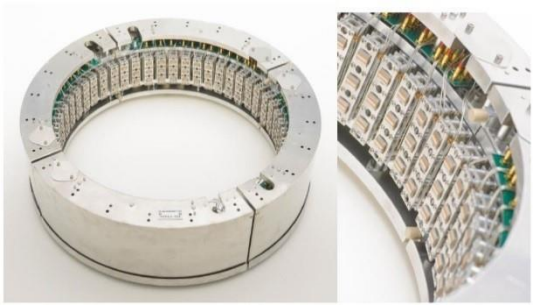
Institution: Brunel University London		
Unit of Assessment: 12 Engineering		
Title of case study: Creating Safe and Sustainable Nuclear Power Stations		
Period when the underpinning research was undertaken: 2005-2013		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
1) Tat-Hean Gan	1) Prof of Structural Integrity	1) 10/2009-present
2) Wamadeva Balachandran	2) Research Professor	2) 09/1995-present
Period when the claimed impact occurred: 2014 – December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

High-temperature transducers (HT transducers) developed by Brunel academics were used to detect a fully penetrating crack (text removed for publication) in a boiler at Heysham 1 nuclear plant operated by EDF Energy in July 2014, leading to the immediate closure of both Heysham 1 and its sister station Hartlepool. These plants were able to resume their full operation quickly, within 5 to 6 months, because EDF installed the HT transducers on the boiler spines in 8 systems in each of the 4 stations (in total 32 systems) that enable early detection of aging pipes through continuous monitoring. (text removed for publication) In-situ monitoring by HT transducers allows a proactive strategy for managing ageing plants, extending their operating lifetime and significantly reducing the potential for unscheduled outages through a targeted maintenance and repair. Consequently, both nuclear plants, originally scheduled to close in 2019, will continue to operate for another 5 years, until 2024, contributing to sustaining the nuclear energy supply in the UK. Given that EDF provides 25% of the total nuclear generating capacity of the UK, an unplanned outage or a failure to detect faults could have led to a national disaster.

2. Underpinning research (indicative maximum 500 words)



Brunel has been collaborating with The Welding Institute (TWI) and other industrial partners for over a decade to develop technologies for non-destructive testing of major infrastructure. It currently holds a grant portfolio of over GBP10,000,000.

To achieve reduced CO_2 emissions, improved efficiency and availability, nuclear power plants are operating at harsher conditions (such as high process-temperature and pressures) and cyclic duty schedules. These conditions have an adverse effect on the structural integrity of key components and increase their risk of critical failure. In particular, high temperature pipework can suffer from accelerated and severe creep-fatigue damage, which can lead to catastrophic failures. The Ultrasonic Guided Wave (UGW) technique has been widely used for the routine inspection of pipework in power plants to manage and minimise outage, but it can be both costly and time consuming.

To enable in-service monitoring of pipelines, Brunel and TWI realised that both signal processing (software) and high temperature (HT) ultrasonic transducers (hardware) needed to be enhanced. The research was led by Professors Gan and Balachandran at Brunel who worked closely with

TWI. Using numerical modelling and experimental investigations, Professor Balachandran has identified appropriate wave modes and excitation/reception conditions needed to inspect different sections of rails. [Ref 1]

In 2011, Brunel was awarded an EU-funded R&D Project, Hotscan which developed a long-range ultrasonic system with high temperature capability for continuous in-service inspection and structural health monitoring of high-temperature pipes in power generation plants and refineries. The HT transducers then-available could only operate up to temperatures of around 150°C.

The initial research evaluated the performance of existing piezoelectric materials at high temperatures and established the methodology to characterise piezoelectric materials at up to 350°C. [Ref 2]

Subsequently, the methodology was enhanced to enable the testing of the characteristics of the piezoelectric materials for ultrasonic guided wave at a temperature of up to 600°C [Ref 3]. Using this research finding in 2013, Brunel academics in collaboration with colleagues at TWI developed a number of HT transducers with enhanced temperature capabilities (continuous operation at a target temperature of up to 580°C) for a UGW monitoring system for steam lines. This enabled continuous in-service structural health monitoring of HT pipes and early detection of defects, therefore preventing failures.

3. References to the research (indicative maximum of six references)

Ref 1) Gharaibeh Y, Sanderson R, Mudge P, Ennaceur C, Balachandran W, "Investigation of the behaviour of selected ultrasonic guided wave modes to inspect rails for long-range testing and monitoring", Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, V0l.225, (2011), pp 311-324 http://dx.doi.org/10.1243/09544097JRRT413

Ref 2) Mohimi, A., Richardson, P., Catton, P., Gan, T.H., Balachandran, W., Selcuk, C., 2013. High Temperature Dielectric, Elastic and Piezoelectric Coefficients of Shear Type Lithium Niobate Crystals. Key Engineering Materials 543, 117-120 https://doi.org/10.4028/www.scientific.net/kem.543.117

Ref 3) Mohimi A, Gan T-H, Balachandran W (2014) Development of high temperature ultrasonic guided wave transducer for continuous in service monitoring of steam lines using non-stoichiometric lithium niobate piezoelectric ceramic, Sensors and Actuators A:Physical, 216, 432-442 https://doi.org/10.1016/j.sna.2013.10.008

EU Research Grant

Hotscan (No 262574) 2011-2013, funded by the European Union's Seventh Framework Programme (FP7) EUR1,500,000 (equivalent to GBP1,325,700 [01-2021]).

4. Details of the impact (indicative maximum 750 words)

Brunel researchers' development of the HT transducers that could endure continuous operation at high temperatures of up to 200°C enabled the engineers to detect the fully penetrating crack (text removed for publication) in a boiler operated by EDF Energy. [E2 p9] In July 2014, the detection of the crack on a boiler spine at Heysham 1 caused EDF to shut down immediately, Heysham 1 and its sister station, Hartlepool power station, because they both share the same design specifications. Heysham is the only site in the UK to have 2 operating nuclear power stations. Given that EDF manages and operates power stations generating 25% of the total nuclear generating capacity of the UK, the power outages by EDF

Energy led the National Grid to 'fast-forward an emergency plan' to secure more electricity in case of a possible shortfall. [E7]

Brunel researchers' guided wave technology was used to inspect all the boilers associated with the 2 nuclear reactors at Heysham 1 and Hartlepool. In order to allow the power stations to

begin operating again, they then installed HT transducers (Figure – the 'ring') on the boiler spines in 8 systems in each of the 4 stations operated by EDF Energy (in total 32 systems), which enable early detection of aging pipes by sending signals to the boiler. [E1]

With the permanent installation of HT transducers with 100% volume inspection coverage, both sites were able to quickly return to service by late 2014 and early 2015, causing little to no adverse impact to the national energy supply in the UK.

(Text removed for publication)

Since then, Brunel researchers have been supporting the TWI team in the analysis and interpretation of the data from the systems.

Safety Measures – Preparing for the Future

This incident highlights the challenges that Britain is already facing – a power capacity crunch due to ageing nuclear and coal plants. Many of our reactors were built in the 1980s and are approaching the end of their service life. Both Heysham 1 and Hartlepool were commissioned in 1983 and were due to come out of service in 2019. [E8]

The importance of regular monitoring and early detection of faults cannot be underestimated – the 2011 Fukushima nuclear disaster in Japan clearly demonstrated the potential damage that a critical failure at a nuclear power plant can cause.

Significant parts of piping systems are partly or entirely inaccessible to non-destructive inspection techniques. Therefore, installing the HT transducers in fixed positions allows EDF to monitor and collect repeatable results and build a robust model to estimate the operational resilience of nuclear plants. Consequently, EDF have developed a proactive strategy for managing ageing plants, extending their operating lifetime and significantly reducing the potential for unscheduled outages. This is achieved by accurately monitoring their condition and then strategically intervening with a targeted maintenance and repair regime. EDF Energy has extended the scheduled closure dates for Heysham 1 and Hartlepool by 5 years from 2019 to 2024.

5. Sources to corroborate the impact (indicative maximum of 10 references)

All evidence submitted in PDF.

E1) Corroborating Letter from Chief Executive, The Welding Institute Ltd.

E2) Office for Nuclear Regulation, Project Assessment Report: Hartlepool and Heysham 1 Boiler Spines Return to Service, 2015

E3) Full-year results up in 2014 Solid performance in low-carbon energies 2018 ambition reiterated: EDF Press Release 12 Feb 2015

E4) EDF group Reference Document: 2015 Annual Financial Report https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-_finance-en/financial-information/regulated-information/reference-document/edf-ddr_2015-va.pdf

News report:

E5) 11 Aug 2014, *BBC*, EDF shuts two nuclear power stations temporarily https://www.bbc.co.uk/news/business-28738074

E6) 12 Aug 2014, *Nuclear Matters,* Heysham 1 and Hartlepool operational update http://nuclearmatters.co.uk/2014/08/heysham-1-and-hartlepool-operational-update/

E7) 4 Sept 2014, *The Guardian*, Two nuclear power stations could be out of action until December, says EDF https://www.theguardian.com/environment/2014/sep/04/nuclear-power-stations-out-december-edf

E8) 11 Aug 2014, *Financial Times,* EDF Energy shuts down four UK nuclear reactors https://www.ft.com/content/4d5c670e-212f-11e4-b96e-00144feabdc0