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Temperature fixed-points for high accuracy thermometry between 1000 and 2500 °C

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Conseil national de recherches Canada

Canada

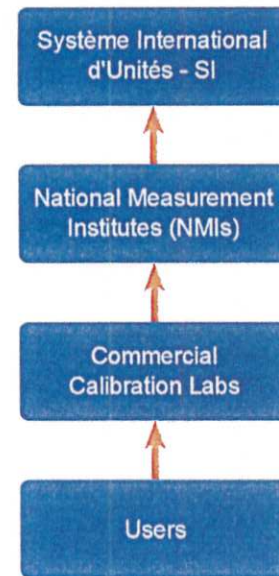
Outline

- role of a national measurement institute (NMI)
- where high-accuracy, high temperature thermometry stands now and what we are doing to improve it
- high temperature fixed points
- assignment of temperatures and future implementation
- two examples of early applications

What an NMI does

National measurement institutes maintain a country's link to the SI and ensures equivalence of measured quantities between countries.

Uncertainties in the calibrations increase with the "distance" from the NMI

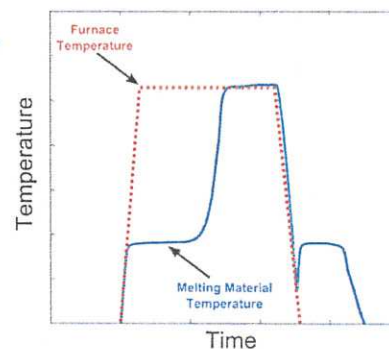


Thermometry

In thermometry NMIs (usually) disseminate the *International Temperature Scale of 1990 (ITS-90)*.

The ITS-90 is a **defined** scale.

The reference points of the ITS-90 are defined and have zero uncertainty.



The highest temperature fixed points in the ITS-90 are the freezing point of silver (961.78 °C), gold (1064.18 °C) and copper (1084.62 °C)

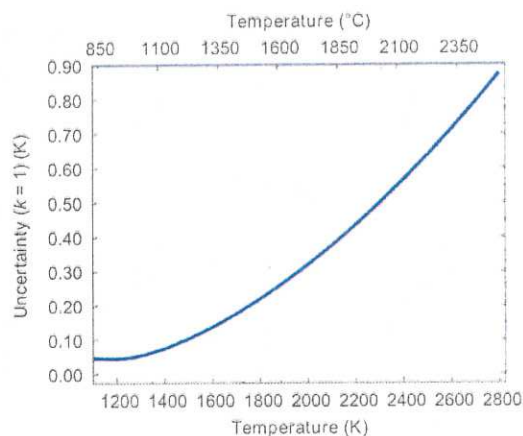
Current state of high temperature metrology: contact thermometry



- For thermocouples, calibration points go as high as Ag/Au/Cu and may include a Pd wire bridge
- Leads to uncertainties of ~ 3 °C (95 %) for type S thermocouples at 1500 °C

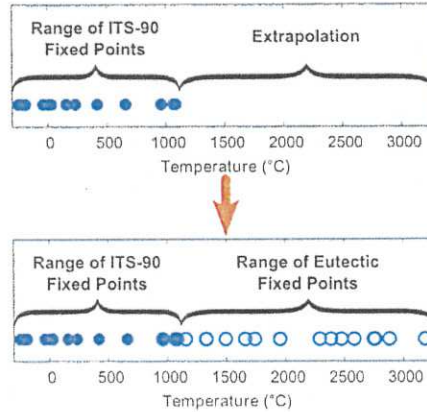
Current state of high temperature metrology: radiation thermometry

- Above ~ 962 °C the ITS-90 is defined by the extrapolation (using Planck's Law) of a radiation thermometer and a Ag, Au or Cu fixed point.
- Leads to uncertainties of ~ 2 °C (95 %) at 2500 °C at the NMI level

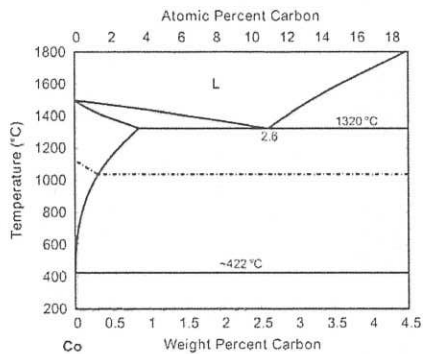


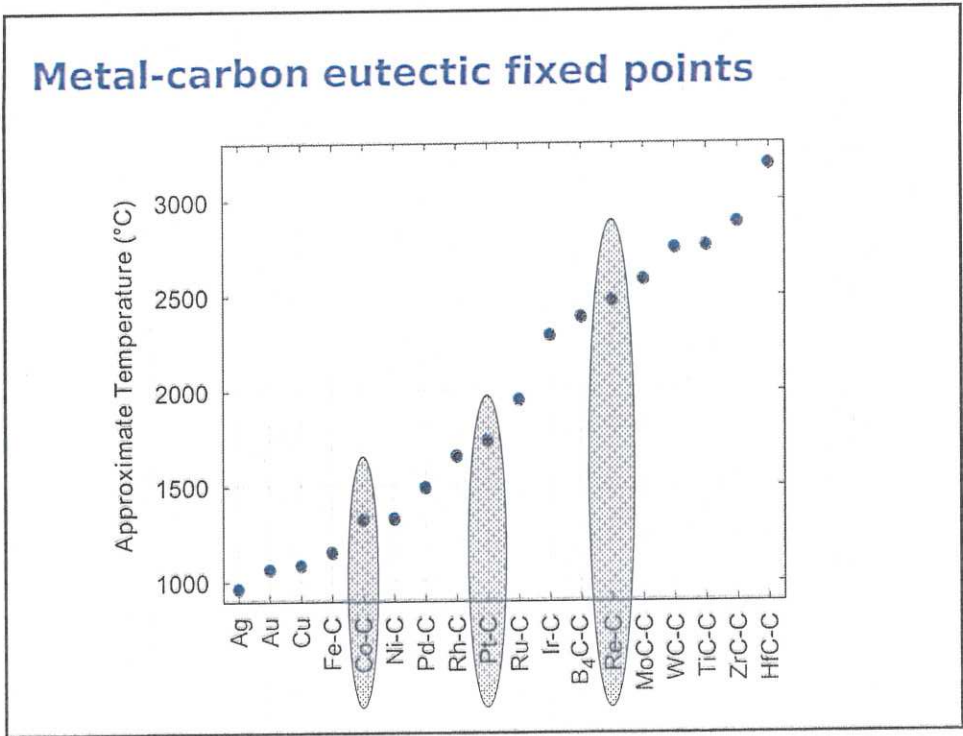
How can NMIs improve the situation at high temperatures?

Remove the extrapolation and replace with high temperature fixed points → lower uncertainties



Metal-carbon eutectic fixed points





International effort to measure the melting temperatures of Co-C, Pt-C and Re-C

As part of working group 5 (radiation thermometry) of the Consultative Committee of Thermometry (CCT-WG5) there is a project to measure the absolute melting temperatures of HTFPs

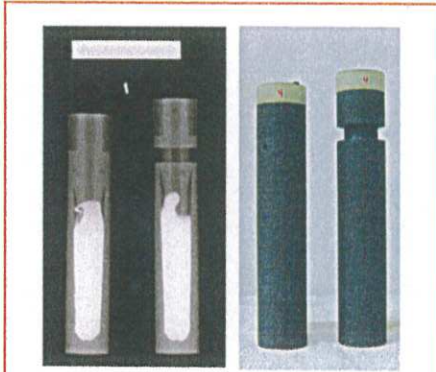
System	Temperature (K)
Co-C	1600
Pt-C	2000
Re-C	2750

5 work packages:

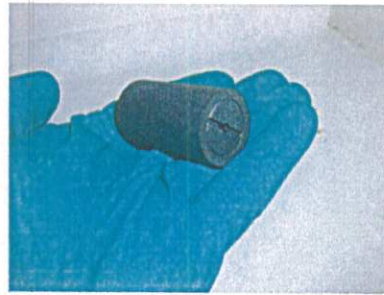
- WP1: long term stability
- WP2: HTFP construction methods
- WP3: uncertainties and analysis
- WP4: preliminary assessment
- WP5: assignment of temperature

How do we know (assign) a melting temperature?

use absolute radiometry

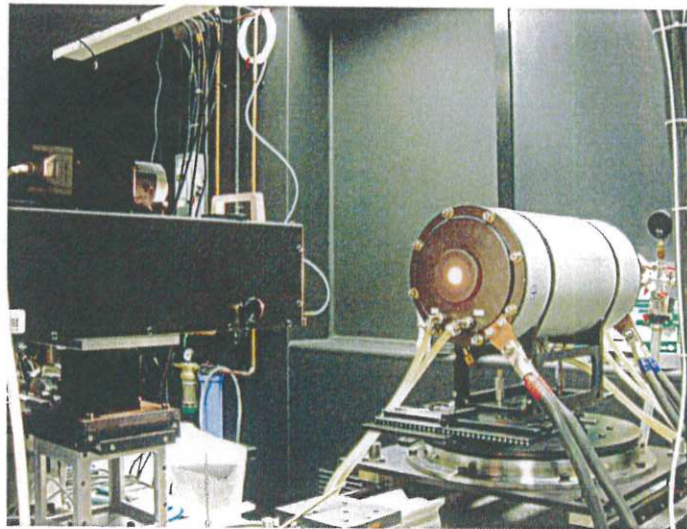


Contact thermometry cells



Radiation thermometry cell

Furnace to Realize HTFPs at NRC



Traceability: cryogenic electrical substitution radiometer (W)

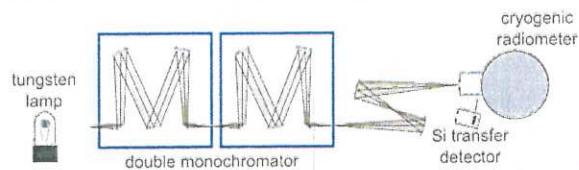
Cryogenic ESR matches a known electrical power to an unknown optical power

Electrical current and resistance can be measured much more accurately than optical power

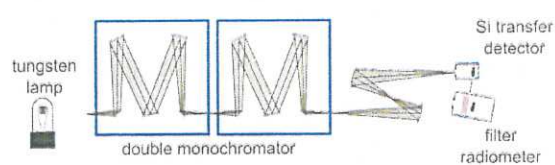
Also requires traceability in *length* (m) for the apertures used



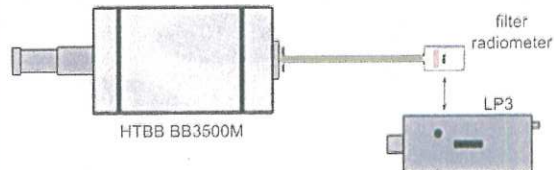
1. Calibrate transfer radiometer against the cryogenic radiometer

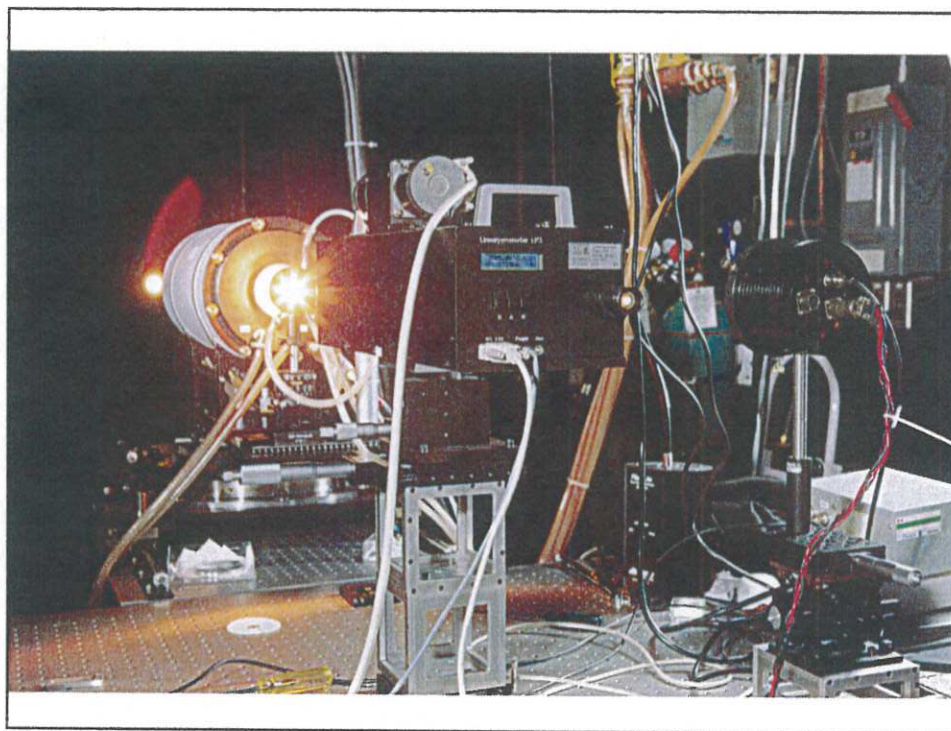


2. Calibrate the filter radiometer against the transfer radiometer



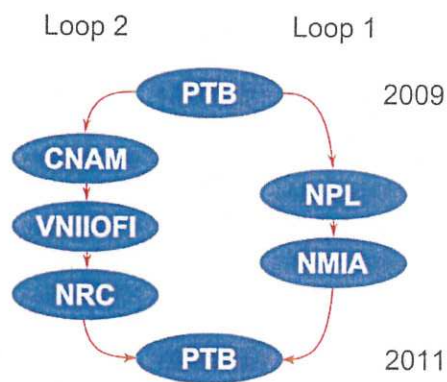
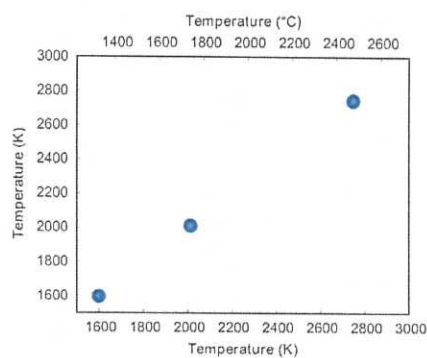
3. Calibrate the LP3 with the FR at the temperatures of interest using the HTBB





Preliminary measurements of transition temperatures

Part of this project was a preliminary comparison of two sets of HTFPs to assess how well NMIs could measure

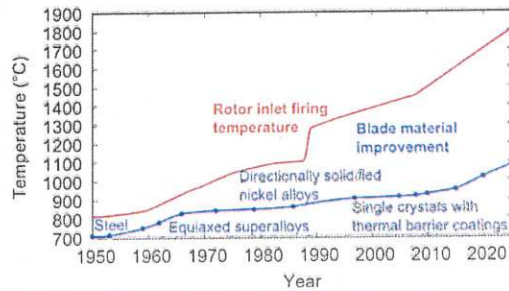


Example 1: heat treatment of turbine blades

Applies to both aerospace and stationary electricity generation

Heat treatment of single crystal blades (typically using alloys that contain expensive rare element like Re)

Efficiency improves with higher operating temperatures



A. Saini, "High-temperature materials increase the efficiency of gas power plants", *MRS Bulletin*, **37**, JUNE 2012 www.mrs.org/bulletin • Energy Quarterly

Example 1: heat treatment of turbine blades

For aerospace engine blade heat treatments, tight temperature control is required

Calibration of the process thermocouples using a Co-C fixed point (1324 °C)

Expectation is that with new materials coming online, even tighter control at higher temperatures will be required

J.V. Pearce, G. Machin, T. Ford, and S. Wardle, "Optimizing heat treatment of gas turbine blades with a Co-C fixed-point for improved in-service thermocouples", *Int. J. Thermophys.*, **29** pp 222-230 (2008)

Example 2: self-validating W-Re-type thermocouples

The tungsten-rhenium family of thermocouples are very prone to drift (as large as 30 °C) and are difficult/impossible to re-calibrate because they become brittle

Can include a small fixed-point with the thermocouple so that it can be re-normalized *in situ*

J.V. Pearce, M. De Podesta, C. Elliott, and G. Machin,
"Improving temperature sensing for new reactors", *Nuclear Engineering International* 56 (688) , pp. 18-20

Conclusions

New high-temperature fixed points will enable high accuracy contact and non-contact thermometry

Enable a reduction in uncertainties (by a factor of 4 or greater at the highest temperatures) at high temperatures (radiation and contact thermometry)

Expect final assignment of temperature to the Co-C (~1324 °C), Pt-C (~1711 °C) and Re-C (2474 °C) fixed points to be completed by end of 2014

