Radiation protection for K2K

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Boundary conditions for radiation protection

- Beam loss conditions in the fast extraction mode
  - Maximum beam power: 12 GeV, 3×10^{12} proton/s ~ 5.8 kW
  - Point loss: Q12 (3%), Target (80%), Dump (100%)
  - Line loss: 0.2% / 100 m ~ 0.12W/m
- Radiation limits
  - Dose rate in the area of "restricted access" < 20 μSv/hr
  - Dose rate at the boundary of "controlled area" < 1.5 μSv/hr
  - Dose rate at the KEK site boundary < 50 μSv/y
  - Activation of circulating air < 6×10^{-4} Bq/cc (^{15}O, ^{13}N, ^{11}C)
  - Activation of cooling water < 5×10^{-3} Bq/cc (^{3}H)
  - Surface radiation density < 4 Bq/cm^2

Evaluation of Radiation shield

- Moyer model --- Beam line
  - $H_m[\mu Sv/h]=H_0\ J\ \exp(-b\theta)/r^2\ \exp(-\Sigma d_i/\sin\theta/\lambda_i)$ (Point loss)
  - $H_m[\mu Sv/h]=H_0\ dJ/dL \int \exp(-b\theta)\ \exp(-l/\sin\theta)d\theta$ (Line loss)
    - $H_0 = 3.2\times10^{-4}[(\mu Sv/h)m^2/(GeV/s)]\times2$
    - J[GeV/s]=12[GeV] $\times3\times10^{12}$ [proton/s] $\times$(Loss rate)

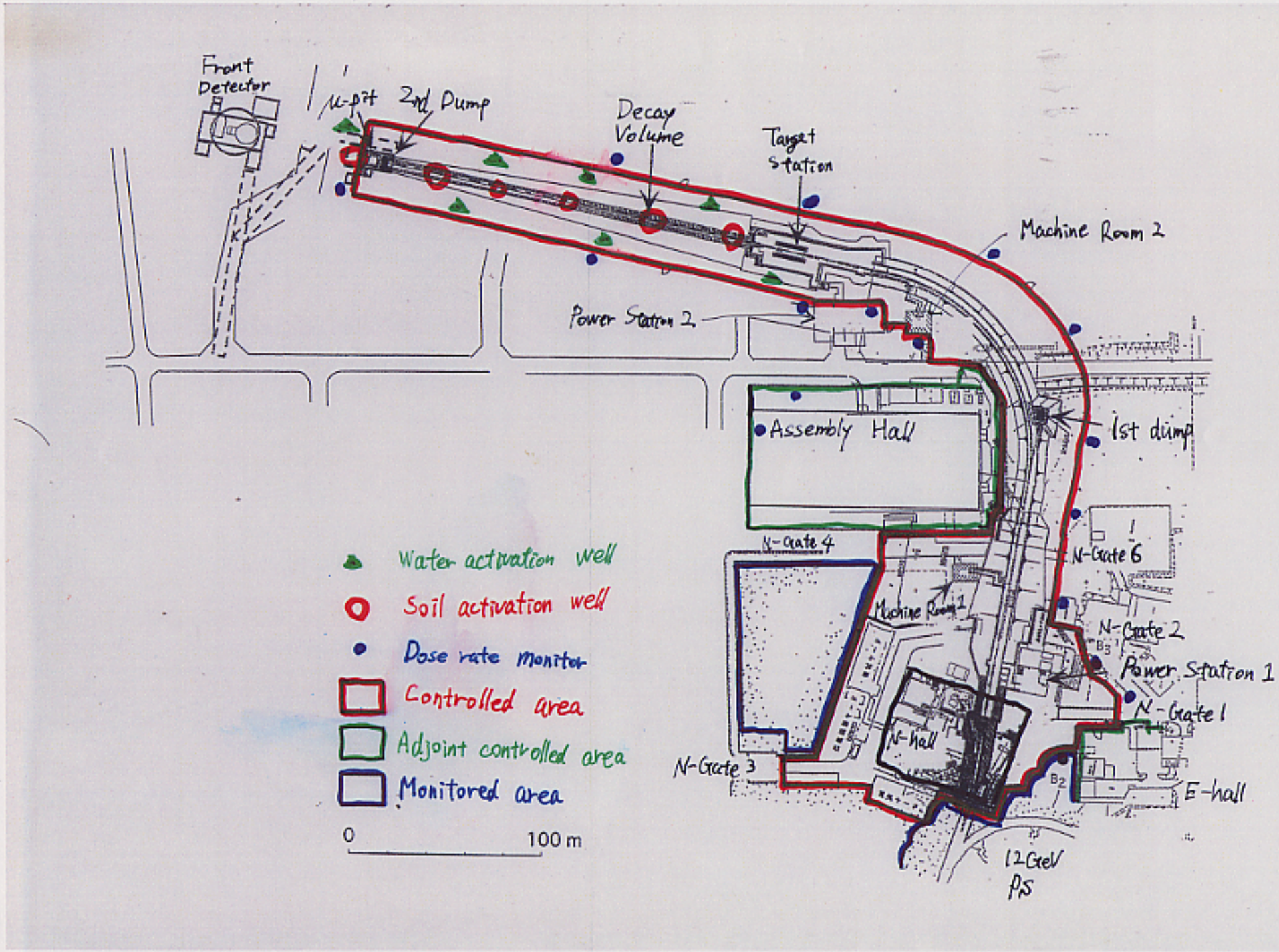
      λ_i= 139 [g/cm^2] : Soil (ρ=1.6 [g/cm^3])
      - = 143 [g/cm^2] : Normal concrete (ρ=2.3 [g/cm^3])
      - = 163 [g/cm^2] : Heavy concrete (ρ=3.5 [g/cm^3])
      - = 188 [g/cm^2] : Iron (ρ=7.2 [g/cm^3])
- Thomas-Stevenson model --- Beam dump
  - $H=2\times3\times1012[p/s]\ \exp(-\Sigma d_i/\lambda_i)\times3600$

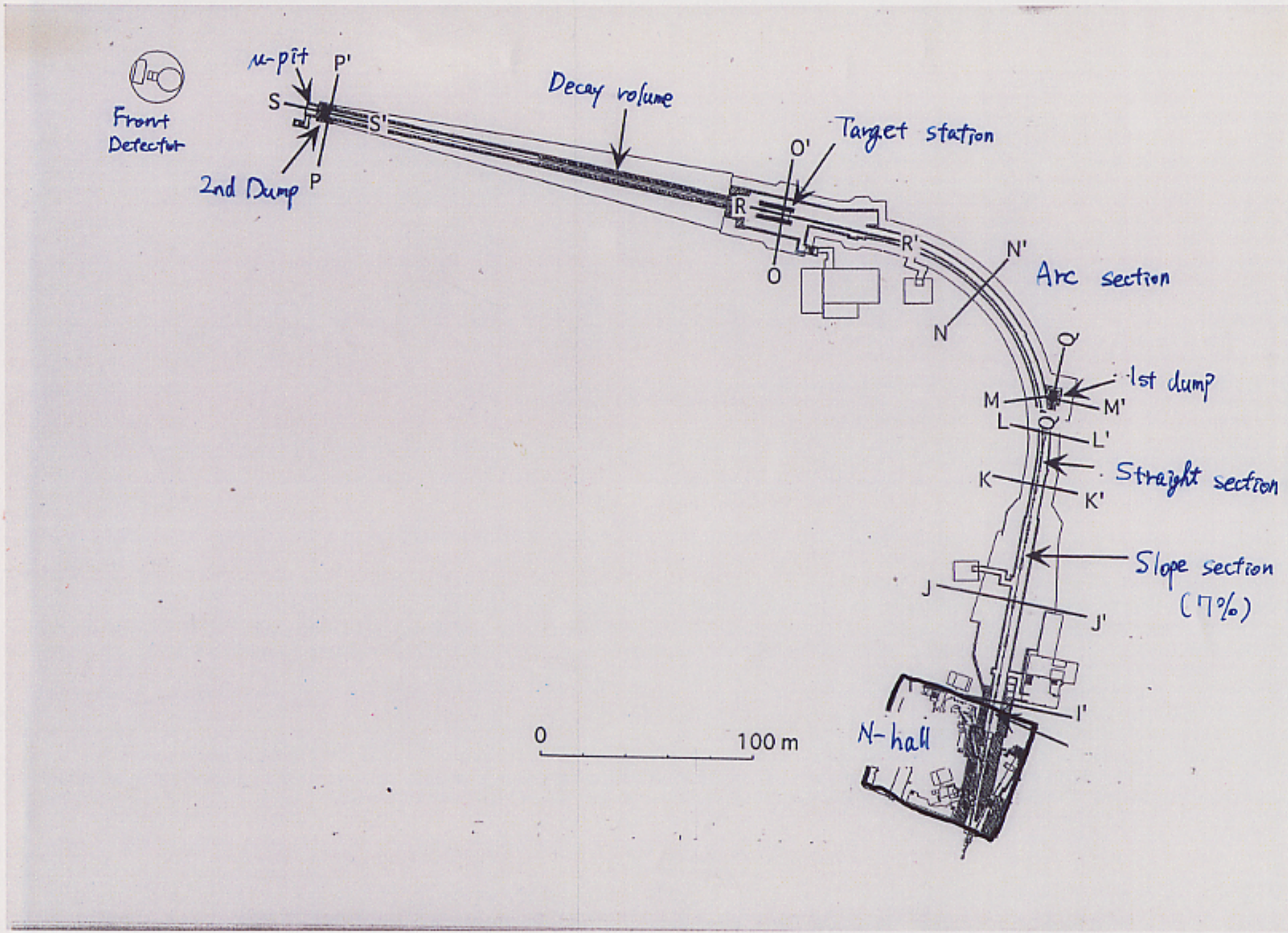
    λ_i= 117 [g/cm^2] : Normal concrete (ρ=2.40 [g/cm^3])
    - = 170 [g/cm^2] : Iron (ρ=7.88 [g/cm^3])
- MARS --- Target Station / Decay Volume

- Dumping factor in maze -- Path to outside buildings
  - $\eta = \Phi_n / \Phi_0 = \Pi\,(h_i\, w_i \times 1/3) / (2\pi\, l_i^2)\ \mathrm{cosec}\ \psi_i$ if $h_i\, w_i / 4 l_i^2 < 0.1$
    - h_i, w_i, l_i : Height, Width, Length of each section

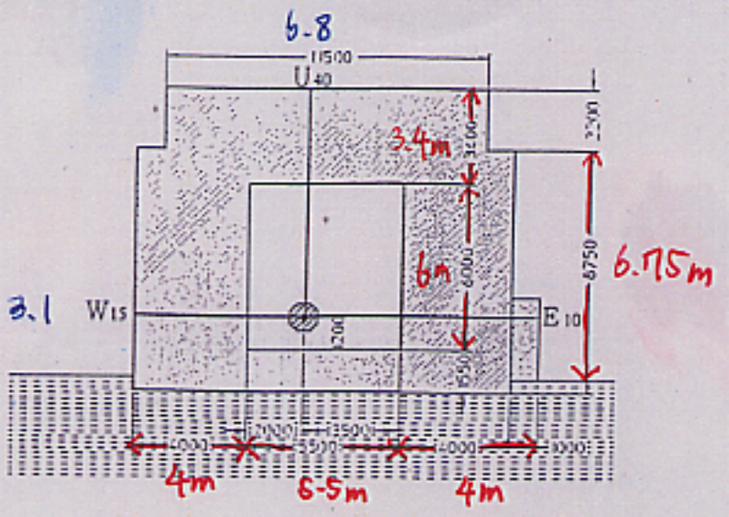
      Φ_n , Φ_0 : Neutron flux
  - Dose rate by thermal neutron : $H_n = \Phi_n / \alpha$
  - Dose rate by fast neutron : $H_o = H_i \times \eta$
- Sky-shine effect -- Site boundary
  - $H_{ss}\ [\mu Sv/h] = c \int Hs\ ds\ \exp(-R/\lambda_a) / (4\pi R^2)$
    - c : Build-up constant

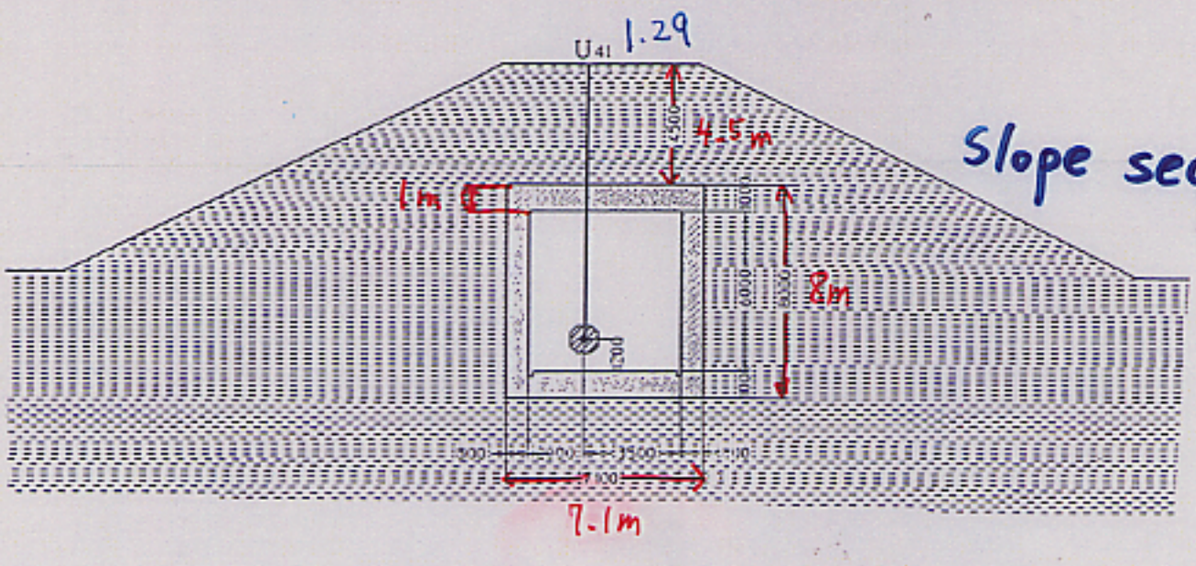
      λ_a : Mean free path in air (850 m)
    - $\int H_s\, ds = H_m\, \pi\, (r/2)^2$ for point loss
    - $\int H_s\, ds = H_m\, rL$ for Line loss


Front Detector
K-pit
2nd Pump
Decay Volume
Target Station
Machine Room 2
Power Station 2
Assembly Hall
1st dump
K-Gate 4
N-Gate 6
Machine Room 1
N-Gate 2
Power Station 1
N-Gate 1
N-hall
N-Gate 3
E-hall
12GeV PS
Water activation well
Soil activation well
Dose rate monitor
Controlled area
Adjoint controlled area
Monitored area
0
100 m

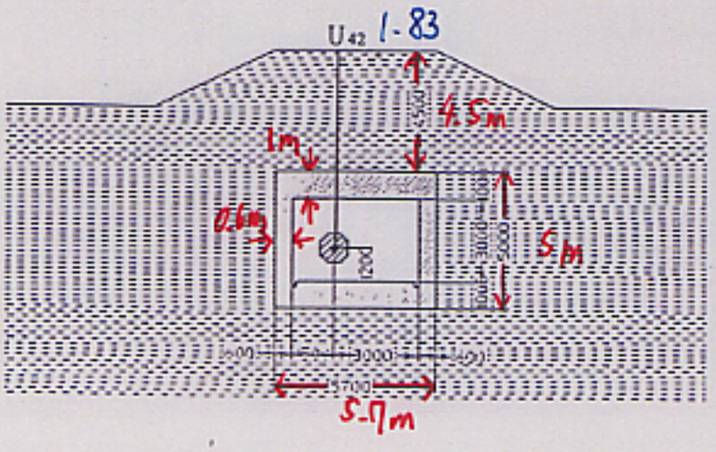

Front Detector
μ-pit
P'
S
S'
2nd Dump
P
Decay volume
O'
Target station
R
R'
O
N'
N
Arc section
Q'
1st dump
M
M'
L
Q
L'
K
Straight section
K'
Slope section
(7%)
J
J'
I'
N-hall
0
100 m

Unit : μSv/hr





Slope section

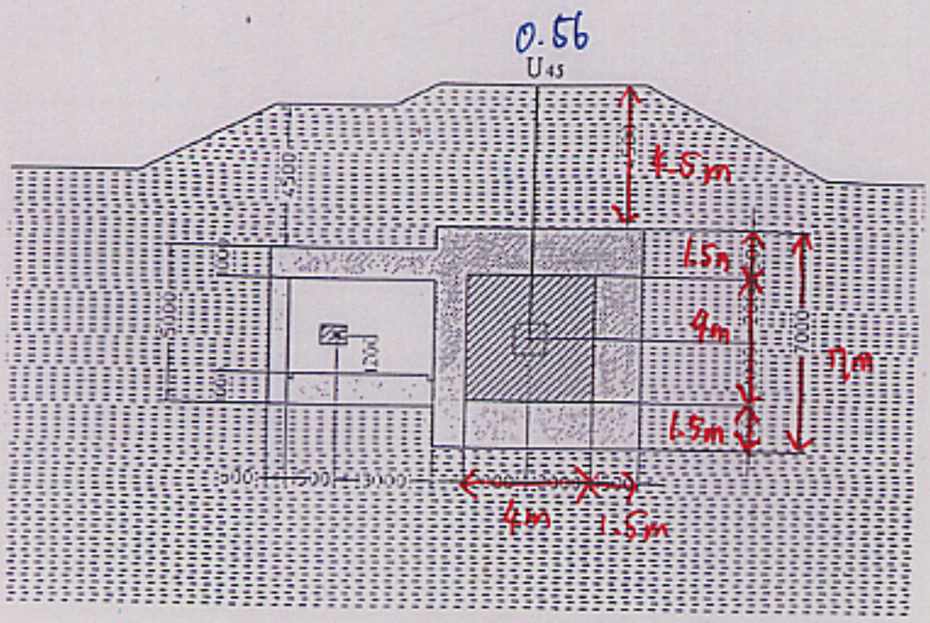


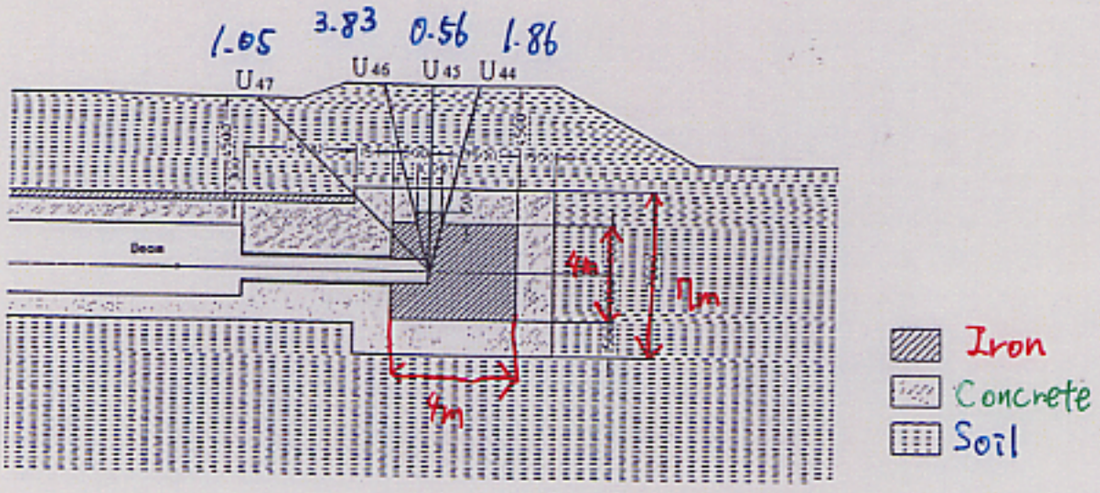
straight section

Iron
Concrete
Soil

1st dump

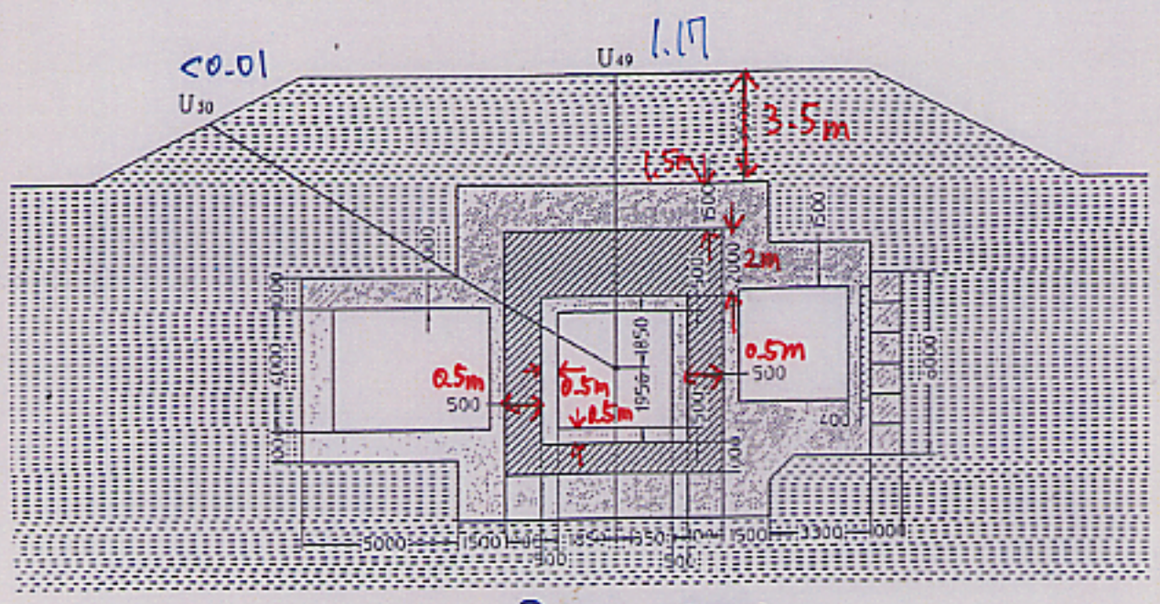
Unit : μSv/hr



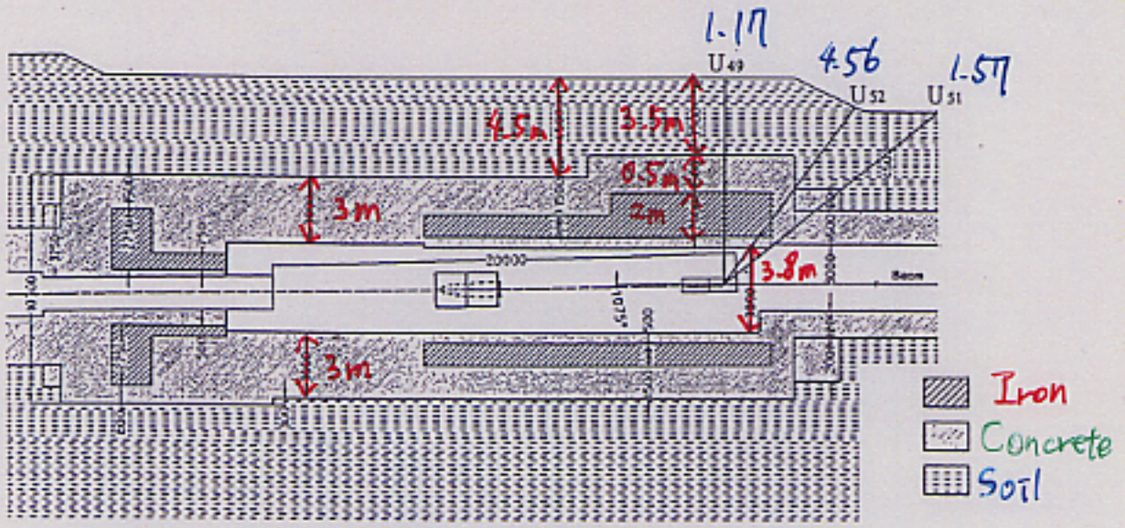


Target station

Unit : μSv/hr

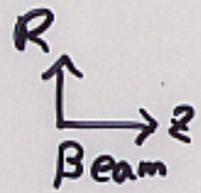


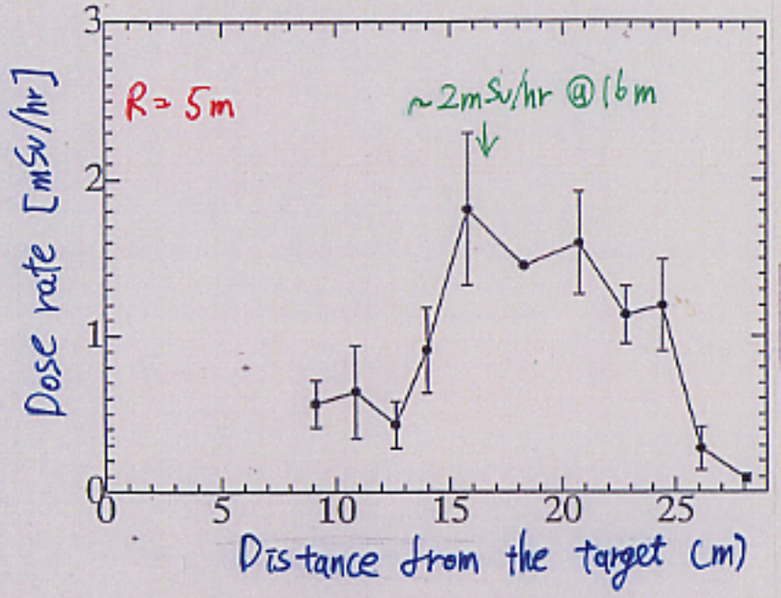
Beam view

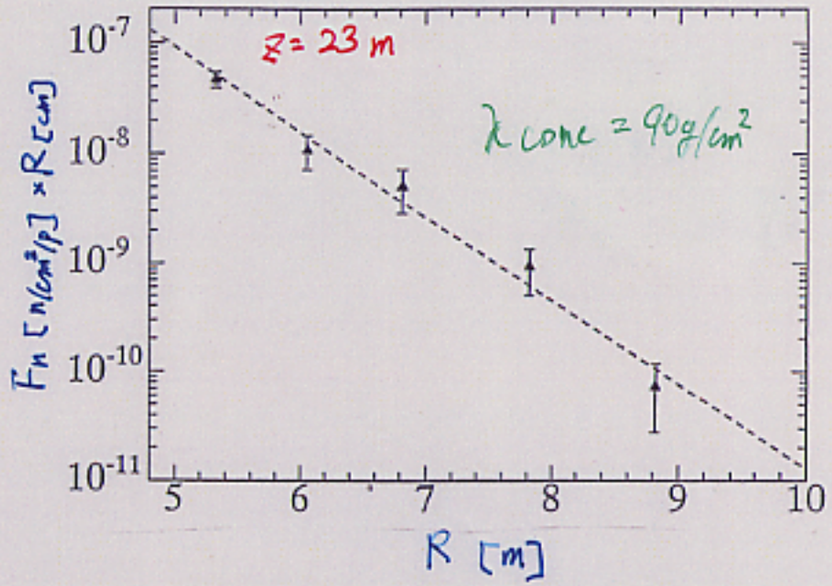


Side view

Dose rate evaluation at Target station by MARS

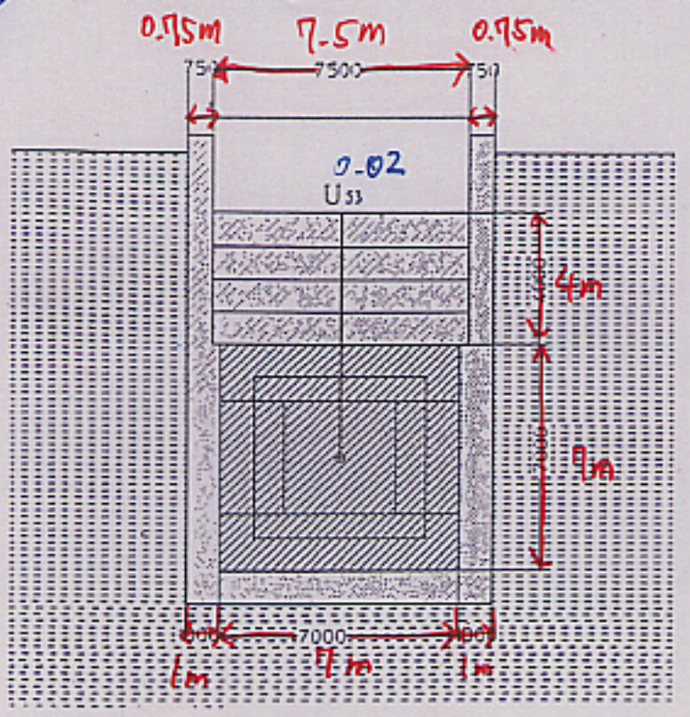


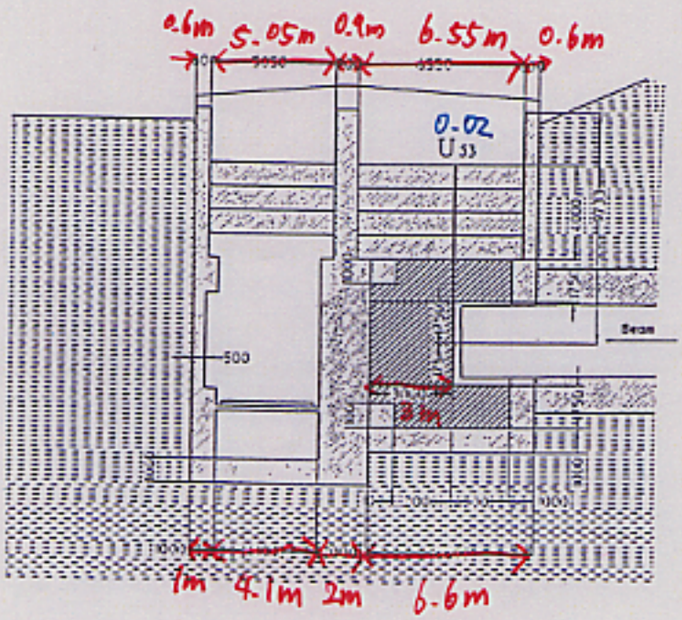




2nd Dump

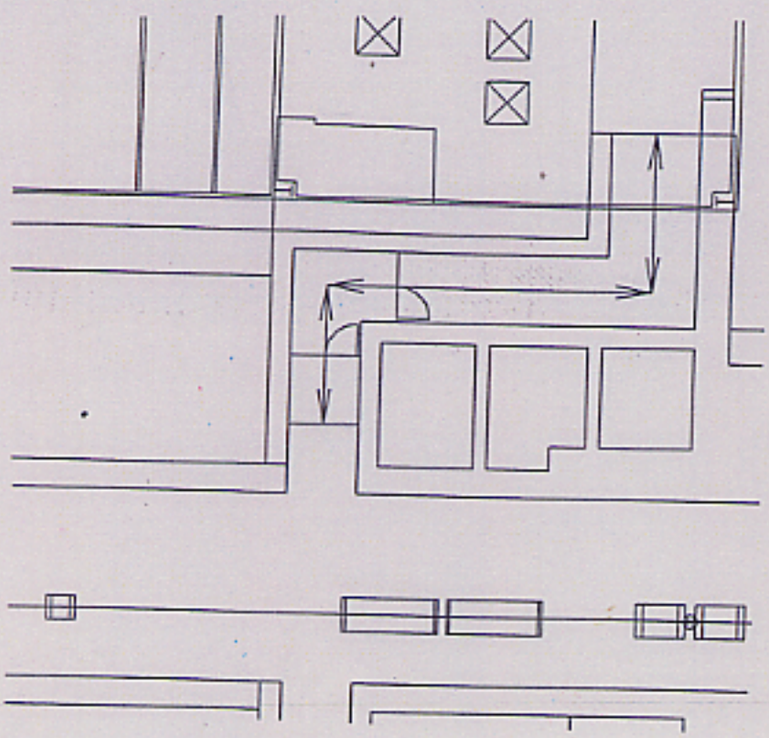
Unit : μSv/hr





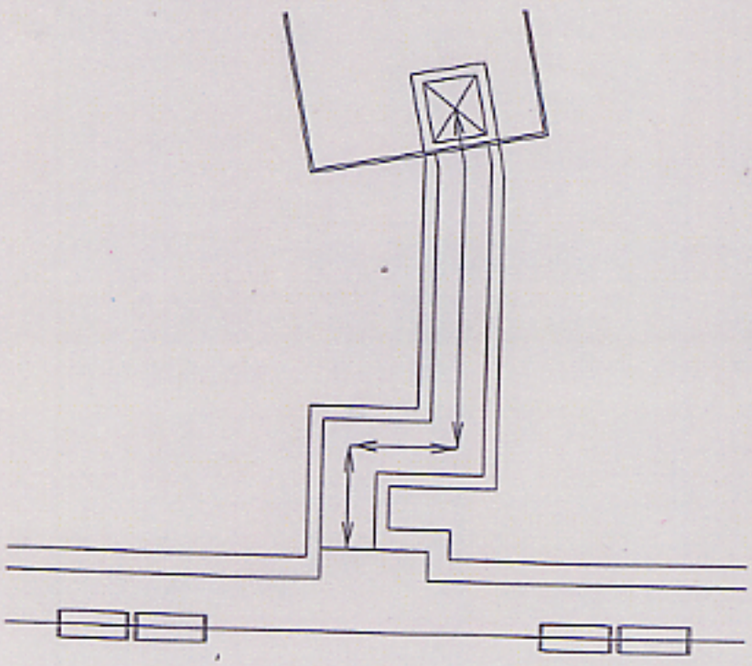
Iron
Concrete
Soil

Path to PS1



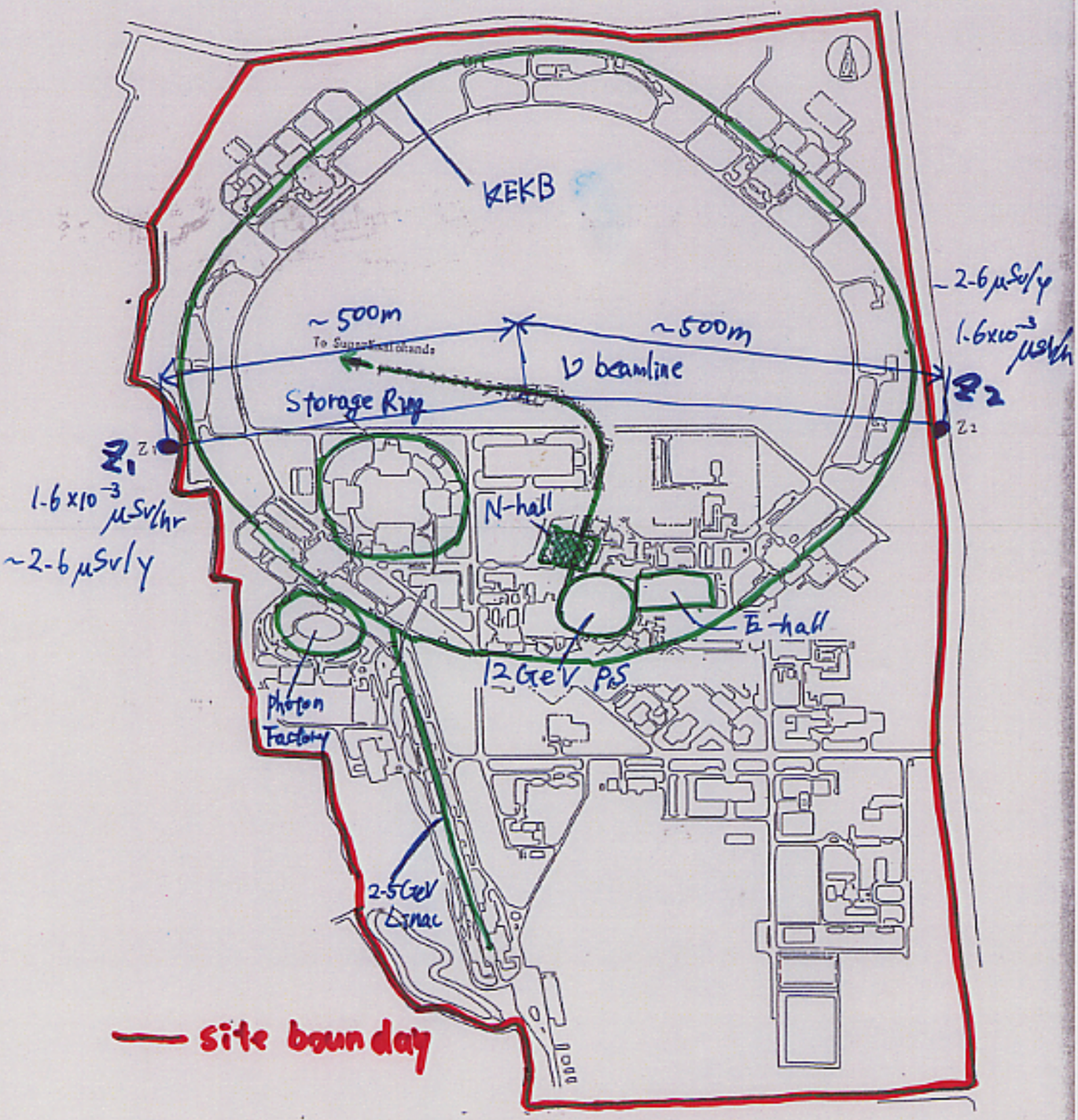
L_1=400[cm]
L_2=915
L_3=450
H =250
W =250
$\eta = 1.34 \times 10^{-6}$

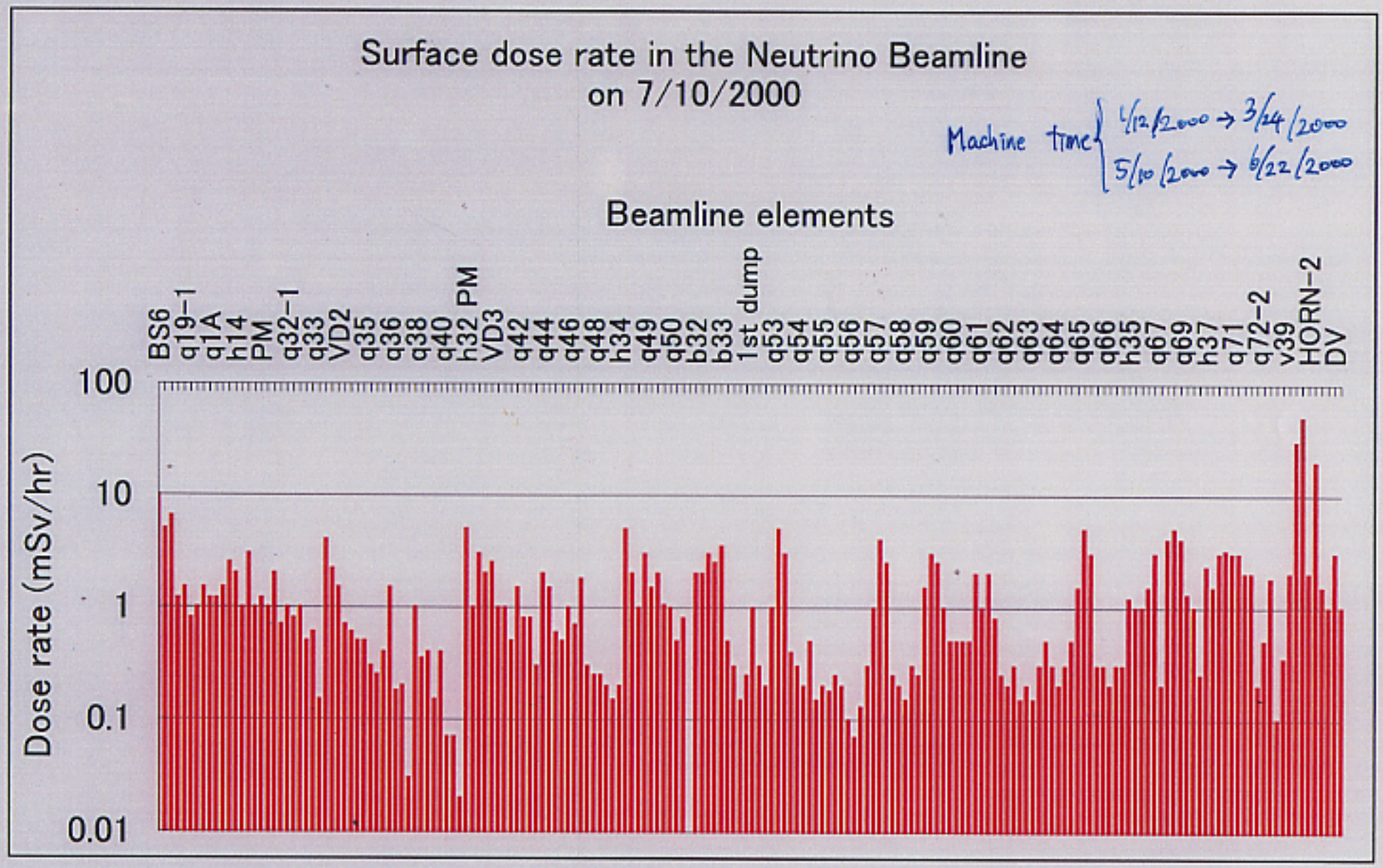
Path to MN1



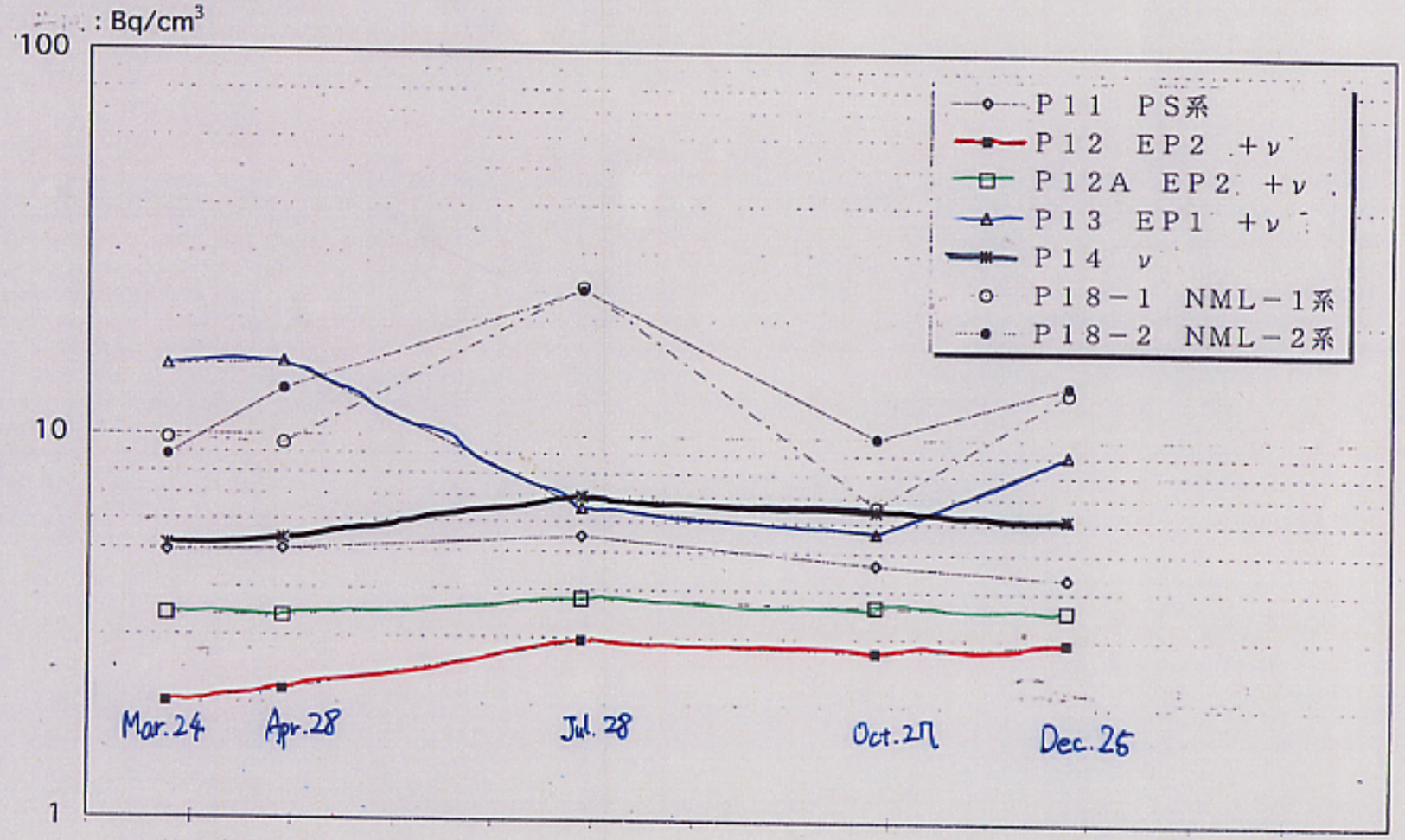
L_1=400[cm]
L_2=400
L_3=1318
L_4=483
H =250
W =200
$\eta = 4.77 \times 10^{-9}$

KEK site boundary




Surface dose rate in the Neutrino Beamline
on 7/10/2000
Machine time
4/12/2000 → 3/24/2000
5/10/2000 → 6/22/2000
Beamline elements
BS6
q19-1
q1A
h14
PM
q32-1
q33
VD2
q35
q36
q38
q40
h32 PM
VD3
q42
q44
q46
q48
h34
q49
q50
b32
b33
1st dump
q53
q54
q55
q56
q57
q58
q59
q60
q61
q62
q63
q64
q65
q66
h35
q67
q69
h37
q71
q72-2
v39
HORN-2
DV
Dose rate (mSv/hr)
100
10
1
0.1
0.01

^3H density in cooling water -- Year 2000



Concluding remarks

- Neutrino beam line for K2K experiment has been safely operated since 1999 without any serious trouble about radiation safety.
- Empirical formulae and monte-carlo calculation work nicely for design of radiation protection.
- Radiation protection in the future JHF-ν project would be the vital part in the design and construction of the facility.