# Development of Zinc-plated Regenerator Material

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# Introduction



- Today, lead spheres with a typical diameter of approximately 300 μm are used as regenerator materials. However, spheres have a larger pressure drop than screen discs.

- In 2014, Waldauf et al. reported that the performance of a pulse tube cryocooler was improved with a lead wire mesh. However, lead is one of the substances restricted by Restriction of Hazardous Substances (RoHS) directive.

- In 2016, Xu et al. reported that the cooling capacity of the 1st stage increased by about 14% at 40 K and 90% at 30 K when using tin-plated screens at the cold end of the 1st stage regenerator. (ICEC 26)

- However, the reliability of tin at low temperatures is still not verified fully because of its phase transition from a normal β phase to an abnormal α phase, which may result in a significant reduction of the mechanical strength.

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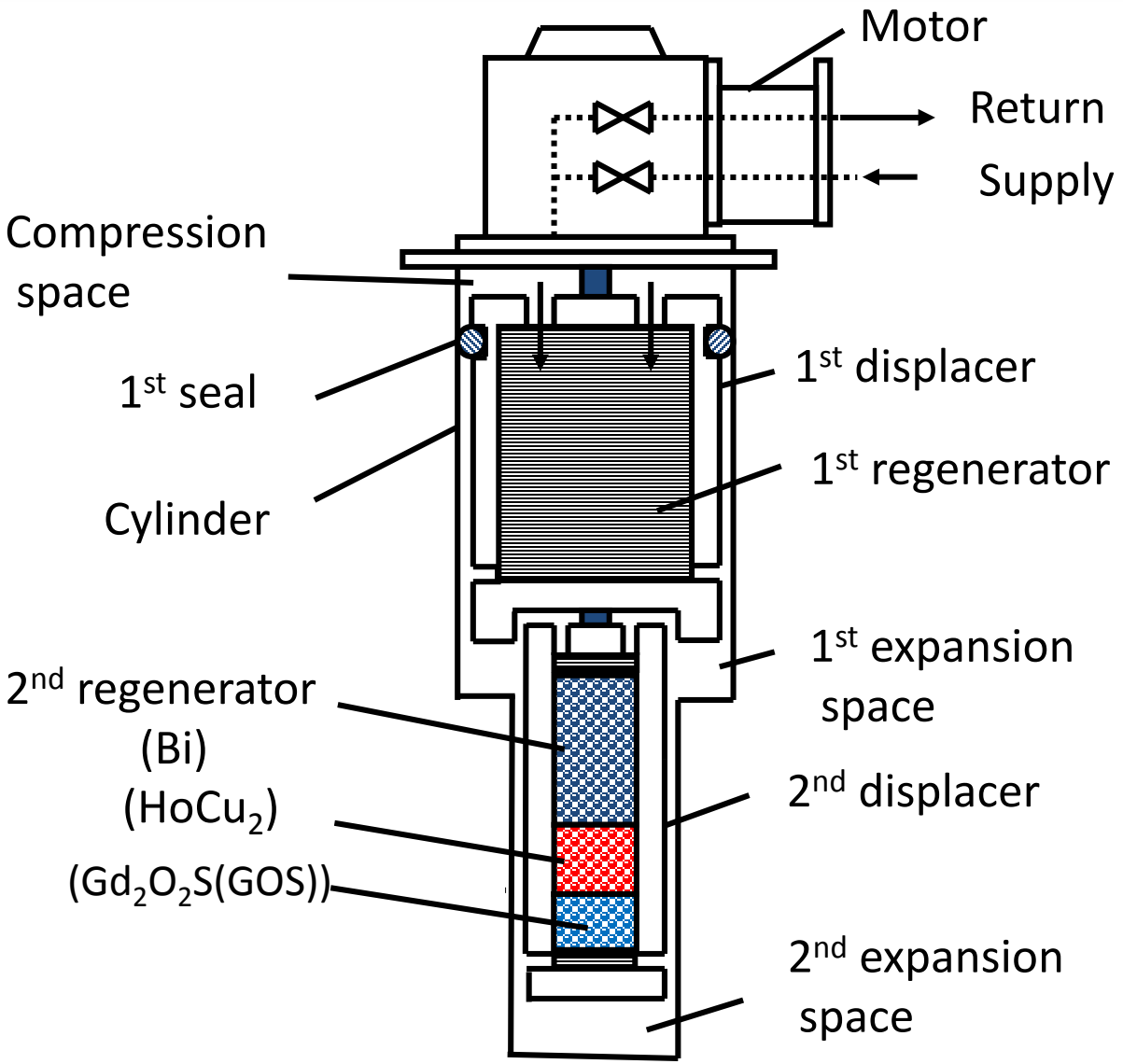
# Two-stage GM Cryocooler



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# Cooling Capacity and Losses (Simulation)

CEC-ICMC 2017 C3OrD-4

| | 1st stage at 40 K (W) | 2nd stage at 4.2 K (W) |
|---|---|---|
| P-V power | 90.1 | 19.33 |
| Cooling capacity after considering real gas effect | 89.3 | 3.54 |
| Regenerator loss | -23.2 | -1.85 |
| Shuttle loss | -7.8 | -0.16 |
| Pumping loss | -0.4 | -0.12 |
| Pulse tube cooling effect in clearance/spiral groove | 0 | +0.02 |
| Thermal conduction loss through walls | -5.4 | -0.33 |
| Radiation loss | -5.7 | -0 |
| Net cooling capacity | 46.9 | 1.11 |

*Xu M Y and Morie T, Cryocoolers 17 (2012), pp. 253-9*


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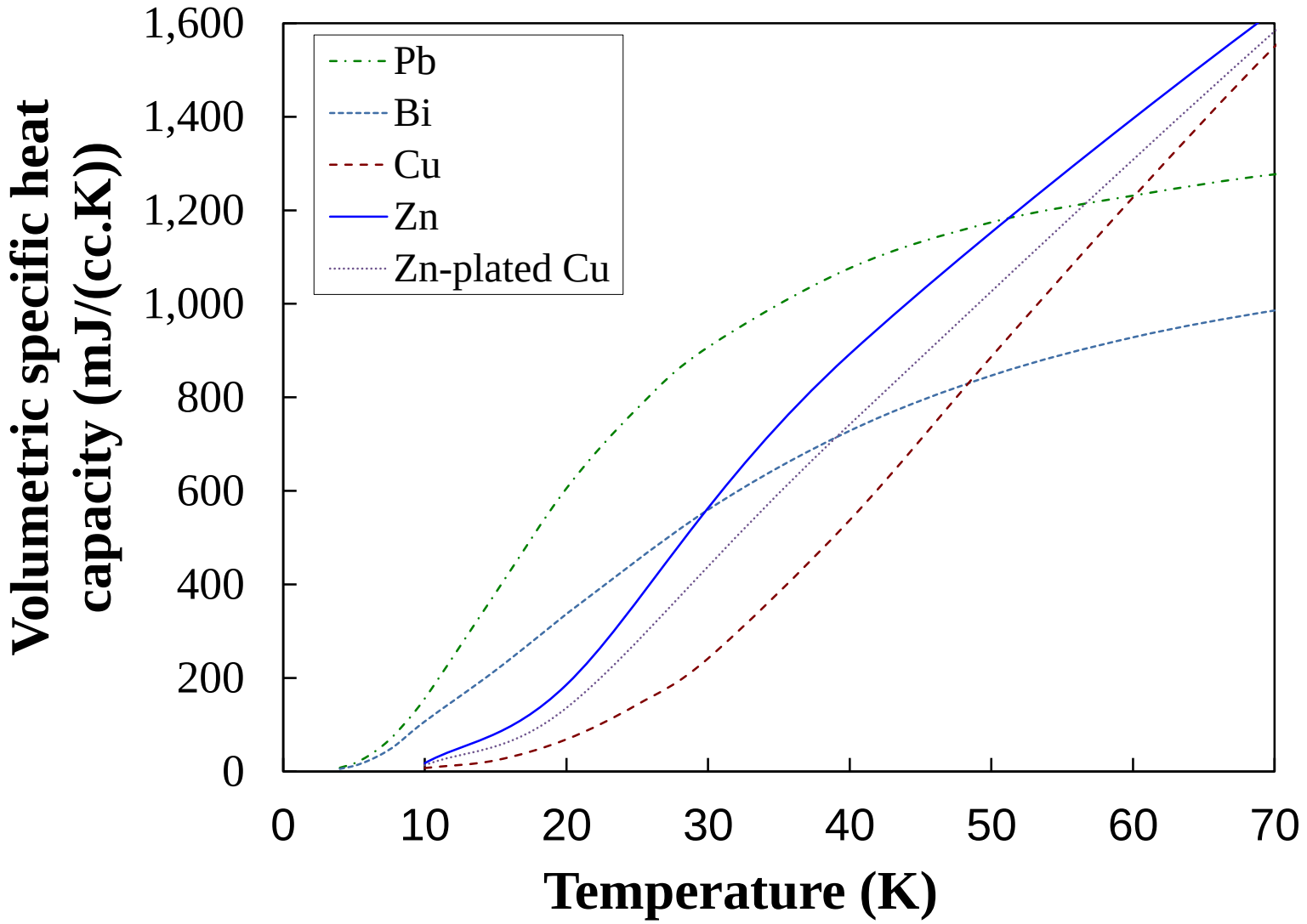
# Heat Capacity



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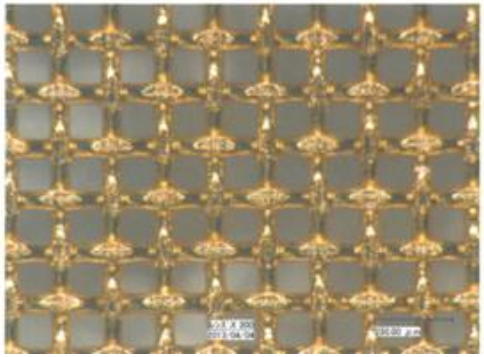
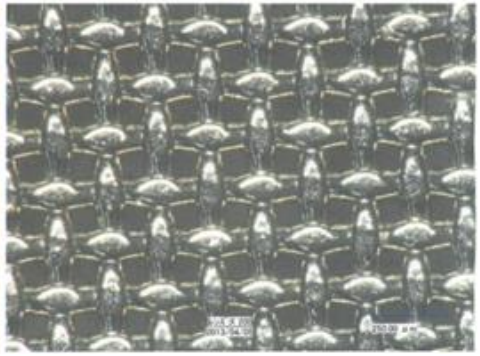
# Zinc-plated Screen



Before



After



## Fabrication process

- #150 Phosphorous bronze (wire dia. 66 μm, thickness 132 μm)

↓ *Press*

- Thickness 92 μm

↓ *Zinc deposition*

- Thickness 135 μm

- Zinc electrolyte deposition is a mature technology and commonly used in the construction industry, etc.
- Zinc can be deposited easily on copper or stainless steel screen using a common electrolyte deposition process.

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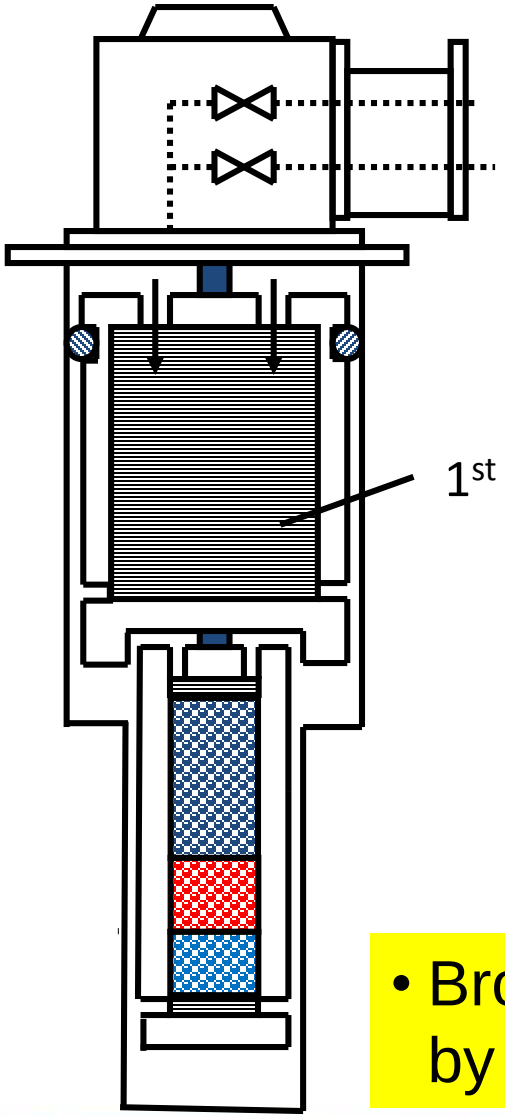
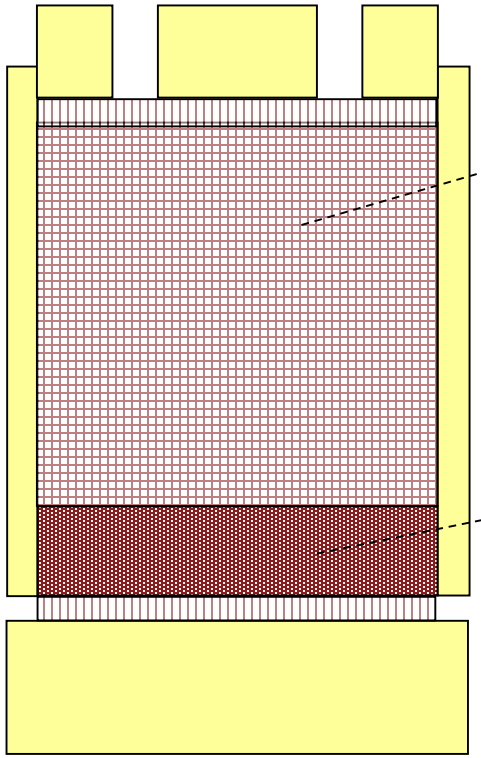
# 1st Stage Regenerator Configuration






- Bronze screens at the cold end were replaced by zinc-plated screens.

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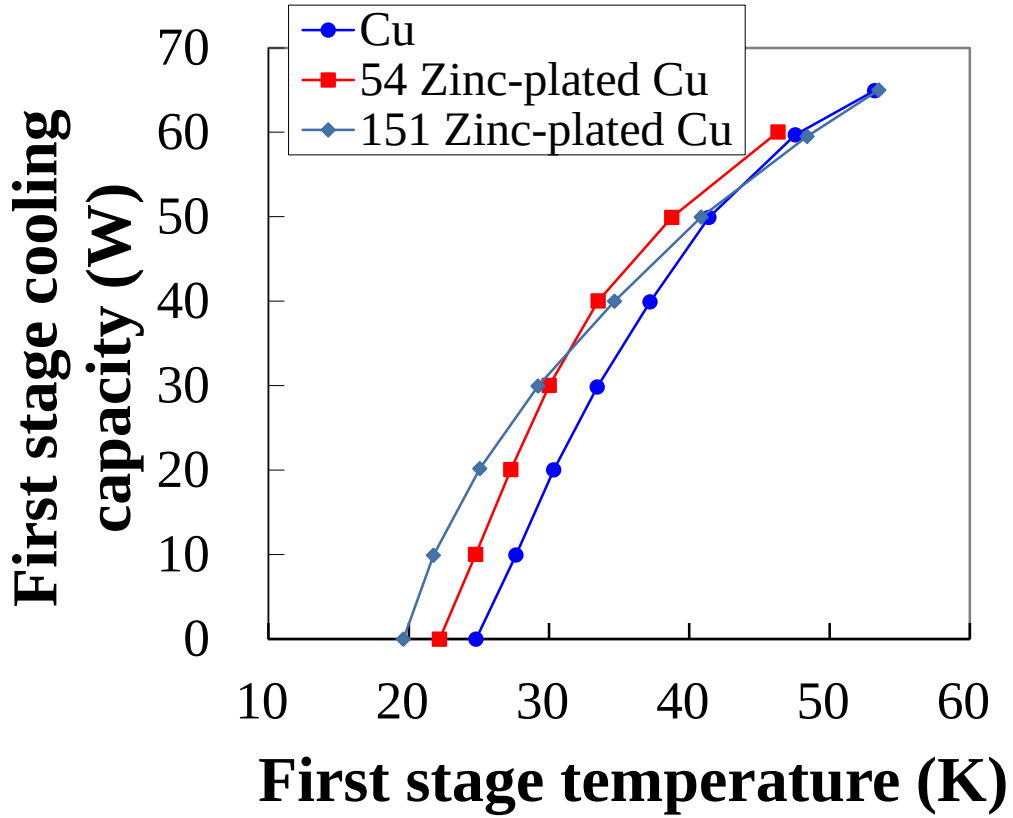
# 1st Stage Cooling Capacity Comparison






- With only bronze screens, the cooling capacity at the 1st stage was 50 W at 41.4 K or 10 W at 27.4 K.
- With 54 discs of zinc-plated screens at the cold end, the cooling capacity at the 1st stage was 50 W at 38.8 K or 30 W at 30.0 K.

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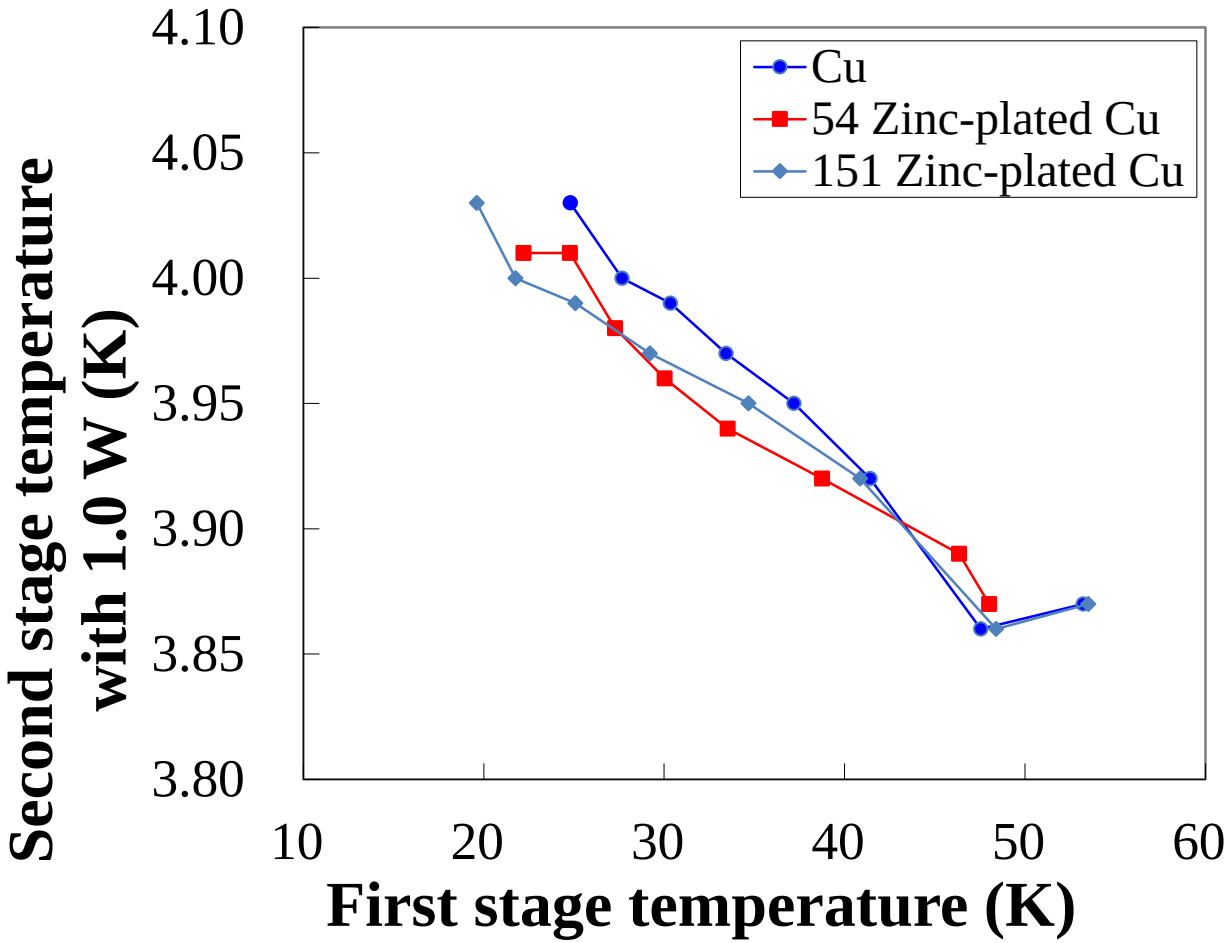
# 2nd Stage Cooling Capacity Comparison






- With zinc-plated screens at the cold end, the 2nd stage cooling performance was slightly better than that with bronze screens.

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# Cooling Performance Comparison

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| | Warm End | | Cold End | | Measured First Stage Cooling Capacity | |
|---|---|---|---|---|---|---|
| | | | | | at 40K | at 30K |
| **Case 1** | #150 bronze | 1097 discs | #150 bronze | 100 discs | 46.6 | 18.7 |
| **Case 2** | #150 bronze | 1097 discs | Zinc-plated screen | 54 discs | 51.6 | 30.0 |
| **Case 3** | #150 bronze | 945 discs | Zinc-plated screen | 151 discs | 48.6 | 31.4 |
| **Case 4** | #150 bronze | 920 discs | Bi sphere | 335 g | 50.5 | 33.9 |

- Compared to a regenerator filled with bronze screens, the cooling capacity of the 1st stage increased about 11% at 40 K and 60% at 30 K with these zinc-plated screens.

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# Conclusions



- ✓ A new, low pressure loss zinc-plated screen, is proposed.
- ✓ Compared to a regenerator filled with bronze screens, the cooling capacity of the first stage increased by about 11% at 40 K and 60% at 30 K with these zinc-plated screens.
- ✓ Compared to a regenerator filled with 335 g bismuth spheres at the cold end, the first stage cooling capacity was slightly worse with a regenerator partially filled with zinc-plated screens.
- ✓ The second stage temperature with 1.0 W heat load decreased by about 0.04 K when bronze screens at the cold end were replaced by zinc-plated screens.

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*Thank you!*


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