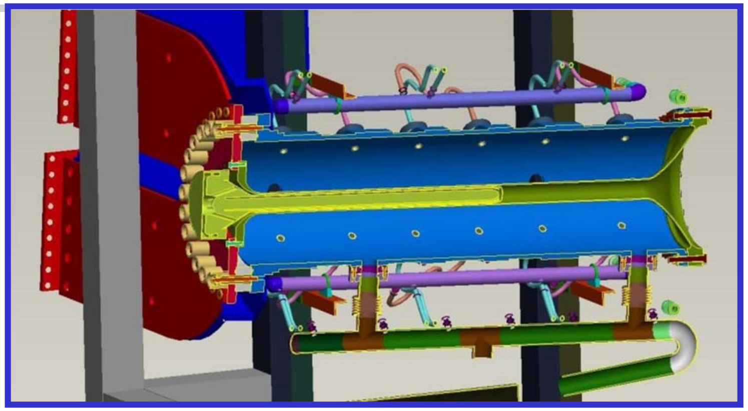
He vessel around 1st horn

Horn is suspended by support module

Target and first horn

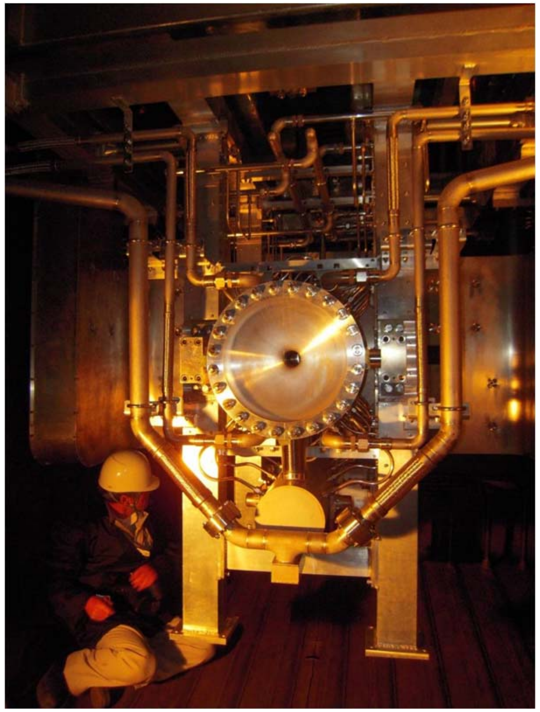


Target extracted from horn



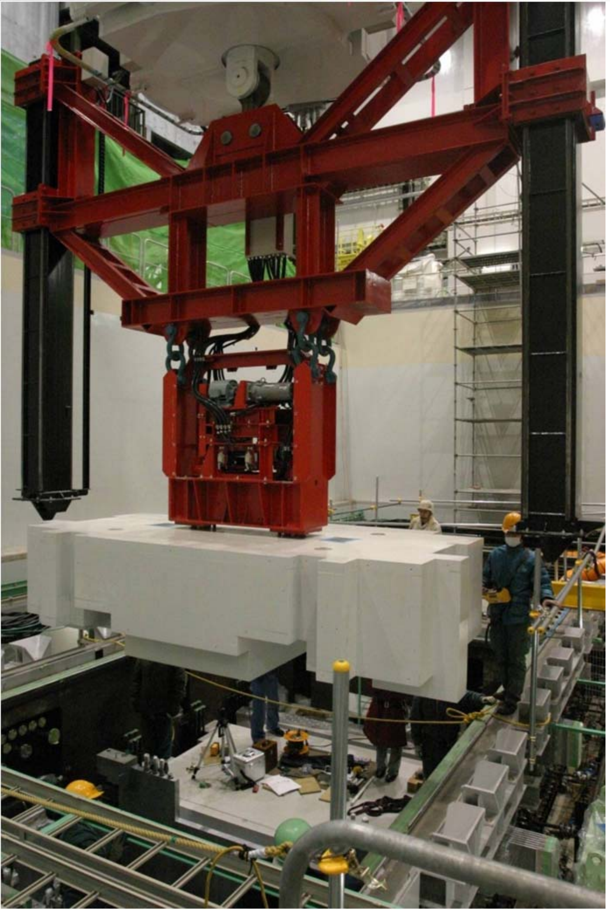
Target: 26mm-ϕ x 900mm-L graphite

Down-stream side of 1st horn



Iron and Concrete shields

2.2m-t inner iron shields
remotely installed
by crane into
horn support module



1m-t inner concrete shields
H2O around surface of concrete
may be reason of additional ^{3}H
Production in He vessel.

Final monitor of FF & Beam window


Oct. 22, 2008

Beam monitors in between
FF section and TS He vessel

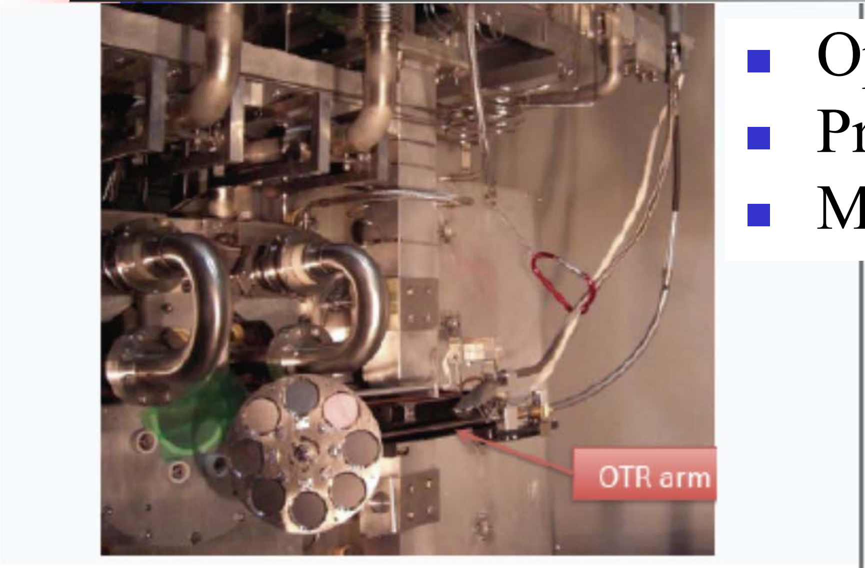

Oct. 23, 2008

The Ti-alloy beam window
cooled by He gas

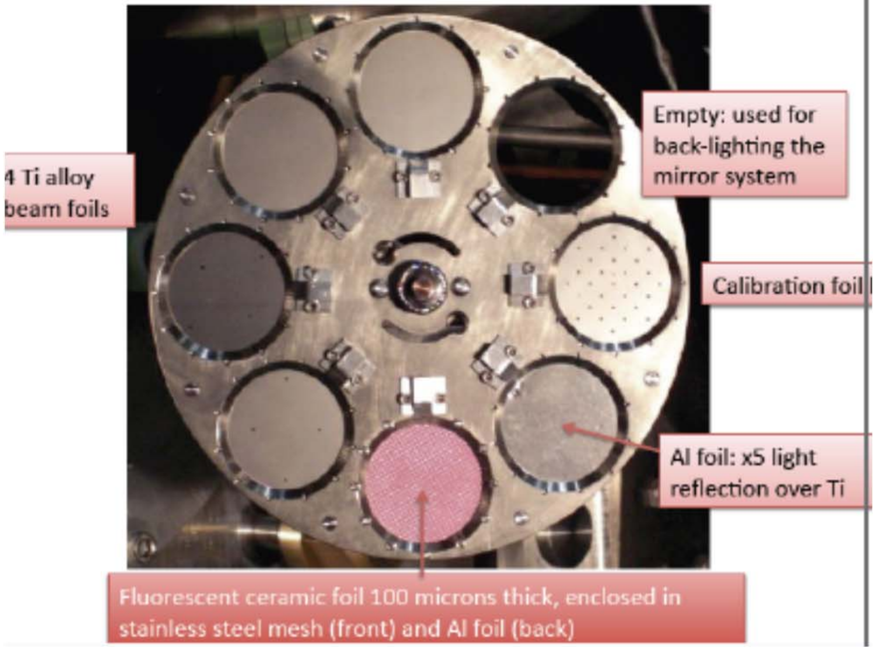
P28

Beam monitor near target: OTR

- Optical Transition Radiation detector
- Profile monitor just in front of target
- Made by Canadian group



OTR arm



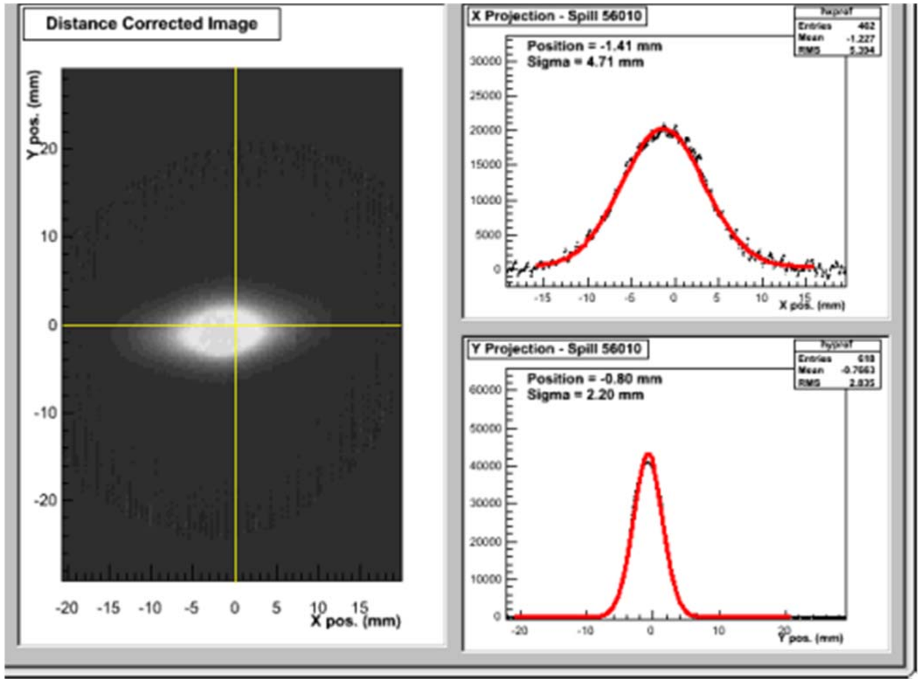
4 Ti alloy beam foils

Empty: used for back-lighting the mirror system

Calibration foil

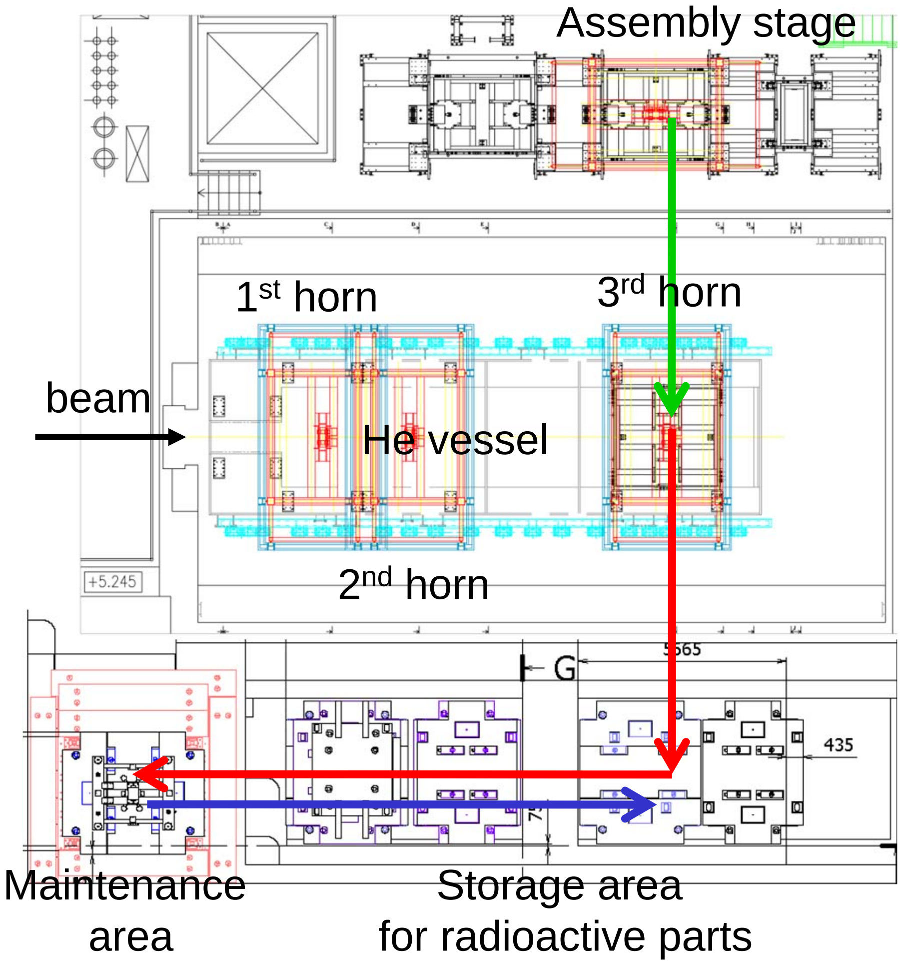
Al foil: x5 light reflection over Ti

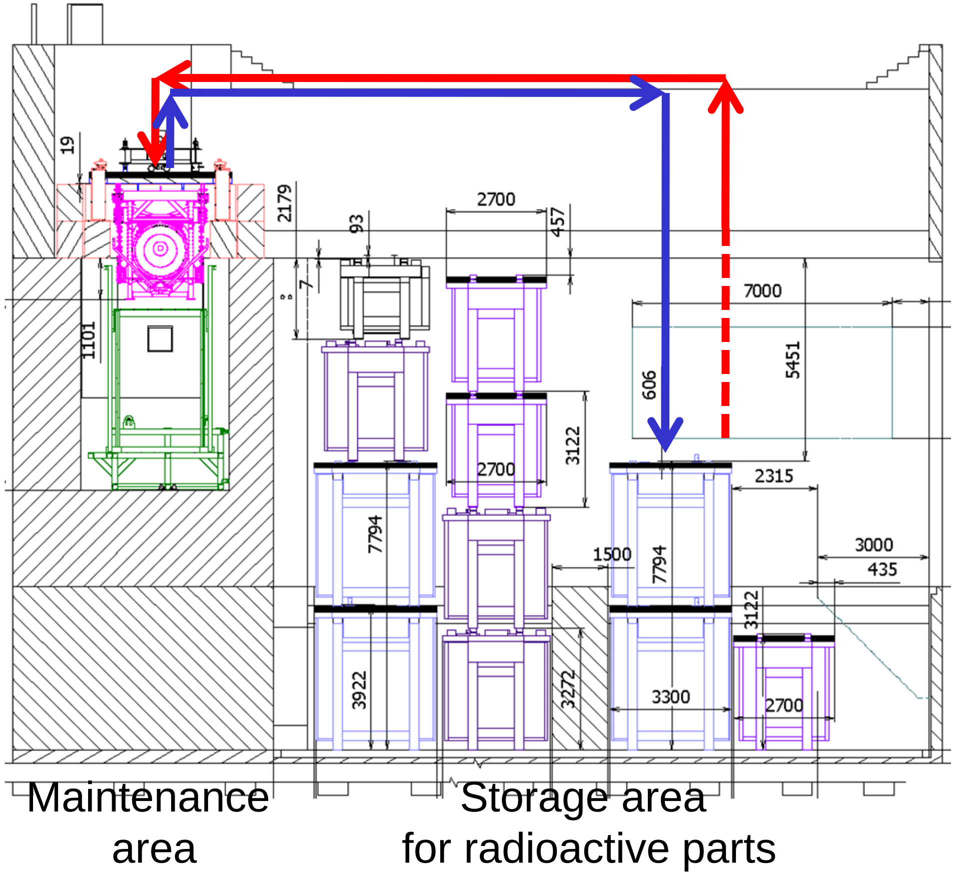
Fluorescent ceramic foil 100 microns thick, enclosed in stainless steel mesh (front) and Al foil (back)



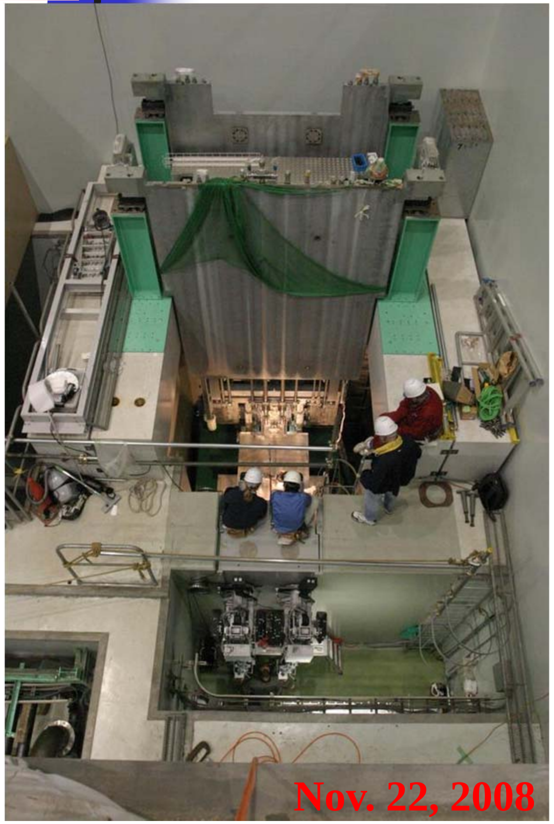
Remote exchange of 1st-Horn in 2011

- Old horn is moved from He vessel to maintenance area.
- Horn is disconnected from support module and moved into cask in storage area.
- New horn/support module are connected on assembly stage and set into He vessel.

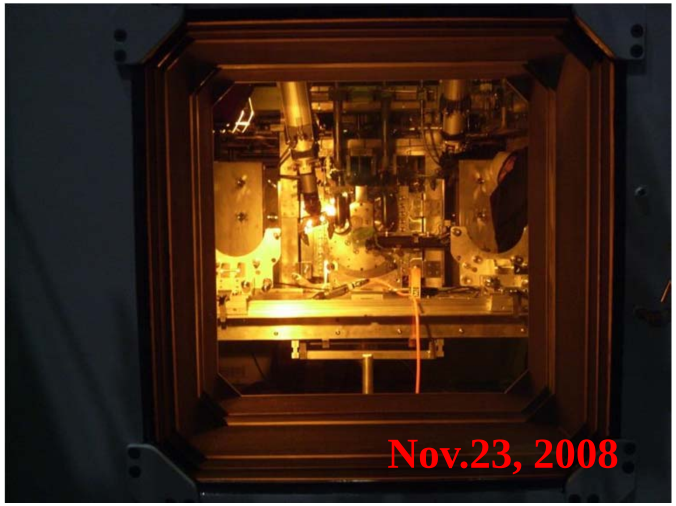




Maintenance Area

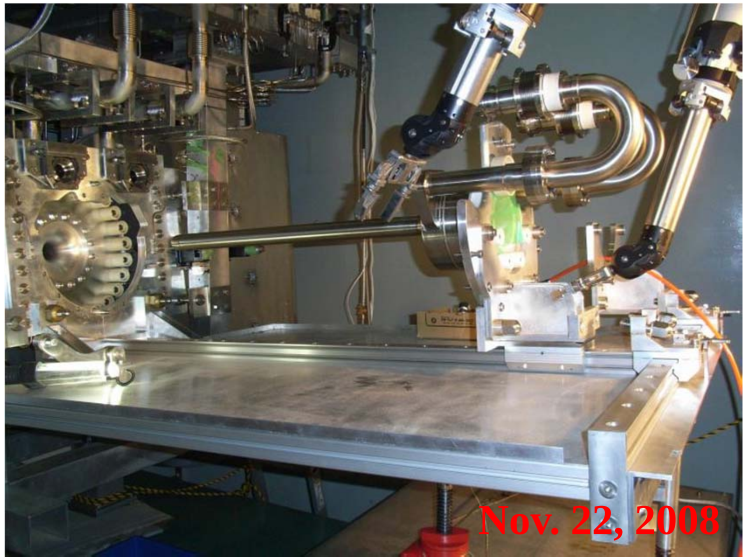

Nov. 22, 2008

Maintenance area


Nov.23, 2008

Lead glass window from TRIUMF

- Target & horns will be activated up to ~15Sv/h after 3years 750kW operation
- Horn is remotely removed from support
- Target can be remotely removed from horn

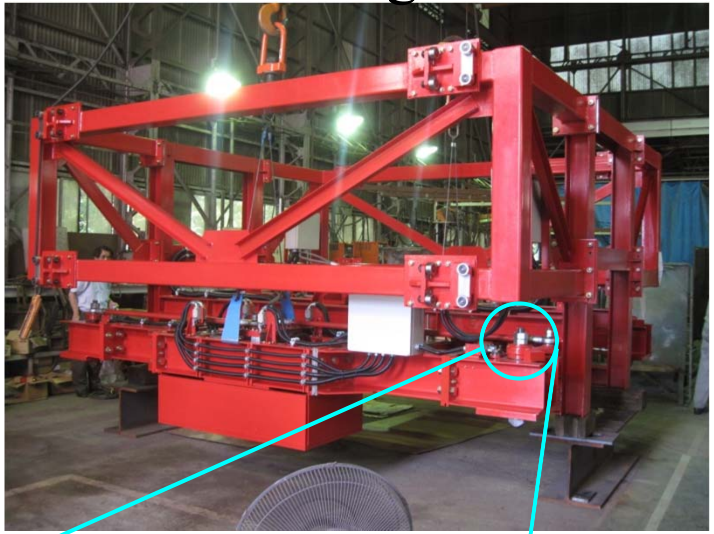

Nov. 22, 2008

Target exchanger from RAL

Remote installation of Horn

How to sling the horn → Twist-lock system
How to set the horn on requested position → Guide cell

Horn handling machine



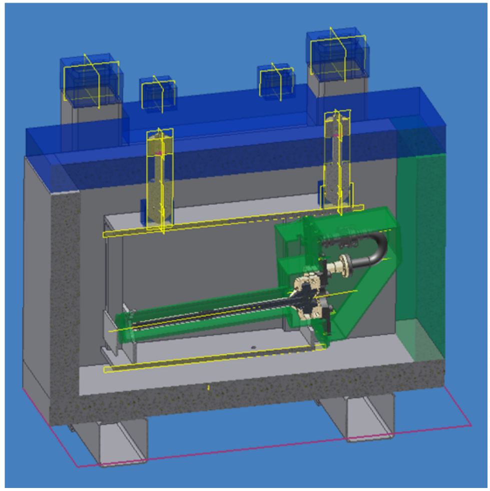
Twist-lock pin

Crane

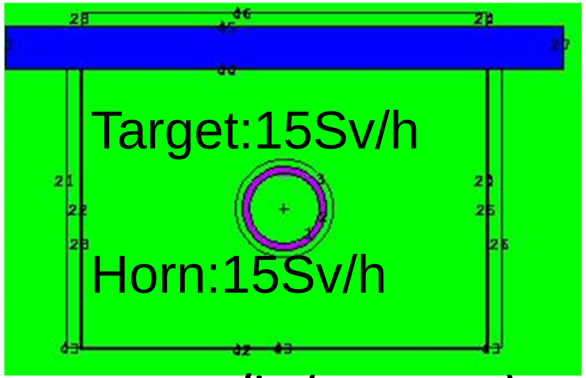
Guile cell

Casket

Casket for horn



5μSv/h (10cm-t)



0.3mSv/h (10cm-t)

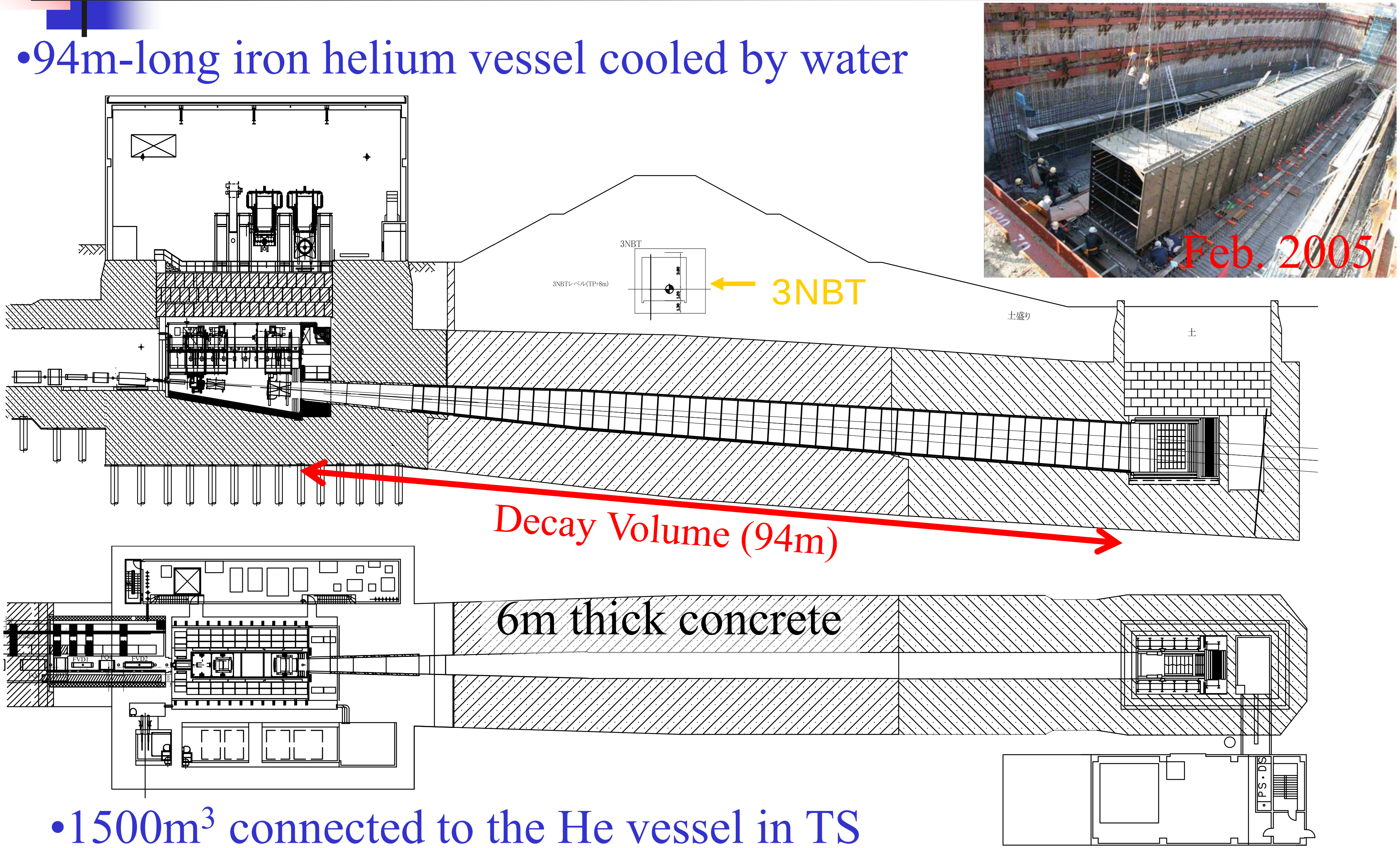
Casket for target

After 3-years 750kw
operation and
3-month cooling

Nine horn-casks can be stocked in Target Station.

Decay Volume (DV)

- 94m-long iron helium vessel cooled by water



Feb. 2005

- 1500m^3 connected to the He vessel in TS
- Evacuated (up to 100Pa) before filling 1-atm. He gas

DV: Iron tunnel cooled by water

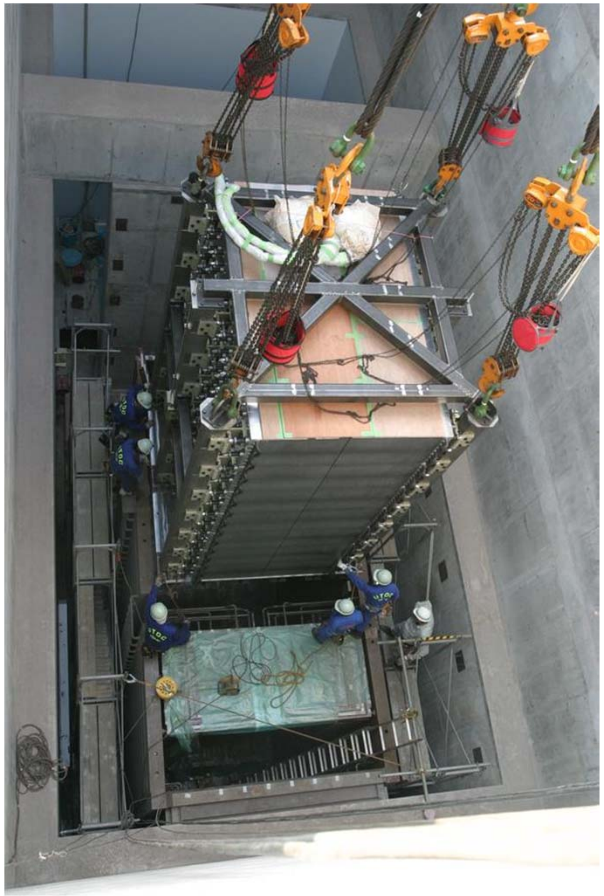
Sep. 9, 2005

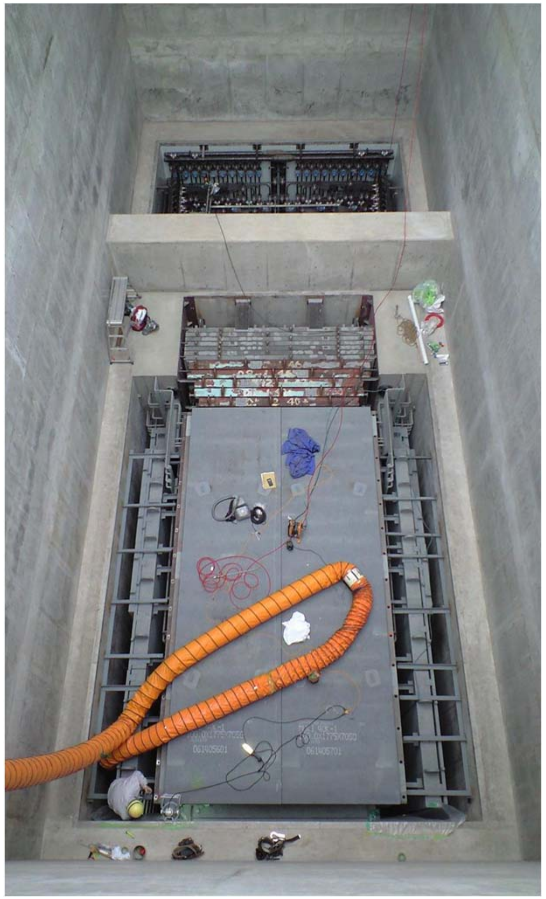
All cooling channels connected by 1080 U-shape pipes.

Oct. 14, 2005

- 3m-W, 4~5m-H
- 16mm thick iron plates cooled by water channels inside

Beam Dump (BD)





- •Core consists of 7x2x7=98 graphite blocks
- •Each block is cooled by side aluminum module cooled by water
- •170ºC at 750kW operation

Expected/unexpected radioactivity

- **Radioactivity as expected**
  - Radiation level in TS
  - Residual dose in TS
  - ^{3}H production in cooling water
  - ^{3}H production in He gas
- **Unexpected:**
  - Leak of thermal neutrons from gap of concrete shields
  - ^{7}Be adhesion in cooling system
  - Leak of radioactive air from underground
  - Additional HTO gas in He vessel after evacuations
  - ^{22}Na from underground water at Muon-pit
  - Too much drain water into DP-tanks from air conditioners
  - More strict limit on ^{7}Be and ^{22}Na by local government

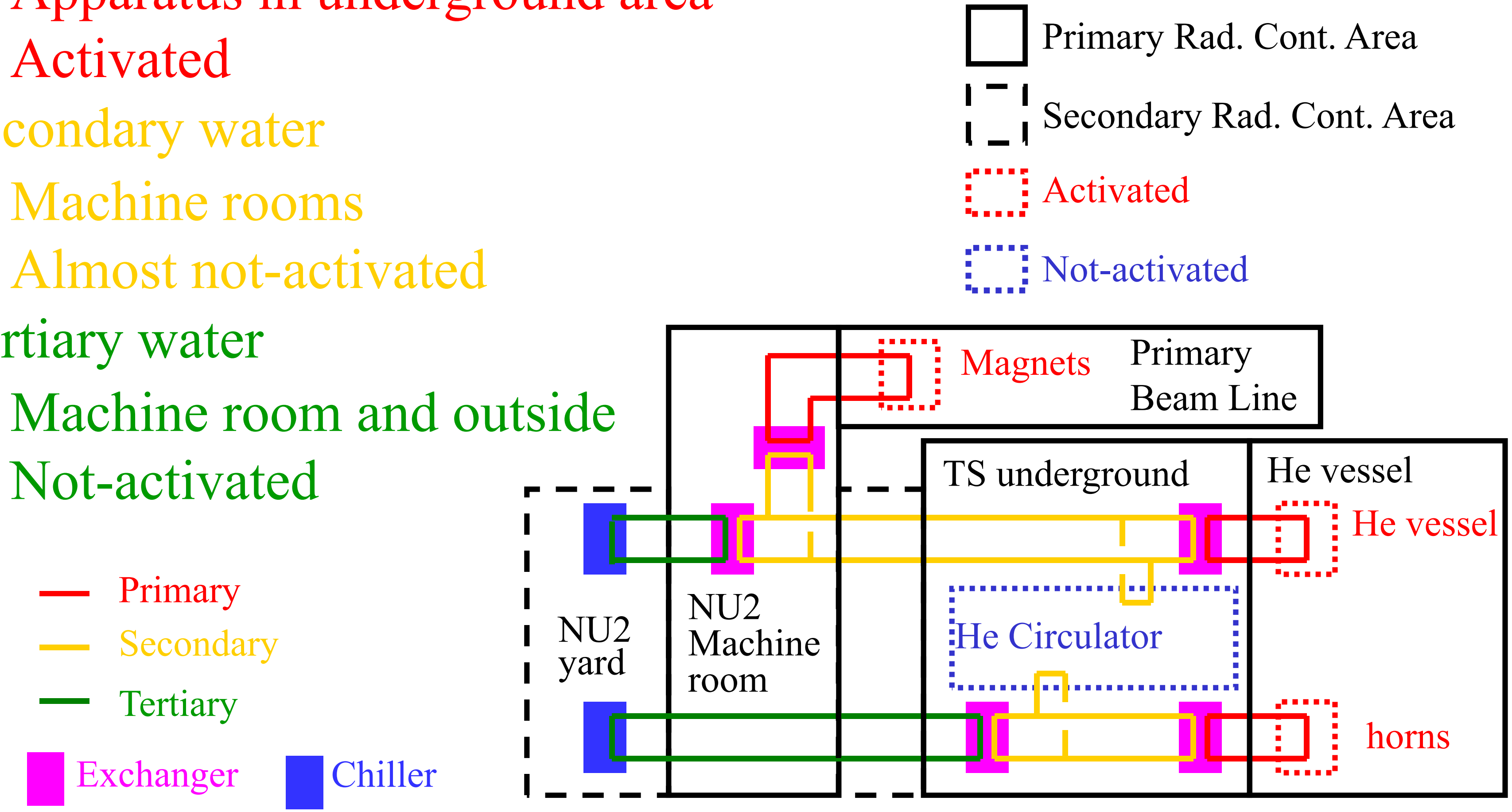
Energy deposit and cooling

	750kW	4MW	Cooling method
Helium vessel	173 kW	922 kW	Water
Inner iron shield	29 kW	155 kW	Water
Bottom iron shield	12 kW	65 kW	Air
Side iron shield	25 kW	131 kW	Air (Add water-cooled plates at 4MW run)
DV collimator (inside)	85 kW	454 kW	Water
DV collimator (outside)	10 kW	53 kW	Air
Decay Volume (upstream)	128 kW	680 kW	Water
Total	462 kW	2460 kW	

- Components in the helium vessel are cooled by water and kept less than 60 ºC.
- Outer components are cooled by air.

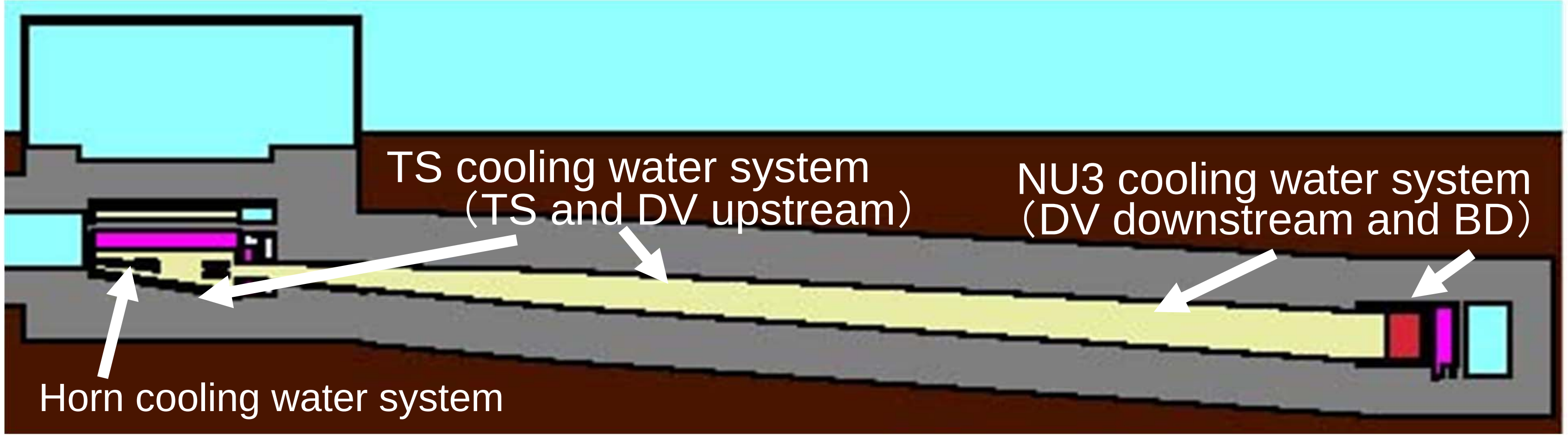
Cooling system in TS

- Three stages to avoid radioactivity outside
  - Primary water
    Apparatus in underground area
    Activated
  - Secondary water
    Machine rooms
    Almost not-activated
  - Tertiary water
    Machine room and outside
    Not-activated



Radioactivity in water

Three independent cooling water systems

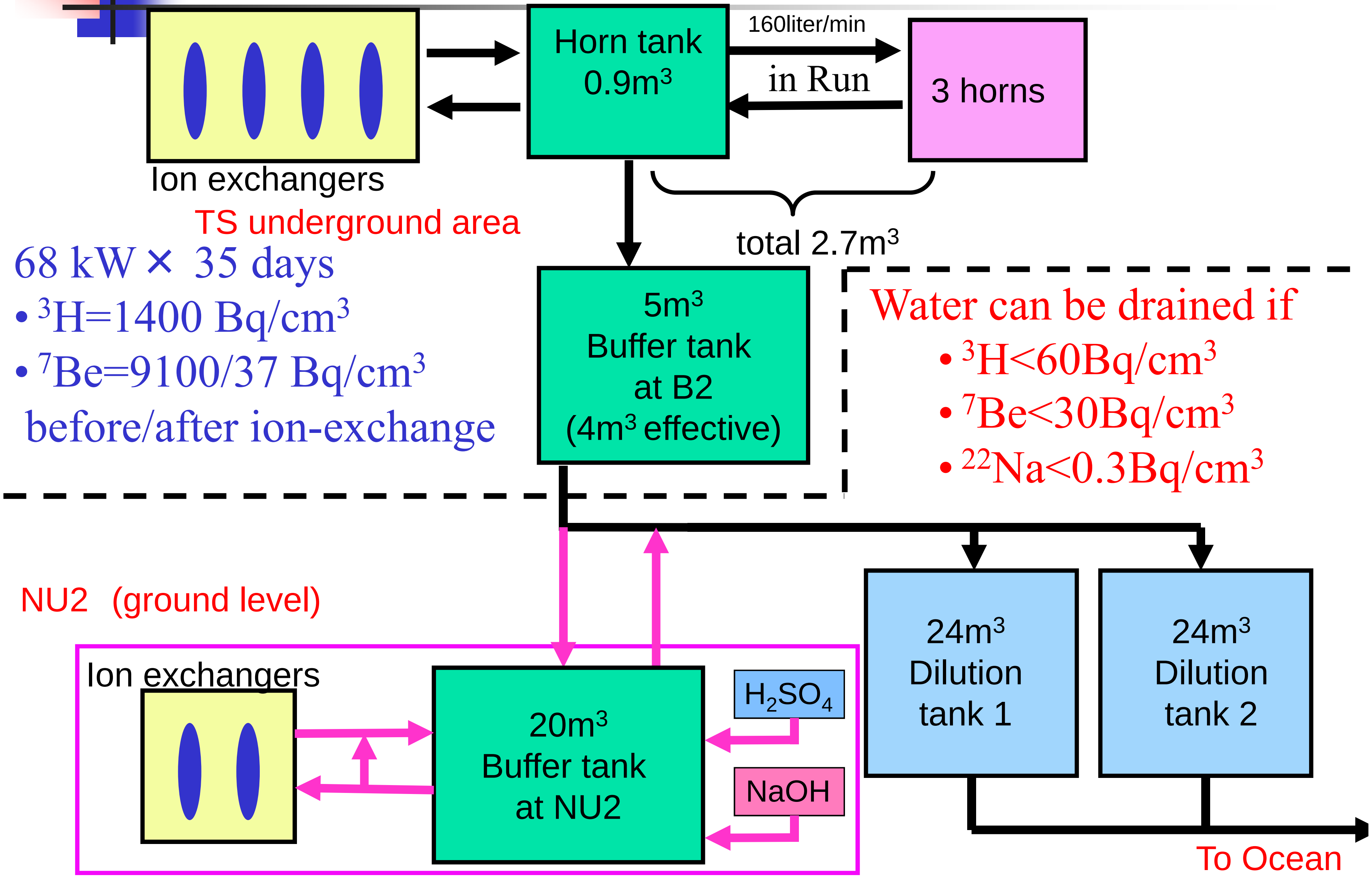


750kW ×120d	Volume (m^3)	^{3}H(GBq)		^{7}Be(GBq)	
		data	Calc.	data	Calc.
(1)Horn	2.7	146	180	935	2159
(2)TS	7.8	195	165	48	1975
(3)BD	10.0	49	36	24	428
Total	20.5	390	381	834	4562

^{7}Be

- adheres to tubes, filters & heat-exchangers.
- reduced by ion-exchanger to 1%

Disposal of Horn water



68 kW × 35 days

- ^{3}H=1400 Bq/cm^{3}
- ^{7}Be=9100/37 Bq/cm^{3}

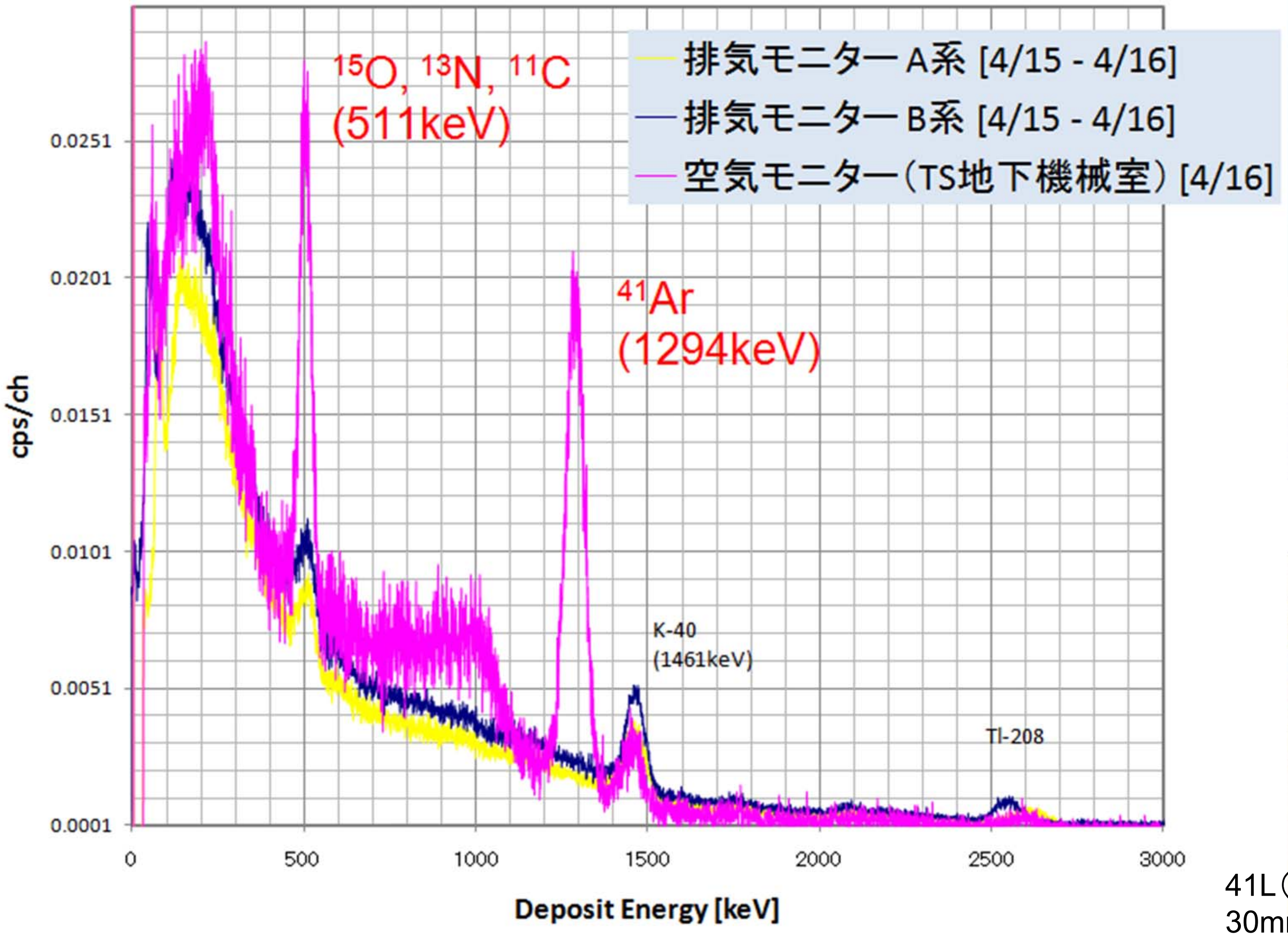
before/after ion-exchange

Water can be drained if

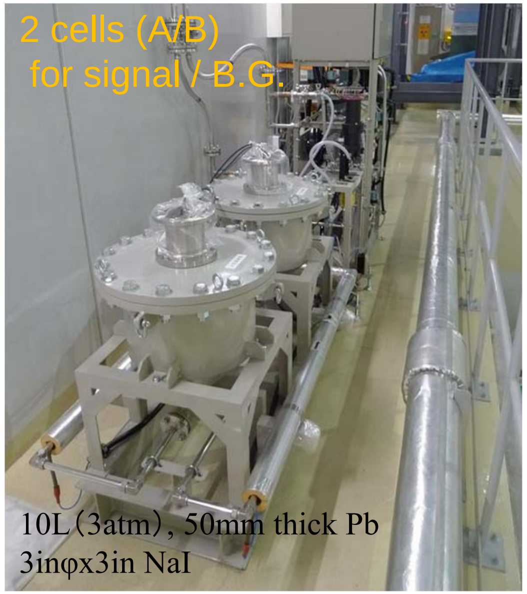
- $^{3}H<60Bq/cm^{3}$
- $^{7}Be<30Bq/cm^{3}$
- $^{22}Na<0.3Bq/cm^{3}$

Radioactivity in underground air

Radioactivity in underground air



Exhaust air monitor



2 cells (A/B)
for signal / B.G.

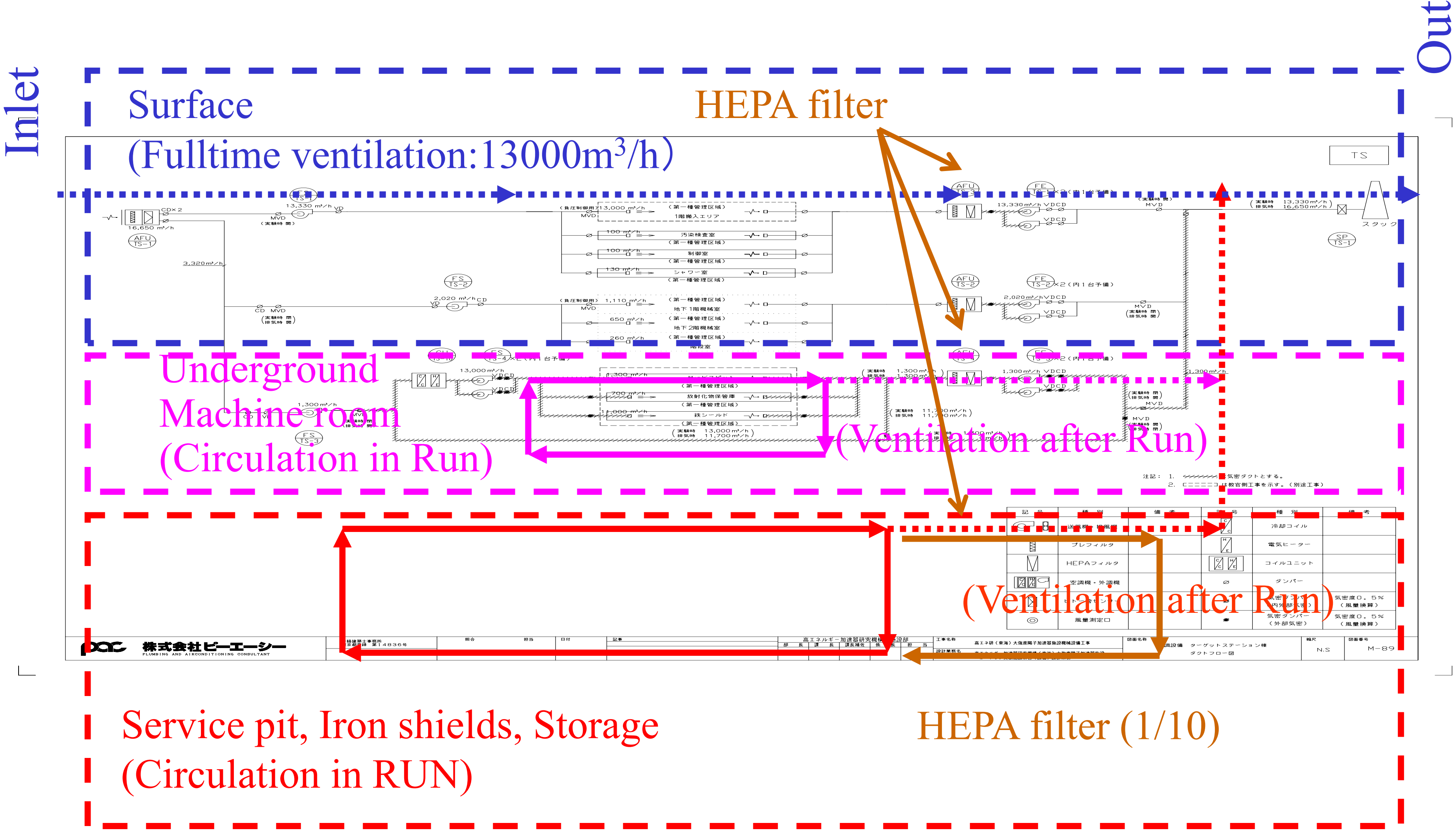
10L（3atm）, 50mm thick Pb
3inφx3in NaI

Air monitor for underground

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

Ventilation in TS

- Regulation in exhausted air : ^{3}H<5mBq/cm^{3}, ^{41}Ar<0.5mBq/cm^{3}



Inlet

Outlet

Surface
(Fulltime ventilation:13000m^{3}/h)

HEPA filter

Underground
Machine room
(Circulation in Run)

(Ventilation after Run)

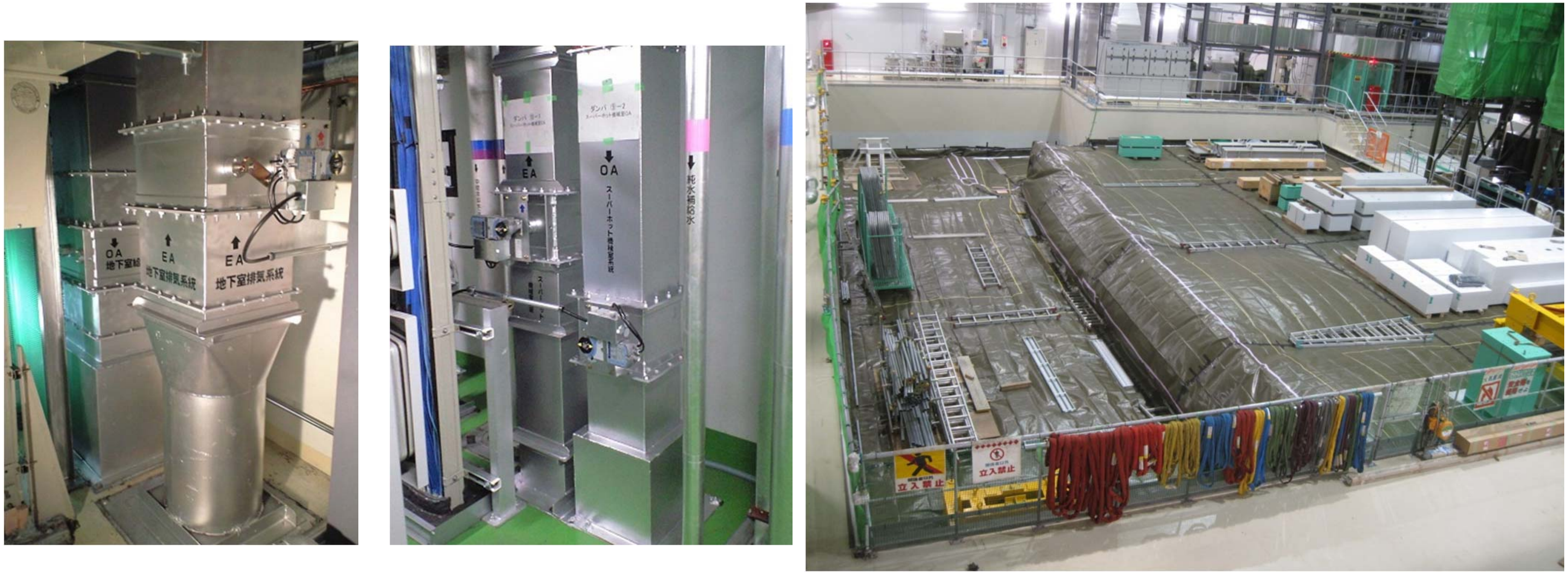
(Ventilation after Run)

Service pit, Iron shields, Storage
(Circulation in RUN)

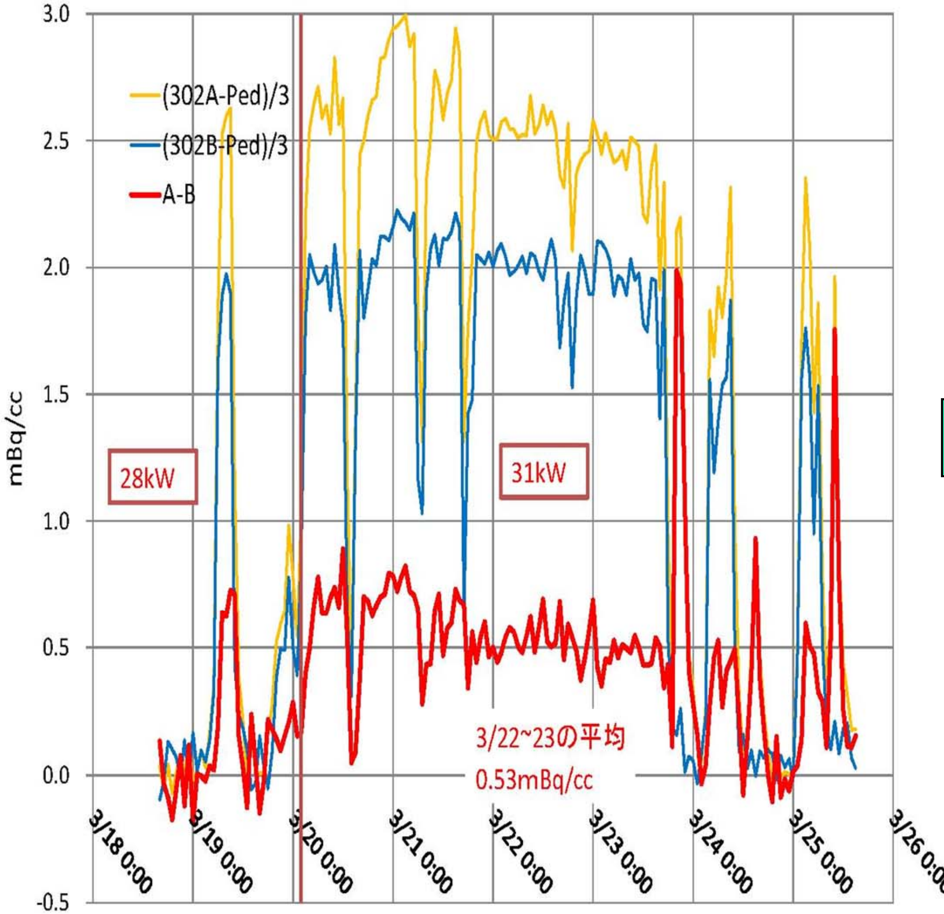
HEPA filter (1/10)

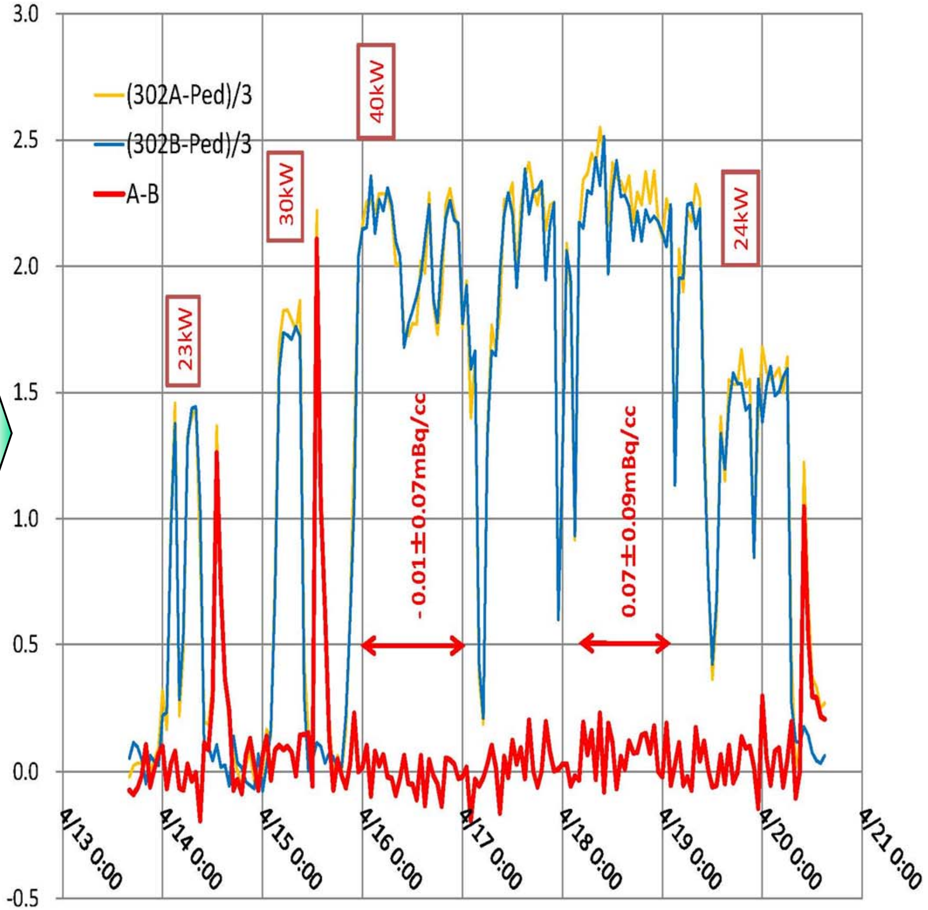
Leak of ^{41}Ar from underground

- Radioactive air was leaked from TS and BD.
- Radioactivity in the air at stack exceeded the limit (< 0.5mBq/cc).
  - Air-tightening for cable hole, door …… (TS,BD)
  - New air-tightened Dumpers (TS,BD)
  - Cover whole surface of concrete blocks (TS)



Reduction of ^{41}Ar by sheets

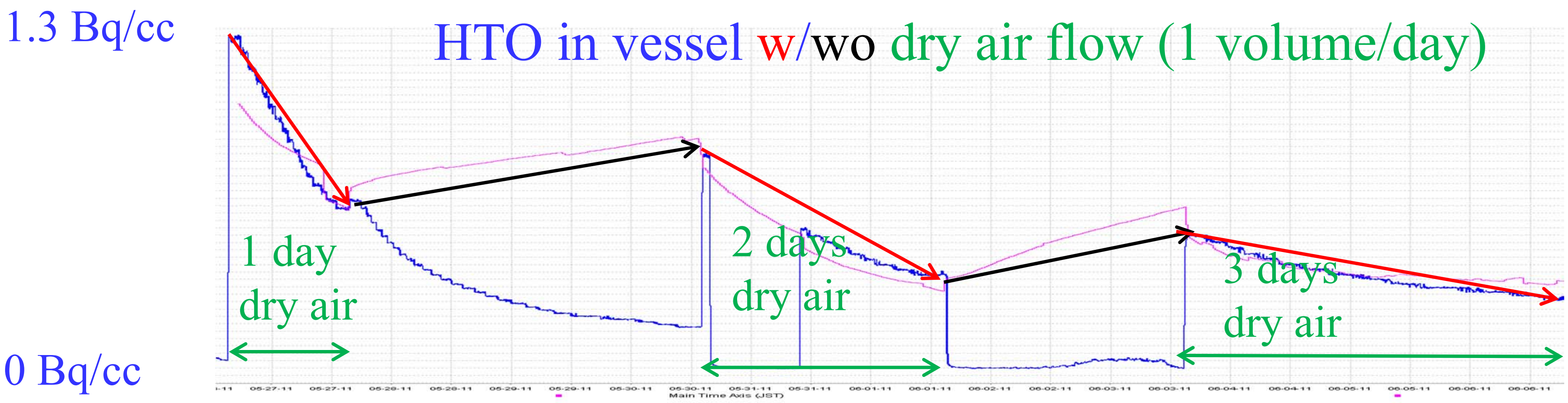




- Radioactivity was improved by covering shield blocks with sheets
- 0.5mBq/cc (=limit) at 250kW will still remain.
- Air tight sheets will be installed.

Unexpected ^{3}H in He vessel

- Run from Nov. 2010 to Mar. 2011: 52kW × 120 days
- Expected ^{3}H=T form He gas in He vessel : 0.42 Bq/cc
- Measured HTO : ~1.0 Bq/cc
- Unexpected part may come from H_2O in He vessel (humidity 100%)
  - same level even after an evacuation/air-charge of He vessel
  - being reduced by flowing dry air through He vessel.
  - causes a few mBq/cc ^{3}H at 1st floor of Target Station when the lid is opened, though exhaust limit is 5 mBq/cc.



Summary

- Neutrino Beam Line of J-PARC was designed considering:
  - Radiation level and residual dose
  - Remote maintenance of activated apparatus
  - Radioactivity and disposal scenario for cooling water and air
  - Personal Protection System
- Remote exchange of 1st horn is planed in this summer.
- Observed radioactivity is almost as expected except for
  - Leak of ^{41}Ar from underground area
  - Additional production of ^{3}H in He vessel