# MODEL 881 THERMOCOUPLE HOMOGENEITY FAQ

1) **Q**: *Is scanning at 100 °C sufficient to detect inhomogeneities at the correct magnitude and are these scalable to higher temperatures?*

   **A**: Yes, for most base- (K, T, E, J and T) and rare-metal (S and R) thermocouples there is good evidence for the scalability of inhomogeneities detected at lower temperatures. The size of these changes can be used to infer similar changes at higher temperatures, see for example, [1, 4, 5].
   Related to this problem is the requirement that the thermocouple-under-test not change during the scanning process. Base-metal thermocouples can start changing at temperatures as low as 70 °C [2]. However, these changes occur very slowly and over times much greater than the time taken to make a scan. Type R and S rare-metal thermocouples start changing at temperatures above about 170 °C [3]. Therefore, scanning at lower temperatures is essential to ensure the thermocouple remains in the same state as it was before the scan.
   There are further complexities in regard to scaling, especially with base-metal types as the act of using them above 200 °C rapidly changes their metallurgical state. In fact, the reference tables themselves intrinsically contain emf valves which have been affected by drift. Therefore, it is an extremely complex task to disentangle the drift that has occurred in-use to that which is inherent in the reference function. It is usually best to err on the side of caution and treat all changes from the as-received state as drift in use.
   There is little data on the scanning of Pt-Pd or Au-Pt thermocouples at low temperatures and the scalability of the inhomogeneities to other temperatures. This is work still to be conducted and will require effort from several key NMIs. The low temperature ISOTECH scanner cannot be used for Type B, because the emf output of this thermocouple is too small, and not of a useful magnitude until about 500 °C. Scans of Type B must be conducted in a salt-bath or similar device with a sufficiently narrow temperature gradient to allow localised inhomogeneities to be detected.

2) **Q**: *How can the high-resolution scans be translated into real uncertainties, given most real-world temperature gradients are far wider?*

   **A**: Dividing the peak-to-peak inhomogeneity emf ($\mathrm{emf}_{max} - \mathrm{emf}_{min}$) by the difference in the average emf at the scanning temperature to that at ambient ($\mathrm{emf}_{T\mathrm{scan}} - \mathrm{emf}_{T\mathrm{amb}}$) and then dividing further by a rectangular distribution (√12), to account for the wide number of possible in-use gradients, gives a useable inhomogeneity percentage for uncertainty calculations. We can now multiply this uncertainty percentage by the emf measured at other temperatures ($\mathrm{emf}_T$), as shown in *eq*. 1 to get a standard uncertainty ($u_T$). An example is given below:

   $$u_T\,(\mu\mathrm{V}) = \pm\left(\left(\mathrm{emf}_{max} - \mathrm{emf}_{min}\right)/\left(\mathrm{emf}_{T\mathrm{scan}} - \mathrm{emf}_{T\mathrm{amb}}\right)/\sqrt{12}\right)\cdot \mathrm{emf}_T \qquad 1$$

   If the $\mathrm{emf}_{max} - \mathrm{emf}_{min}$ value is 0.5 µV, the $\mathrm{emf}_{T\mathrm{scan}} - \mathrm{emf}_{T\mathrm{amb}}$ value 533 µV (646 – 113), and $\mathrm{emf}_T$ at say 962 °C (Ag) is 9151 µV, then we would need to include **±2.5 µV** (~0.25 °C) to our uncertainty budget.

3) **Q**: *Are salt and oil bath scanners still ok to use?*

   **A**: Only in certain cases, where the scanning temperature is ≤100 °C (oil) for base-metal thermocouples and ≤200 °C (salt) for rare-metal thermocouples. However, neither of these bath scanning mediums can be used directly with the thermocouple-under-test. Therefore, a re-entrant tube is required, which inherently limits heat transfer from the bath to the thermocouple, widening the scanning gradient and greatly extending the scanning time. Typically, the scanning gradient will be five times wider and require six times longer to scan in a bath, when compared to the direct immersion ISOTECH scanner.
   In addition, the large conduction errors and wide temperature gradient of the bath systems prohibit detection of inhomogeneities of the first 100 mm of the thermocouple, often the most important region under test. This is the region often exposed to fixed point cells and where contamination is a major concern.

4) Q: *Why can't I just use a double gradient scanner technique, like a hot air gun, to detect and quantify inhomogeneities?*

   **A**: These systems not only misinterpret the magnitude of inhomogeneities they also are blind to inhomogeneities that occur over integer lengths of the double gradient width, see for example [6]. The only time this system may be of use is for the detection of gross inhomogeneities, for example use of incorrect extension wire type or reverse wiring in a thermocouple plug. Any other use will likely give false confidence, underestimating the magnitude of any errors.


[1] F Jahan and M. Ballico. A study of the temperature dependence of inhomogeneity in platinum-based thermocouples. In D. C. Ripple, editor, *Temperature, its measurement and control in science and industry*, volume 7, pages 469–474. AIP, 2003.

[2] E. S. Webster. Low-temperature drift in MIMS base-metal thermocouples. *Int. J. Thermophys.*, 35:574–595, 2014.

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[4] E. S. Webster. Thermal preconditioning of MIMS Type K thermocouples to reduce drift. *Int. J. Thermophys.*, 38:1–14, 2016.

[5] E. S. Webster, R. S. Mason, A. Greenen, and J. Pearce. A system for high-temperature homogeneity scanning of noble-metal thermocouples. *Int. J. Thermophys.*, 36:2922–2939, 2015.

[6] E. S. Webster and D. R. White. Thermocouple homogeneity scanning. *Metrologia*, 52:130–144, 2015.