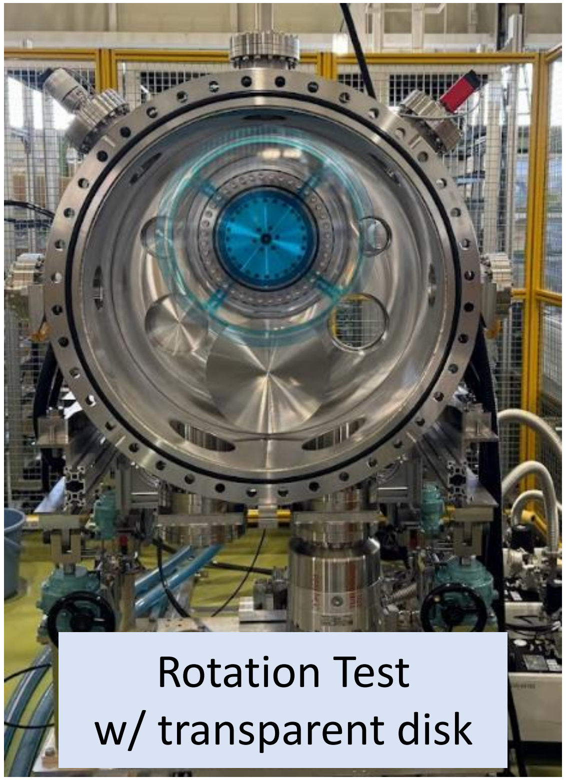
Development of ILC e-driven positron target

〇Yu Morikawa(KEK)

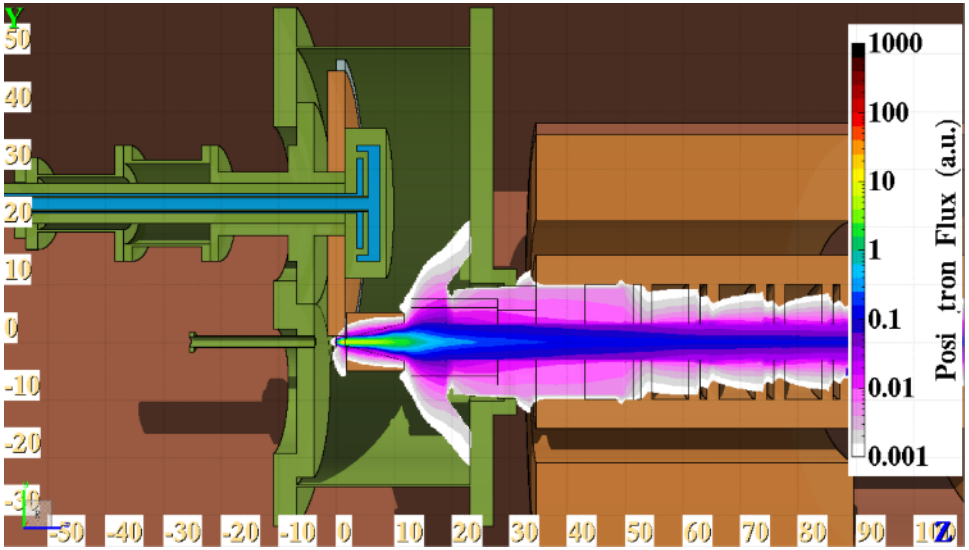

Rotation Mechanism Assemble


Total Assemble

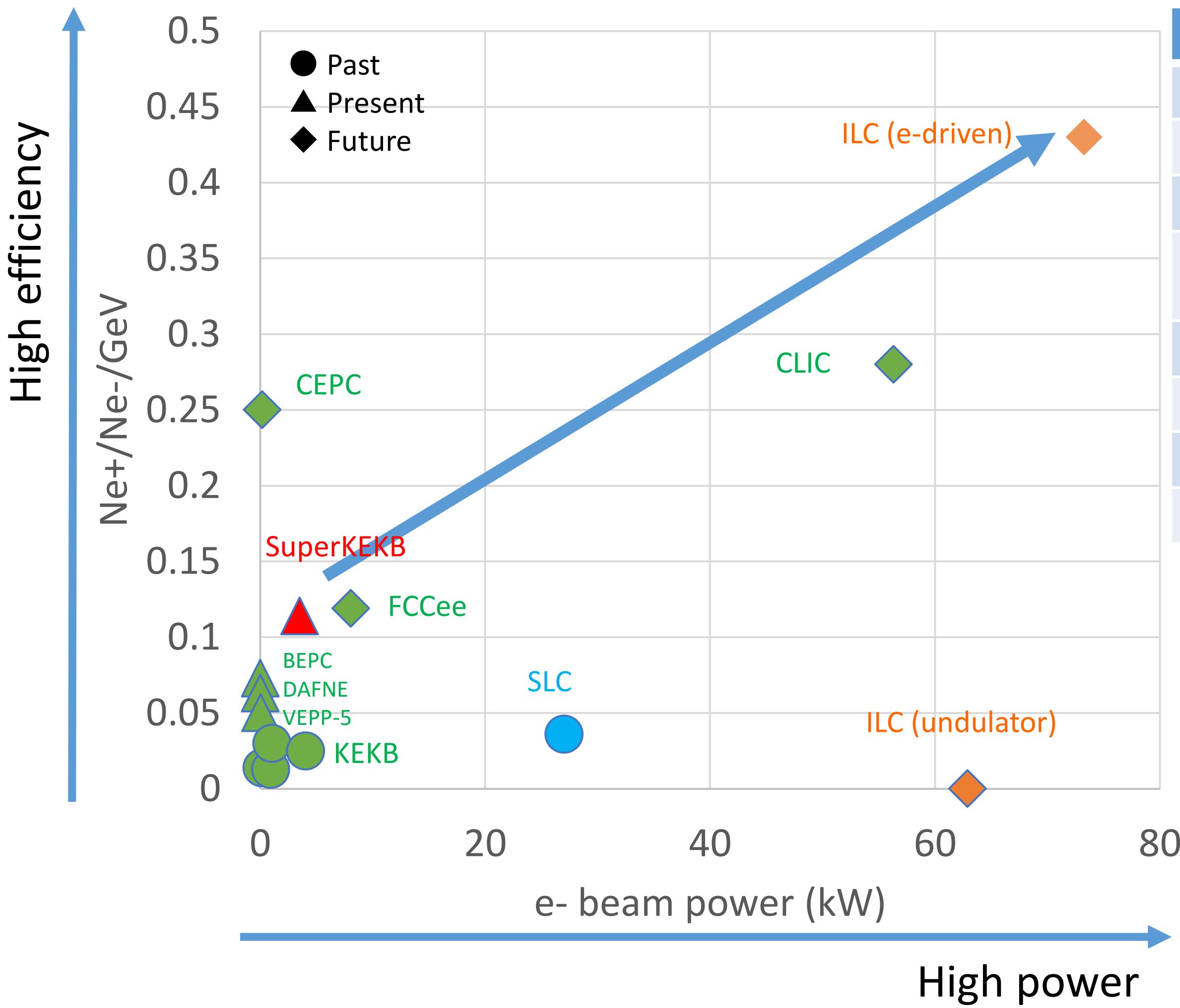

Rotation Test w/ transparent disk

e^- e^+

1. **Comparison of positron production targets**
   - A) Past to future positron target
   - B) Motivation for rotating target
2. Design and R&D status
3. Development in this fiscal year
4. Summary and outlook



Comparison of e+ Targets

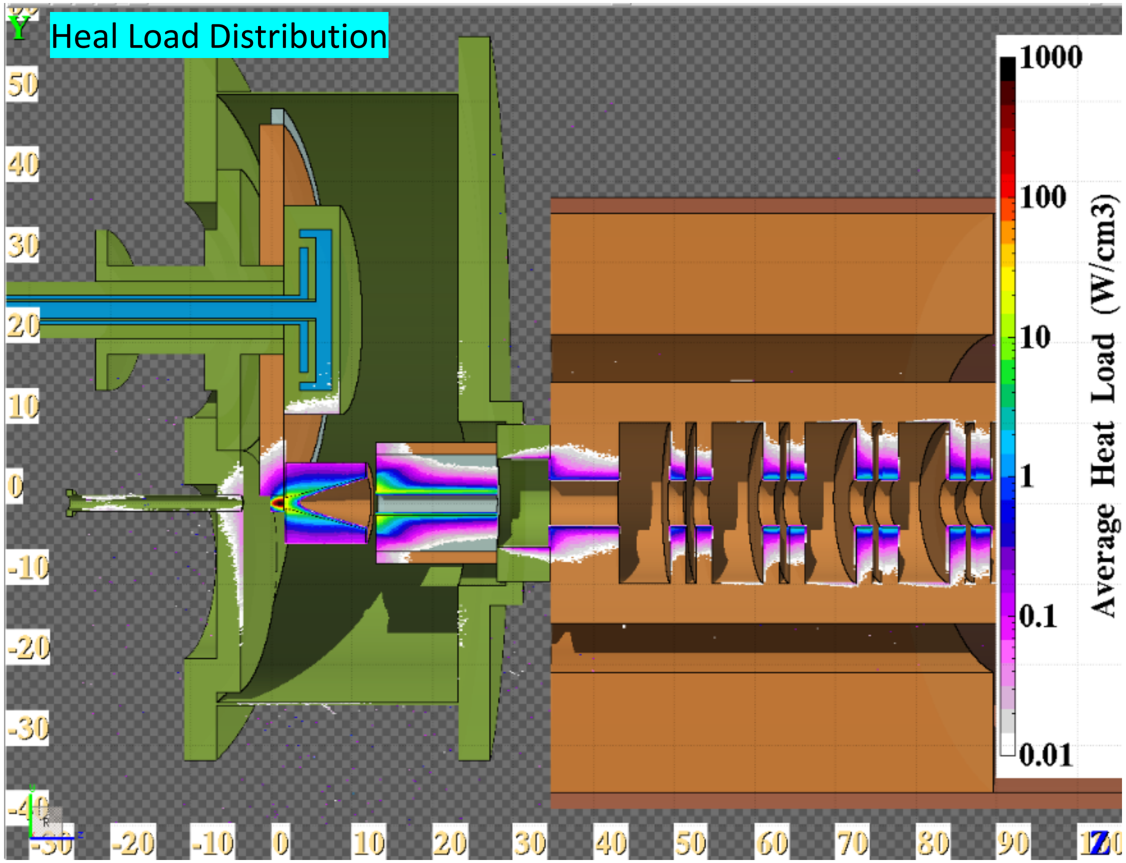


	SKEKB	ILC
e- energy	3.2 GeV	3 GeV
e- charge/bunch	10 nC	3.7 nC
Repetition	50 (25) Hz	5 Hz
Num. bunches	2	1320 = (33+33) x 20
Total charge / s	1000 (500) nC	24667 nC
Drive Beam power	3.2 kW	74 kW
Heat load on target	0.5 kW	18.8 kW
PEDD*	27.5 J/g	35.6 J/g

ILC Heat Load = 38 × SKEKB !

Heat Load on ILC positron target(e-driven)

Drive Electron Beam for positron production	
Energy (GeV)	3
Repetition Rate (Hz) (Pulse clock (Hz))	5 (300)
micro pulse / pulse	20
Charge/micro pulse (nC)	244
Pulse length(msec)	63
RMS Beam Size (mm)	2
Beam Power(kW)	**74**



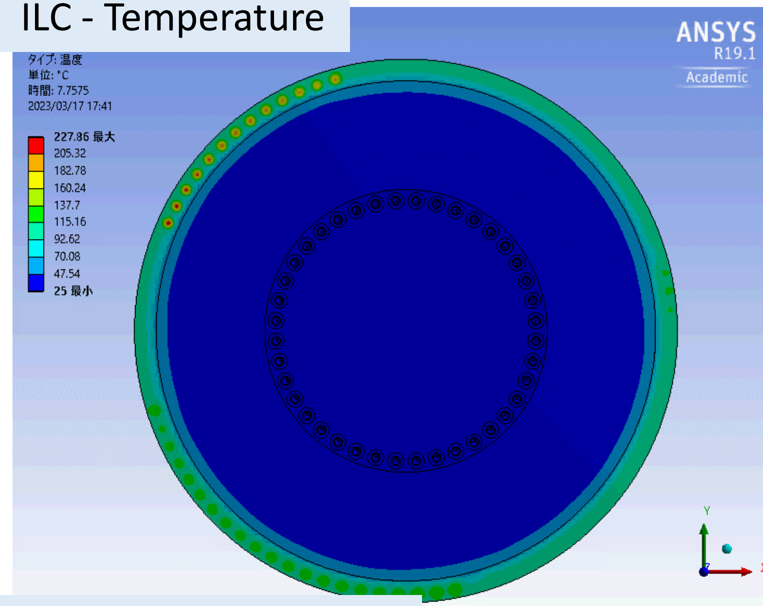
- ✓ Total Heat Load on target is 18.8kW
- ✓ Peak Energy Deposition Density per micro pulse is 35.6 J/g,
  It corresponds to temperature increase of 258 K.

Motivation for Rotating target

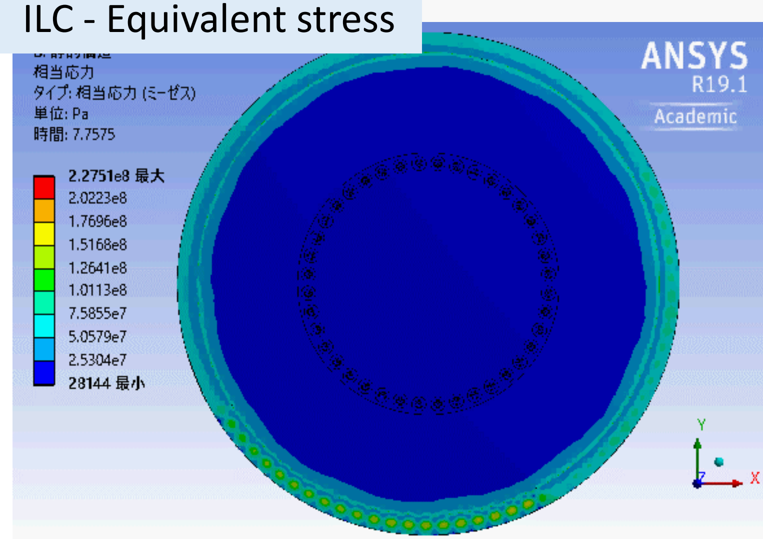
Simulation Results

	SKEKB	ILC e-driven
Primary electron energy(e^-) [GeV]	3.2	3
e^- Beam power [kW]	3	74
e^- Beam size on target [σ - mm]	0.4	2
Target material	W	W (or W alloy)
Target thickness	$4X_0$-(14mm)	$4.5X_0$-(15.7mm)
Power deposition on target [kW]	0.5	18.8
PEDD [J/g]	27.5	35.6
Max temp of Cu (alloy) [°C]	140	130
Max temp of W [°C]	360	420
Max equiv. stress at W/Cu junction [MPa]	500 (@Edge)	150
Max equiv. stress at W [MPa]	500 (@Edge)	250
Num. of stress cycle per year	9×10^8	$<1.8\times10^7$
Max alternating Stress at W [MPa]	150	110

ILC - Temperature



ILC - Equivalent stress

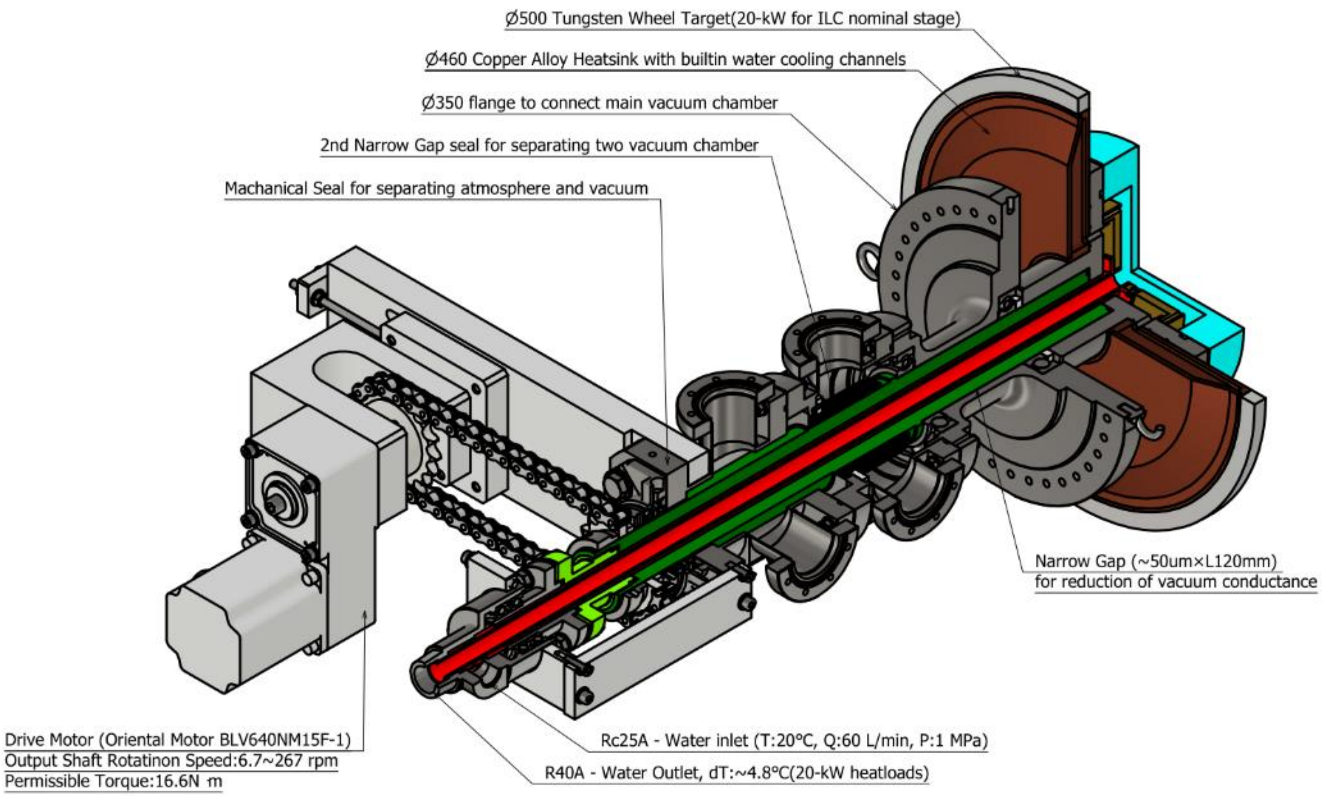


- ✓ Large disk (ϕ500mm) and rotation reduce heat flux, max temp and stress are equiv. to SKEKB.
- ✓ Compared to SKEKB, both the num of stress loading and stress amplitude are smaller. It is advantageous in terms of material fatigue.

1. Comparison of positron production targets
2. **Design and R&D status**
   A) Design and rotating mechanism
   B) Prototype test
   C) W/Cu junction test
   D) Joint research with JLAB, NIFS
3. Development in this fiscal year
4. Summary and outlook

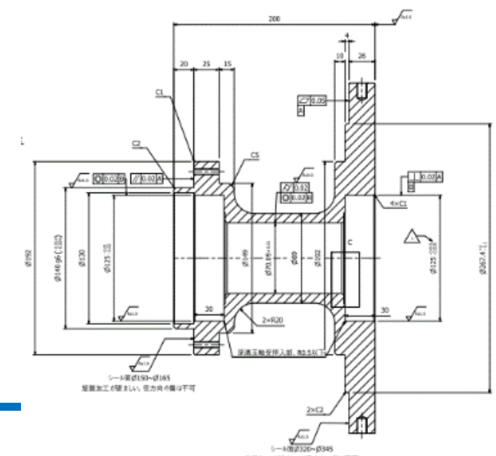
e^- e^+

Design of positron target



【Features】

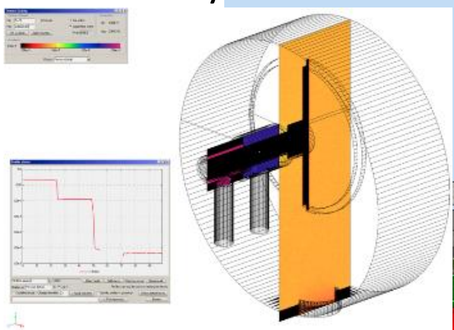
- ✓ **ϕ500 × t15.7mm tungsten disk**
- ✓ ϕ460mm copper alloy heat sink
- ✓ Rotation Speed : 225 rpm
- ✓ Water cooling (70L/min)
- ✓ ϕ70mm shaft with embedded water channel
- ✓ Required vacuum ~1e-6Pa
- ✓ **Differential pumping**
  - **2 additional chamber**
  - **Narrow Gap, Mechanical Seal**



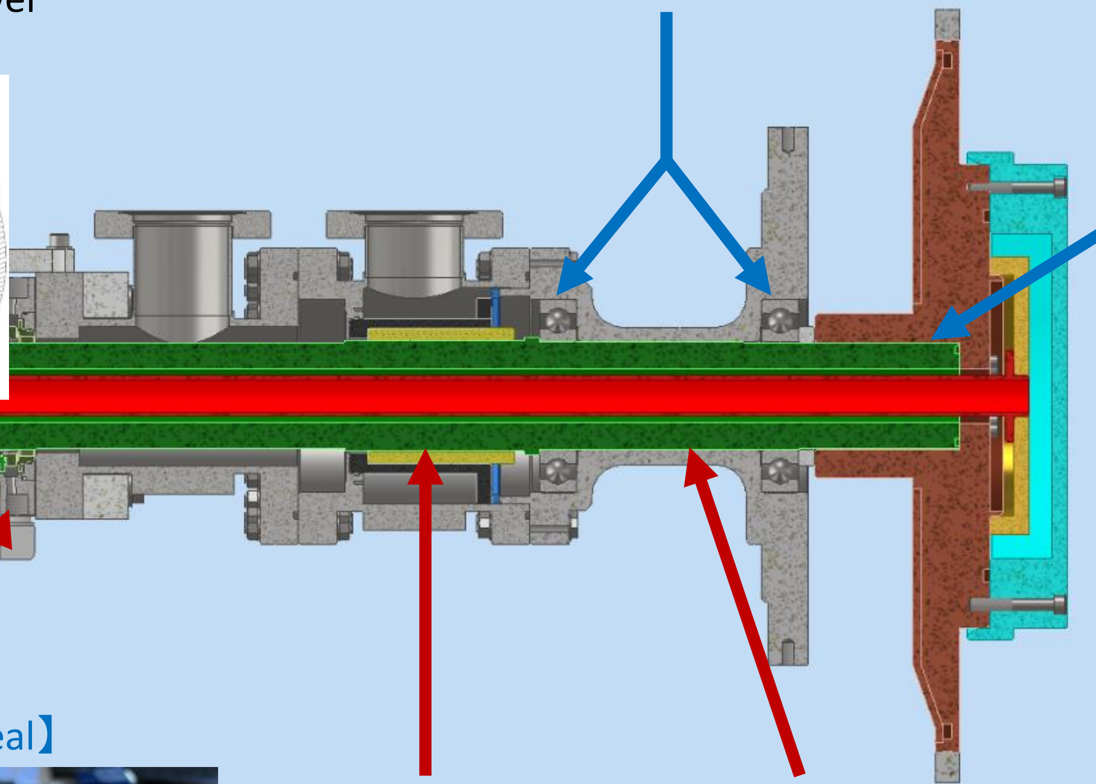
- ✓ Except for the rotating disk, **the components were manufactured and tested in last fiscal year.**
- ✓ **All 3D models and 2D drawings were created by our group !**

Rotating Mechanism

【Vacuum performance design】
Conductance, Vacuum level
simulated by Molflow

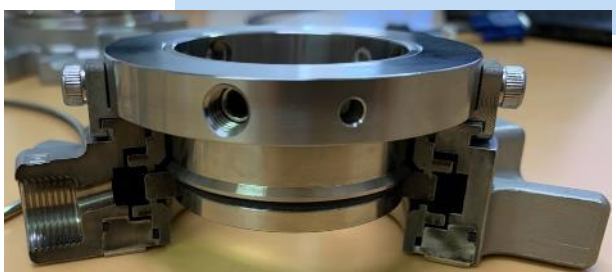


【Bearing-6214/P0C3】
- Fluorine-based vacuum grease
  ⇒ Radiation-resistant vacuum grease.
- Both inner and outer rings were shrink-fitted.



【Main Shaft】
Total runout : <5um
Cylindricity : 3um

【 Mechanical Seal】

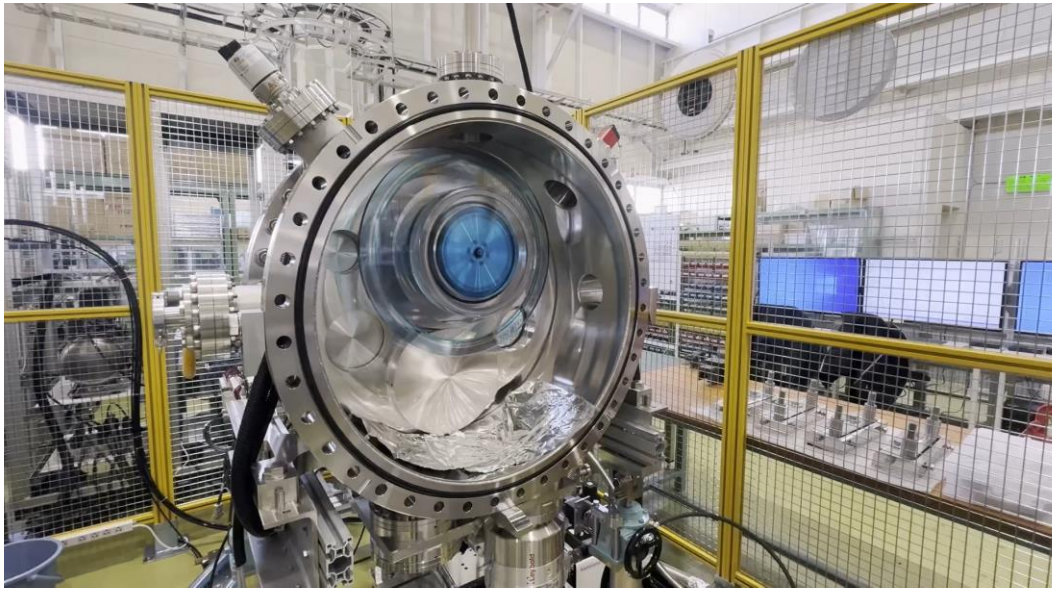


【2nd Narrow Gap】
Side Gap : 105um
Cylindricity : <10um
Coaxiality : <10um

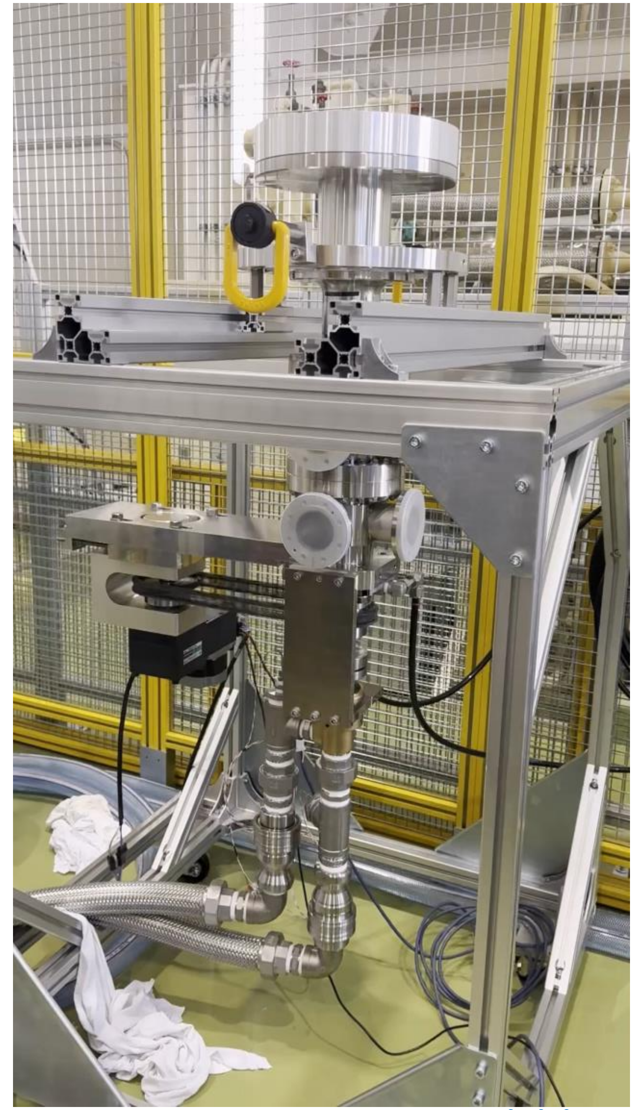
【1st Narrow Gap】
Side Gap : 38um
Cylindricity : 1.5um
Coaxiality (shaft-bearing) : 6um
+ The gap was filled with radiation-resistant vacuum grease

e^- e^+

Prototype Test

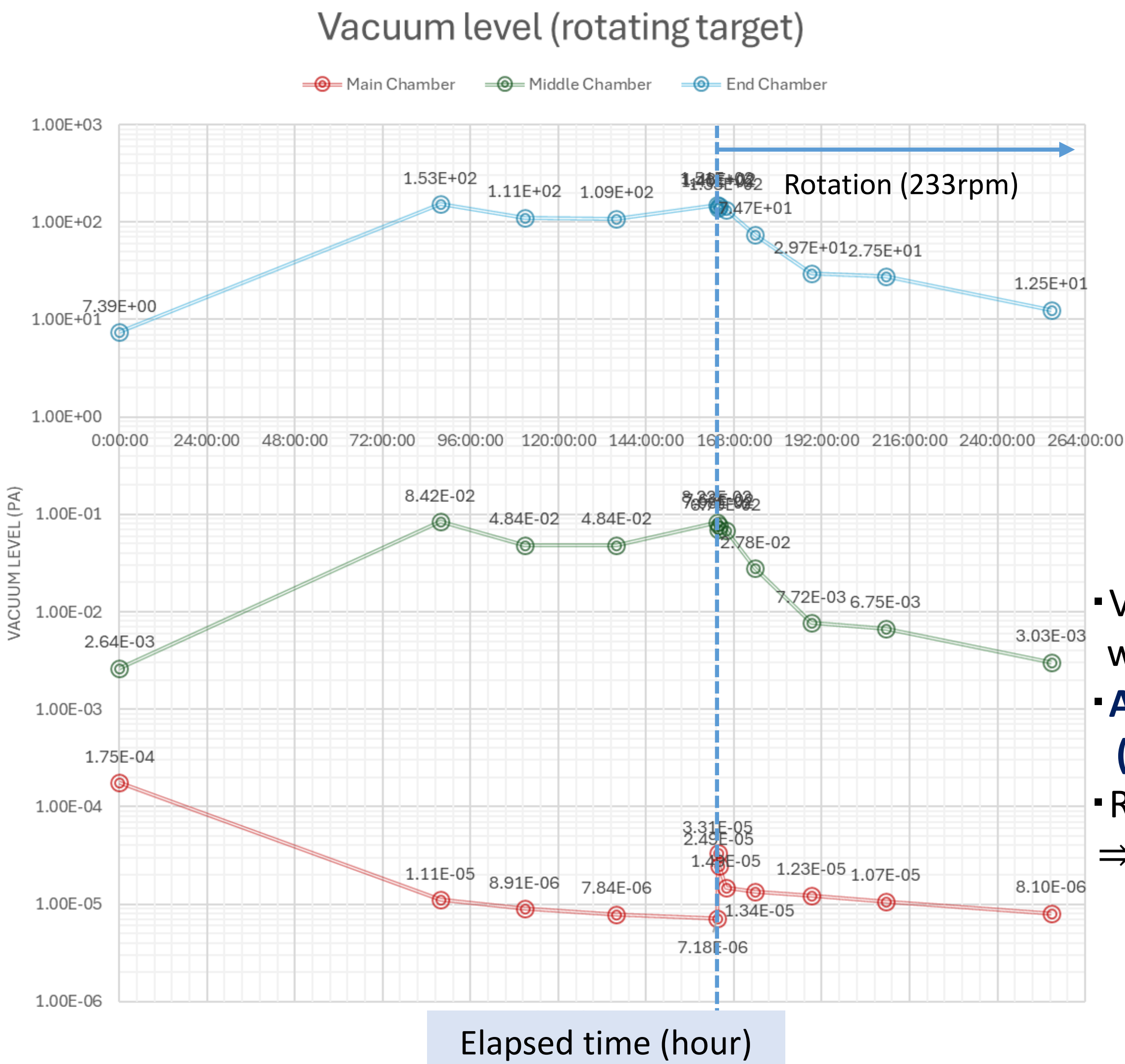


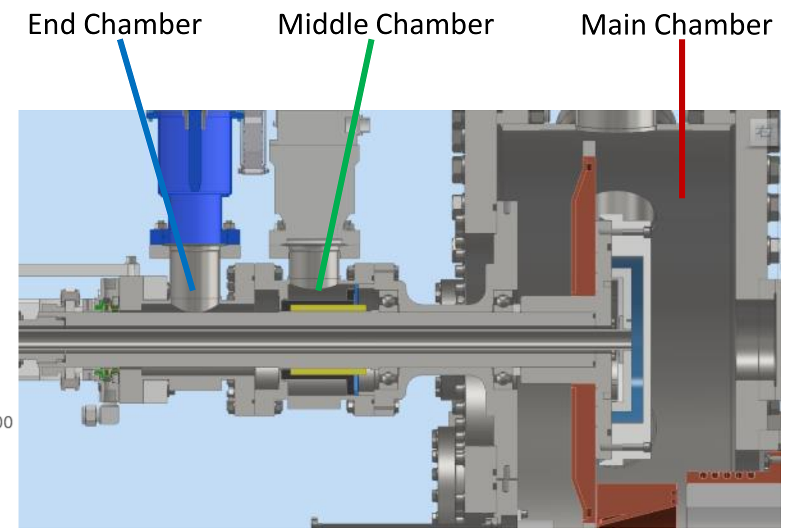
- Confirmed performance as designed.



e^- e

Vacuum performance





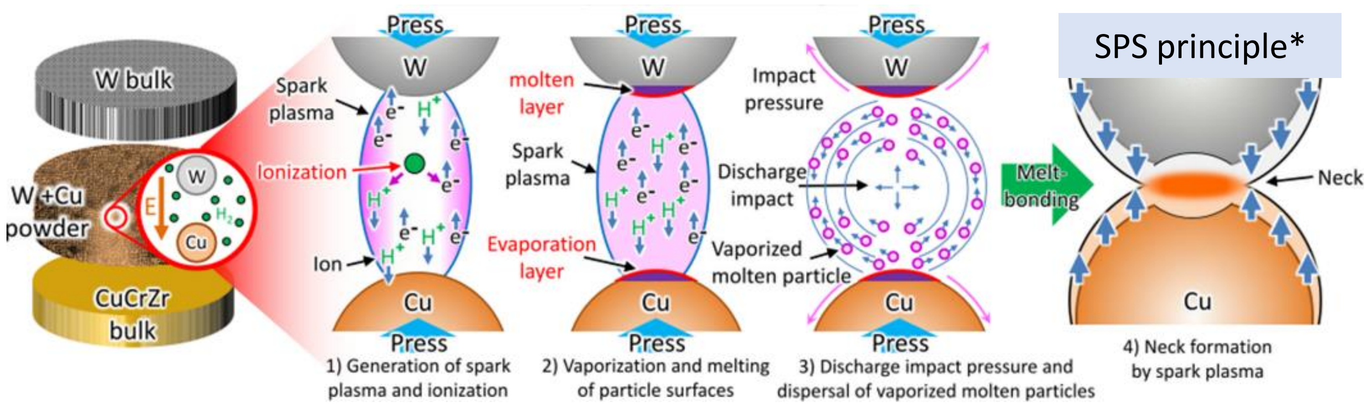
- Vacuum test w/ rotation(233rpm) and water cooling(~24L/min).
- **Achieved vacuum level : ~6e-6(Pa) w/ Target (: ~5e-6(Pa) w/o target)**
- Residual gas is predominantly H_2O.

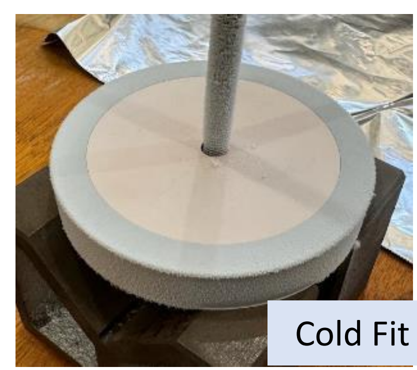
⇒Extended vacuum pumping time or baking

e^- e^+

Candidate methods of W/Cu Alloy junction

			Tested last fiscal year			Other Candidate?	
	Brazing	**EB weld**	**HIP**	**SPS**	**Interference fit (cold fit)**	**Change Cu to Mo**	**W-alloy Monolithic**
Junction Principle	Anchor	Weld	Anchor Diffusion	Anchor Diffusion	Interference pressure	･Diffusion?	-
Process Temp ℃	800~1000	Partially melt	900~1000	900~1000	-200~200	~2000	-
Thermal Strain	Whole	Welding path	Whole	Whole	Interference part	Whole	None
Recrystallization Embrittlement	No	Yes	No	No	No	Yes	No
Note		･Shallow melt depth	･Plating	Buffer layer	･Less contact stress ･Contact resistance	･Less thermal strain ･High temp process ?	･No thermal strain ･Material availability

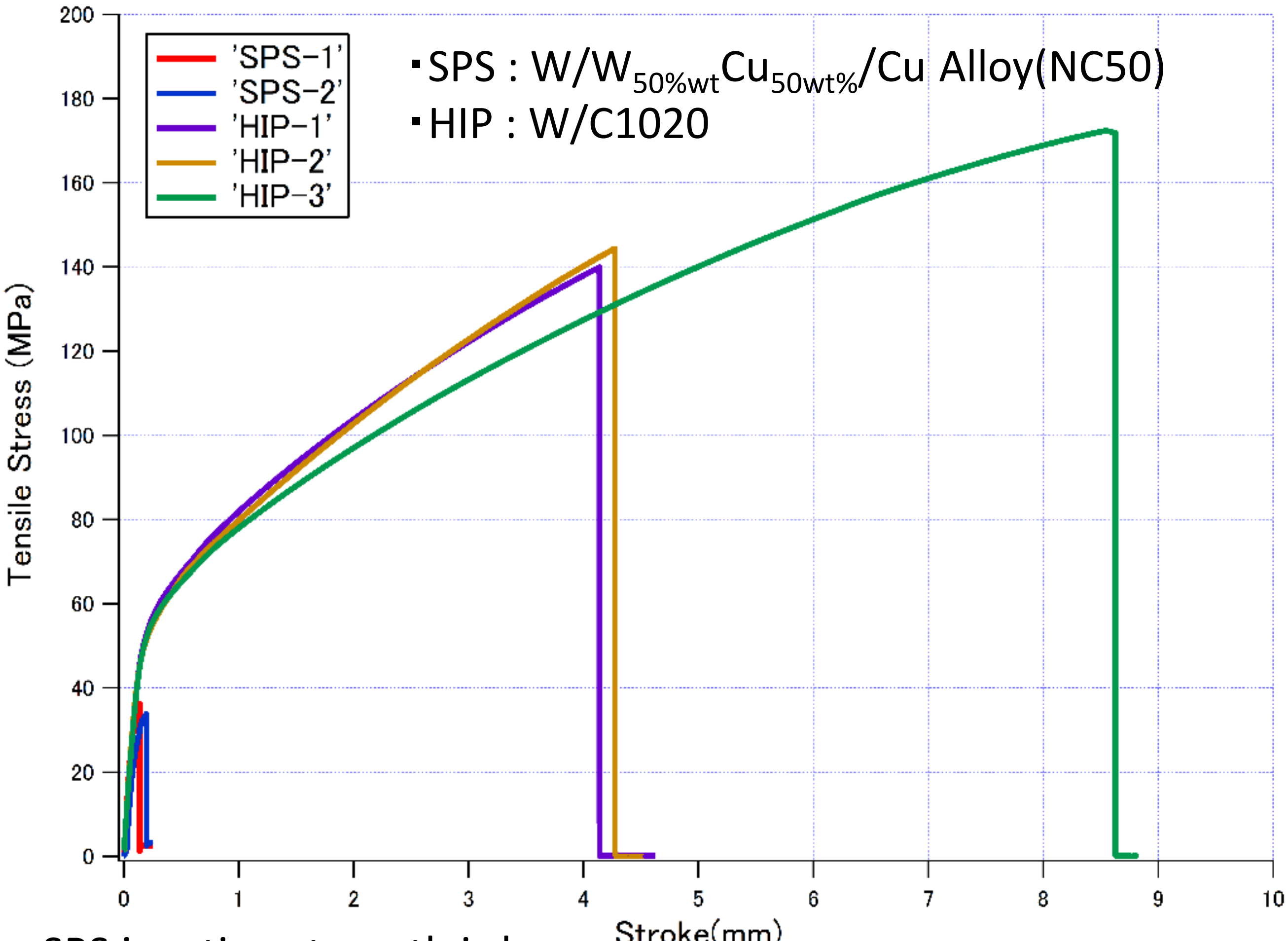




* Investigation of Joining Quality in Tungsten and Copper Alloy Joints using Spark Plasma Sintering for Plasma Facing Materials, MURASE Takanori, et al. SOFT 2022.

e^- e^+

Results of Tensile Test



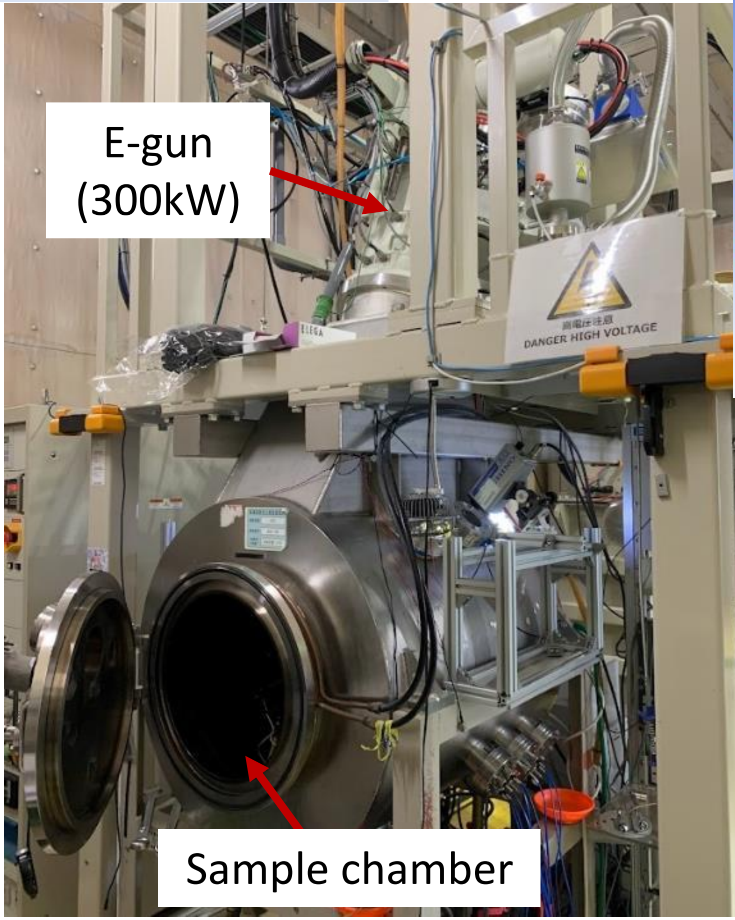
HIP(W/Plating Cu/Cu alloy(NC50))

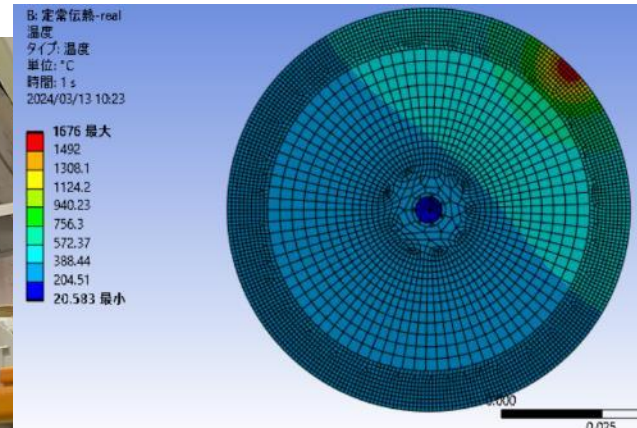
- SPS junction strength is low.
- HIP(W/C1020) has better junction strength.
- HIP(W/Plating Cu/Cu alloy(NC50)) samples were made and under preparation for test.
  We made 2 samples but 1 was broken during machining due to thermal strain.

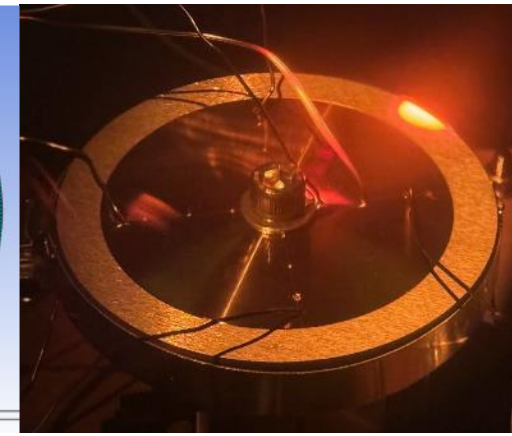
ACT2 - heat load test

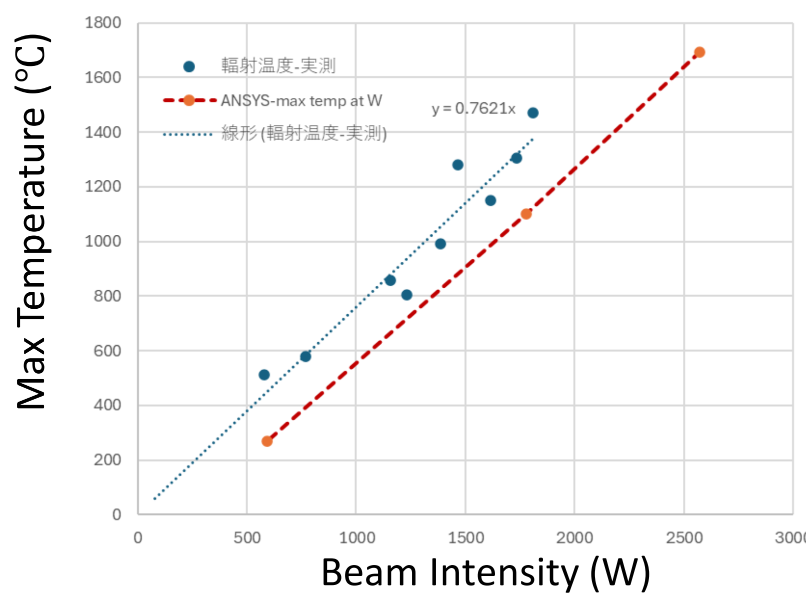
Joint research with National Institute for Fusion Science (NIFS) from 2023~

ACT2@ NIFS









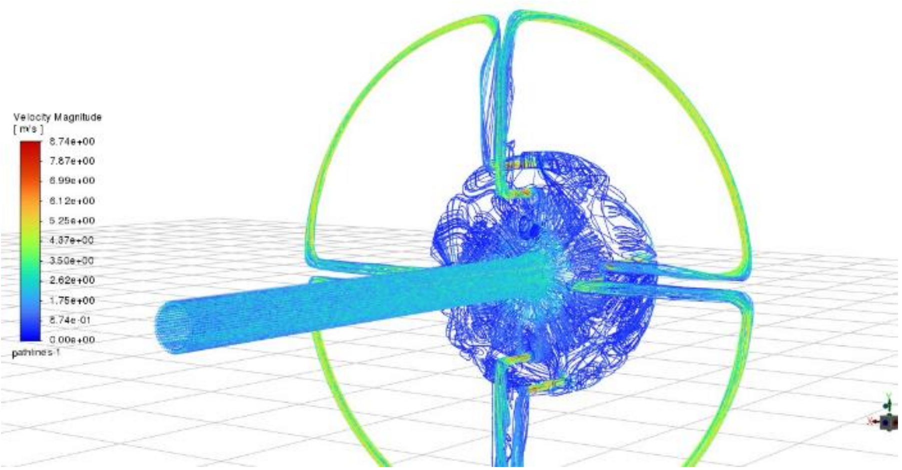
- ϕ100mm – interference fit sample
- Withstands temperature rise and fall up to 1100℃
- W-ring exits during cooling after reaching 1500℃

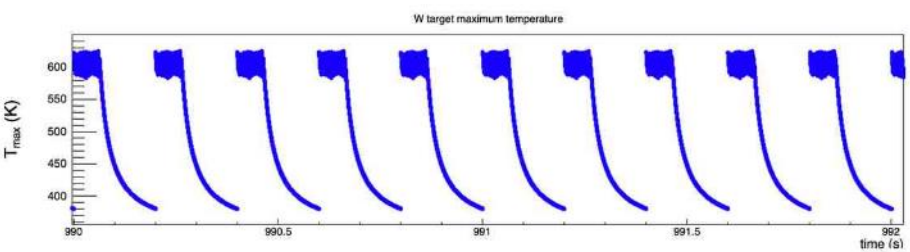
e^- e^+

CFD simulation and PIV test

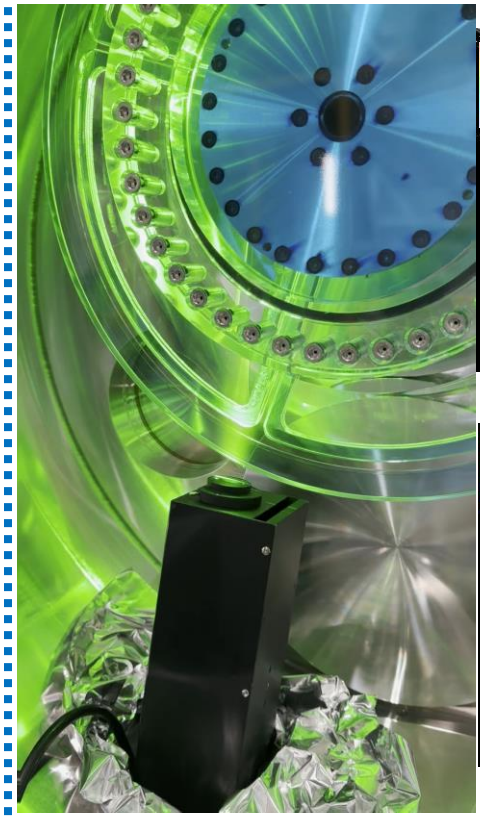
Joint research with JLAB (Silviu-san) from 2023~

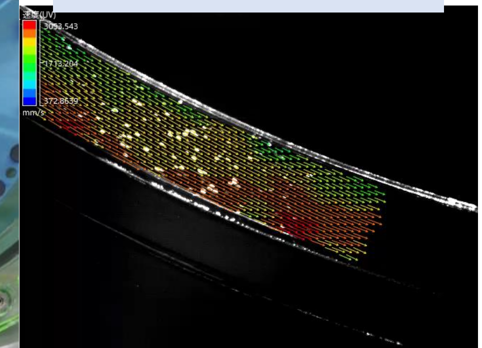
CFD simulation (20kW, 70L/min-design)

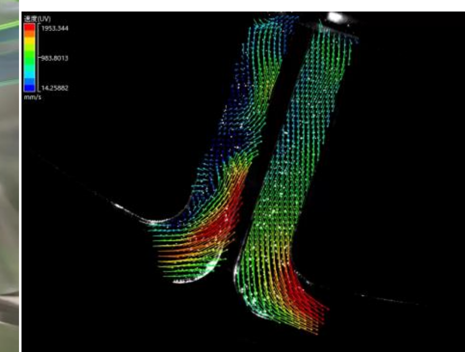




PIV test (24L/min)

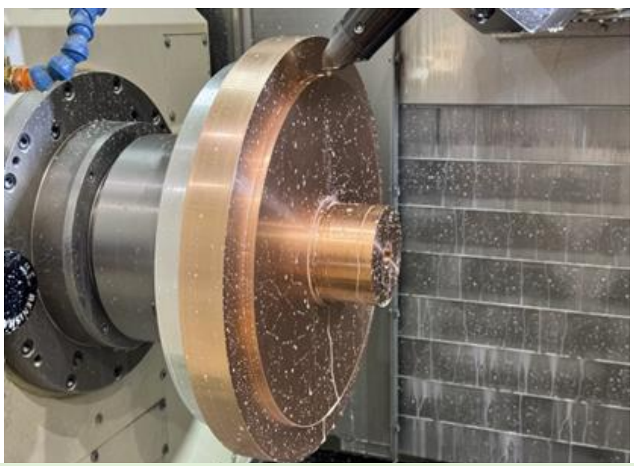




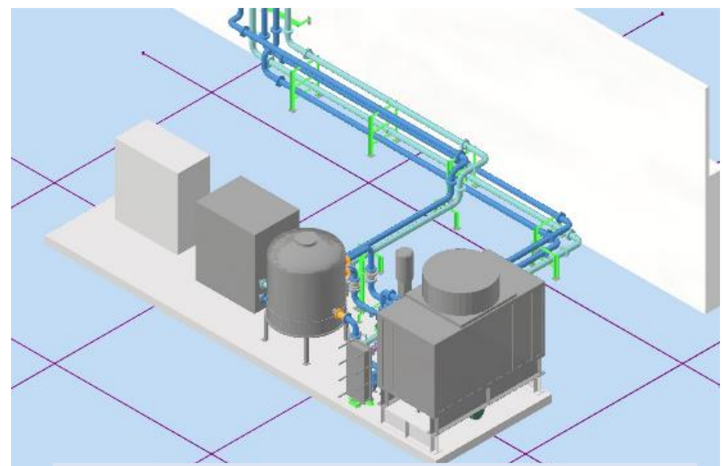


- CFD simulation was done by J-Lab, and evaluated max temp, heat transfer coefficient(HTC), etc. This simulation shows max temp is ~350°C. This value is lower than our previous thermal analysis which use conservative HTC.
- Particle image velocimetry(PIV) test to validate the simulation and get deeper understanding.

1. Comparison of positron production targets
2. Design and R&D status
   A) Design and rotating mechanism
   B) Prototype test
   C) W/Cu junction test
   D) Joint research with JLAB, NIFS
3. **Development in this fiscal year**
4. Summary and outlook



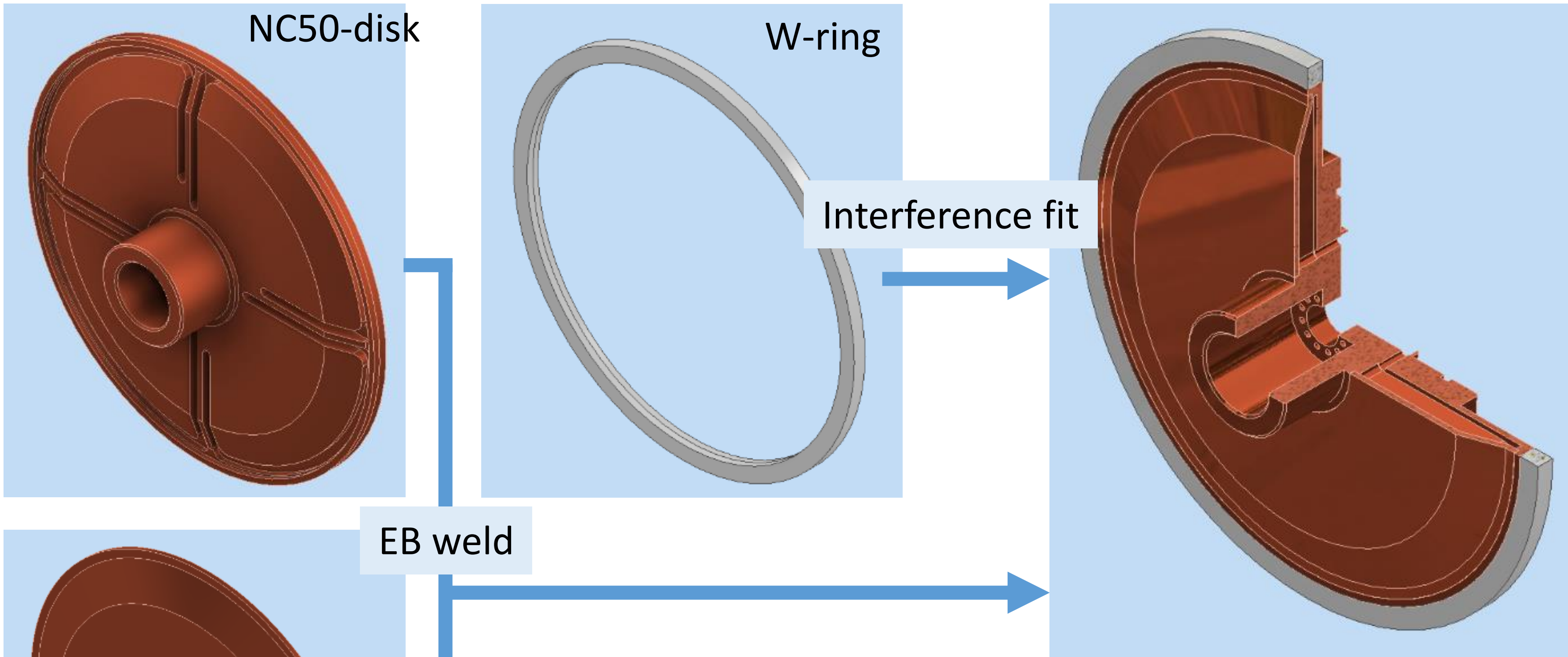
ϕ500mm disk
(ϕ460mm heat sink in machining)

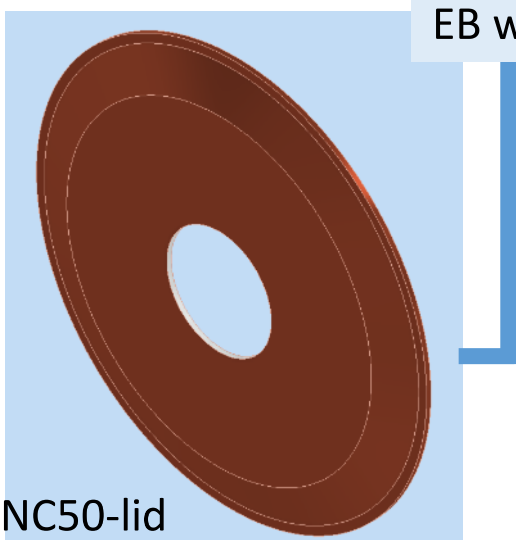


Water supply facility for
positron test bench

e^-

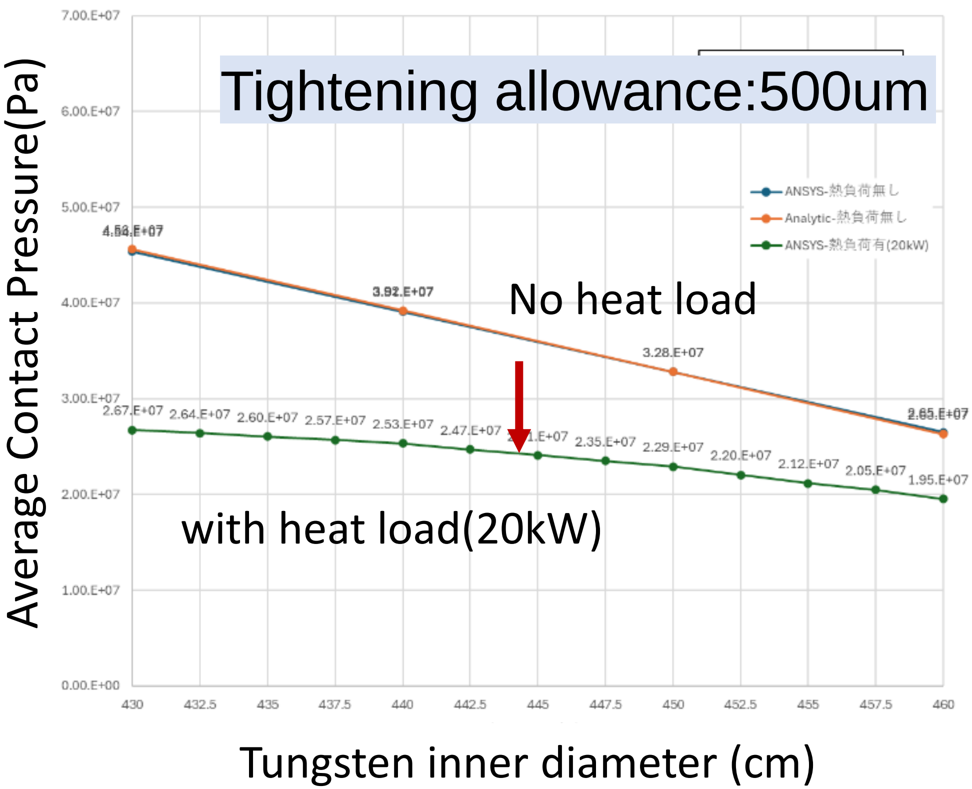
Manufacturing of Φ500mm disk

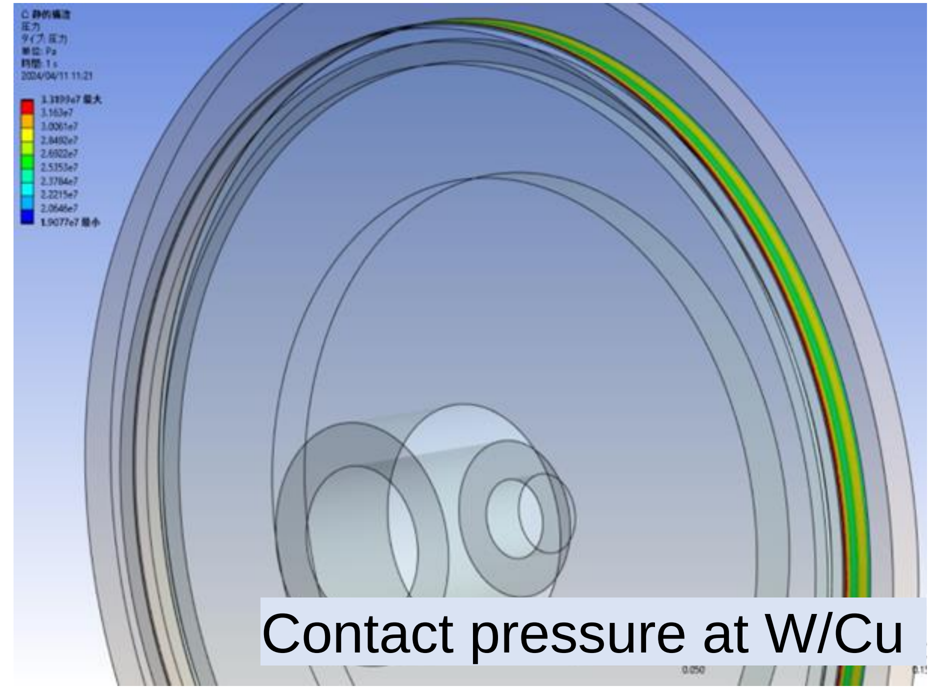




- High-temperature process is only EB welding between copper alloys (NC50).
- W-ring is set by interference fit.
- Manufacturing will be completed in this September.

Structural analysis





- With 500um tightening allowance of 500um, contact pressure will be ~20 MPa.
- Under pressure of 20MPa, temperature rise due to contact thermal resistance can be estimated ~10℃ by using empirical formula(Tachibana's equation, etc).

1. Comparison of particle production targets
2. Current Design and R&D status
    A) Current design
    B) Water cooled UHV compatible rotating mechanism
    C) W-Cu connection
3. Development in this fiscal year
    A) ϕ500mm target disk
    B) W-Cu connection
4. Summary and outlook

e^- e^+

Rotating target in Japan

	e^+	μ	Hadrons	RIBF
Institute	ILC (e-driven)	J-PARC	J-PARC	RIKEN
Primary particle	e^-	p	p	C~U
Target material	W	C	Au or W	Be, W
Repetition [Hz]	100 / 300	25	0.19	CW (1puA)
Beam Power [kW]	**74**	**1000**	**150**	**82**
Deposited power [kW]	**18.8**	**3.1**	**11**	**18**
PEDD [J/g]	33.6	20	Slow extraction	CW
Status	**Prototype**	**In operating**	**Prototype**	**In operating**
Cooling	**Water**	**Radiation**	**He**	**Water**
Remarks	**In vacuum(e-6 Pa)**	**In vacuum(e-6 Pa)**	**In He gas**	**In vacuum, large space**

【ILC e-driven】
Rotation/Vacuum/Water cooling /Space saving/high precision
⇒Our target have achieved various technical elements.

Summary & Outlook

✓ **Water cooled UHV compatible rotating mechanism**

- Differential pumping by narrow gaps.
- The results of the prototype test are satisfactory.

✓ **W-Cu Disk**

- Tested junction methods : HIP, SPS, Interference fit.
- The ACT2 test for cold fit sample shows the potential for enough cooling performance, while also highlighting the importance of tightening management.

✓ **Manufacturing of ϕ500mm target**

- In progress. Scheduled for completion in September.
- Heat load test will be conducted.

Our target will become versatile target suitable for various projects!

Backup Slide

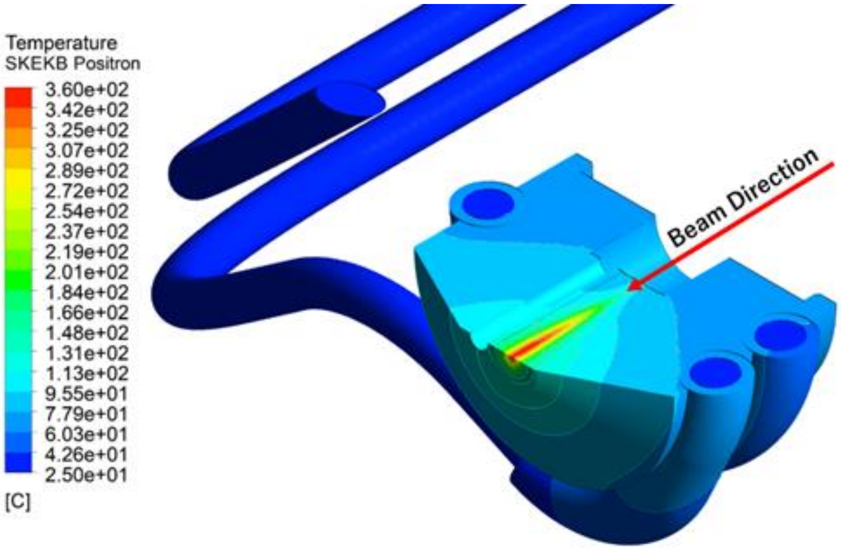
Comparison of Particle Production Targets

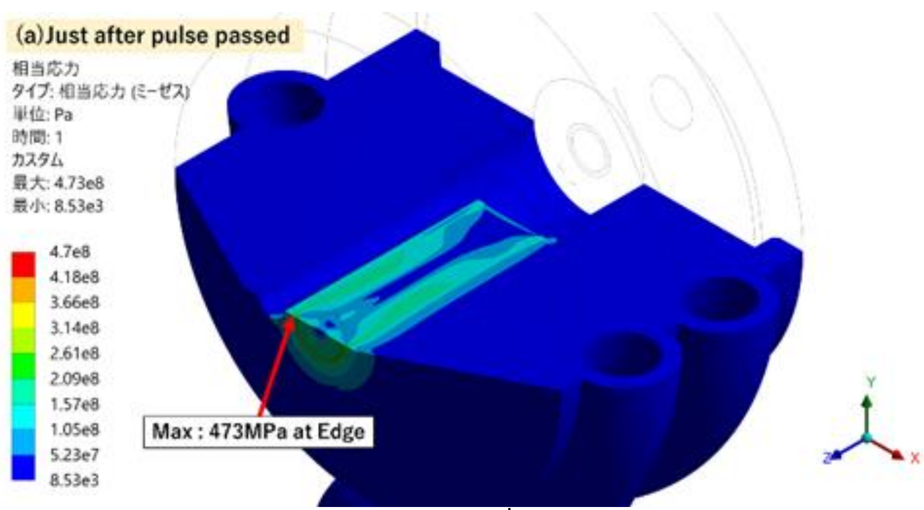
No.	Drive Particle	Production Particle	Labolatory (Project)	Target Material		Primary Beam	Deposition at Main Absorber		Remarks
				Material	Dimensions	**Power (kW)**	Ratio of deposit	**Deposit Power(kW)**	
1	Electron	Slow Positron	KEK	Ta	t4mm	**0.6**	0.26	**0.16**	水冷
2	Electron	Positron	SLAC	W74-Re26	t20.6mm	**44**	0.18	**8.13**	トロール+水冷
3	Electron	Positron	KEKB	W	t14mm	**4**	0.14	**0.52**	水冷
4	Electron	Positron	SKEKB	W	t14mm	**4**	0.14	**0.51**	水冷
5	Electron	Positron	ILC	W75-Re25	t16mm	**73**	0.26	**18.95**	回転＋水冷(E-driven)
6	Proton	Muon	J-PARC	C	ϕ70mm×t20mm	**1000**	0.00	**2.92**	回転+輻射冷却
7	Proton	Neutron	J-PARC	Hg	~L2000mm	**1000**	0.39	**386.67**	流体
8	Proton	Neutrino	J-PARC	C	ϕ26mm×L909mm	**750**	0.02	**13.50**	ガス冷却
9	Proton	Hadrons	J-PARC	Au	t11mm×6set	**80**	0.11	**8.98**	水冷-遅い取り出し(~2sec)
10	Proton	Neutron	SNS at USA	Hg	~L2000mm	**1400**	0.34	**478.80**	流体
11	Proton	Neutron	ESS	W	~L1200mm	**5000**	0.46	**2297.50**	回転＋ガス冷却
12	~ U238	Rare Isotopes	RIKEN(RIBF)	C,Be,Ta···	Be-t 5.4mm,etc···	**83**	0.27	**22.00**	回転＋水冷
13	(O16 ~ U238)	Rare Isotopes	FRIB	C	t0.15mm×2-9disk	**400**	0.17	**68.74**	回転+輻射冷却

- **In positron targets,**
  deposited heat at target is around 20% of the driving beam power.
  ⇒10kWビームで ~2kW, 100kWビームで ~20kW程度の熱量を標的で受ける。
- **Trend is to start using rotating mechanism when the deposited heat reaches around 10 kW.**
  ⇒更には~100kW以上から流体標的や巨大回転標的(ESS ~ϕ2.6m)が登場する。

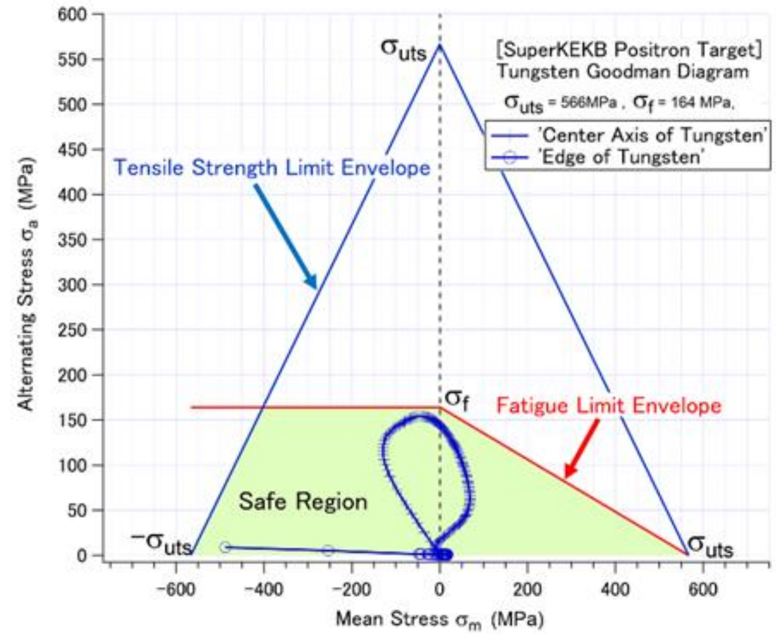
e- e+

SKEKB thermal analysis





Goodman diagram



Range of The Fluid Types Products

Product name	MORESCO-HIRAD RP-42	MORESCO-HIRAD RP-42R	MORESCO-HIRAD RP-42S
Appearance	Colorless Transparent	Light yellow Transparent	Colorless transparent
Density 15℃ g/cm^3	1.166	0.989	1.040
Viscosity 40℃ mm^2/S	128.6	279.9	42.0
Viscosity index	-111	63	52
Pour point ℃	0.0 (*1)	-17.5	-22.5
Flash point ℃	268	296	250
Total Acid number mgKOH/g	0.00	0.00	0.00
Radiation-resistance Upper limit / MGy (*2)	30	15	15
Types of packing (*3)	500ml bottle		

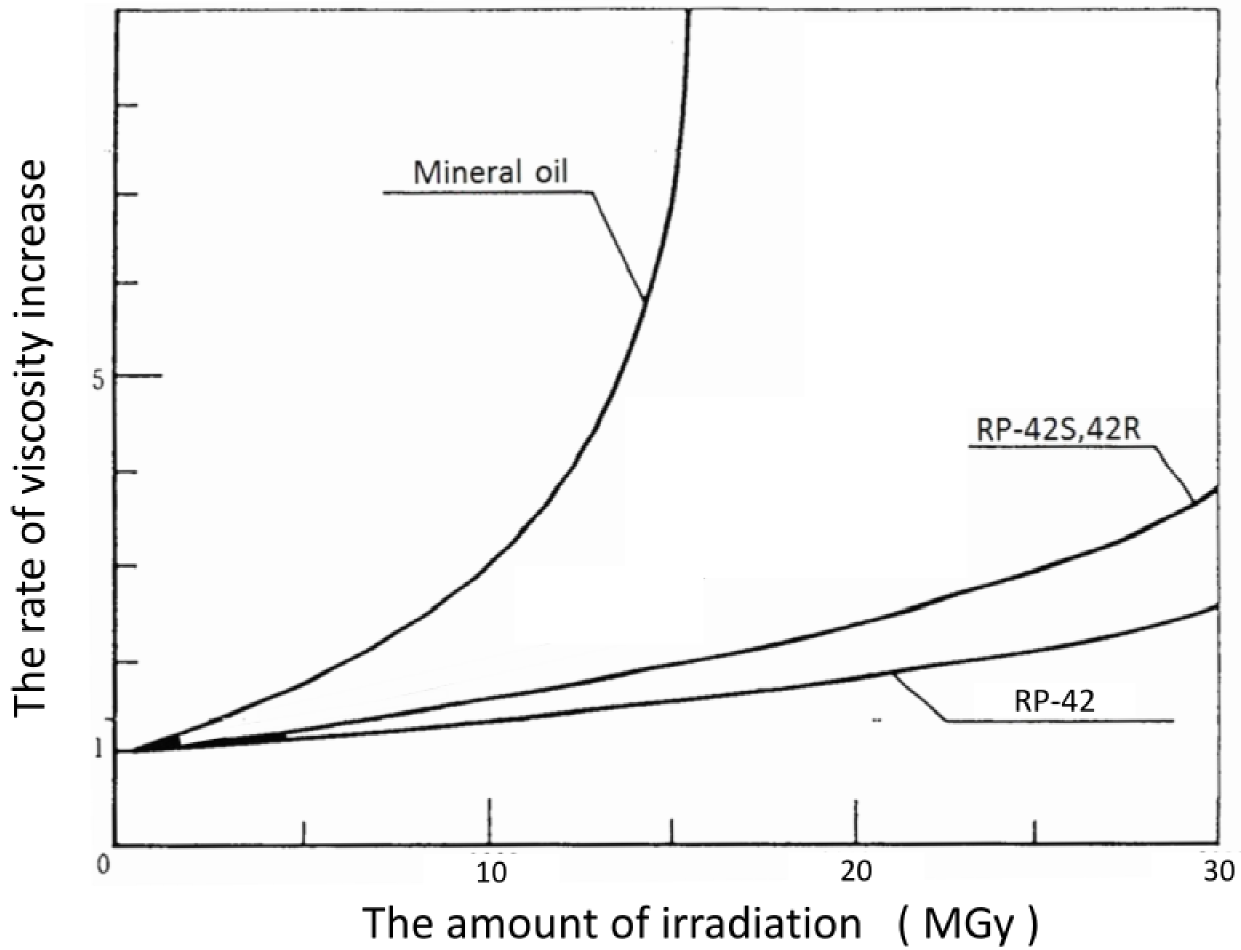
Note： (*1) Although its pour point is 2.5 degree Celsius, it is 10 degree Celsius that the lower limit of our quality guarantee temperature on this product.

(*2) In a room temperature and atmospheric environment

(*3) We are able to deliver more big packages of quantities which meet your needs. however, an additional lead time will be required for their realization.

- **Some countries ban importing of these lubricants or require procedures such as submission of application for approval and/or quantity report. Hence, there may be some cases where exporting of these lubricants for replenishment may not be possible. The importer will be subject to penalties if these lubricants are imported against legal restrictions in the importing country. Please contact me (hayashi@moresco.co.jp) in advance if you intend to export these lubricants and/or parts containing the lubricants.**

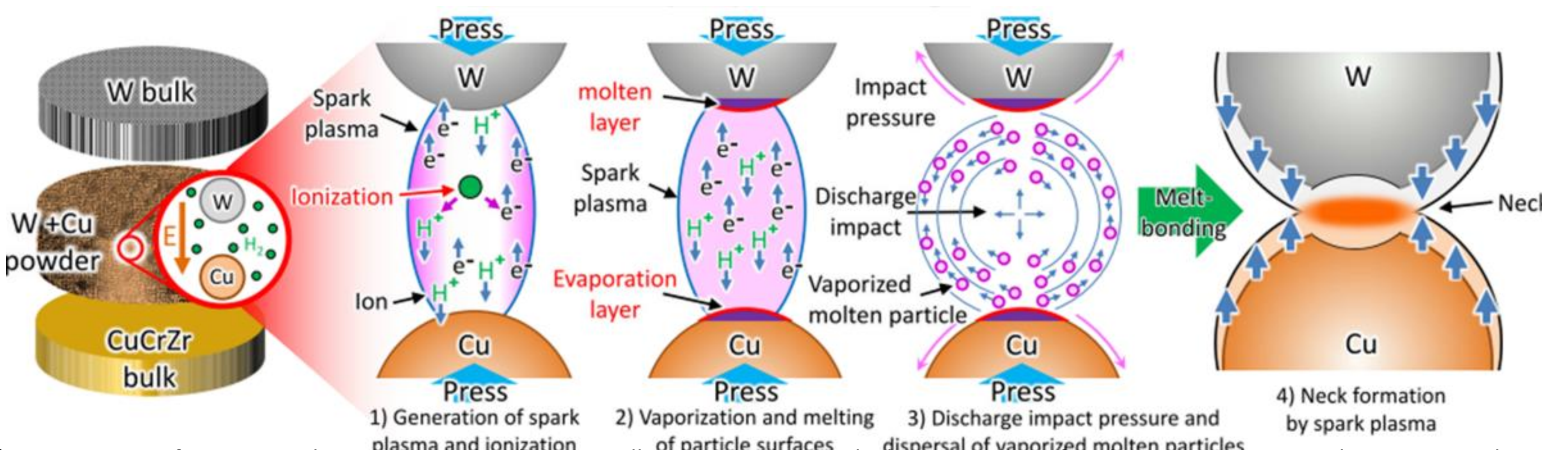
The Performance of The Radiation Resistance from a Gamma Ray (2)



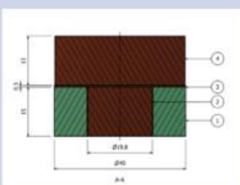
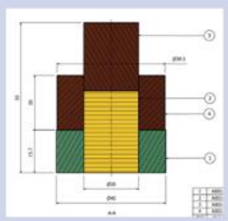
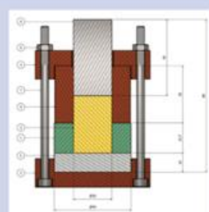
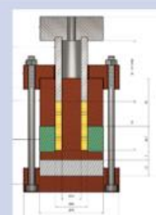
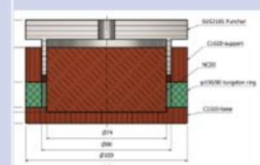
【 Fig 1. The effect of a gamma ray for the viscosity 】

Fluids with a small rate in viscosity increase are excellent.

Spark Plasma Sintering(SPS)



* Investigation of Joining Quality in Tungsten and Copper Alloy Joints using Spark Plasma Sintering for Plasma Facing Materials, MURASE Takanori, et al. SOFT 2022.

	Sample No.1 (ϕ40mm)	Sample No.2 (ϕ40mm)	Sample No.3 (ϕ40mm)	Sample No.4 (ϕ40mm)	Sample No.5 (ϕ100mm)
構造断面					
結果/接合後	・NIFS先行研究と同等構造 ・プロセスは完了 ・W/SPS/Cuの引張試験 ~40MPaでW/SPS部で破断 	・W-ring内をSPS層で埋める。 ・銅製パンチャーがたわみ プロセス未完 	・W-ring内をSPS層で埋める。 ・SUSパンチャーに変更 ・プロセス完了 ・機械試験用に切出し中に 割れ発生  	・W-ring/銅間にSPS挿入 ・プロセスは完了 ・機械試験用に切出し中に 割れ発生 	・W-ring/銅間にSPS挿入 ・No.4のϕ100版 ・銅部は銅合金NC50に変更 ・プロセスは完了 ・機械試験用に切出し中に 割れ発生 

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・苦戦中