ILC Beam Dump design

【Situation & motivation】
・Pre-lab phase of ILC will start from April.2022
・We wants to discuss about R&D items of ILC dumps in pre-lab phase.

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At the beginning

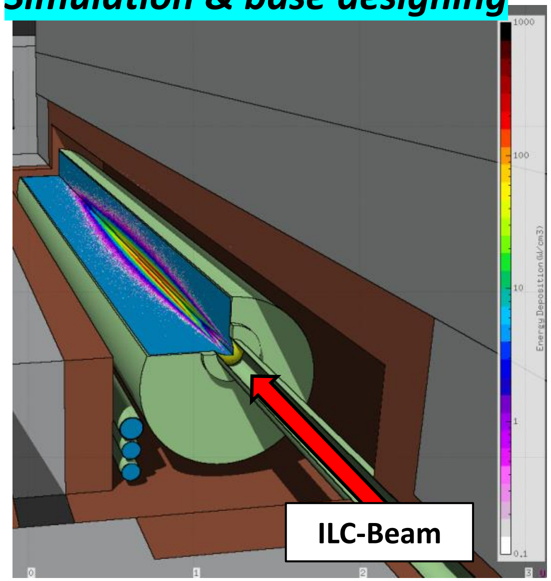
This time, I will talk about overview of main and tune-up dumps.

(Photon dump introduced last time is a special one.)

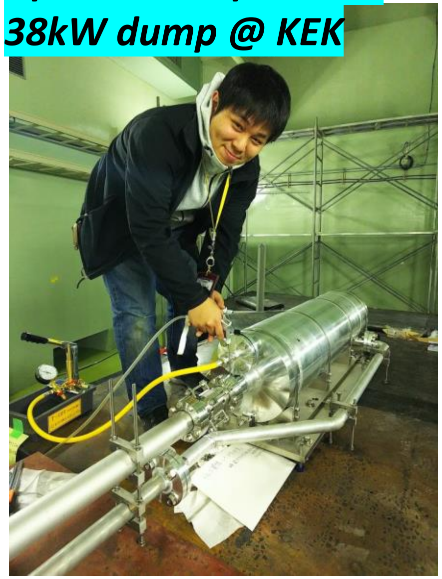
【Development in the last few years】

- Our team is responsible for ILC beam dump R&Ds and radiation protection issues.
- We proceeded the following R&Ds with limited budget and manpower.
- Recently, the movement toward the realization of the ILC has become active internationally. In Japan, R&Ds with companies have begun on dump development.

Simulation & base designing

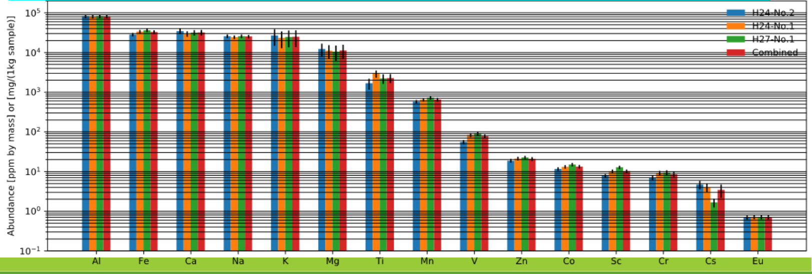


Operation experience 38kW dump @ KEK

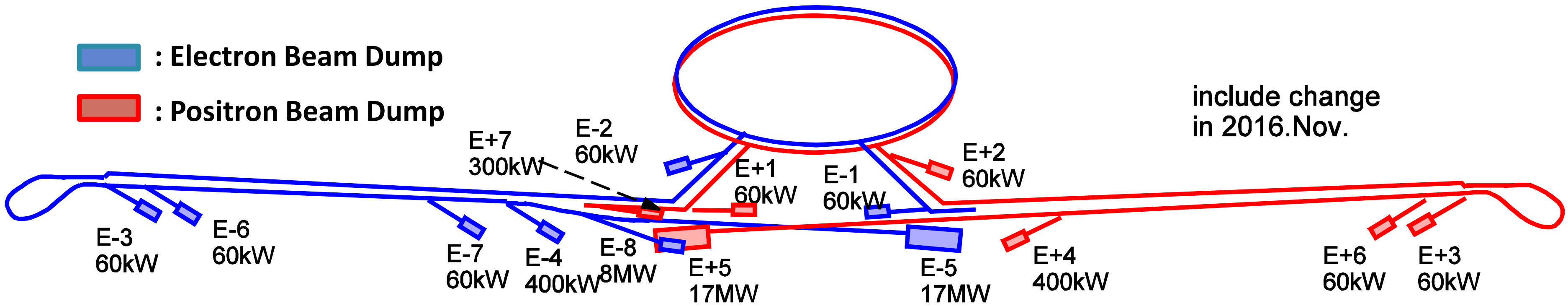


Learn from the origin water dump @SLAC

Elemental analysis of ILC-sight rock by neutron activation



ILC Beam Dumps



There are 15 beam dumps in the ILC

Type	Particle	Power	Absorber	Remarks
Tune-up	e^-/e^+	60 kW	Aluminum	For accelerator tuning.
	e^-/e^+	400 kW	Graphite	For main linac tuning. It's also used for beam abort in emergency of main dump.
Undulator photon	Photon	300 kW Include safety factor	Graphite or water	Undulator photons.
10 Hz operation	e^-	8 MW	Water	Required for positron generation during low energy operation.
Main Dump	e^-/e^+	17 MW Include safety factor	Water	Operation time : ~5000 hour/ year

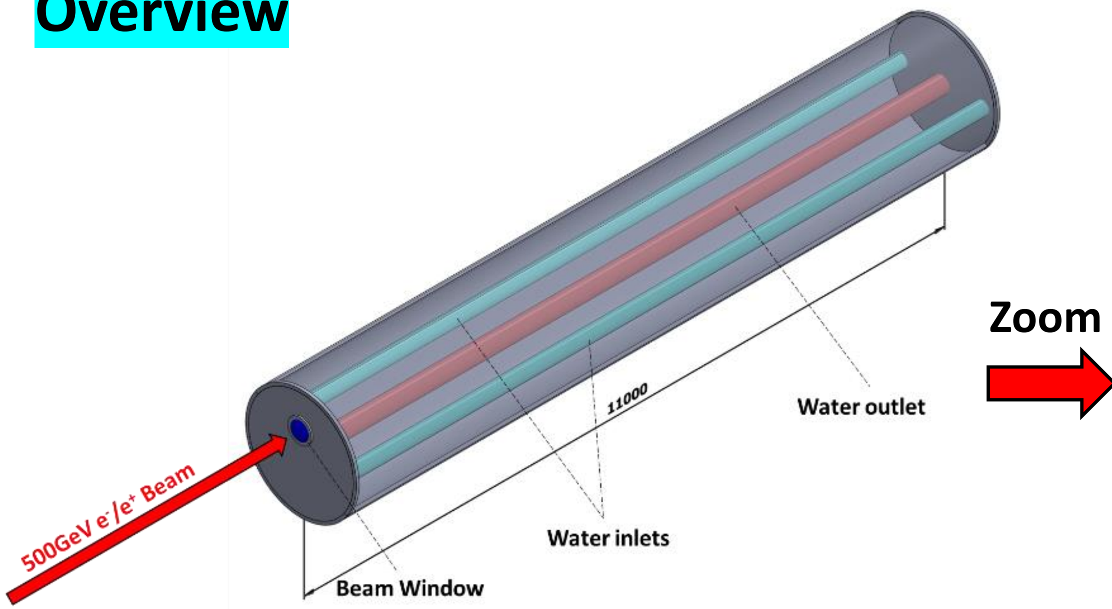
Main Beam Dump

- Base designing is already done and published in NIM*.
- In order to proceed the more detailed designing,
  now we have started discussions with companies(especially window).

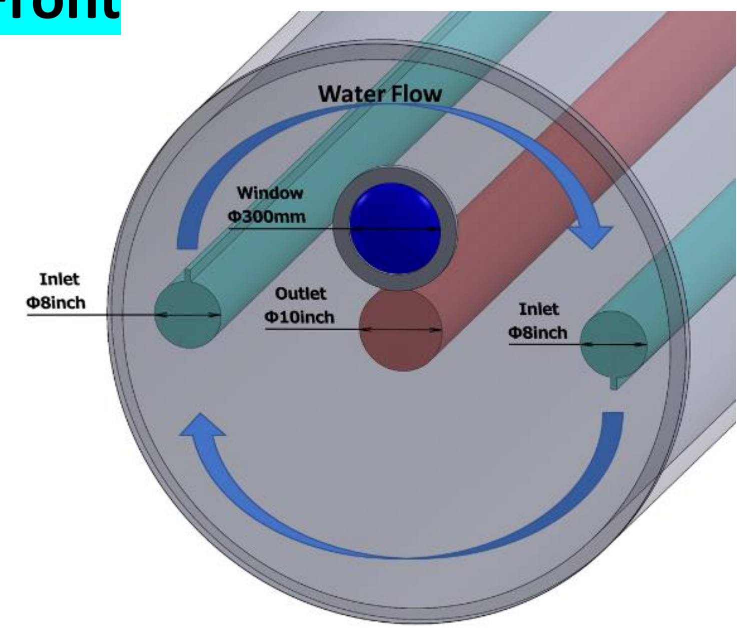
*P. Satyamurthy, et.al., NIM A 679 (2012)

Base Design of ILC Main Beam Dump

Overview



Front



【Base Design】

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

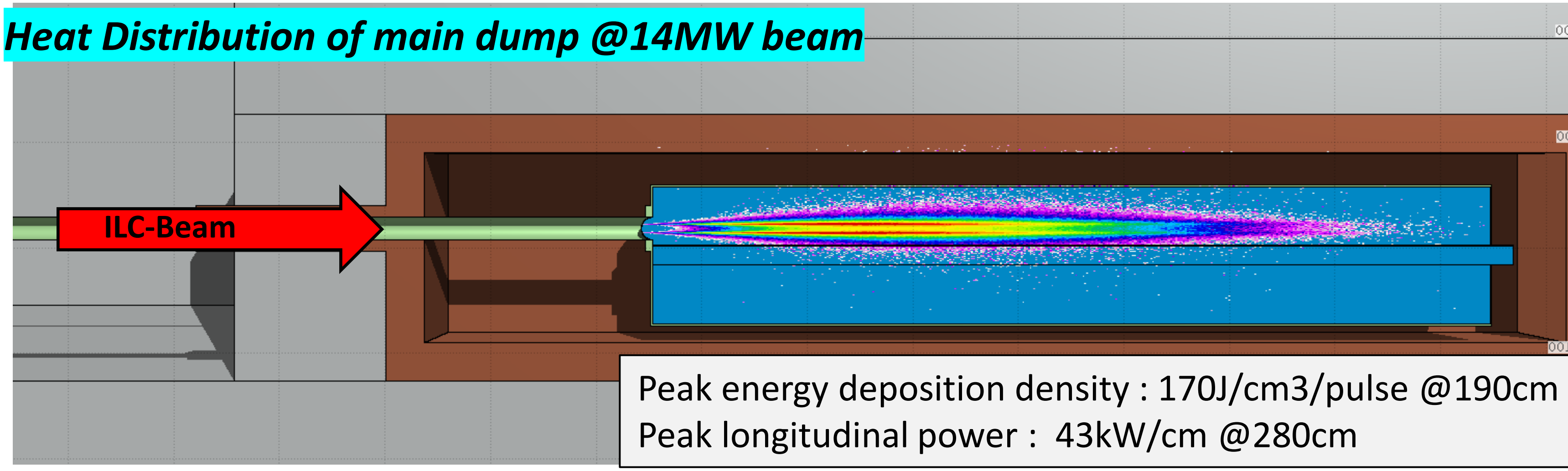
* Water tank body : ϕ180cm × 1100cm = ~28m^3, 31.5 radiation length.
* Water is pressurized **1 MPa** ⇒ **boiling temp 180℃**
* Vortex water flow ⇒ Mass flow rate : **104.5kg/s** each inlet, Ave flow velocity **2.17m/s**

・Beam Window made of **Ti-6Al-4V**.

Beam sweep : 1kHz sweep, sweep radius : **6cm**

Cooling capacity

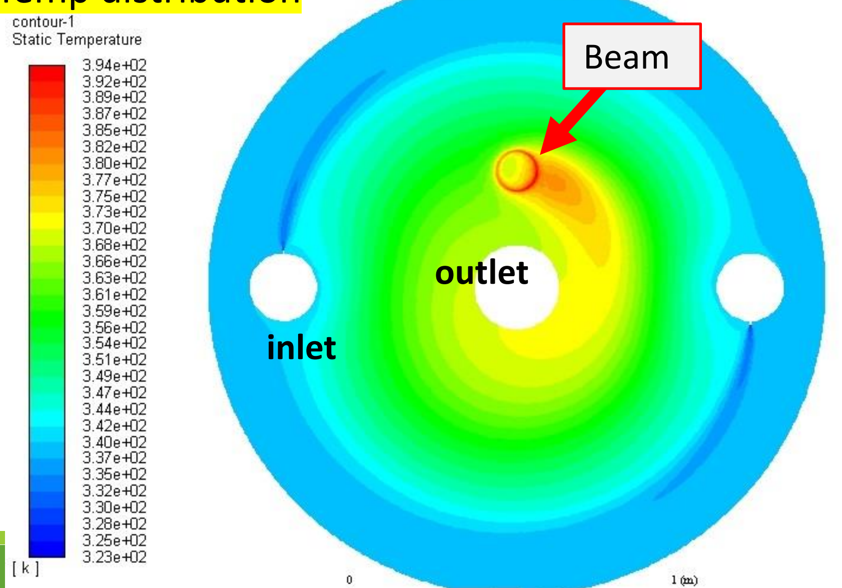
Heat Distribution of main dump @14MW beam



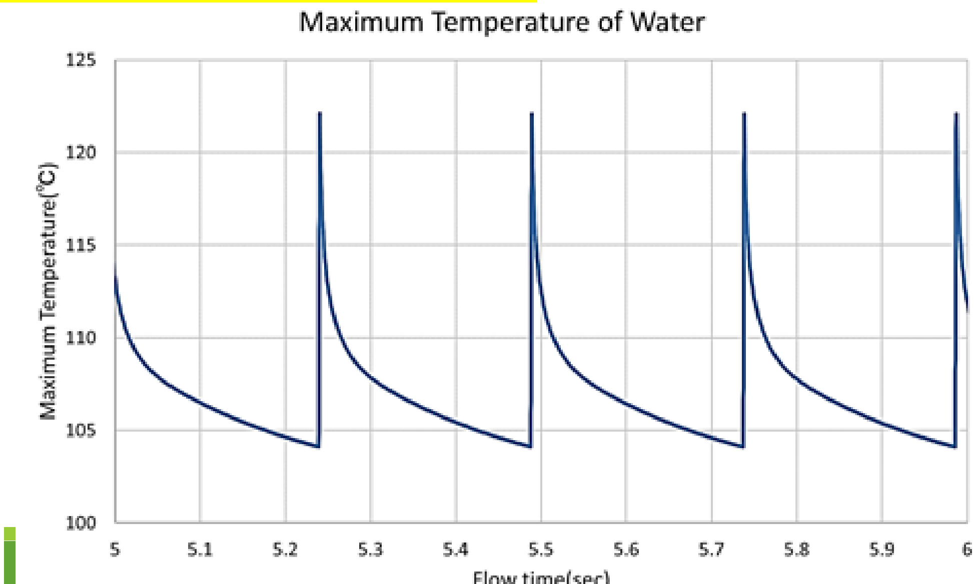
Peak energy deposition density : 170J/cm3/pulse @190cm
Peak longitudinal power : 43kW/cm @280cm

Temp response @14MW beam

Temp distribution

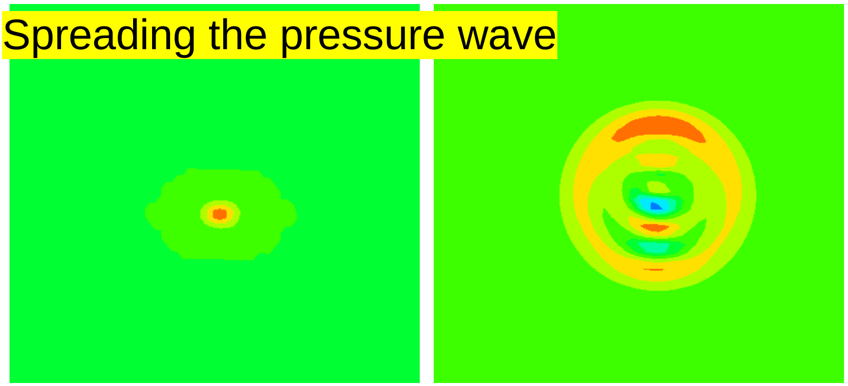


Time variation of max temp



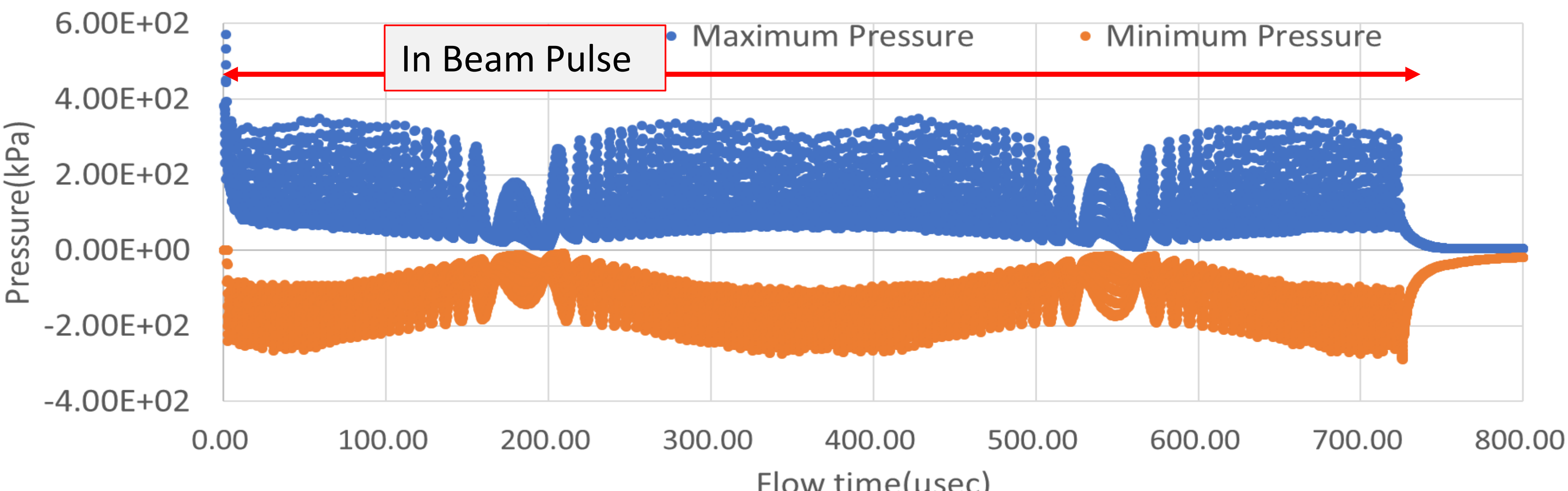
Pressure wave in water @ 250GeV stage

Pressure wave 2D-simulation by ANSYS-AUTODYN



- Thermal expansion due to beam heat generates the pressure waves
- Since the pressure wave also produces negative pressure, cavitation (bubble formation) occurs depending on the intensity.
- The negative pressure intensity of the pressure wave is about -3 atm, and the water is pressurized at 10 atm.

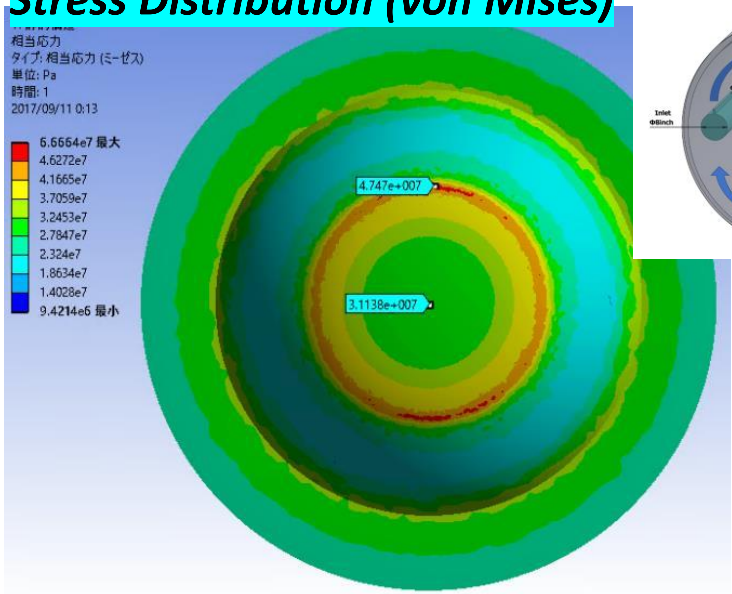
Time variation of Max & Min Pressure in water @Z=115cm

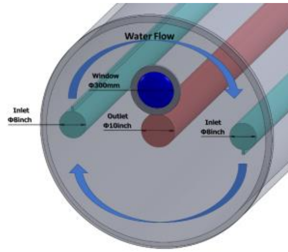


Window – thickness optimization

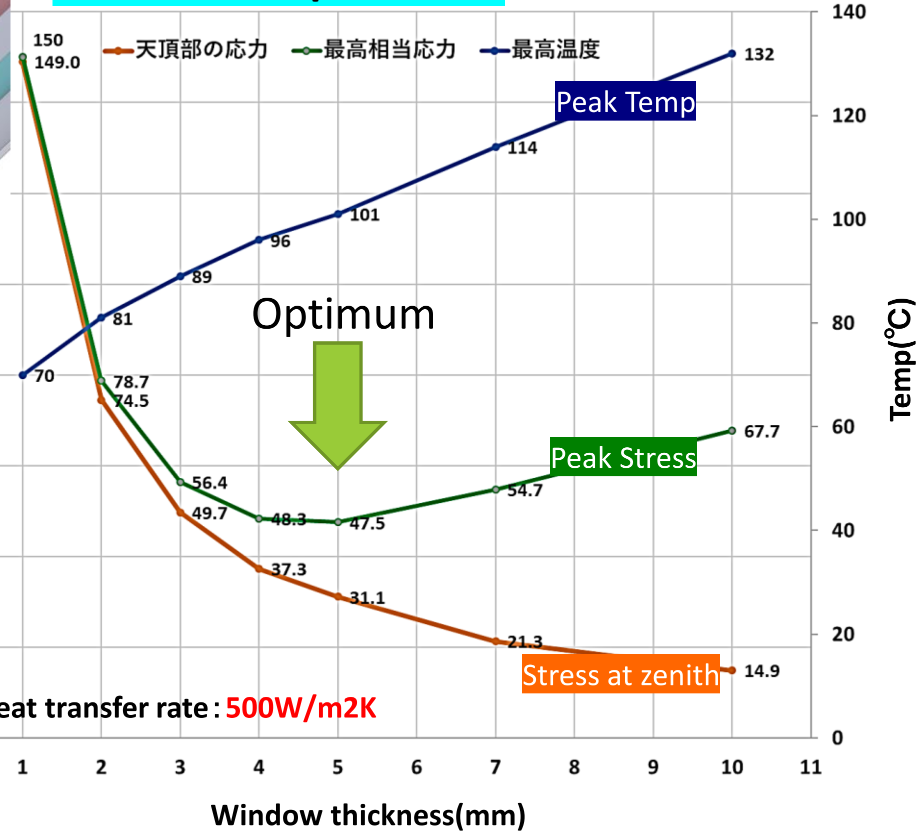
・Water Pressure 1MPa, ビーム入射した際の応力と温度、、、

Stress Distribution (von Mises)





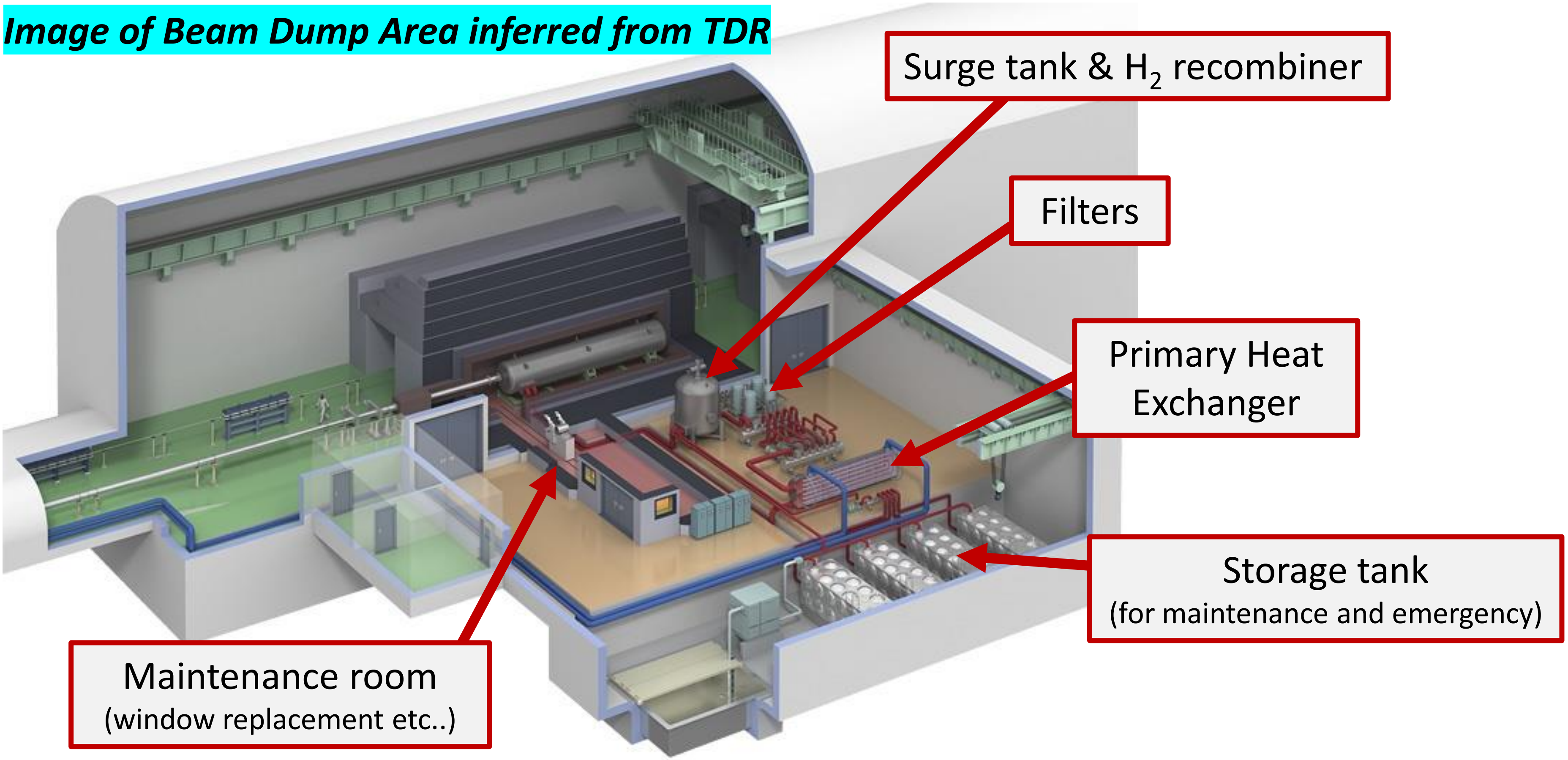
Thickness Dependence



・Window thickness:5mm
・Heat Transfer rate:500W/m2K
・Zenith Stress:31MPa
・Max Stress:47MPa

- The baseline thickness is 1 mm.
- From result of simulation, stress is the lowest when the thickness is 5mm.
  (Tensile stress of Ti6Al4V ~ 1GPa, and peak stress of window is ~50MPa @t=5mm.)

Beam Dump Area



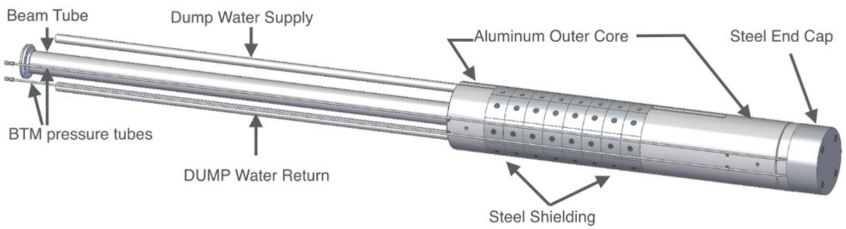
- We have no concrete design yet, we will proceed it.
- It is also important to take measures against leakage of activated water.
  The ILC site does not flush radiated water.

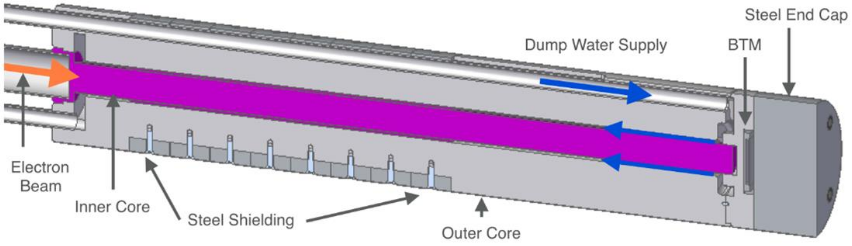
Tune up Beam Dump(60kW)

・Mainly used in initial commissioning

Examples of multi-10kW dump

【LCLS-Ⅱ dump】





LCLS-II TN-17-12
LCLS-II Beam Dumps

- **Max 120 kW = 4GeV × 30μA**
- **Absorber : A6061-T6**

【E-XFEL dump(Tune-up)】

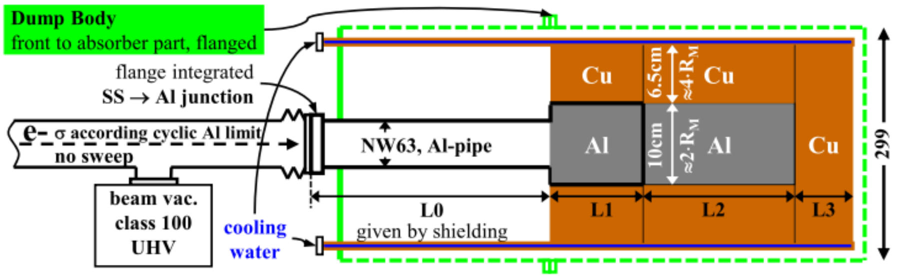


Figure 16: Common design scheme for all low energy dumps (INJ, BC1 and BC2).

Max 12kW = 300MeV × 40μA, Aluminum

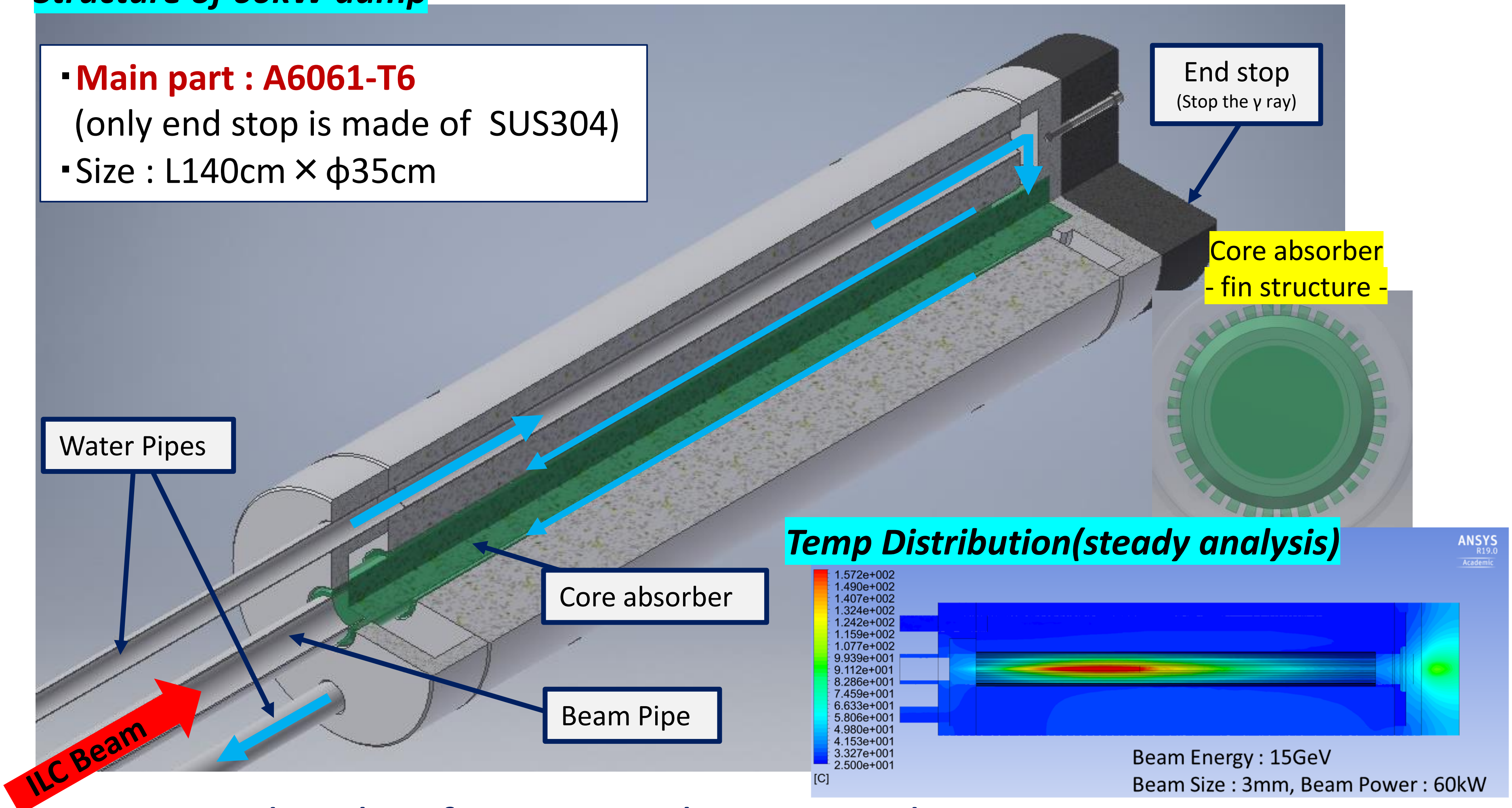
Description of the beam dump systems for the European XFEL, 20.12. 2013

- There are good examples in the world.
- It needs to be well designed, but it's not a big obstacle.

Base Design - 60kW

Structure of 60kW dump

- **Main part : A6061-T6**
  (only end stop is made of SUS304)
- Size : L140cm × ϕ35cm



Temp Distribution(steady analysis)

PEDD:32(J/g/pulse) @ Z=30cm
Peak Longitudinal Power:880W/cm @Z=45cm

- Designed with reference to the LCLS-2 dump
- We think there is no problem with thermal issues.

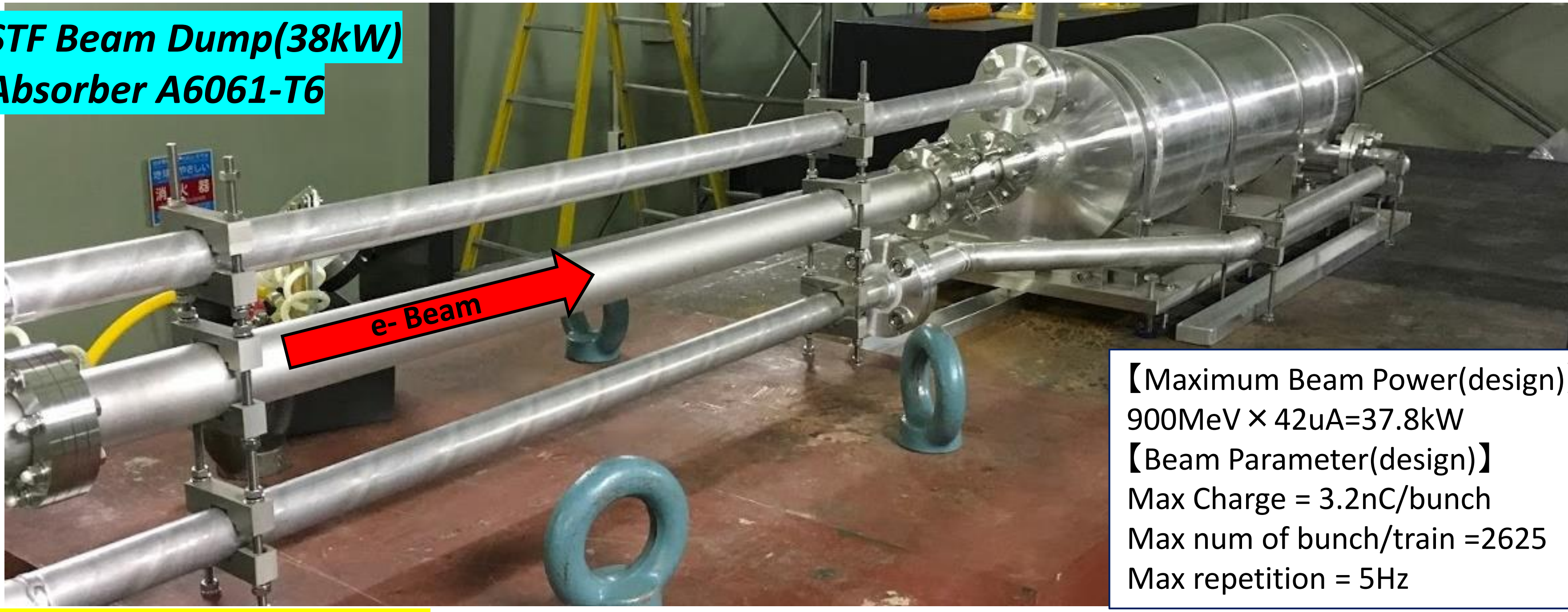
Beam Dump operation for STF @KEK

Test accelerator for R&D of Superconducting RF @KEK
ILC-like beam!

【Beam spec】
- Particle : electron
- Energy : 900MeV
- ave Current : 42μA
- Power : 37.8 kW

STF Beam Dump – 38kW

STF Beam Dump(38kW)
Absorber A6061-T6



【Maximum Beam Power(design)】
900MeV × 42uA=37.8kW
【Beam Parameter(design)】
Max Charge = 3.2nC/bunch
Max num of bunch/train =2625
Max repetition = 5Hz

Core part before assemble

Core absorber

- STF dump was designed with reference to LCLS-Ⅱ dump. Commissioned from March 2019. It’s good training for dump operation at ILC.
- **Beam power is being gradually upgraded.**
  (F.Y.2020(now) :1.35kW , F.Y.2021 :13.5kW , F.Y.2022~ :135kW?)

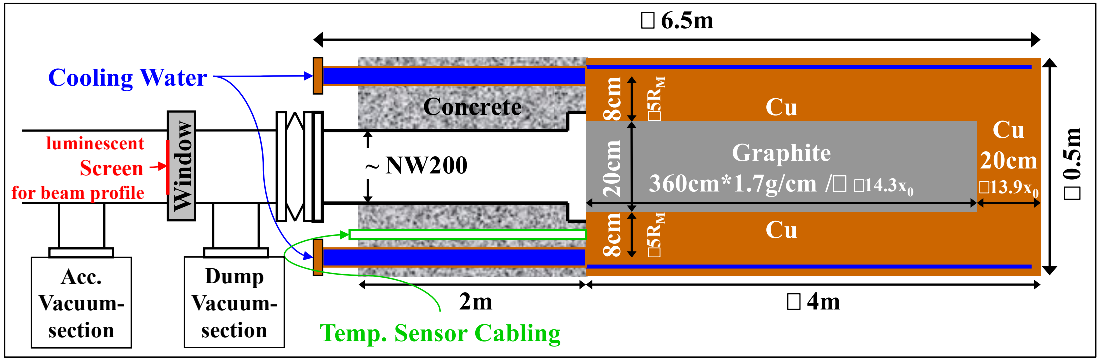
*STF : Test accelerator for R&D of Superconducting RF @KEK

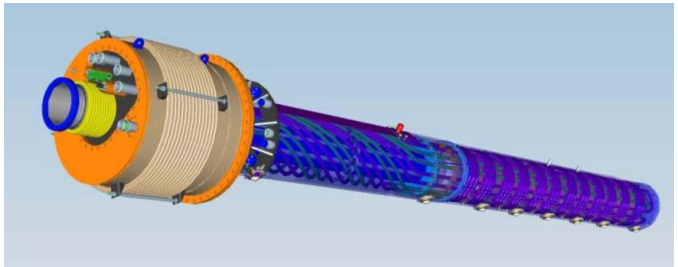
Tune up Beam Dump(400kW)

- Mainly used in initial LINAC commissioning
- Beam abort in emergency of main dump.

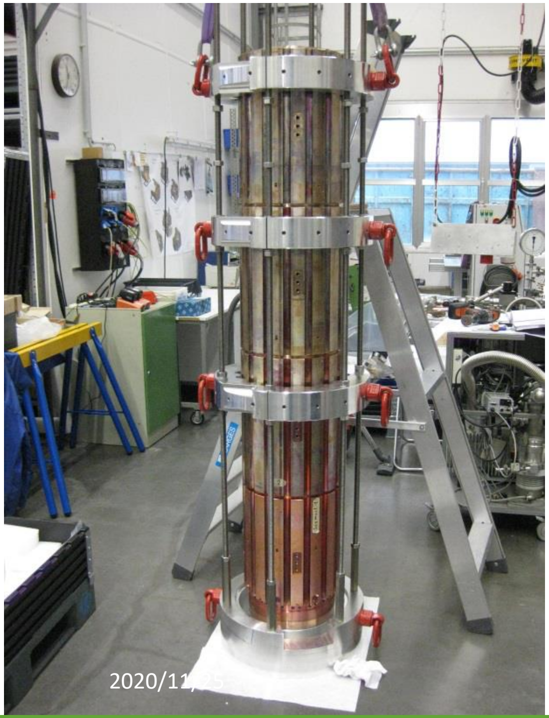
Example of 400kW dump

- E-XFEL main dump will be good example of ILC 400kW dump
- Max Power = 300kW (typical 25GeV × 12μA), Graphite core.



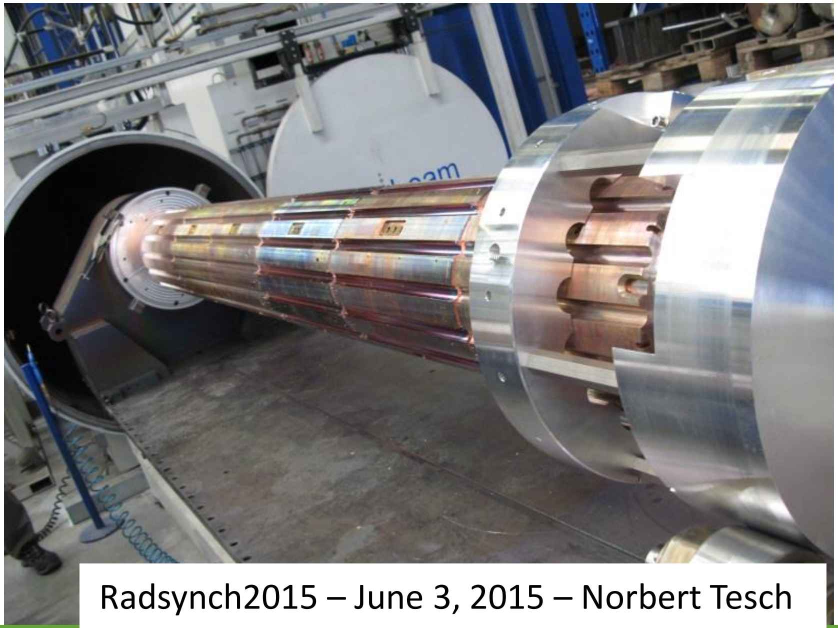


Main dump with muff for Argon system



Main dump segments before EB welding

Main dump segments after EB welding



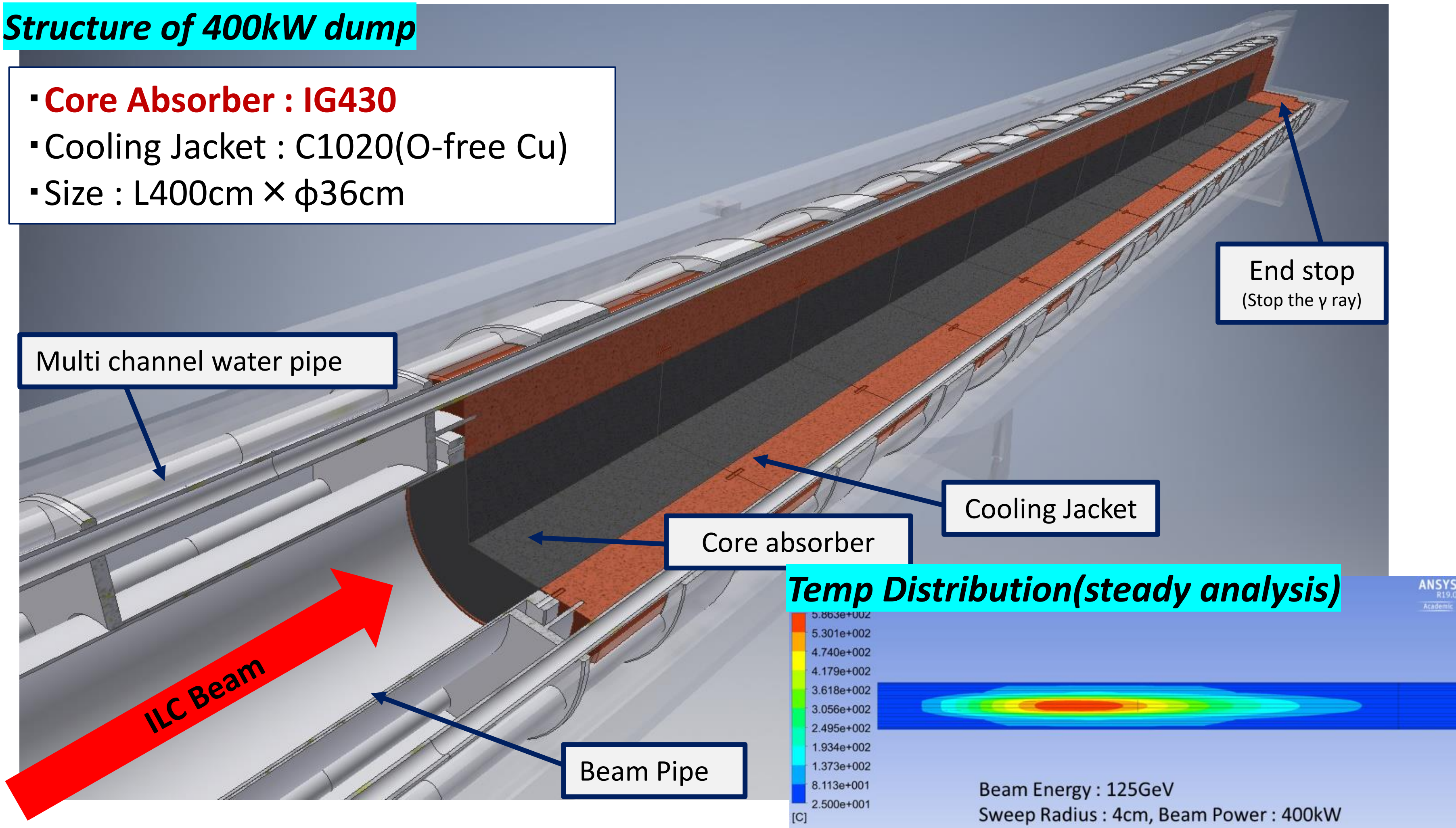
Radsynch2015 – June 3, 2015 – Norbert Tesch

Base Design - 400kW

Structure of 400kW dump

- **Core Absorber : IG430**
- Cooling Jacket : C1020(O-free Cu)
- Size : L400cm × ϕ36cm

Temp Distribution(steady analysis)



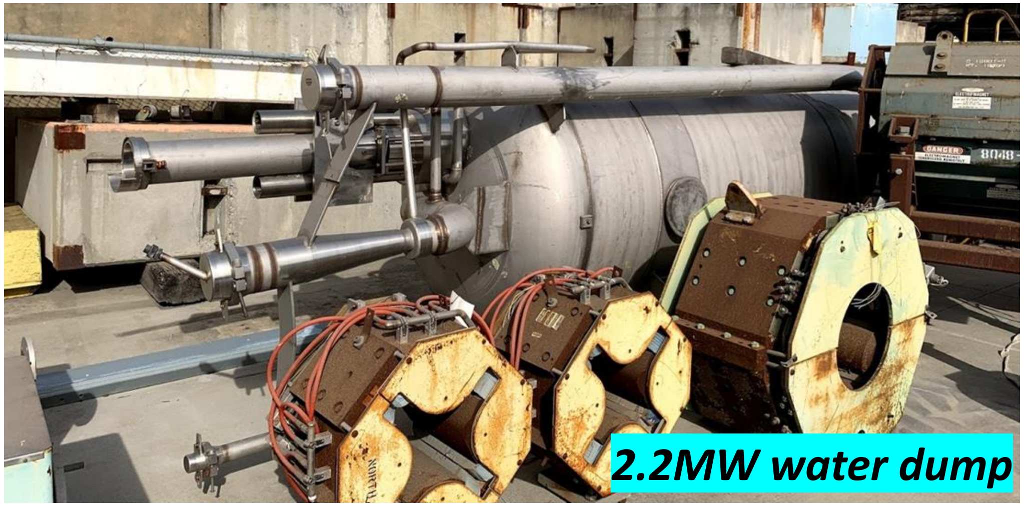
PEDD:240(J/g/pulse) @ Z=110cm
Peak Longitudinal Power:6.5W/cm @Z=160cm

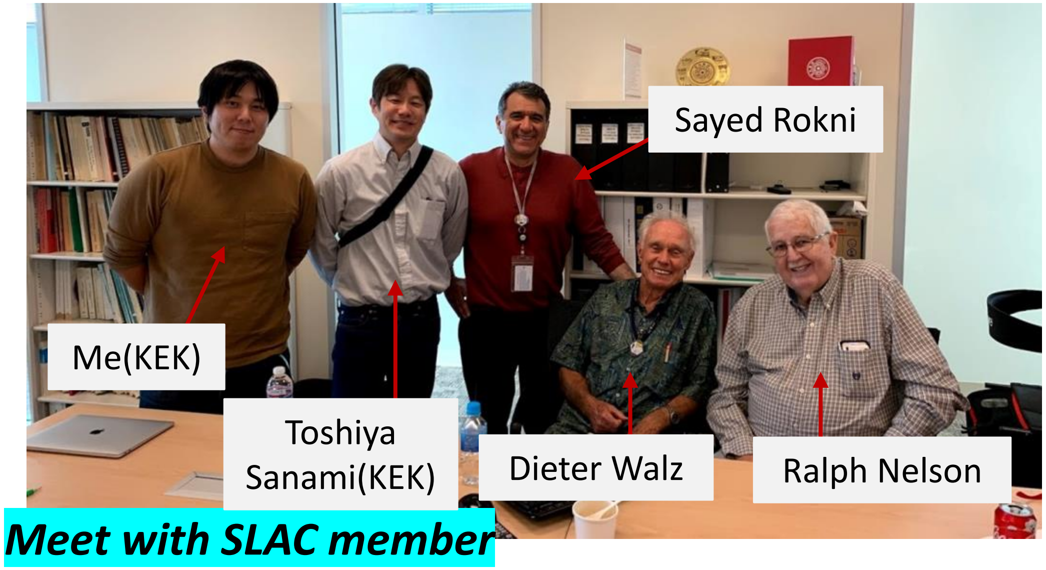
- Beam sweep : ϕ8cm
- We think there is no problem with thermal issues.

Water dumps in USA

- Original of ILC water dump @SLAC
- Water dump still in operation @JLab

SLAC - Water dump





Nov.2019, We visited to SLAC.

【Contact Person】

・Sayed Rokni(Radiation ,Head)

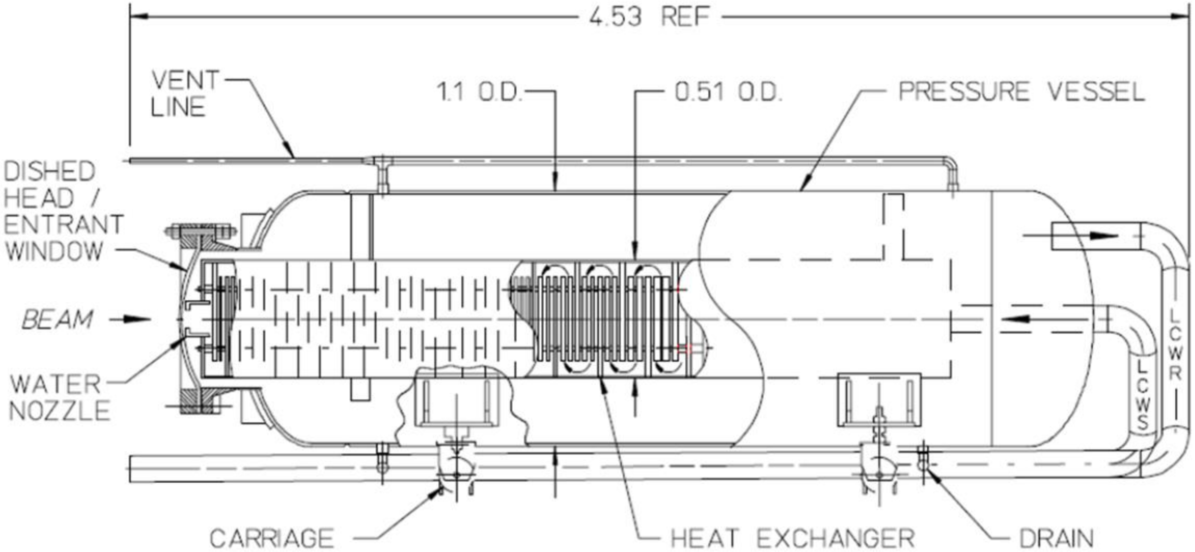
・Santana Mario(Radiation)

・Dieter Walz(OB, Developer of water dump)

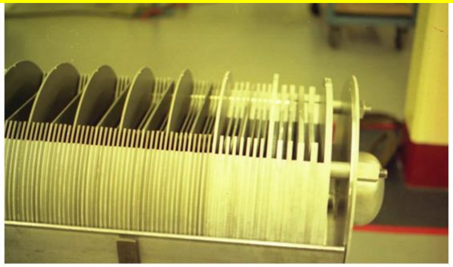
・Ralph Nelson(OB)

JLab - Water dump

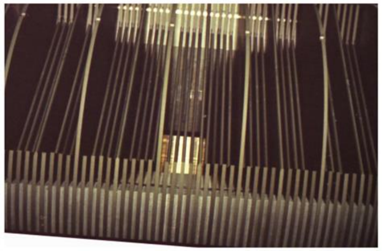
Water Dump @JLab - 10GeV ×100uA = 1MW



Aluminum Plate(A6061-T6)

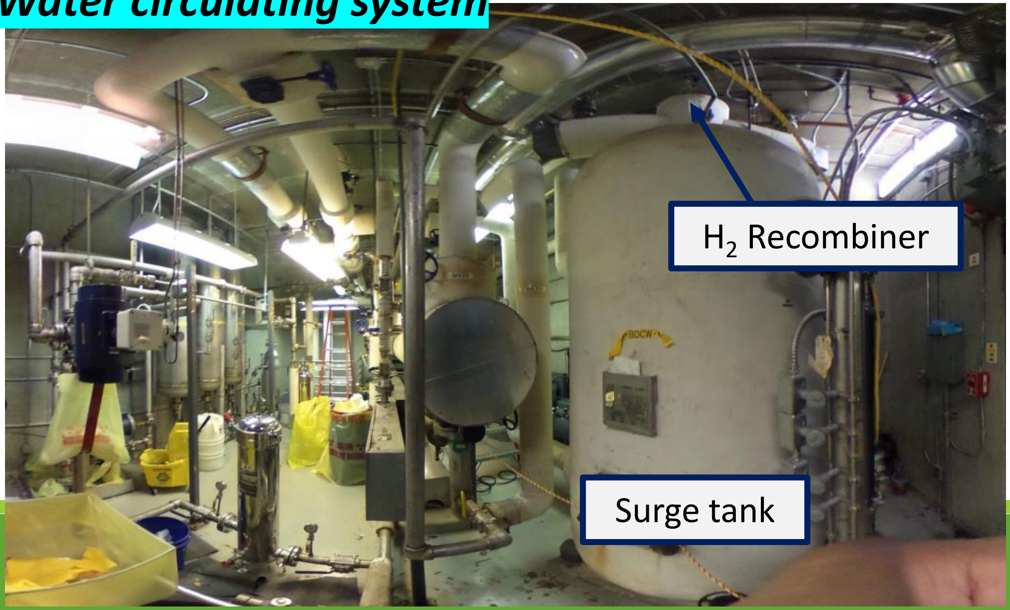


Front section with nozzle



Top view of HX plates. Thinnest plates 3/16" thick

Water circulating system



Nov.2019, We visited to JLAB.
【Contact Person】
・Rong-Li Geng(SRF scientist)
・Mark Wiseman(Engineering division)
・Tim Michalski(Engineering division)

Keep contact to discuss about water dump experiences.

For the pre-lab phase

【Situation & motivation】

・Pre-lab phase of ILC will start from April 2022.

・We wants to discuss about R&D items of ILC dumps in the pre-lab phase.

【Current status】

・Base designing is done with reference to examples in the world.
Especially Main dump system was published in NIM*.

・ In order to proceed the more detailed designing,
now we have started discussions with companies.

【R&D items】

・Details of main dump body, inlet & outlet pipes to realize designed water flow.

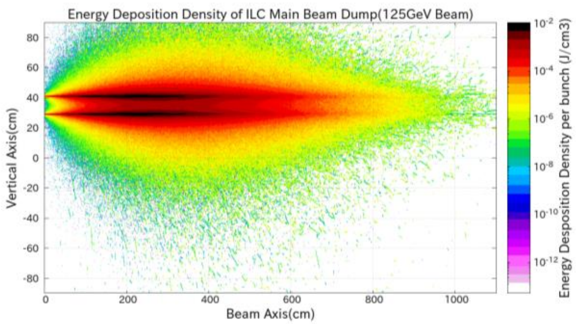
・Details of beam window replacement system. Second beam window, etc

・Management of radioactive components. water, filters, components replaced, etc.

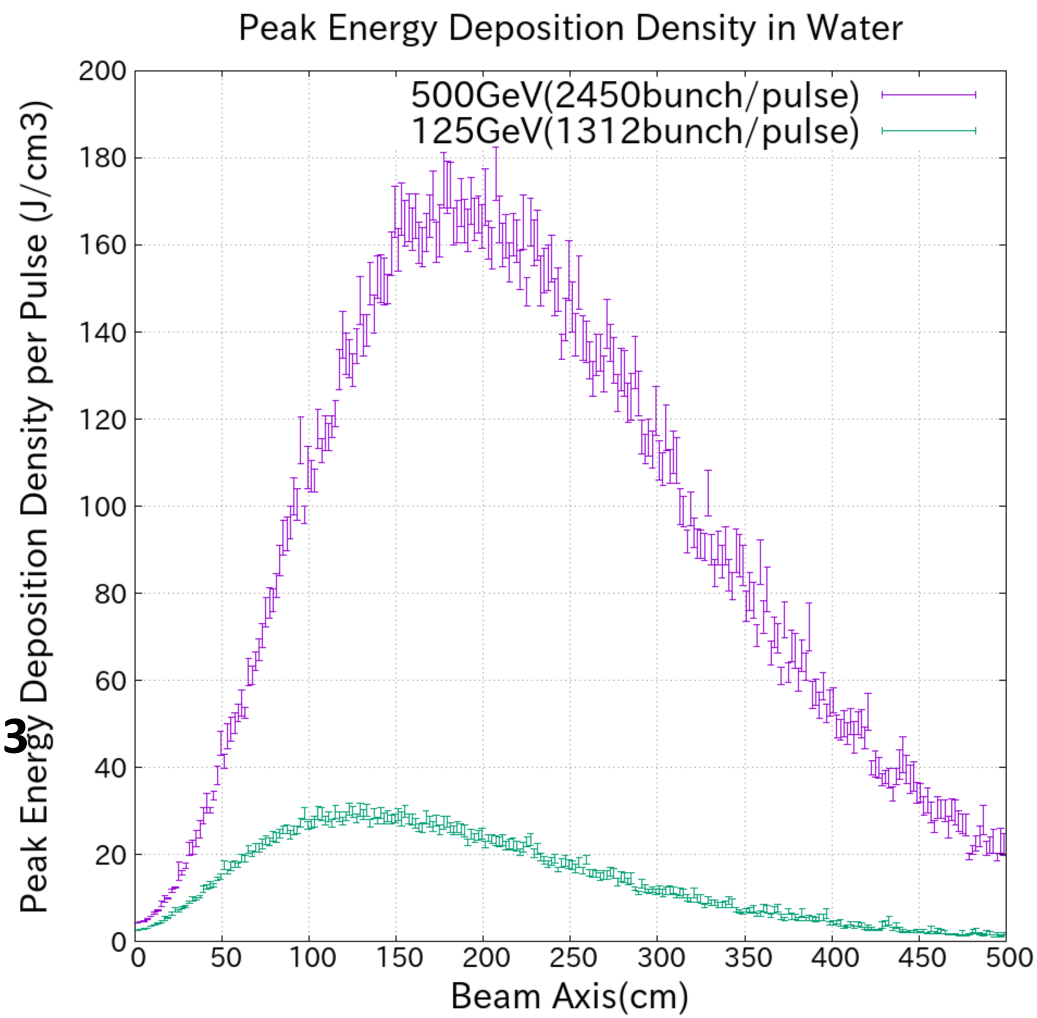
Appendix

Peak Energy Deposition Density

FLUKA simulation



Max value along beam axis



【250GeV nominal】

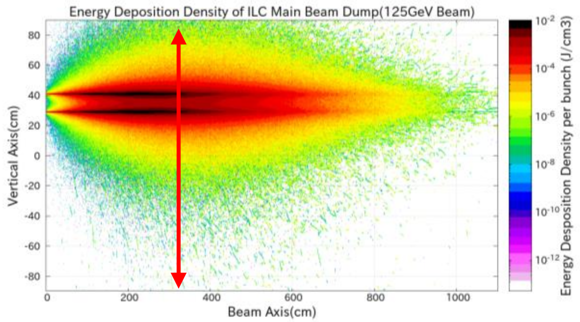
Max PEDD = 28J/cm3
@ Z=125cm

【1TeV stage】

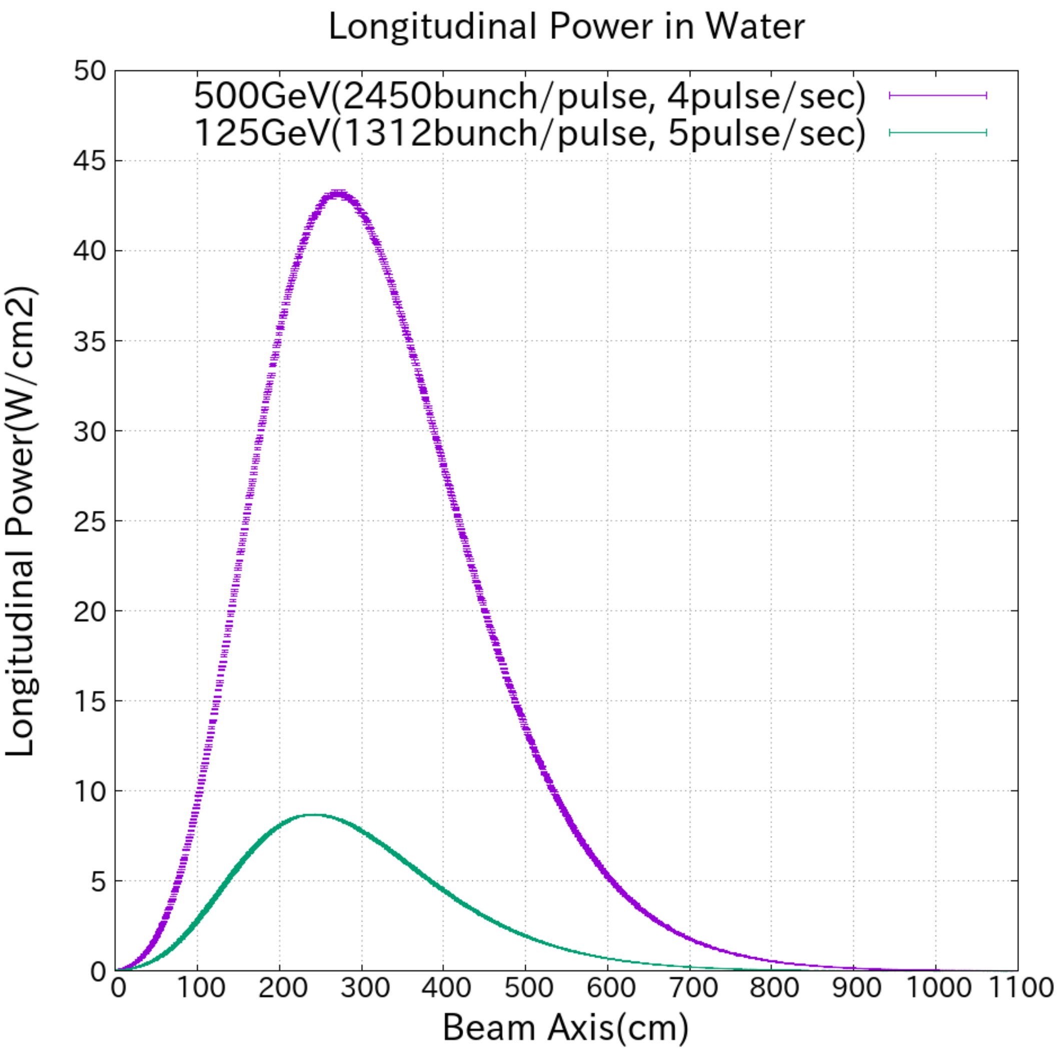
Max PEDD = 170J/cm3
@ Z=190cm

Longitudinal Power

FLUKA simulation



Integrate transverse



【250GeV nominal】
Max Longitudinal Power = 43kW/cm @ Z=280cm
【1TeV stage】
Max Longitudinal Power = 8.4kW/cm @ Z=230cm

Heat Load of Beam Window

Nominal

	250GeV nominal	500GeV TDR baseline	500GeV Lum. Upgrade	1TeV Energy upgrade	1TeV TDR design
Beam Energy	125GeV	250GeV	250GeV	500GeV	500GeV
Electrons per Bunch	2×10^{10} (3.2nC)	2×10^{10} (3.2nC)	2×10^{10} (3.2nC)	1.74×10^{10} (2.79nC)	2×10^{10} (3.2nC)
Bunches per Pulse	1312	1312	2625	2450	2820
Pulse Energy	0.52MJ	1.05 MJ	2.10 MJ	3.41 MJ	4.5MJ
Rep rate	5Hz	5Hz	5Hz	4Hz	4Hz
Average Power	2.6 MW	5.25 MW	10.5 MW	13.7 MW	18MW
Max Energy deposition density per pulse	**10J/cm3 Δ3.9℃**	10J/cm3 Δ3.9℃	**20J/cm3 Δ7.7℃**	16.3J/cm3 Δ6.3℃	22.5J/cm3 Δ8.3℃
Total deposition power	**14.2W**	14.2W	**28.5W**	18.5W	24.5W
Max DPA value Per pulse	**1.1×10^{-9}**	1.1×10^{-9}	**2.1×10^{-9}**	1.7×10^{-9}	2.3×10^{-9}
DPA after 5000hour	**0.1**	0.1	**0.19**	0.12	0.17

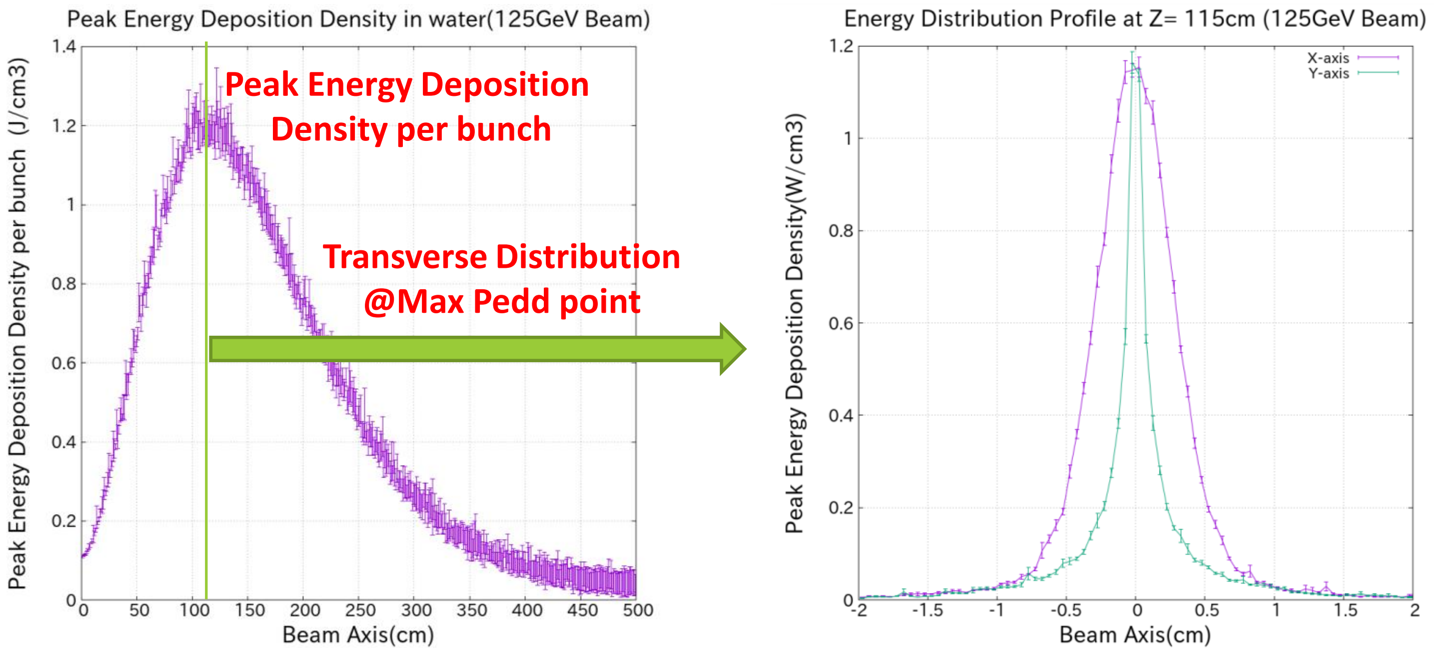
The most severe condition

- **Compare to TDR 1TeV status, Heat load of 250GeV nominal is 42%↓ decreased.**

FLUKA simulation

1bunch energy deposition in water

Pressure rise is occurred by thermal expansion and propagate as pressure wave.
In water of main beam dump, pressure wave is generated by each bunch.



- **Max PEDD : 1.2J/cm3 @Z=115cm**
- **Heat Distribution @Z=115cm : σx=2.55mm, σy=0.53mm**

Pressure wave simulation

◆ Pressure Wave Evaluation

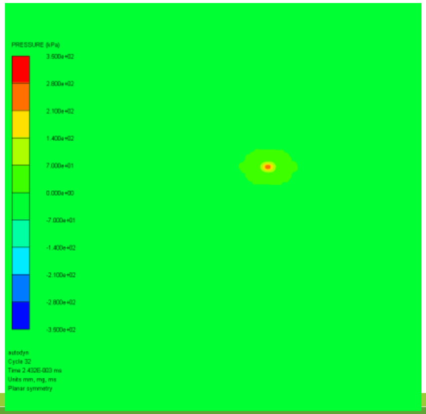
- Mie Gruneisen Shock Equation $P = P_H + \Gamma\rho(e - e_H) \quad \Rightarrow \quad \delta P = \Gamma\rho\delta e$

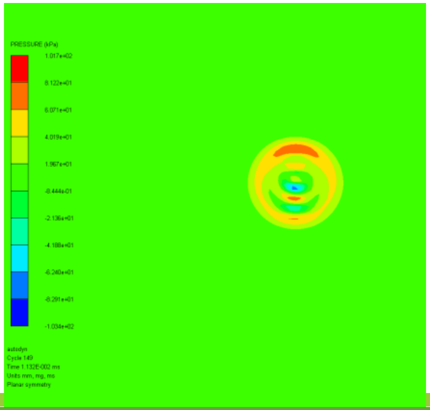
  Γ:Gruneisen Gamma, ρ : density, e : energy deposition density
  Γ=0.32 for 60℃ water

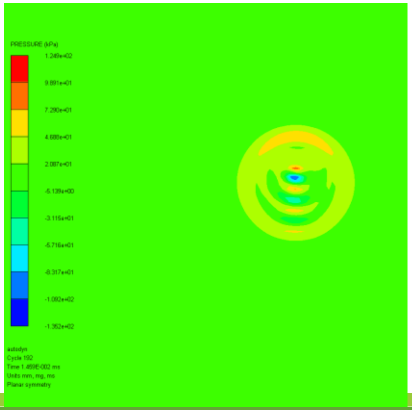
⇒ 1bunch pressure rise dP=0.32×1.2J/cm3 = 3.84bar

◆ Pressure Wave Simulation

- Thermal shock can be evaluated by Hydrocode(This time, I used Autodyn).
- 2D simulation @Peak Energy Deposition density observed(Z=115cm) to evaluate the negative pressure in water(Cavitation)

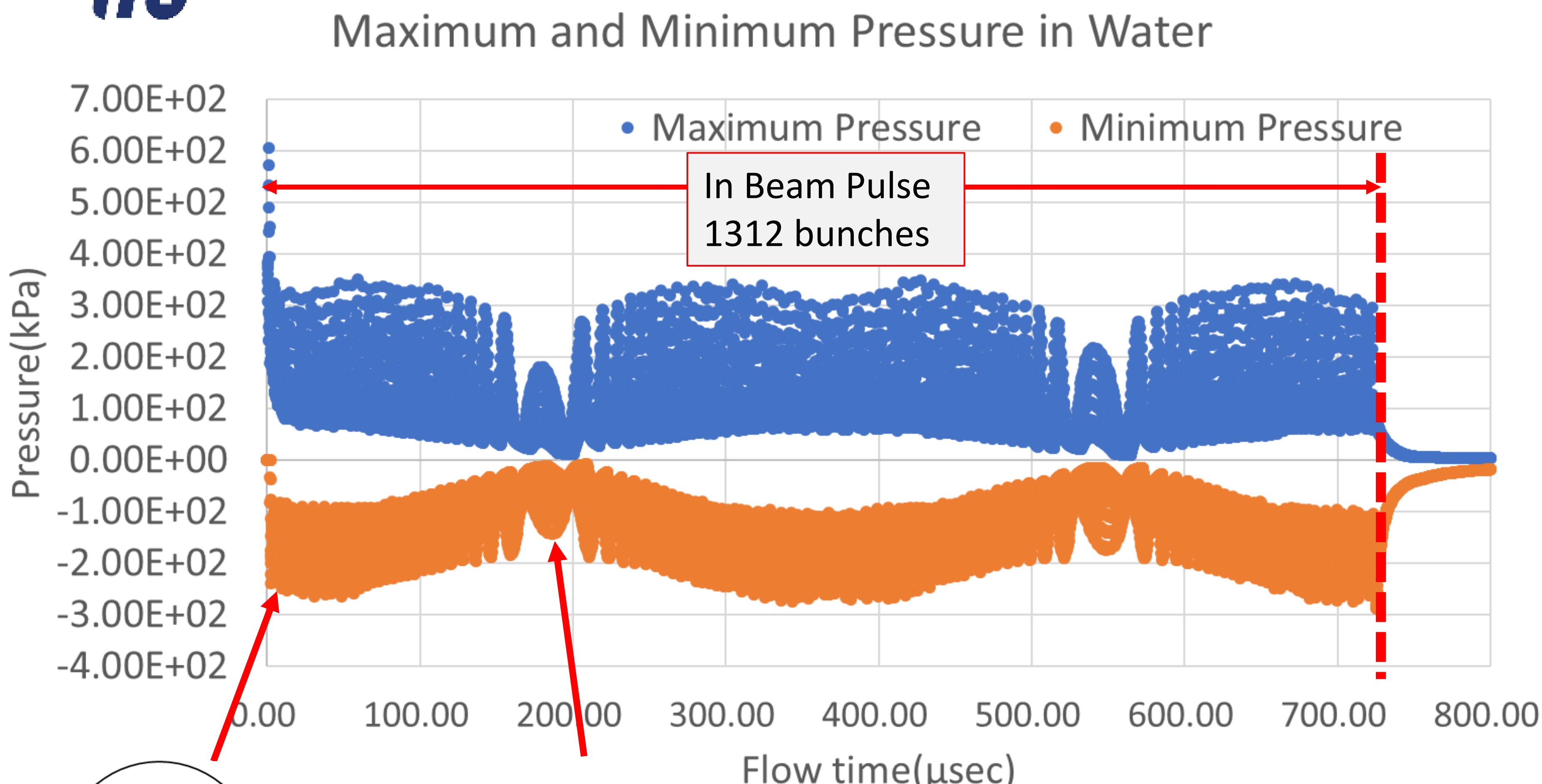


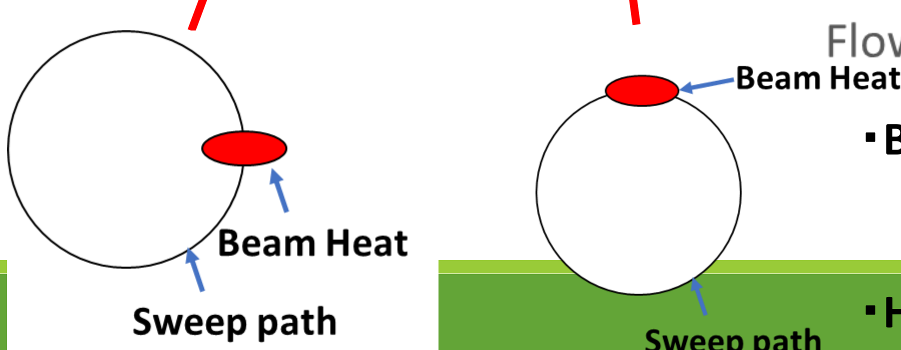




ANSYS simulation

Max and Min Pressure Intensity

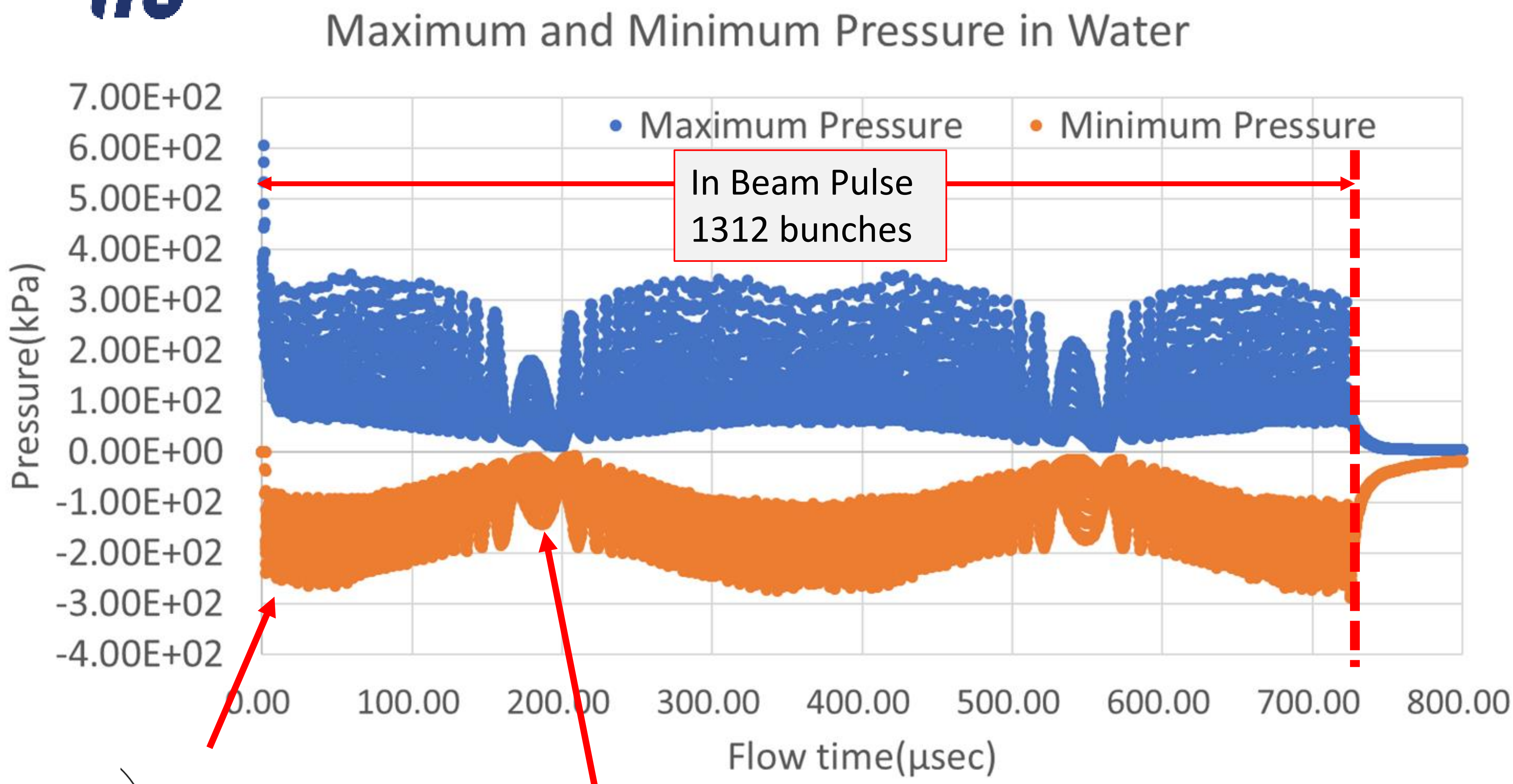


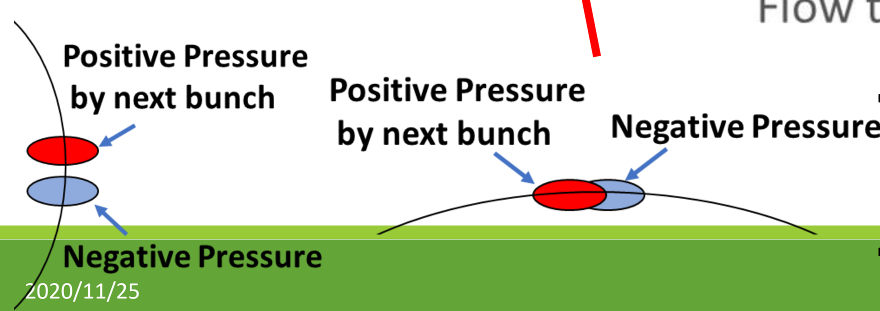


- Bunch space is 556nsec
  ⇒pressure wave will advance 0.92mm.
  (wave velocity=1650m/sec)
- Heat distribution is σx=2.55mm, σy=0.53mm.

ANSYS simulation

Max and Min Pressure Intensity

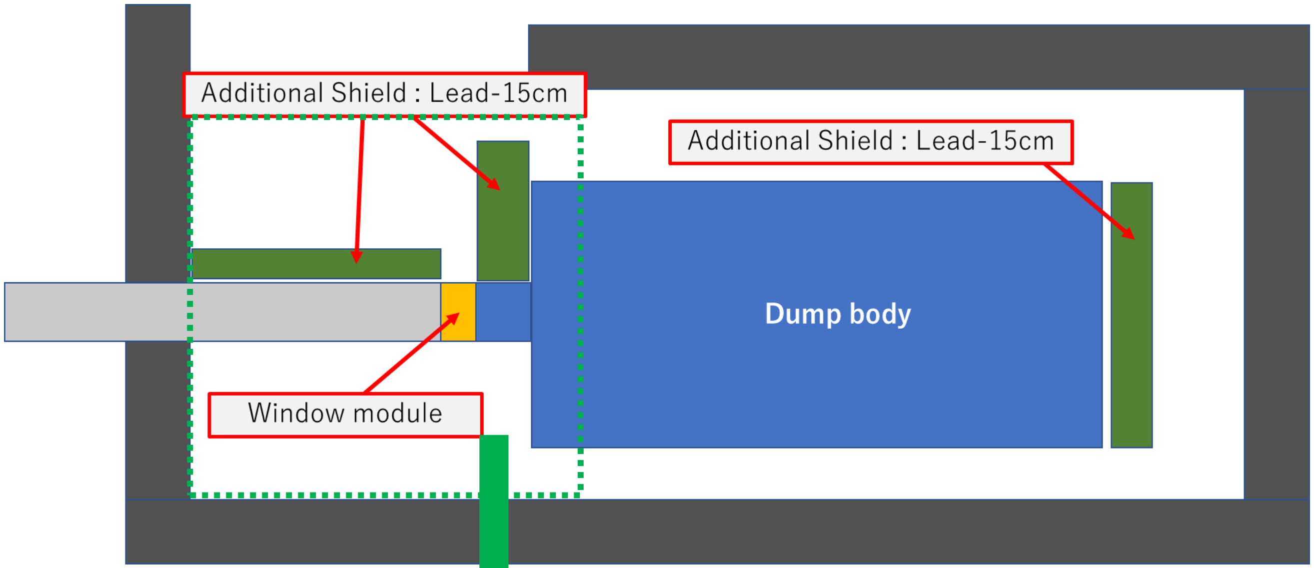


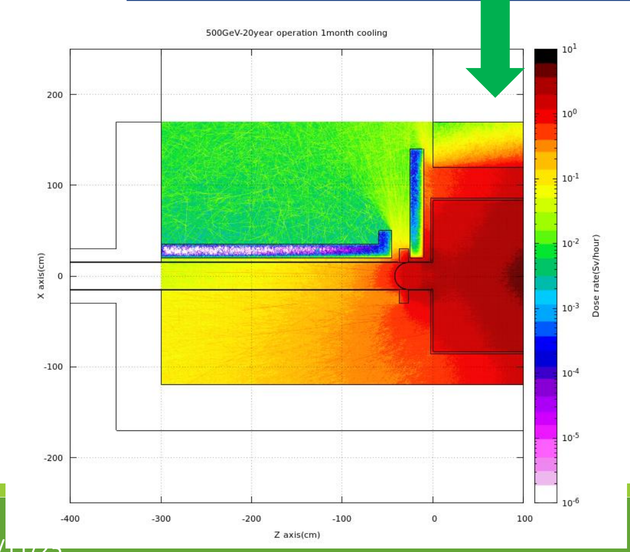


- Bunch space is 556nsec
  ⇒pressure wave will advance 0.92mm.
  (wave velocity=1650m/sec)
- Heat distribution is σx=2.55mm, σy=0.53mm.

Dose rate around Main Dump

14MW(500GeV) ×20year operation + 1month cooling

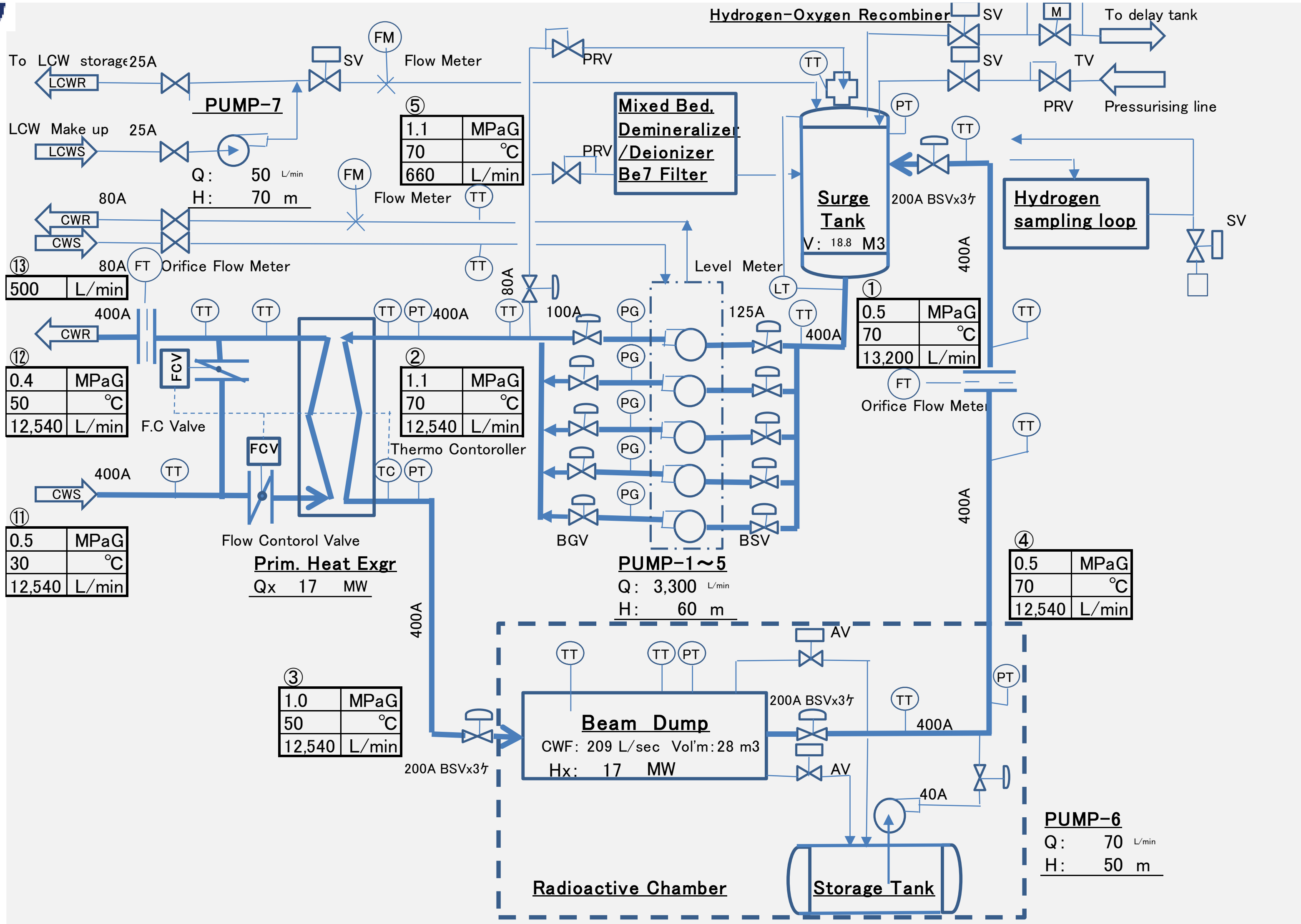




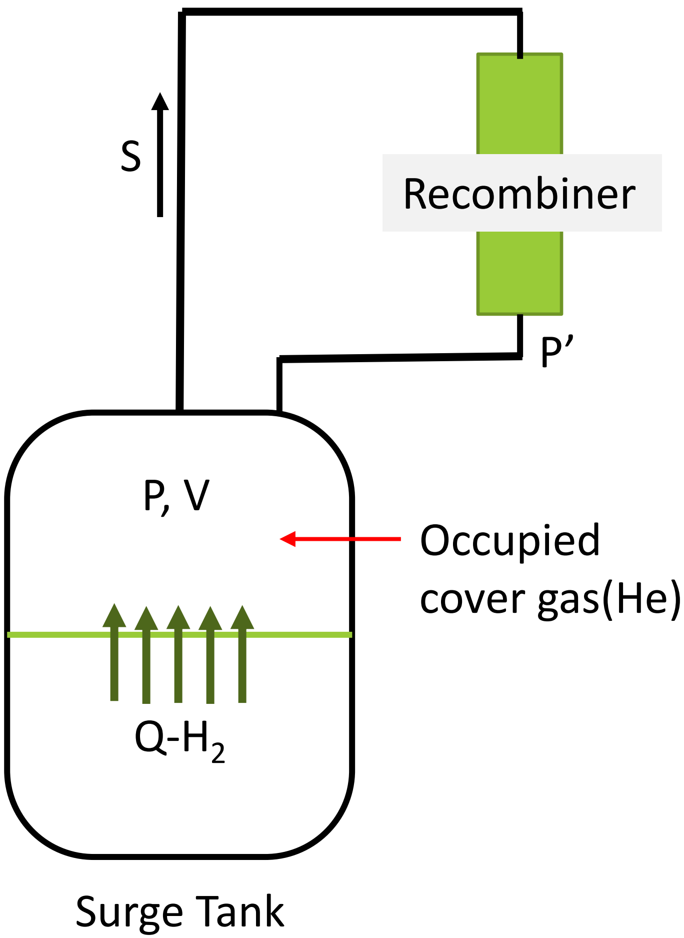
【Dose rate】

- Front side of dump : ~10mSv/hour
- Back side of dump : ~1mSv/hour

Cooling Water System



Hydrogen Recombiner



◆H_2 pressure

$$-V\frac{dP}{dt} = S(P - P') - Q$$

V:gas volume, S: volume flow, Q : gas generation velocity
P : pressure before recombiner, P' : pressure after recombiner

⇒steady state Q=S(P-P')
$Q(H_2)=0.035*8.314*(50+273.15)=94Pa\text{-}m^3/sec$
When recombine efficiency is 80%, P-P'=0.8P
Hydrogen Pressure(steady) P_{H2} = Q/(0.8 × S)

If S = 50L/sec ($0.05m^3/sec$), P_{H2}= 2350Pa

◆Volume fraction of H_2

If cover gas pressure is 3bar,
Total Pressure : 302,350Pa
Volume fraction of H2 : 2350/302350 *100
Lower Explosion limit of H_2 : 4 vol%
0.78 vol%

Required System : **Recombine Efficiency ~80%, Volume Flow ~50L/sec**