

# Ultra-High Temperature Thermocouples for In-Pile Applications

## Motivation:

High temperature gas reactor experiments and certain reactor fuel experiments require temperature measurements in the range of 1100°C – 1400°C, and create unique challenges for thermocouples. Commonly used high-temperature commercial thermocouples such as platinum-rhodium (Types S, R, and B) and tungsten-rhenium (Type C), suffer dramatic drift as a result of the interaction with neutrons. The thermoelements undergo transmutation, which produces a time-dependent change in composition and, as a consequence, a time-dependent drift of the thermocouple signal. Type K and Type N thermocouples are affected by neutron irradiation only to a limited extent. However, the use of these nickel-based thermocouples is limited when the temperature exceeds 1050°C due to drift arising from minor alloying elements migrating from the thermocouple's metal sheath to the thermoelements. This change in the thermoelements' composition results in significant decalibration of the signal.

## Approach:

INL researchers are working to meet these temperature measurement challenges using two approaches:

1. By means of a special Type N thermocouple design developed by researchers at Cambridge University and fabricated locally by Idaho Laboratories, Inc. This Type N thermocouple uses a special high-nickel alloy sheath, which minimizes contamination of the thermoelements by minor alloying agents in the sheath, resulting in substantial reduction in drift when operated at temperatures above 1100°C.
2. By means of refractory based thermocouples developed by INL researchers. In 2005 an INL instrumentation research team developed a High Temperature Irradiation Resistant (HTIR) thermocouple based on molybdenum and niobium thermoelements. Recent efforts have been undertaken at INL's High Temperature Test Lab (HTTL) to update this design to provide better accuracy and reduced drift. The current HTIR thermocouple design is completely manufactured and calibrated at HTTL. Additionally, since this design also incorporates a refractory (niobium) sheath, joining techniques have historically been problematic. Efforts were undertaken to develop brazing techniques which would allow these thermocouples to be reliably installed in sealed capsules.

## Results:

Figure 1 shows a drift comparison between Standard Type N thermocouples, Cambridge Type N thermocouples with a protective sleeve of Nb, and a Cambridge Type N thermocouple with a protective sleeve of Mo. The Standard Type N thermocouples drifted more than 40°C during a 4500 hr test at a furnace temperature of 1100°C to 1250°C. During the same period and same furnace conditions, a pair of Cambridge Type N thermocouples surrounded by Nb sleeves drifted only 18°C. An even better performance was achieved by a Cambridge Type N thermocouple, with a Mo sleeve which operated for 2000 hrs at 1225°C. Its drift was less than 7°C. The customized sheath of the Cambridge thermocouples clearly reduces drift compared to standard designs when operated at high temperatures for extended time periods.

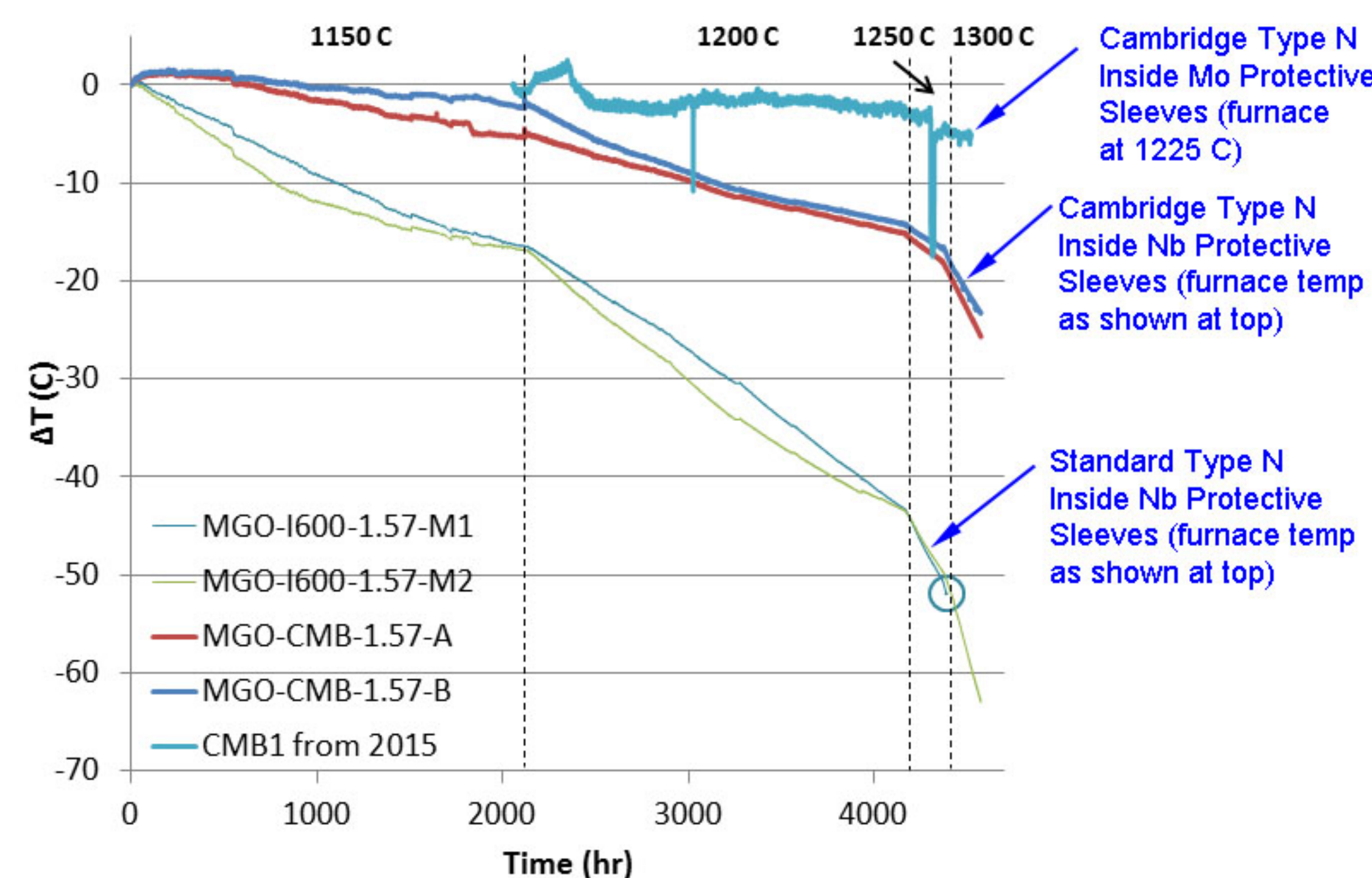


Figure 1. Long Term Performance of Cambridge and Standard Type N TCs

Figure 2 shows long term temperature trends of HTIR thermocouples which were heat treated at two different temperatures. Both thermocouples were placed in a furnace operating at 1315°C for 2000 hrs. The HTIR thermocouple that was heat treated at 1450°C drifted 24°C (almost 2%), while the HTIR thermocouple heat treated at 1600°C drifted only 6°C (less than 0.5%). The higher temperature heat treatment clearly had a stabilizing effect on the performance of the Mo/Nb based thermocouple (HTIR) design.

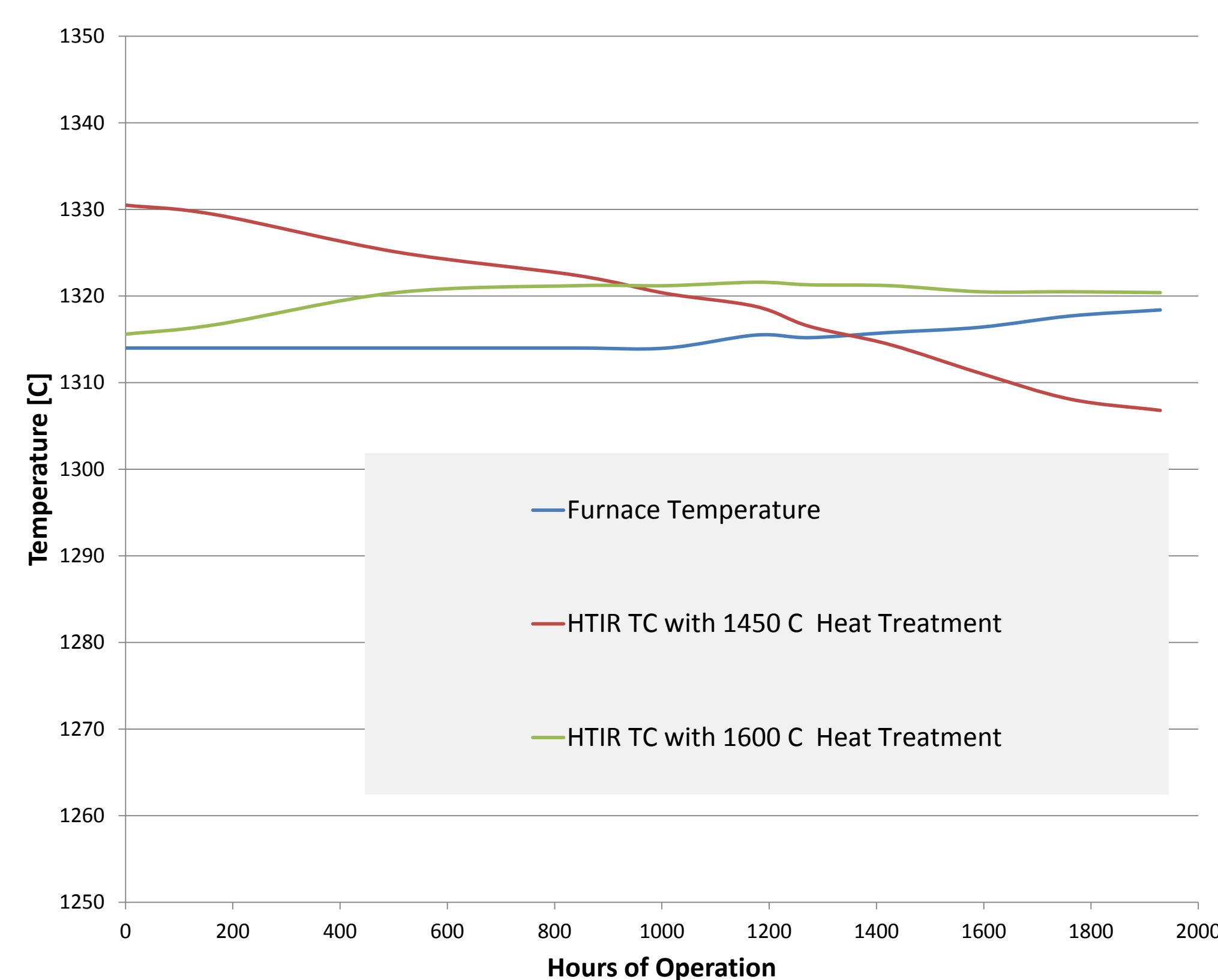


Figure 2. Long Term Performance of HTIR TCs

## Principle Investigators:

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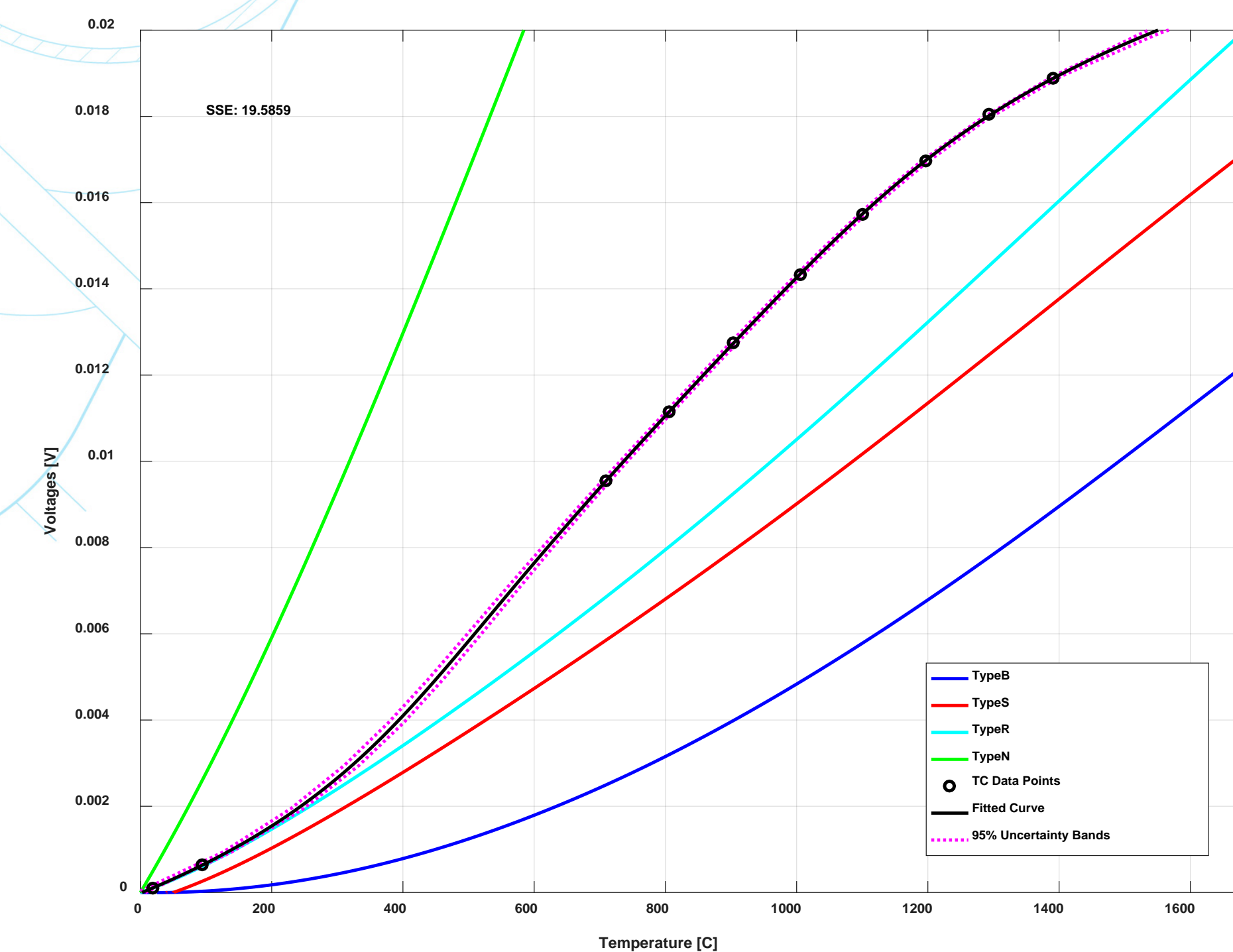


Figure 3. Calibration of HTIR Thermocouples

Figure 3 provides a temperature vs voltage curve for a HTIR thermocouple (magenta with black uncertainty bands) compared to other thermocouple types. As illustrated by Figure 2, calibration of these thermocouples is quite accurate (<0.5% error for the 1600°C heat treated version). This was accomplished by fitting a fifth order polynomial to the data. Other polynomial fits, both higher and lower order, were also evaluated. The standard error performance of each curve fit for the HTIR thermocouples was sequentially computed and recorded starting at 3rd order and increasing to 6th order. There was considerable error reduction from 3rd to 4th order, and again from 4th to 5th order. Finally, from 5th to 6th order there was not much by way of error reduction. This led to utilizing a 5th order polynomial as the best fit for each HTIR thermocouple calibrated.

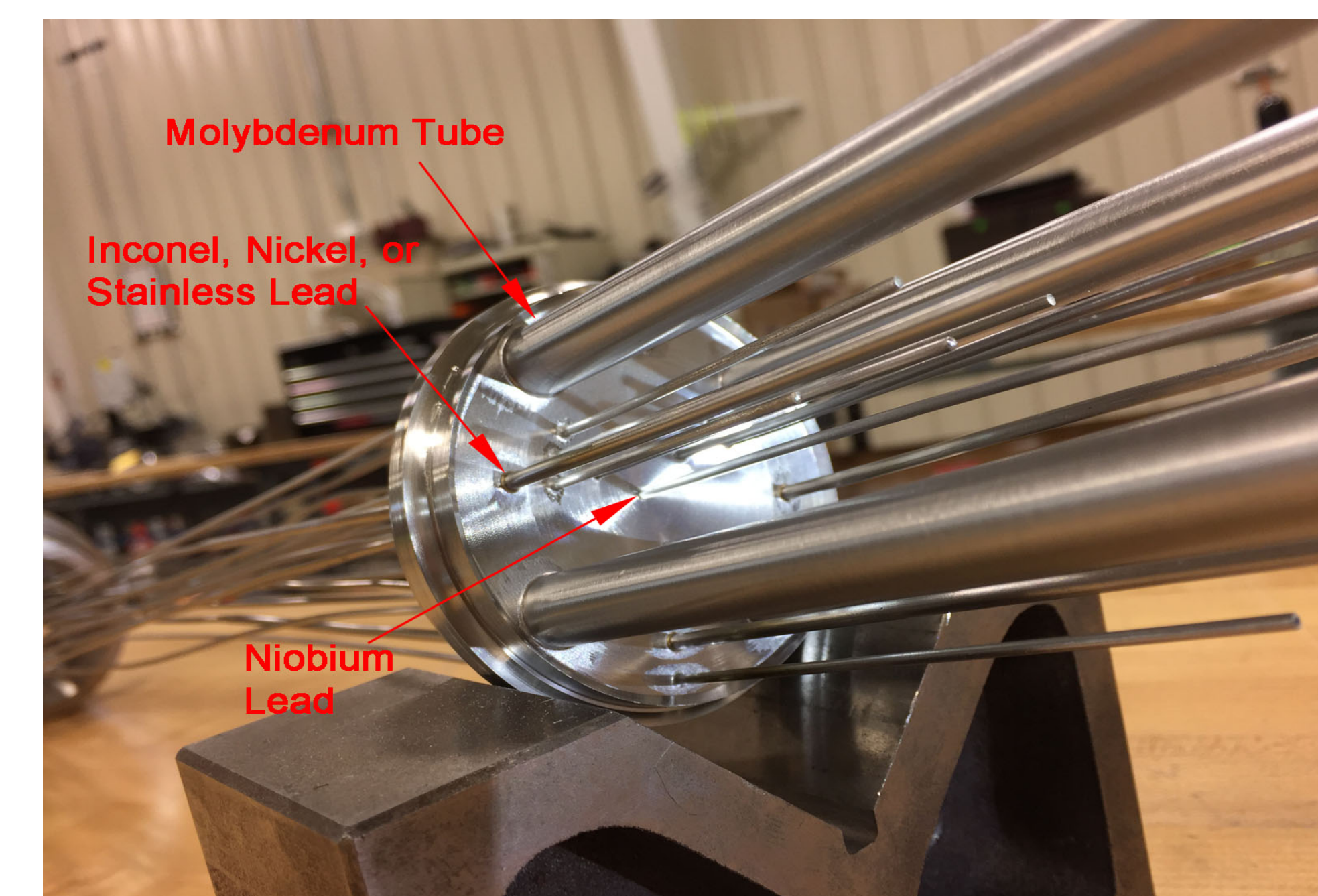


Figure 4. Successful Brazing of Refractory Metals as Well as Nickel Alloys

Figure 4 shows the top head for an experiment capsule used for high temperature gas reactor experiments. There are 17 small leads passing through the head and four larger ones for a total of 21 leads. Every lead has a full fillet and there is no evidence of oxidation. There are four different materials passing through the head: SST, Inconel, molybdenum, and niobium. The two refractory materials are particularly difficult to braze. Note the center penetration, "Niobium Lead" - it is very difficult to braze this center penetration without melting the rim of the head. This result was achieved by induction brazing in a completely inert environment while using AWS BNI-12 filler metal.