

# **UK/US Collaboration in Energy R&D: Clean Coal Technology**

## **Advanced Materials Program**

**John Oakey and Ian Wright**

- Background
- Why Collaborate?
- Collaboration Framework
- Phase 1 Tasks - Outputs and Benefits
- Plans for Phase 2

- **MOU Renewal**

- Under discussion 1999 - 2000
- Signed 6<sup>th</sup> November 2000
- Materials identified as a priority topic for collaboration

- **DOE/DTI Workshop**

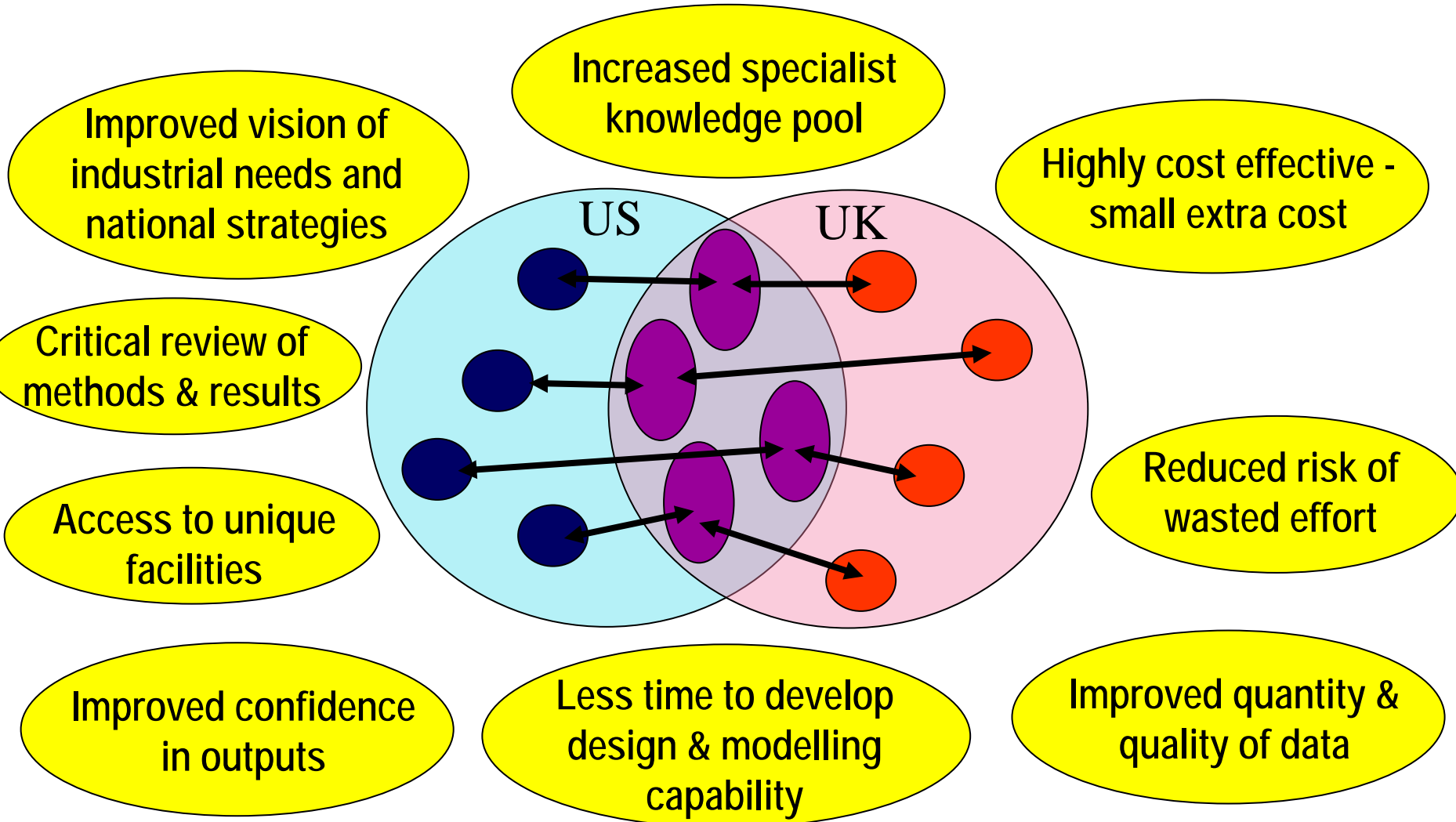
- Held in Knoxville, Tennessee in June 2001
- Workshop identified many topics of common interest where collaboration would be possible
- Text for Implementing Arrangement revised
- Materials, Virtual Plant Demonstration, Near-zero Emission Power Plants, CO<sub>2</sub> Capture & Sequestration, Distributed Generation listed as ‘tasks’ to be developed

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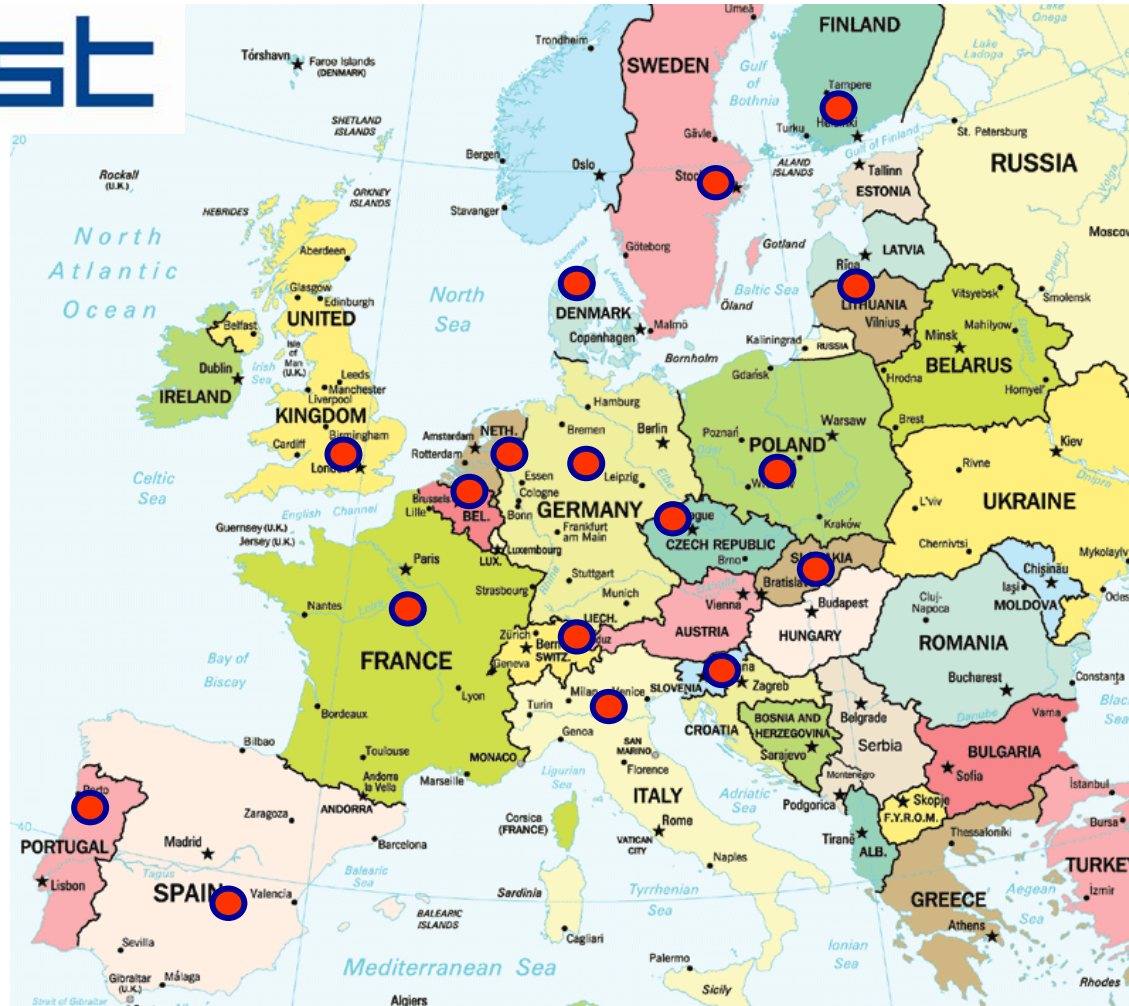
- **Implementing Arrangement for Fossil Energy RTD**
  - Signed 10<sup>th</sup> March 2003
  - Sets a framework for collaborative 'tasks' with named UK and US leaders
  - Followed up with workshop at NETL, Pittsburgh in June 2003
  - Agreed to proceed with collaborative tasks on Materials and Virtual Plant Simulation
  - Draft tasks prepared at the workshop
- **Framework for Materials Collaborative Task**
  - Contributions from nationally-funded public domain research
  - Task proposals define equitable research collaboration
  - Detailed work program aligning UK and US activities to maximise exchanges and benefits
  - Exchange and sharing methodology based on EU COST Program
- **Collaboration starts April 2004**

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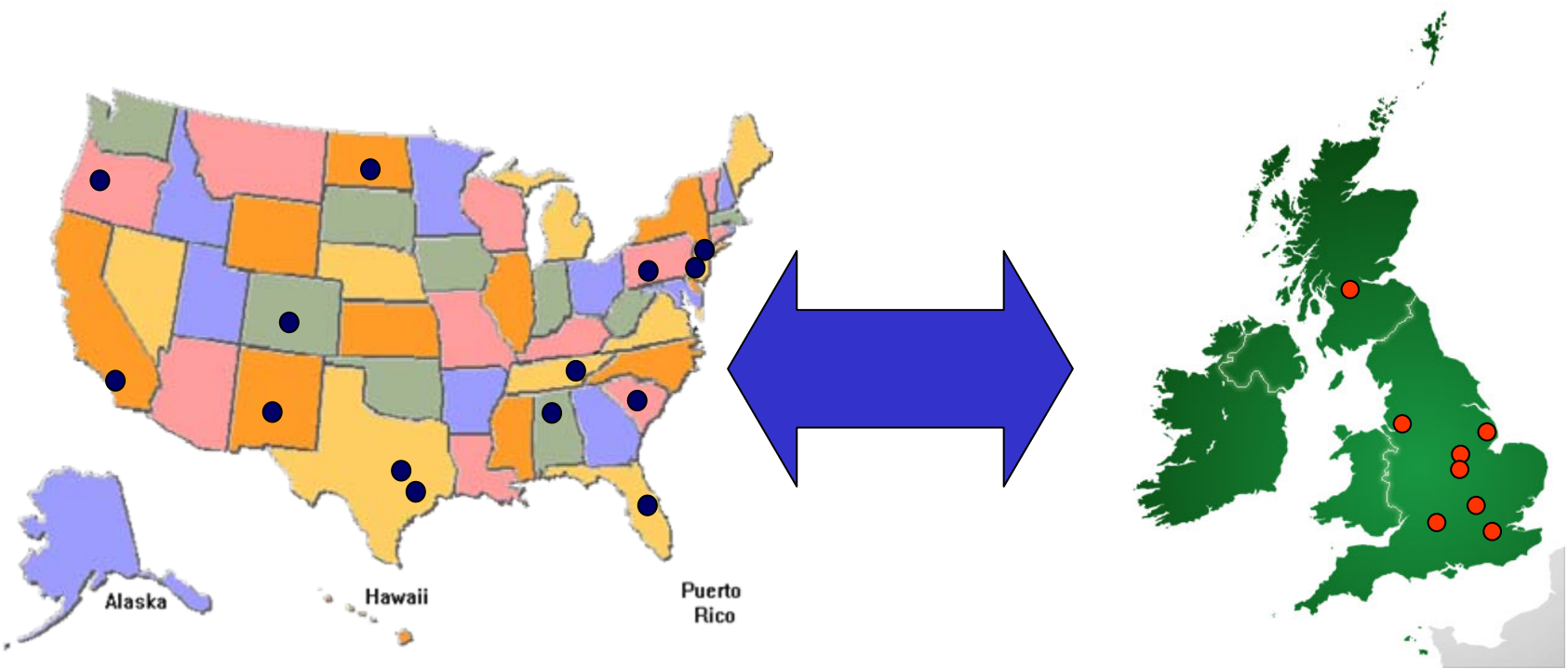
# Why Collaborate?



# EU COST Program



# UK/US Collaboration on Advanced Materials



# Phase 1 Tasks

All tasks aimed at increased plant efficiency and reduced emissions

- Steam Oxidation
- Boiler Corrosion & Monitoring
- Gas Turbines Fired on Syngas and Other Fuel Gases
- Oxide Dispersion-Strengthened (ODS) Alloys
- Standards & Databases

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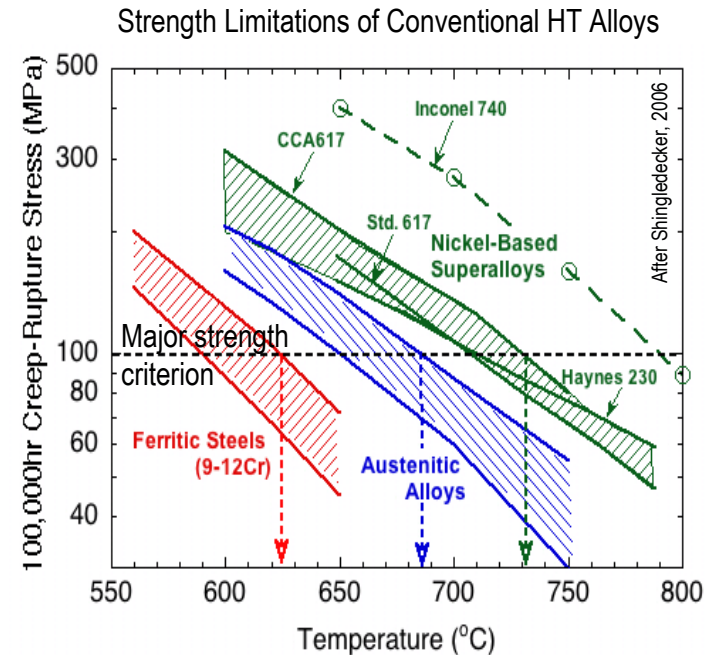


## Why?

- Advanced steam cycles = increased efficiency = increased temperature
- New alloys needed to achieve these goals
- Need basis for confident service life prediction

## Challenges

- Higher temperatures = reduced lifetime
- No reliable design data
- Potential failure modes unknown

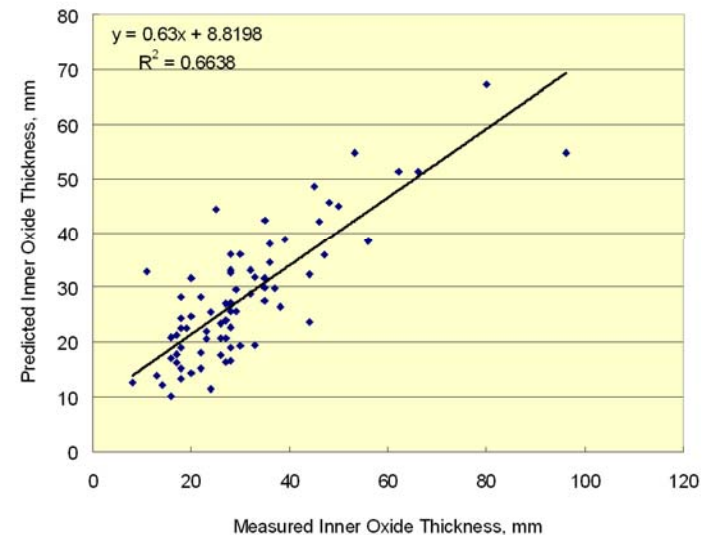
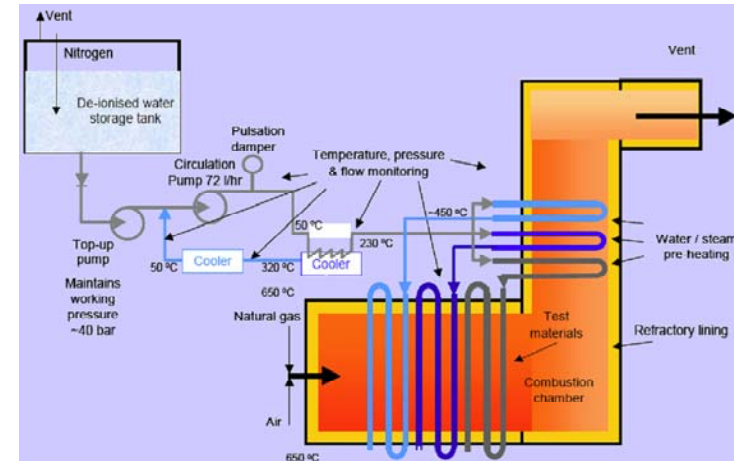


## Outputs & Benefits

- New testing capabilities
- >1m hours of specimen exposures
- Tools for data qualification & extrapolation
- New degradation models

## Proposed Work Plan (Phase 2)

- Standardized testing approach
- Correlate lab. data to plant experience
- Lifetime model development



# Boiler Corrosion & Monitoring

## Why?

- Alternative fuels, emission controls, advanced cycles increase operating risks
- Understand impact on materials performance
- On-line condition monitoring to improve plant operation

## Challenges

- Quantify specific fuel effects on materials behavior
- Develop reliable monitoring techniques
- Correlate lab. data to plant experience



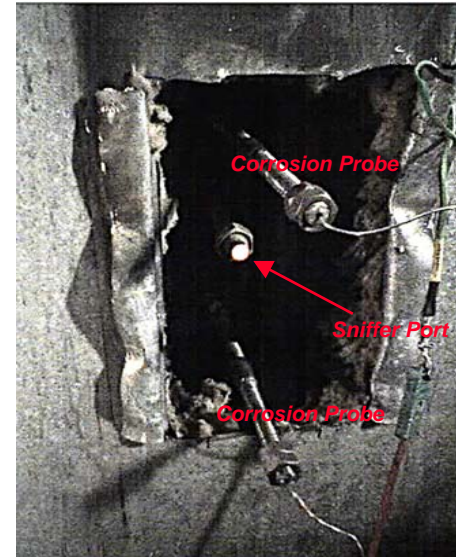
# Boiler Corrosion & Monitoring

## Outputs & Benefits

- Ranked alloys in simulated operating environments
- Established limitations of current probe designs
- Identified approaches for monitoring probe design improvements

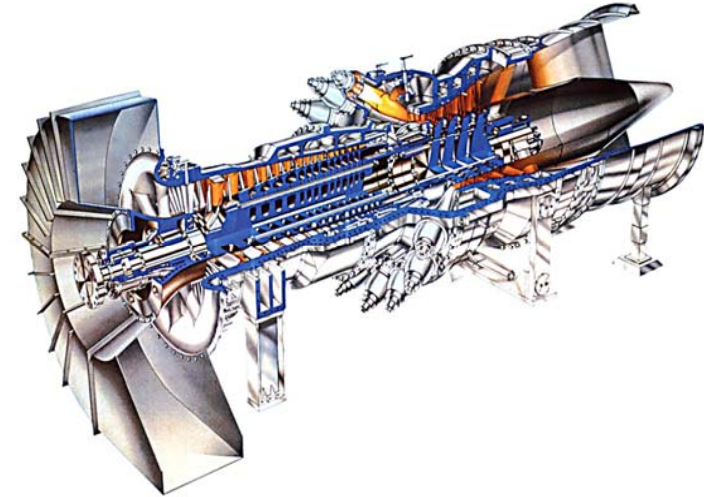
## Proposed Work Plan (Phase 2)

- Advanced lab. testing procedures
- Further development of corrosion monitoring probes (electrochemical)
- Emphasis on oxy-firing, co-firing, advanced cycles



## Why?

- Enable the use of SOA GTs with fuels derived from gasification of coal and/or biomass
- Understand impact on critical hot gas path components
- Ensure reliable operation and reduce risk



## Challenges

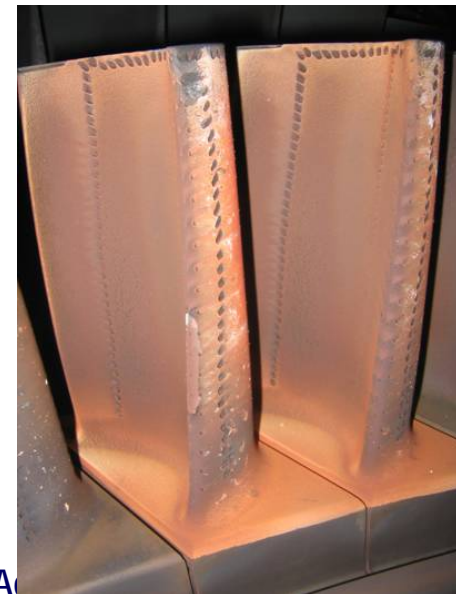
- Understand and predict threat from these combustion environments
- Provide a versatile simulation testing facility
- Quantify impact on alloy and coating performance
- Identify cost-effective alloy and coating combinations to reduce operational risks

## Outputs & Benefits

- Demonstrated ability to correctly simulate plant environments
- >650,000h of specimen exposures
- Validated predictions of damage modes
- Predicted component lives for plant systems

## Proposed Work Plan (Phase 2)

- Expansion of life predictions to new systems
- Generation of input for GT life prediction models
- Integration with advanced NDE techniques

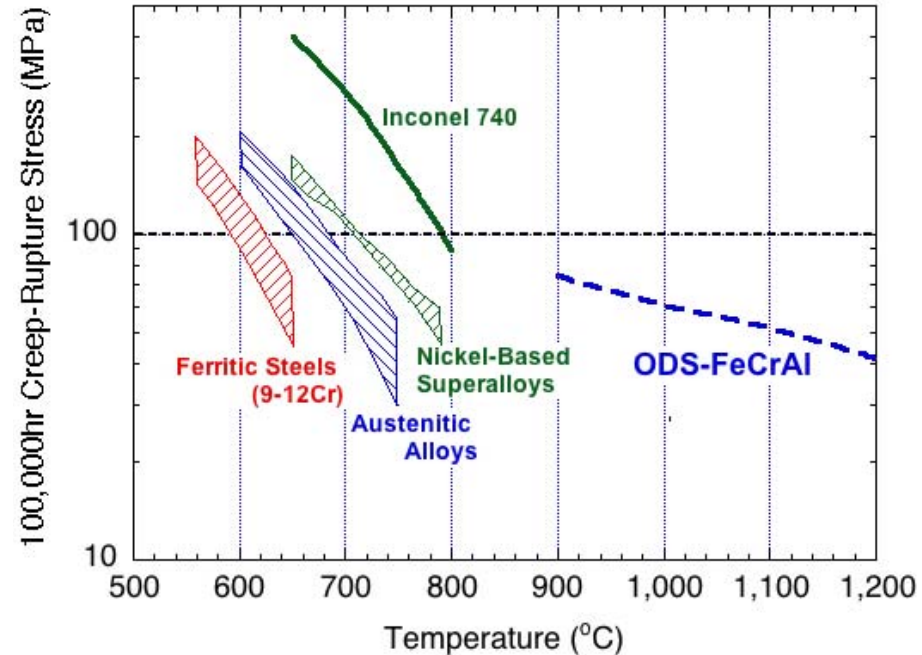


## Why?

- Class of materials with exceptional characteristics, but challenges to practical application
- Opportunity for step change in performance of existing and new plant components

## Challenges

- Need for better joining techniques
- Processing for improving strength of tubes
- Improved oxidation resistance



## Outputs & Benefits

- Identified viable joining techniques
- Commercial processing routes for strength improvement
- Identified coating for improved high-temperature service life
- Proposed Work Plan (Phase 2)
- Qualify *new commercial ODS alloy*
- Alternative processing routes for strength improvement
- Fabricate demonstration components
- Explore novel process for making components from ODS alloys





## Why?

- Need test results from different partners to be directly comparable
- Need ability to share and compare data and testing methods among different laboratories

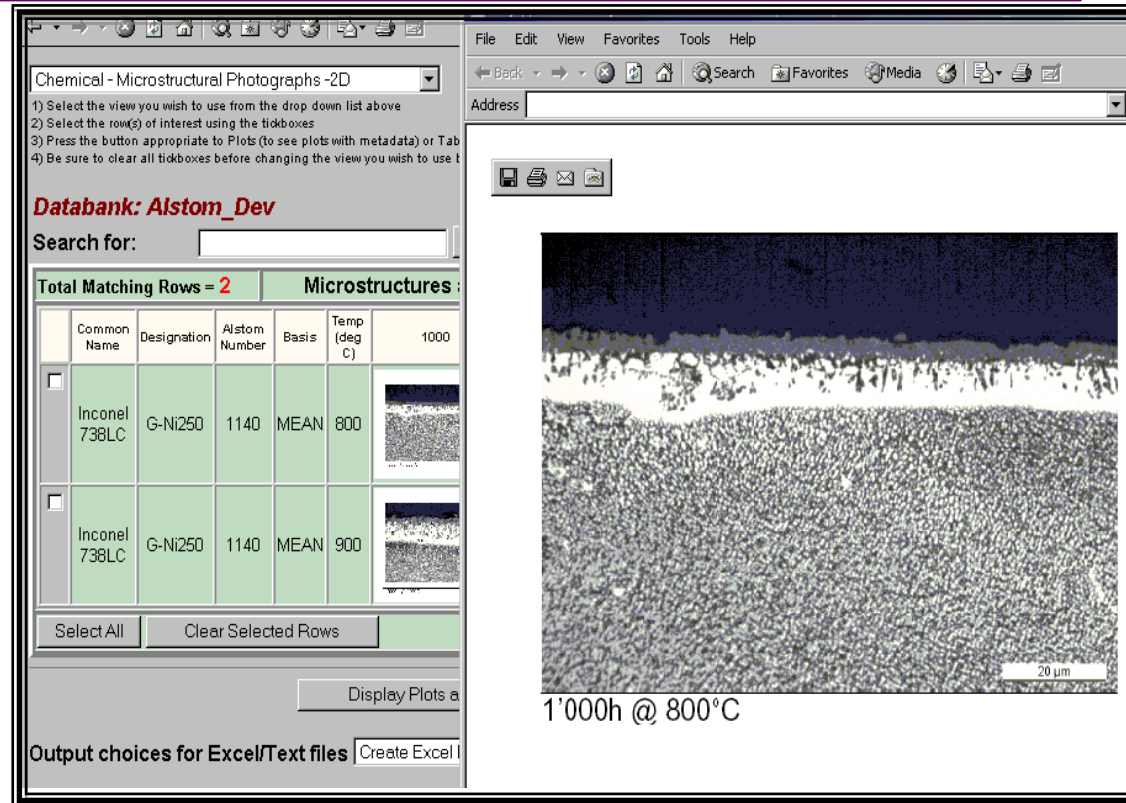


## Challenges

- System for data collection, analysis, and exchange
- Ensure full and consistent record keeping
- Enable full, future replication of testing

## Outputs & Benefits

- Identified sources of differences in data among tests by partners
- Standardized approaches
- Developed a full-featured database
- Provided secure, central access to all partners





Chemical - Microstructural Photographs -2D

- 1) Select the view you wish to use from the drop down list above
- 2) Select the row(s) of interest using the tickboxes
- 3) Press the button appropriate to Plots (to see plots with metadata) or Tab
- 4) Be sure to clear all tickboxes before changing the view you wish to use

**Databank: Alstom\_Dev**

Search for:

Total Matching Rows = 2      Microstructures :

	Common Name	Designation	Alstom Number	Basis	Temp (deg C)	1000
<input type="checkbox"/>	Inconel 738LC	G-Ni250	1140	MEAN	800	
<input type="checkbox"/>	Inconel 738LC	G-Ni250	1140	MEAN	900	

Select All      Clear Selected Rows      Display Plots a

Output choices for Excel/Text files      Create Excel

1'000h @ 800°C

20 μm

## Proposed Work Plan (Phase 2)

- Task completed, separate future activities not required

# Summary of Phase 1 Experience


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- Accelerated progress in complex areas
- Extensive and faster data development
- Effective working relationships to face new challenges
- Shared experience improves outputs and reduces risks
- Awareness of current testing limitations
- Formulation of new approaches
- Effective benchmarking and data qualification
- Improved awareness of industrial needs and national priorities

# Approved Phase 2 Tasks

- Steam Oxidation
- Materials for Advanced Boilers and Oxy-Combustion Systems
- Gas Turbine Materials Life Assessment and Non-Destructive Evaluation
- Oxide Dispersion-Strengthened Alloys

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# More Information

**Advanced Materials Program Overview**

**background**  
Under the auspices of the UK-US Memorandum of Understanding (MOU) and the associated Implementing Agreement for Fossil Energy Research and Technology Development, a number of organizations from the UK and US have participated in a five-year collaboration on advanced materials supported by the UK Department of Energy and Climate Change (DECC) and the US Department of Energy (DOE).

As one of the areas under the MOU, advanced materials was identified as a key underlying technology. The development, characterization and understanding of advanced materials will help the UK and US fossil energy industries to develop new and cleaner power generation systems with lower costs, improved time-to-market, and reduced technical and commercial risks.

A developed understanding of advanced materials is a key prerequisite which must be satisfied in order to achieve the targets of any future energy policy. Improved environmental and efficiency targets will necessitate the development of more advanced materials and components, systems, manufacturing methods and improved life assessment methods. The impact of changes such as, full scale plant operating performance and the introduction of CO<sub>2</sub> capture technology will also place severe demands on the materials and components used in power plant equipment.

**objectives**  
The key objective of the UK-US collaboration was to share and develop the partner's knowledge and expertise in the key area of high-temperature materials for advanced fossil energy power plant applications.

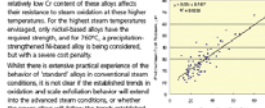
This would be achieved through such mechanisms as sharing of test facilities and best practices, development of common tools and methods, and industrial techniques. The opportunity to develop long-term cooperation in advanced materials from the experience gained during project collaborations was also an aim.

- More specific:
  - Optimize
  - Concept
  - Material
  - Design
  - Thick wall
  - Arrangement
  - Steam
  - Gas turbine
  - Standard
  - oxide

**Steam Oxidation**

**background**  
In recent years interest in the development of steam-generating power plants with increased efficiencies has led to the need to develop and qualify materials capable of operating at stresses, temperatures and pressures significantly higher than those employed in current power plants. Ongoing programs in Europe and Japan envisage steam conditions increasing in stages from 600°C to 700°C (1120°F to 1292°F), and in the USA to 700°C (1292°F). The overall focus of these activities is to develop materials capable of withstanding these high temperature conditions, before switching to austenitic steels or Fe-based alloys.

As a result, there has been considerable emphasis on improving the high temperature creep properties of 9-12% Cr ferritic steels which currently appear to be capable of use up to approximately 650°C (1200°F) and 50 MPa (7250 psi).



While there is extensive practical experience of the behavior of 'hardened' alloys in conventional steam conditions, it is not clear if the established trends in oxidation and creep behavior will extend into the advanced steam conditions, or whether the most alloy will follow the trends established for conventional ferritic and austenitic steels. Further, there are also data for the steam oxidation of the higher-temperature austenitic steels, and data are very sparse for Fe-based alloys in steam.

The overall intent of this task was to leverage efforts in the UK and US to provide a better insight of the steam oxidation of these classes of alloys by collaborating on the evaluation of available information, and the generation of data still needed to provide the basis for confident use and prediction of steam oxidation behavior.

- objectives**
- To establish the current state of knowledge regarding steam oxidation of materials used in fossil-fueled power plants
  - To collect and analyze existing information to identify missing critical data
  - To generate critical data as required which could be used in subsequent design and life prediction of components
  - To develop mechanistic models for the evaluation of oxide growth under steam environments

**Boiler Corrosion and Monitoring**

**background**  
Incidence of excessive boiler tube metal wastage due to fretting corrosion has long been a significant issue for coal-fired utility boilers. Boiler design rules and features introduced in the 1950s and 1960s in response to corrosion problems at that time have proven reasonably successful with the assumption of excessive corrosion being inevitably new.

However a number of developments are changing this position:

1. Denser NOx emission control technologies, which implement burn furnace conditions
2. Co-firing non-conventional fuels (e.g. biomass) in coal-fired boilers, which affect air deposits
3. Advanced coal-fired boiler operating conditions producing higher steam pressures and temperatures
4. Digital firing technology producing very high heat flux and species concentrations such as SO<sub>2</sub>, CO<sub>2</sub>, and H<sub>2</sub>O

As a result, the ability to control flue gas composition to acceptable levels is imperative for the successful operation of advanced coal-fired boilers. The programme of work was designed to gain a better understanding of three key issues by bringing together UK-US organizations with specific expertise and interest in boiler corrosion.

**objectives**

- To increase plant operators' awareness and understanding of boiler corrosion
- To develop and apply optimized in-situ monitoring and detection techniques for applications that include biomass co-firing, outdoor firing and waste incineration
- To evaluate combustion laboratory characterisation of boiler corrosion processes relevant to advanced power plant and to model the nature and mechanisms of degradation involved and to develop a predictive capability relevant to real world conditions

**Gas Turbines Fired on Syngas and other Fuel Gases**

**background**  
In moving towards higher efficiency power generation systems that produce lower CO<sub>2</sub> emissions, the use of gasification based combined cycle technologies becomes increasingly attractive. These systems can be used to generate fuel gases from a wide range of solid fuels including coal, biomass and waste products. These fuel gases need to be cleaned before use in gas turbines, but they can also be processed by reforming CO<sub>2</sub> and to produce fuel gases that have high hydrogen contents.

This task was focused on investigating the impact of changes expected in the future use of fuel gases in power generation gas turbines focusing in particular on the impact on hot gas path components in the power turbine such as blades, vanes and combustor cans. Improved corrosion, erosion and deposition on these components as a result of using gasifier derived fuel gases could reduce component lifetimes and so reduce the stability of such gas turbines. However, the correct selection of advanced materials including corrosion resistant and thermal barrier coatings provides a route to counter the effects caused by future fuel gases with higher levels of contaminants.

**objectives**

- To quantify the major degradation effects on gas turbine materials operating with fuel gases, including gas corrosion and wear-related issues, in order to improve component design and life prediction methods
- To characterize the range of fuel gas atmospheres anticipated in solid fuel gasification systems
- To expose selected alloying combinations in burner testing and determine degradation rates and the erosion and corrosion resistance of state-of-the-art gas turbine materials systems over the appropriate operating temperature ranges
- To identify candidate alloy and coating systems, that are appropriate for use in fuel gases

**work programme**  
The work programme was divided into two main activities:

- Assessment of future fuels for power generation gas turbines and their effects on the operating environments around critical components in the gas turbine hot gas path. This used thermodynamic and kinetic modelling to follow major, minor and trace elements from a fuel through processing stages, into a gas turbine combustion chamber and through a power turbine. For example, UK-US coal and biomass fuel gasification systems with differing degrees of hot gas cleaning before gas turbine combustion
- Carrying out four 1000-hour high velocity burner rig exposures at Cranfield University, Gasco, vapor phase and solid contaminants were added adjacent to the natural gas flame to generate four target environments from the fuels indicated below:
  - Diesel fuel with maximum allowable contaminants
  - High NOx HCC syngas
  - Hydrogen content gases

**work programme**

**Standards and Databases**

**background**  
With the continued drive for the development of new and improved materials and the general use of existing materials in a cost effective manner, the ability to share and compare data and testing methods from laboratories is of increasing importance. Collaborative programmes such as this offer clear financial and technological advantages for those involved, through the sharing of resources, results and complementary laboratory work. With the ever-increasing global partnerships and national testing systems founded on co-operative materials testing programmes, the need for comparability between results and an efficient, comprehensive method for data collection, analysis and exchange is essential.

Recognizing that the overall UK-US programme would generate a significant amount of test data using common test methods with each of its tasks and in order to capture the information and include any difference in results, a Framework and Database task was established. The overarching aim was to provide standardised tools for the entire programme that would:

- Allow transfer of data between partners and between tasks by setting up a consistent and easily accessed data transfer format
- Ensure that the testing techniques applied by the various partners would be directly comparable
- Create a database structure suitable for storage and retrieval of materials and manufacturing data

With the variety of data envisaged and the quantities that were projected to be generated, the UK-US collaboration provided a highly visible arena in which to build and update such tools. Within the developed structure, the methods used and the data generated in all tasks have been recorded and stored. This task's long-term goal is for future cooperative projects to adopt the tools produced and continue to populate and use them, within the limits of the collaborative agreement.

**objectives**

- To identify critical information parameters, standards for assessment of data, test methods and standards
- To identify properties
- To identify high level requirements
- To build existing
- To build existing
- To build existing
- To build existing
- To build existing
- To build existing
- To build existing

**Oxide Dispersion-Strengthened Alloys**

**background**  
The global imperative for reducing CO<sub>2</sub> emissions from fossil power plants is driving the design and construction of plants with higher efficiencies, along with coating and ODS turbine technologies.

Steels in several cycle applications generally involve increasing the maximum operating temperature of the power plant. Such improvements have and will continue to be enabled by the development of materials with increasingly high temperature capabilities. Oxide Dispersion-Strengthened (ODS) alloys have excellent potential for use in next-generation high-temperature applications where superior creep strength and oxidation resistance compared to current alloys is required. Possible applications include: turbine for high-temperature heat exchangers and shafts for burners and combustion chambers.

These challenges need that currently exist are of three types:

- Relatively high processing costs
- Materials fabricated by conventional fusion welding techniques have low creep strength at high temperatures
- Secondary crystallization needs to be optimized to produce microstructures where large grains can be custom-tailored with respect to the principal stress/strain directions

**objectives**

- To establish and review the current state of knowledge regarding joining of ODS alloys
- To identify and quantify the properties of the most appropriate techniques for joining steel and ODS alloys, including non-fusion joining and fabrication processes for high-temperature heat exchanger
- To establish and extend the current state of knowledge regarding the microstructural control of ODS alloys, especially in thermally-oriented structures and hot-press
- To establish and improve the maximum operating performance parameters of ODS alloys in real-world power plant including application of coatings
- To establish and improve the critical hoop stress performance for ODS alloys through microstructural modification via thermo-mechanical processing

Thank you for your attention

<http://us-uk.fossil.energy.gov/>

