Radiation Protection in J-PARC neutrino beam line

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Happy birthday to me!

Summary of Regulations

The design of neutrino beamline must satisfy following radiation level.

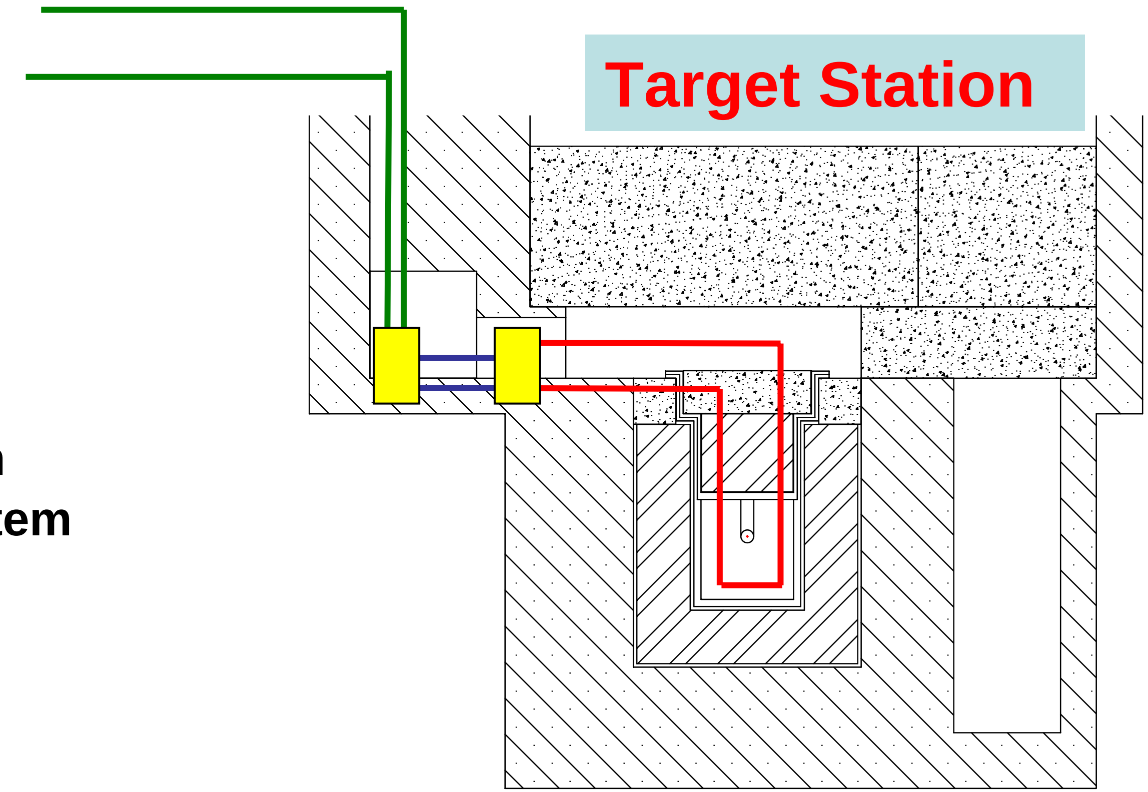
- H < 0.25μSv/h for free access area
- H < 12.5μSv/h for control area
  (Human access limit is < 1mSv/week)
- H < 5mSv/h (line loss) and H < 11mSv/h (point loss)
  for soil around buildings
- Radioactive waters can be disposed to outside (ocean) if the radioactivity is less than 30Bq/cc.
- Radioactive gas (air/Helium) can be ventilated to environment if the radioactivity is less than 5mBq/cc.

Overview

- Works on radiation protection are essentially adjustments of radiation shielding thickness. The calculations are based on the MARS simulation and other utilities.
- Studies on Proton Beamline, Target Station, Decay Volume, Beam Dump/Muon Pit and access tunnels were already discussed in the previous NBI workshops.
  See http://www-nu.kek.jp/~oyama/nbi2003.oyama.ppt
- After a hundred times of iterations between geometry change and radiation calculation, the final design were almost fixed. They were reported in the individual talks.
- In my talk, I would like to concentrate on management of cooling waters and Air/Helium.

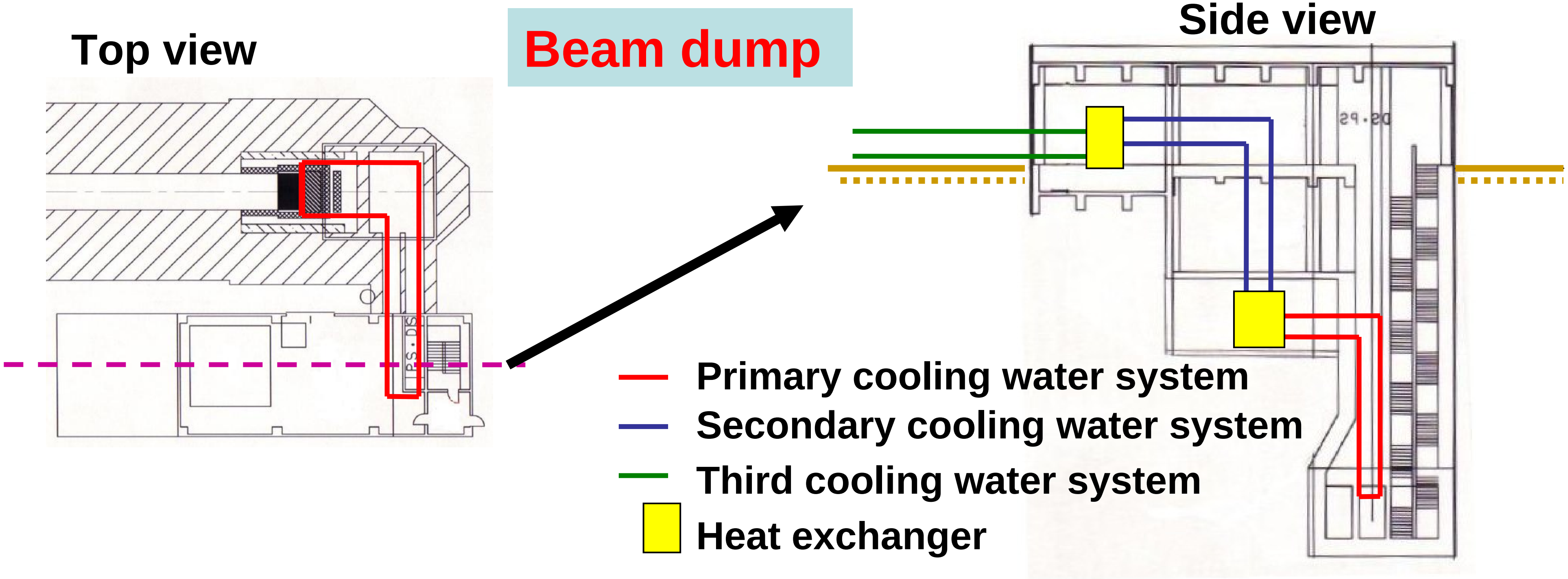
Cooling Water Systems(1)

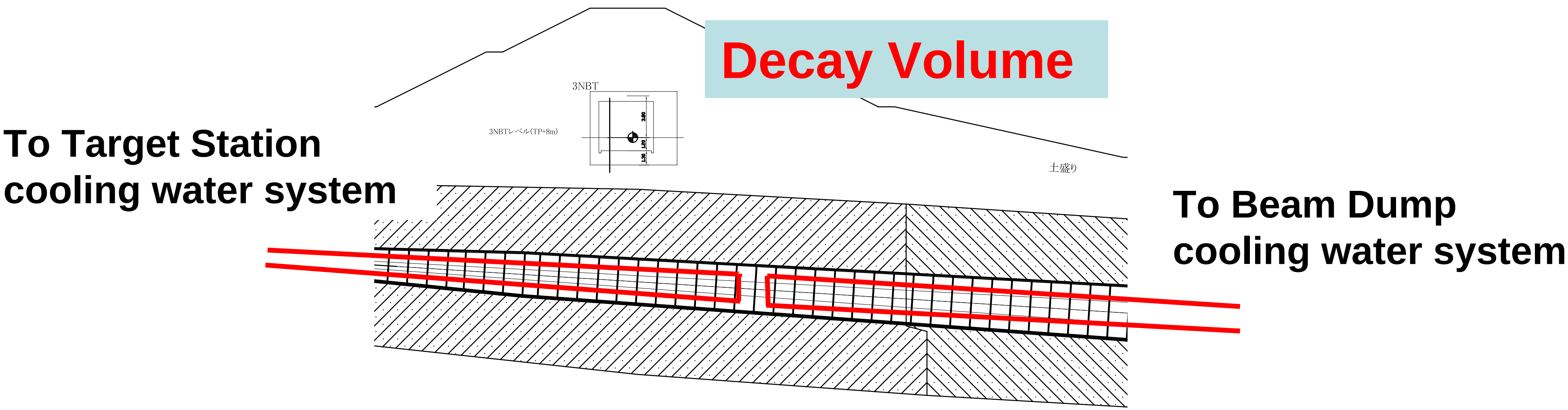
- Primary cooling waters are highly radio-activated when they travel the beam surroundings. They are circulated only in the underground control area during 20 days of beam period.
- They are serious radioactive sources when they pass the heat exchanger.
- They must be disposed to outside (ocean) after the beam stop.



- Primary cooling water system
- Secondary cooling water system
- Third cooling water system
- Heat exchanger

Cooling Water Systems(2)





Requirements for cooling water

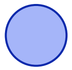
(A) **When primary cooling waters pass the heat exchanger during beam period, radiation level from radio-activated waters should not exceed the requirements from the regulation. They are H < 12.5μSv/h for control area, and H < 0.25μSv/h for free access area**

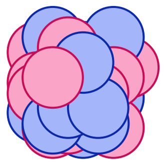
(B) **After one cycle (20 days) of 0.75MW beam operation, radio-activated primary cooling waters should be disposed to ocean. For this purpose, concentration of radioactivity in the water must be less than 30Bq/cc.**

Radio-activation of cooling water

- **Radioisotopes are produced from Oxygen in H_2O.**

  Neutrons from the beam with energy larger than ~20MeV break the $^{16}_{8}O$ nuclei.





- **Several kinds of isotopes with Z O 8 and N O 8 are made as spallation products.**

  They are ^{3}He, ^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{14}O, ^{16}N, ^{14}C.

  Nominal cross sections are ~30mb.

- **Production rate of the radioisotope is obtained from (neutron flux) x (cross section) x (volume of water).**

Isotopes generated in cooling water

	E(MeV)	lifetime	comments
^{3}H	0.0186	12.3y	main obstacle in disposal
^{7}Be	0.478 (10%)	53.3d	removed by ion filters
^{11}C	0.511x2	20m	Radiation sources in heat exchanger Negligible after a few hours of cooling
^{13}N	0.511x2	10m	
^{15}O	0.511x2	2m	
^{14}O	2.3	70s	
^{16}N	6	7s	
^{14}C	0.156	5730y	decay rate is negligible

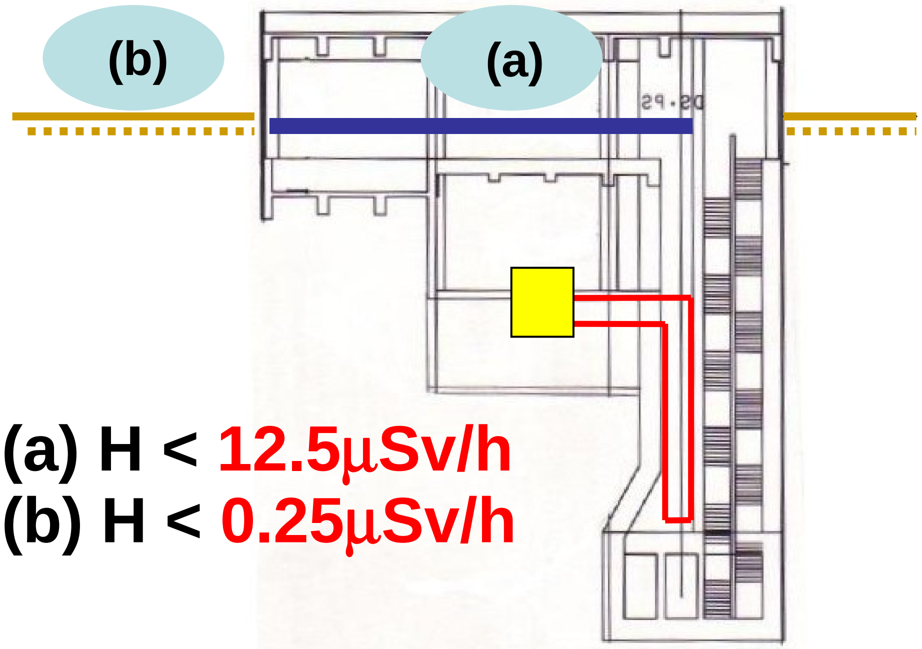
(A) During the beam operation, ^{11}C, ^{13}N, ^{15}O, ^{14}O, ^{16}N in the heat exchanger are the radiation sources.

(B) In the disposal scenario, ^{3}H is the dominant radioactive source.

Radioactive water in heat exchanger

- **All short-life radioisotopes are in (production rate) = (decay rate) equilibrium.**

Example : Beam dump and Decay volume



(a) H < 12.5μSv/h
(b) H < 0.25μSv/h

	(GBq)	E(MeV)	lifetime	H(μSv/h)
^{11}C	400	0.511x2	20m	16 / 0.4
^{13}N	400	0.511x2	10m	15 / 0.4
^{15}O	400	0.511x2	2m	13 / 0.3
^{14}O	400	2.3	70s	110 / 12
^{16}N	400	6	7s	27 / 6

(a) / (b), floor thickness = 20cm,
time from beam exposure = 30sec

- **Thick floor concrete is effective for ^{11}C, ^{13}N, ^{15}O**
  ^{11}C : 16μSv/h (20cm) → 0.02μSv/h (60cm)
- **Long travel time of water is effective for ^{16}N**
  ^{16}N : 27μSv/h (30sec) → 0.03μSv/h (100sec)
- **From simulations of all radioisotopes, we conclude that concrete thickness 70cm and travel time 100sec are needed.**

Disposal procedure of radioactive water

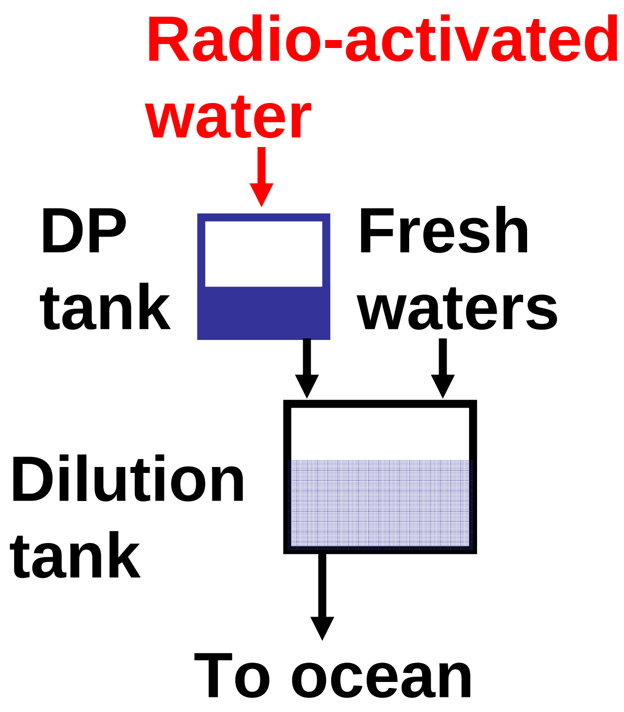
- After 20 days of beam operation, we wait several hours. All radioisotopes with short lifetime decay.

- Primary cooling waters are moved to DP tank. The water volume is small (< $10m^3$), but it is highly radio-activated (100~500Bq/cc).

  (1) Appropriate volume of radio-active waters are moved to the dilution tank, and mixed with fresh waters.

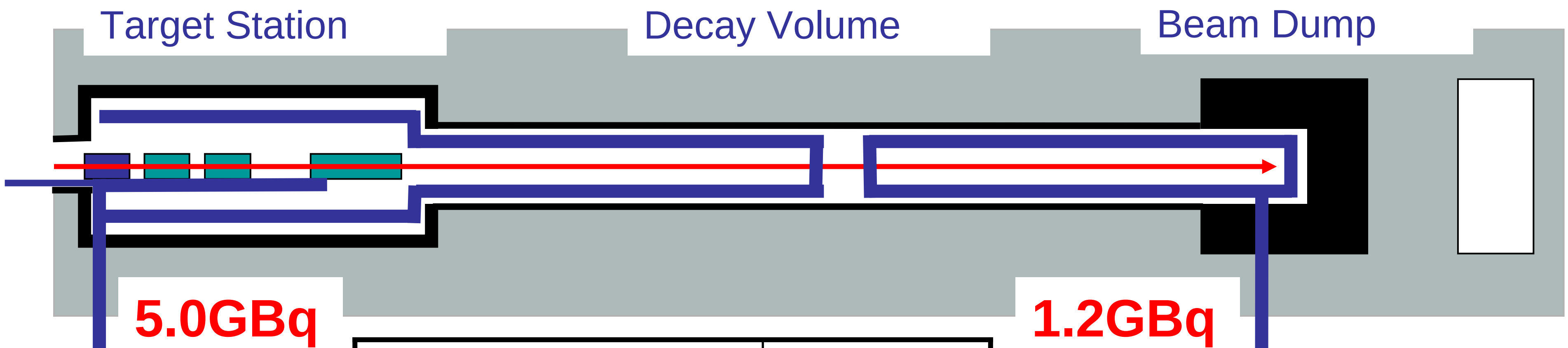
  (2) The radioactivity in of the diluted waters is measured.

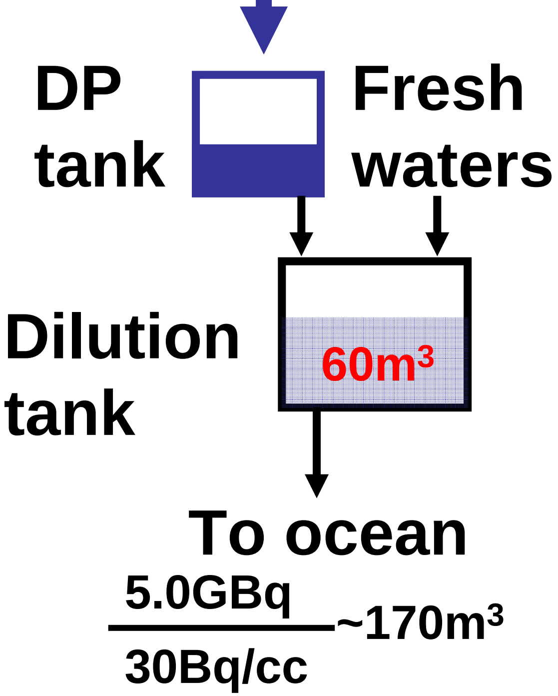
  (3) The waters are disposed to the outside (ocean) if the radiation is less than 30Bq/cc.



- Repeat process (1)~(3) until the DP tank become empty. It takes 2 days for one cycle.

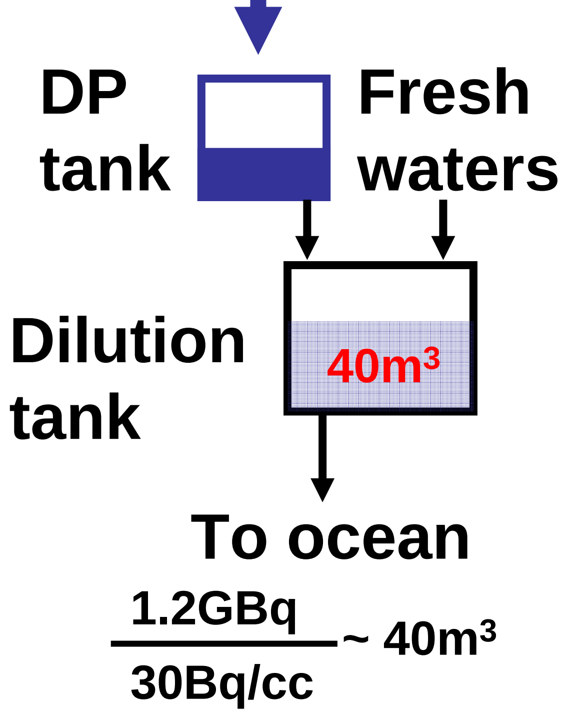
Summary of cooling water disposal





component	^{3}H (GBq)
Norm. Cond. Mag.	0.1
Horn x 3	1.0x3
Target Station	1.4
Decay Volume (u)	0.5
Upstream Total	5.0

component	^{3}H (GBq)
Decay Volume (d)	0.4
Beam Dump	0.8
Downstream Total	1.2



3cycles/20days

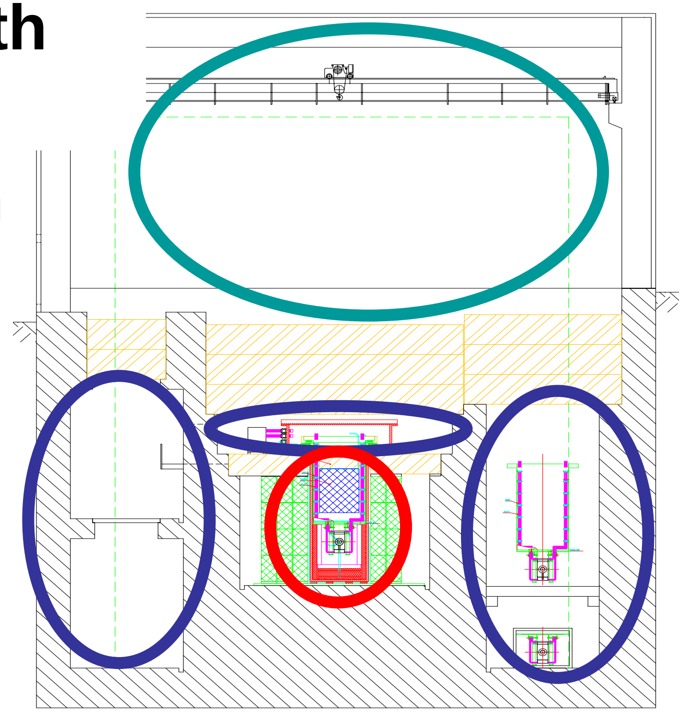
1cycle/20days

Radio-activation of Air/Helium

- **Radioactive gas (Air/Helium) can be ventilated to environment if radioactivity is less than 5mBq/cc. If the radiation level exceeds this requirement, it must be ventilated by mixing with fresh air.**
- **The dominant radioactive source in air is ^{3}H. They are spallation products from ^{16}O/^{14}N and neutrons with energy larger than 20MeV. The process is almost the same as the case of the cooling waters.**
- **Production rate of ^{3}H from Helium is smaller than that from air: $\sigma_{He} \sim \sigma_{Air}/25$. It is because He nuclei is hard to break.**

Ventilation procedure (Target Station)

- We are planning to make a ventilation system of 13000m^3/h capability in the target station.
- Air in the surface building is always ventilated even in the beam period.
- After 20 days 0.75MW beam operation, radio-activation of air in service pit, machine room, radioactive storage are less than 10^{-2}mBq/cc. They can be ventilated without mixing with fresh air. It takes less than 1 hour.
- Radio-activation of cooling air for the iron shielding, Helium in target station and decay volume are more than 1Bq/cc. They must be ventilated by mixing with fresh air. It takes about 2 days after 20days beam. Even after one year of operation, it takes less than one month.



Summary of Air/Helium ventilation in Target Station

0.75MW , 20days operation σ_{air}=30mb, σ_{He}~σ_{air}/25

component	volume (m^3)	Neutron fluence ($/p/cm^2$)	Radio-activation (Bq/cc)	Total tritium (Bq)	Ventilation time(h)
Surface building	13000	1×10^{-19}	4×10^{-14}	-------	realtime
Service pit	230	5×10^{-12}	3×10^{-6}	$7\text{x}10^{2}$	0.02(direct)
U.g. machine room	330	5×10^{-12}	3×10^{-6}	$1\text{x}10^{3}$	0.03(direct)
radioactive storage	780	5×10^{-12}	3×10^{-6}	$2\text{x}10^{3}$	0.06(direct)
Iron cooling	30	10^{-10}~ 5×10^{-6}	$5\text{x}10^{-5}$ ~2.6	$1.6\text{x}10^{7}$	0.25(mixed)
TS Helium	135	2×10^{-4}	3.2	$6.3\text{x}10^{8}$	10(mixed)
DV Helium	1600	5×10^{-5}	0.8	$1.9\text{x}10^{9}$	30(mixed)

Summary

- **Calculations of radiation shielding were almost done.**

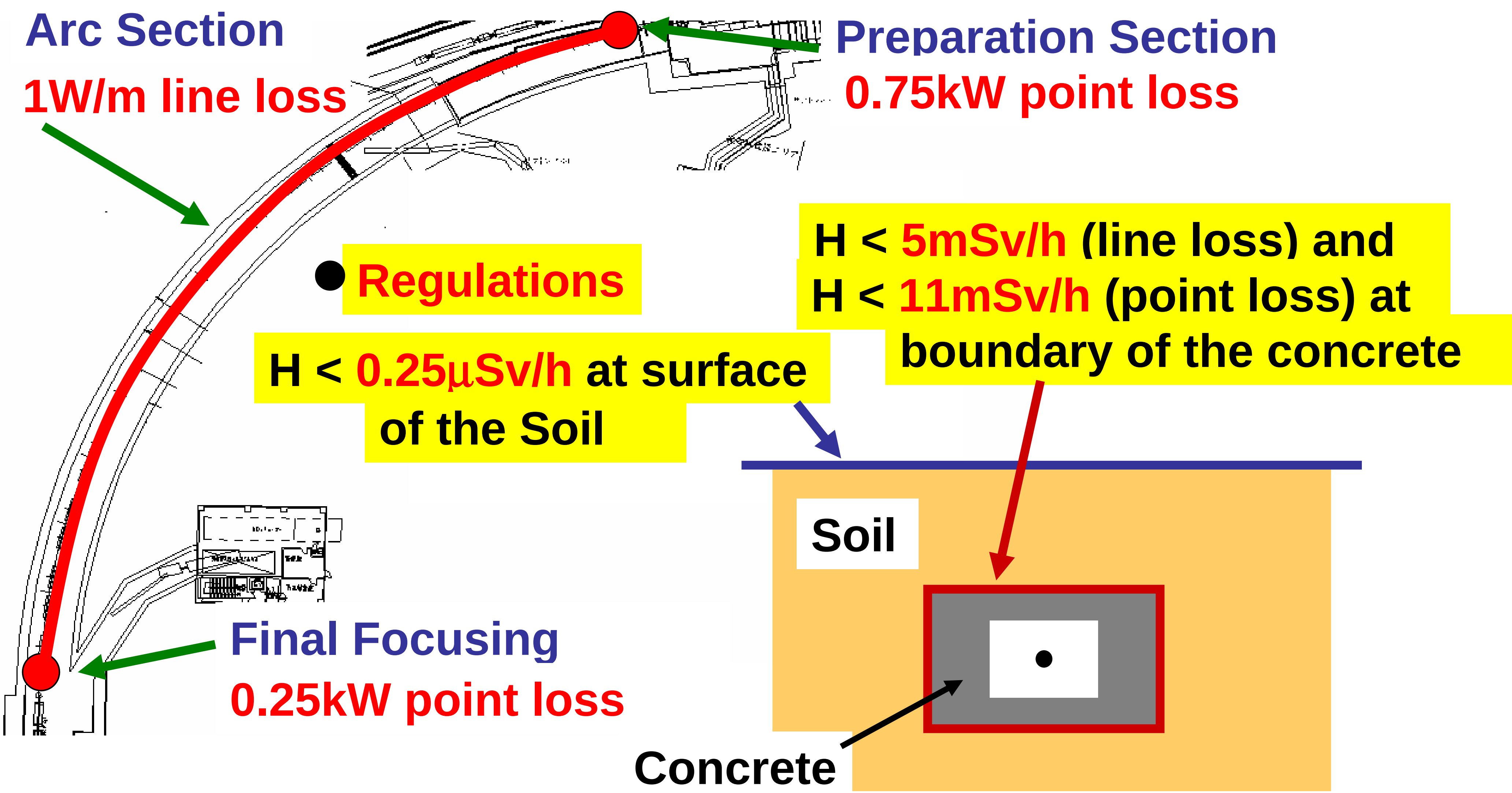
- **Management of cooling waters and Air/Helium are established for beam operation period as well as for their disposal/ventilation.**

Lunch time!

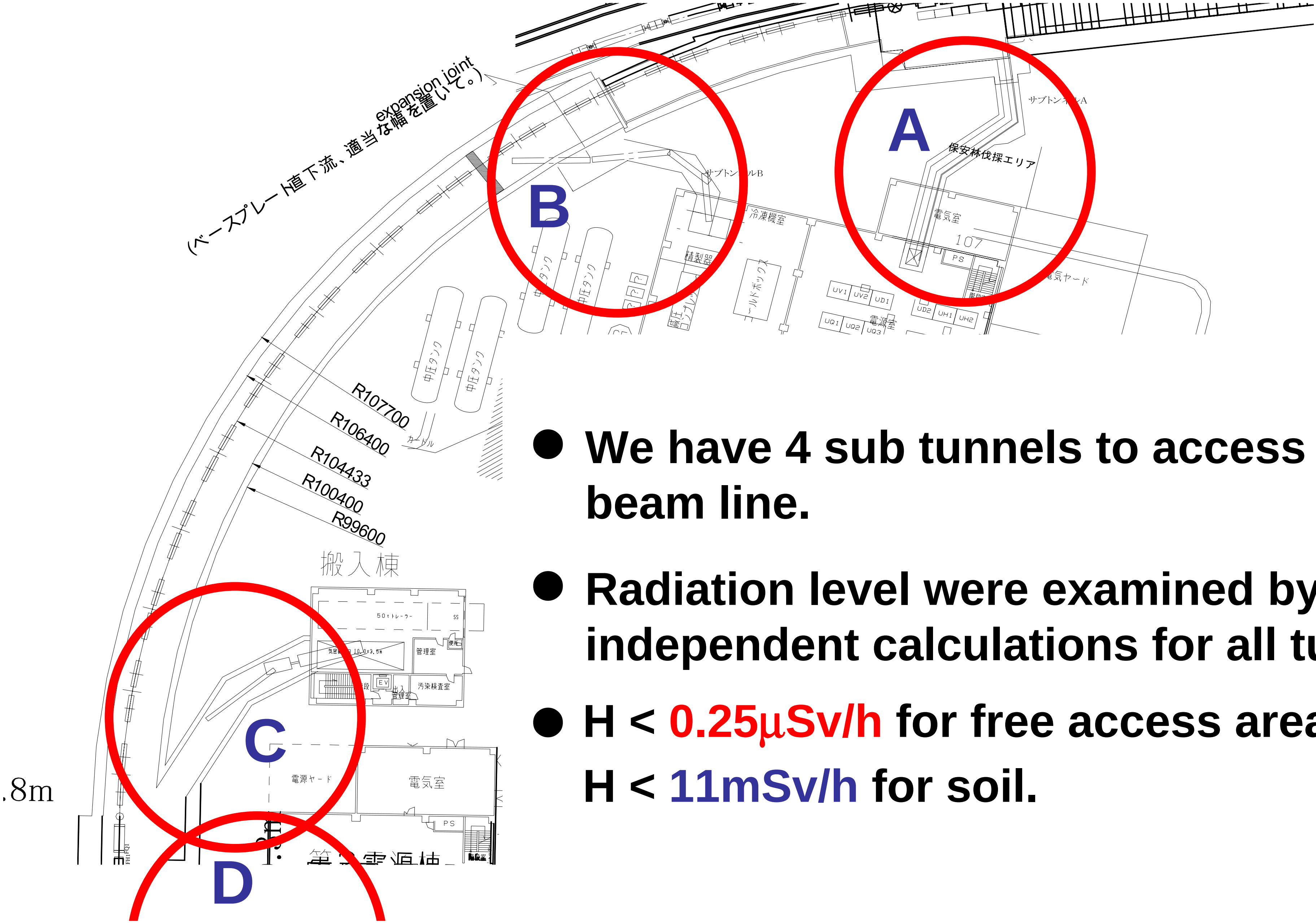
Supplements

Radiations in the Proton Beamline

- Following energy loss are assumed from our experience.



Sub Tunnels



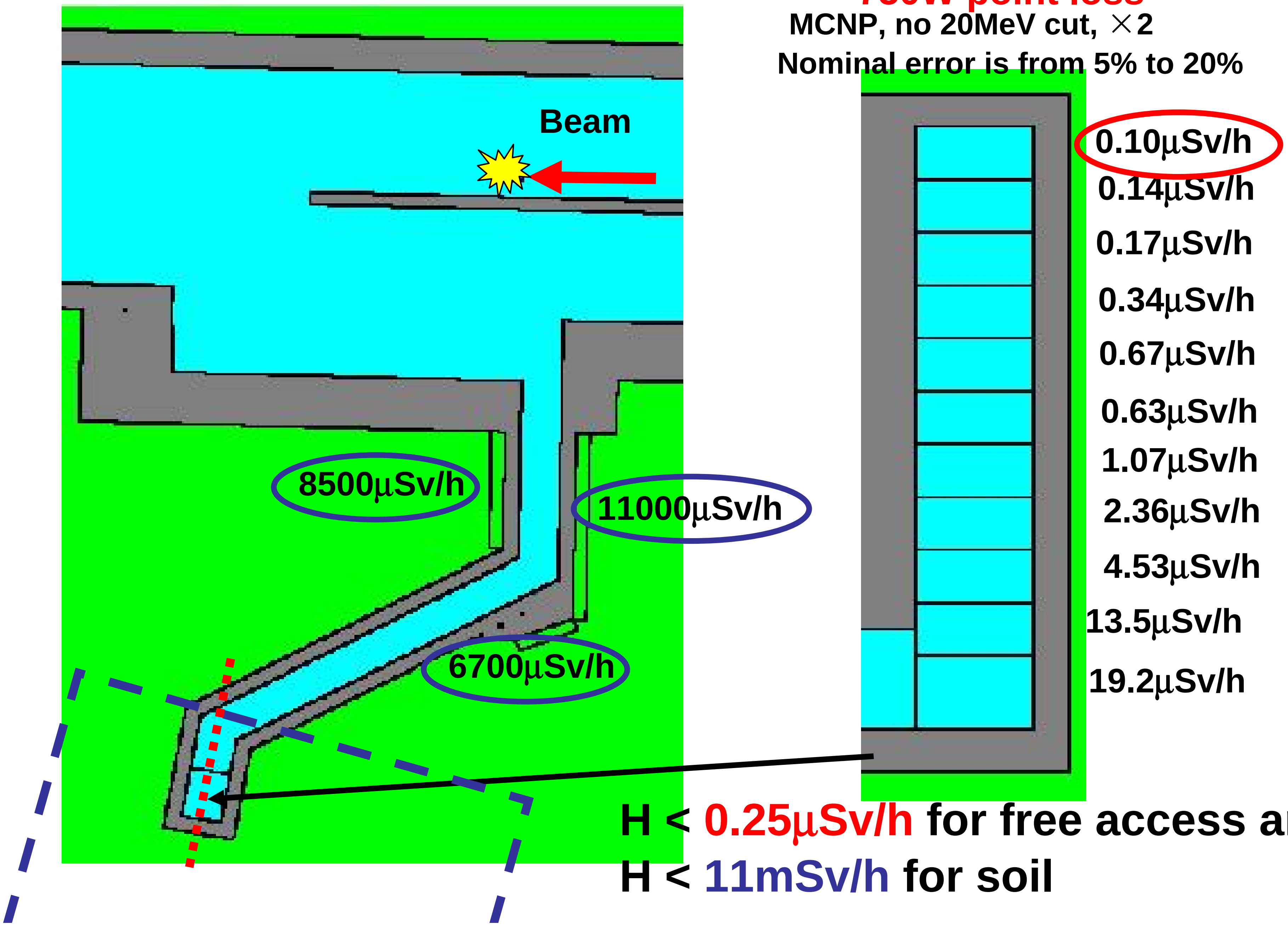
- We have 4 sub tunnels to access the beam line.
- Radiation level were examined by 2 independent calculations for all tunnels.
- H < 0.25μSv/h for free access area and
  H < 11mSv/h for soil.

Sub Tunnel A

750W point loss

MCNP, no 20MeV cut, ×2

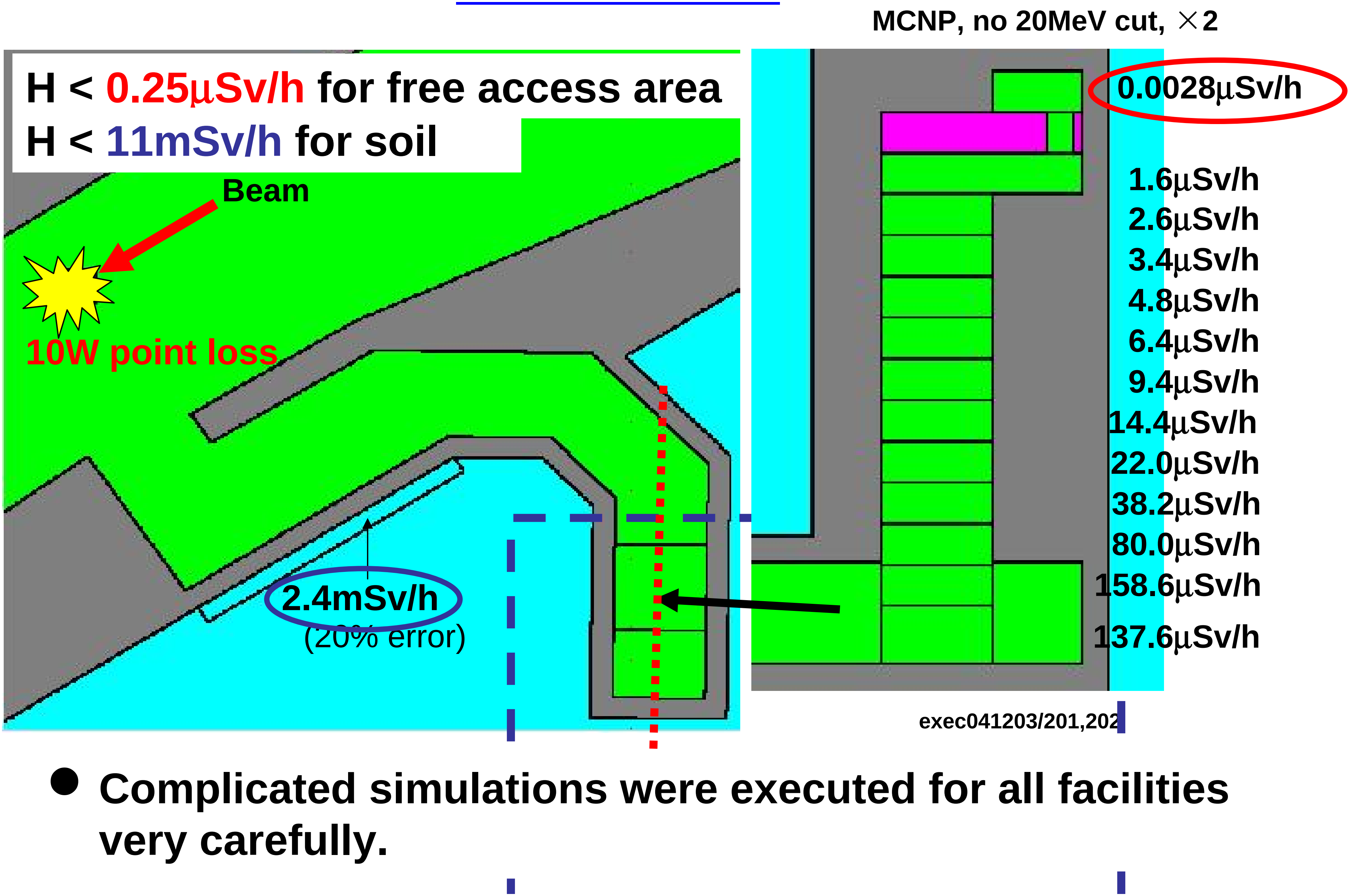
Nominal error is from 5% to 20%



H < 0.25µSv/h for free access area

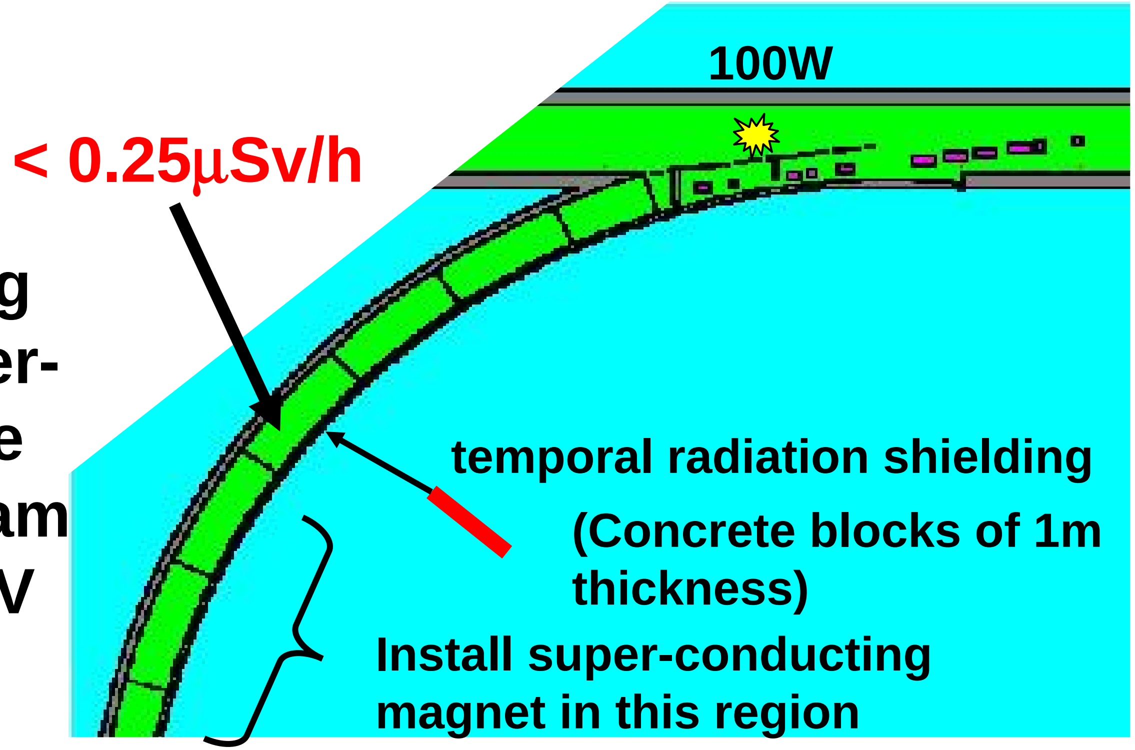
H < 11mSv/h for soil

Sub Tunnel B



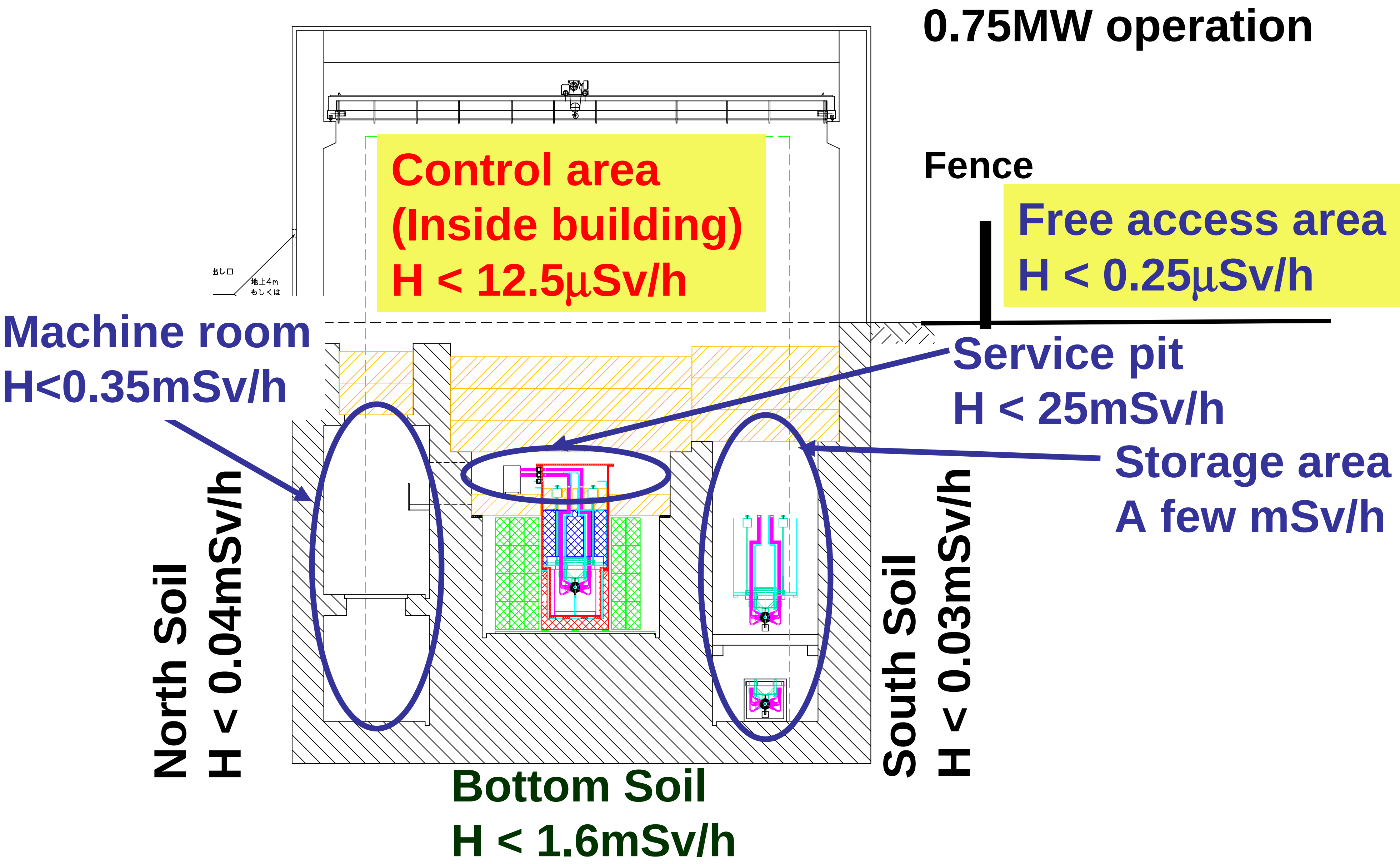
- Complicated simulations were executed for all facilities very carefully.

Radiation in the Proton beam line during the commission of 50GeV main ring



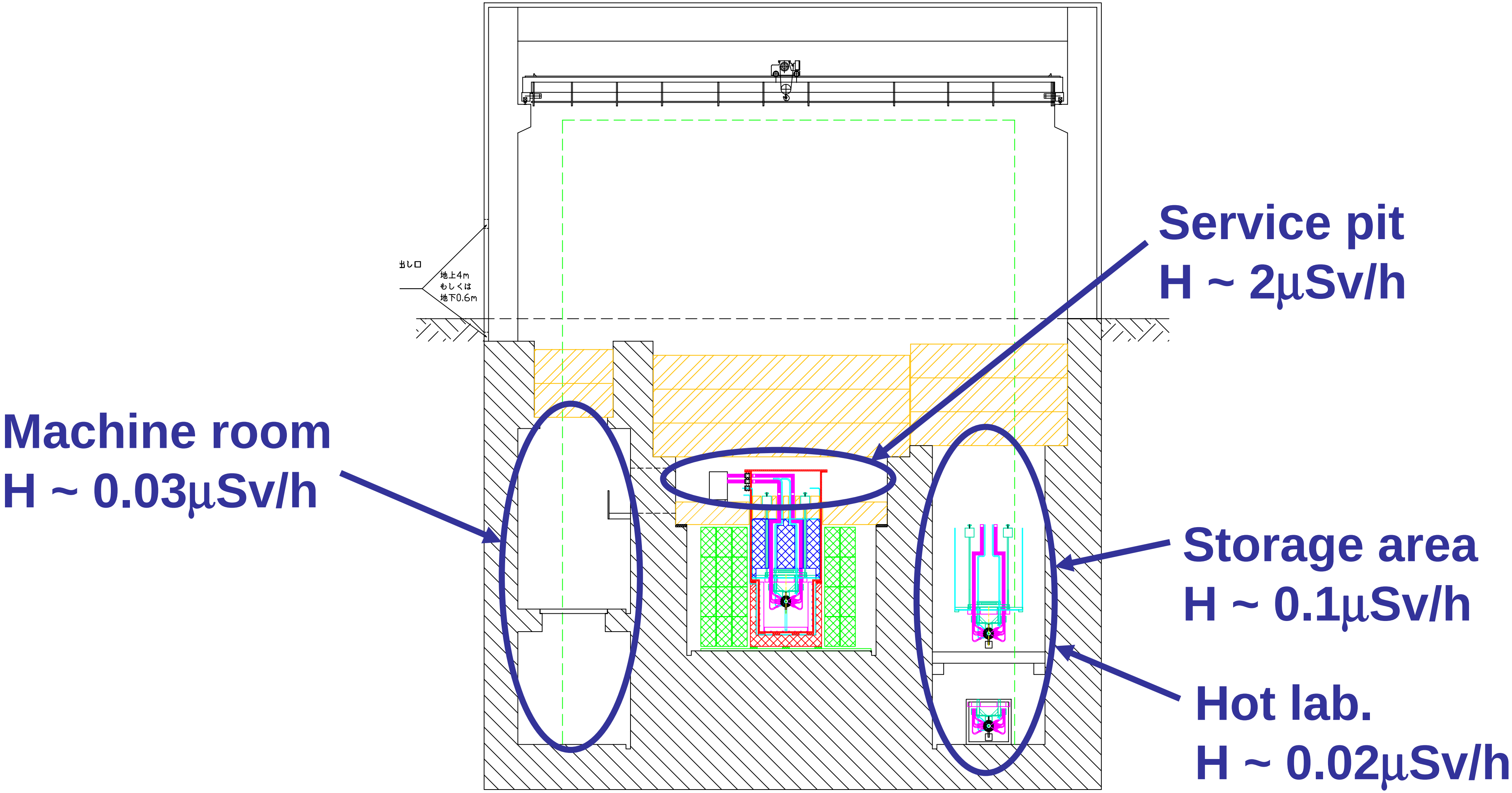
- From end of 2007 to spring 2008, we must install super-conducting magnets in the downstream of proton beam line. Commission of 50GeV ring has been started.
- If we install temporal radiation shielding and possible maximum energy loss is adjusted to be 100W, radiation level in the working area is less than 0.25μSv/h.
- Moving magnet installation schedule to 2008 summer shutdown is also under consideration.

Radiation dose during beam operation



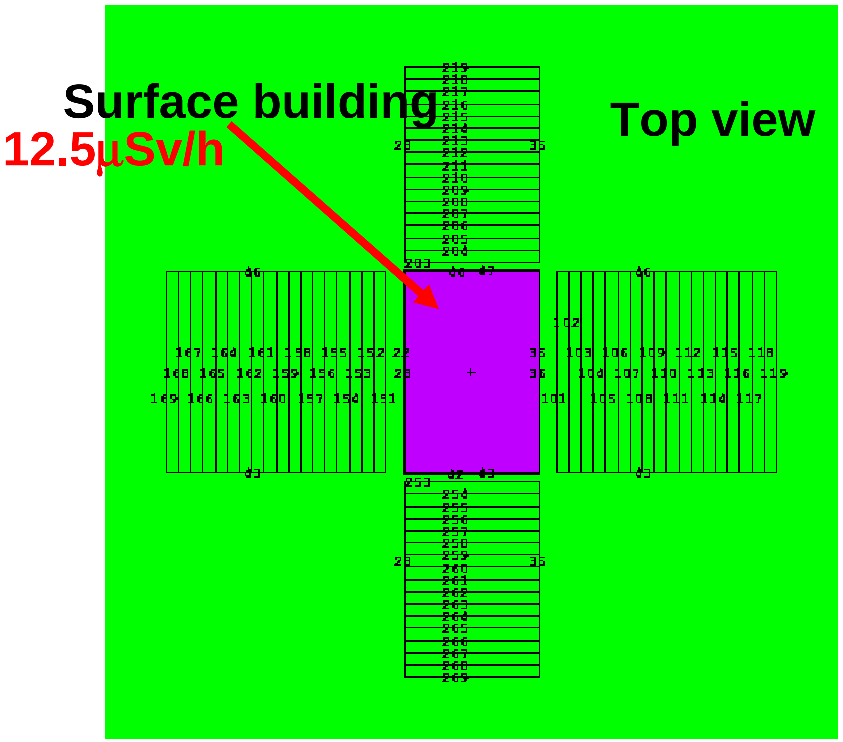
Residual dose after beam stop

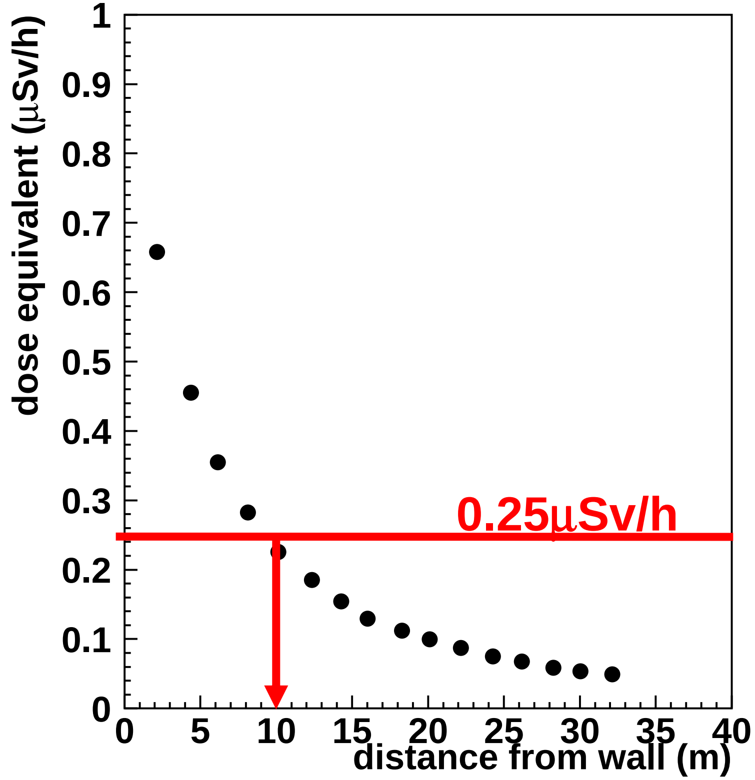
30 days operation and one day cooling



Determination of the control area boundary by MCNP

- **Neutron sources are defined on the floor, and the dose above the floor is adjusted to be 12.5μSv/h.**

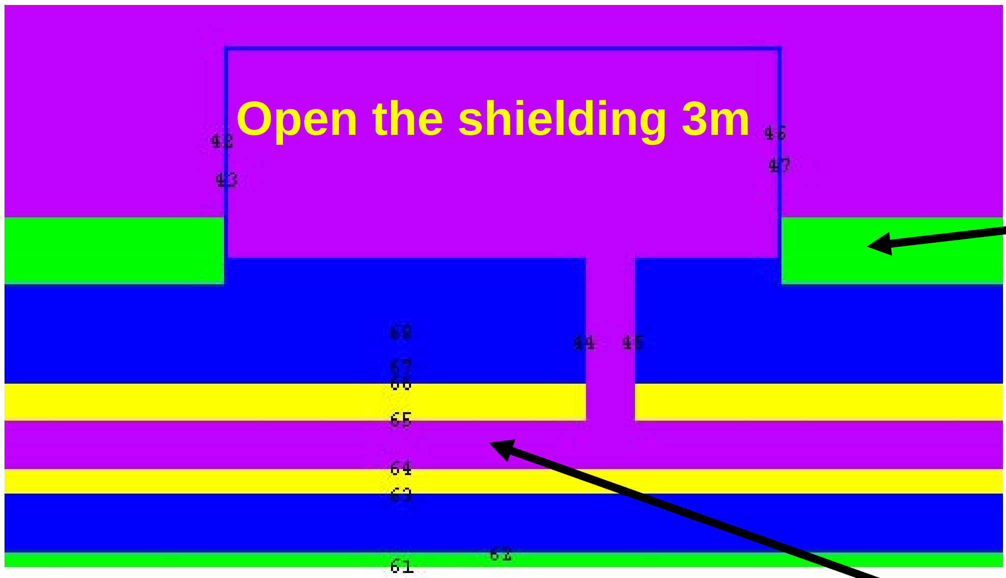




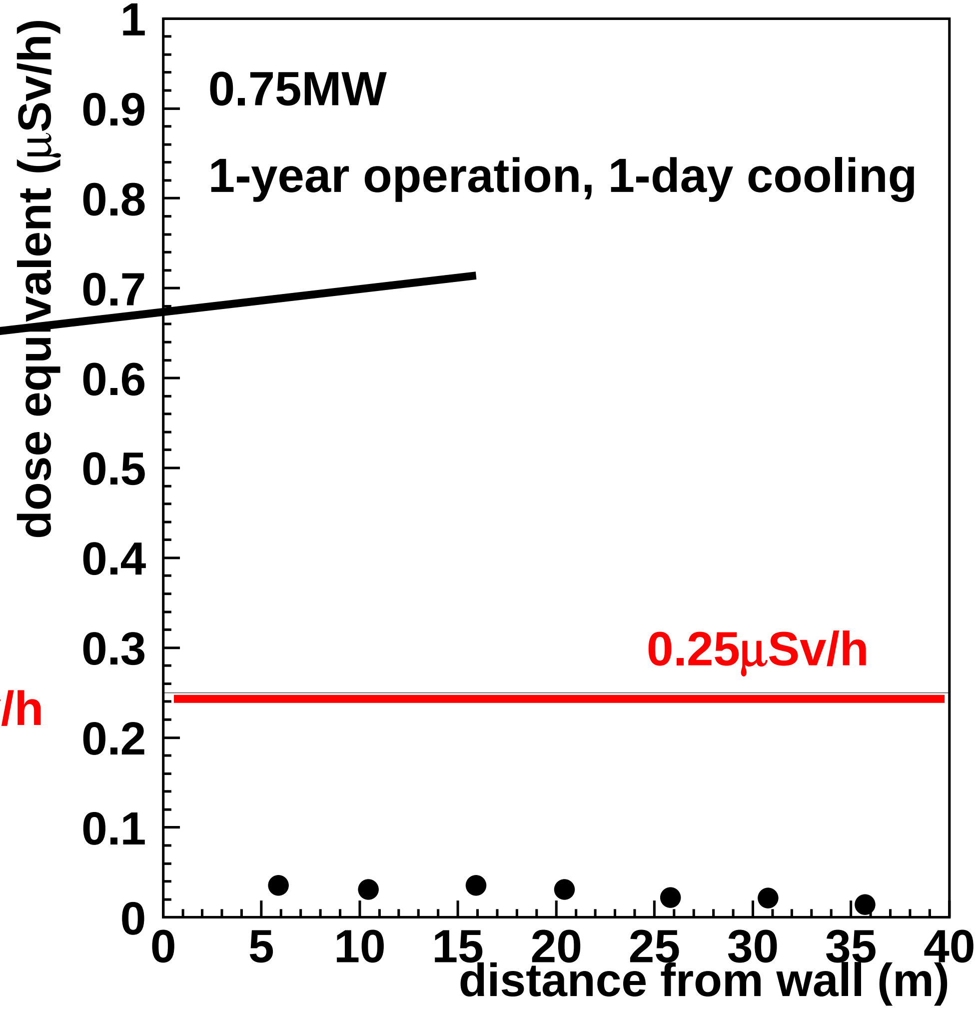
- **We need 10m between the surface building and the fence**

Requirement for the boundary during the maintenance

- MCNP is used. γ-ray source are defined on the Al tunnel surface.

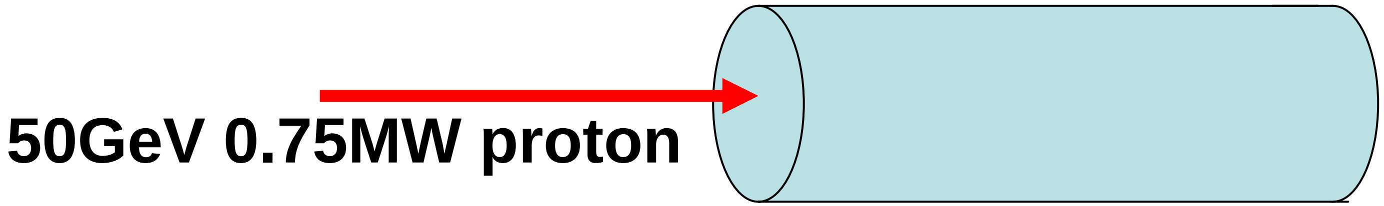


- Radiation from residual dose in the tunnel is satisfactory small.



Residual dose of the Target/Horn

- Residual dose of 3cmΦ x 90cm Carbon Graphite target (in a Al container) and 1st magnetic horn is calculated.



	Target	Target	Horn
	(1)(Sv/h)	(2)(Sv/h)	(1)(Sv/h)
1 day	16.9	18	18
1 month	11.6	12.3	3.9
1 year	0.148	0.16	2.8
5 year	8.3x10^{-10}	8.9x10^{-10}	------
10 year	------	------	0.25
20 year	------	------	1.7x10^{-5}

After 1 year operation

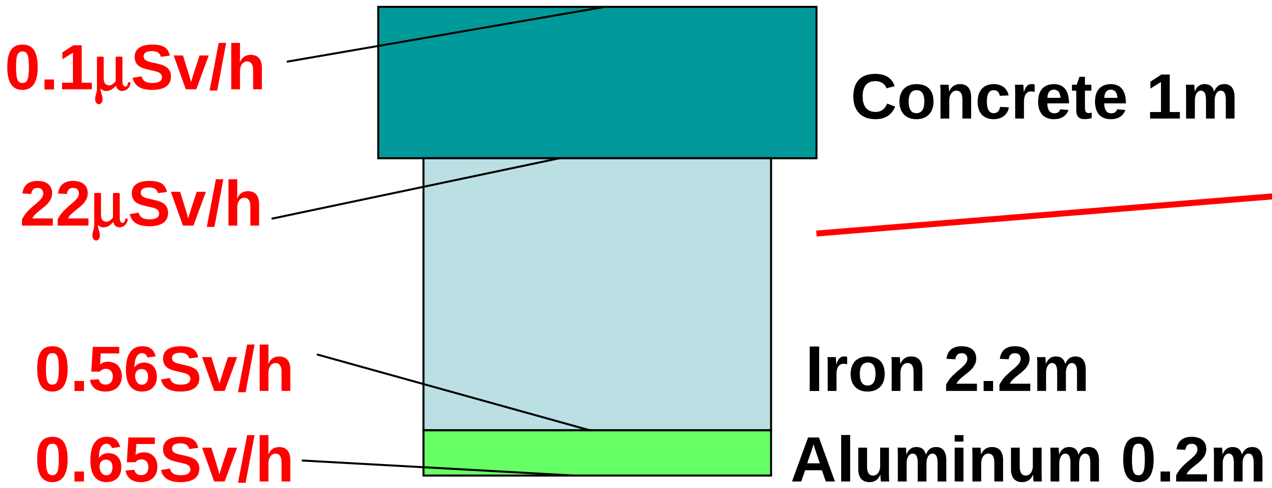
(1)NMTC/JAM(nmtclib95)
+ DCHAIN-SP
+ QAD-CGGP2

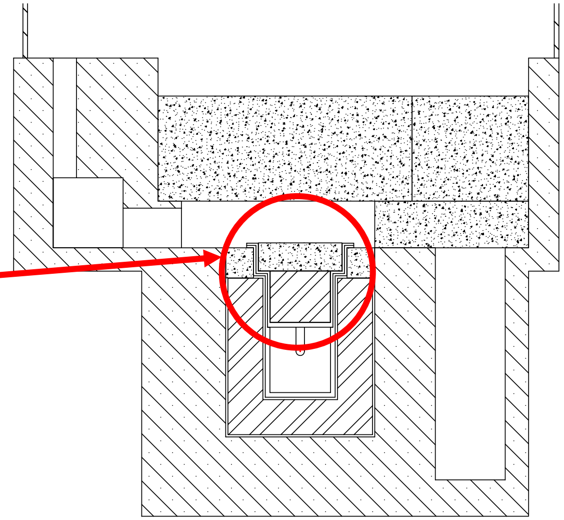
(2)Hadron fluence(MARS)
+ cross section(9mb)
+ ^{7}Be life

- Horn must be kept in the storage for more than 10 years.

Residual dose of the Shielding

- Residual dose of the shielding calculated by MARS (1 year operation, 1 day cooling, 0.75MW)



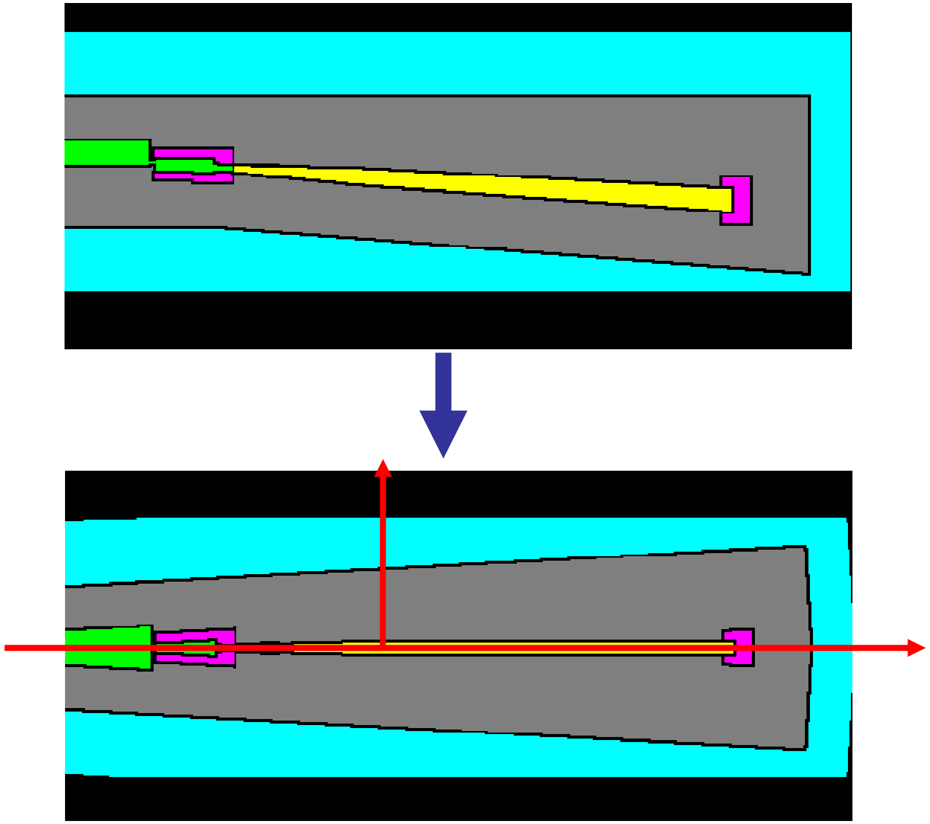


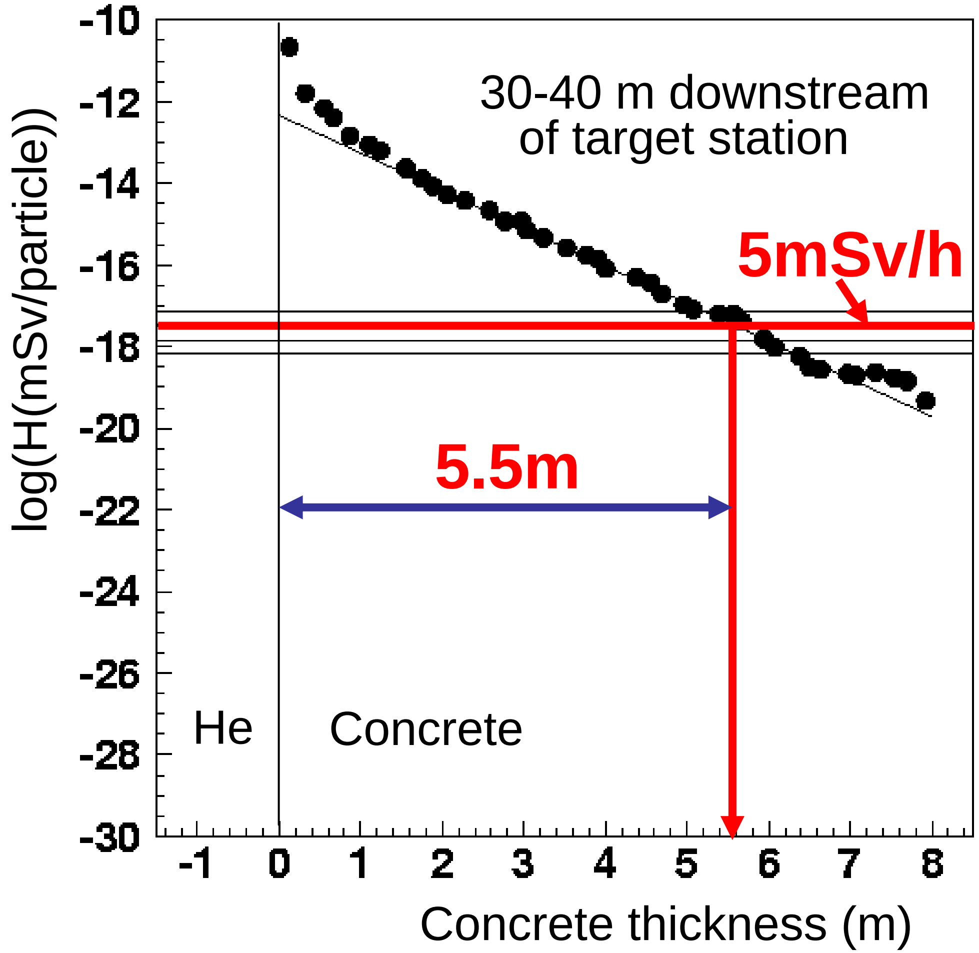
- Use of Al surface reduce the radiation about one order of magnitude.

- Further calculation is needed after the “scenario” is fixed.

Calculation of Decay Volume Shielding

- **As the target station, virtual cylindrical geometry is used in the MARS calculation.**





- **5.0～5.9m of concrete and additional ～6m of soil are needed to satisfy concrete and soil surface condition**

End