

# Beryllium and Aluminum Cavities

Operating at High Electrical Gradients in High Magnetic Fields

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## Introduction

- **805 MHz RF gradient fell: 40 to 13 MeV/m as B field rose. Magnetic fields appear to guide emitted electrons and enhance breakdown.**
- **805 MHz RF copper iris was damaged, but not Be window. Some materials may be more resistant to damage than others.**
- **Need baseline high gradient cavity for efficient muon cooling.**

## RF Cavity Materials Menu

Metal	Alloy %	Electrical Conductivity 300K / 80K	Yield Strength MPa	dE/dx MeV/cm	Melting Point °C	Thermal Expansion $10^{-6}/^{\circ}\text{C}$	200 MHz $\mu\text{m}$ Skin Depth 300K / 80K
Copper	0.0	100 / 800	150	12	1085	17	4.6 / 1.6
Cu-Zr	0.15	92 / —	400	12		17	4.8 / —
Cu-Ag	25	78 / —	670	12		18	5.2 / —
Cu-Be	0.5	50 / —	825	12	1050	17	6.5 / —
Al	0.0	61 / 700	120	4.3	660	23	5.9 / 1.7
Al 6063-T6	1.1	53 / —	210	4.3	650	23	6.3 / —
AlBeMet 162	62	49 / 560	270	3.4	1080	14	6.6 / 2.0
Be (98.5%)	1.5	41 / —	220	2.9	1280	11	7.2 / —
Be (99.8%)	0.2	45 / 550	220	2.9	1280	11	6.8 / 2.0
Be (Pure)	0.0	45 / 2200	220	2.9	1280	11	6.8 / 1.0

- **CLIC is exploring Copper-Zirconium for RF Cavities.**  
**High Strength Copper-Silver is used for Bitter Magnet Coils.**  
 **$\text{Al}_2\text{O}_3$  has high secondary electron emission.**  
**PEP-II uses Aluminum 6063 RF cavities with 100 nm of TiN.**  
**AlBeMet 162 is more ductile (less brittle) than beryllium.**  
**Without annealing, beryllium has higher resistivity than shown**  
 **$e^-$  go in much more than 4 skin depths. Cu coated Be or Al?**  
**“Be (Pure)” is a single beryllium crystal. Cu gives high Q.**

## Beryllium Resistivity Measurement Details

# Observed DC Resistivity of Cu, Be, and AlBeMet Strips

Agilent 4-probe 34420A Ohm Meter, 2  $\mu\Omega$  accuracy

Material	Strip Size	300 K $\mu\Omega - \text{cm}$	80 K $\mu\Omega - \text{cm}$
Cu 3M 1181 Tape	.0033 x 2.54 x 23 cm	1.6	0.20
Be IF-1 99.8%	.0152 x 2.032 x 10 cm	3.7	0.32
AlBeMet 162	.0508 x 2.032 x 12 cm	3.4	0.30

Expected DC resistivity for pure copper and single crystal beryllium

Material	300 K	80 K
Copper	1.72 $\mu\Omega - \text{cm}$	0.21 $\mu\Omega - \text{cm}$
Beryllium	3.76 $\mu\Omega - \text{cm}$	0.075 $\mu\Omega - \text{cm}$

See R. W. Powell, Phil. Mag. 44 (1953) 645-663.

## Ideal RF Cavity Material to Lower Thermal Strain of Sparks

Metal	Alloy %	Electrical Conductivity 300K / 80K	Yield Strength MPa	dE/dx MeV/cm	Melting Point °C	Thermal Expansion 10 <sup>-6</sup> /°C	200 MHz $\mu$ m Skin Depth 300K / 80K
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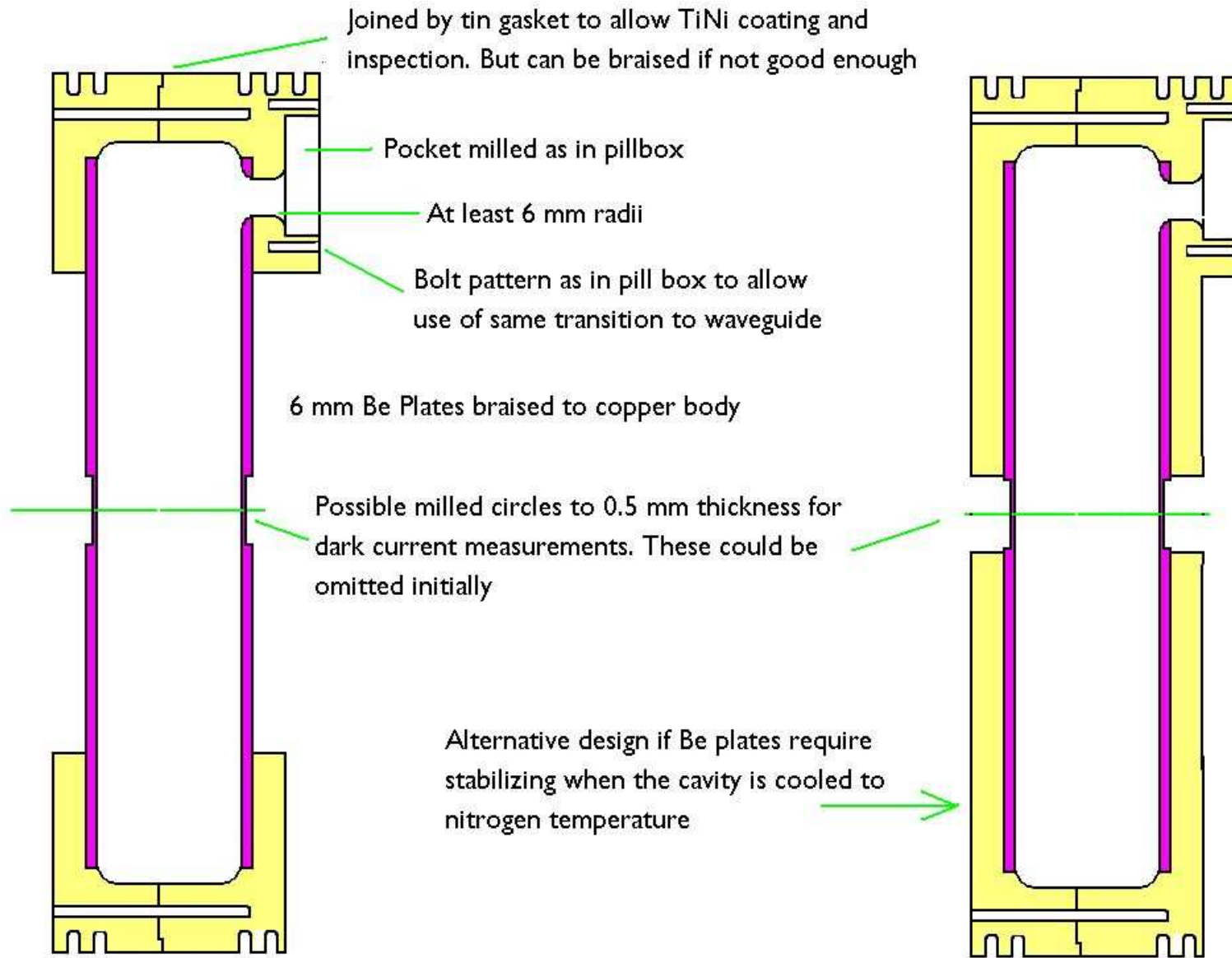
- High conductivity, Q, and heat capacity. Low dE/dx. Strong and ductile.**  
**Specific Heat. Be : Al : Cu = 16 : 24 : 24 Joules/(mole-K)**  
**Specific Heat. Be : Al : Cu = 1.8 : 0.9 : 0.4 Joules/(gram-K)**  
**Specific Heat. Be : Al : Cu = 3.2 : 2.4 : 3.6 Joules/(cc-K)**  
**(Specific Heat)/(dE/dx) = Be : Al : Cu = 1.1 : 0.6 : 0.3**  
**Conclusion: Electrons heat beryllium 4x less than copper.**  
**Strength and toughness at high temperature should also be folded in.**

## How does ITER deal with the deposition of energy?

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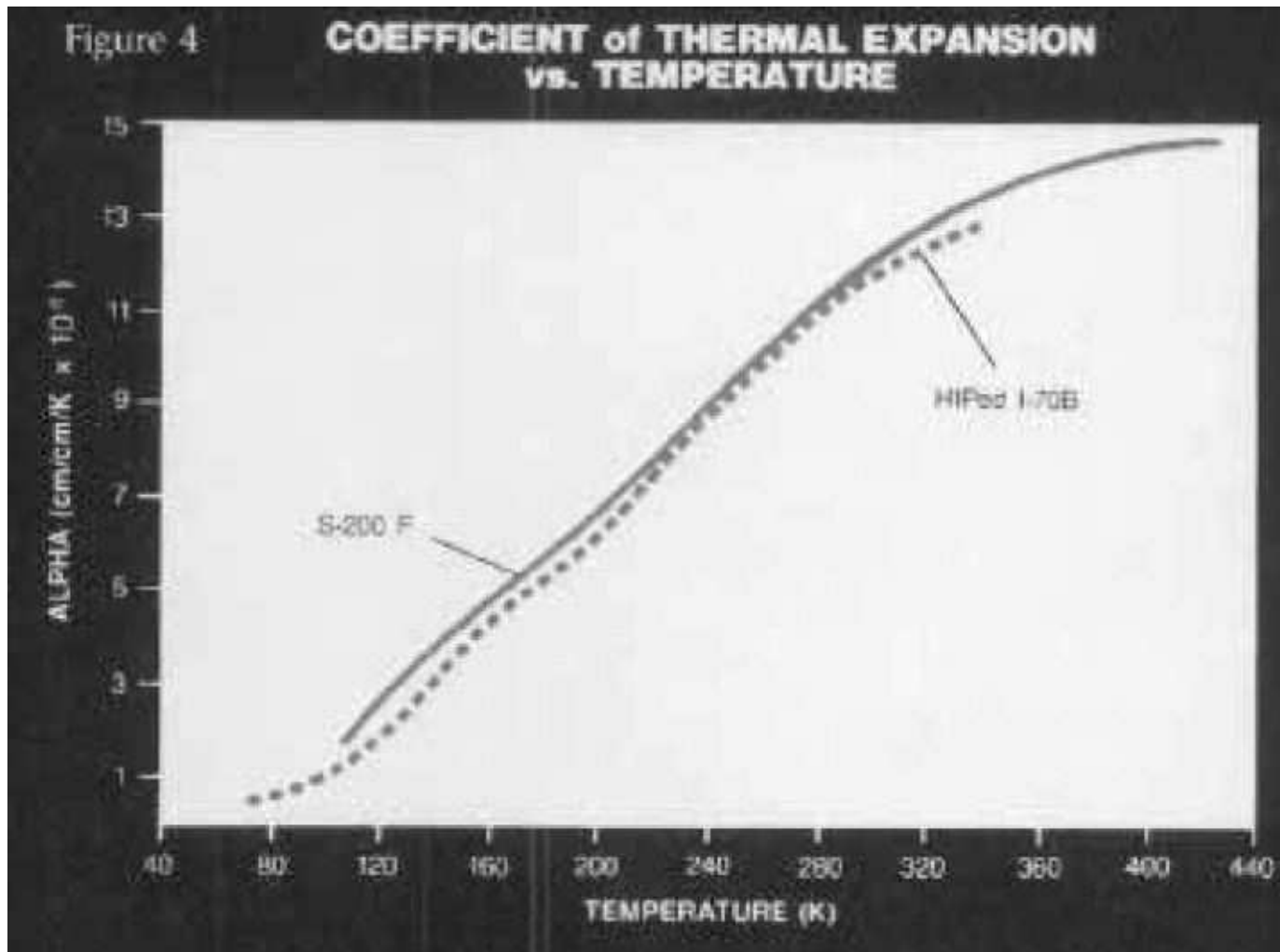
- ITER: International Thermonuclear Experimental Reactor.**  
 Walls must survive  $10 \text{ MJ/m}^2$  from the nuclear fusion reactions.  
 ITER plasma sprays beryllium onto copper and Inconel tiles.  
 K. J. Hollis et al., J. Thermal Spray Technol. 16: 96-103, 2007.  
 T. Hirai et al., Phys. Scripta T128: 166-170, 2007.  
 M. J. Rubel et al., J. Phys. Conf. Ser. 100: 062028, 2008.
- Los Alamos can plasma spray beryllium onto 8 x 12 inch plates.**  
 Typical thickness: 100 to 500 microns. Coat an RF test button?  
 Thick coating concern: Differential thermal expansion.

# Possible layouts: 805 MHz RF cavities with beryllium faces



• Thanks to Bob Palmer for the drawings.

## Thermal Expansion of Beryllium versus Temperature



- Ideal Be support metal would match 80K LN<sub>2</sub> to 1000K diffusion bonding. Expansion at 300K: Beryllium = 11, Stainless Steel 316L =  $16 \times 10^{-6}/^{\circ}\text{C}$  Iron and Hastelloy C (Ni, Cr, Mo) match at 300K, but not whole range. Beryllium windows have been used with liquid hydrogen bubble chambers.

## Quote for 12.6 inch diameter beryllium 805 MHz RF plates

Beryllium Grade	Beryllium Process	Percentage BeO	0.125 inch Thickness	0.250 inch Thickness
SR-200	Rolled	1.5	\$4982/plate	\$7621/plate
S-200-F	Pressed	1.5	\$6907/plate	\$6805/plate

- Cost of machining RF port & diffusion bonding not included.
- Beryllium ballpark cost for a thousand 201 MHz RF cavities.  $1000 \times 2 \times \$6805 \times (805/201)^2 = \$220$  million order of mag.



One of 18 beryllium (O-30 grade) mirror segments being made for the James Webb infrared space telescope at Axsys Technologies in Cullman, Alabama. The mirror segments are about the same diameter as a 201 MHz RF cavity. The mirrors will operate at 33 K.

## Summary

- 805 MHz RF gradient fell: 40 to 13 MeV/m as B field rose.
- 805 MHz RF copper iris was damaged, but not Be window.
- Need baseline high gradient cavity for efficient muon cooling.
- Cavity with beryllium faces might provide working baseline.