EMPRESS Workshop

Enhanced process efficiency through improved temperature measurement

22 March 2017
Advanced Forming Research Centre, UK
www.npl.co.uk/events

Invited speakers from Rolls-Royce (keynote), BAE Systems, Cambridge University, CCPI Europe, DLR, Elkem, Loughborough University, Metrosol, MUT Advanced Heating, Oxford University, Strathclyde University

Technologies

- *Thermocouples*
- *Phosphor thermometry*
- *Surface temperature probes*
- *Combustion & flame thermometer*

Application areas

- *Furnace control*
- *Heat treatment*
- *Casting*
- *Forming*
- *Welding*
- *Forging*
- *Gas turbines*
- *Internal combustion engines*

EMPRESS is a European project with the goal of enhancing process efficiency through improved temperature measurement. The consortium comprises 18 partners across government, industry and academia.

This workshop is an excellent opportunity to bring together scientists and engineers from academia, research institutes and industrial establishments to present and discuss both

- **The latest developments in the field of traceable temperature measurement for process control**
- **End-users' requirements and challenges**

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AFRC ADVANCED FORMING RESEARCH CENTRE UNIVERSITY OF STRATHCLYDE

Co-sponsored by

Institute of Measurement and Control

IOP Institute of Physics

EMPRESS TEMPERATURE METROLOGY FOR PROCESS EFFICIENCY

61 delegates

41 organisations

9 NMIs
12 Manufacturing
20 Instrumentation

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EMPRESS TEMPERATURE METROLOGY FOR PROCESS EFFICIENCY

EMPRESS: A European project to enhance process efficiency through improved temperature measurement

Jonathan Pearce
Frank Edler
Claire Elliott
Lucia Rosso
Gavin Sutton
Aurik Andreu
Graham Machin

IOP Institute of Physics
Instrument Science and Technology Group

Institute of Measurement and Control

1. Solve specific process control problems in advanced manufacturing

2. Establish traceability to ITS-90 in-situ

- Driftless thermocouples and other contact thermometers (WP1,2)
  - Heat treatment of aerospace alloys
  - Casting of aerospace alloys
  - Forming and forging of automotive components
  - Industrial furnace manufacture
  - Silicon processing
  - Ceramic manufacturing
- Surface thermometry (WP3)
  - Forming of Al alloys and composite materials
  - Welding pre- and post- heat treatment of marine structures
  - Coating of marine structures
- Combustion thermometry (WP4)
  - Internal combustion engine, gas turbine, and fuel development

Start May 2015

Finish May 2018

8 NMIs

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PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

DANISH TECHNOLOGICAL INSTITUTE

BRML 1864

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

CEM CENTRO ESPAÑOL DE METROLOGÍA

CMI CZECH METROLOGY INSTITUTE

Justervesenet

RMG

6 Companies

MUT ADVANCED HEATING

BAE SYSTEMS

Elkem

CCPI Europe Limited

AFRC ADVANCED FORMING RESEARCH CENTRE UNIVERSITY OF STRATHCLYDE

gamma forgiati SRL

4 Universities

UNIVERSIDAD CARLOS III DE MADRID

UNIVERSITY OF OXFORD

UNIVERSITY OF CAMBRIDGE

DTU

5 Collaborators

Bodycote

- United Kingdom
- Romania

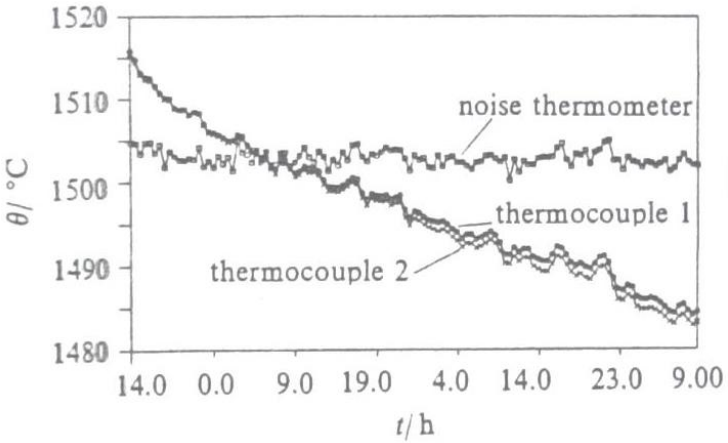
ICPECA

Imperial College London

KRISS 한국표준과학연구원 Korea Research Institute of Standards and Science

WP1 Low-drift contact temperature sensors to > 2000 °C (PTB)

- Silicon processing, aerospace heat treatment, process furnace manufacture
- Pt-Rh thermocouples OK to about 1500 °C
- W-Re thermocouples to 2300 °C, not very stable
- Determine optimum Pt-Rh composition
- Sapphire tube blackbody device
- Carbon thermocouples to >2000 °C
- End-user trials: AFRC, A&D, HTRC, possibly RR



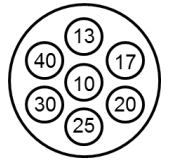
NPL, PTB, CCPI Develop new, optimised Pt-Rh thermocouples	TRIAL IN-PROCESS	**PTB, NPL, MUT, STRAT, CCPI** Test Pt-Rh thermocouples (aerospace manufacturing)	*Collaborators* *Bodycote* *KRISS*
JV, Elkem Develop sapphire tube thermometer	TRIAL IN-PROCESS	**JV, Elkem** Test sapphire tube thermometer (silicon processing plant)	
PTB, NPL, MUT Develop carbon thermocouples	TRIAL IN-PROCESS	**MUT, PTB** Test carbon thermocouples (industrial furnace manufacturing)	

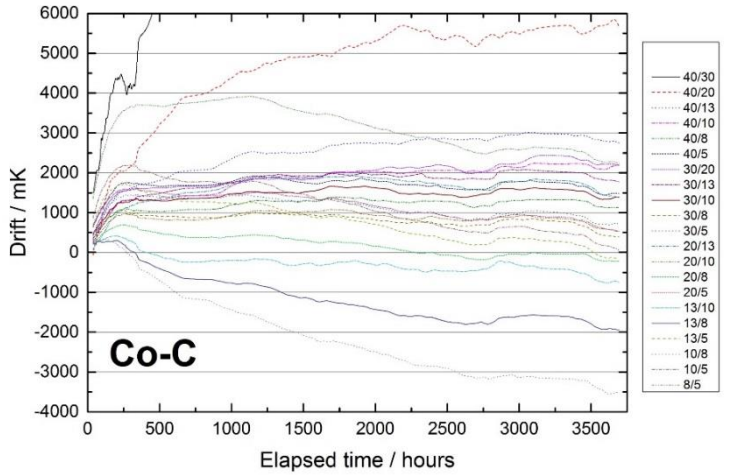
Retortenöfen/ HochVakuum-Retortenofen
Retort Furnace/ Higt-Vacuum Retort Furnace

WP1 Low-drift contact temperature sensors to > 2000 °C (PTB)

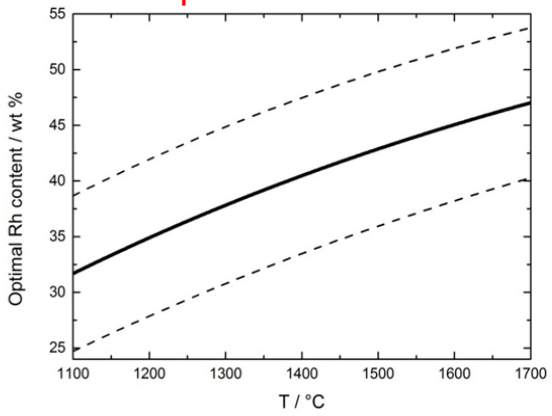
- Multi-wire Pt-Rh thermocouple stability evaluated to about 1500 °C
- NPL: Sophisticated modelling of Pt-Rh thermocouple drift mechanisms
- JV/Elkem: Sapphire tube blackbody device constructed & operational
- PTB/MUT: Carbon thermocouples to >2000 °C constructed and tested to 1300 °C with promising results
- End-user trials: AFRC, A&D, HTRC, possibly RR, JM

Stability of multi-wire thermocouple measured with Co-C *in-situ*

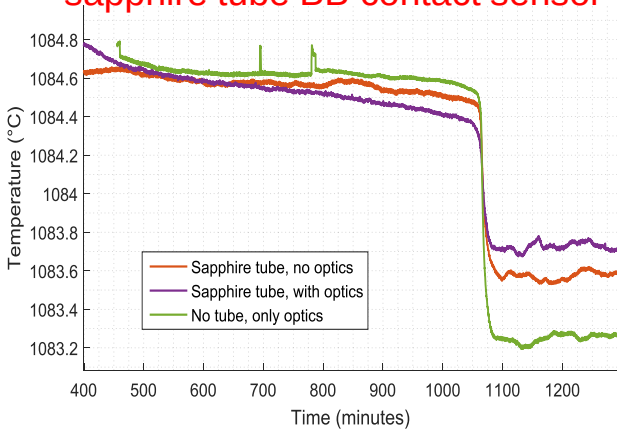




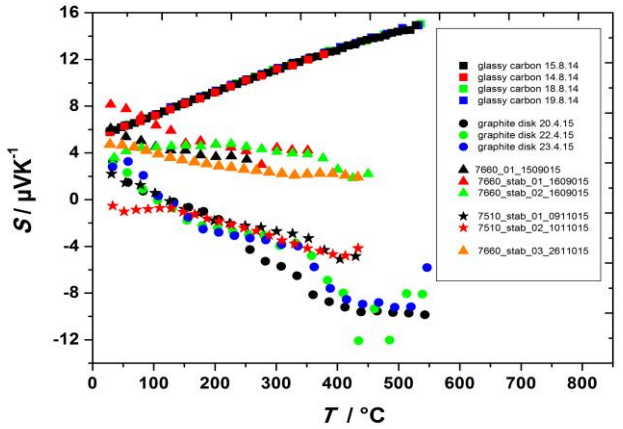
Pt-Rh oxide vapour transport model – optimum Rh %



Freezing of Cu measured with sapphire tube BB contact sensor

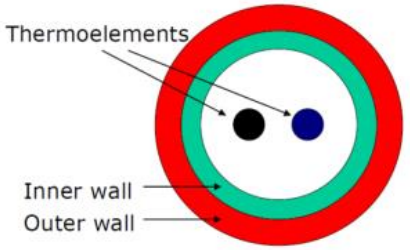


Seebeck coefficients of graphite thermoelements



WP2 Zero-drift contact temperature sensors to 1350 °C (NPL)

- Aerospace heat treatment, ceramic manufacture, forming and forging
- For some applications e.g. long-term heat treatment, direct in-situ traceability is needed
- Self-validating thermocouples
- Reduce size of FP to enable same form factor
- A cheaper alternative is the novel double-sheathed MI cable developed by UCAM



NPL, CCPI, STRAT
Develop self-validating thermocouples with same form factor as existing sensors

TRIAL IN-PROCESS

NPL, BRML, STRAT, CCPI
Test self-validating sensors (aerospace turbine blade heat treatment)

Collaborators
Bodycote Romania

UCAM, PTB, NPL
Evaluate novel MI ultra-stable thermocouples

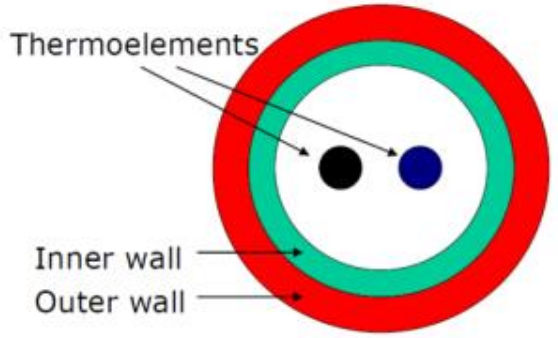
TRIAL IN-PROCESS

UCAM, BRML, STRAT
Trial ultra-stable MI thermocouples (ceramic manufacturing, aerospace heat treatment)

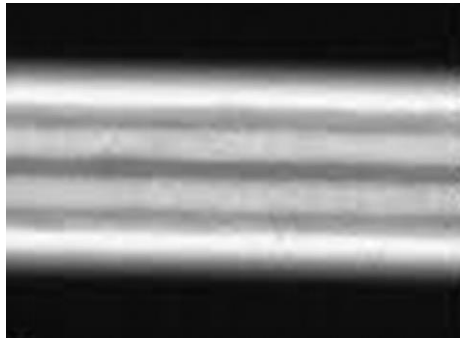
Collaborators
ICPE-CA
Bodycote UK

WP2 Zero-drift contact temperature sensors to 1350 °C (NPL)

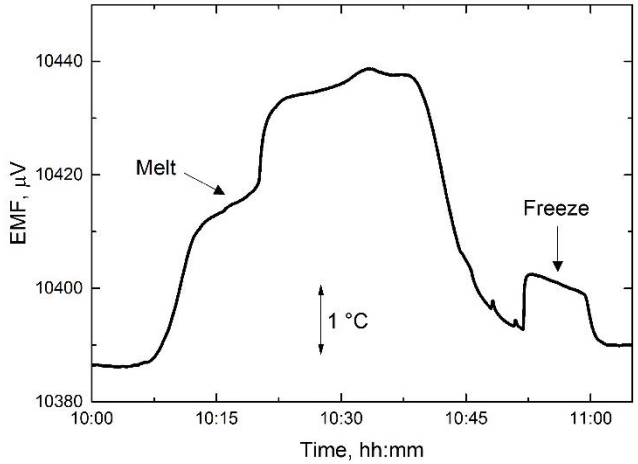
- For some applications e.g. long-term heat treatment, direct in-situ traceability is needed
- NPL: Self-validating thermocouples constructed and working
- UCAM/PTB: MI cable developed by UCAM, metrologically characterised by PTB
- End-user trials: AFRC, A&D, ICPE-CA, Bodycote



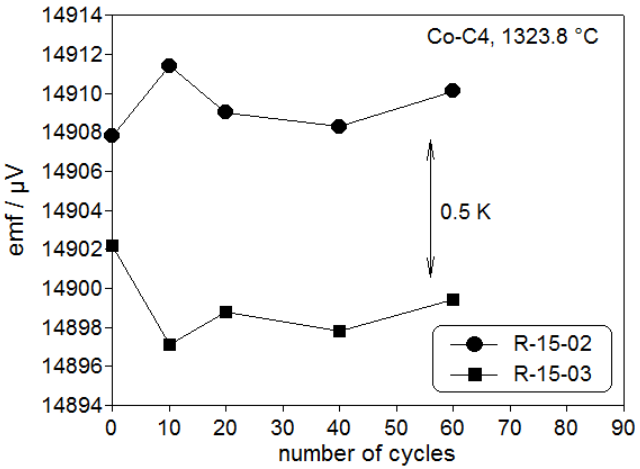
X-ray of double-walled MI thermocouple



Melting and freezing of miniature FP crucible (Pt-Rh thermocouple, all in 7 mm o.d. sheath)



Stability of UCAM MI thermocouple on cycling



WP1 & WP2 in-situ trials

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Elkem

Bodycote

AFRC
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UNIVERSITY OF STRATHCLYDE

ICPECA

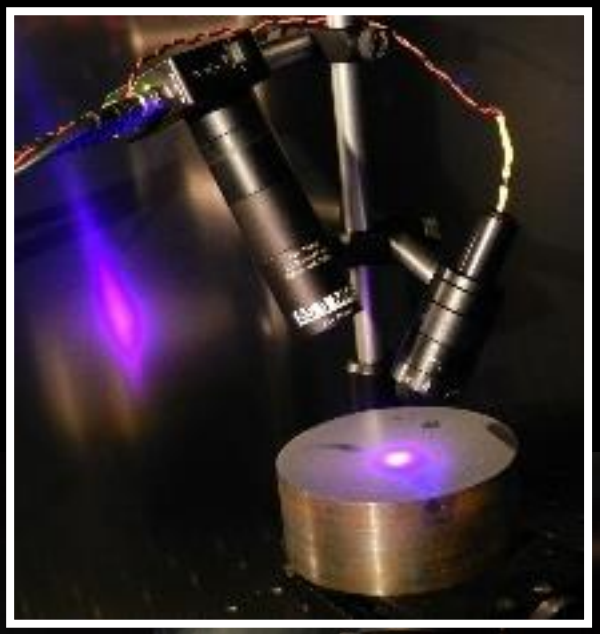
- Heat treatment
- Forming and forging
- Ceramic manufacture

WP3 Surface temperature (INRIM)

- Forming, forging, welding heat treatment, coating
- Contact thermometers for surface temperature measurement are subject to large errors
- Fluorescence thermometer

  Surface temperature calibrator

  Directly applied to surface
- Heat flow compensating sensor



INRIM, DTI, NPL
Develop fluorescence sensor for surface temperature measurement

TRIAL IN-PROCESS → **NPL, BAE**
Test fluorescence thermometer in welding and coating treatment (marine structure fabrication)

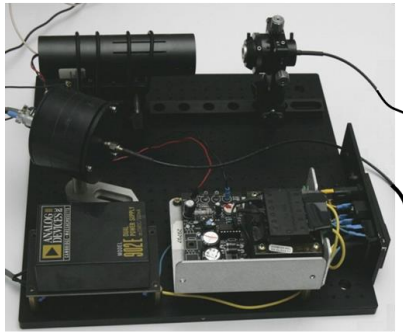
TRIAL IN-PROCESS → **INRIM, Gamma**
Test fluorescence thermometer in metal forging and forming (automotive manufacturing)

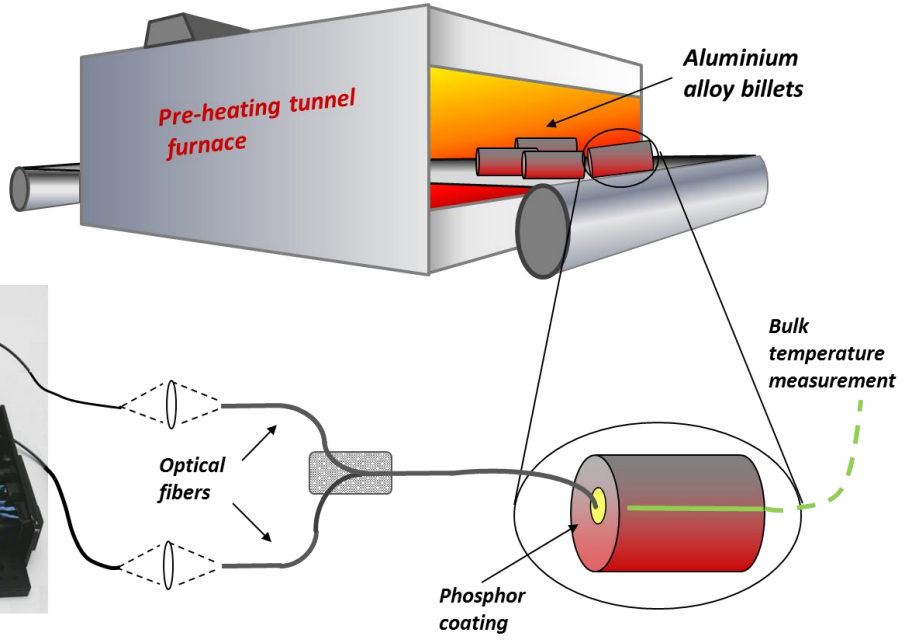
CMI
Develop heat flow compensated sensor for surface temperature measurement

TRIAL IN-PROCESS → **CMI, Collaborators**
Test heat flow compensated thermometer in forming application (automotive)

WP3 Surface temperature (INRiM)

- End-user trials
- BAE Systems
- Gamma Forgiati





WP4 Combustion temperature (NPL)

- ICE, gas turbines, fuel development
- There is currently no traceability of flame and combustion temperature measurements
- Develop portable standard flame
- Validate it & assign traceable temperature
- Make it available to end-users

NPL
Develop portable standard flame

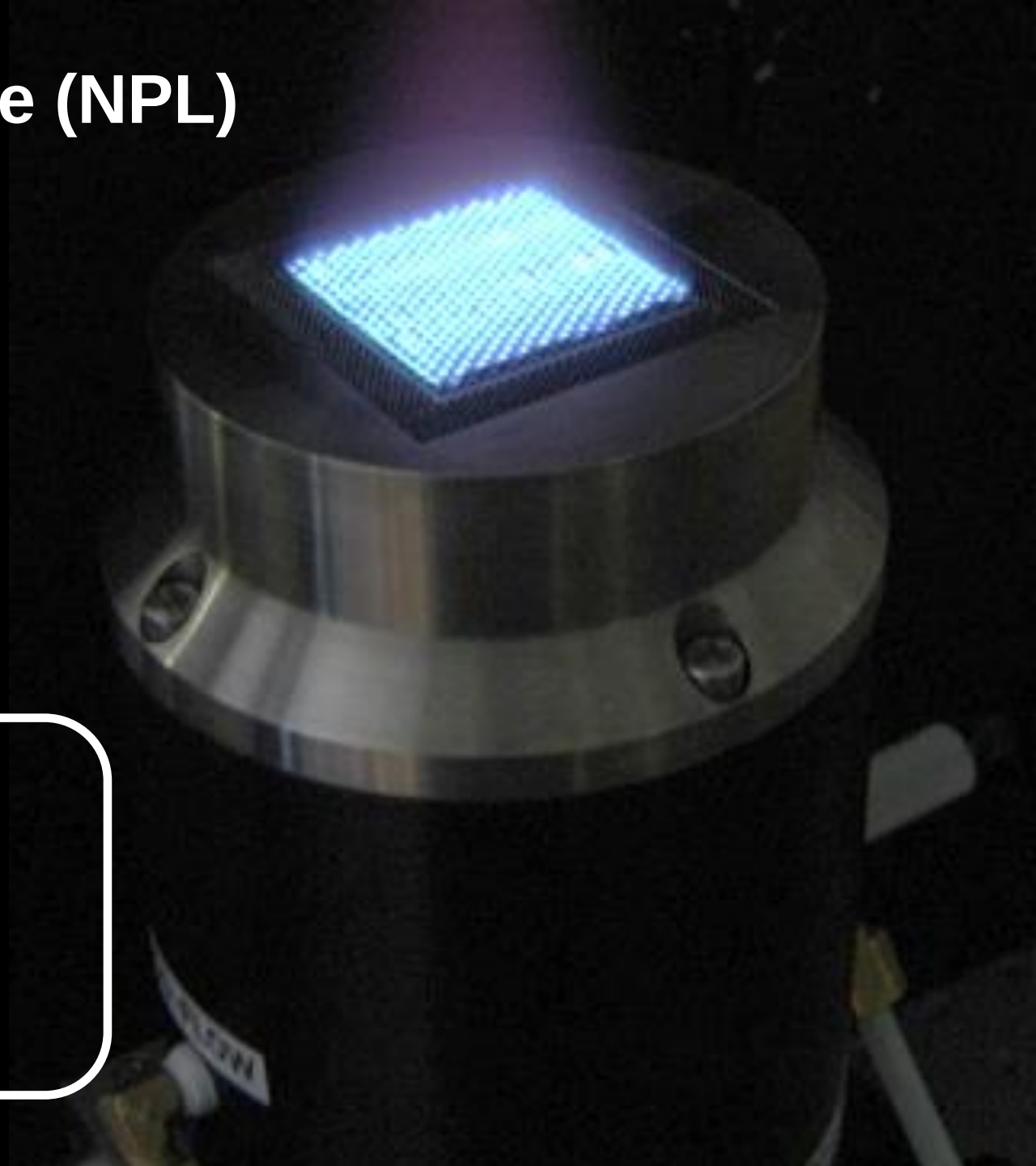
EVALUATE

NPL
Develop Rayleigh scattering flame thermometry system

UC3M, CEM, DTU, NPL
Develop FTIR flame thermometry system

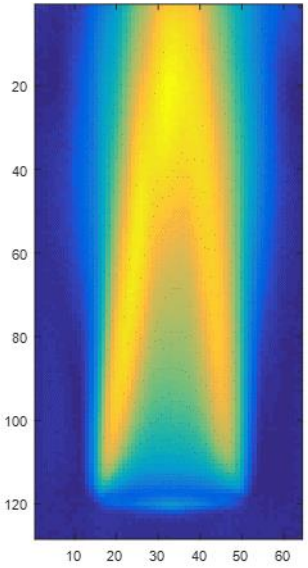
DTU, UC3M, NPL
Develop UV flame thermometry system

UOXF, NPL
Develop DFWM and LIGS flame thermometry system

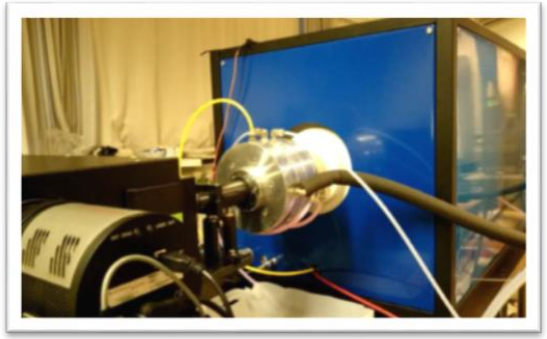


WP4 Combustion temperature (NPL)

- NPL: portable standard flame commissioned
- CEM/UC3M: adaption of hyperspectral imager to measure flames complete
- DTU: UV spectrometer measurements on hot gas underway, compilation of UV CO2 and H2O absorption spectral database
- UOXF: DFWM and LIGS models under development; DFWM measurements of OH in McKenna burner methane/air flame – excellent results; LIGS results for heated water vapour successful
- End-user linkage via universities (mainly automotive)



Hyperspectral image


UV spectrometer observing the hot gas cell.

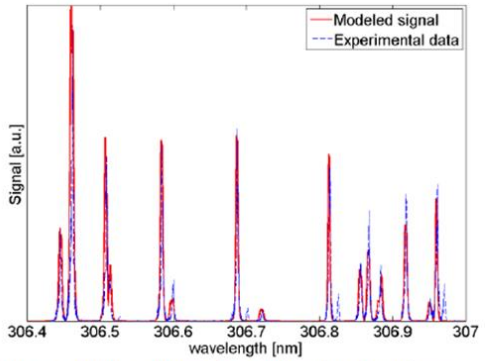


Figure 2. DFWM spectrum of OH and analytical simulation

Thermocouple users group

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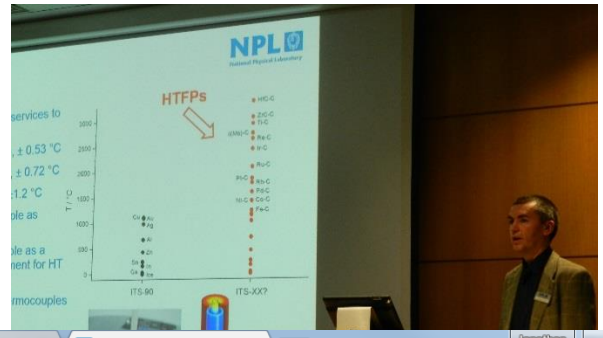
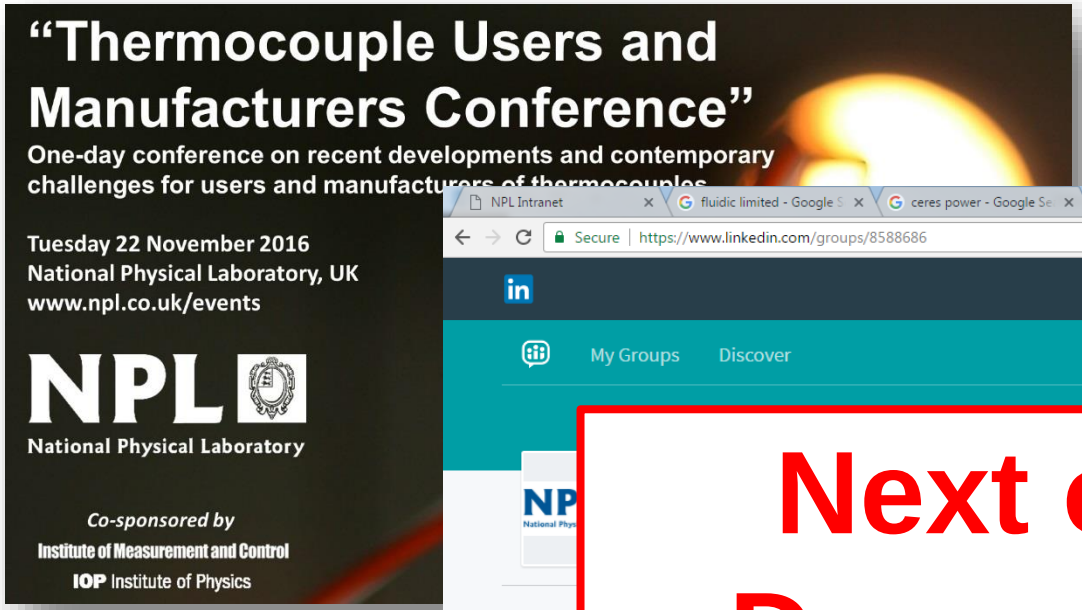
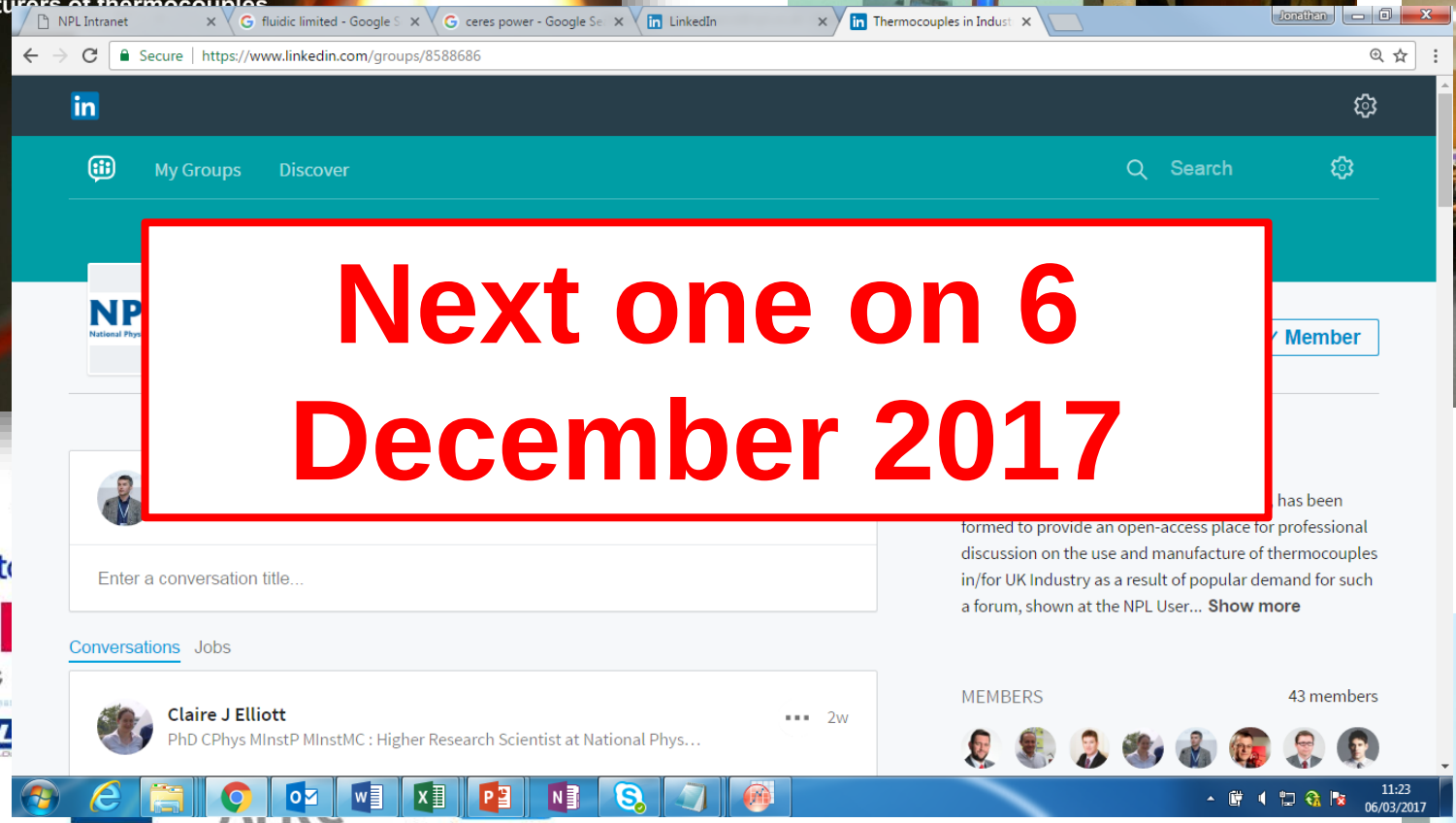
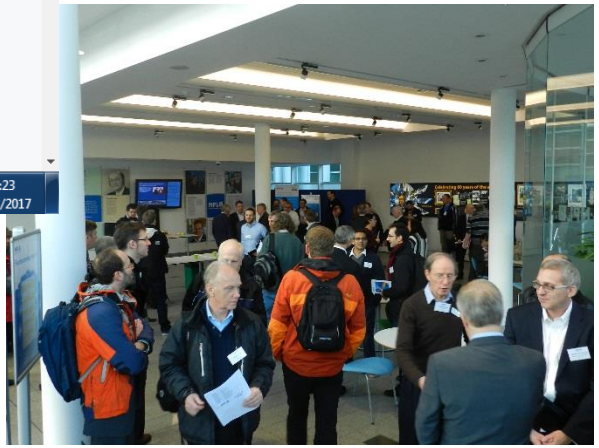






Next one on 6 December 2017



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Agenda

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Wednesday 22 March 2017			
9.00	Arrival and registration		Introduction & keynote
9.30	Welcome to the AFRC	David Jones, AFRC	
9.35	Welcome and introduction	Graham Machin, NPL	
9.40	Overview of the EMPRESS project	Jonathan Pearce, NPL	
10.00	Keynote: Temperature measurement for better processes to create better products and services	Pete Loftus, Rolls-Royce	
10.40	Overview of WP1: Low-drift contact temperature sensors to above 2000 °C	Frank Edler, PTB	
10.50	Overview of WP2: Zero-drift contact temperature sensors to 1350 °C	Claire Elliott, NPL	
11.00	**Coffee break**		
11.30	Introduction to a new low drift base metal thermocouple mineral insulated cable technology	Michele Scervini, Cambridge University & Trevor Ford, CCPI Europe Ltd	Contact thermometry
11.50	Optical based contact thermometer using SiC, quartz tubes and sapphire fibre	Sigurd Simonsen, Elkem	
12.10	High-temperature measurement in industrial practice	Jurgen Blüm, MUT	
12.30	**Lunch**		
13.30	Overview of WP3: Traceable surface temperature measurement with contact sensors	Lucia Rosso, INRiM	Phosphor thermometry
13.40	Thermocouples in industrial environments	Mark Thomas, BAE Systems	
14.00	Surface thermometry in low TRL testing of combustor cooling concepts	Clare Bonham, Loughborough University	
14.20	Industrial uses of thermographic phosphors	Andy Heyes, Strathclyde University	
14.40	**Tea break and networking**		
15.10	Overview of WP4: Traceable combustion temperature measurement	Gavin Sutton, NPL	Combustion thermometry
15.20	Laser techniques for flame and combustion thermometry	Paul Ewart, Oxford University	
15.40	Temperature measurements in turbulent flames using Raman spectroscopy	Wolfgang Meier, DLR	
16.00	A practical Johnson noise thermometer	David Cruickshank, Metrosol	
16.20	**Tour of AFRC**		

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EURAMET

EMPRESS
TEMPERATURE METROLOGY FOR PROCESS EFFICIENCY

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