CFD and measurement analysis for components of CSNS target station

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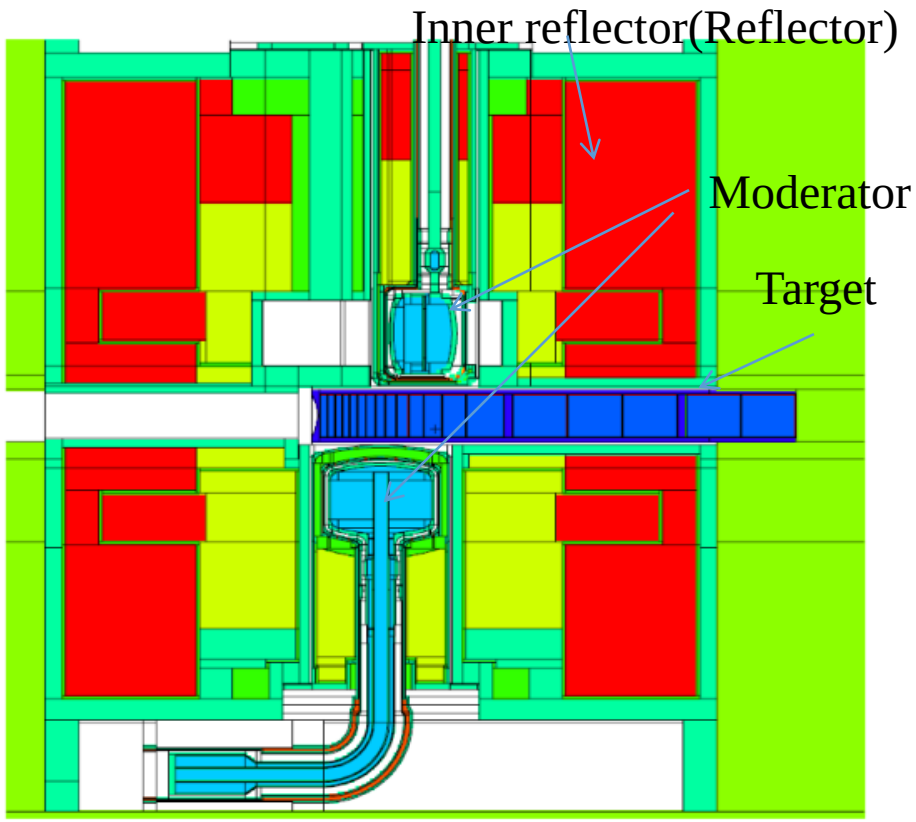
- Background
- CFD and measurement analysis of Target
- CFD and measurement analysis of Reflector
- Summary

Background

- The heat load distribution of target station
- 87.68% deposited in target station, 76%in target and reflector
- Target and Reflector are key compoents

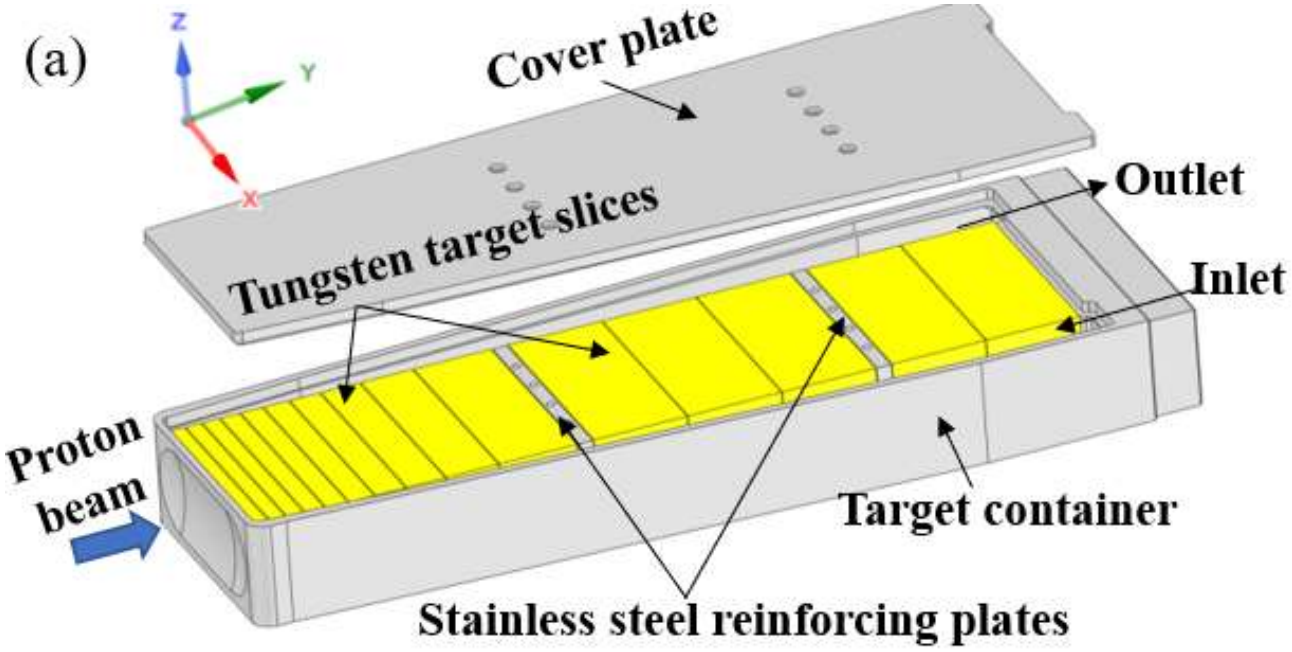


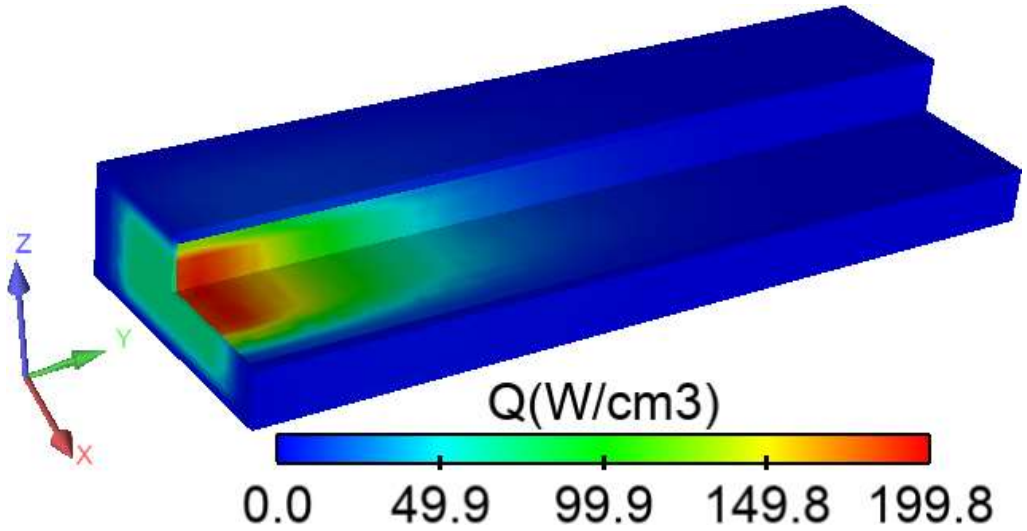
- Proton Power：140kW
- Date：2023.7.15 3:30~5:30am

Compoents		Heat load	ratio (heatload/ proton beam power)	MCNP (Gauss~Uniform Proton Porifle)
		kW	%	%
HWS	Target	76.42	54.58	56.3~55.2
	Reflector	30.11	21.50	20.8~21.4
Light Water Loop 1	Decoupled	1.69	1.20	
	Water Moderator	0.12	0.09	
	Pre Moderator	1.63	1.17	
Light Water Loop2	Core Vessel	2.08	1.48	
	Outer Reflector	9.44	6.74	
	Sheilding	0.46	0.33	
Hydrogen loop	Coupled hydrogen Moderator	0.48	0.34	
	Decoupled Hydrogen and Poisoned Moderator	0.34	0.24	
Summary		122.75	87.68	

1.1 Introduciton of CSNS Target

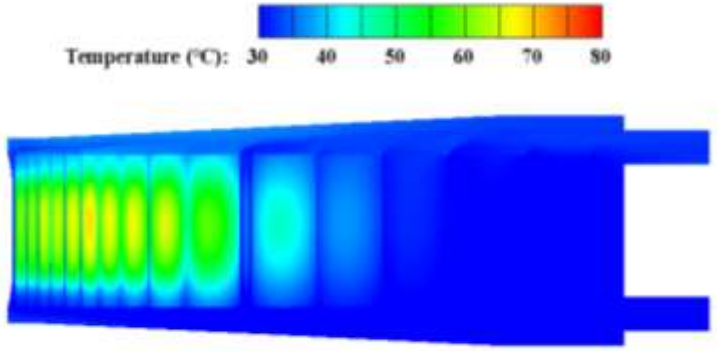
- Operating conditions: 1.6 GeV proton beam is directed at a tungsten target (with a tantalum layer), ~55% of proton beam heat is deposited in the target. This heat is removed by a water cooling system.
- Decay heat conditions: generation of new nuclides within the target material introduces a certain amount of decay heat and decay period. Maximum heat load is 1~2% of operation conditions. The heat is absorption through the target station or by a small cooling loop.

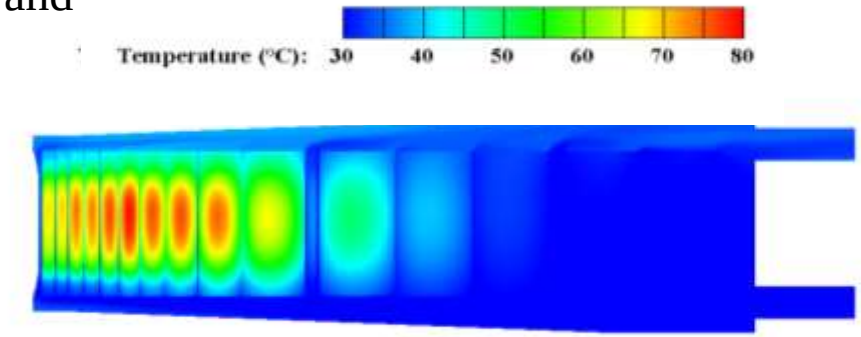


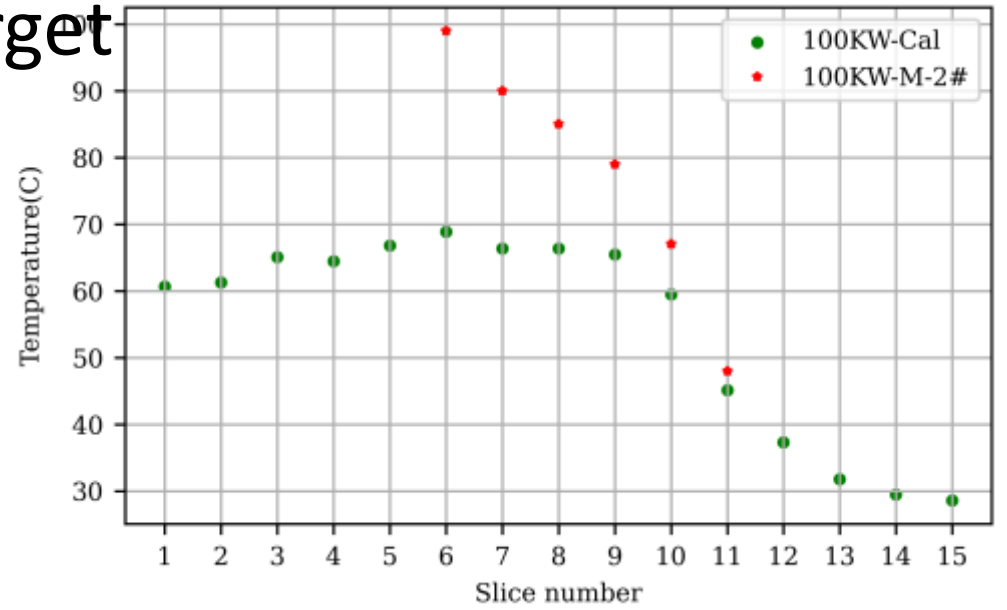


1.2 Target： CFD VS measurement of 2# Target

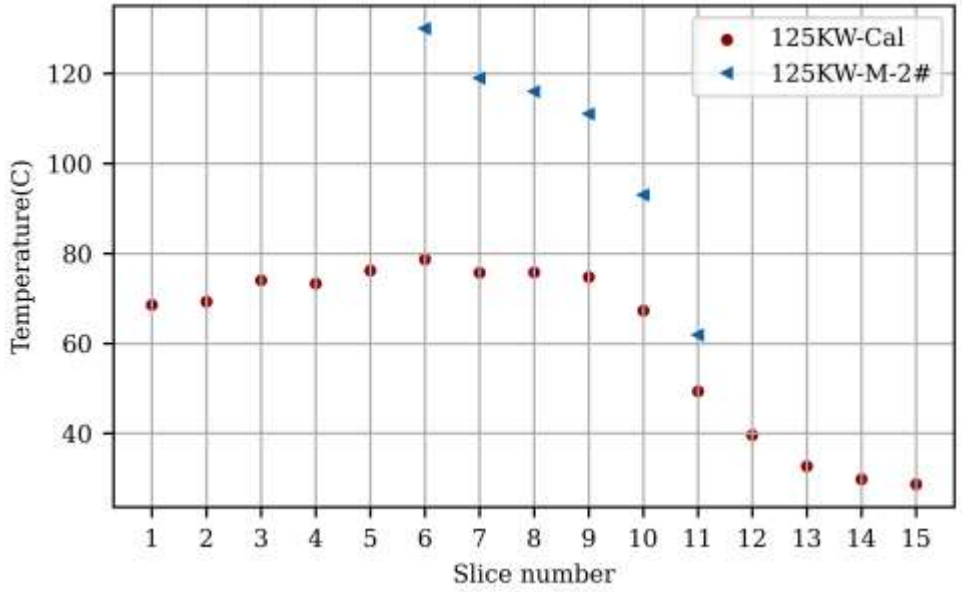
- Steady state
- Proton power=100KW、125KW
- Flow rate：2.538kg/s（9.18m^3/h，153L/min）
- Inlet T：~30℃；
- Uniform proton beam spot
- The results were consistent when calculated using both Fluent and CFX simultaneously.
- Turbulent Model: SST-kw







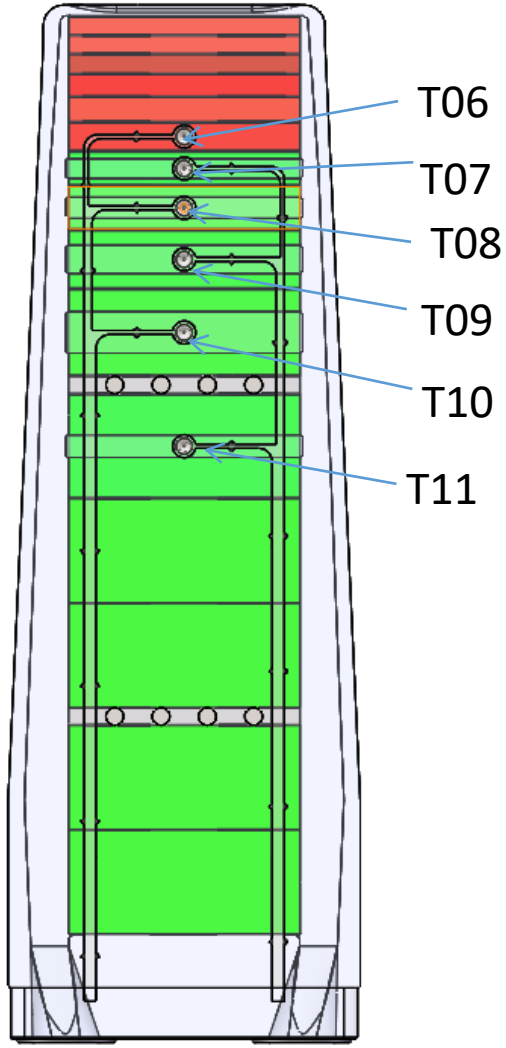
Temperature of 2# target at 100kW



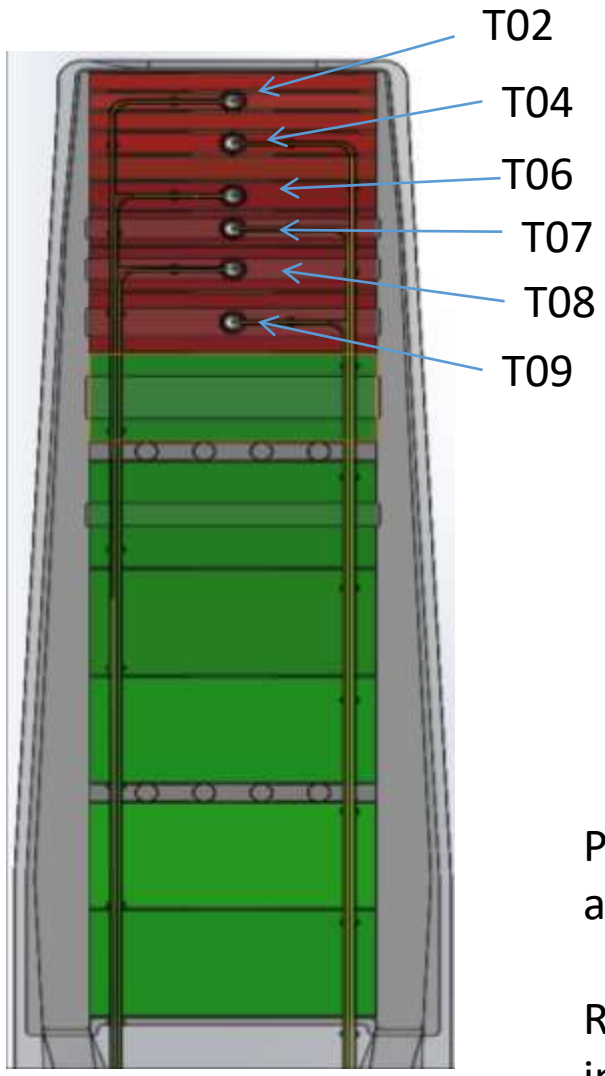
Temperature of 2# target at 125kW

1.2 Target： 2# Target vs 3# Target

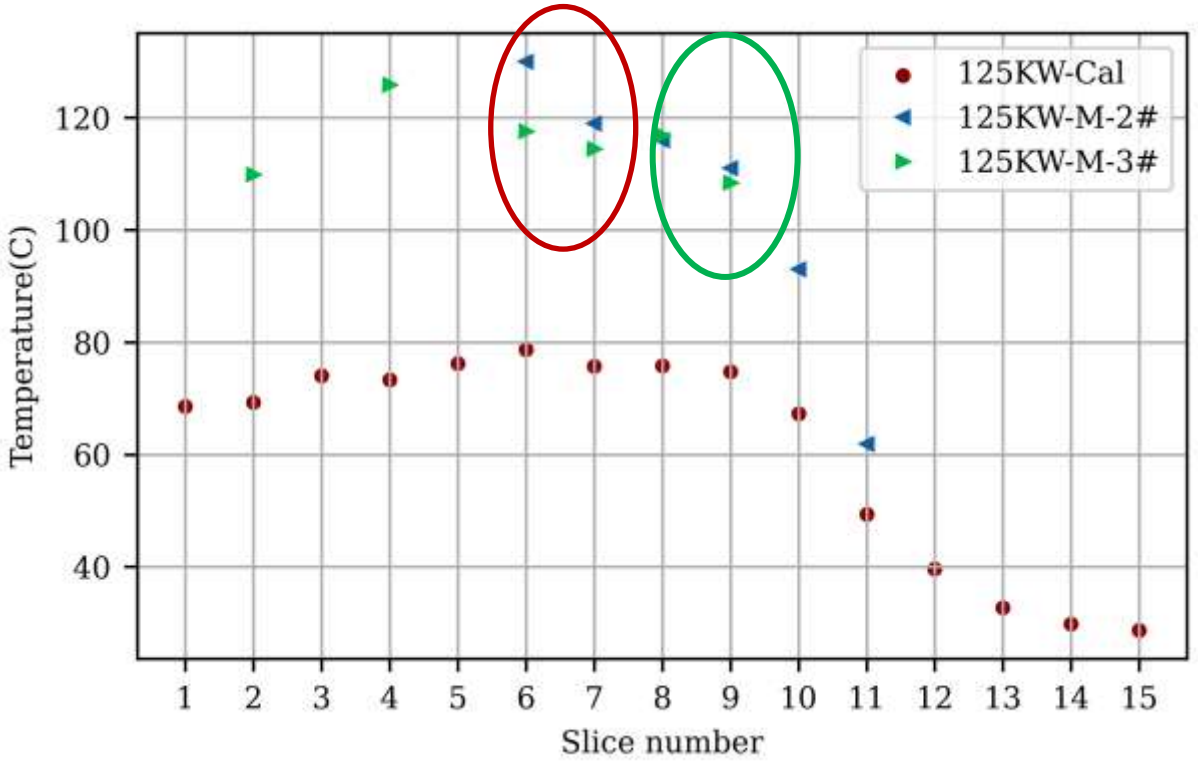
- 2#target and 3#target: (1)Same structure; (2)same proton beam profile; (3)Thermocouples are placed in different positions



2# Target



3# Target



Problems: Measure results do not agree well between 2# and 3#target,especially in slice 6

Reasons: The installation processes of Thermocouples are inconsistent;

1.3 Target： Proton size and conductivtiy effect

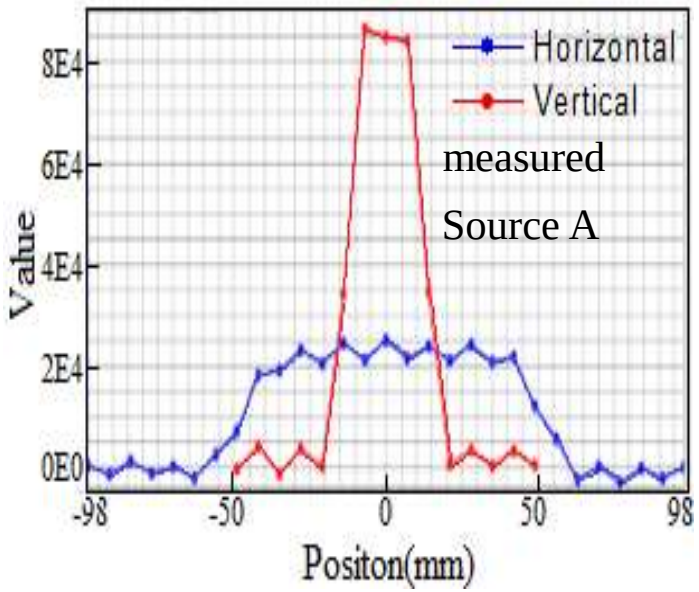
- CFD VS measurement under 100kW:

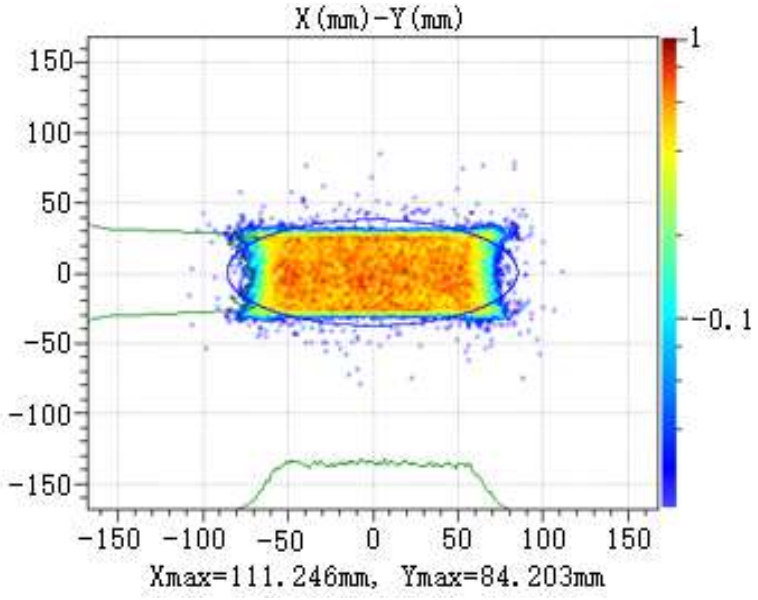
➢ Proton beam profile size: from -3~3cm (12X6cm,from acceleator)

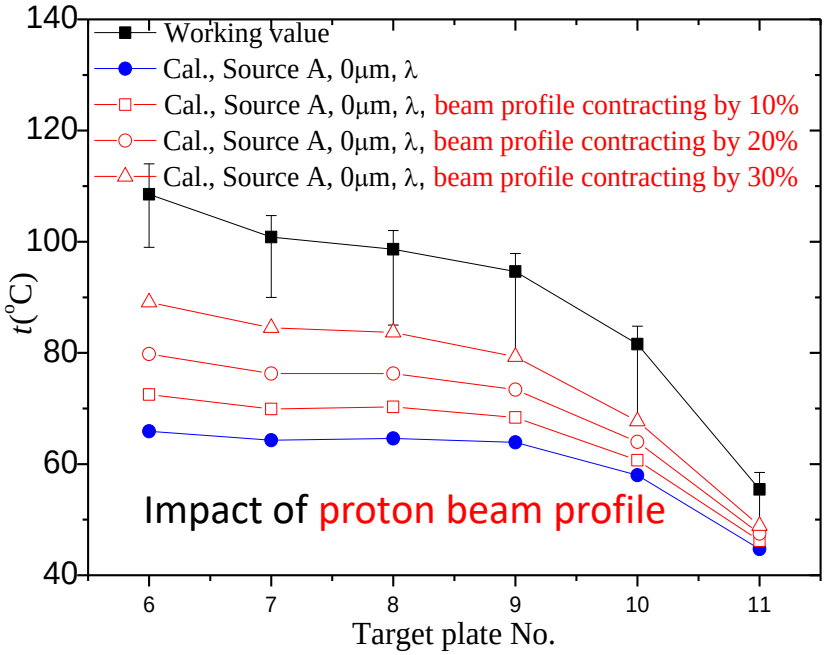
➢ Thermal conductivity reduction of target: all solid materials decrease to 0.5, 0.8

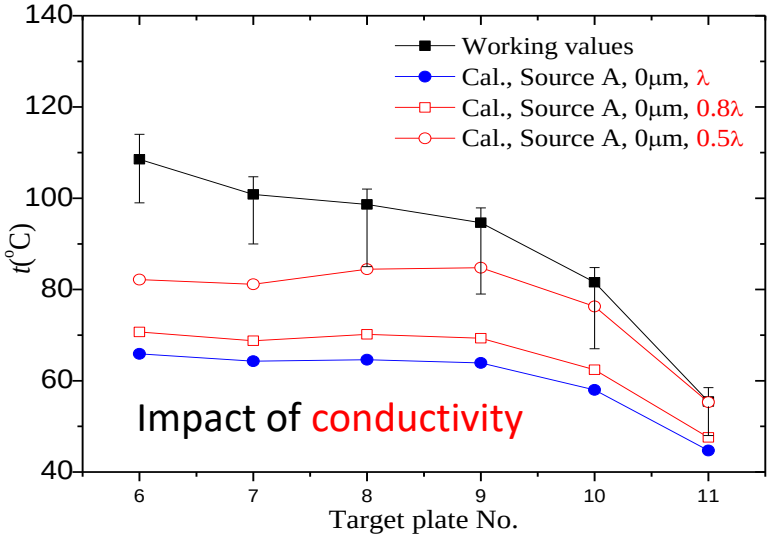
➢ Thermocouple:

- Installation clearance & internal heat in thermocouple



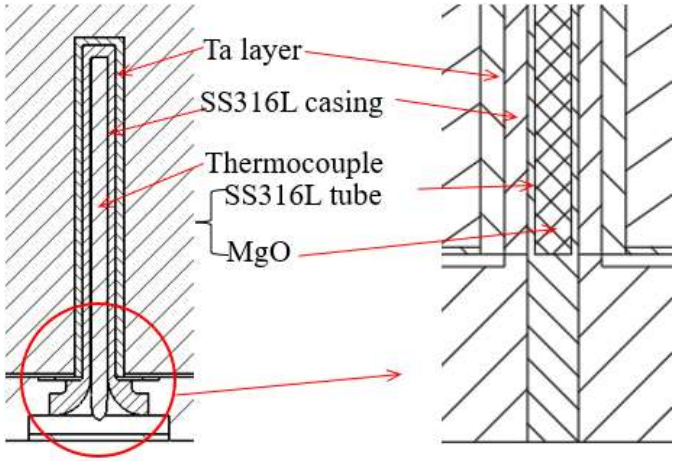


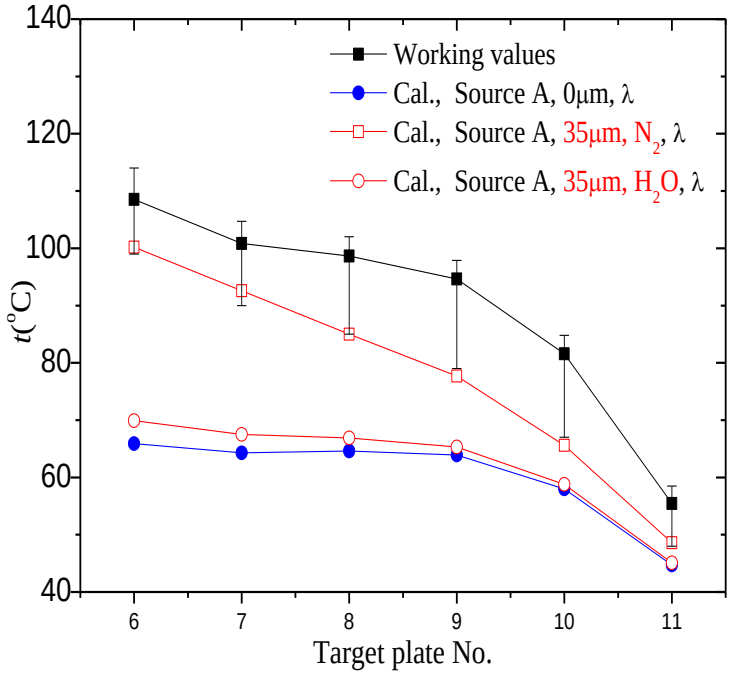




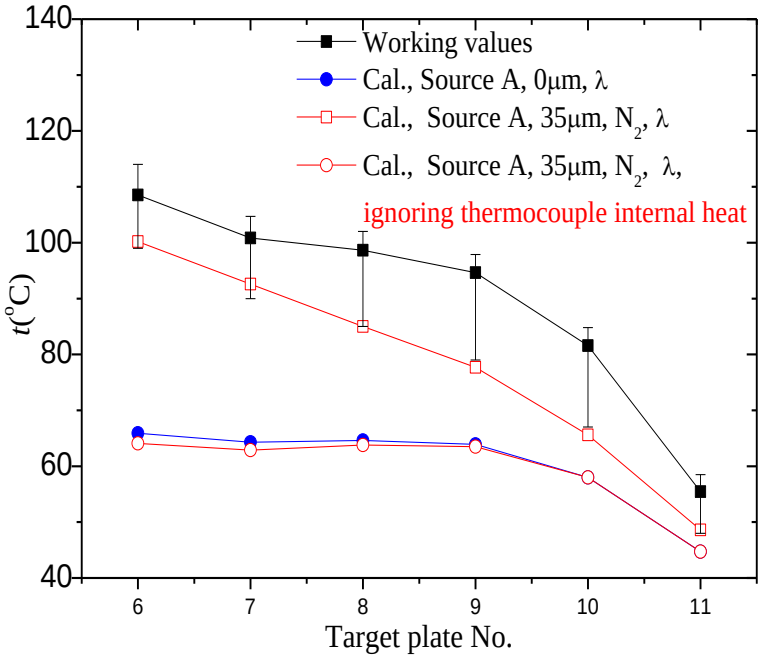
1.4 Target： Thermocouple effect

- CFD VS measurement under 100kW:
  - Proton beam profile size: from -3~3cm
  - Thermal conductivity reduction of target: all solid materials decrease to 0.5, 0.8
  - Thermocouple:
    - Installation clearance & internal heat in thermocouple





Materials in Installation clearance



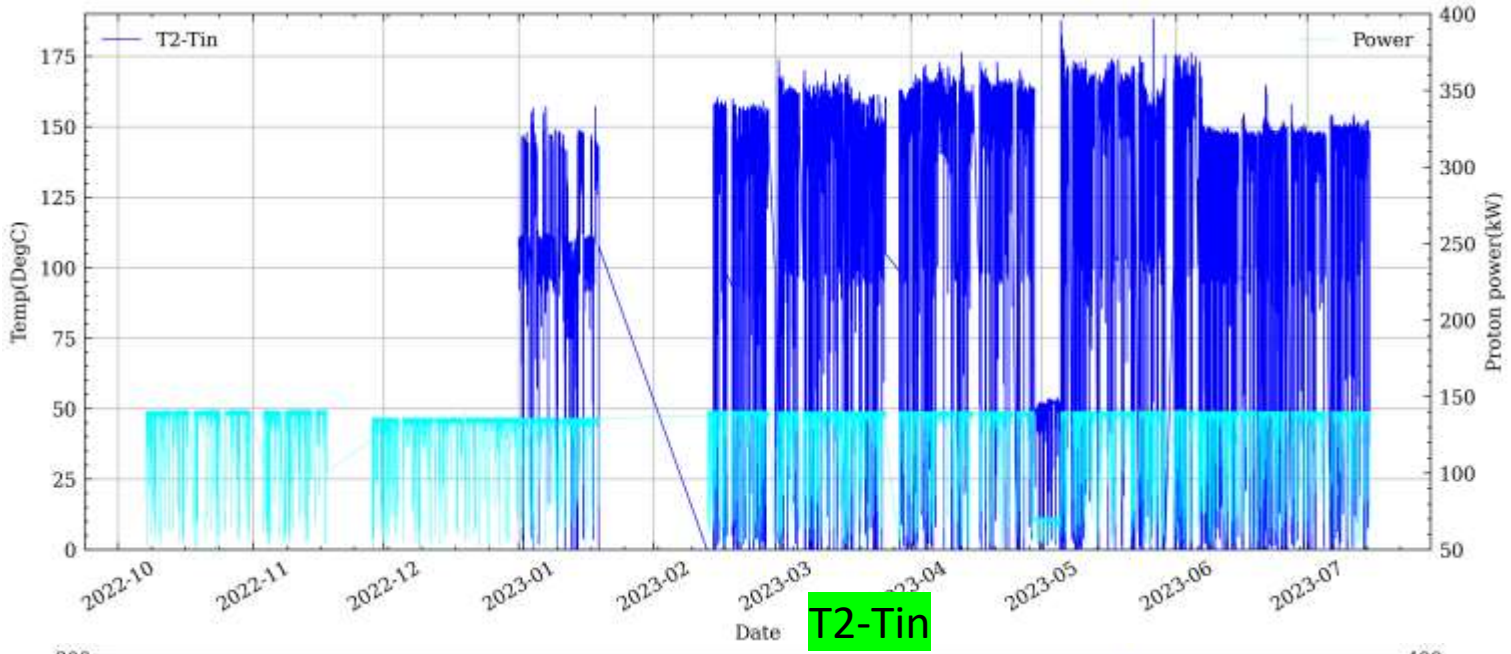
With or without heat source in thermocouple

1.5 Target： Slice2&4 in 3# Target

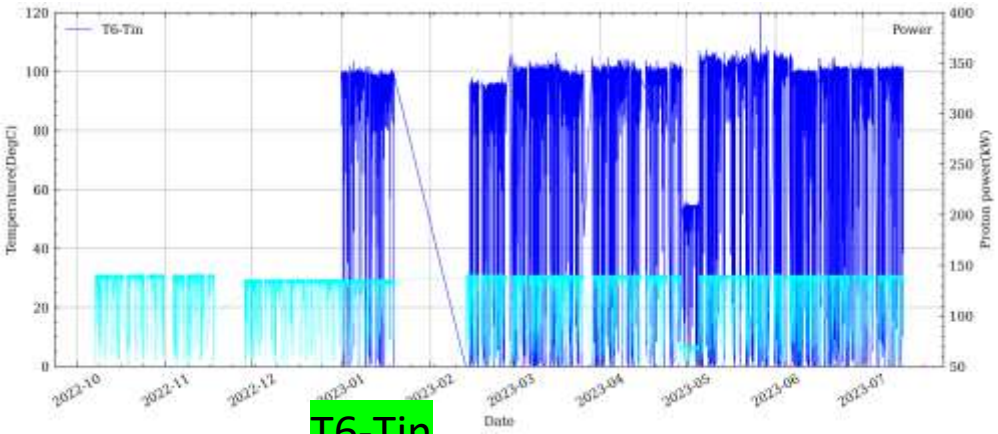
- The temperature of both T2 and T4 suddenly increased at 140 kW(The process of change was not fully recorded in the database.)

- T2-Tin: 53℃ @70kW, ~160℃@140kW ~3times
- T4-Tin: 54℃@70kW, 160~180℃@140kW ~3times
- T6-Tin: 55℃@70kW,105℃@140kW ~2times

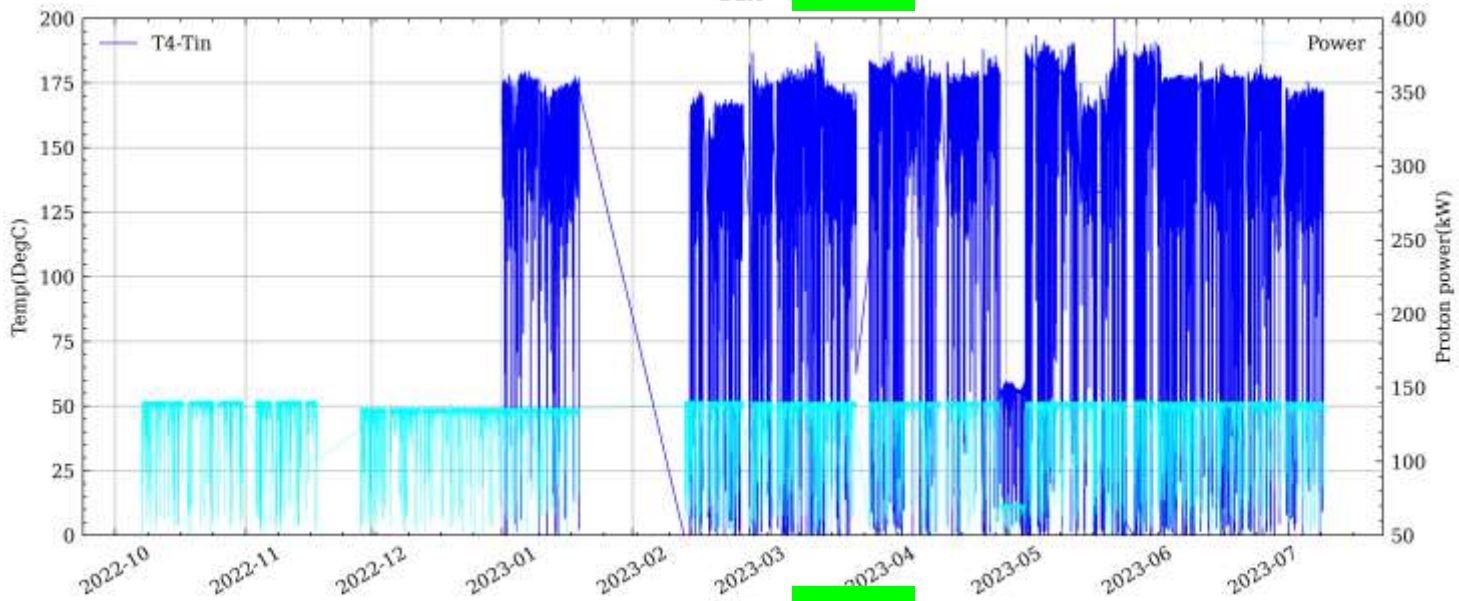
Possible causes:
(1) Vaporization (proton beam size);
(2) Thermal resistance of installation clearance



T2-Tin

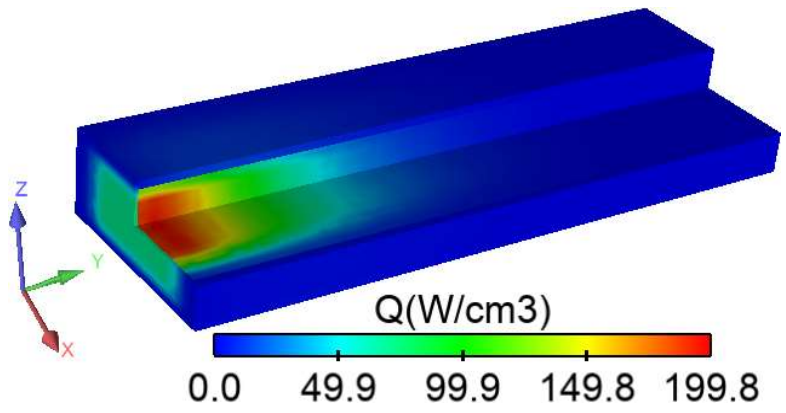


T6-Tin

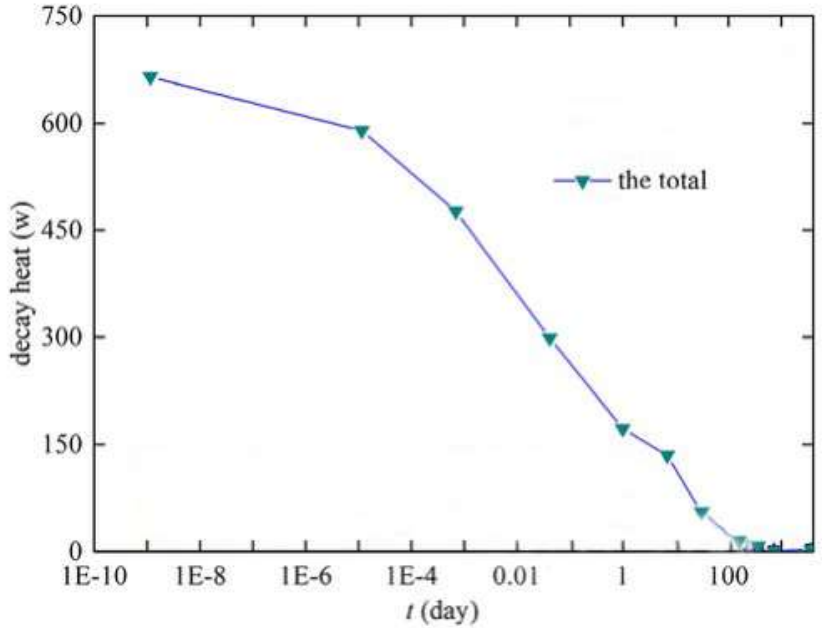


T4-Tin

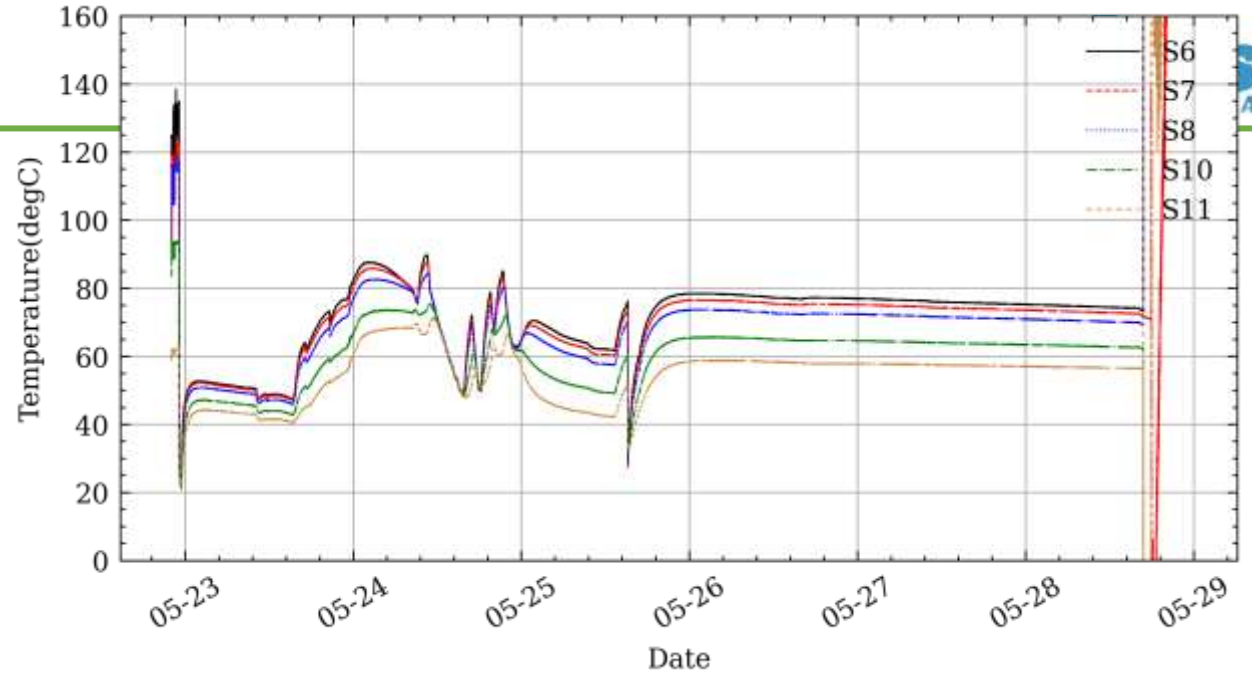
1.6 Decay heat of target：

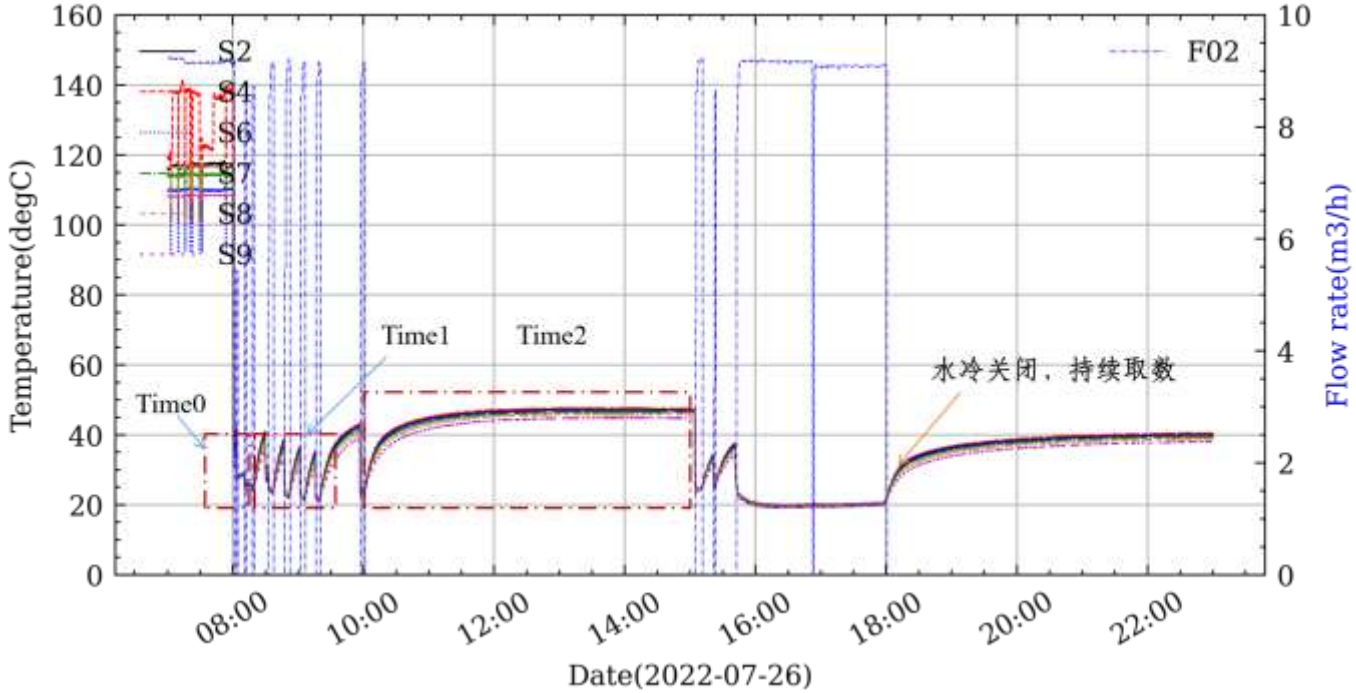


decay is about < 2% of operation heat source

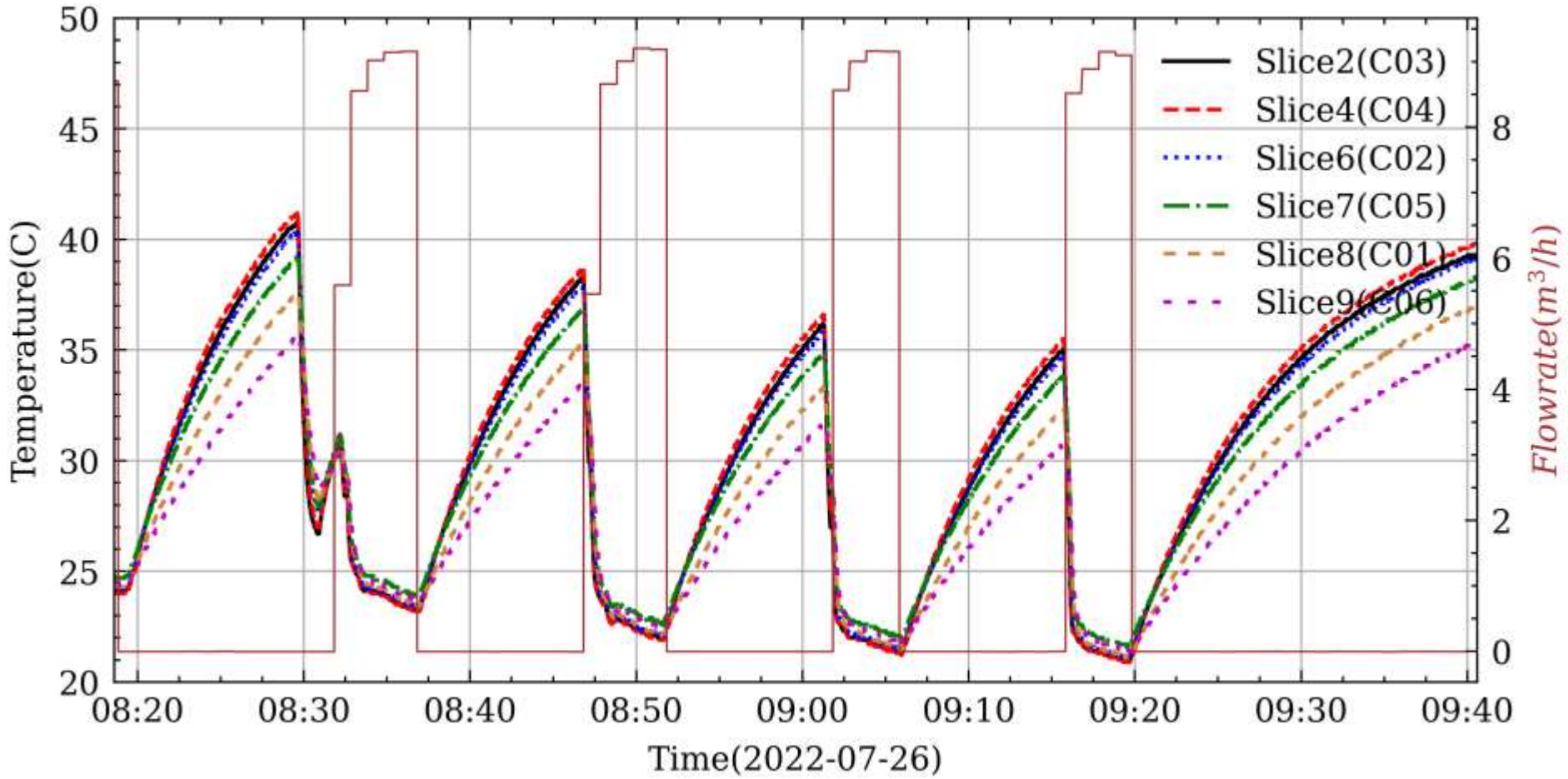


Decay heat the target varing with time





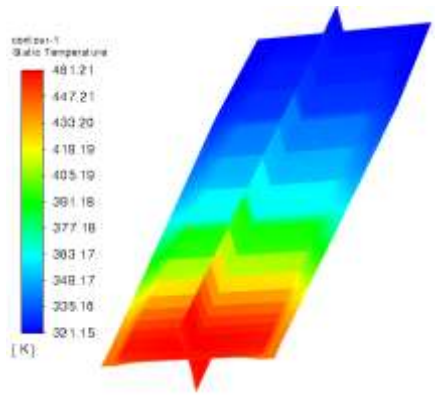
1.6 Decay heat： measurment results



■ Cooling 3mins, Stop cooling 10mins； repeat 5 times

- 8:29， Open valve after target, the temperature of target decrease ；
- 8:31， The temperature of target increase；
- 8:33， Start pump；

1.6 Decay heat： compared with different boundaries

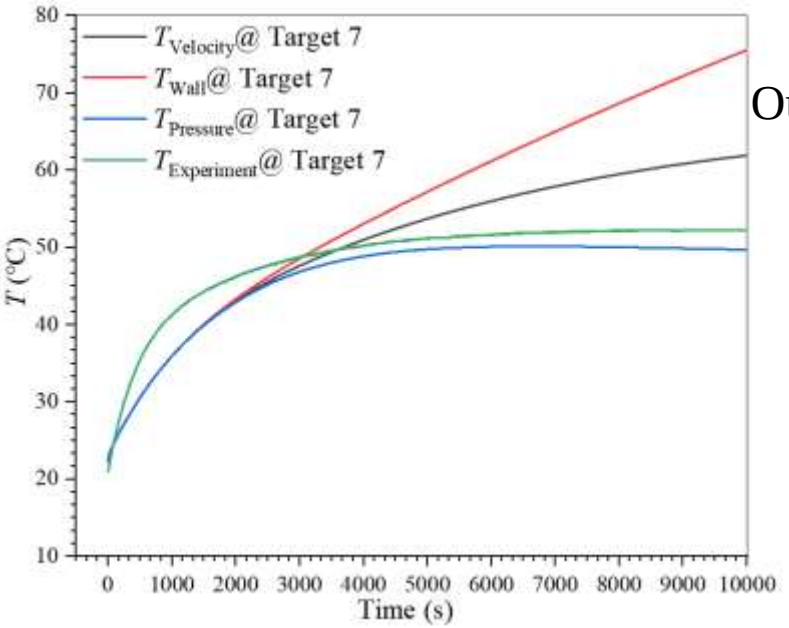


Case A all set as solid

The total heat load is 520w

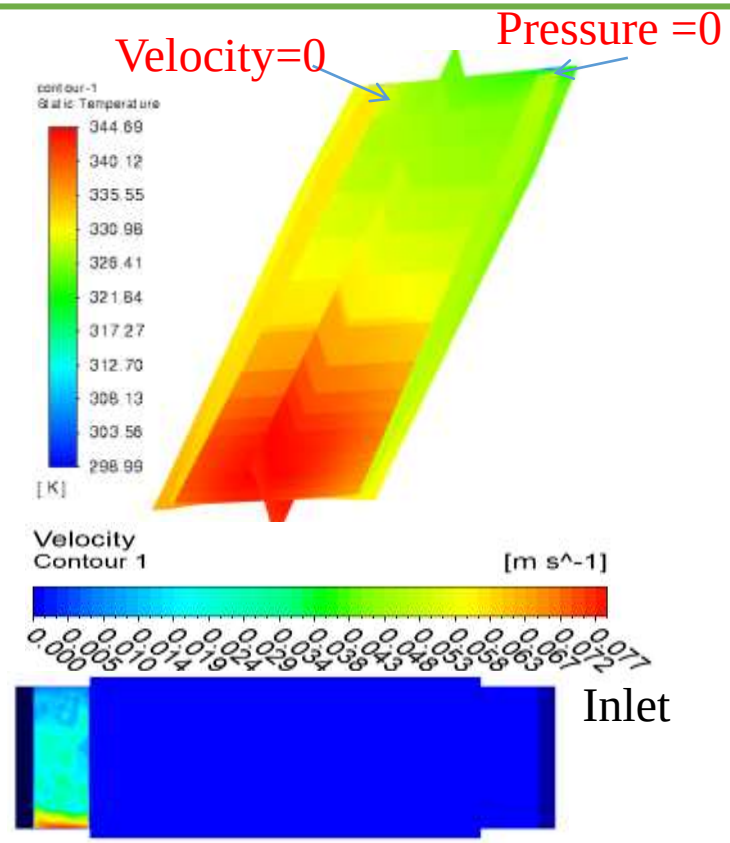
Outer surface:15W/(m²°C)

Case B



Velocity=0

Pressure =0



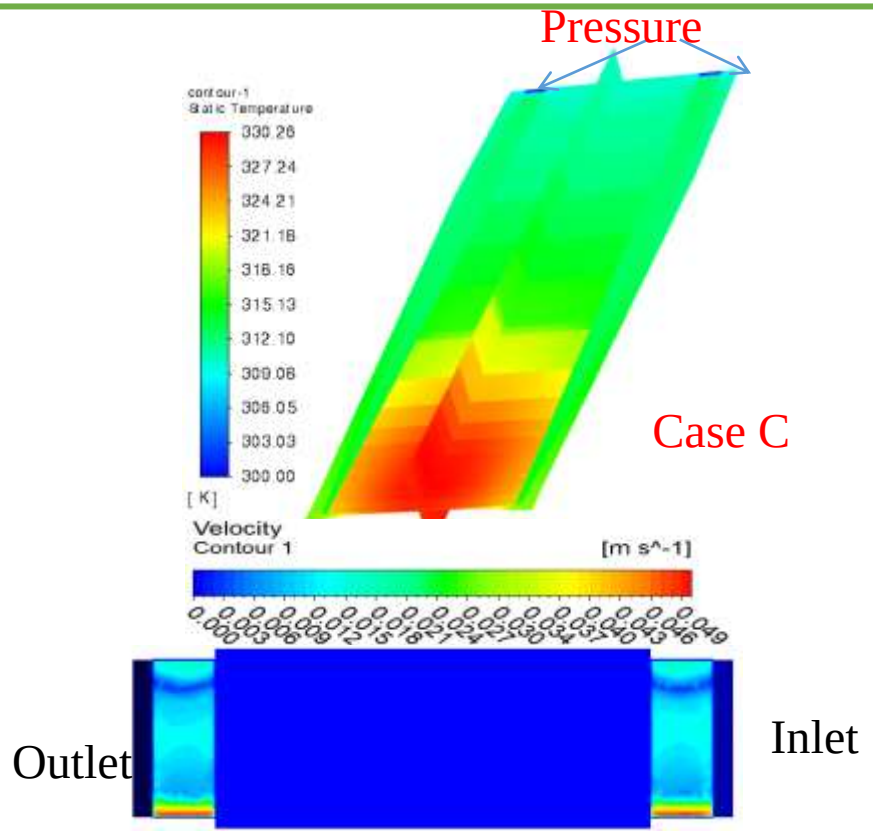
inlet:V=0

outlet:P=0

The fluid is water with variable thermodynamic properties

Pressure

Case C



Inlet:P=0

Outlet:P=0

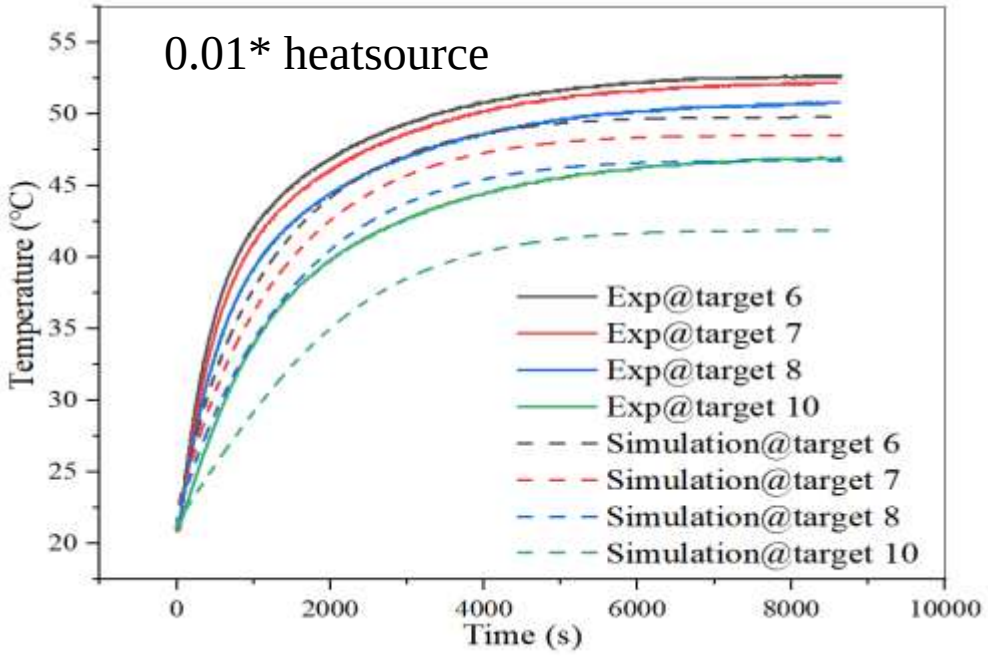
Variable thermodynamic properties

- 3 Cases with different calculation
- Compared the trend of temperature to measurement

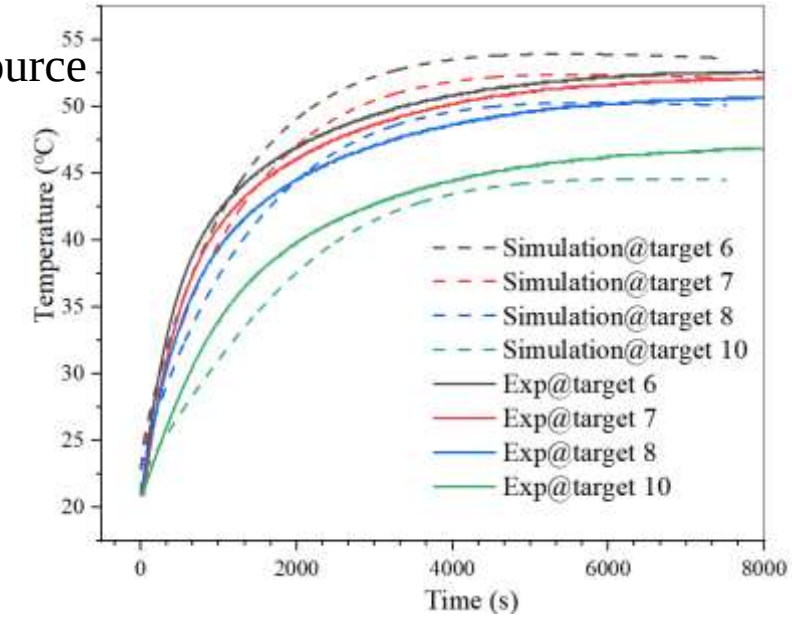
1.6 Decay heat： compared with different heat load

- Related with operation time, and decay time
- using the 1% of operation heat source(tungsten)
- outer surface： 15W/(m^2·℃)
- Time： 6000s
- Results： with an open boundary condition, both the trend and the maximum value are comparable to the measured results.

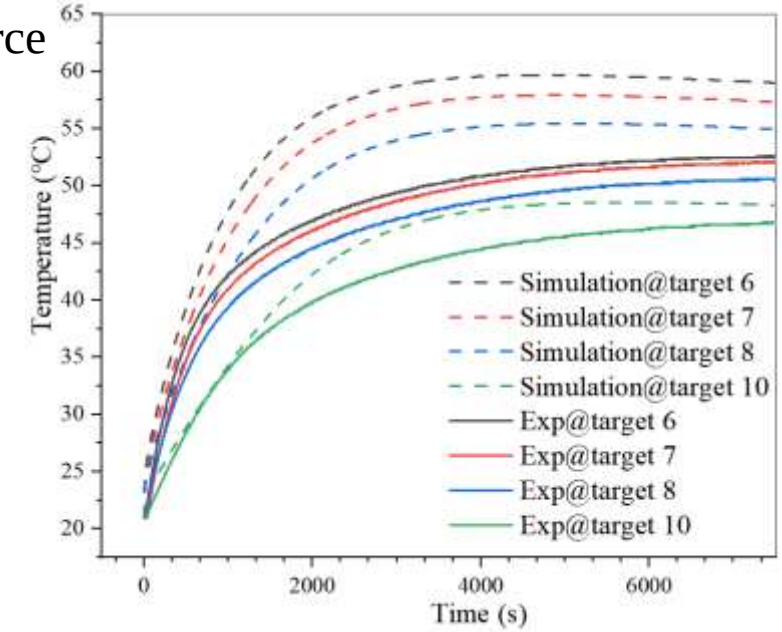
0.01* heatsource



1.5*0.01* heatsource

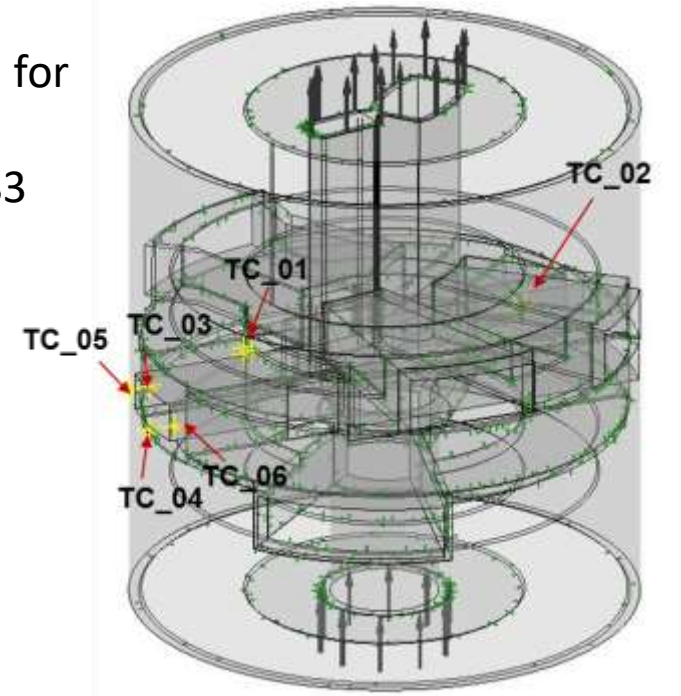


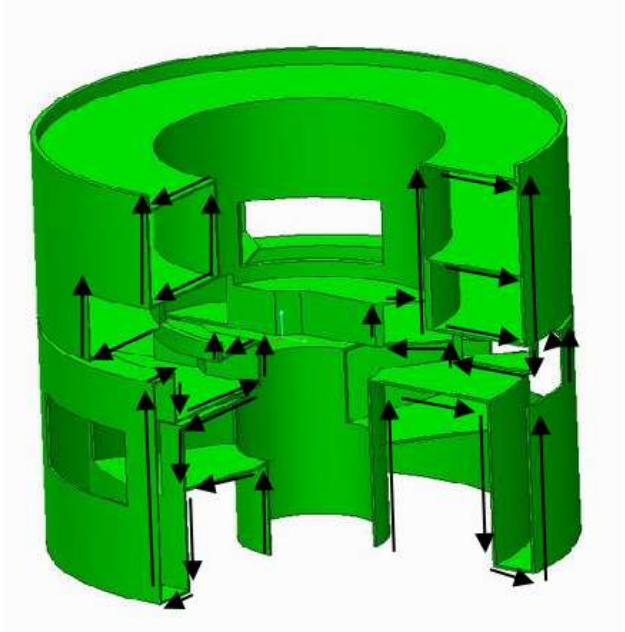
2*0.01* heatsource

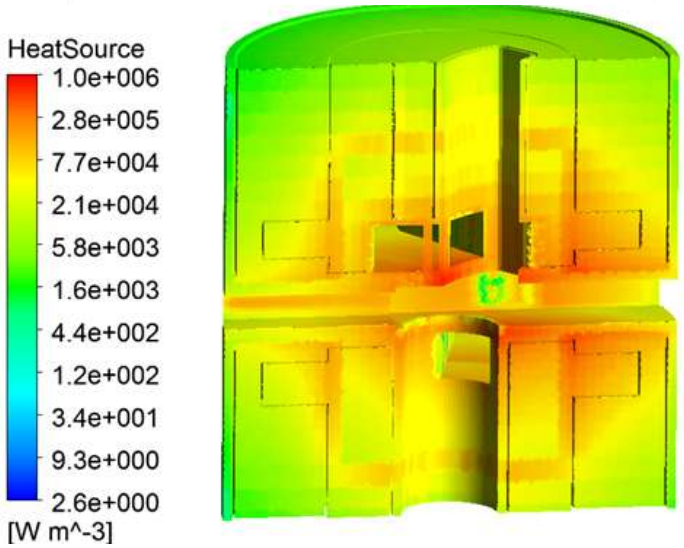


2. Reflector (Calculation model)

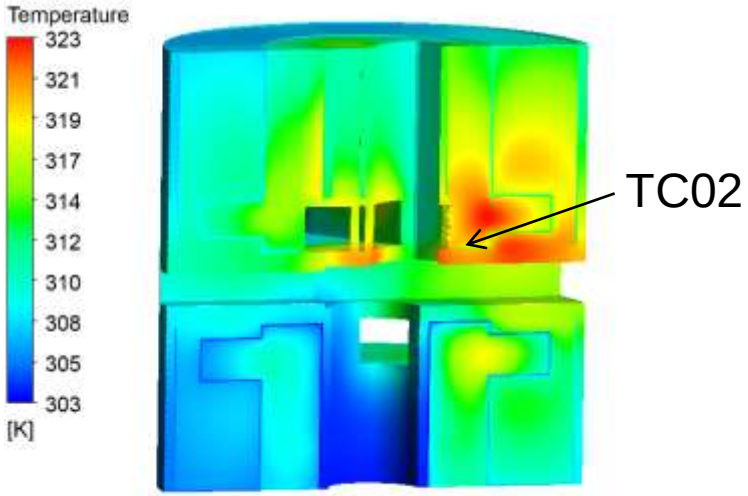
- Thermal design of the reflector for 100 kW.
- The container material is Al 5083
- 1 cooling loop
- 6 thermocouples
- Inlet mass flow rate: 1kg/s
- Inlet Temperature: 25~40℃



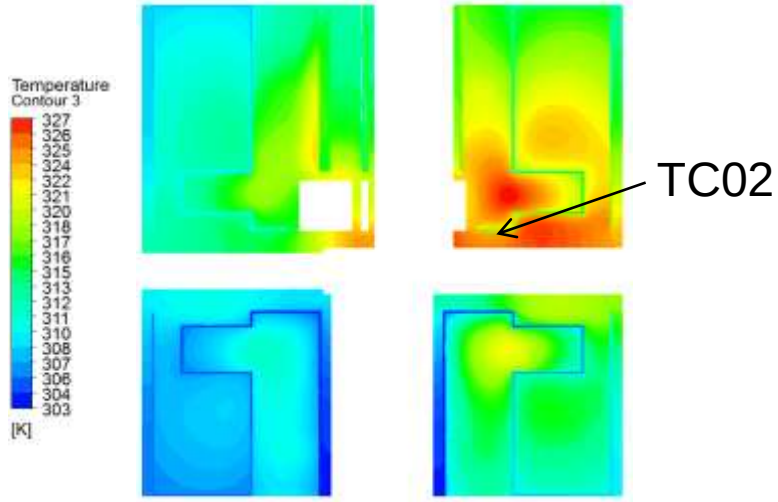




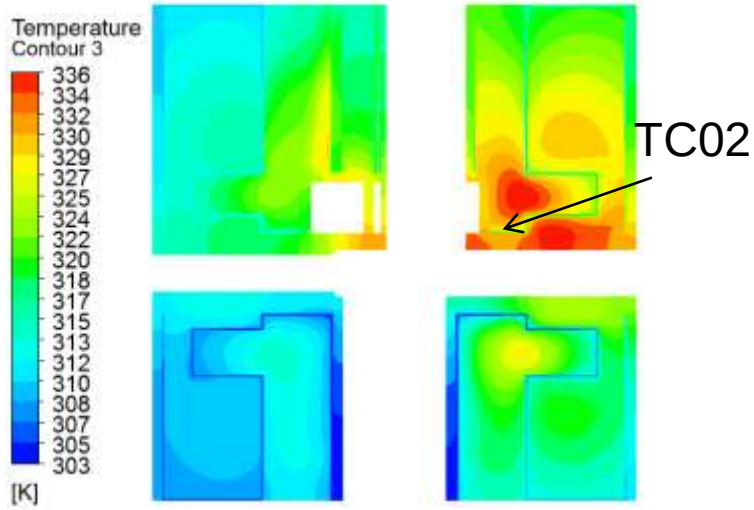
2.1 Reflector (initial CFD vs Measurement)



125kW，1kg/s， Int T=30℃, TC02=323
TC02-Tin=20℃ （1.6℃/10kW）

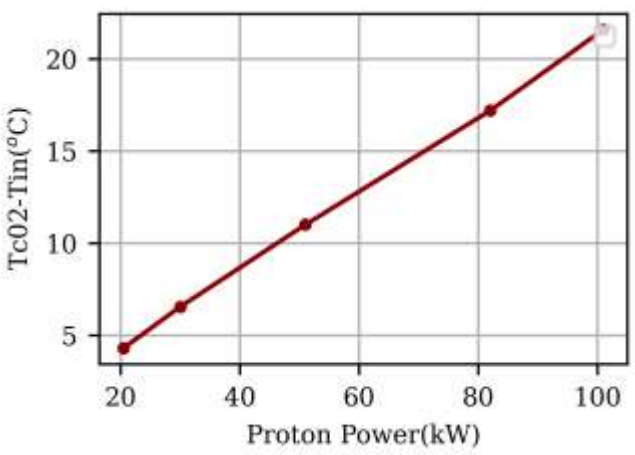


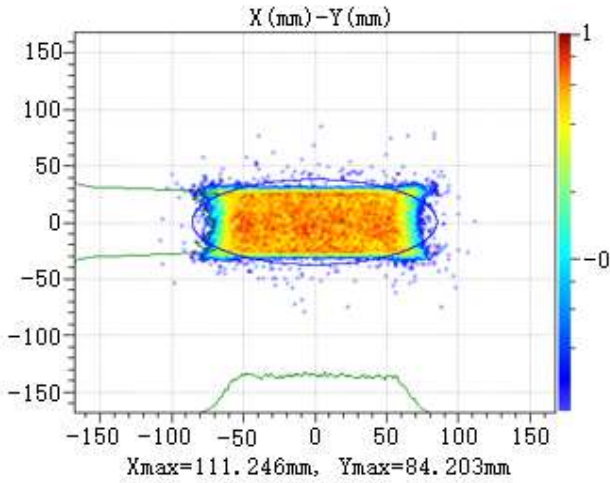
150kW，1kg/s， Int T=30℃, TC02=327K
TC02-Tin=24℃ （1.6℃/10kW）



200kW，1kg/s， Int T=30℃,
TC02=335K,TC02-Tin=32℃
（1.6℃/10kW）

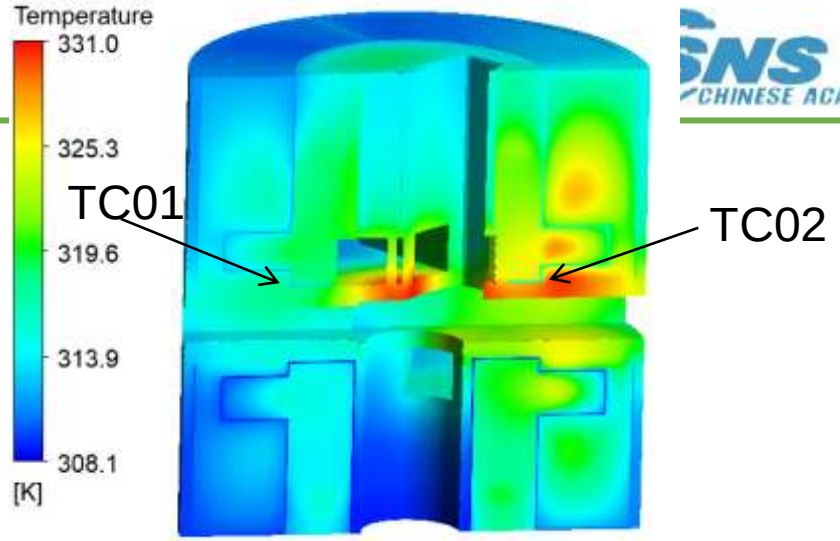
- Copmared with different proton beam powers, and predicted the calculated tempertuare of CFD is about 1.6k/10kW with initial heat source
- The measured temperature of TC02 is 2.2K/10kW.
- The reasons:
- (1) The heat source
- (2)The deformation of cooling channel



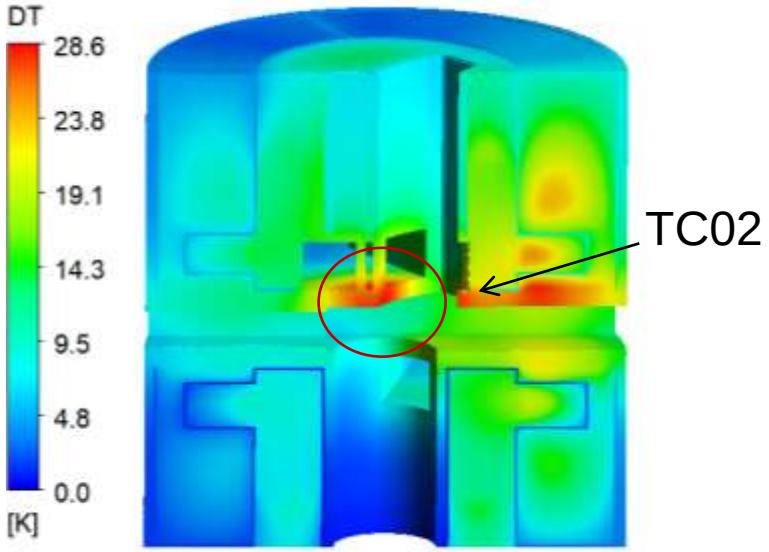


2.2 Reflector (modified heat source)

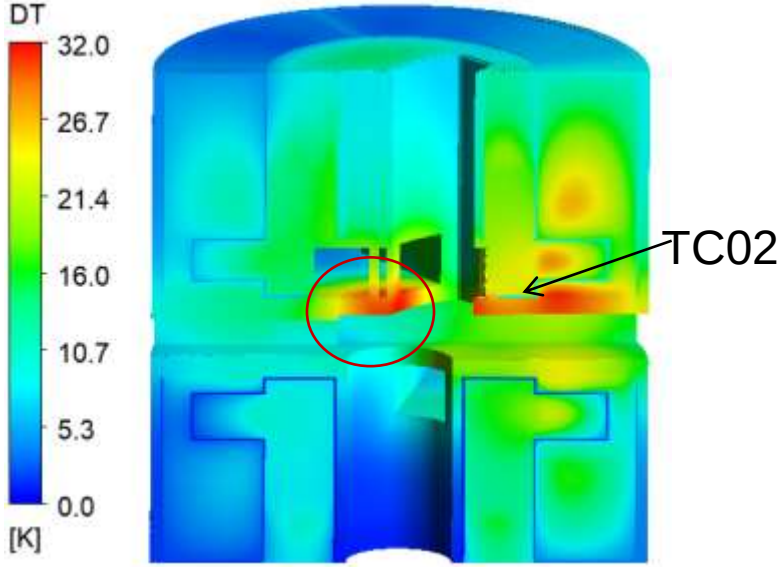
- Copmared with different proton beam powers, with additial 7% more heat load on the reflector.
- The temperature rise TC02- Tin is 21.8k/100kW， and remains constant.
- Below 100kW, the maximum is near the thermocouple of TC02, but move the the center of reflector whith higher proton beam power



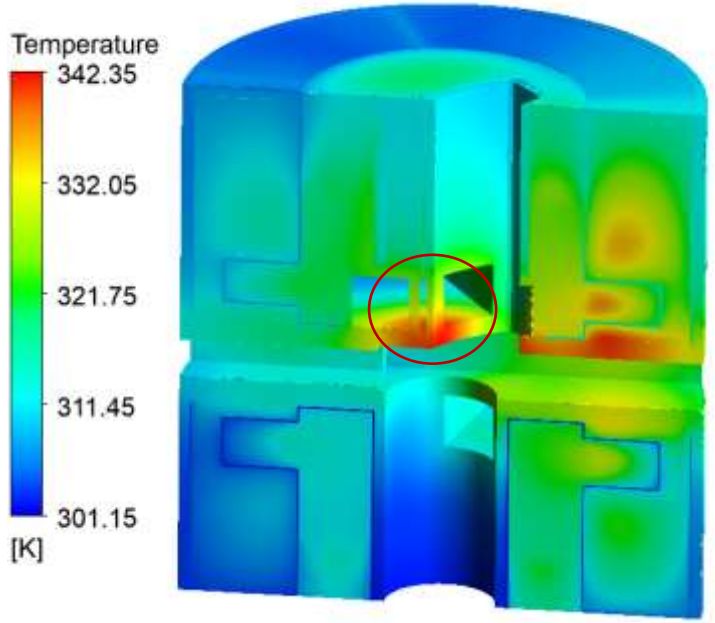
- 100kW，1kg/s，1.07*heatsource
- TC02-Tin=21.85℃（2.19℃/10kW）



- 125kW，1.07*heatsource, Tc02-Tin=27.4;
- 21.84K/100kW

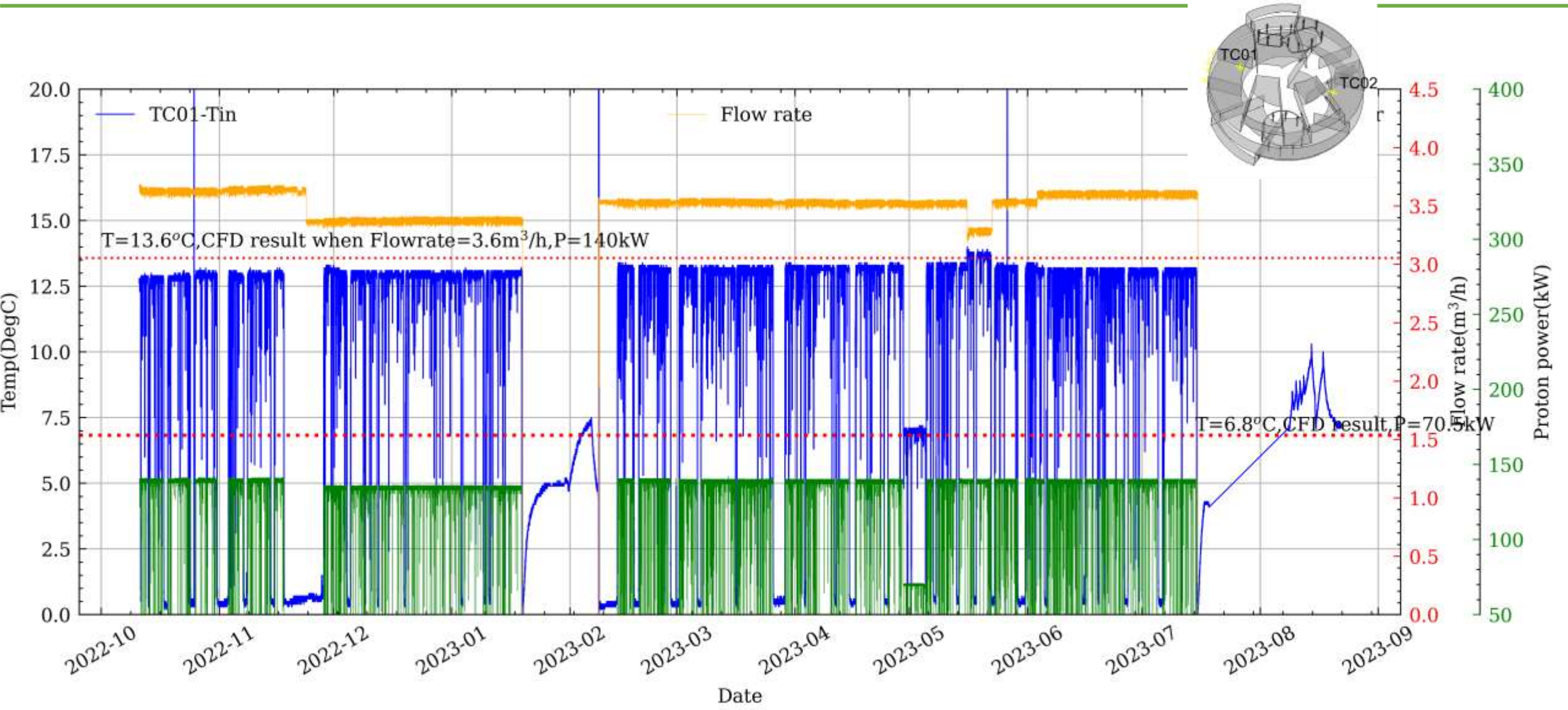


- 140kW,1kg/s,1.07*heatsource, Tc02-Tin=30.6K，21.85K/100kW

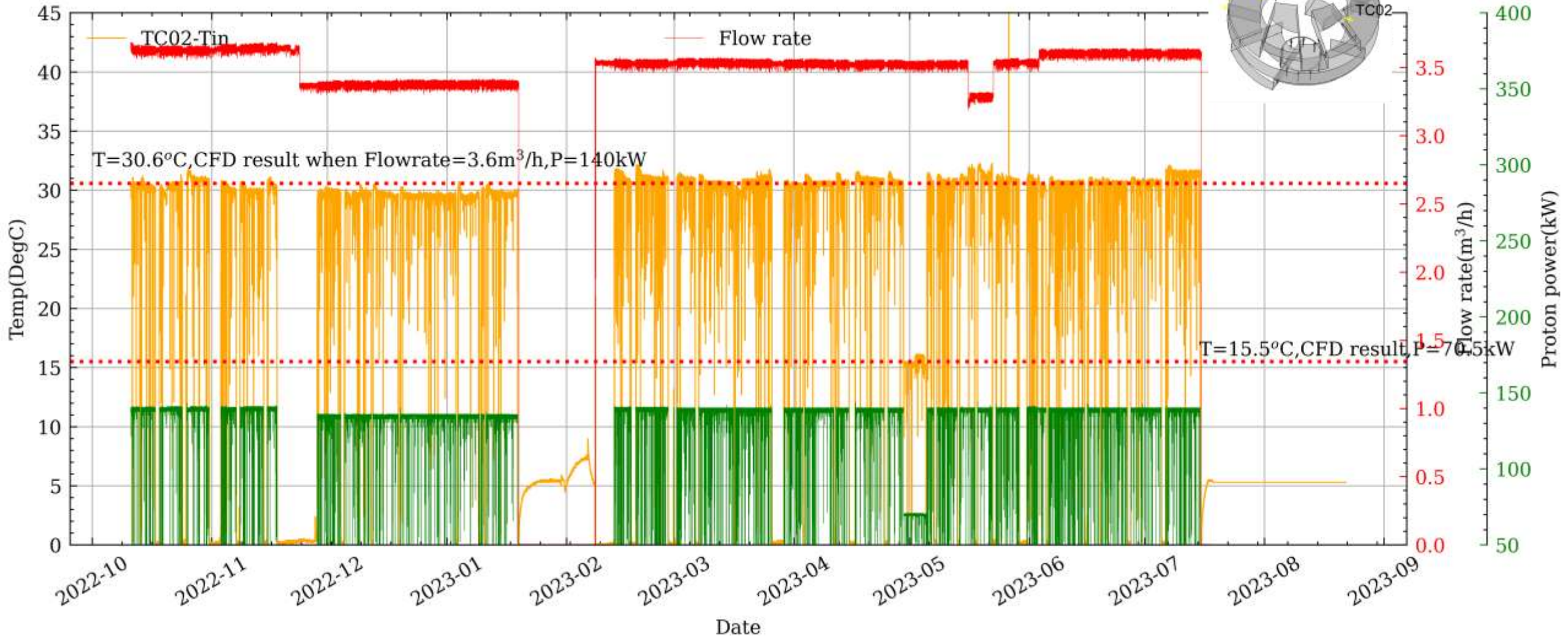


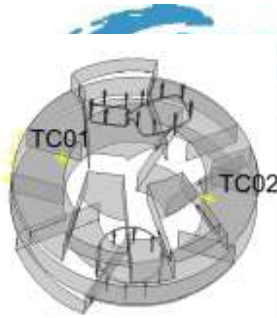
- 180kW,1.07*heatsource，1kg/s, Tc02-Tin=39.35K，21.86K/100kW

2.3 Reflector (TC01 CFD vs Measurement)



2.3 Reflector (TC02 CFD vs Measurement)





Conclusion

■Target：

- During operation , there is a significant discrepancy between the measured results and the CFD simulated outcome.
- During the decay-heat removal process, with open bounday, the CFD and the measured results agree well.

■Reflector：

When the coefficient of the heat source was adjusted to 1.07 times its original value, both the CFD simulation and the measured temperatures of TC01 and TC02 exhibited good agreement.

Thanks