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Metrology needs and measurement challenges across the nuclear energy industry

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National Physical Laboratory (NPL)

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We are the UK's National Metrology Institute (NMI), a world-leading centre of excellence that provides cutting-edge measurement science, engineering and technology that underpins prosperity and quality of life in the UK.

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Executive summary

The UK's civil nuclear energy sector is entering a transformative phase, driven by energy security, decarbonisation, and net-zero emission targets. With a government ambition of 24GW of nuclear capacity by 2050 and over £35bn committed investment since 2018, the sector is expanding across advanced reactors, Small Modular Reactors (SMRs) and fusion technologies. Realising this ambition depends on reducing complex technical risks, accelerating licensing and construction, and controlling spiralling lifetime costs, all needing objective, factual and quantifiable information. This information is often derived from physical measurements of the real world. Science and technology are built on the premise that these real-world measurements are accurate, consistent and repeatable.

Metrology, the science of measurement, provides the standards and methods to ensure measurements are accurate, repeatable, and traceable to internationally agreed units. The National Physical Laboratory (NPL) is the UK's National Metrology Institute (NMI), an independent, government-owned laboratory which provides trusted measurement solutions that underpin innovation, trade, and regulation. Understanding new measurement challenges is important for the strategic development of metrology to support the nuclear sector to address cost issues, technical barriers, regulatory bottlenecks and waste concerns.

This report provides a comprehensive analysis of the measurement challenges and metrology needs across the nuclear energy lifecycle, from fuel development and reactor operation to fusion innovation and decommissioning. Drawing on policy, stakeholder engagement, and scientific literature, this report identifies areas where improved measurement can enable, or is critical to, safe, efficient, and cost-effective nuclear energy. Key focus areas are:

- **Advanced reactors and SMRs**: Require precise dimensional accuracy for component alignment, real-time in-situ monitoring of temperature, pressure, neutron flux and reactor conditions, validated material qualification under extreme environments, and improved nuclear data to reduce modelling uncertainties.

- **Fusion**: Needs robust measurement of synergistic stresses on materials, standards for high-energy neutron and tritium measurement, validated plasma diagnostics, data traceability and expanded facilities for material testing and neutron calibration.
- **Fuels**: Depend on accurate process control and dimensional metrology for fuel fabrication, including isotopic assay, pellet density, coating integrity, and reliable temperature and flow measurement during processing for safety and performance.
- **Decommissioning**: Requires precise, traceable long-term monitoring of waste packages and environments, including temperature, humidity, corrosion, and radiation, supported by validated imaging and remote sensing techniques for safe waste characterisation and environmental compliance.

Several cross-cutting metrology needs emerge across nuclear technologies. These are:

- Calibration, standards and traceability for sensors and monitoring instruments.
- Integrated, precise dimensional metrology across supply chains.
- Validated material characterisation methods and assurance in extreme conditions.
- Enhanced nuclear data libraries, digital frameworks and uncertainty quantification.

This report provides the basis on which NPL will pursue the development of new metrology and underpinning science and sets out opportunities for engagement and collaboration to ensure successful delivery of metrology solutions. The following activities have been identified to support the advancement of nuclear energy:

1. Targeted investment into R&D for advanced measurement technologies and radiation-tolerant, high-temperature sensors tailored to nuclear environments
2. Standardise measurement protocols and data formats for improved interoperability, model validation, efficient regulatory review and foster international collaboration
3. Expand training and skills development to grow expertise in nuclear metrology
4. Integrate metrology from the outset of reactor, fuel and decommissioning design for repeated success, safety, compliance, cost efficiency and investor confidence

The aim of developing and maintaining national measurement infrastructure is to increase confidence, compliance, and the competitiveness of nuclear technologies. By addressing technical uncertainties and enabling innovation early on, metrology supports the long-term success and sustainability of nuclear energy as a key pillar of the clean energy transition.

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Introduction

Purpose of this report

This report draws from policy insights, literature review, knowledge and experience from NPL scientists and engagement with stakeholders to understand measurement challenges and prioritise where metrology can support safe, sustainable and cost-effective growth and decommissioning of the UK's civil nuclear energy sector.

This report aims to:

1. Understand and highlight the measurement challenges and needs of the UK's civil nuclear energy sector.
2. Share the opportunity for better measurement to accelerate industry growth, improve capital investment efficiency, maintain high safety standards and reduce environmental impact.
3. Generate awareness of the role of metrology in improving the quality of measurement in the nuclear industry.
4. Steer NPL investment in metrology and enabling infrastructure.
5. Highlight opportunities for industry, academia and government to collaborate.

Nuclear energy

The British energy sector is undergoing strategic transformation, driven by energy security, decarbonisation and the rising cost of living. Nuclear energy currently provides 14% of UK's electricity, with a capacity of 6.4GW from nine reactors[1,2]. Nuclear power provides a consistent baseload to the energy mix, essential for grid stability and energy security. Nuclear energy, alongside responsible nuclear waste management, offers a clean, carbon free energy source essential to achieve net-zero targets (see figure 1). However, most of the existing reactors are scheduled for decommissioning by the mid-2030s, prompting a need to rebuild nuclear infrastructure. Renewed policy, programmes, and private and public investment over the past decade demonstrates the UK's commitment to nuclear energy expansion in a new 'golden age'[3] of nuclear energy.

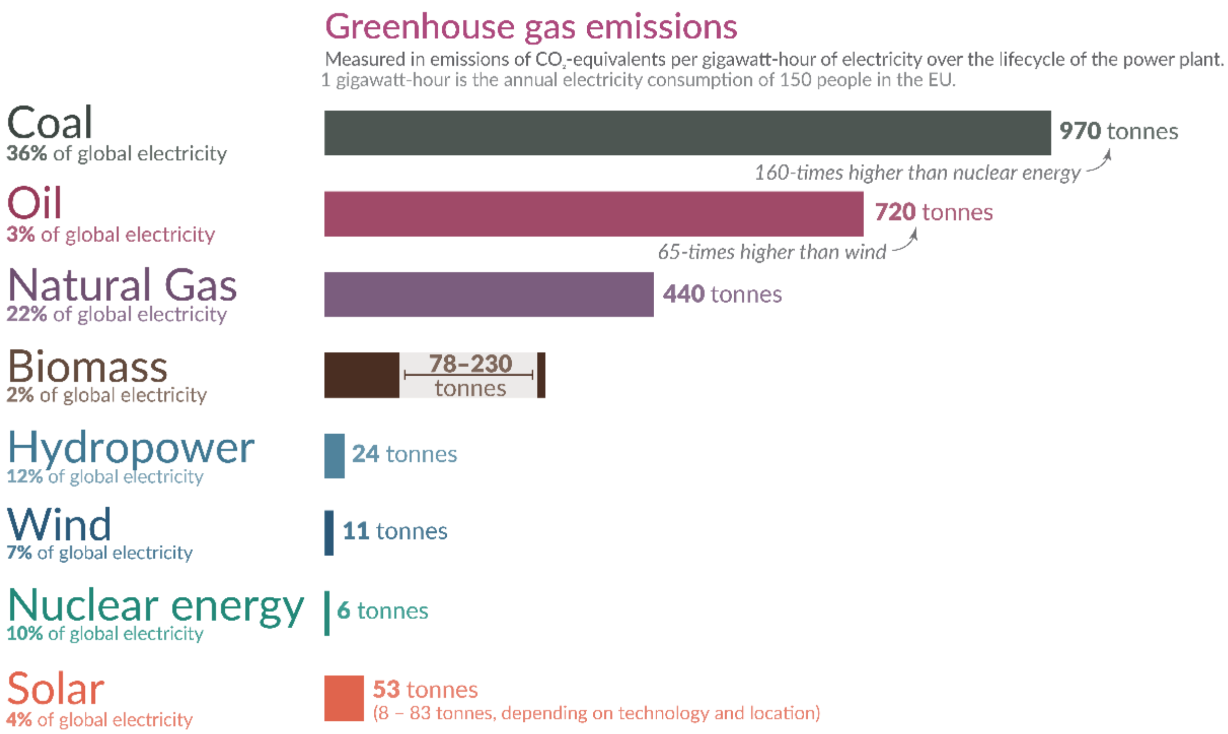


Figure 1: Graph of greenhouse gas emissions per gigawatt-hour by energy source[4]

Nuclear policy

Due to high capital investment requirements for nuclear energy, the nuclear sector is predominantly driven by policy. In 2018, the Industrial Strategy Nuclear Sector Deal promised government investment into advanced nuclear technology, including fusion, and a strategic focus on reducing costs and improving the supply chain[5]. The Prime Minister's 2020 Ten Point Plan highlighted nuclear power as a key factor in a future electricity system, pledging £385M to an Advanced Nuclear Fund and £215M for Small Modular Reactors (SMRs)[6]. The Energy White Paper and UK Fusion Strategy built on this with a commitment to fusion technology and a target to build a prototype fusion power plant by 2040[7],[8].

The 2022 British Energy Security Strategy and Powering Up Britain white papers set the target for nuclear energy to provide 24GW of energy by 2050, representing 20% of future electricity demand[9]. The Department for Energy Security and Net Zero's (DESNZ) 'Civil nuclear: roadmap to 2050' set out the strategic vision for nuclear energy to support Net Zero by 2050[10] and set up Great British Energy - Nuclear (GBE-N), the body responsible for delivering and supporting nuclear growth. Support for new nuclear infrastructure must be contingent upon parallel investment to ensure safe, cost-effective decommissioning to responsibly address societal and environmental challenges including nuclear waste. Hence, UK policy now mandates that all new nuclear facilities be designed with decommissioning in mind[11]. Most significantly, in the 2025 Spending Review, a total of £30bn was committed to nuclear[12]. Investment is spread across new reactor build, SMRs, Advanced Nuclear Technologies (ANTs), fusion, decommissioning and nuclear fuels. In total, over £35bn of public investment has been directed into nuclear energy since 2018.

Investment manifests in private and public programmes, cross cutting technologies throughout the nuclear fuel cycle, aiming to innovate the industry and drive skills, resource and facilities to support the growth of the nuclear energy sector. Successful development and innovation of the UK's nuclear energy sector rely on coordinated efforts of a diverse range of stakeholders. Government departments, regulatory bodies, research institutions, private industry, and international collaborators each play a vital role in shaping the future of nuclear energy.

Key civil nuclear energy stakeholders in the UK

- Department for Energy Security and Net Zero (DESNZ): Leads policy and funding.
- UK Atomic Energy Authority (UKAEA): Undertakes fusion research and programmes and designing a prototype fusion power plant to be operational by 2040.
- Nuclear Decommissioning Authority (NDA): Oversees decommissioning, spent fuel storage and waste management.
- UK National Nuclear Laboratory (UKNNL): UK's civil nuclear laboratory running R&D and the Advanced Fuel Cycle Programme.
- Great British Energy – Nuclear (GBE-N): Delivery body for maturing SMR and advanced reactor technology, advises on nuclear projects and enables supply chain capability and financing to progress the development of SMRs for operation in the 2030s and ANTs beyond this.
- Rolls-Royce SMR Ltd: Leading UK SMR development after being selected as GBE-N's preferred technology partner in the UK SMR competition.
- EDF Energy: Operates the existing fleet and developing partner for Hinkley Point C (HPC) and Sizewell C (SZC), building European Pressurised Reactors (EPRs).
- Urenco & Westinghouse Electric: Uranium enrichment facilities for nuclear fuel supply, with investment to Urenco to build a HALEU enrichment facility for delivery in the 2030s.

Regulation and financing

The Office for Nuclear Regulation (ONR) and Environment Agency (EA) are responsible for safety, licensing and environmental oversight of new and existing nuclear projects in the UK, working closely with developers and operators to ensure safety and compliance. International regulation is governed by the International Atomic Energy Authority (IAEA) who set international safety standards to guide national regulatory frameworks and implement safeguards to ensure peaceful nuclear use[13]. New reactor development must be approved for build and is assessed through a voluntary generic design assessment (GDA) process. However, stringent policy on environmental and planning permits and advisory regulatory expectations often make projects over budget and delayed. UK regulation applies the As Low As Reasonably Practicable (ALARP) principle, requiring risks to be reduced to the lowest level achievable without disproportionate cost, alongside Best Available Techniques (BAT) for planning[14]. While these frameworks promote safety, flexibility and innovation, they often lead to complex, costly processes that slow project delivery. For example, the UK's only new power station in construction, Hinkley Point C, has faced rising costs, delays and supply chain disruptions. Interpretations of ALARP, while essential for safety, risk becoming a barrier to rapid nuclear deployment ambitions. Thus, nuclear energy is going through regulatory reform, addressing some of the obstacles to slow and expensive progress.

A streamlining of regulation is taking place through the Nationally Significant Infrastructure Projects (NSIP) framework and recommendations from a Nuclear Regulatory Taskforce to reform licensing and processes to improve planning and costs[15]. To address high costs and high-risk investment, the introduction of the Nuclear Energy (Financing) Act 2022 enables a Regulated Asset Base (RAB) model to attract private investment[16]. Sizewell C is the first infrastructure project to use the RAB model, with returns on private investment paid upfront by consumer bills to save £2bn a year. Meanwhile, new siting criteria now includes SMRs and advanced reactors for the first time[17], and the fusion industry has been granted a new regulatory process separate to fission[18].

Global nuclear landscape

Globally, nuclear energy is also undergoing a revival, driven by the need for clean, secure, and scalable energy. Over 70 reactors are under development across 15 countries[19], and over 40 countries support nuclear expansion[20]. The European SMR Alliance is coordinating nine pilot projects and pushing for regulatory reform to accelerate deployment[21]. The US Department of Energy and private investment is funding fusion startups and advanced reactor designs. France hosts ITER, the world's largest fusion experiment, to demonstrate and test materials, tritium breeding and exhaust systems in a multi-national collaboration[22]. Global private investment in fusion now exceeds $10bn, highlighting confidence in new nuclear technology[23].

International collaboration is essential for global nuclear supply chains and safety standards. In 2025, UK and US signed a nuclear partnership unlocking over £55 billion in agreements, including investment into Rolls-Royce SMR, Urenco, X-Energy and EDF to develop advanced reactors, SMRs and nuclear fuel supply[3]. The UK has agreements with Romania and Poland to collaborate on nuclear technologies and is part of the Agile Nations collaboration with Japan and Canada, progressing fusion regulation. The UK is not only revitalising its domestic nuclear fleet but shaping international standards and supply chains and participating in global collaboration on nuclear technology and fusion development. A dual focus on deployment and innovation positions the UK as a key player in the global nuclear landscape.

Metrology

Metrology, the science of measurement, provides the standards and methods to ensure measurements are accurate, precise, consistent, and traceable to internationally agreed units. In an industry with stringent regulation where minor deviations can have significant consequences, metrology underpins nuclear energy safety, efficiency, and compliance. Metrology supports the sector through:

- Safety: Nuclear reactors operate under extreme conditions. Accurate monitoring of radiation, temperature, neutron flux, pressure, and structural integrity avoids accidents and ensures public protection.
- Efficiency: Precise measurements optimise reactor and fuel performance, and effective long term diagnostic monitoring of waste containers minimises decommissioning cost, time and waste. Metrology ensures components meet international standards, reducing costly errors and delays.

- Innovation: Emerging technologies like SMRs, advanced reactors and fusion require precise measurements to design and scale with confidence.
- Compliance: Traceable, standardised measurements ensure safe operation and effective nuclear waste management for public trust and regulatory approval.
- Collaboration: Standardised measurement systems enable interoperability, shared data, and mutual agreement of measurement results.

By applying validated, standardised test methods, metrology delivers traceable and reproducible measurements that provide robust evidence that materials and methods are fit for purpose. This assurance drives compliance, certification and commercialisation, while enabling innovation with confidence. Metrology is the foundation of trust and safety in nuclear technologies, essential for a secure, resilient, clean future energy source.

Summary

The UK is advancing its nuclear energy capabilities through a mix of technologies and programmes to meet net-zero targets and energy security. However, the sector has come under scrutiny for its high cost, long timelines, amount of waste and no established route for long-term disposal. The current fleet of reactors are nearing the end of their operational lives, with just two new reactors in development, which face delays, cost increases and criticism. New technology, including European Pressurised Reactors (EPRs), High Temperature Gas Reactors (HTGRs), SMRs, and fusion, require advanced fuels and solutions to decommission new reactor types along with supply chain readiness. As the UK pursues its target of 24GWe, coordinated efforts from stakeholders across the supply chain are critical to drive research and development (R&D), accelerate innovation, and ensure safe, efficient deployment of new nuclear technologies, overcoming technical, regulatory, and supply chain challenges. As technology evolves and new designs operate under more extreme conditions with novel materials, unique and complex challenges arise to ensure durability and maintain precision and accuracy of measurements. The role of measurement science becomes increasingly critical to address technical uncertainties, meet high standards and develop technology efficiently and cost-effectively, demonstrating safety and sustainability for long-term energy resilience. Hence, understanding measurement challenges faced by the industry is important to ensure nuclear metrology roadmaps solve the most pressing challenges, lower costs, increase trust and regulatory compliance and foster success of new nuclear technologies.

Measurement challenges

This report explores measurement challenges across the nuclear lifecycle technologies central to UK policy and investment, where there is the greatest demand for metrology and where measurement challenges can be addressed to create impact. Technical areas of focus are advanced reactors, including the new build of EPRs, development of HTGRs and SMRs, fusion, advanced fuels and decommissioning (figure 2).

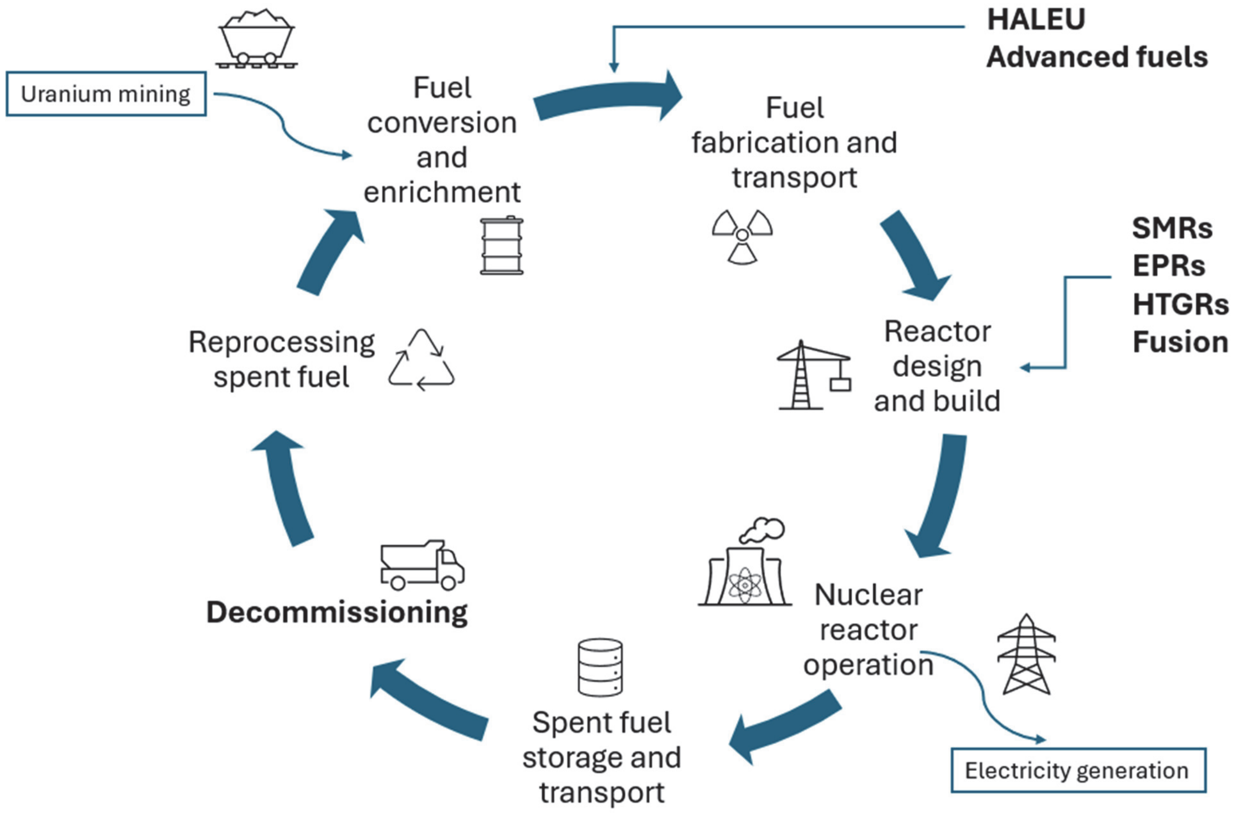


Figure 2: Nuclear energy lifecycle showing the stages of nuclear fuel and reactor development, construction, operation and decommissioning.

Measurement challenges were identified by reviewing key stakeholder roadmaps, strategies and scientific literature, attending conferences and engaging with stakeholders through informal interviews and surveys. Contributions spanned construction, engineering, research, instrument design, materials, manufacture, academia, public and private bodies.

The following section expands on the metrology needs and specific measurement challenges identified for each area of nuclear energy: advanced reactors, SMRs, fusion, fuels and decommissioning.

Advanced reactors

Advanced reactors include several types of technology in development, using novel fuels, coolants, and materials to improve efficiency, safety and cost. The UK government has identified HTGRs as the most feasible advanced reactor to focus on developing a design[24]. HTGRs use High Assay Low-Enriched Uranium (HALEU) fuel, helium coolant and graphite as a moderator. Advanced reactors face challenges related to higher temperatures and the need for accurate tools to remotely monitor the performance of novel fuels, coolants, and component materials during design, manufacture, build and operation.

Sensors, instrumentation and monitoring

To achieve fission safely, reactors must be carefully monitored to prevent an uncontrolled chain reaction of nuclei splitting. Sensors and instruments are crucial for informing operators of the temperature, pressure and neutron flux inside the reactor. However, operating in high-temperature, high-radiation environments presents significant challenges and sensors must be compatible and durable against conditions inside the reactor core[25]. This requires the development and validation of new neutron sensors and detectors which can provide continuous data, in-situ and under extreme conditions[26]. However, a lack of access to high-flux thermal neutron sources and high-energy ion and electron accelerators was identified as a key challenge for testing new sensors[27]. To ensure essential instruments maintain accuracy and to minimise over-engineered safety, thereby reducing costs, sensors need to be regularly calibrated to traceable standards to ensure consistently reliable diagnostics[28],[29].

Dimensional metrology

Dimensional metrology, the science of precise measurement of physical dimensions at a range of scales, plays a critical role in the design, manufacture, build and operation of reactors. Throughout stakeholder engagement, tight tolerances were identified as a key challenge for the manufacture, design and build of new reactors as mis-matched tolerances lead to costly delays and re-work for the supply chain. The industry struggles with inconsistent measurements, standards and tolerances between inspection systems in the factory, during manufacture and in operation. An integrated approach to dimensional measurements and tolerances across the entire supply chain was highlighted as a key need. Also needed are high-accuracy tools for verifying the precise geometry of reactor components, especially during assembly and maintenance. Validated dimensional tools help ensure that components meet stringent tolerances, vital for reactor efficiency and safety. Another challenge identified was a lack of understanding of the importance of metrology for calibration drift and tolerance, and training of the supply chain was expressed as a necessity to overcome this. Additionally, accurate dimensional measurement of fuel pellet density and porosity is needed to ensure the compatibility of novel fuels inside advanced reactors.

Material qualification

Qualification of materials used in heat exchangers and structural components of HTGRs ensures they can withstand extreme heat and radiation for long durations[30]. Oxidation, corrosion and radiation hardening reduces the lifetime of metal reactor components[31], therefore assessing microstructural integrity, residual stress, and dimensional stability of materials and composites is essential for qualifying materials used in high-temperature, corrosive, and radiation-intensive environments. A challenge identified by stakeholders is quantifying how heat affects material structure and grain boundaries. However, measuring material properties such as thermal transport under irradiation is difficult due to the combined effects of heat, radiation, corrosion, neutron flux and material degradation[32]. Furthermore, there is a dearth of dedicated facilities such as test reactors or post-irradiation examination facilities[27] to investigate and understand materials. Therefore, accurate measurement and characterisation of materials to understand how they will behave is crucial. Precise techniques for measuring material properties such as oxide film thickness[33], fission gas release, and validating new techniques are needed to enhance understanding of material behaviour under irradiation. Material science metrology will support the deployment of advanced reactors by using internationally recognised standards, validated protocols, and reference materials to guarantee accuracy and comparability. This is key to ensuring material resistance to extreme conditions, reducing operational risks, lowering costs, and increasing public and investor confidence.

SMRs

Small Modular Reactors (SMRs) are a type of advanced nuclear technology which produce power up to 300MW(e) per unit[34]. Smaller than traditional nuclear power stations, in size and power, SMRs are expected to be simpler in design, with shorter construction times and lower construction costs. Factory assembled components are expected to improve quality, safety and efficiency whilst their smaller size allows them to be assembled in areas with less space and lower grid capacity, to power data centres and micro-grids. Ongoing R&D is focused on advancing the design, development and deployment of SMRs as a viable technology. SMRs present unique measurement challenges due to their modular design, diverse supply chains, and the need for rapid deployment.

Dimensional metrology and standards

A key advantage of SMRs is that they will benefit from repeated design for efficient construction. They are likely to be manufactured and assembled in different locations using a range of suppliers. Ensuring precise alignment and fit of modules during on-site assembly is critical as any deviation from design tolerances can compromise reactor performance and safety. This can be achieved by accurately verifying the dimensional alignment of modular components during manufacture, assembly, and operation using high-accuracy dimensional metrology. Another challenge lies in maintaining consistent measurement standards across a wide range of suppliers and ensuring traceability and repeatability of measurements for quality assurance. Stakeholders stress the importance of integrating metrology into SMR design from the outset, ensuring that measurement systems are embedded and optimised for operation. Standard methods and designs which are validated for repeatability, supported by automated dimensional verification of critical processes during manufacturing will ensure that components meet specifications. This reduces the likelihood of defects, improves safety and enables repeatability of SMRs.

Real time, automated and remote monitoring

Real-time monitoring is essential for detecting dimensional shifts, mechanical stress, vibration, and environmental exposure during transportation, assembly and operation of SMRs, to verify component integrity and reduce the risk of failure. Stakeholders identified the challenge of accurate temperature, coolant condition and flow, radiation, and neutron flux measurements during operation and highlighted the need for automated and remote inspection systems during design, manufacture and operation of SMRs, including weld inspection and non-destructive testing (NDT) techniques. To ensure consistent, trusted measurements, validation and calibration of real-time, in situ remote sensors is needed.

Accurate monitors ensure quality diagnostics and reduce the need for manual intervention in hazardous environments, stopping operation or delays in the supply chain.

Material characterisation

Material characterisation is also a challenge for SMRs, particularly for structural components exposed to high thermal stresses, corrosion, and radiation doses. New reactor conditions may lead to material damage not yet understood, necessitating further research to ensure long-term material resilience[35]. Advanced diagnostics will be needed for accurate material characterisation by monitoring degradation mechanisms such as stress corrosion cracking, which can compromise reactor integrity over time. Material science metrology can support material development, to ensure quality of materials and repeatability of modular components.

Nuclear data and validation

There are significant data gaps and uncertainties in nuclear measurements, particularly in nuclear reaction and decay data, which affect the fidelity of simulations and safety assessments for both HTGRs and SMRs. These gaps can delay innovation and regulatory approval and highlight the need for improved measurement techniques and international collaboration to enhance nuclear data libraries. There is a pressing need for experiments to validate nuclear data for advanced reactors, to design materials and components with an understanding of how neutrons will behave[36]. However, the UK lacks verification and validation facilities such as test reactors[37]. Thus, there is a need for informed data modelling how reactors, fuels and components will behave over long periods, to support the development and longevity of materials. Accurate and traceable measurements of

Measurement challenges for advanced reactors and SMRs - *see table at the end for summary of measurement challenges*

- Real-time, in-situ monitoring of manufacturing and reactor conditions
- Achieving required precision for positioning and dimensional tolerances
- High thermal stresses, corrosion, and radiation damage affecting materials
- Measuring material properties under irradiation
- Lack of verification and validation facilities for testing
- Gaps in nuclear data affecting reactor operation and waste monitoring

neutron flux and nuclear data and accurate cross section measurements with reduced uncertainties[38] are needed to support the design, build and operation of new reactors.

Fusion

Fusion reactors require extremely high temperatures, pressure and density for fusion to take place in ionised gas (plasma). The kinetic energy released from high energy (14MeV) neutrons in fusion reactions is several times higher than in fission, giving fusion the potential to be much more efficient[39]. Fusion also benefits from a significant reduction in long lived radioactive waste compared to fission. Fusion energy systems operate under highly controlled elevated temperatures, intense neutron flux, strong magnetic fields, and ultra-high vacuum environments, which must be continuously maintained. In a tokamak, superconducting magnets will be kept near absolute zero to create the magnetic field to confine the plasma, creating a huge temperature gradient between the plasma and reactor walls. This presents challenges for designing materials and components which can function at extremely high and low temperatures. Additionally, fusion requires large quantities of the hydrogen isotopes deuterium and tritium. While deuterium is abundant in seawater, tritium occurs in trace quantities and is radioactive with a short half-life. Safe, sustainable ways of making tritium can be achieved by breeding lithium. However, achieving the conditions for fusion is technically challenging; sustained fusion has not yet been achieved on Earth.

Materials manufacturing and monitoring

Many fusion components will consist of metal alloys and materials which are still in design and development. Advanced manufacturing techniques for new materials will be needed, such as Hot Isostatic Pressing (HIP), additive manufacturing and electron beam welding. These require performance assessment to ensure quality and repeatability of processes[40]. However, a lack of standardisation of additive manufacturing processes is a barrier to the development of new manufacturing techniques and therefore new materials[41].

For successful fusion, understanding and quantifying the effects of temperature, plasma exposure and radiation on component material stress fracture and corrosion cracking is crucial[42]. Measuring and characterising structural properties and understanding degradation, corrosion, radiation damage, and thermal fatigue can support accurate prediction and validation of radiation dose rates to understand how activated materials will behave[43],[44]. Understanding, measuring and quantifying tritium permeation barriers for tritium breeding blankets is also crucial to develop appropriate materials. A key measurement challenges lies in measuring the synergistic effect of simultaneously applied mechanical, thermal, magnetic, electrical and cryogenic stresses[44]. Underpinning assurance and precision in surface deformation mapping, thermal cycling analysis, impurity measurements and fatigue monitoring at elevated and cryogenic temperatures and irradiation ensures trust in long-lasting fusion components[44]. However, the absence of material test reactors and UK HIP facilities for developing robust materials hinders material design and development.

Sensors and diagnostics

Real time measurements of plasma, alpha particles, neutrons and tritium inventory will be needed to provide diagnostics for material performance and fusion conditions[44]. This requires in-situ detection and measurement systems that can function reliably and be maintained and calibrated remotely in extreme environments[45]. For plasma control and material assessment, high-fidelity neutron and gamma diagnostics, radiation-hardened sensors, and portable NDT systems will be needed to support safe operation and maintenance[44]. Metrology to validate and ensure accuracy of remote, continuous, in-situ measurement techniques such as Thomson scattering, Raman spectroscopy, and interferometry, will be needed. Additionally, accurate dimensional control is needed when building fusion reactors so that the tolerances required for machine operation are achieved, requiring precision sensors[46]. Calibration and standardisation underpin accurate advanced diagnostics and remote sensing measurement techniques.

Tritium and neutron measurement

For fusion, measuring tritium and high energy neutrons are crucial challenges. Quantifying neutron flux is complex due to the nature of neutrons and limited facilities to produce neutrons of known energies to provide reference methods. Stakeholder engagement exposed a need for a standard, integrated approach for 14MeV neutron spectrometry and methods for neutron spectrometry up to 20MeV, with new neutron detection technologies needed. Standardisation of measurements will support consistency and reliability, however, there are a lack of standards for measuring high-energy neutron fields or pulsed fields[45]. Stakeholders identified challenges in validating, testing and developing new neutron detection technologies and a need for new measurement techniques scaling small samples of tritium to those more representative of a fusion reactor. Calibration of neutron detectors and absolute references values for neutron flux maintain accuracy of measurements, while precise measurements of tritium inventory, extraction efficiency, and breeding ratio ensure efficient tritium self-sufficiency[47]. Accurate instruments to monitor tritium testing are crucial for safety, demonstrating compliance, reduced tritium waste and thus cost savings.

Nuclear data

Developing fusion requires understanding of plasma physics, tritiated gas behaviour and impact on materials. As fusion is costly, high-risk and still in development, researchers are reliant on models to predict how materials, neutrons, and tritium will behave. However, improved datasets on neutron cross-sections, decay heat, and uncertainty quantification are needed to ensure trust in fusion models. Metrology informed models provide validation to ensure predictive accuracy and support scaling from small scale models to fusion reactors.

Measurement challenges for fusion - *see table at the end for summary of measurement challenges*

- Accurately measuring and controlling extreme environments including neutron flux, temperature and corrosion in challenging conditions
- Tritium breeding and permeation measurement
- Mapping and understanding material degradation, surface deformation, thermal transport, creep and fatigue under fusion conditions
- Lack of standards for high-energy neutron fields and pulsed fields
- Accurate, traceable data for simulations and models

Fuels

Uranium is conventionally used to fuel fission reactors with fuel pellets enriched with ^{235}U. Enriched, sintered ceramic pellets are loaded into fuel rods, arranged into fuel assemblies and lowered into the reactor core[48]. In the UK, due to safety, security and cost, reactors operate an open fuel cycle with spent fuel containing plutonium, produced during fission, being stored for waste[49]. New advanced fuels which aim to improve safety are in development by Westinghouse and Urenco. These include HALEU, Coated Particle Fuels (CPFs) and Accident Tolerant Fuels (ATFs). By withstanding sustained high temperatures, increasing efficiency and reducing waste, advanced fuels enable the development of smaller reactors with higher output. Currently only Russia and China produce HALEU at scale, with several countries investing in infrastructure to produce HALEU domestically. Increase in reactor capacity will require an increase in fuel capacity and essential to this will be ensuring cost effective uranium production and processes. The development and deployment of advanced fuels and fuel cycles will require new qualification methods, new standards, and regulation to comply with international regulations.

Process control

As uranium is enriched, precisely determining ore grades and the isotopic composition of uranium through accurate measurements of gas flow rates is important for efficient extraction of enriched uranium[50]. Also important is ensuring the quality of enriched uranium meets the specification for downstream processing[50]. Reliable temperature measurement is critical for manufacturing fissile fuel of the right quality during fuel sintering. Measurement techniques will need to be adapted for new fuel designs as isotopic assay and new protocols for process control become important[51]. Real-time, accurate measurements are needed throughout all fuel cycle processes to ensure quality, safety and repeatability.

Dimensional metrology

Accurate measurement of fuel properties ensures the correct concentration of uranium is placed inside the reactor core for efficient and safe operation. This includes precise measurement of pellet diameter, mass, density and porosity. Accurate measurement of coating layers ensures robustness of the fuel and compositional integrity of fuel assemblies[50]. Challenges of accurate measurements of fuel properties under extreme conditions are compounded by the oxidation, carburisation, and corrosion of cladding materials. Determining, characterising and monitoring microstructural integrity, residual stress, and dimensional stability is needed to ensure long-term fuel performance and prolong the duration of reactors, increasing energy production and returns on investment.

Environmental measurement

Uranium enrichment plants could release trace contaminants into the local environment including gases and wastewater. Monitoring is important to ensure environmental and human health is not compromised by fuel enrichment processes. At the end of the fuel cycle, during decommissioning, managing spent fuel and accurately characterising radiation levels is crucial to ensure safe disposal or storage, or recycling, to provide accurate measurements of how much ^{235}U remains in the fuel assembly. Trusted, accurate measurement equipment is needed with calibrations against known radiation sources to verify measurements. Precise, traceable measurements throughout the fuel cycle ensures safety, performance, and regulatory compliance.

Measurement challenges for fuels- *see table at the end for summary of measurement challenges*

- Accurate, precise measurement of fuel properties, microstructural integrity, residual stress, dimensional stability and isotopic assay for advanced fuels
- Real-time monitoring and measuring mass flow and process control
- Measuring oxidation, carburisation and corrosion of fuel cladding materials
- Measurement of fission gas release during fuel enrichment and fabrication

Decommissioning

Nuclear power stations have a limited lifetime, determined by fuel replenishment and component materials. At the end of their lifetime, they need to be safely and securely decommissioned by removing and managing spent fuel, mapping, characterising, storing, recycling and disposing of waste, dismantling structures and environmental remediation. The NDA and its subsidiaries are responsible for safely and efficiently decommissioning the 17 sites in the UK which have been or are undergoing decommissioning and identifying an appropriate long-term site to store high-level waste[52]. Decommissioning nuclear sites is expected to take over 100 years to complete and estimated to cost £120bn[52], with rising costs a significant challenge.

Imaging and waste characterisation

Spent fuel is removed from the reactor after ^{235}U fuel is no longer efficiently producing energy. Remaining hot and radioactive from fission products, spent fuel requires cooling, shielding and storage in pools, containers or casks. Reactor components and material heat and radioactivity must be characterised to determine how the waste should be managed and stored. A key challenge is ensuring precise waste characterisation, however new reactor types and materials may introduce new challenges with managing waste. Thermal imaging techniques are used to detect hot spots, however corrosion and interference from radiation can lead to calibration drift and inaccurate results. Standardised methods for digital image correlation and increased uptake of 3D laser scanning were highlighted as needs by stakeholders to support trusted waste characterisation. Advanced, remote, quantitative imaging techniques support reliable characterisation and containment assessment for safe and efficient decommissioning.

Environmental monitoring

Monitoring decommissioning sites for environmental releases of radioactive gases in air and water ensures sites are not damaging the local environment or human health, critical for public health and regulatory compliance. Stored spent fuel needs to be accurately monitored to ensure structural integrity of storage casks containing radioactive materials and guarantee that nuclear materials do not leak into the environment. Radiation damage, corrosion, and mechanical stress complicate structural assessments[53] and calibrating and maintaining monitors remotely also present challenges in accessing and trusting data. Reliable, accurate thermometry for contact and non-contact long-term monitoring of temperature[54], accurate crack detection, corrosion mapping, vibration analysis, humidity measurements and accurate radiation monitoring were all identified as significant challenges. Stakeholders also referenced difficulty measuring environmental conditions such as asbestos in older plants without materials documentation or site mapping, and the challenge of evolving and embracing new scanning technology and imaging techniques. Therefore, real-time detection of harmful substances which could be released during decommissioning is important to protect workers. Precise radiological monitoring instruments which demonstrate accuracy and traceability are needed, which can be achieved through calibration of equipment. However, a further challenge identified is ensuring traceability of the radioactivity source used to calibrate radioactive detection equipment, requiring calibration to primary radioactivity standards.

Sensors and instrumentation

Sensors and instruments used to measure and assess radiation and temperature must be accurate, reliable and traceable, however several temperature monitoring techniques experience large uncertainties[55]. Stakeholder engagement revealed challenges such as outdated methods and limited availability of ^{3}He for neutron detection, which increases costs, requiring new innovative methods to detect radiation. Development and validation of new technologies for instrumentation and sensors and exploring new assay methods is needed. This includes remote, autonomous, and radiation-hardened tools capable of real-time continuous monitoring and validating the accuracy and precision of sensors and robotic systems. Metrology is a critical enabler to certify sensors to ensure traceability, accuracy, and innovation in nuclear decommissioning, reducing harmful exposure, lowering operational costs, reducing waste, and enhancing trust in decommissioning processes.

Measurement challenges for decommissioning - *see table at the end for summary of measurement challenges*

- Accurate identification and classification of waste
- Reliable methods for long term temperature monitoring, crack detection, corrosion mapping and waste monitoring
- Real time measurement of asbestos and radioactive contamination
- Ensuring traceability and repeatability of measurements in hazardous environments

Summary

Across all nuclear technologies several key measurement challenges emerge:

- Extreme temperatures, intense radiation fields, and corrosive conditions complicate the design, development, testing, deployment and longevity of measurement instruments and sensors, requiring validation and calibration to ensure reliability and accuracy.

- Outdated monitoring methods can hinder diagnostics, leading to inefficiencies and increased risk. Accurate, real-time and reliable long-term monitoring is needed for reactors, waste, spent fuel and the surrounding environment.
- The manufacturing and design of reactors faces challenges with dimensional accuracy, with modular reactors needing precise tools and standard designs to ensure alignment and fit during construction.
- The need to understand and predict material behaviour under nuclear conditions, supported by validated and standardised methods for material characterisation is critical for safety and performance.
- Significant data gaps and uncertainties in nuclear data affect the fidelity of simulations and safety assessments, highlighting a need for traceable and reliable nuclear data.

The role of metrology

Accurate, traceable, repeatable and trusted measurement underpins every aspect of the nuclear energy sector, from reactor performance and fuel cycle management to environmental monitoring and waste management. Key areas where metrology can have the greatest impact are:

- Calibration, standards, traceability and reference materials for diagnostics, monitoring and measurement instrument assurance
- Precise, traceable radioactivity measurements and accurate, calibrated imaging techniques for structural assurance and environment and health protection
- Underpinning assurance in material characterisation methods for material confidence
- Process control, dimensional precision and accuracy
- Data assurance and digital traceability

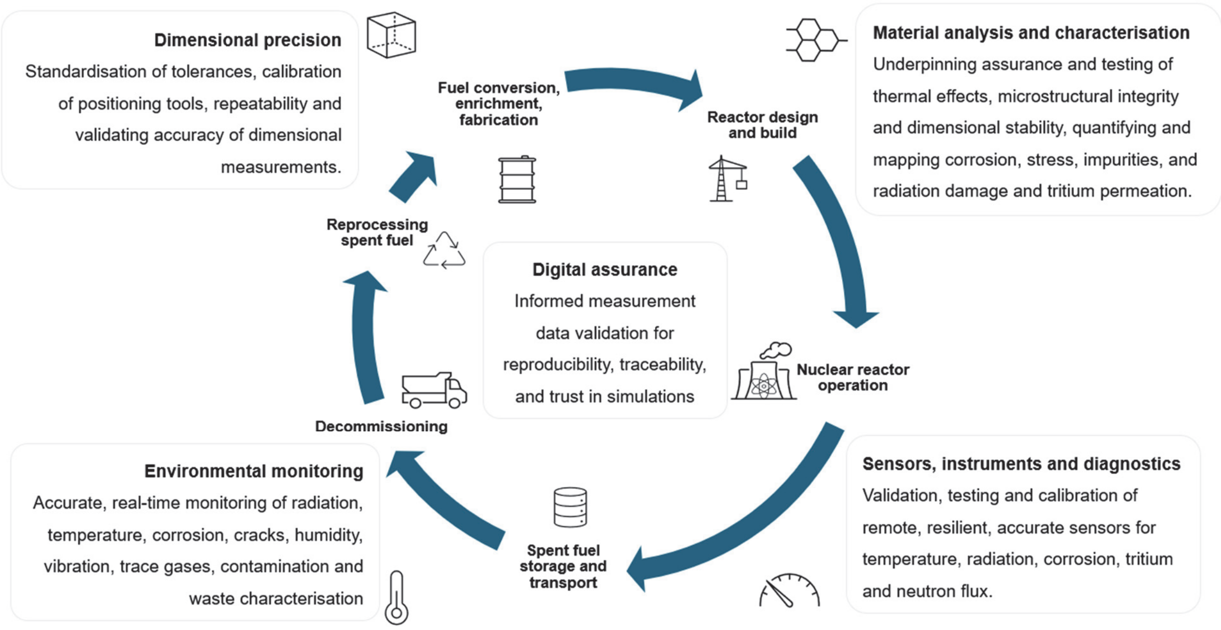


Figure 3: Summary of underpinning metrology to address measurement challenges across the nuclear fuel cycle.

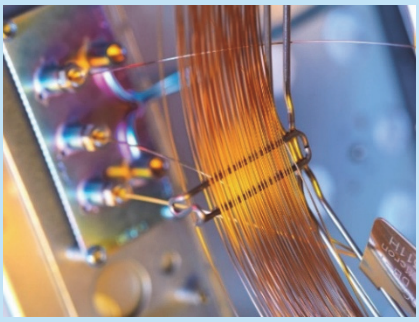
From reactor design and fuel cycle optimisation to environmental monitoring and waste management, metrology underpins the nuclear life cycle (figure 3). Details of specific NPL measurement science and metrology capabilities which address measurement challenges can be found in the summary table at the end of this report.

Accurate, validated, trusted instrumentation

Safe, efficient nuclear energy relies on accurate diagnostics to evaluate fuel properties, reactor conditions and decommissioning sites for routine operation. The resilience of monitoring systems to high radiation doses and thermal stress is essential for longevity and trust in measurements. Measurement instruments must verify their accuracy before and during operation, requiring accurate calibration. Radionuclide standards with traceability, high purity and low uncertainties ensure precise calibration, supported by proficiency testing to maintain accreditation and measurement consistency. NPL's capabilities to produce, measure and validate neutron source emission rates and neutrons of known energies ensure traceability, essential for regulatory compliance and the development and testing of new neutron sensors which can operate remotely. NPL also offers consultancy and training, guiding best practices for calibration and regulatory compliance. Repeatability, measurement accuracy, and reducing uncertainty ensures reliability of detectors and sensors, enabling early detection of faults, improving operational safety and reducing downtime.

Case study: Development of bespoke gas composition measurement method for nuclear decommissioning

NPL's Energy Gas Metrology and Nuclear Metrology groups applied expert gas metrology knowledge to solve a complex challenge to measure very small quantities of gases (<1mL) in challenging environments over long time periods. The project resulted in the successful development of primary reference materials and a concept design for an experiment to measure gases produced by spent nuclear fuel. The NPL design was used to validate the safety of long-term nuclear waste storage and inform the proposal for a dedicated testing facility.



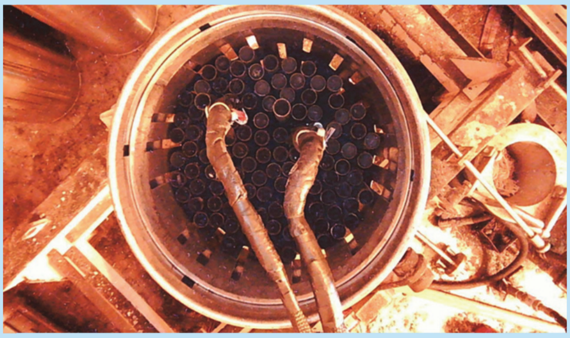
NPL gas chromatography instrument used to deliver high accuracy gas composition measurement

Precise, traceable monitoring and imaging

Monitoring and imaging techniques which accurately assess temperature, radioactivity, corrosion, humidity, emissions and crack formation are vital for ensuring the structural integrity of reactor components and containment systems and underpin long-term remote monitoring of heat-generating waste in and around nuclear facilities. Reliable imaging and thermometry to assess microstructural changes, radiation damage, temperature fluctuations and chemical composition underpins safety and informs R&D of new materials. Standardisation of digital image correlation validates high accuracy inspection systems to remotely detect corrosion, movement, vibration, and material degradation in nuclear waste containers with quantified uncertainty. For ultrasound and acoustic measurements, traceable calibration standards validate imaging systems in high-temperature and thick-material environments. For radioactivity, highly sensitive instruments which can detect radioactivity at trace levels require regular calibration against the primary standard for radioactivity to ensure regulatory compliance. At fuel enrichment sites, reactors and decommissioning facilities, emissions monitoring is supported by radioactive gas standards, compositions and calibrations. Thus, metrology facilitates environmental compliance, safe and cost-effective decommissioning, waste segregation, safe long-term monitoring, and hence storage and integrity of waste packages. Validation of advanced monitoring and imaging techniques provides accurate radioactivity detection and traceable measurements for regulatory compliance, public safety, reducing inefficiencies and lowering costs.

Case study: Traceable temperature measurements of fuel pins during pond storage

NPL's Temperature and Humidity group determined the temperature of spent fuel pins to provide validation data for fuel pin temperature models during pond storage. Thermocouples were exposed to representative doses of radiation at NPL to ensure reliable measurements in harsh spent fuel environments. To simulate thermal behaviour, sintered ceramic pellets with similar thermophysical properties to UO_2 were prepared and resistive heaters were used to simulate decay heat. Two dummy pins, instrumented with thermocouples internally and externally to measure temperature differences were installed in the storage pond at Sellafield and temperature measurements were performed. In collaboration with UKNNL, this work informed the safety case for Sellafield to increase storage pond capacity.



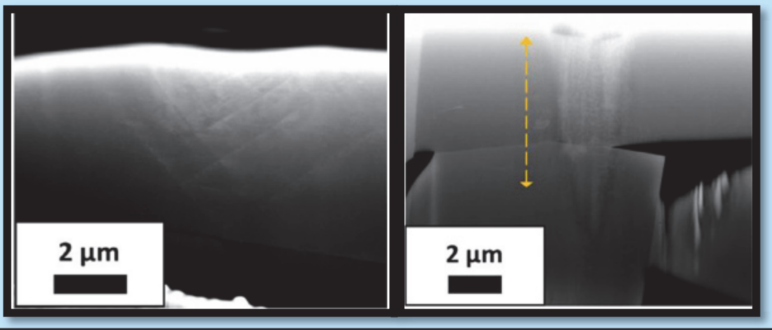
NPL dummy pins among used fuel pins

Underpinning assurance in material characterisation

Materials characterisation will become increasingly important as new materials are designed for advanced reactors and fusion. Metrology validates tools to assess the microstructure and degradation of containment materials and provides underpinning assurance for new safer and longer-lasting materials. Characterisation of materials under environmental stress, including salinity, radiation and corrosion in combination with analysis tools to assess corrosive resistance, thickness, texture and nanoscale surface topographic measurements unpinned by metrology supports quality assurance for reactor and plasma facing components. Validation of NDT techniques, imaging techniques and chemical and structural analysis tools to understand material grain structure, material behaviour and validate assessments under different conditions ensures accurate material and moisture analysis for long-term performance of reactors and storage containment.

Case study: Nanoindentation of tungsten carbide for nuclear applications

NPL's Advanced Engineering Materials Group used nanoindentation testing to investigate the micromechanical behaviour of tungsten carbide (WC) single crystals, a hard and thermally stable material. Tests on basal and prismatic orientations revealed pronounced anisotropy: basal planes had higher hardness and pop-in loads, linked to calculated shear stresses of ~30.8 GPa compared to ~24.4 GPa for prismatic planes. Electron Channelling Contrast Imaging (ECCI) confirmed orientation-dependent slip systems and subsurface deformation. Elevated-temperature tests up to 700 °C showed progressive softening, with hardness reductions of 70–75% and crack formation above 500 °C. High strain-rate nano-impact tests indicated increased hardness at low temperatures, suggesting rate-sensitive deformation. These findings provide essential insights for optimising WC-based components design for extreme nuclear conditions, supporting standards development and predictive modelling for long-term performance.



Cross-section ECCI micrographs of WC prismatic and basal grains after spherical indentation at room temperature. The dashed line shows the direction of plastic deformation.

Materials assurance at the extremes of temperatures is crucial to reinforce material design for fusion and advanced reactors. Measurement science supports the validation of new materials and uncertainty estimates and increases efficiency through more credible long-term predictions of component performance, reduced risk of material failure and reduced waste of materials. This leads to reduced costs and enables reliable decision-making to support regulatory approval, attract investment, and build trust in the design and construction of a new era of nuclear technology.

Dimensional accuracy and process control

Precision in alignment, positioning, and fit is critical during the manufacturing and assembly of reactor components and fuel assemblies. Standardisation and dimensional accuracy are particularly crucial for modular reactor designs and tolerances to ensure components and systems are compatible, enabling efficient construction, repeatability, performance and safety. High accuracy and precision measurement systems using X-ray interferometry and optical interferometry for traceable measurements at the nano- and pico-scale supports precision of components, providing confidence in dimensional measurements across the nuclear supply chain. International standardisation of designs to ensure repeatability and support the manufacture of modular parts requires an integrated approach to embed metrology principles across the entire reactor lifecycle, from laboratory research, to manufacturing and operation. Integration ensures measurements are consistent, traceable, and reliable, supporting both safety and performance of modular reactors.

Underpinning data assurance

Measurement challenges of accessing and predicting high radiation environments can be supported by accurate simulations to determine and optimise fuel enrichment processes, progress design of fusion reactors and provide deeper insights into advanced reactor behaviour. Validated simulations of nuclear systems underpinned by high quality, trusted data with rigorous uncertainty quantification will produce reliable predictions of how neutrons will behave with new materials in new designs. However, improved datasets on neutron cross-sections, decay heat, and associated uncertainty quantification are needed to produce data with confidence for use in models. A trusted database of neutron decay data can be built by producing and measuring neutrons of known energies. This combination of trusted data and evaluated uncertainties will directly impact safety and decision-making. Predictive maintenance tools and robotic systems supported by trusted data and real-time uncertainty analysis can enable remote inspection to anticipate and address issues before they escalate, enhancing responsiveness, reliability, safety, and long-term confidence in nuclear systems[56,57]. Ensuring the accuracy and relevance of nuclear simulations requires data quality frameworks, structured data and metadata capture and use of appropriate semantic technologies to maintain data integrity, metrological traceability, and reliable data provenance and ensure that data gaps and weaknesses are highlighted and addressed. Metrology supported digital infrastructure embeds trusted, traceable measurement data into nuclear systems, enabling integration with simulations, smart monitoring systems, and automated diagnostics, supporting transparency, reproducibility, and regulatory compliance.

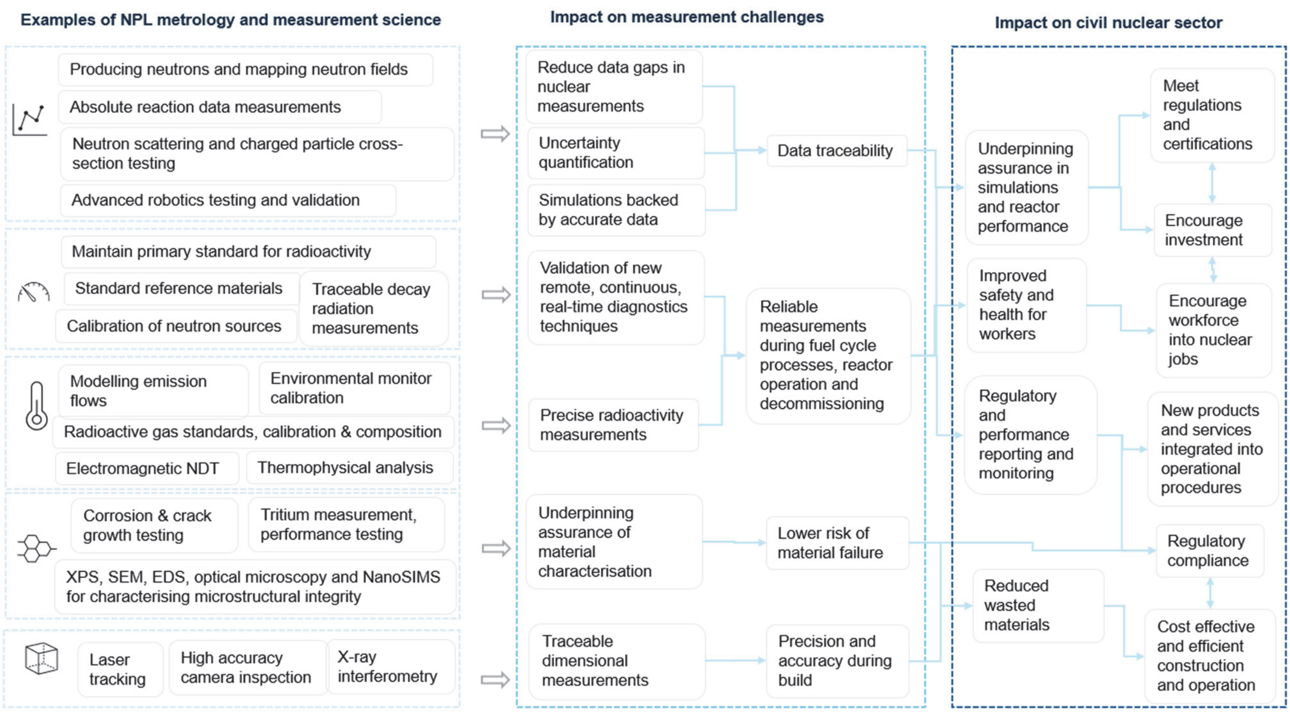


Figure 4: Flow chart illustrating how metrology supports the nuclear energy sector

Conclusions & looking forward

The British civil nuclear sector is at a pivotal point. As nuclear energy investment, research and technology evolve to meet energy demands and net zero targets, the barriers facing the sector demand imminent focus for successful clean energy transition. As the challenges of extreme environments, long development timelines, regulatory complexity, increasing costs and the integration of novel materials and digital technologies persist, the need for accurate, traceable, and trusted measurement becomes increasingly critical.

Key measurement challenges which need to be addressed for safe and cost-effective development of nuclear technologies are:

- Accurate, validated, durable instrumentation for real time diagnostics
- Precise, traceable, monitoring and imaging techniques
- Dimensional accuracy and process control
- Underpinning assurance of novel material testing and development
- Reliable, traceable nuclear data and digital technologies

Metrology provides the basis for addressing these challenges by providing underpinning assurance, testing and validation to ensure safety, support compliance and reduce associated regulatory and safety costs and timelines. Robust measurement frameworks support the qualification of new materials to enable innovation, improving risk informed decision making and fostering confidence in emerging technologies – essential for public acceptance and continued investment. Metrology forms the foundation for innovation, safety, and efficiency in the nuclear energy sector (see figure 5). By addressing technical uncertainties and enabling innovation early on, metrology supports the long-term success and sustainability of nuclear energy as a key pillar of the clean energy transition.

NPL plays a fundamental role in this landscape, not in isolation but in close collaboration with industry, academia, and government, facilitating international collaboration and representing the needs of UK stakeholders on international committees. Hence, this report was developed to be shared. It identifies and recommends many opportunities for collaboration and R&D across the sector to address the nuclear energy measurement challenges:

- Investment to develop and validate novel, innovative advanced sensors and instrumentation
- Coordinate across the supply chain to ensure consistent measurement standards and integrated metrology from the earliest stages of design and development of nuclear infrastructure to maximise impact
- Enhance understanding of synergistic effects on materials using metrology supported testing and development
- Build high quality nuclear databases through international cooperation to enable traceability in simulations and validation of digital technologies
- Develop new shared, accessible testing facilities for nuclear applications
- Develop and invest in training programmes to address metrology skills gaps and grow expertise in nuclear metrology
- Establish metrology governance frameworks and infrastructure to embed metrology principles across the sector, collaborating with national metrology institutes and international bodies to underpin measurements and research with metrology.

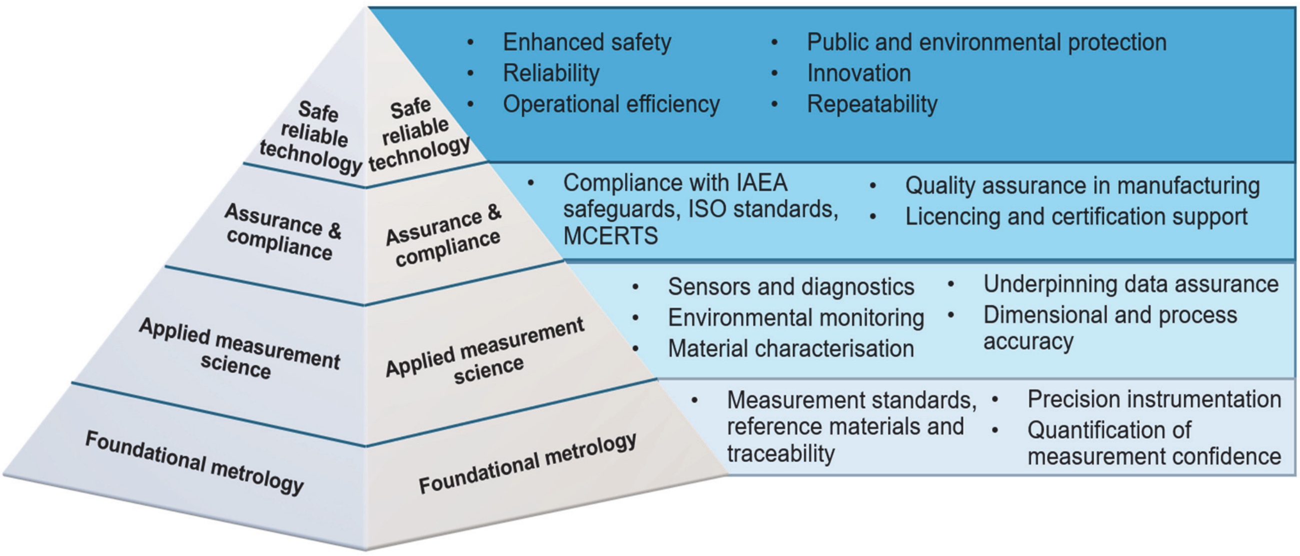


Figure 5: Pyramid chart highlighting the foundational impact of metrology

Summary of measurement challenges

Measurement challenges	Existing NPL capabilities	Technology
Validation of sensors, diagnostics and instrumentation		
Validate and calibrate new remote, continuous, in-situ, radiation-hardened monitoring systems and sensors	Calibration of environmental monitors, contamination monitors, ionisation chambers, proficiency testing, corrosion testing of non-irradiated materials	All
Testing and developing sensors that operate at extreme temperatures	Robotic sensors, proficiency testing, validation of advanced sensing techniques	All
High-energy ion and electron accelerator facilities	Particle accelerator facility	Advanced reactors, fusion
Real-time precise measurements of enriched uranium and isotopic assay	Nuclear fuel monitoring, mass spectrometry	Fuels, decommissioning
Development and validation of new neutron detectors and monitors	Neutron & gamma detectors, onsite mapping of neutron fields	All
Calibration of neutron detectors using traceable standards	Radionuclide neutron source calibration facility, traceable decay radiation measurements	All
Development of high-flux thermal neutron sources, standard high energy neutron spectrometry methods and absolute values for neutron flux	Primary standardisation of neutron emission rates, radionuclide source-based fluence, monoenergetic & thermal neutrons	All
Alpha particle tracking and tritium inventory measurements	Tritium testing	Fusion
High-fidelity neutron and gamma diagnostics	Electromagnetic NDT techniques	Advanced reactors, decommissioning, fusion
Dimensional precision		
Standard and consistent tolerances	Length standardisation, HAIS	Advanced reactors, fusion
Calibration and validation of dimensional and positioning tools	X-ray interferometry, laser tracking, optical interferometry	Advanced reactors, fusion
Characterisation and verification of dimensional alignment of modular components with accurate precision sensors	High accuracy camera inspection	Advanced reactors, fusion
Accurate measurement of fuel pellet dimensions, coating and characteristics	Film and coating measurements, microstructural characterisation, nanoindentation	Fuels
Validating accuracy of fuel assembly	HAIS	Fuels
Material characterisation assurance		

Accurate characterisation of new materials	NanoSIMS, NMR Relaxometry, XPS, microstructural characterisation (SEM; EDS/WDS, EBSD, FIB), optical microscopy, mechanical, XRD, certified reference materials (modulus)	Advanced reactors, fusion
Quantifying, mapping and validating assessments of microstructural integrity and dimensional stability, grain boundaries, oxide film thickness	XPS, microstructural characterisation, optical microscopy, NanoSIMS, self-loaded deformation and high temperature dimension stability test, SEM-FIB	All
Validating assessments of corrosion, oxidation, carburisation of materials and quantifying the impact of radiation on thermal and mechanical structure and properties	Thermal testing and imaging, SEM, EDS, EBSD, NanoSIMS, XPS, exposure testing (air, process gases, salts), autoclaves and chemical digestion, mechanical testing, microstructural characterisation, Nanoindentation, electron channelling contrast imaging, inverse modelling of material properties	All
Quantifying stress fracture and residual stress	Reference materials, residual stress across the length scales, fractography	All
Accurately measuring thermal fatigue and impurities in novel materials	Material characterisation, TMF, LCF, thermal fatigue testing, creep analysis	All
Understanding cryogenic temperatures effects on materials	Cryogenic temperature macro and micro, nano- mechanical testing, cold stage under SEM for microstructural analysis.	Fusion
Isolating measurements of temperature and corrosion to understand individual and combined effects on materials	Microstructural characterisation, DIC, SEM-DIC, chemical corrosion and molten salt corrosion tests	Advanced reactors, decommissioning, fusion
Understand how activated materials will behave for predicting radiation dose rates	Irradiations, microstructural characterisation, crystal plasticity modelling, dosimetry	Advanced reactors, decommissioning, fusion
Precise, accurate waste characterisation	Electromagnetic NDT techniques, microstructural characterisation, thermal, physical and mechanical property testing	Decommissioning
Validation of advanced imaging techniques	High accuracy camera inspection, SEM, direct strain measurement, reference materials.	Decommissioning
Understanding tritium permeation rate and retention	Tritium measurement performance testing, Raman spectroscopy	Fusion
Quantifying tritium permeation barriers and breeding materials	NanoSIMS for fusion material analysis, microstructural characterisation, mechanical testing and autoclaving and chemical digest.	Fusion
Validation of advanced materials and manufacturing techniques	Reference materials, microstructural characterisation, mechanical testing, thermal testing	All
Materials test reactor and PIE facility		All

Standardisation of additive manufacturing	Microstructural characterisation, mechanical testing	All
Precise environmental monitoring		
Development and validation of precise radiological monitoring instruments	Calibration of environmental monitors, contamination monitors, ionisation chambers, standard development for new monitoring techniques	All
Reliable, accurate thermometry	Phosphor thermometry and calibration, traceable temperature measurement (thermocouples, PRTs), Thermal modelling and validation	All
Reliable corrosion mapping techniques	SECM (scanning electrochemical microscopy), scanning kelvin probe, digital image correlation	All
Accurate crack detection and growth monitoring	In situ crack monitoring techniques including direct current potential drop, alternating current potential drop, digital image correlation, microstructural characterisation	All
Vibration and acoustics analysis	Underwater inspection & acoustics	All
Humidity measurements	Moisture content analysis	All
Contamination mapping including trace contaminant gas measurements and fission gas release	Tritium measurement & leak detection, gas composition measurement, radioactive gas standards and calibration, tandem plasma mass spectrometry, trace gas analysis and calibration, Raman spectroscopy for gaseous tritium, phase transformation (in situ EBSD)	All
Validating accuracy and traceability of the radioactivity source used to calibrate radioactive detection equipment	Certification of customer supplied radionuclides, wide area reference source calibration, secondary standardisation of customer samples, thermometer calibration, tandem plasma mass spectrometry	All
Understanding calibration drift on remote sensors from radiation interference		All
Data traceability and digital assurance		
Informed measurement data with experiments to validate nuclear data for reactor, component and process designs	Measurement & validation for modelling and safety, uncertainty evaluation, on-line material condition monitoring	All
Traceable measurements of neutron flux and nuclear data	Mapping of neutron fields, data quality frameworks	All
Accurate cross section measurements and validation	Neutron scattering and charged particle cross-section testing	All
Quantifying and reducing measurement uncertainties	Absolute reaction data measurements, uncertainty evaluation	All
Standardised data and reproducibility and traceability in simulations	Recommended values for nuclear data sets, traceable digital frameworks	All

Glossary

ATFs Accident tolerant fuels
ANT Advanced Nuclear Technology
BAT Best Available Technique
CPFs Coated particle fuels
DESNZ Department for Energy Security and Net Zero
DIC Digital Image Correlation
EA Environment Agency
EBSD Electron Back Scattered Diffraction
EDS/WDS Energy/Wavelength Dispersive Spectroscopy
EPR European pressurised reactor
GDA Generic Design Assessment
GBE-N Great British Energy – Nuclear
HAIS High Accuracy Inspection Systems
HALEU High Assay Low Enriched Uranium
HTGR High temperature gas cooled reactor
HPC Hinkley Point C
HIP Hot Isostatic Pressing
IAEA International Atomic Energy Authority
LCF Low-Cycle Fatigue
NanoSIMS Nanoscale Secondary Ion Mass Spectrometry
NMI National Metrology Institute
NMR Nuclear Magnetic Resonance
NPL National Physical Laboratory
NSIP Nationally Significant Infrastructure Project
NDT Non-Destructive Testing
NDA Nuclear Decommissioning Authority
ONR Office for Nuclear Regulation
PIE Post Irradiation Examination
RAB Regulated Asset Base
R&D Research and Development
SECM Scanning Electrochemical Microscopy
SEM Scanning Electron Microscopy
SZC Sizewell C
SMRs Small Modular Reactors
TMF Thermo-Mechanical Fatigue
UKAEA United Kingdom Atomic Energy Agency
UKNNL United Kingdom National Nuclear Laboratory
XRD X-ray Diffraction
XPS X-ray Photoelectron Spectroscopy

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- Nuclear Metrology
- Surface Technology
- Temperature and Humidity

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