# Radiation Shield around ILC Beam Dumps

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# Goal of this talk

➢ Estimate the required thickness of radiation shield. (especially transverse direction)

The amount of radioactive isotope generated in shield materials was evaluated by Monte Carlo simulation (FLUKA).

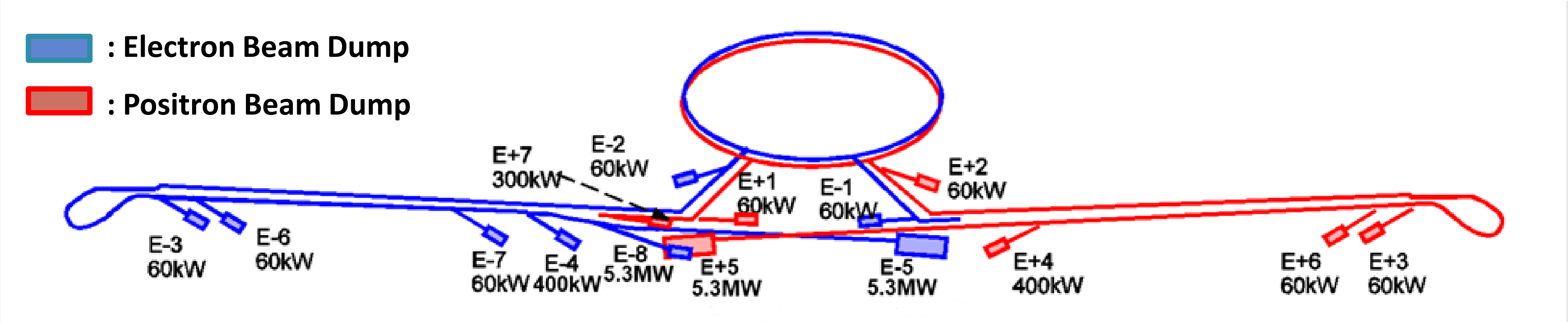
✓ We take special care to estimate the thickness of the shield so that there is no activation effect outside the tunnel.

Contents of this talks

1. Brief Introduction of ILC beam dumps
2. Simulation of radioactive isotope production in shield materials

# Brief Introduction of ILC Beam Dumps

# ILC Beam Dumps

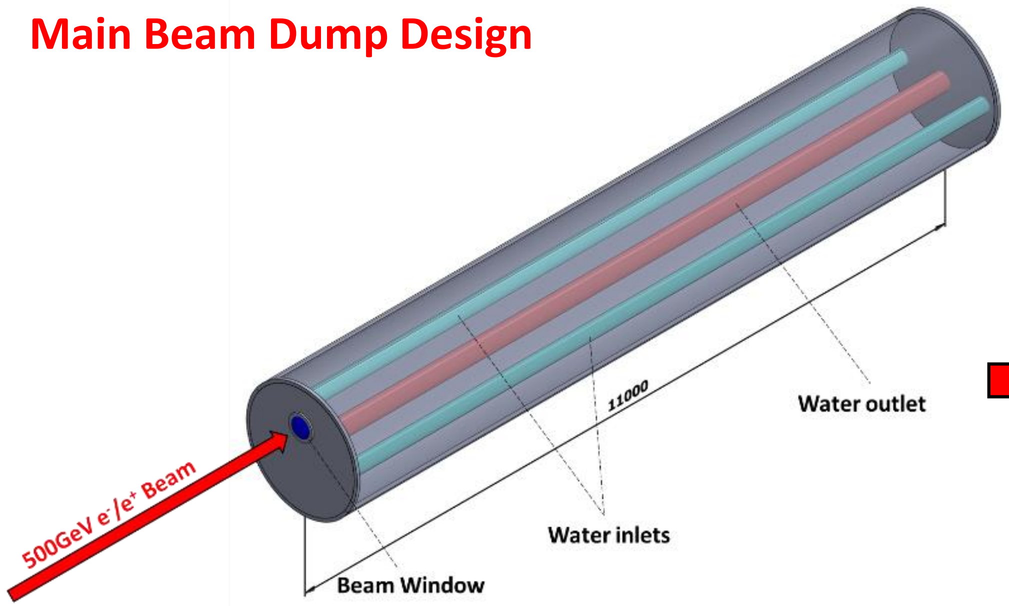



| Type | Power | Purpose | Absorber | Place |
|---|---|---|---|---|
| A | 60kW | Tune-up & Emergency | Solid material | 9[E-1,E-2,E-3,E-6,E-7,E+1,E+2,E+3,E+6] |
| B | 400kW | Tune-up & Emergency | Solid material | 2[E-4,E+4] |
| C | 300kW | Photon Dump | Water ? Graphite? | 1[E+7] |
| D | 8MW | 5 + 5 Hz Operation | Liquid-water | 1[E-8] |
| E | 17MW | Main Beam-Dump | Liquid-water | 2[E-5,E+5] |

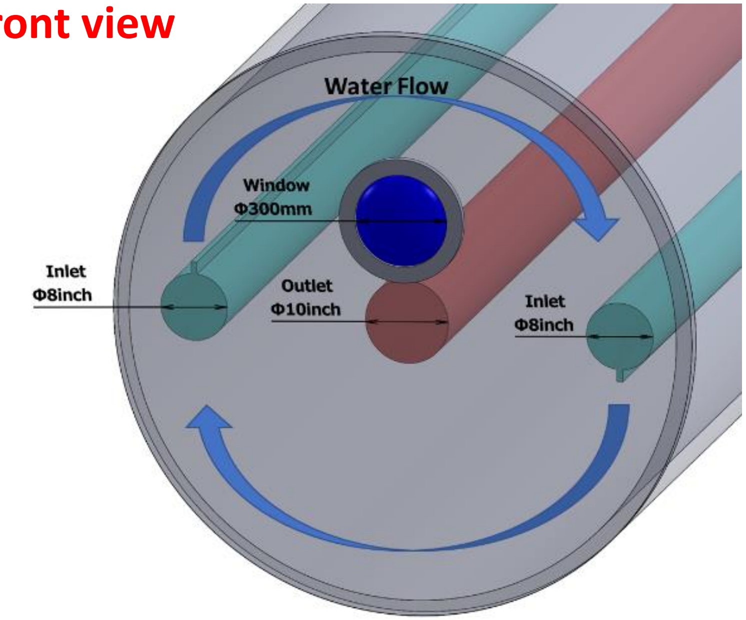
**Total 15 Beam dumps in ILC . Beam dumps are classified into 5 types.**

# Main Beam Dump (Water , type D&E)

**Main Beam Dump Design**




**Front view**




**【Beam Power @ 1TeV Beam operation】**

・500GeV×2.79nC×2450Bunches×4pulses/sec : **13.7MW** + **20% safety margin** ≒ **17MW**

**【Base Design*】**

・**Water power absorber** and **forced convection** to extract the heat.

  ＊ Water is compressed **1 MPa** ⇒ **boiling temp 180℃**

  ＊ Vortex water flow ⇒ Mass flow rate : **104.5kg/s** each inlet, flow velocity **2.17m/s**

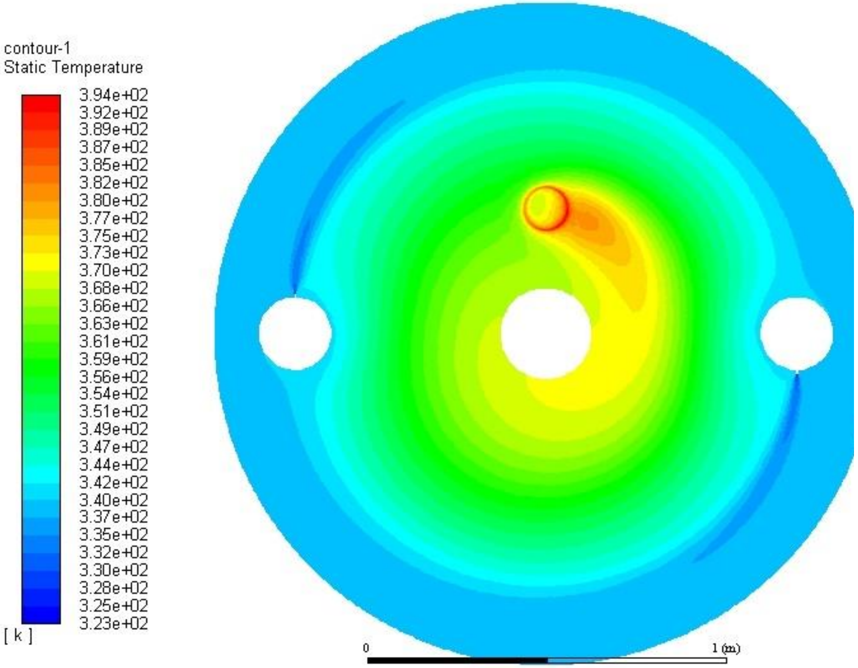
・**1mm thick** Beam Window made of **Ti-6Al-4V**.

＊Base design of ILC Main Beam Dump : P. Satyamurthy, et.al., NIM A 679 (2012)

# Main Beam Dump (Water , type D&E)

**Many simulations have been performed on this beam dump performance.***

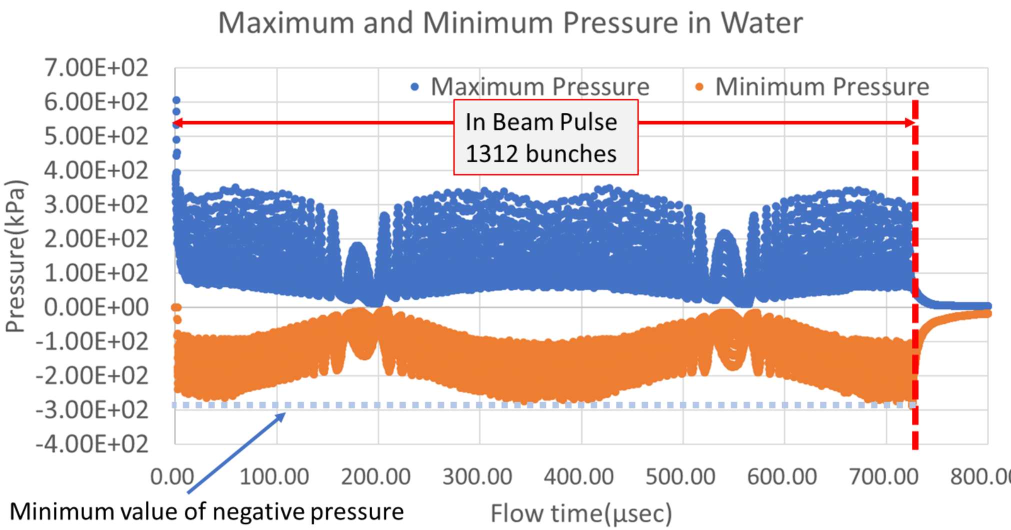
**Temperature simulation**
**@1TeV Status** (500GeV, 2450bunch/pulse, 4pulse/sec)




**【Max Temperature】**

**250GeV-nominal : 68℃ , 1TeV : 121℃**

**Pressure wave simulation**
**@250GeV-nominal**(125GeV, 1312bunch/pulse, 5pulse/sec)

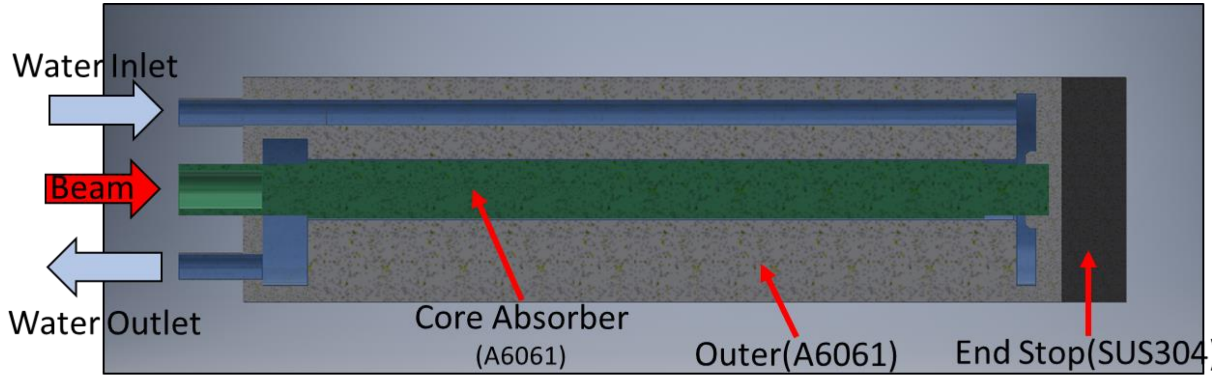


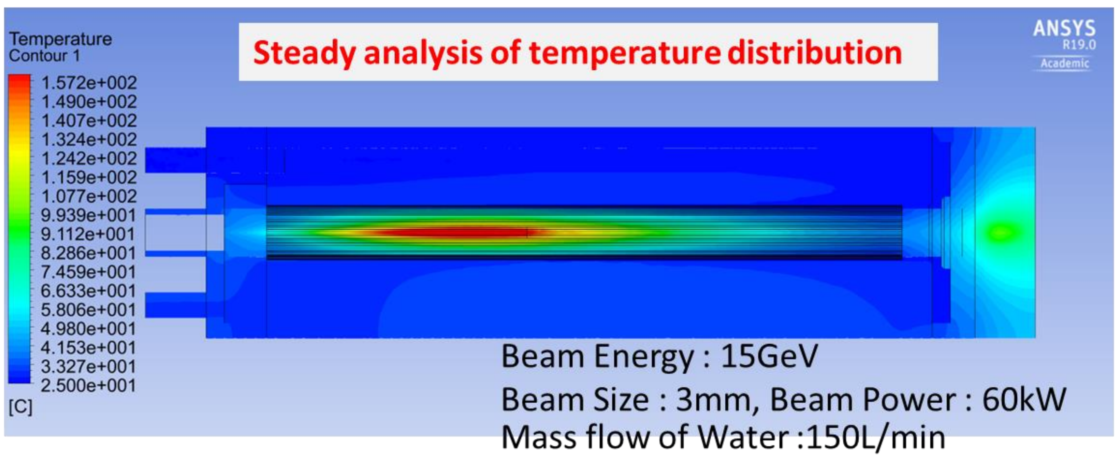

**Highest Pressure : 6.2 bar , Lowest Pressure : -2.8bar**

＊Design check of ILC Main Beam Dump :Y. Morikawa, LCWS2018

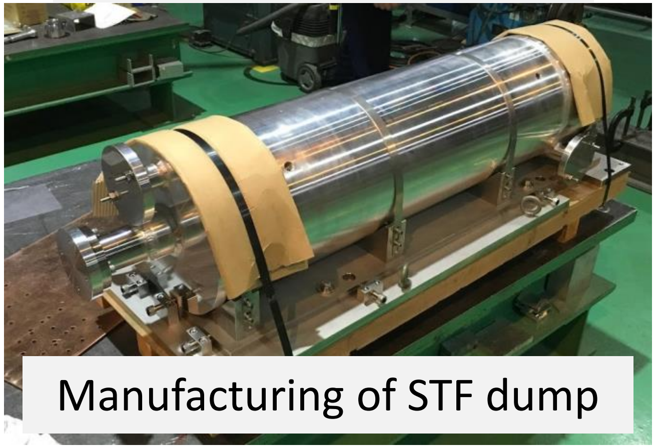
# 60kW Beam Dump (Aluminum , type A)

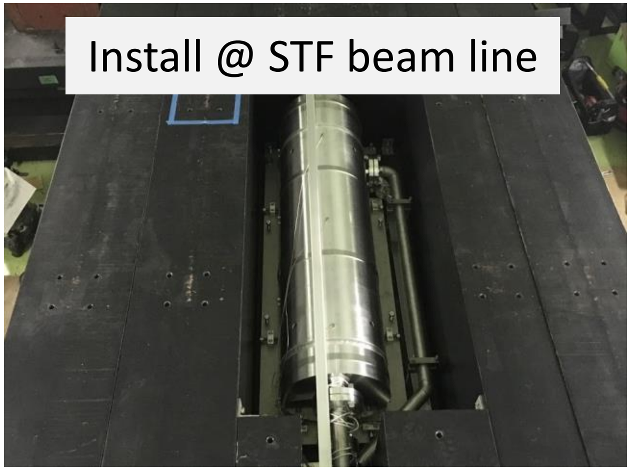
**[Base Design of Type A] Made of Aluminum Alloy*1**




**Performance Test @ STF*2**



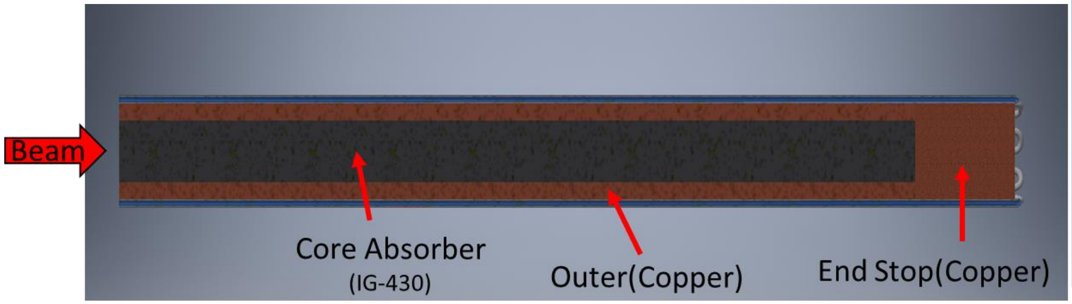

- Prototype of this beam dump was already made and has being tested at STF.

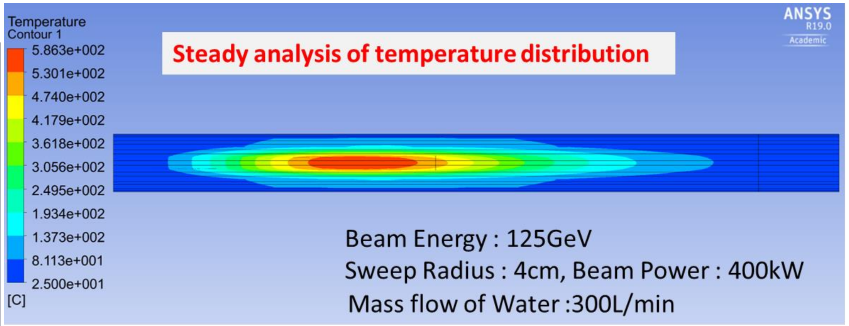
＊1 Design of other beam dumps :Y. Morikawa, LCWS2018,

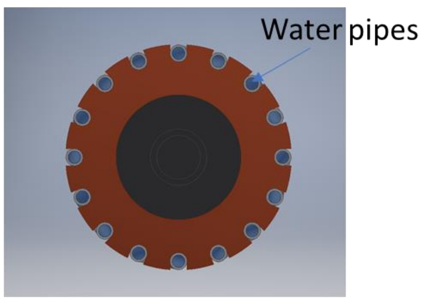
＊2 Development of STF Beam Dump :Y. Morikawa et al ., Particle Accelerator Society of Japan 16(2019)

# 400kW Beam Dump (Graphite , type B)

## [Base Design of Type B] Made of Graphite*1



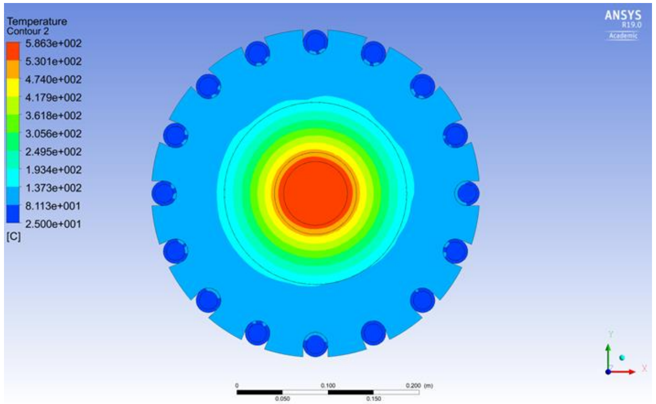




【Manufacture Issues】

・Graphite is shrink fitted into copper outer.
⇒Thermal contact resistance make temperature rise

・Graphite/Copper part is divide to some pieces for manufacturing and connected by welding.



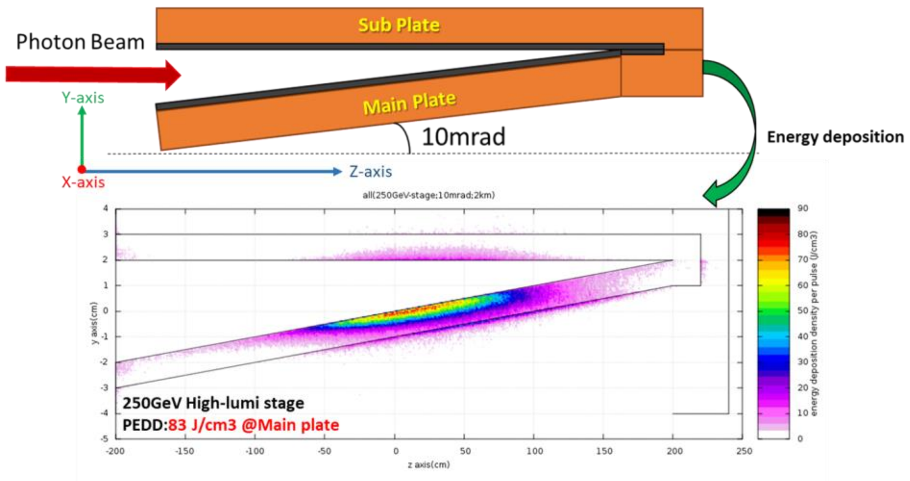

◆ Core absorber is cooled via copper outer.
Core Absorber(Temporary Design) : L4000 × 200ϕ(mm).
＊Radiation Length(Graphite) :23.9cm , Morier radius(Graphite) : 5.9cm

・Base design was created with reference to E-XFEL beam dump.

＊1 Design of other beam dumps :Y. Morikawa, LCWS2018,

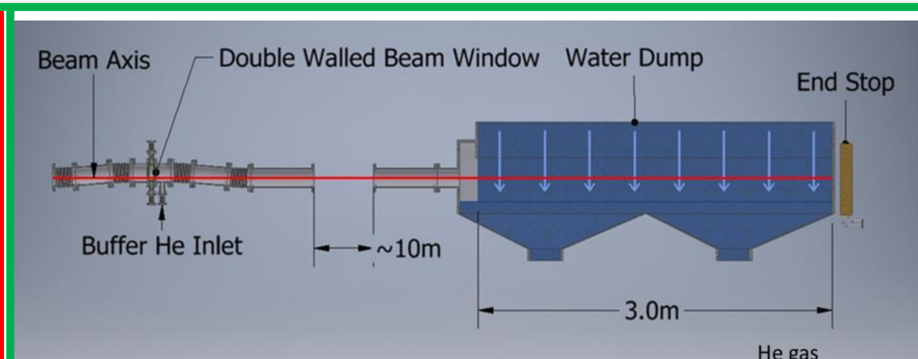
# Photon Beam Dump (Graphite or Water, type C)

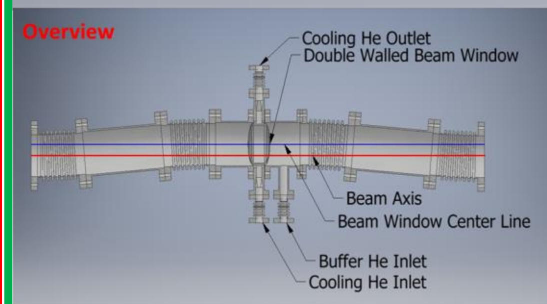
## Tilted Graphite dump(no need beam window)*

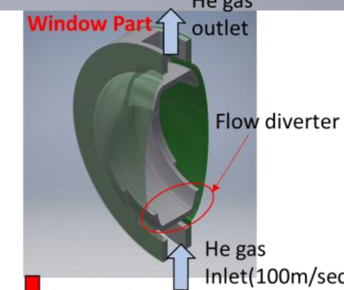



- **Increasing the effective beam size by making beam incident on tilted graphite.**
- **Max temp for 250GeV-High lumi stage**
  **614℃(887K) @ Main plate**
  **143℃(416K) @ Sub plate**

## Water Curtain dump & tumbling beam window*

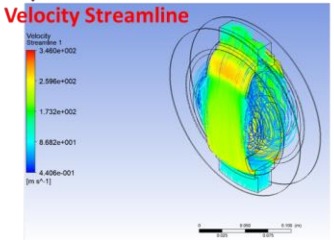



Flow Analysis

Velocity Streamline



- Elliptical shape ϕ15cm(long axis), ϕ4cm(Short axis)
- Tumbling Window by bellows system.
  Tumbling radius=3cm, 1.9sec/turn(0.53Hz)
- Helium gas cooling
  Gas velocity of introductory part:100m/sec,
  Heat transfer coefficient : ~0.1W/cm2K

- We have 2 design candidates. Water Curtain and Graphite design.
- Basic thermal analysis was already done. Next issue will be how we can make the robust system with industrial technology.

＊Photon Dump Design and R&D plan :Y. Morikawa,POSIPOL2018,

# Simulation of radioactive isotope production in shield materials

# FLUKA Simulation Settings

## ◆ Beam Dump Structure & Beam intensity

| Type | Beam Dump Structure | Beam Energy(GeV) | Beam Power(kW) | Operation Scenario |
|---|---|---|---|---|
| A | Aluminum :ϕ450×1500(mm) | 5,15 | 60 | 500hour/year×20year |
| B | Graphite :ϕ 500×4000(mm) | 500 | 400 | 500hour/year×20year |
| C | Graphite : t100×2000(mm) | **Undulator Photon** | 120 | 5000hour/year×20year |
| D,E | Water : ϕ1800×L11000(mm) | 500 | 17,000 | 5000hour/year×20year |

- Beam dump structure is simplified.
- Type B & D & E, beam energy is set to 500GeV for future energy upgrade. (initial is 125GeV)

## ◆ Radiation Shield

- Iron Shield thickness is set to 50cm. Behind Iron Shield, Concrete shield is set.
  ⇒Estimate the required concrete thickness
  for the radioactivity density in concrete to be below the clearance level(Next slide).
- Co & Eu are highly effective in viewpoint of residual nuclide. I added more then usual.

**Concrete composition(density 0.22g/cm3)***

Usual(wt%):Co~0.002,Eu~0.0002

| Element | H | O | Na | Mg | Al | Si | K | Ca | Fe | Co | Eu |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wt% | 0.19 | 46.3 | 1.66 | 0.50 | 8.95 | 25.6 | 1.06 | 9.18 | 6.12 | 0.01 | 0.001 |

＊from HAZAMA ANDO corporation technical report 2015.vol3

# Clearance Level

## ➢ Clearance Level*

**<u>The standard of radioactivity concentration</u>** that is determined so as not to affect the human body regardless of how it is used or disposed of.

The clearance level ⇒radioactive concentration at which the amount of <u>radiation received per year is 0.01 mSv.</u> <u>This dose is less than 1 / 100th of the dose we receive from natural radiation,</u> and it is recognized internationally that even if multiple effects overlap, we can ignore the effects on human health .

## ➢ Clearance evaluation

- Summation of each radioactivity / each nuclei's clearance level.
- This summation should be less than 1.

Clearance Level for each radioactivity

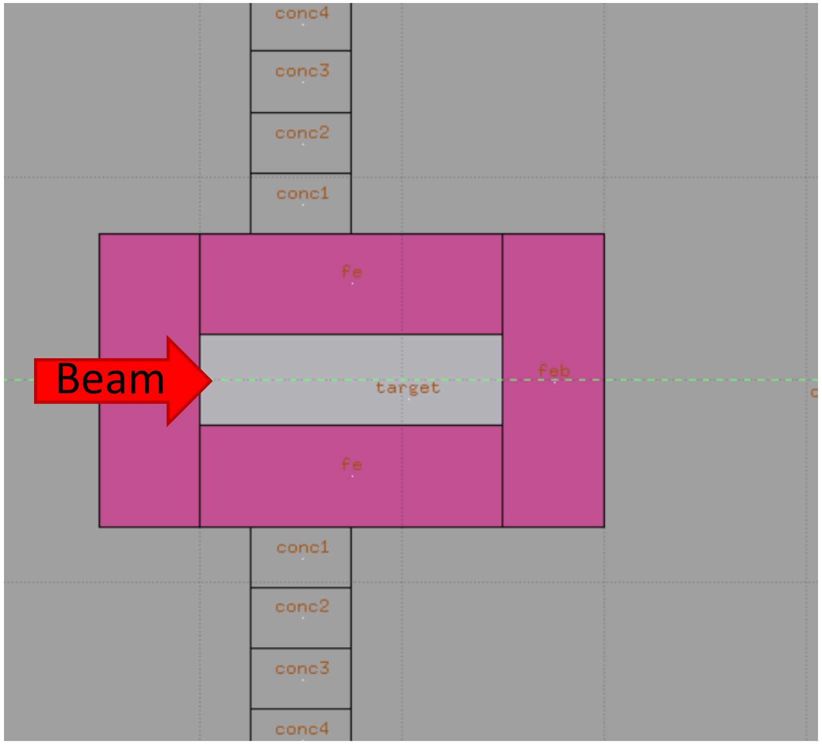
| | | |
|---|---|---|
| 二　放射線発生装置から発生した放射線により生じた放射線を放出する同位元素によつて汚染された物であつて金属くず又はコンクリート破片 | $^{3}H$ | 100 |
| | $^{7}Be$ | 10 |
| | $^{14}C$ | 1 |
| | $^{22}Na$ | 0.1 |
| | $^{36}Cl$ | 1 |
| | $^{41}Ca$ | 100 |
| | $^{45}Ca$ | 100 |
| | $^{46}Sc$ | 0.1 |
| | $^{44}Ti$ | 0.1 |
| | $^{54}Mn$ | 0.1 |
| | $^{55}Fe$ | 1000 |
| | $^{59}Fe$ | 1 |
| | $^{56}Co$ | 0.1 |
| | $^{57}Co$ | 1 |
| | $^{58}Co$ | 1 |
| | $^{60}Co$ | 0.1 |
| | $^{59}Ni$ | 100 |
| | $^{63}Ni$ | 100 |
| | $^{65}Zn$ | 0.1 |
| | $^{93m}Nb$ | 10 |
| | $^{94}Nb$ | 0.1 |
| | $^{108m}Ag$ | 0.1 |
| | $^{110m}Ag$ | 0.1 |
| | $^{113}Sn$ | 1 |
| | $^{124}Sb$ | 1 |
| | $^{125}Sb$ | 0.1 |
| | $^{123m}Te$ | 1 |
| | $^{134}Cs$ | 0.1 |
| | $^{137}Cs$ | 0.1 |
| | $^{133}Ba$ | 0.1 |
| | $^{139}Ce$ | 1 |
| | $^{152}Eu$ | 0.1 |
| | $^{154}Eu$ | 0.1 |
| | $^{160}Tb$ | 1 |
| | $^{182}Ta$ | 0.1 |
| | $^{195}Au$ | 10 |
| | $^{203}Hg$ | 10 |

Unit : Bq/g

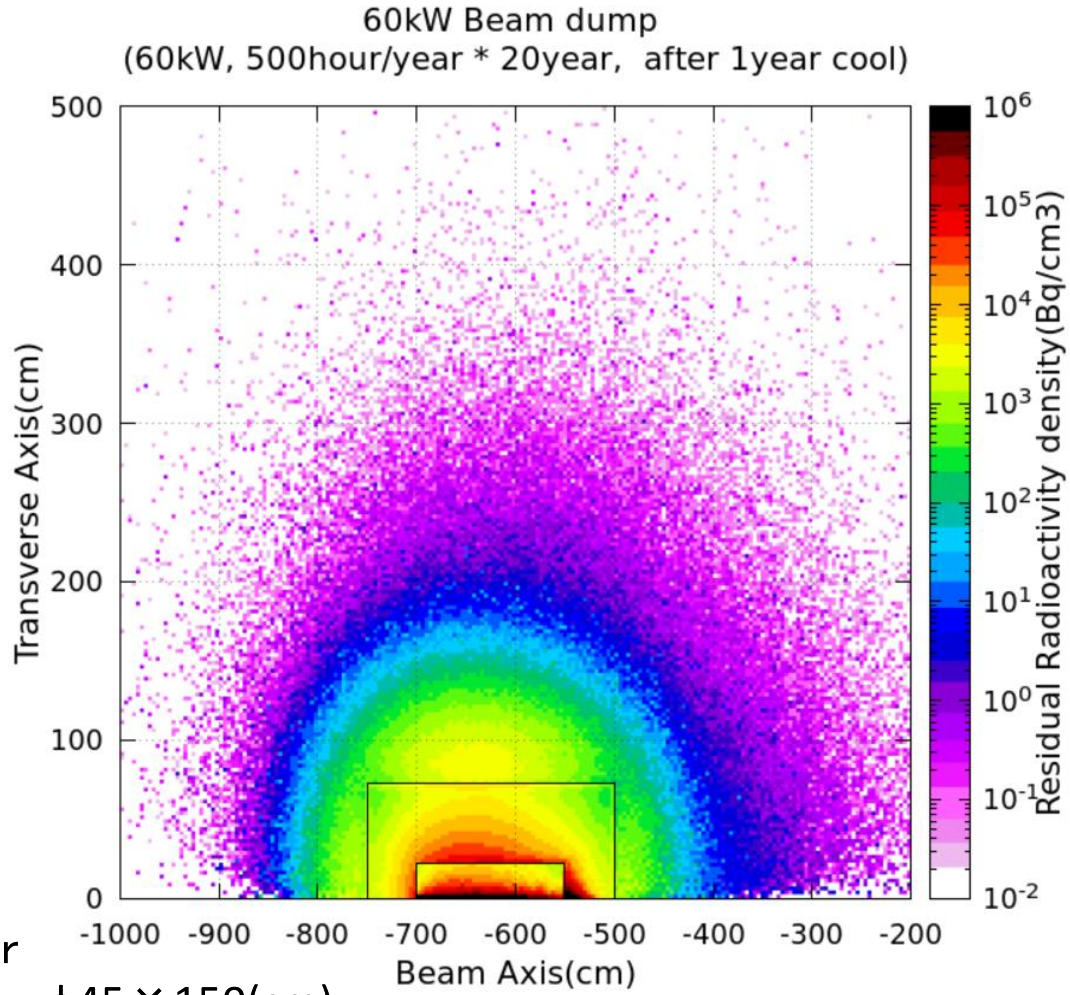
*[JAPAN Clearance system] https://www.fepc.or.jp/nuclear/haishisochi/clearance/index.html

# 60kW Beam dump (Aluminum , type A)

Simulation Geometry

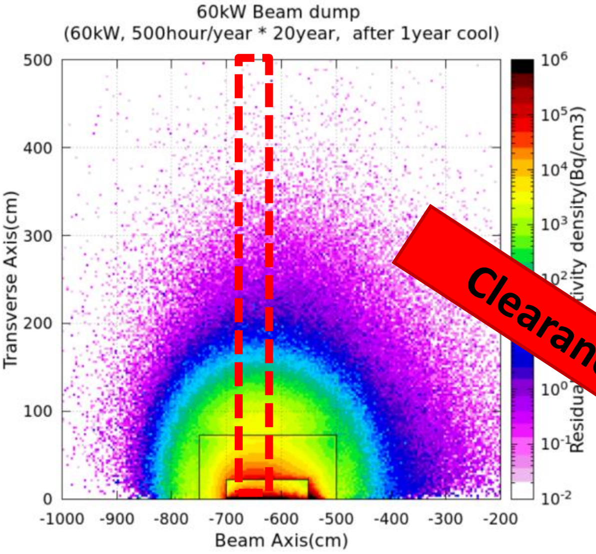


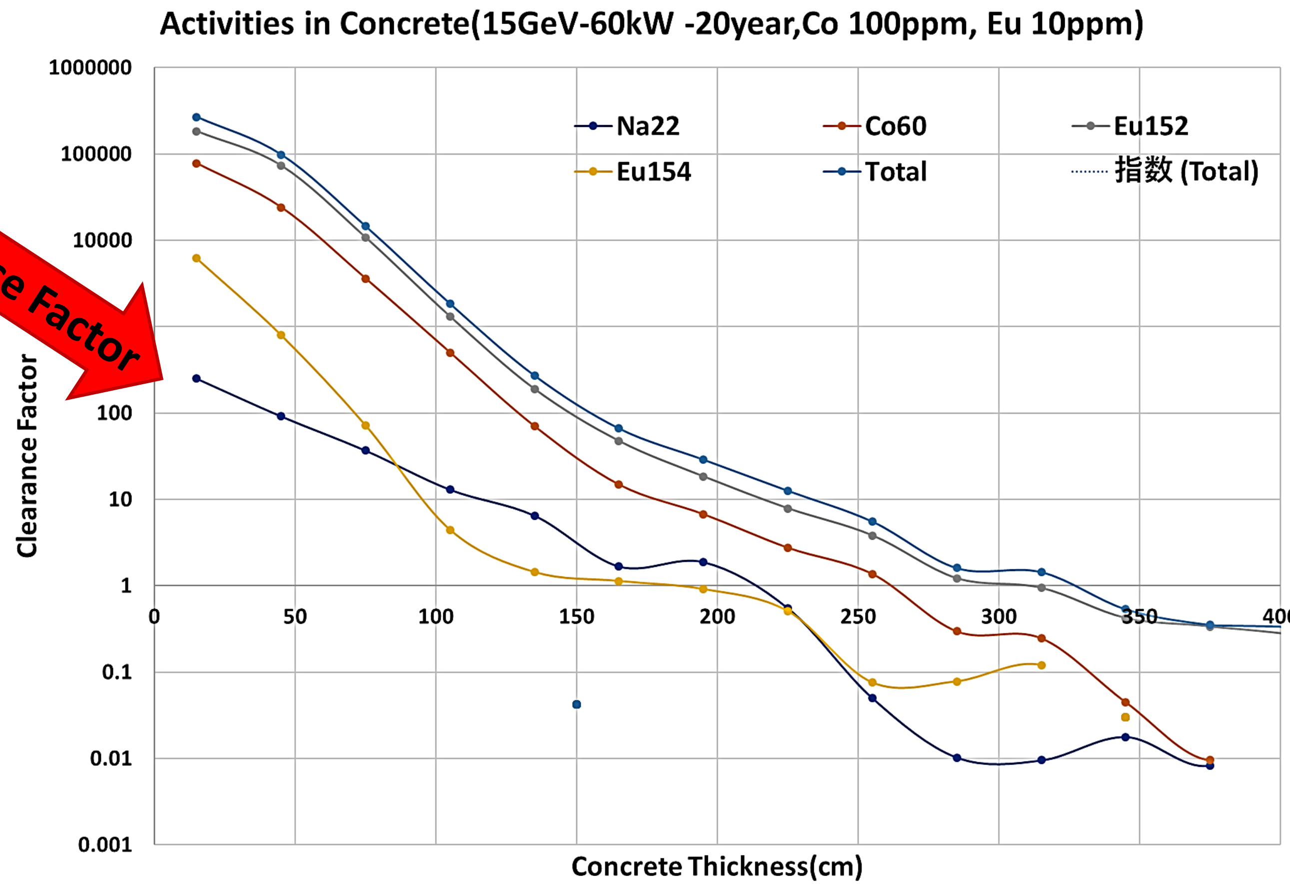

Residual activity density




・Beam operation : 500hour/year × 20year
・Main Absorber of dump : Aluminum Alloy ϕ45 × 150(cm)

# 60kW Beam dump (Aluminum , type A)

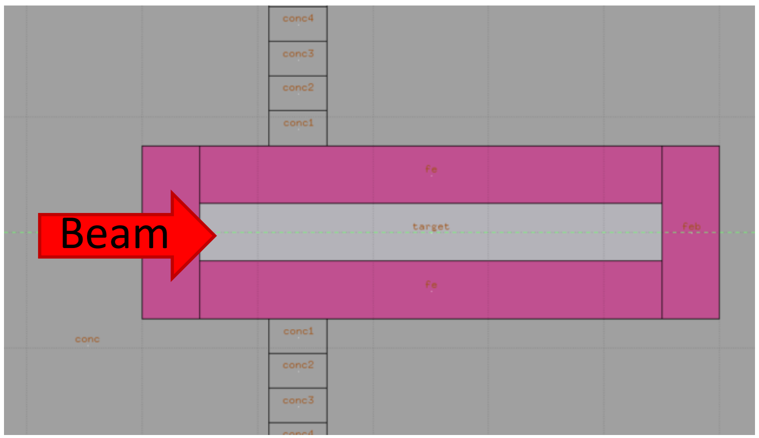


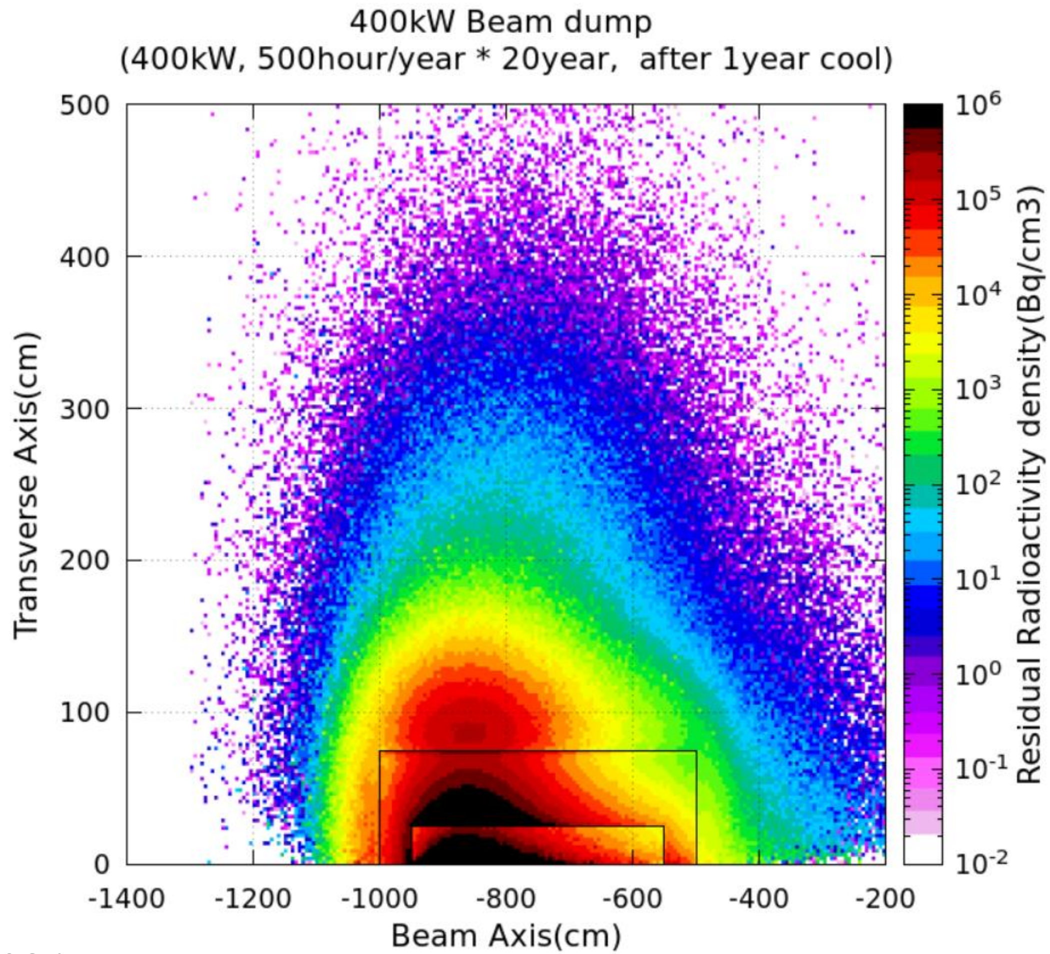

- To make clearance factor less than 1,
  Minimum concrete thickness will be ~3.5m at most activated place
  (20cm away from beam dump front).

# 400kW Beam dump (Graphite , type B)

Simulation Geometry



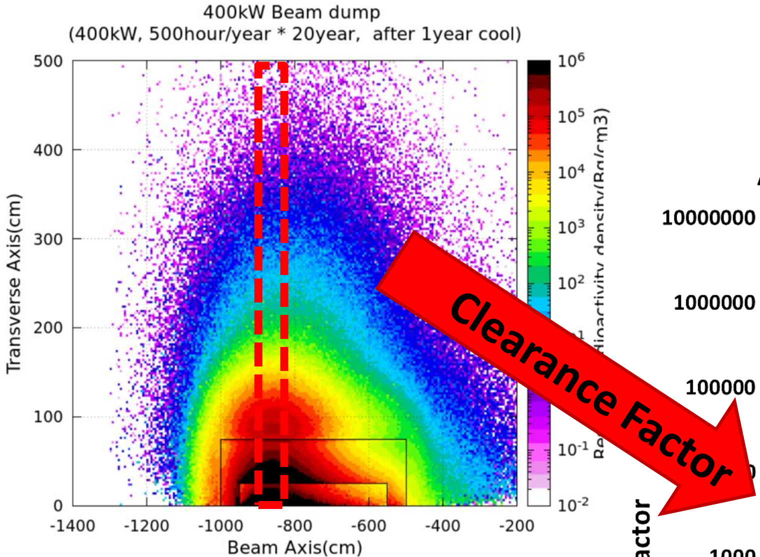

Residual activity density

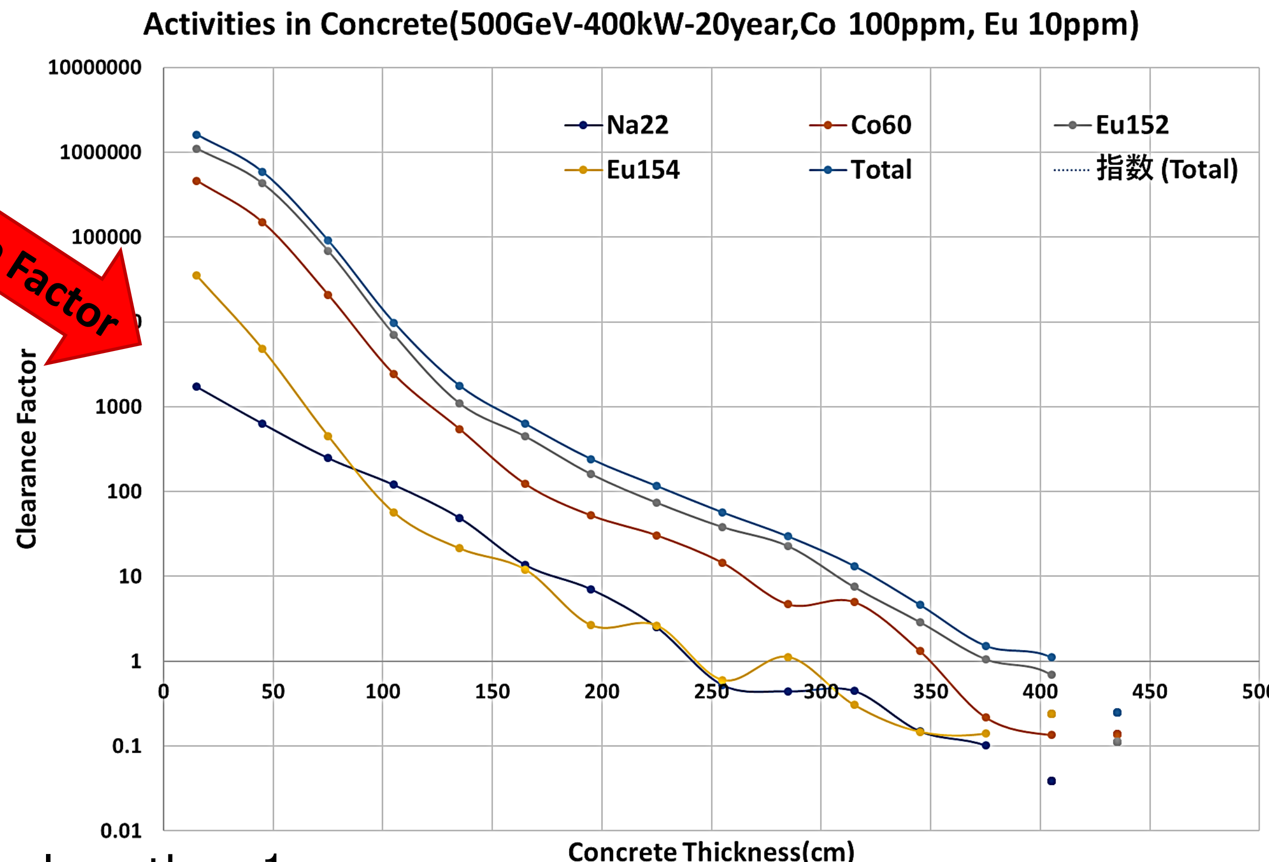



・Beam operation : 500hour/year × 20year

・Main Absorber of dump : Graphite ϕ50 × 400(cm)

# 400kW Beam dump (Graphite , type B)

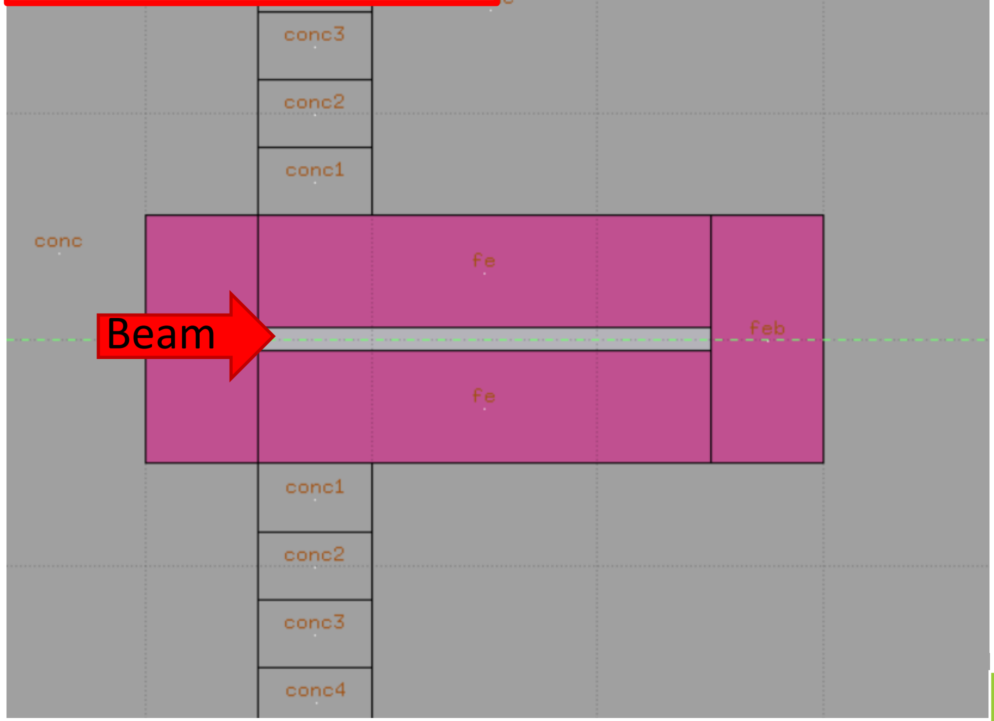



- To make clearance factor less than 1,
  Minimum concrete thickness will be ˜4.5m at most activated place
  (100cm away from beam dump front).

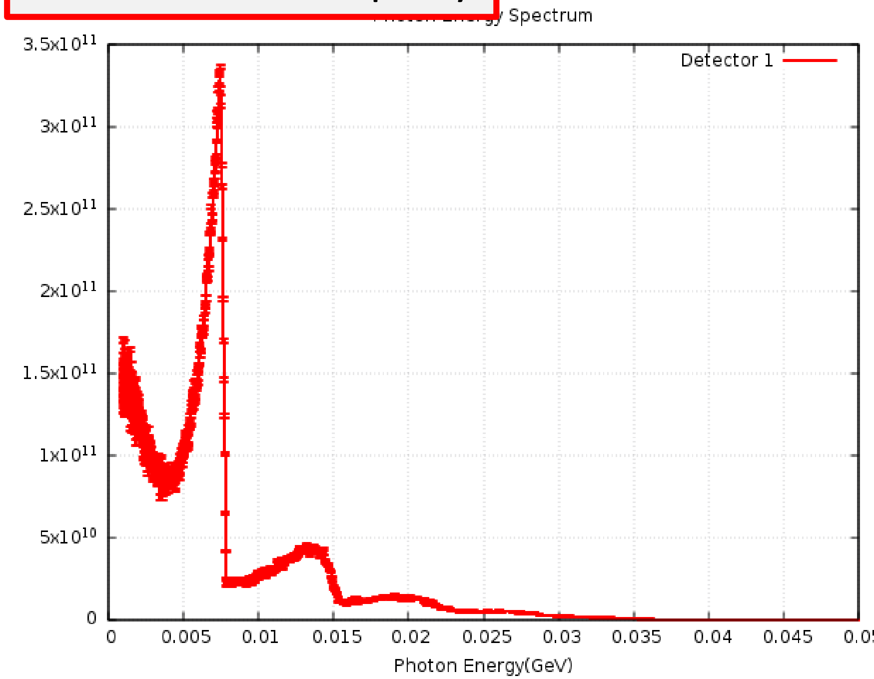
# Photon Beam dump (Graphite , type C)

## Simulation Geometry




- Beam operation : 5000hour/year × 20year
- Main Absorber of dump : Graphite t10 × 200(cm)

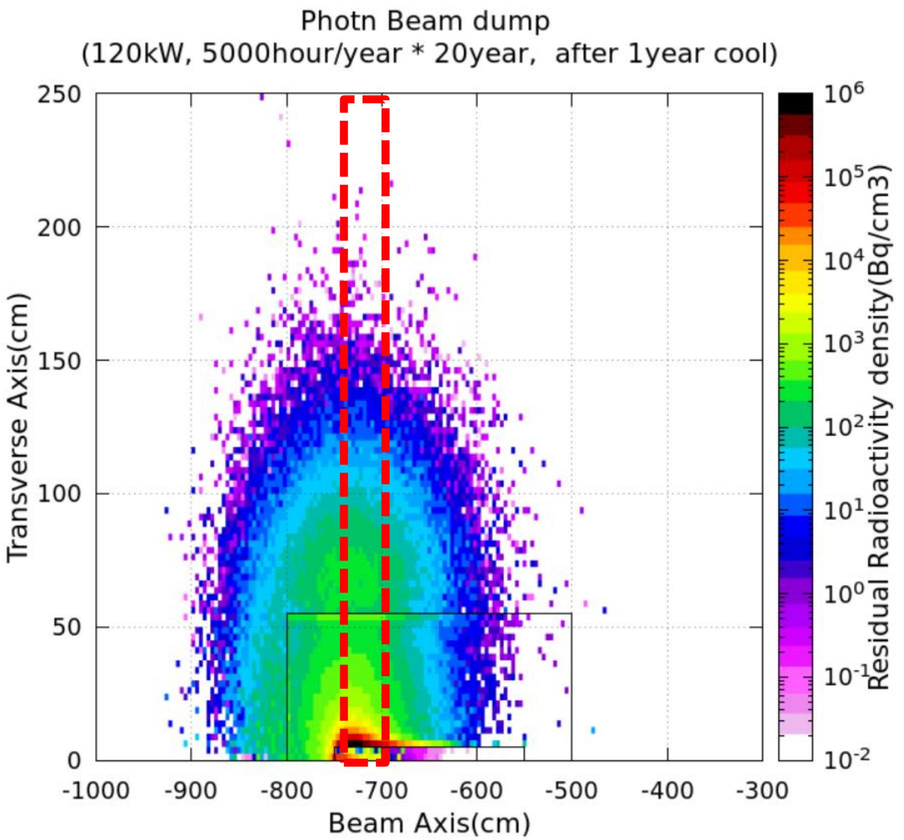
## Photon Beam Property

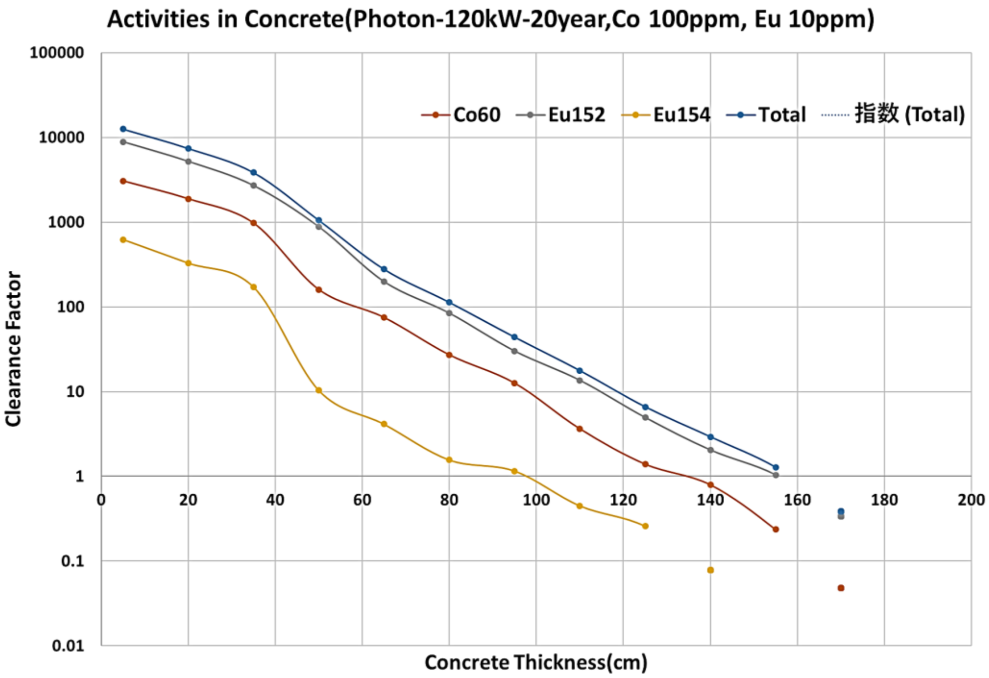



| Photon Beam | 250GeV stage |
|---|---|
| Num of photons/bunch | 8E12 |
| Num of bunches/pulse | 2625 |
| Pulse repetition | 5Hz |
| Peak Photon Energy | 7MeV, 14MeV... |
| Beam power | 120kW |

# Photon Beam dump (Graphite , type C)

Residual activity density

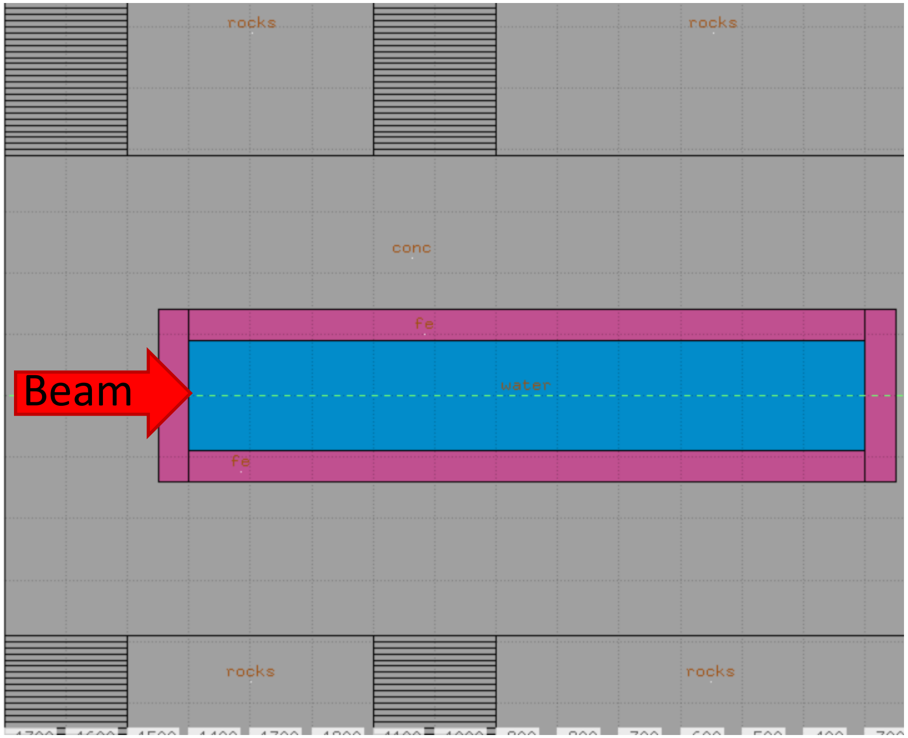


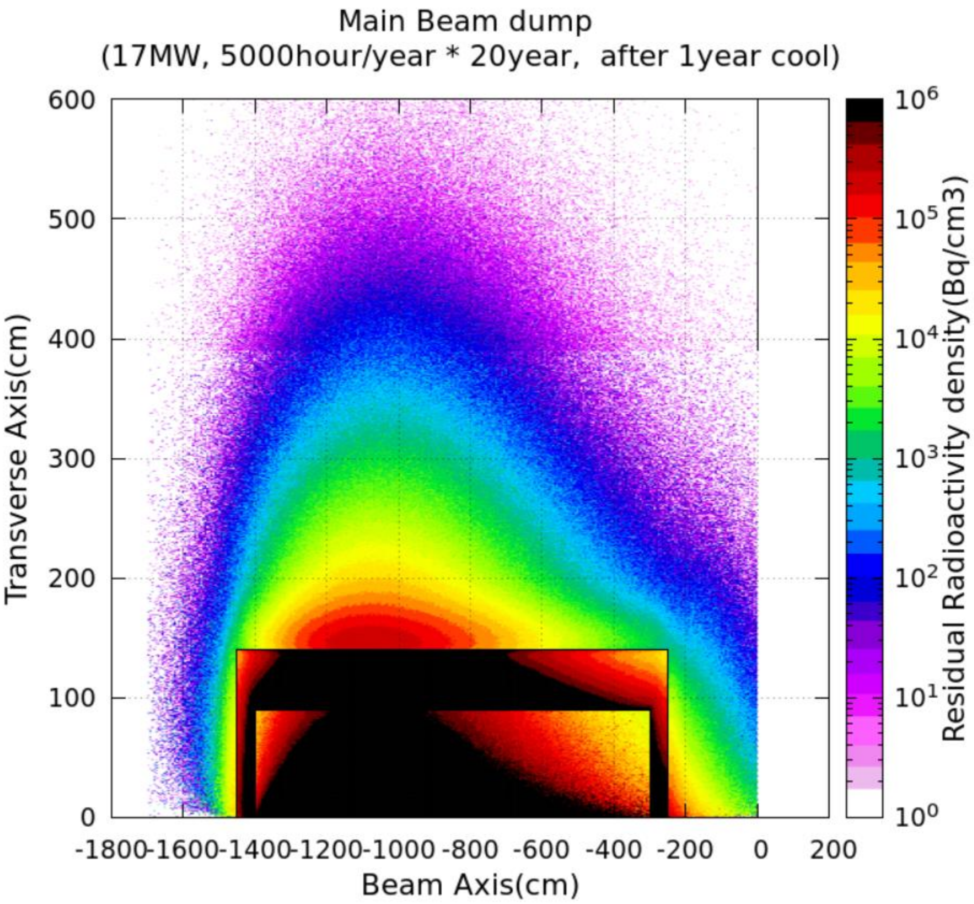

・To make clearance factor less than 1,
Minimum concrete thickness will be ~2.0m at most activated place
(10cm away from beam dump front).

# Main Beam Dump (Water , type D&E)

Simulation Geometry



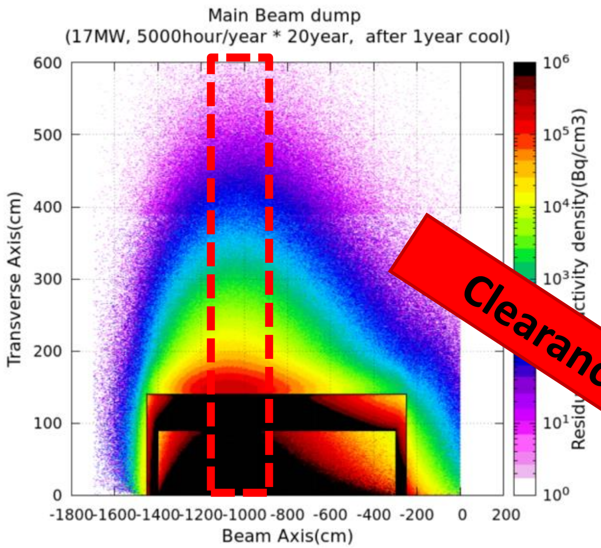

Residual activity density

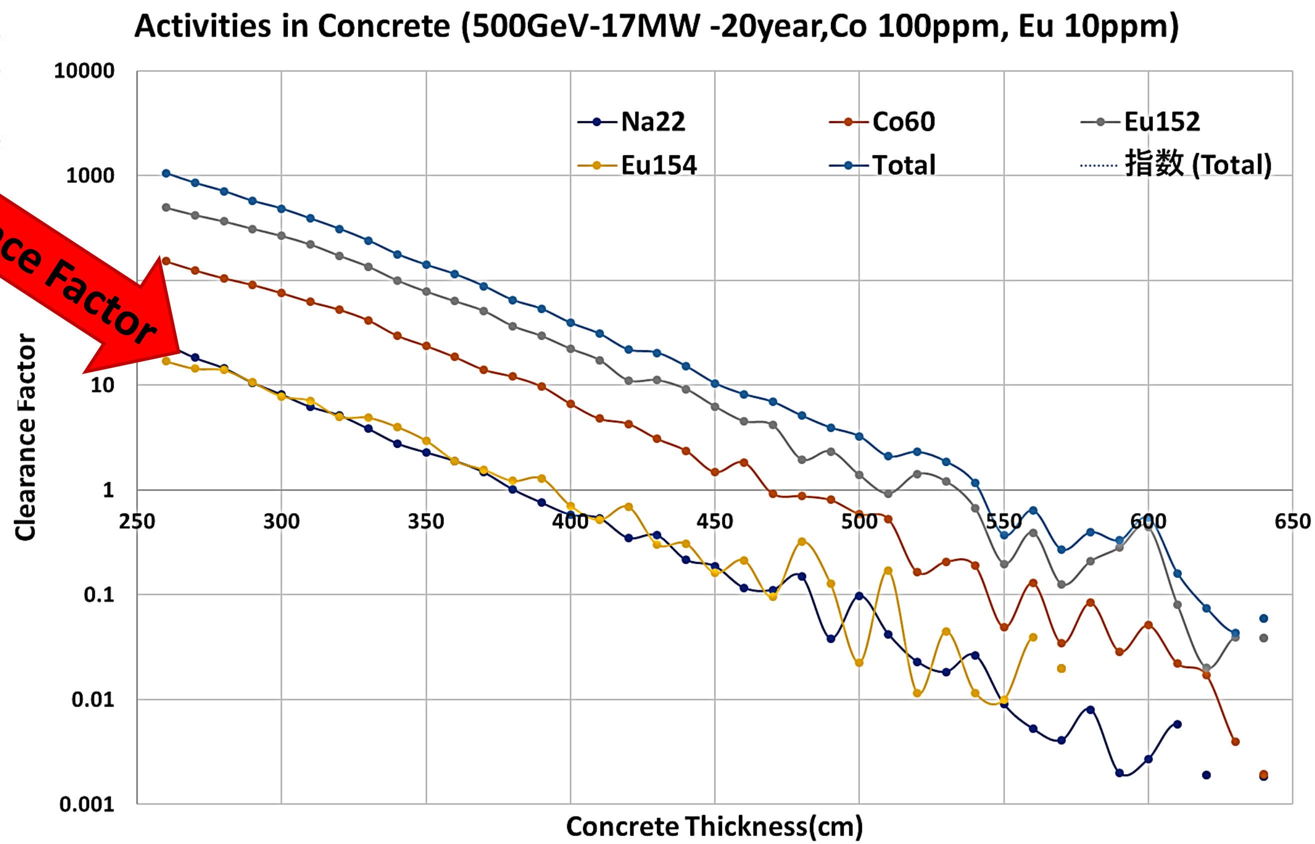



・Beam operation : 5000hour/year × 20year

・Main Absorber of dump : Water ϕ180 × 1100(cm)

# Main Beam Dump (Water , type D&E)




・To make clearance factor less than 1,
Minimum concrete thickness will be ~5.5m at most activated place
(4m away from beam dump front).

# Summary

# Summary & Next Step

- Estimate the required thickness of radiation shield so that there is no activation effect outside the tunnel.
- Co60, Eu152 are main components of activities in the shield material. These are produced by thermal neutron.

| Type | Beam Energy(GeV) | Beam Power(kW) | Operation Scenario | Concrete Thickness @ the most severely activated areas |
|---|---|---|---|---|
| A | 15 | 60 | 500hour/year × 20year | ~3.5m |
| B | 500 | 400 | 500hour/year × 20year | ~4.5m |
| C | Undulator Photon | 120 | 5000hour/year × 20year | ~2.0m |
| D,E | 500 | 17,000 | 5000hour/year × 20year | ~5.5m |

## Next Step

- Back side shield of Main dump. Muon penetration! (Next talk , Sakaki-san)
- Tunnel design to set these shield.
- To reduce the thermal neutrons effectively, Consider using boron and gadolinium(some special components?).