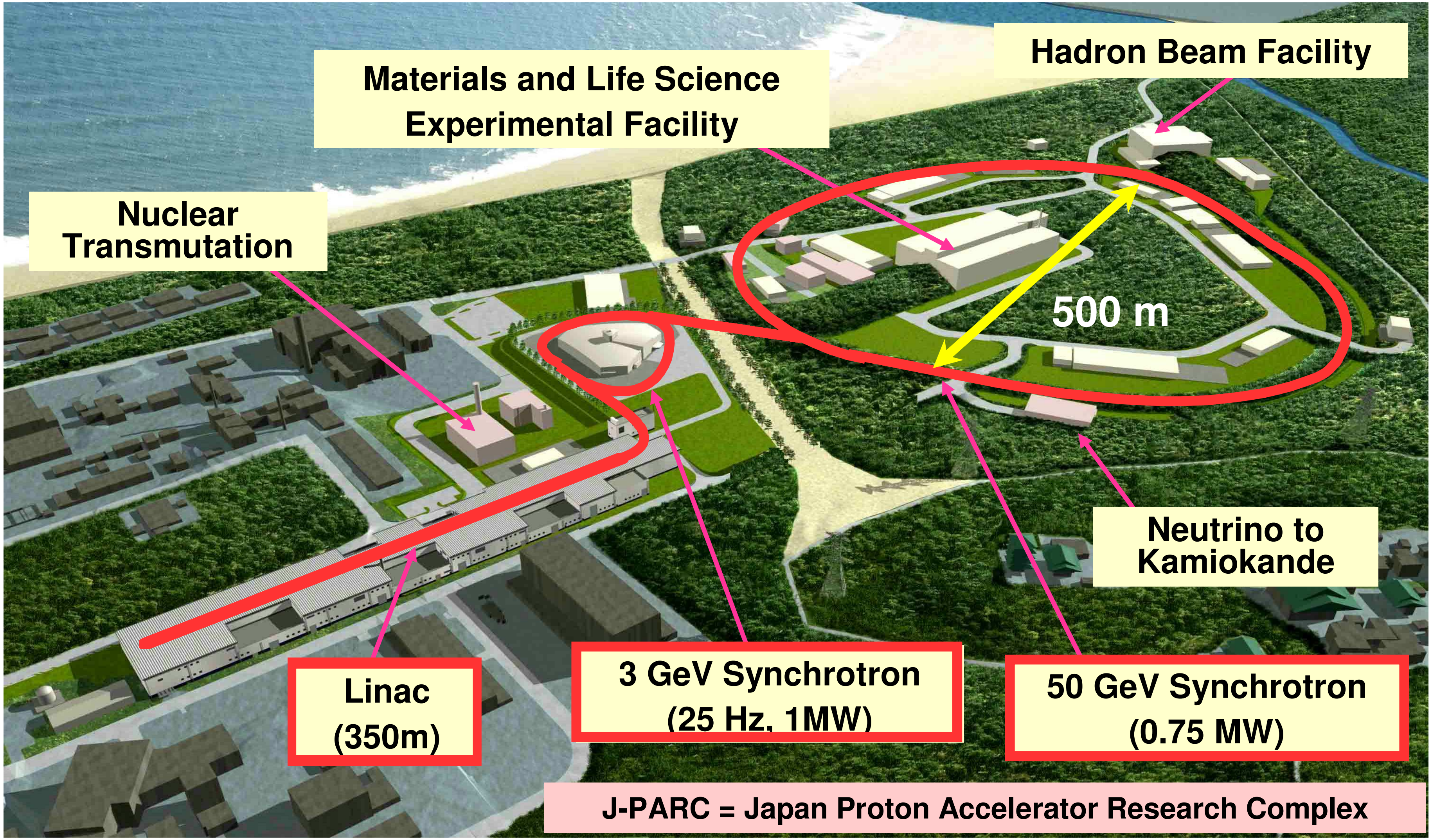
October 12, 2006
EURISOL

Radiological Safety for the J-PARC Project

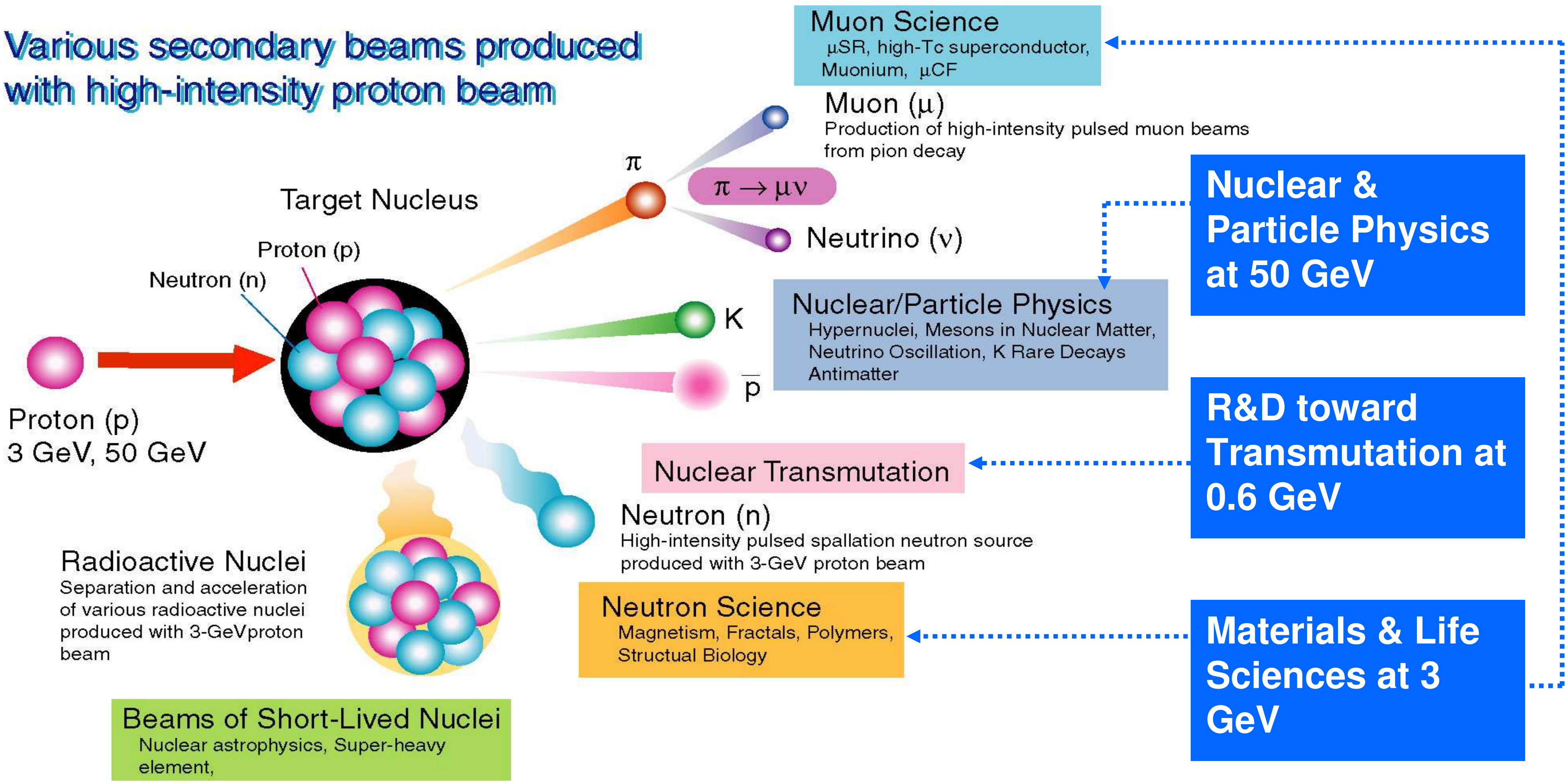
Hiroshi Nakashima
J-PARC

J-PARC Facility



Joint Project between KEK and JAERI

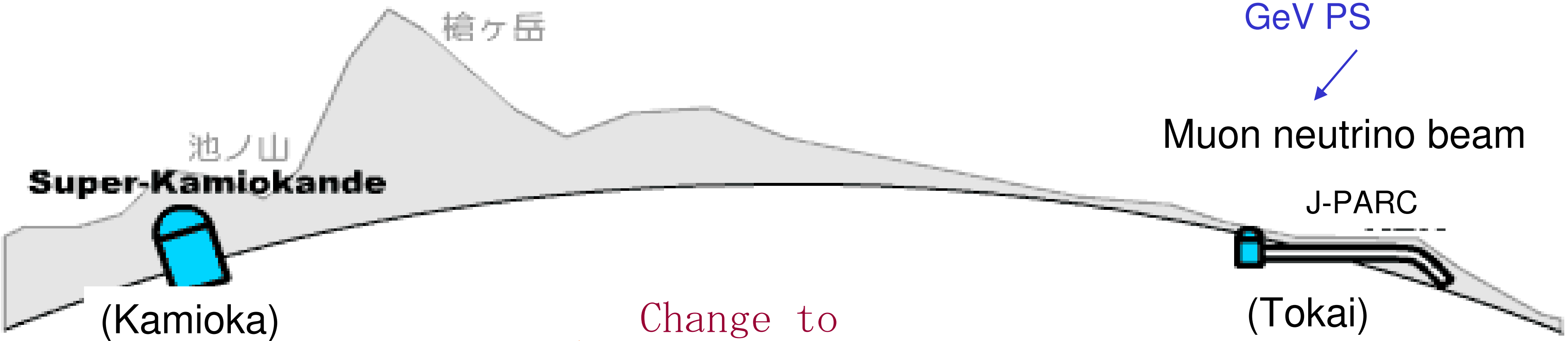
Secondary particles from high energy proton reaction



T2K Experiment

T2K = Tokai to Kamioka

Intense neutrino beam by 100 times at KEK 12 GeV PS



ν_τ ← Change to ← ν_μ

ν_e ← Change to ← ν_μ

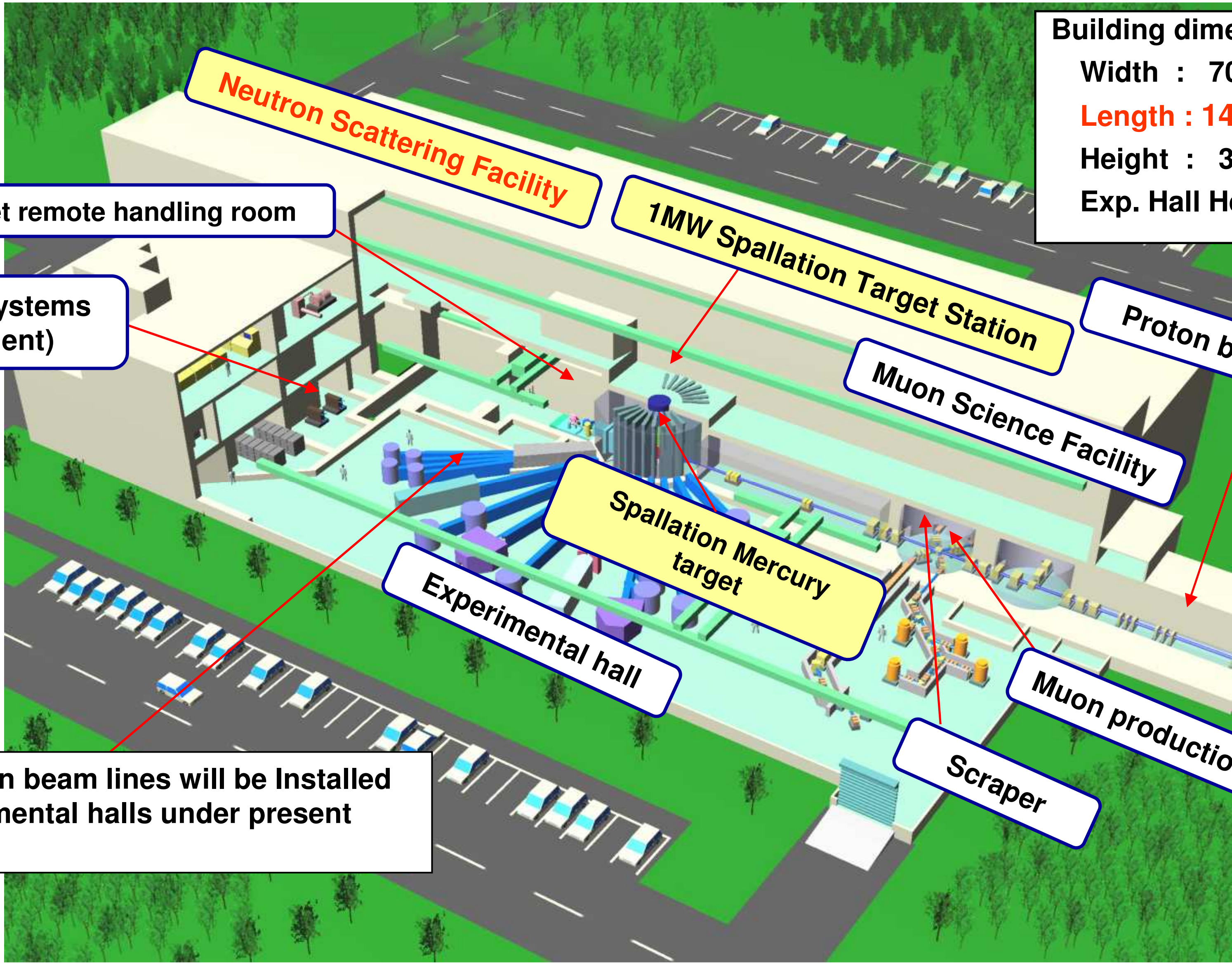
Disappearance of ν_μ ↔ High Statistics T2K

（Five year data at KEK-PS can be measured within a few weeks at J-PARC ）

Detection of ν_e at Super Kamiokande ↔ Totally new experiment

Materials and Life Science Experimental Facility

Neutron and Muon

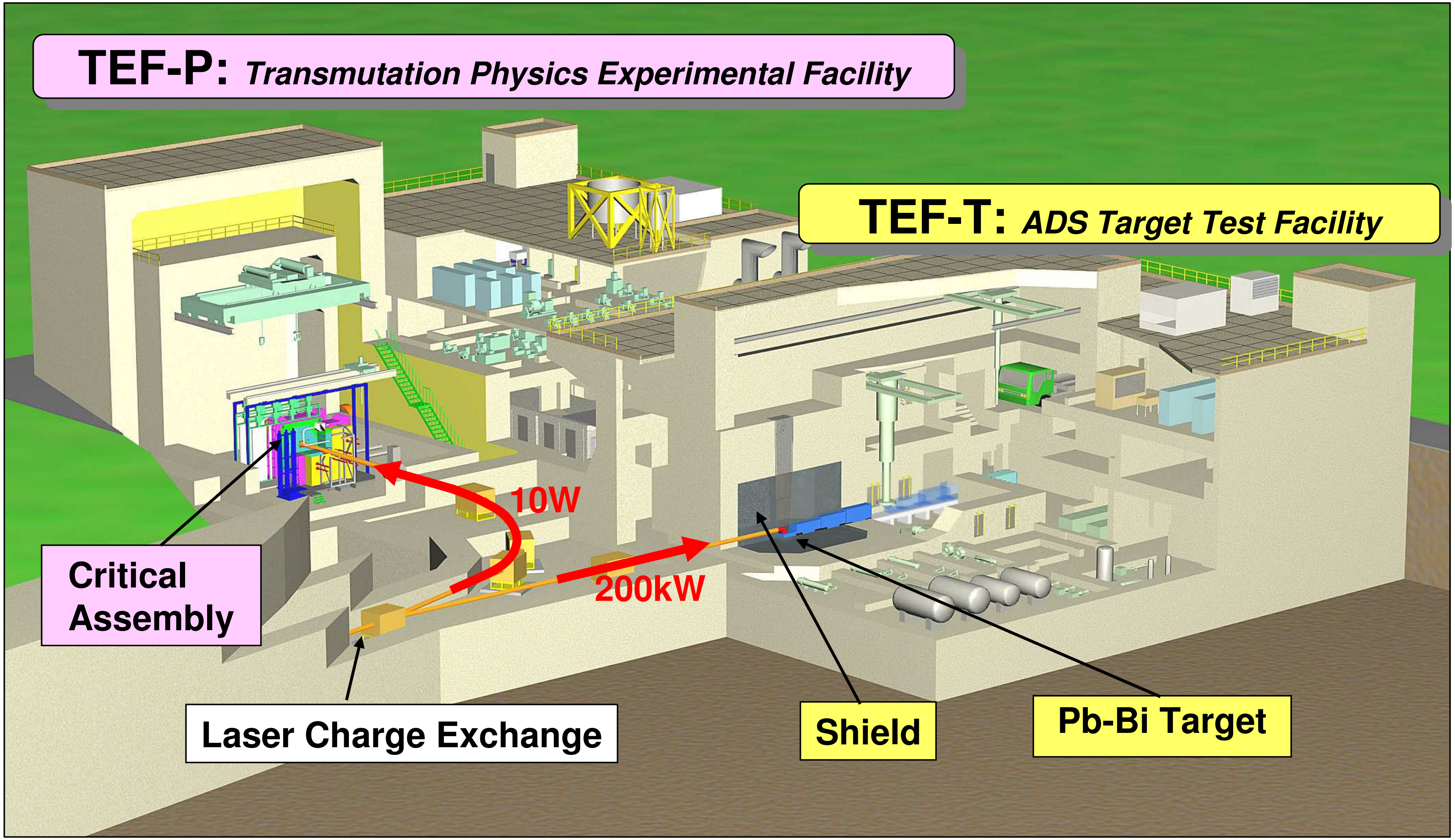


Building dimension :
Width : 70m
Length : 146m
Height : 30m
Exp. Hall Height : 22m

3GeV, 1MW proton beam

23 neutron beam lines will be Installed in experimental halls under present design.

Transmutation Experimental Facilities



Characteristics of J-PARC from the view point of safety

- **Characteristics**
  - High beam power (up to 1MW)
  - High beam energy (up to 50GeV)
  - Large-scale accelerator complex (about 3.2 km in length)

- **Radiation problems**
  - Widely distributed radiation source
  - Thick shield
  - Activation

  etc…

Safety issues

- Design method is basically simplified method,
  Detailed method for complicated geometry.(1)
- Confinement of activated air during operation. (2)
  Ventilation after cooling-down.
- Closed cycle for cooling water and mercury.
  Release after measuring T activity.
- Underground(3)
  Design criteria for soil should have been decided.
- Target issues(4)
  Nuclear heating, Activation, Radiation damage, Pressure wave

Design Criteria

- Controlled Area: 12.5μSv/h

  1/2 of regulation (1mSv/40h:1week)
- In-site： 0.25μSv/h

  1/2 of regulation (250μSv/500h:3 months）
- Site boundary Radiation: 50μSv/ year

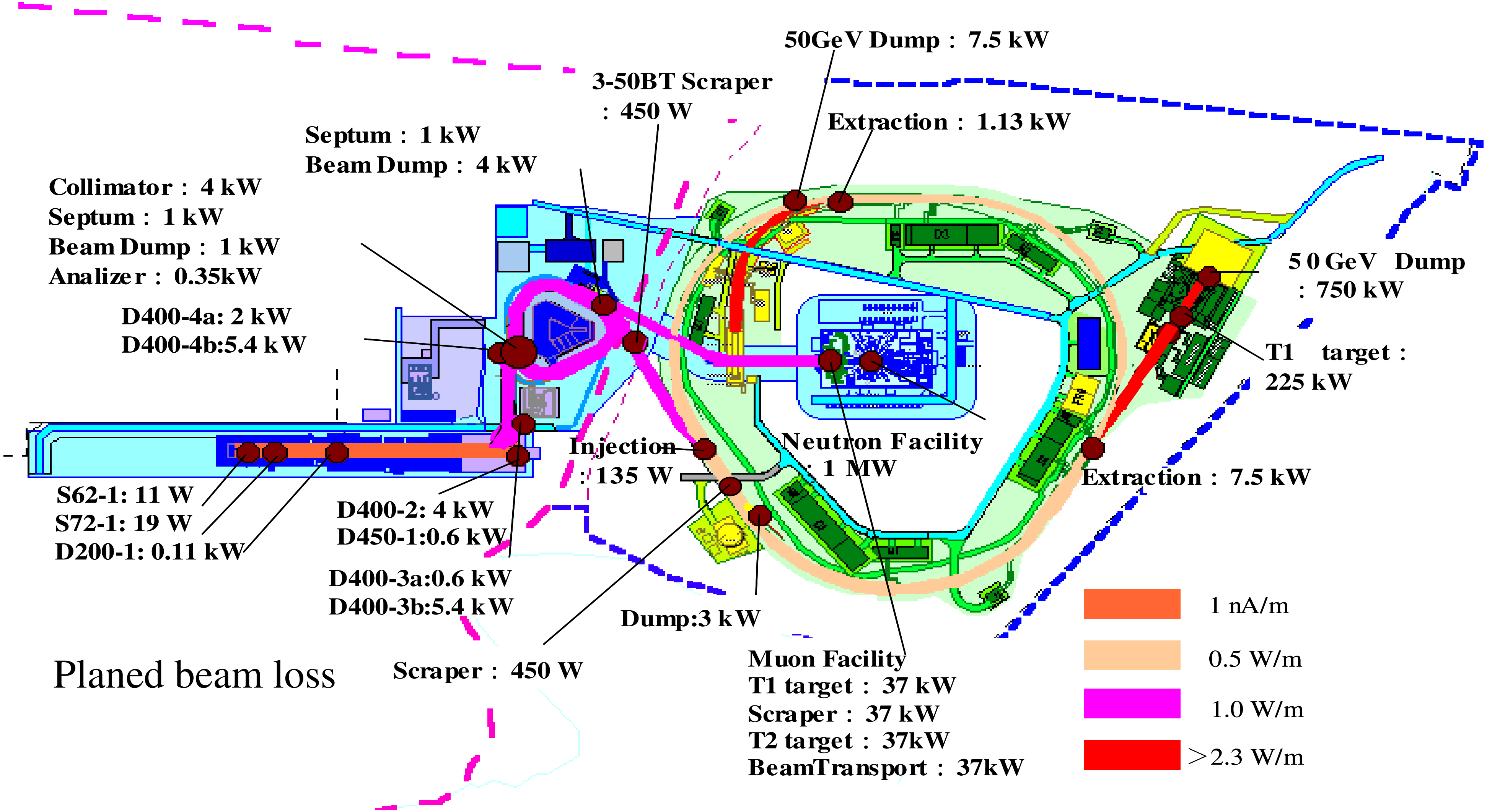
  1/20 of regulation (1mSv/year ）
- Gasious waste: Regulation

  Concentration and total amount by government and local government
- Liquid waste: Regulation

  Concentration and total amount by government and local government
- Soil activation: 5mSv/h

  No regulation.

Assumption of beam loss distribution



Planed beam loss

Criteria of hands on maintenance

(1)

- Simplified methods

  For bulk shielding

  ・ Moyer model (KEK parameter: H_0, λ)[$\geq$1GeV]

  ・Tesch's equation[<1GeV]

  For streaming

  ・Nakamura/Uwamino's equation

  ・DUCT-III（Shin's equation)

  For skyshine

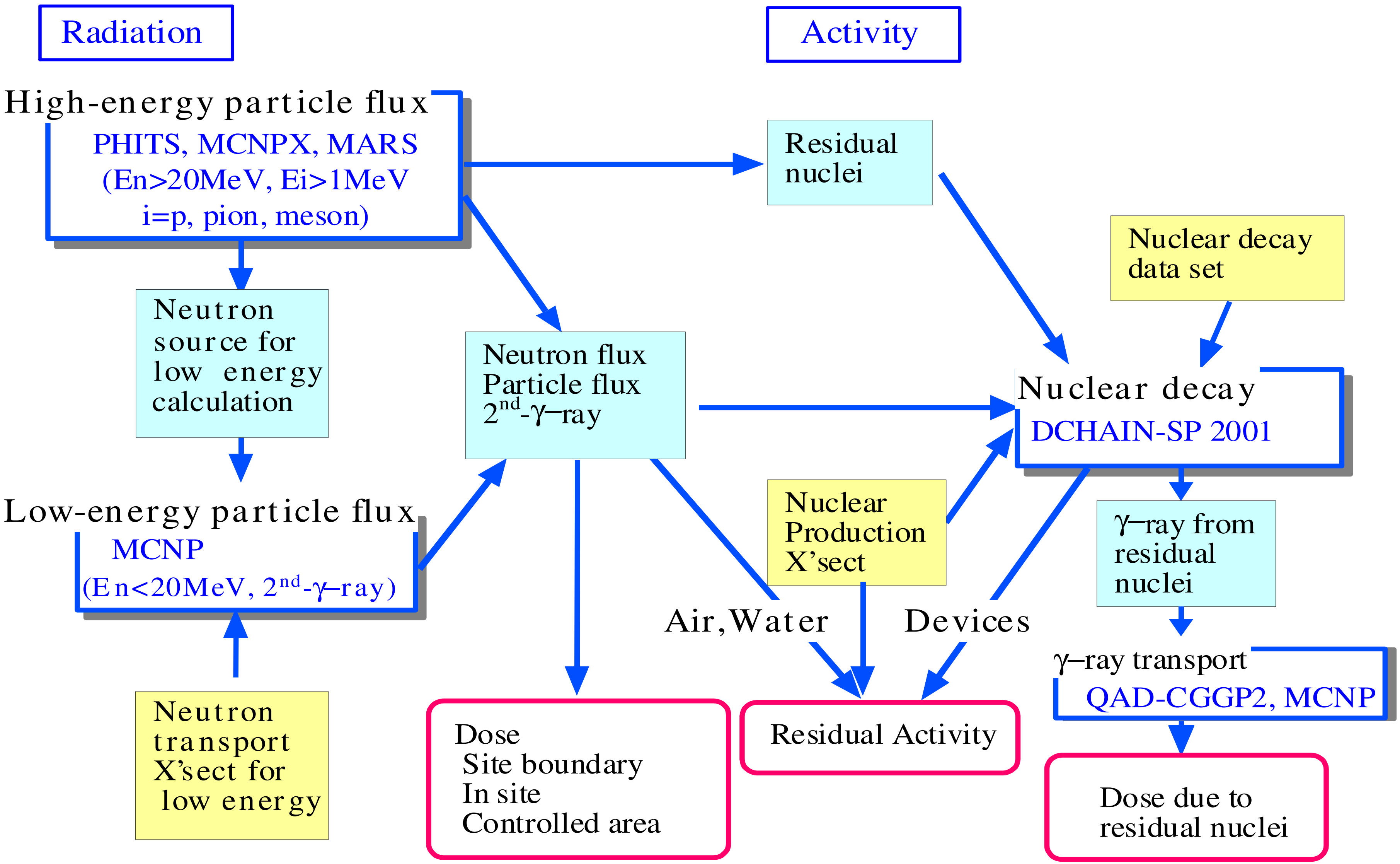
  ・Stapleton's equation

- Monte-Carlo codes

  ・PHITS, MARS, MCNPX

- Parameters

  ・Dose conversion factor

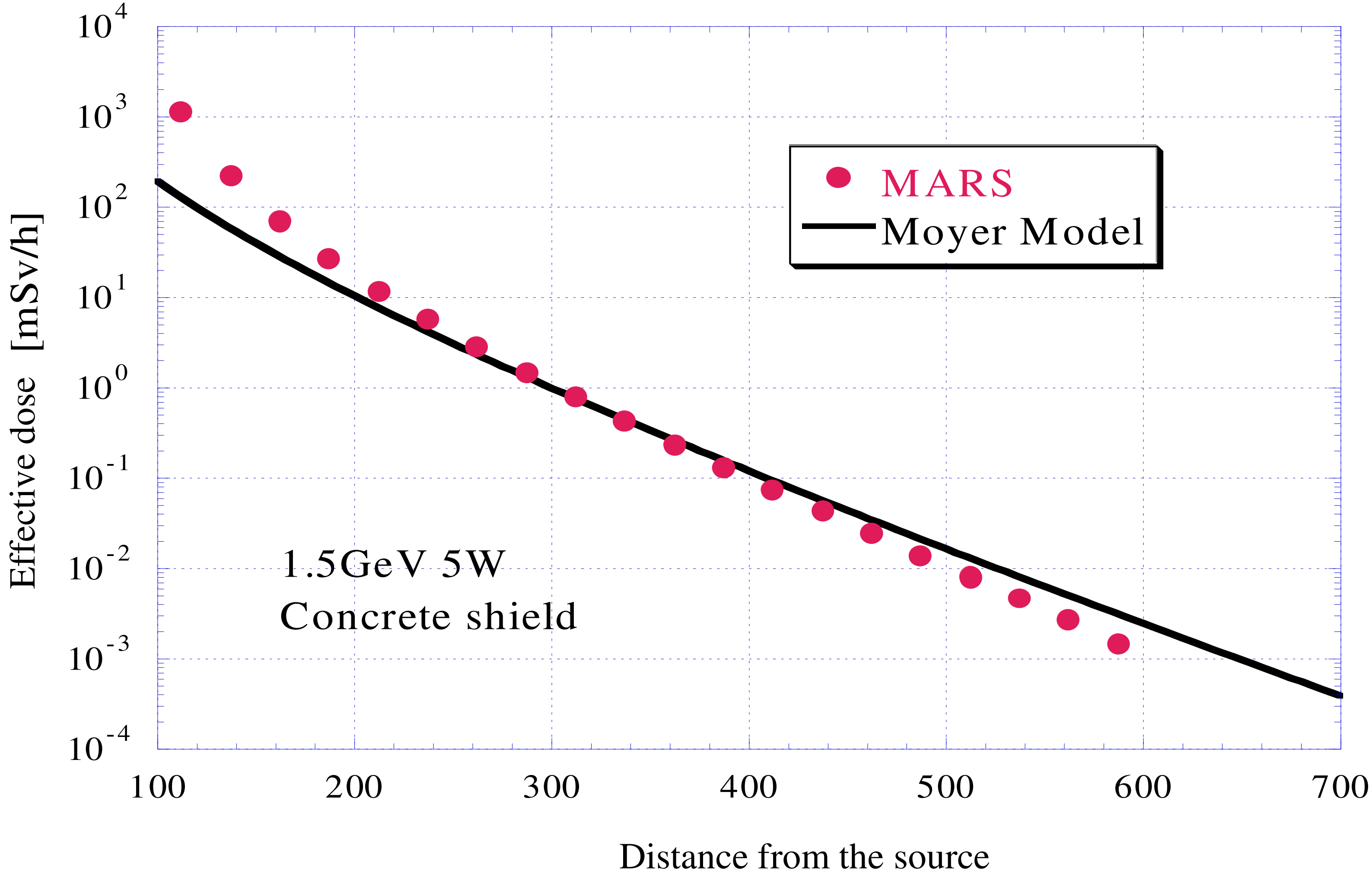


Radiation
Activity
High-energy particle flux
PHITS, MCNPX, MARS
(En>20MeV, Ei>1MeV
i=p, pion, meson)
Residual nuclei
Nuclear decay data set
Neutron source for low energy calculation
Neutron flux
Particle flux
2nd-γ–ray
Nuclear decay
DCHAIN-SP 2001
Low-energy particle flux
MCNP
(En<20MeV, 2nd-γ–ray)
Nuclear Production X'sect
γ–ray from residual nuclei
Air,Water
Devices
γ–ray transport
QAD-CGGP2, MCNP
Neutron transport X'sect for low energy
Dose
Site boundary
In site
Controlled area
Residual Activity
Dose due to residual nuclei

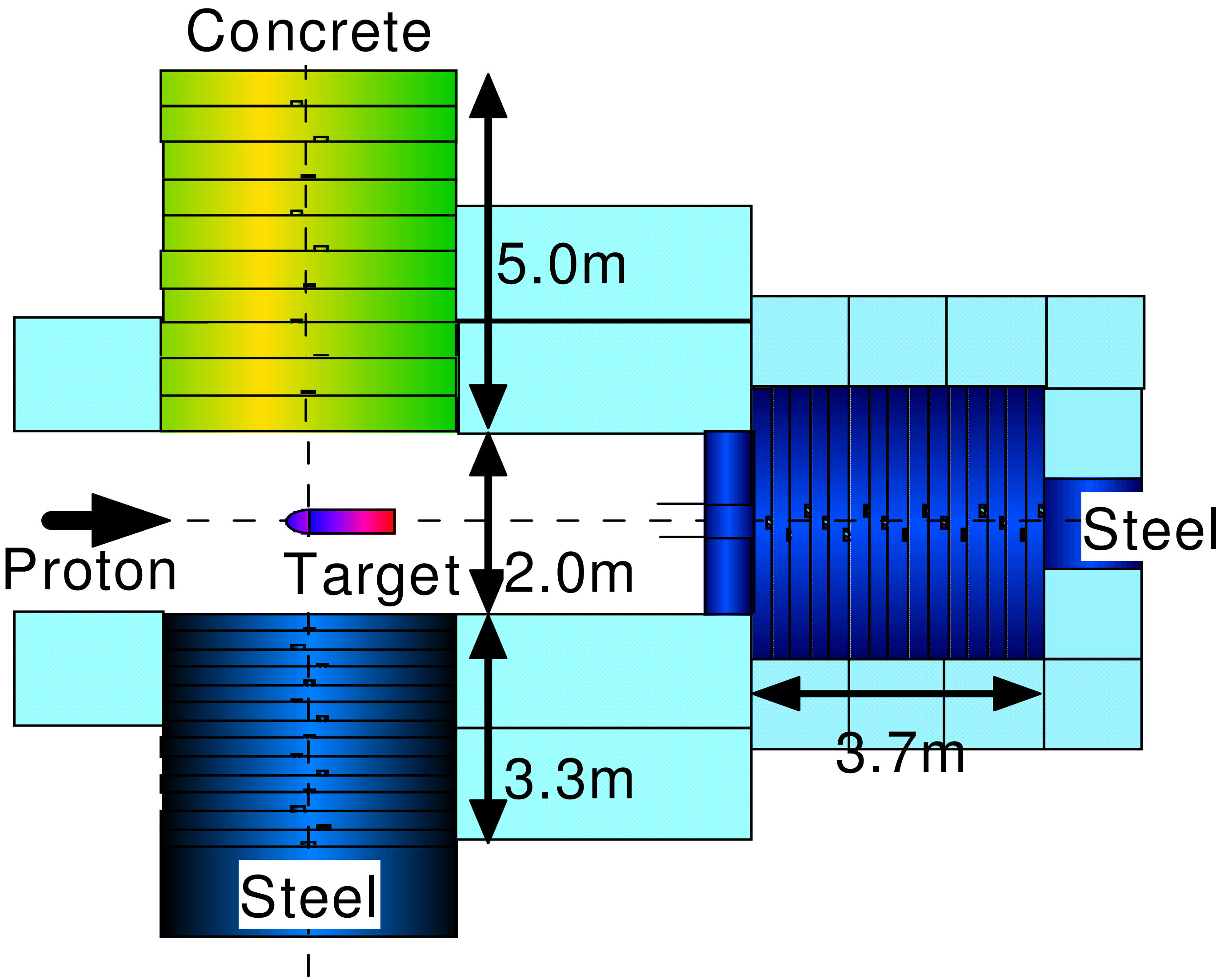
Benchmark analyses

- Thick Target neutron Yield (TTY)
  LANL, KEK, etc.
- Beam dump
  KEK, BNL/AGS
- Deep penetration
  TIARA, BNL/AGS
- Streaming
  TIARA, NIMROD, KEK
- Skyshine
  comparison

Comparison of neutron attenuation between simplified and detailed methods



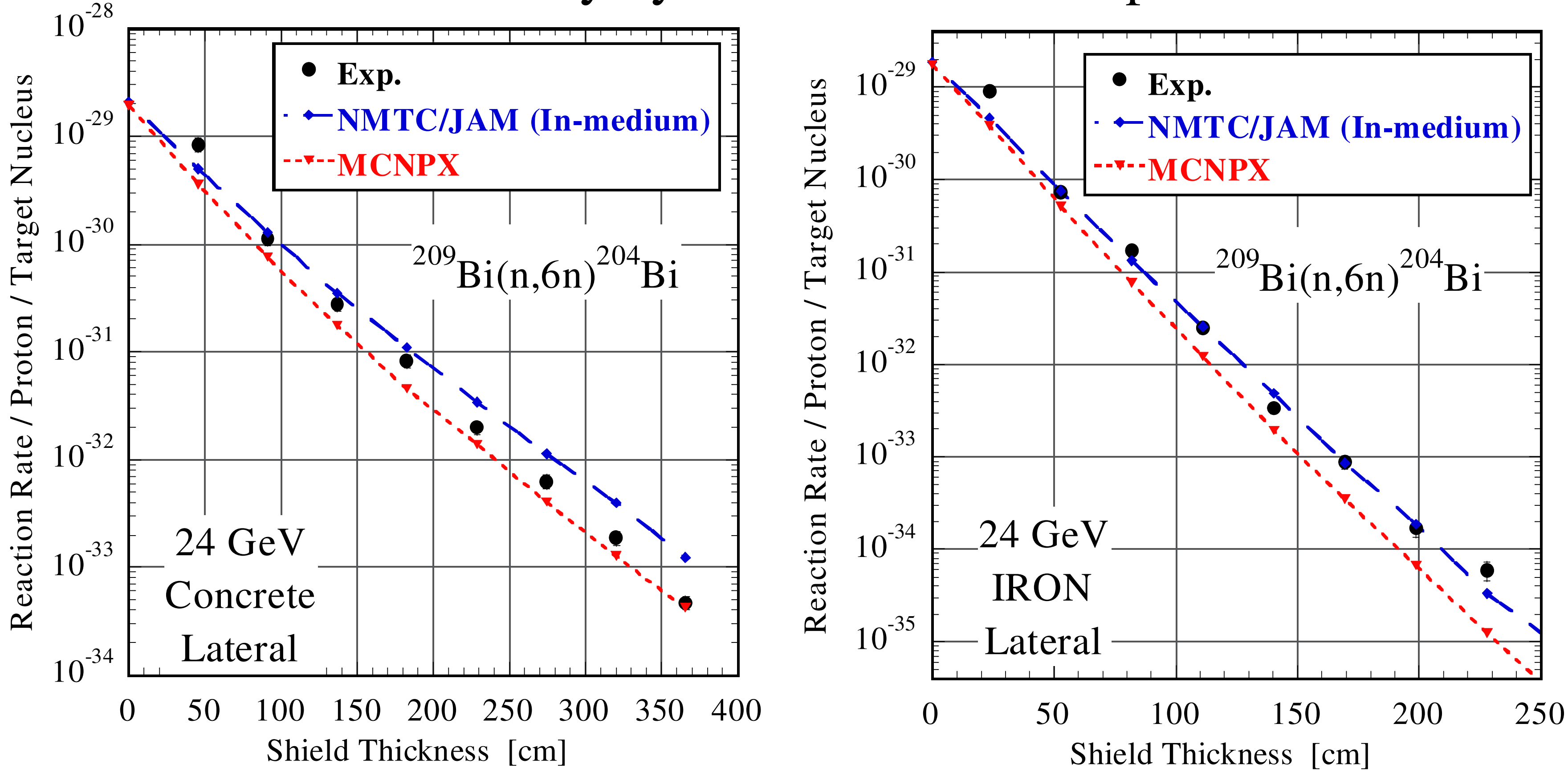
AGS Shielding Experiment



AGS shielding experiment

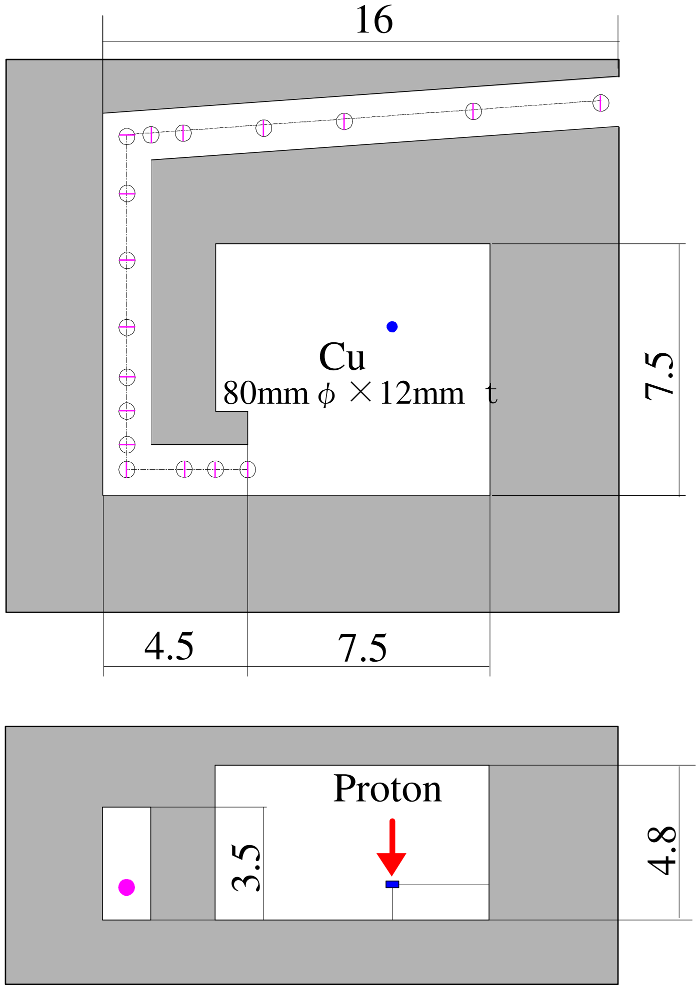
AGS Experiment (Neutron deep penetration experiments)

Source neutrons : Mercury by 2.83- and 24-GeV-protons.



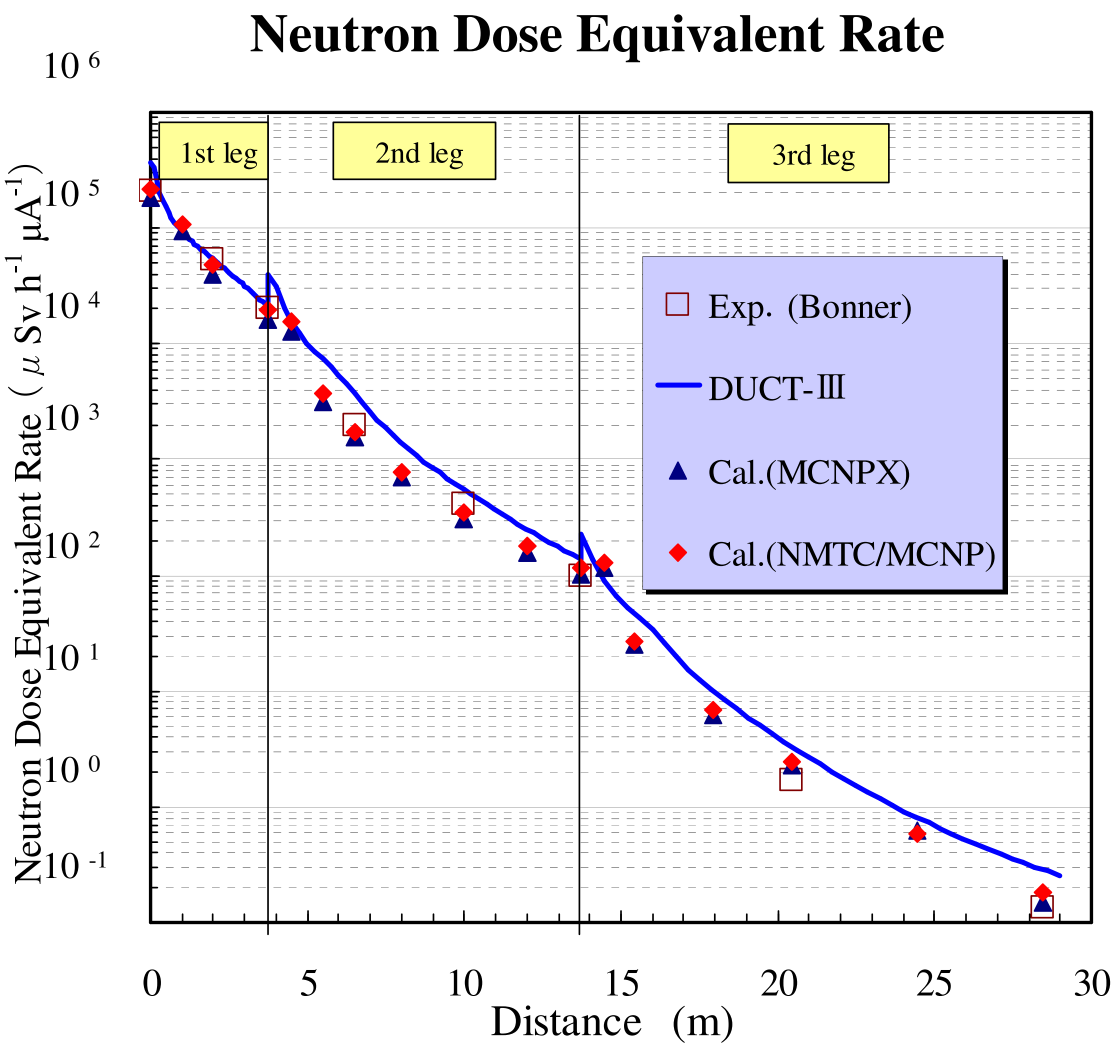
Agreement within a factor of two

TIARA experiment



Ep 68 MeV

(Unit: m)



Agreement within a factor of two/three

Activation Estimation

- Estimation from measurements at existing facilities, e.g. KEK, etc.

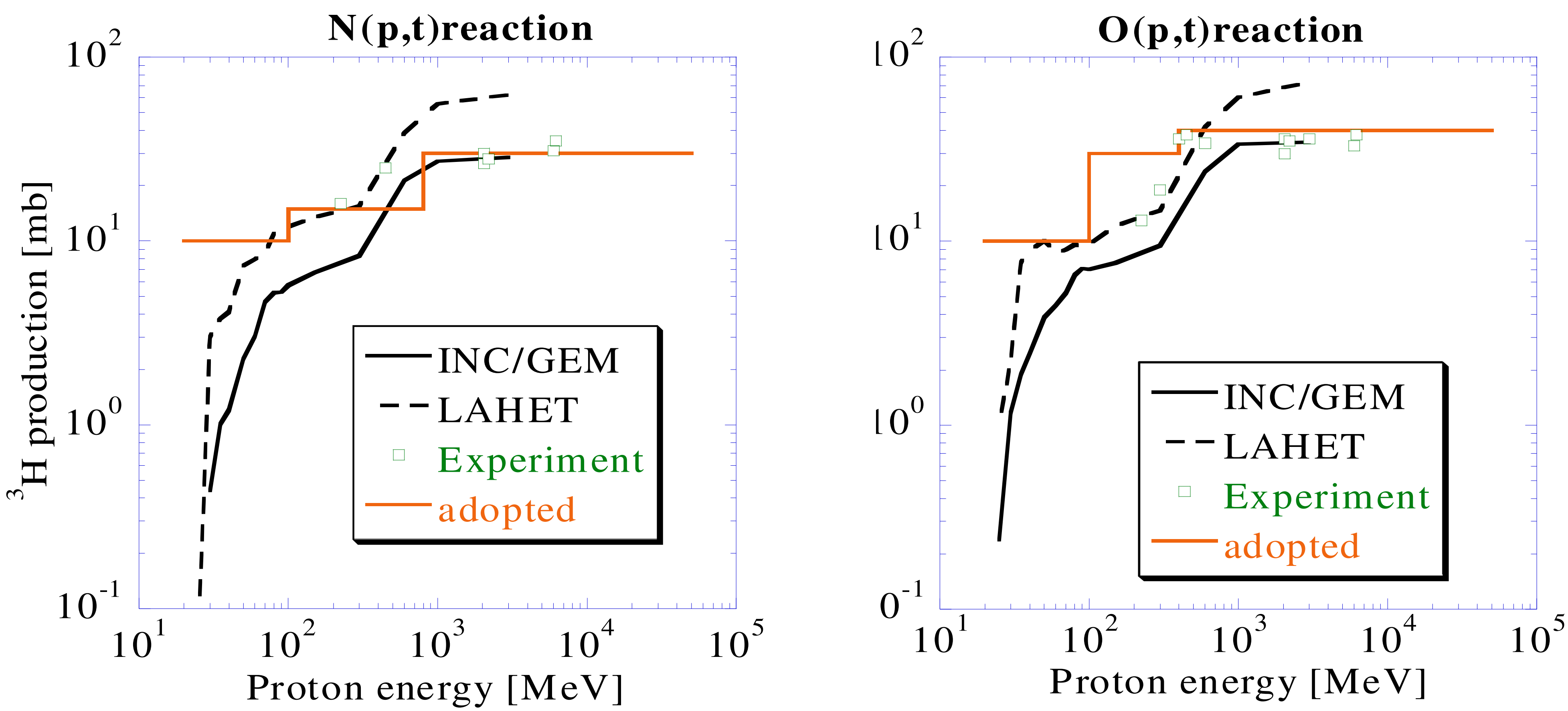
- Activation estimation for devices and soils
  Detailed estimation by PHITS-DCHAIN/SP/2001.

- Activation estimation for air
  Calculation of average proton and neutron fluxes by PHITS.
  Activation cross section evaluated from measured and calculated by INC/GEM.

- Activation estimation for cooling-water
  Calculation of leaked proton and neutron fluxes by PHITS.
  Activation cross sections evaluated from measured and calculated by INC/GEM.

Cross Sections for Activation Estimation

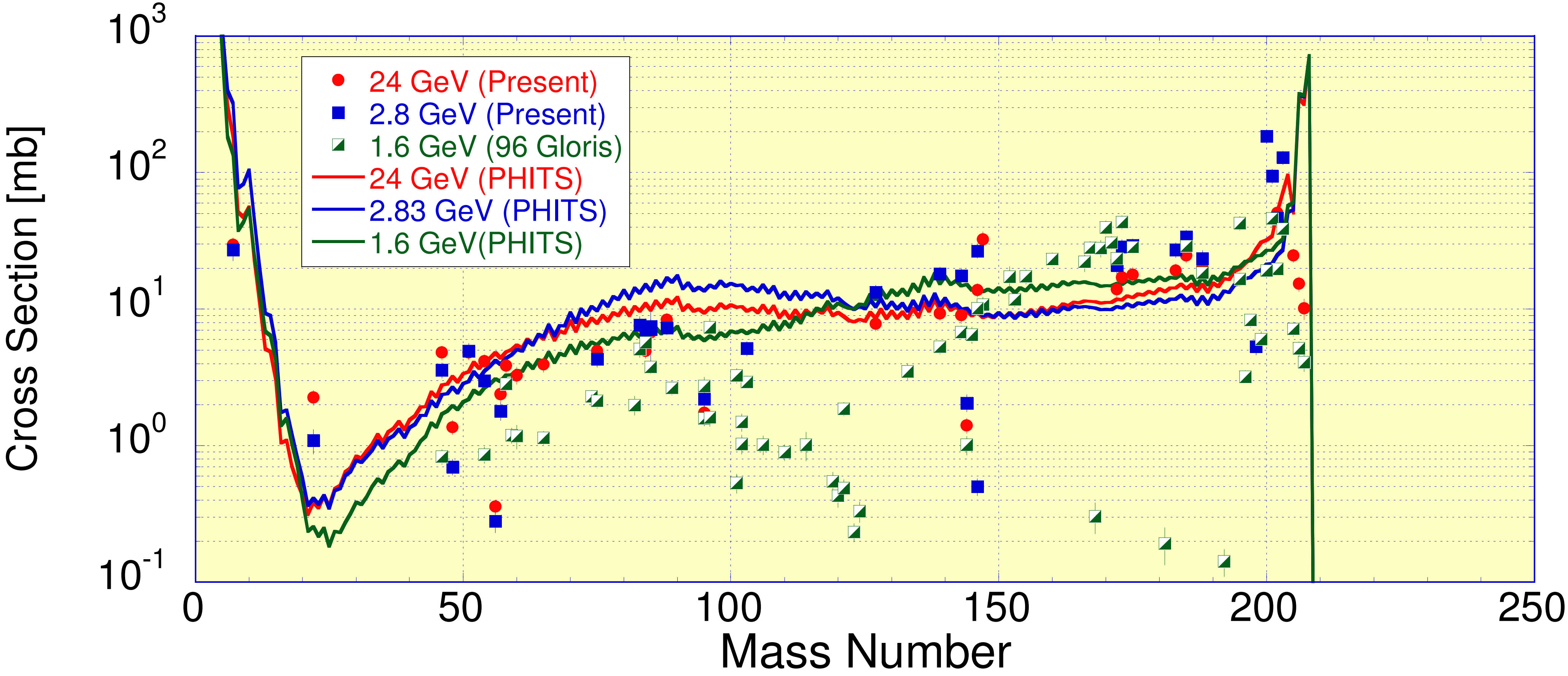
Tritium production cross sections



AGS activity experiment

J-PARC

Mass distribution of Hg irradiated by proton



(2) Handling of activity produced in air

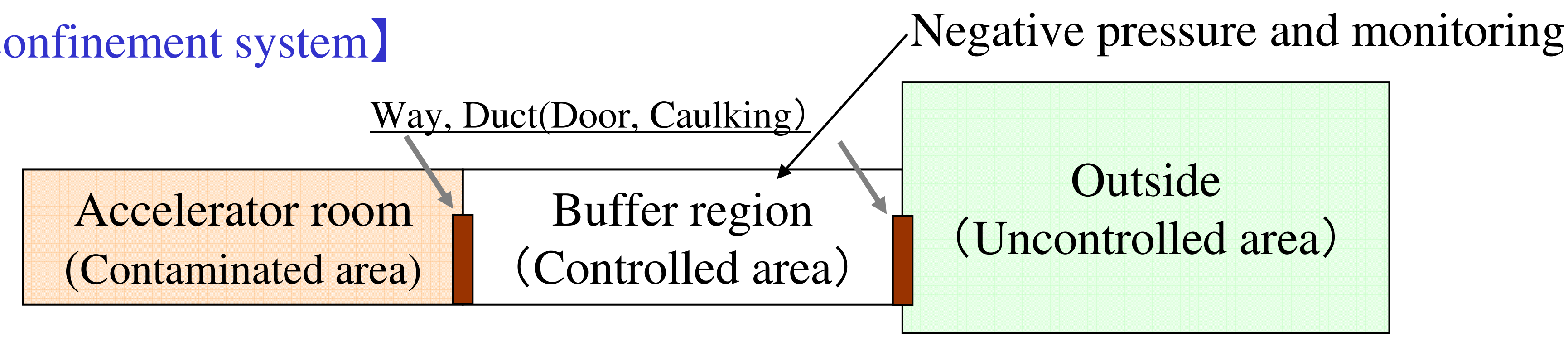
【Typical nuclei produced in air】

^{13}N ($T_{1/2}$ 9.97min.)、^{11}C ($T_{1/2}$ 20.4min.)、^{15}O ($T_{1/2}$ 2.04min.)、
^{41}Ar ($T_{1/2}$ 1.83hour)、^{3}H ($T_{1/2}$ 12.3year)、^{7}Be ($T_{1/2}$ 53.3day)

【Handling】

- Confinement in accelerator room during operation
  (Circulation for cooling)
  (Negative pressure and monitoring in buffer region)
- Decay of nuclei with short life after operation
- Remove ^{7}Be with HEPA filter in ventilation eqipment

【Confinement system】



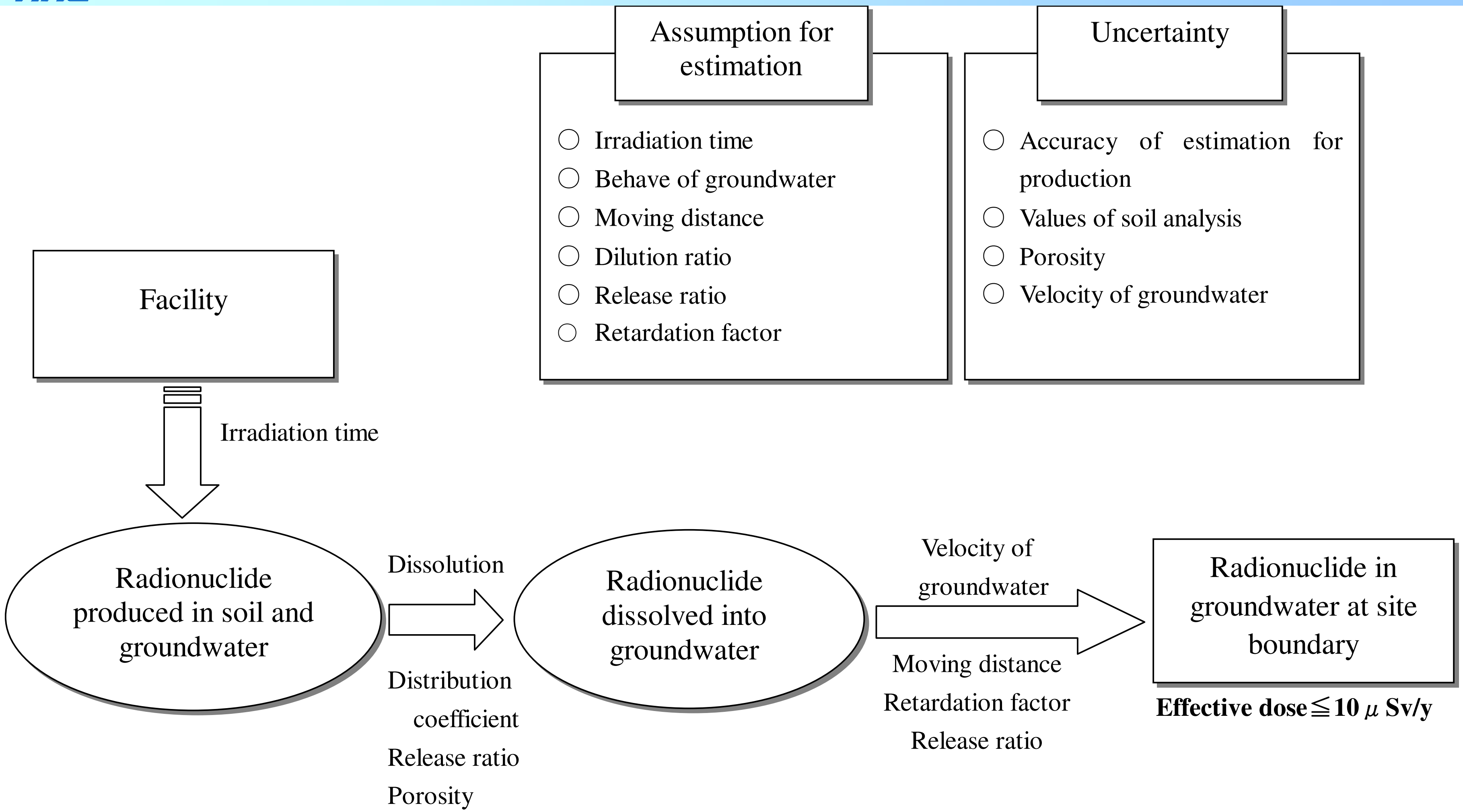
(3) Design criteria for activation of soil (groundwater)

- Groundwater should be regarded as uncontrolled water.

- The level of trivial individual effective dose equivalent would be in the range of 10-100 μ Sv per year.
  "Principles for the Exemption of Radiation Sources and Practices from Regulatory Control", IAEA safety series No.89
  "International Baisc Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources", IAEA safety series No.115

- Criterion for environmental impact due to nuclei generated in soil and groundwater by this facility
  : 10 μ Sv/y at site boundary

Estimation procedure for transition of radionuclide



1. Production of radio nuclide in soil and water around accelerator facilities
2. Radionuclide generated in soil solve in groundwater
3. Radionuclide solved out in groundwater make the transition to site boundary

Criteria from estimated results for shielding calculation

- Average dose and radio nuclide activity on shielding surface are about 10 mSv/h and 1.6 Bq/g, respectively. They are equivalent to 10 μ Sv/y at site boundary.

- Design criteria are defined 5mSv/h and 0.8Bq/g, which are half of estimated values.

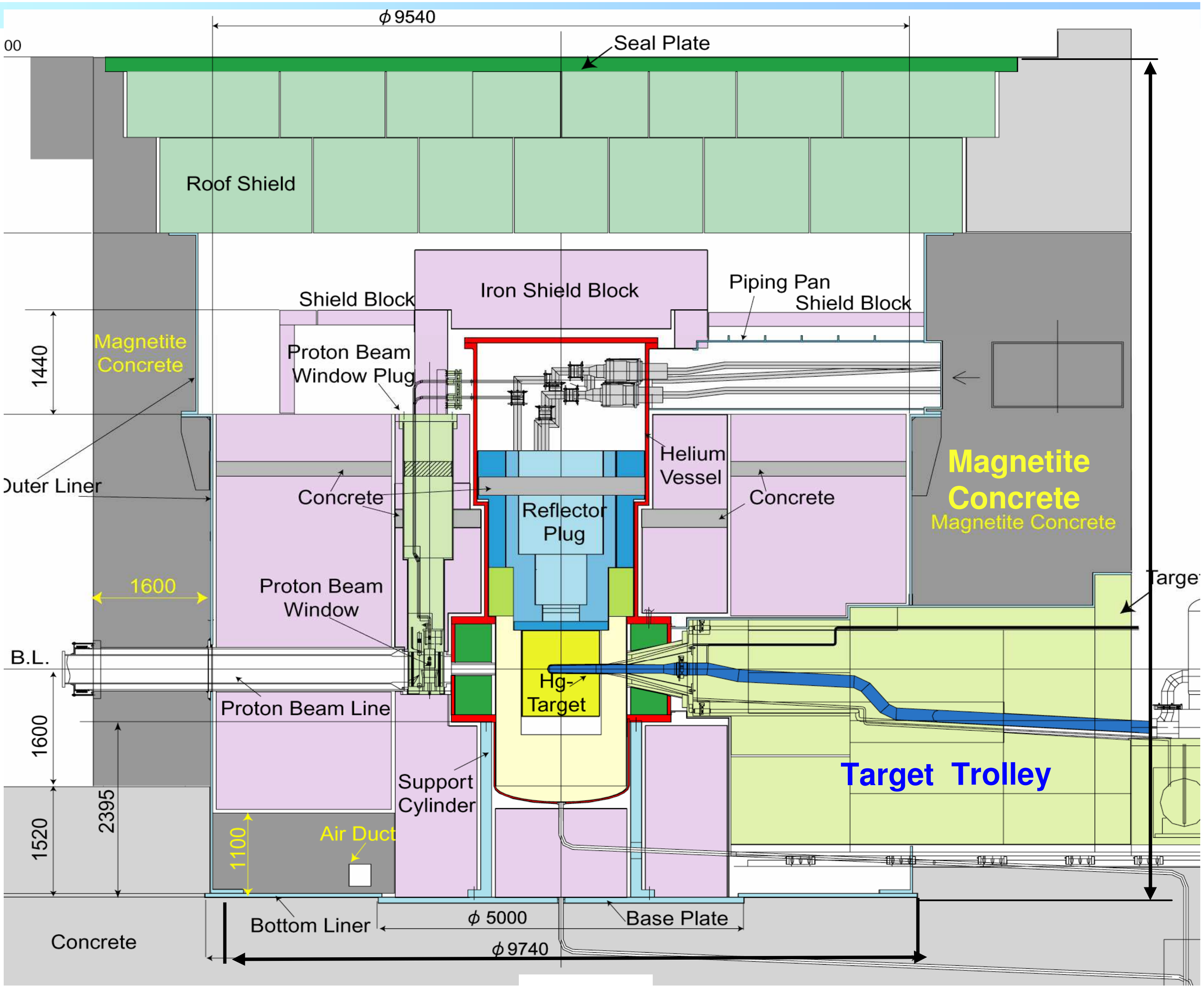
Natural radioactivity of soil : about 0.8Bq/g

Uncertainty : about 0.1Bq/g

(4) Mercury target issues
Vertical cross section of MLF

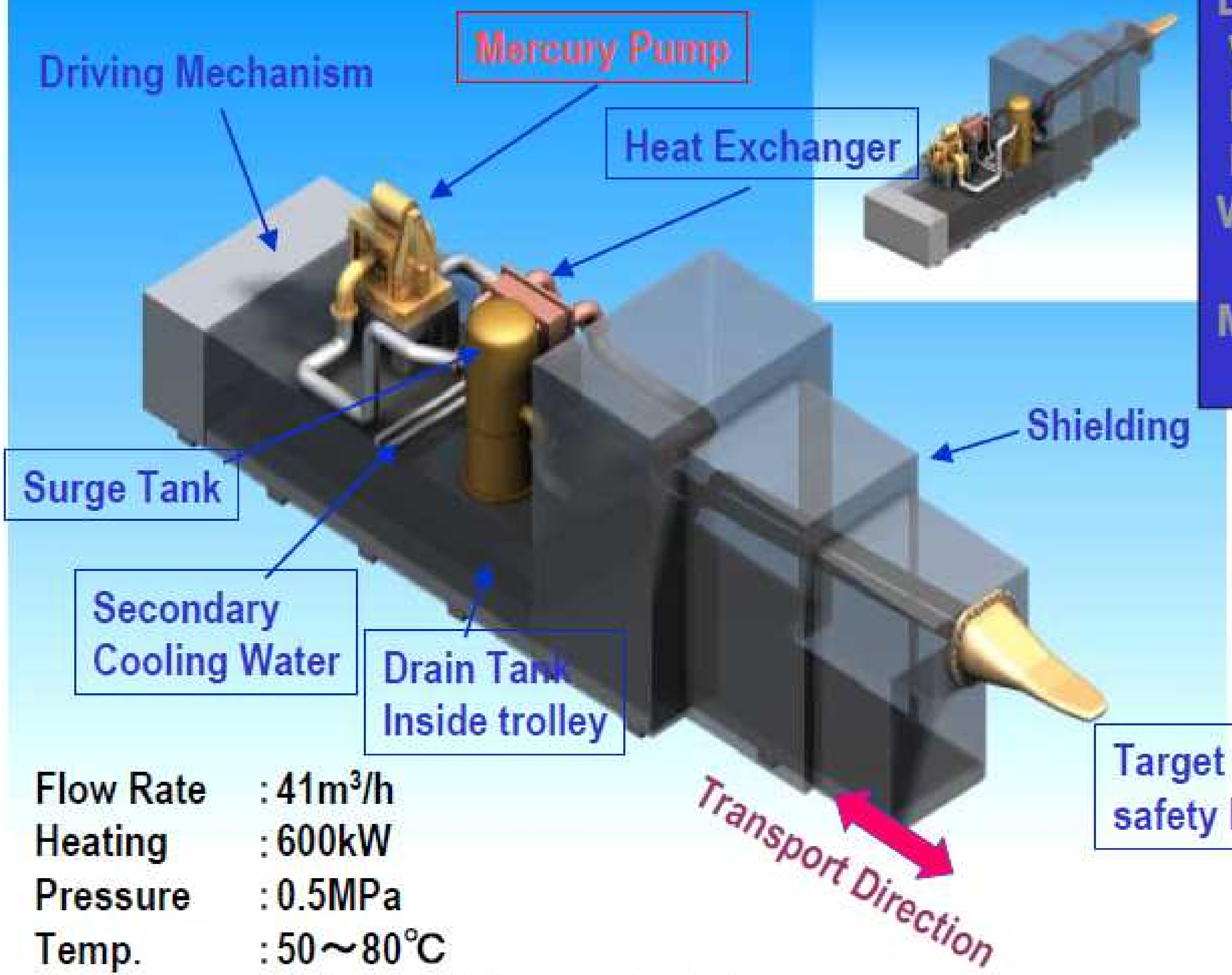
Specification

- 3GeV, 1MW, 25Hz Proton beam
- Mercury target of 1.4m^3
- Three moderator with liquid hydrogen of 260l
- Shield of about 10,000t
- Movable target structure



φ 9740

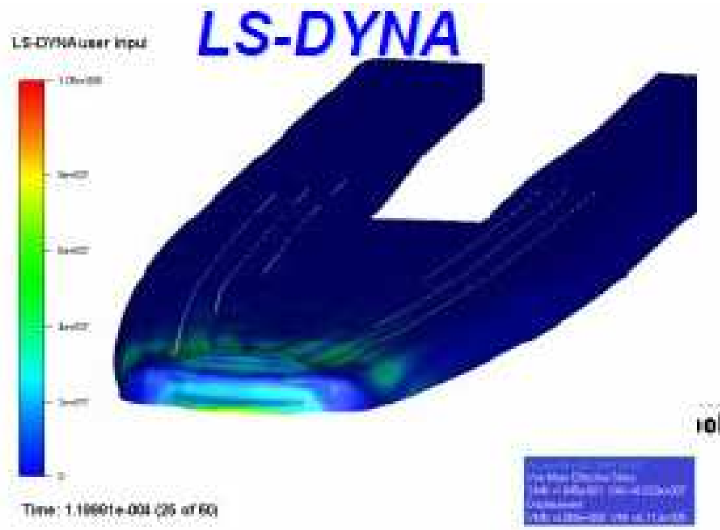
Outline of Mercury Flow System

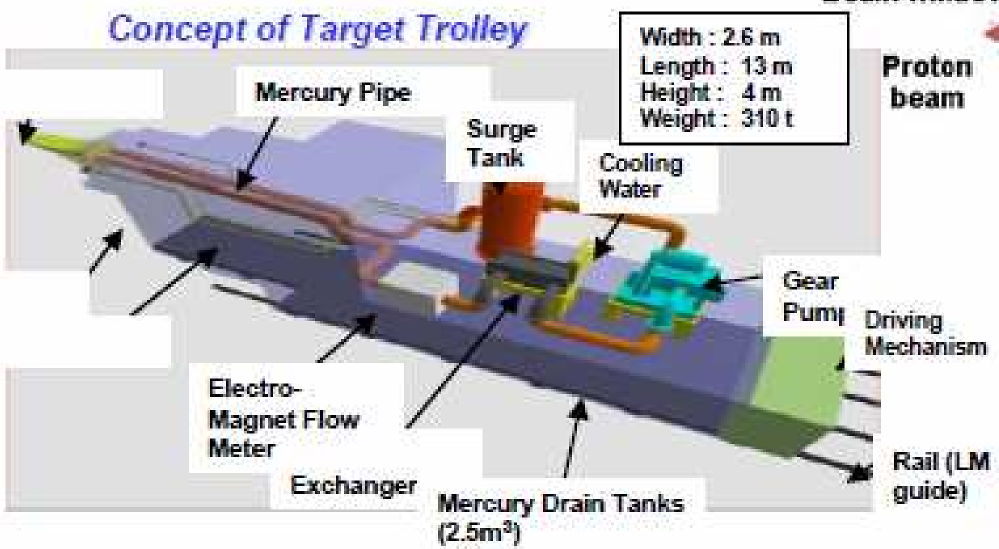


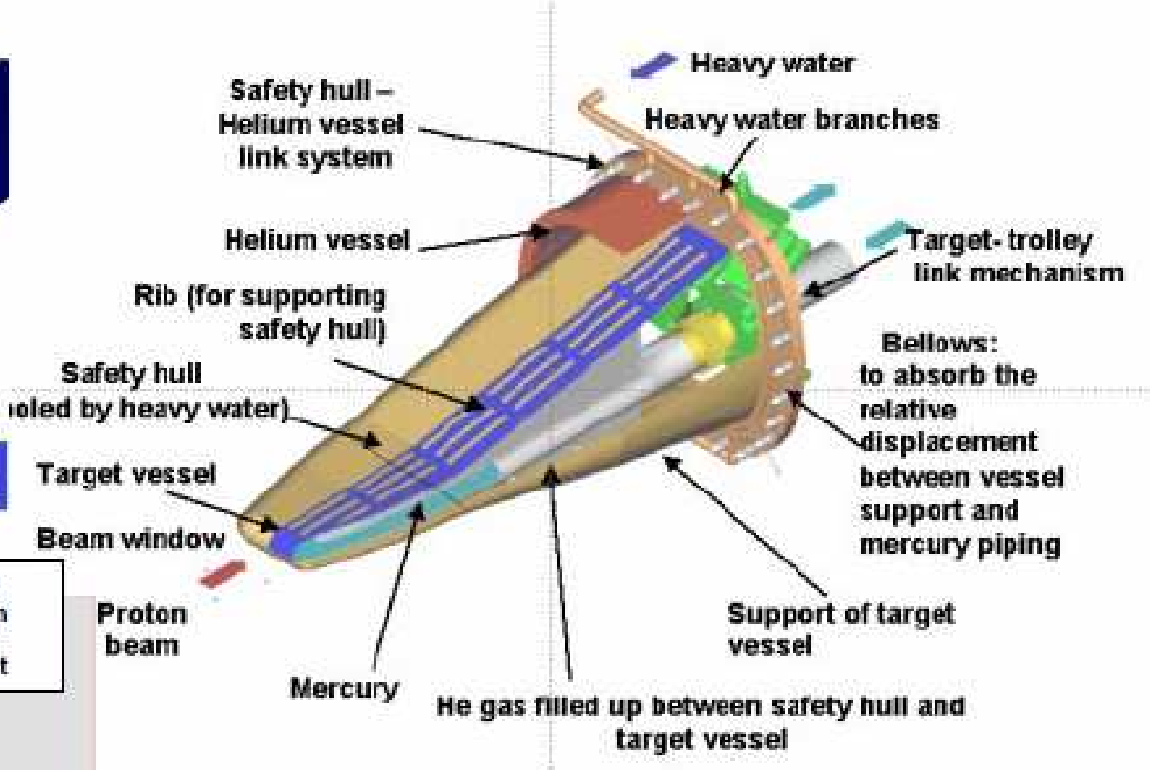
Dimension :
Width 2.6 m
Length 13.0 m
Height 4.0 m
Weight :
about 260 ton
Moving Distance :
22 m

Flow Rate	: $41m^3/h$
Heating	: 600kW
Pressure	: 0.5MPa
Temp.	: 50～80℃
Piping	: 150A-Sch80(t=11mm), SUS316L

Mercury target design

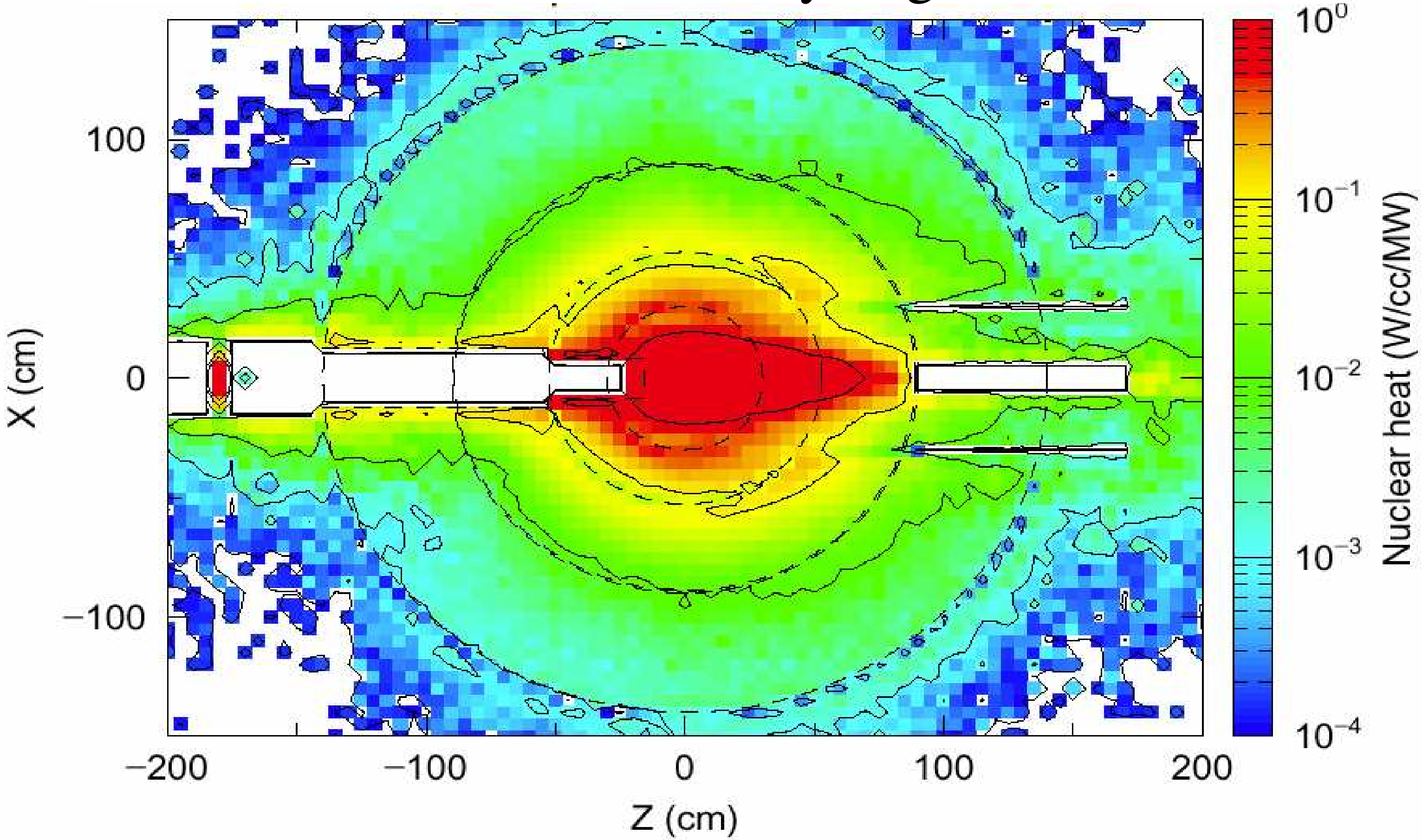






Estimation of nuclear heating

Distribution of nuclear heat on horizontal plane
around mercury target



Nuclear heating results

- **Heat Load [kW]**
  - **Target** 533.9
  - **Reflector** 196.4
  - **Reflector plug** 11.0
  - **Moderator**
    - **H2** 4.2
    - **H2O** 18.9
  - **Proton beam window** 3.1
  - **Water-cooled shield** 94.2
  - **Helium vessel** 28.1
  - **Shield** ~10.0
  - **Total** ~ 900 kW

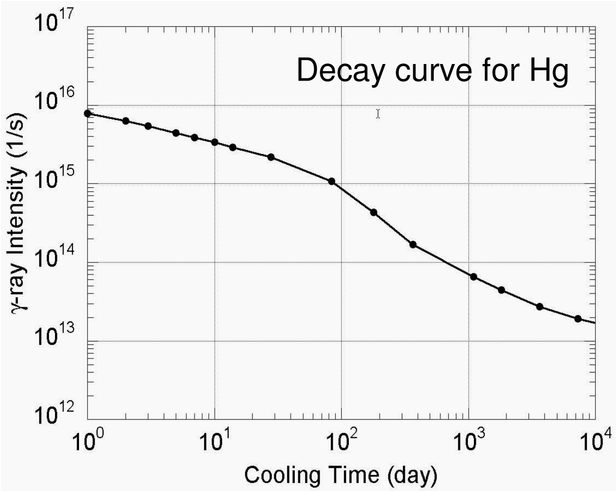
- **Peak heat density [W/cm^3]**

Proton beam window Inconel-718		310
Target	630	Hg
	320	SS-316L
Reflector	6.0	Al
Moderator	3.4	Al
	1.2	H2
Water-cooled shield	0.8	SS-316L
Helium vessel	0.2	SS-316L

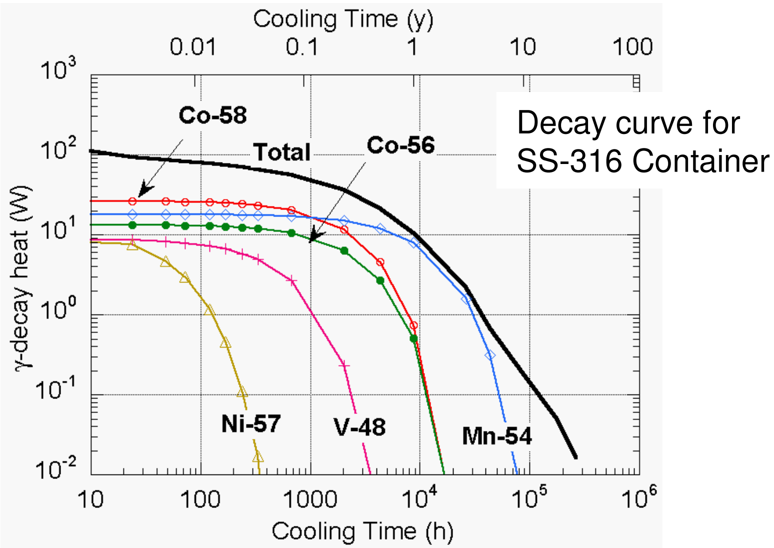
Values for 1 MW @ the PBW

Results of induced activity in target

TARGET



1 MW - 5000 hr. operation, 48 hr. cooling



Major radioactivity in mercury

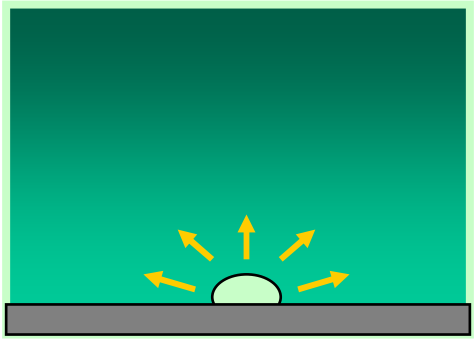
Nuclide	Half-Life	Activity [TBq]
H-3	12.3 y	92.0
I-125	59.4 d	15.0
Xe-122	20.1 h	1.3
Xe-127	36.4 d	13.0
Hg-194	520 y	0.3
Hg-195g	9.9 h	94.0
Hg-195m	41.5 h	120.0
Hg-197g	64.1 h	1,600.0
Hg-197m	23.8 h	230.0
Hg-203	46.6 d	2,300.0

Radiation damage:DPA results

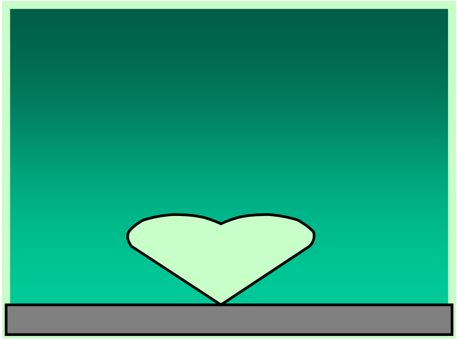
- Maximum DPA for 1 MW, 5000 hr

Proton beam window:	4.0	Inconel-718
Mercury target:	10.0	SS-316L
Moderator:	3.0	Aluminum alloy
Reflector:	3.5	Aluminum alloy
Water-cooled shield:	~ 0.03	SS-316L
Helium Vessel:	~ 0.01	SS-316L

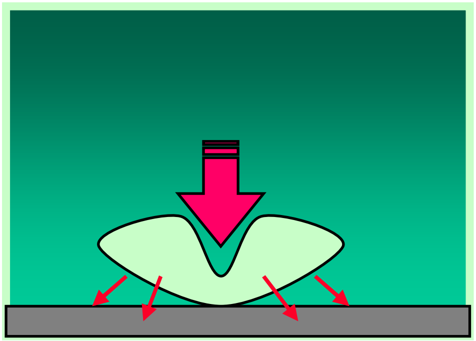
Pitting formation(1)



Negative pressure is generated nearby the interface between liquid and solid metals. Bubble core are created on the interface.

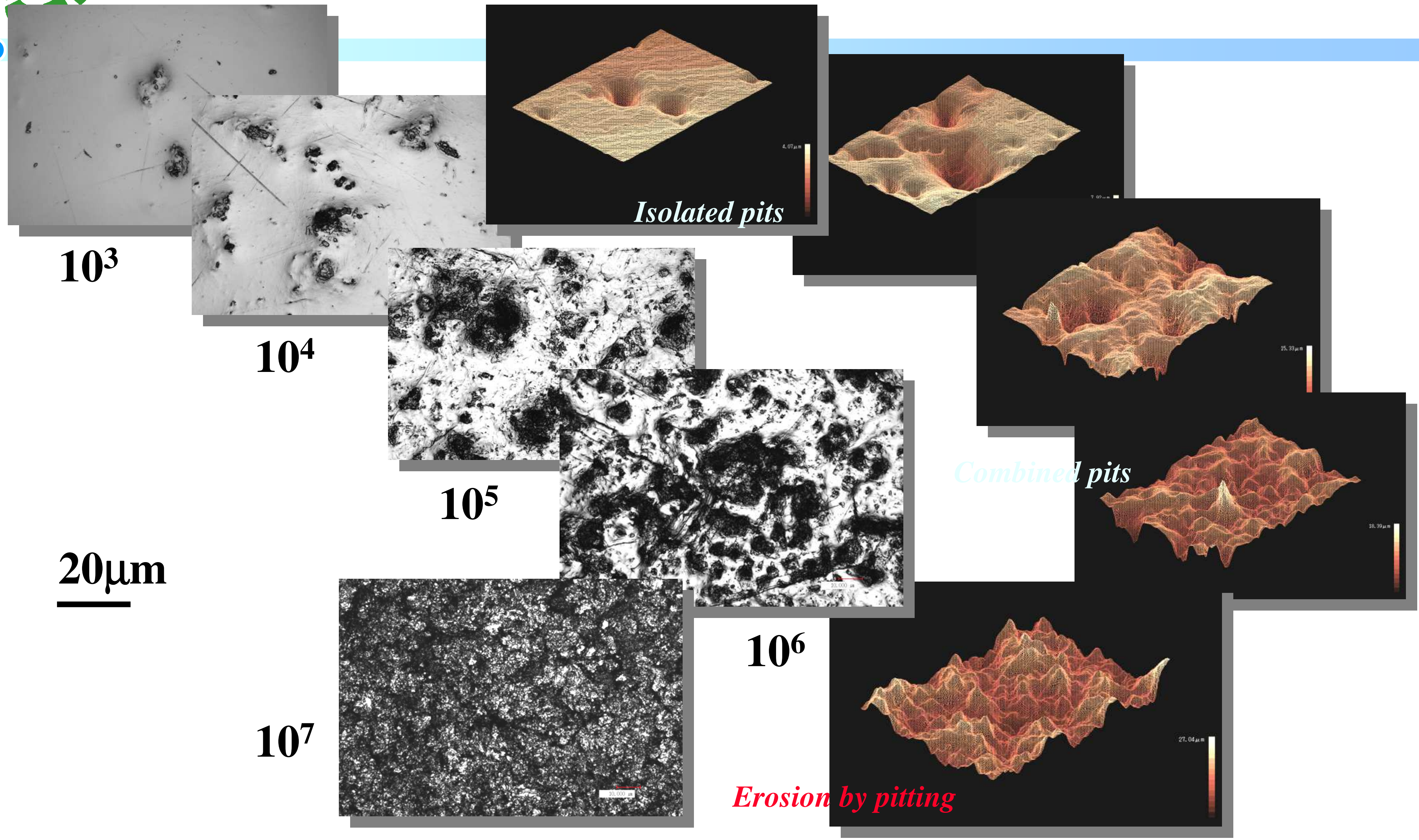


The bubble becomes bigger. Due to unsteady condition along mercury surface, bubble collapse occurs



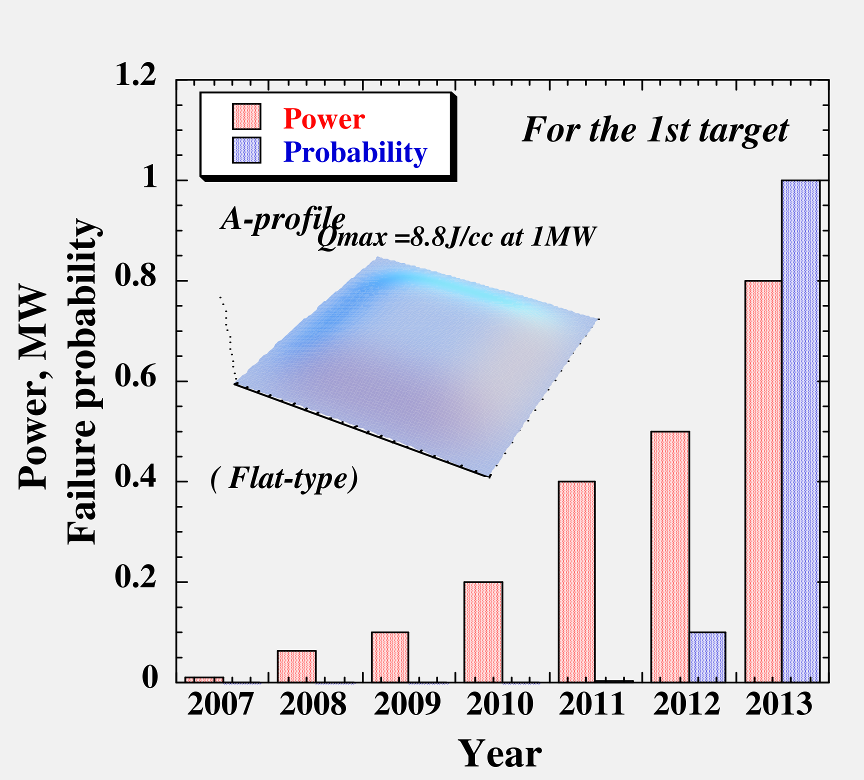
Microjet impact against solid interface. The pressure beyond the yield stress for localized deformation. Pits are formed as impact erosion.

Pitting formation (2)



Pitting damage data are accumulated up to over 10 million

Pitting formation

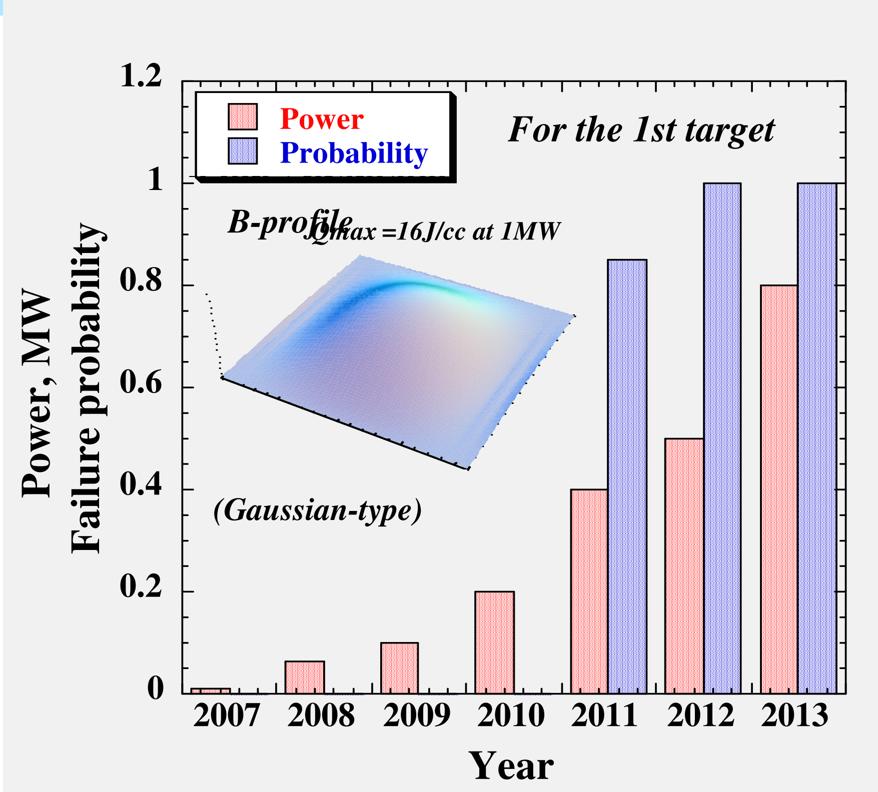


For a target(2500h)

0.5MW ΣPf=0.7%, Σdose=1 dpa

0.8MW ΣPf=60%, Σdose=1.6 dpa

1MW ΣPf=99.9%, Σdose= 2dpa



For a target(2500h)

0.5MW ΣPf=6%, Σdose=1.8 dpa

0.8MW ΣPf=99.9%, Σdose=2.9 dpa

1MW ΣPf=99.9%, Σdose= 3.6dpa

Failure probability of Hg vessel window was estimated as taking the fatigue strength degradation due to pitting and radiation damages into account. FP is strongly dependent on the beam power and profile. In particular, the effect of pitting damage becomes prominent over 0.5 MW.

Summary

- J-PARC is a large-scale experimental facility consisting mainly of a high-intensity, high-energy proton accelerator of top world class.

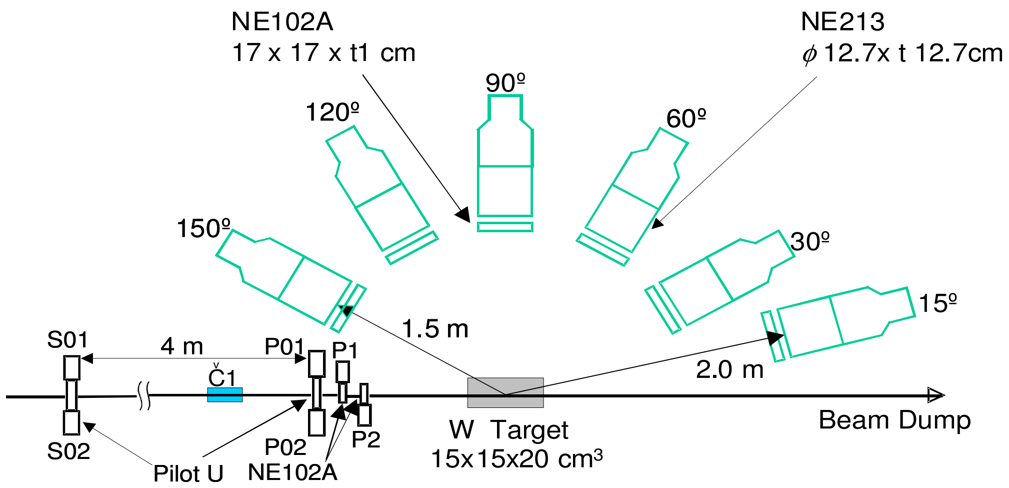
- In order to secure safety, many kinds of techniques are applied.
  - ・Shielding design methods
  - ・Confinement system
  - ・Underground water issues
  - ・Target issues: Activity management, Damage estimation, Pitting issue

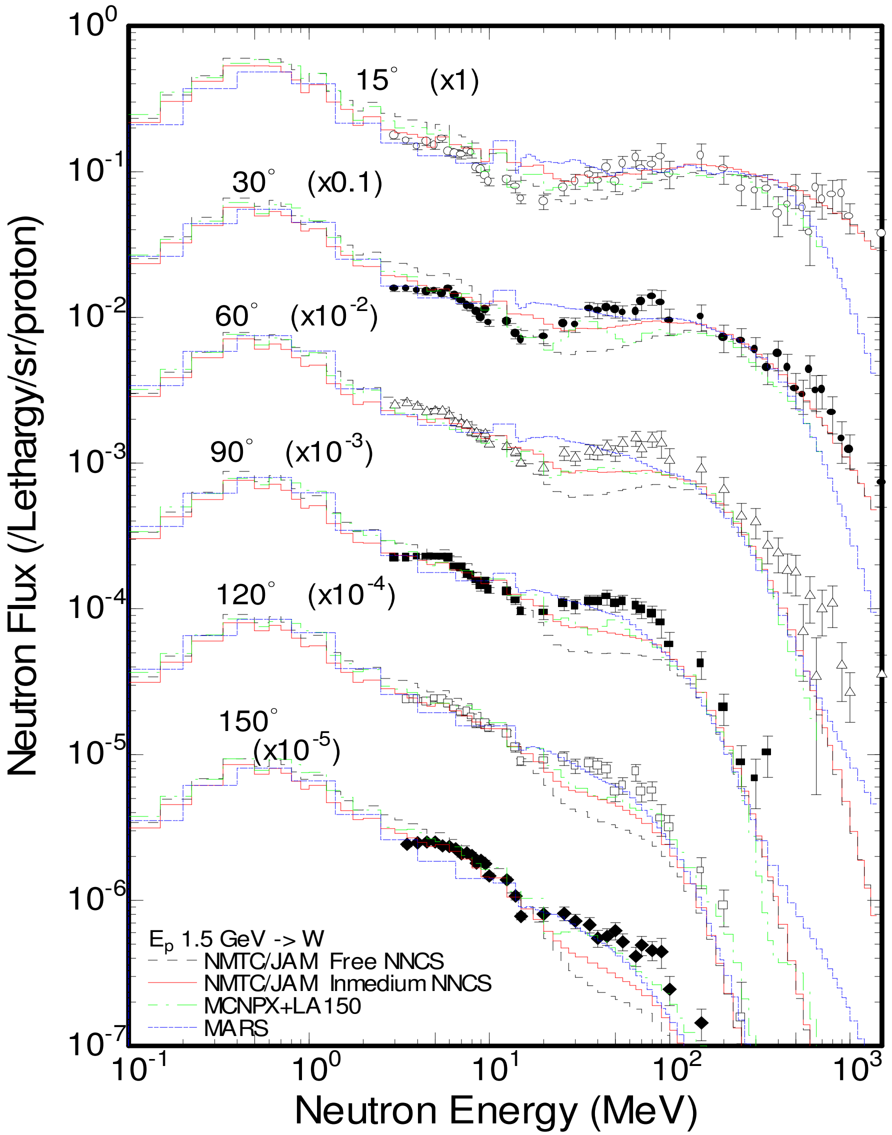
- As the first step of a safety review, we obtained an approval for use of LINAC. Safety review will be done for approval in use of other facilities: 3GeVRCS, 50GeVMR, MLF, NP and ν, in near future.

- The validation of the shielding design method for the second phase: ADS, is already started.

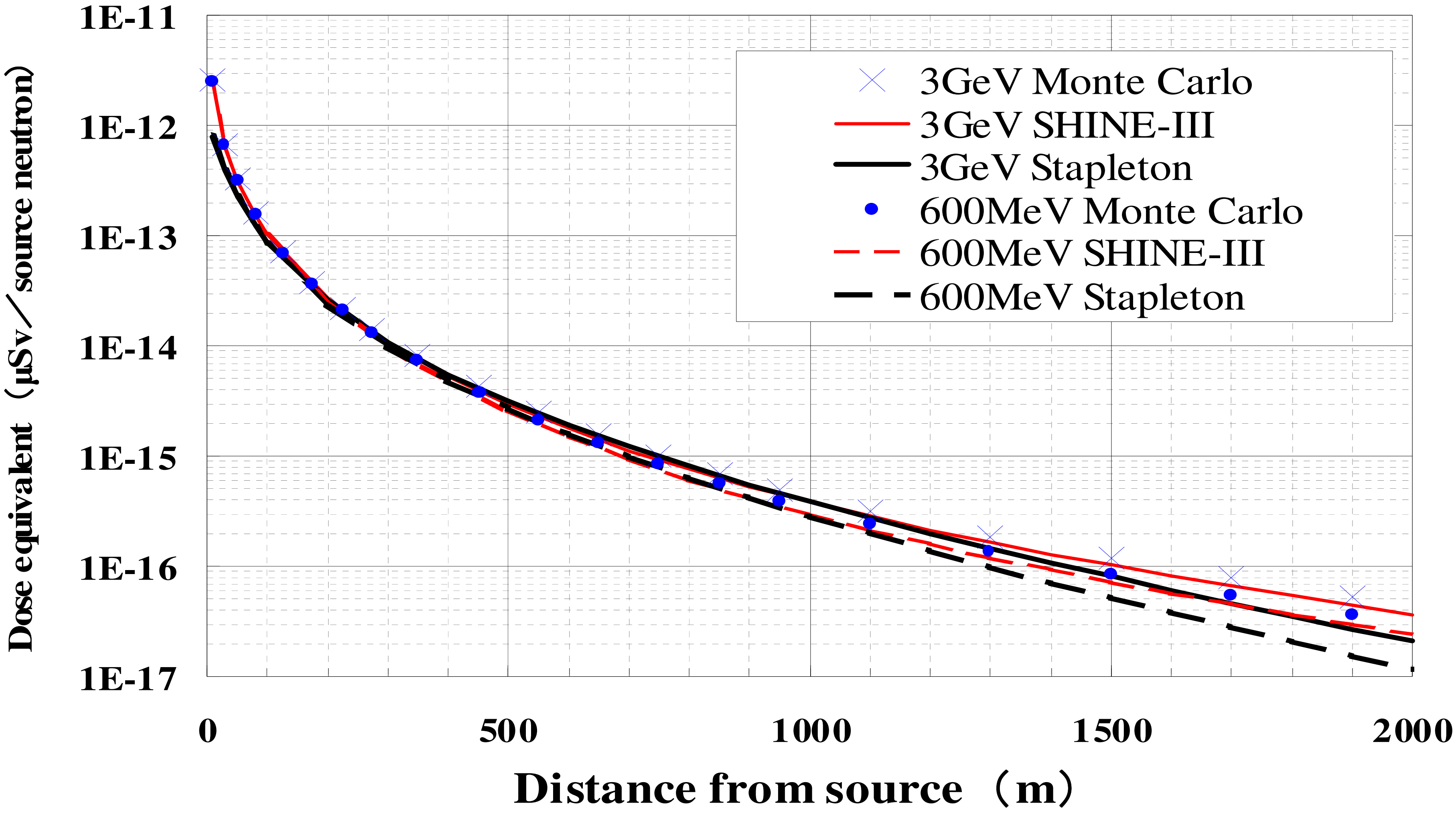
KEK TTY experiment

1.5-GeV-protons : Tungsten target





Comparison of neutron skyshine dose attenuation among simplified and detailed methods



Agreement within a factor of two

Estimation of Erosion Rate

Velocity 0.7m/s, (Straight Region)

Thickness Decreasing

1000hr(Test Time)	: 2.7 μm
5000hr (1 year commutation)	: 13 μm
30 year commutation	: 390 μm

150A-Sch80——
Thickness 11mm

Mechanical Strength

Inner pressure ; 1.0MPa

SUS316L
Allowable Stress : 115MPa

	t=11mm		t=10mm
Stress	13.7MPa	→	15.1MPa

Decrease of wall thickness by erosion

No effect on the mechanical strength.

J-PARC Construction Schedule

Feb. 27 2006