



CHALLENGE:

Smart inline analysis for future plutonium processing

Sellafield Ltd is seeking innovative approaches to support automated inline or in-situ analysis and data management within a future plutonium processing plant. The aim is to carry out safety, quality and compliance checks directly within, or immediately alongside, key production stages for plutonium-bearing powders, pellets, cans and storage packages, enabling more frequent analysis, less manual intervention, stronger traceability and integrated digital quality assurance records.

Introduction

The UK Government has identified plutonium immobilisation as the preferred long-term approach for managing the UK's civil plutonium inventory.¹ This involves converting plutonium-bearing material into stable waste forms such as pellets (Figure 1) that can be safely stored and eventually disposed of in a Geological Disposal Facility. To support this, the NDA and Sellafield Ltd are planning a future plutonium processing plant, expected to be required from the mid-2030s.

The production process for these pellets is within a glovebox and is broadly comparable to a highly controlled powder processing and ceramics manufacturing operation. Powders are blended, pressed into small cylindrical pellets (12mm diameter x 15mm tall) and fired in a furnace before the dense pellets (few hundred) are canned

(Figure 2) and placed into storage. At each stage, different chemical, radiometric and physical properties need to be understood and verified. These include:

- Isotopic composition
- Blend consistency
- Gadolinium presence
- Sintering conditions
- Off-gas composition
- Pellet mass and geometry
- Can contents and can weld quality
- Storage condition monitoring

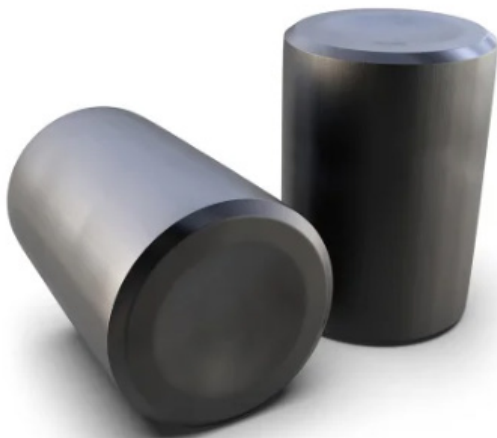


Figure 1: Example of pellets produced as a stabilised waste form for safe storage in sealed cans.



Figure 2: Example of sealed cans used to safely store the pellets.

At present, many of these checks rely on taking samples from the process and sending them to an offsite laboratory for analysis. While this provides important assurance, it can be slow, costly and labour-intensive. It also requires people to handle and transfer samples away from the production line and limits the number of samples that can practically be tested.

This challenge is seeking innovative approaches that could enable more testing to be carried out inline, or in-situ, as close to the production

process as possible. The aim is not to prescribe one specific technology, but to identify promising measurement, analysis and data integration approaches that could support a future smart plutonium processing plant.

Because the future plant is still at an early planning stage, there is a rare opportunity to develop these smart analysis and data systems now, so they can be built into the design rather than added later as costly retrofits. Solutions are expected to be beyond early concept stage, around TRL 4 or above, and capable of further development towards deployment in a secure, highly controlled nuclear environment. Hardware-led approaches are of particular interest, especially where they can integrate with software or digital systems to support a single quality assurance record for each package. Applications are invited for partial or full solutions. Please specify the process stage(s) targeted by your application.

¹ <https://questions-statements.parliament.uk/written-statements/detail/2025-01-24/hcws388>

Current Practice

Current practice for analysing plutonium-bearing powders and pellets is based on staged, offline testing at selected points in the production process. Chemical checks are generally carried out early in the process, while physical checks are completed later, as summarised in Table 1. Samples are removed from the process and sent for laboratory analysis to confirm that the material remains within the required safety, quality and process limits.

Although this approach provides important assurance, it is slow, costly and labour-intensive. Turnaround times vary depending on the type of analysis required, with some results taking 1 to 2 weeks. This limits the opportunity to use analysis data for rapid process feedback, early fault identification or real-time decision-making.

The scale of sampling is also constrained. In some cases, only a small number of pellets may be selected from a batch containing hundreds of pellets. This provides confidence in the sampled material but does not offer the same level of assurance as more frequent, automated or continuous measurement across the wider process.

Current data capture is also fragmented. Results from different analysis points may be issued on paper or by email, stored locally across separate systems, and manually transferred into spreadsheets before they can be combined. This creates inefficiency, increases reliance on manual handling of quality assurance data, and makes it harder to build a complete digital record for each package.

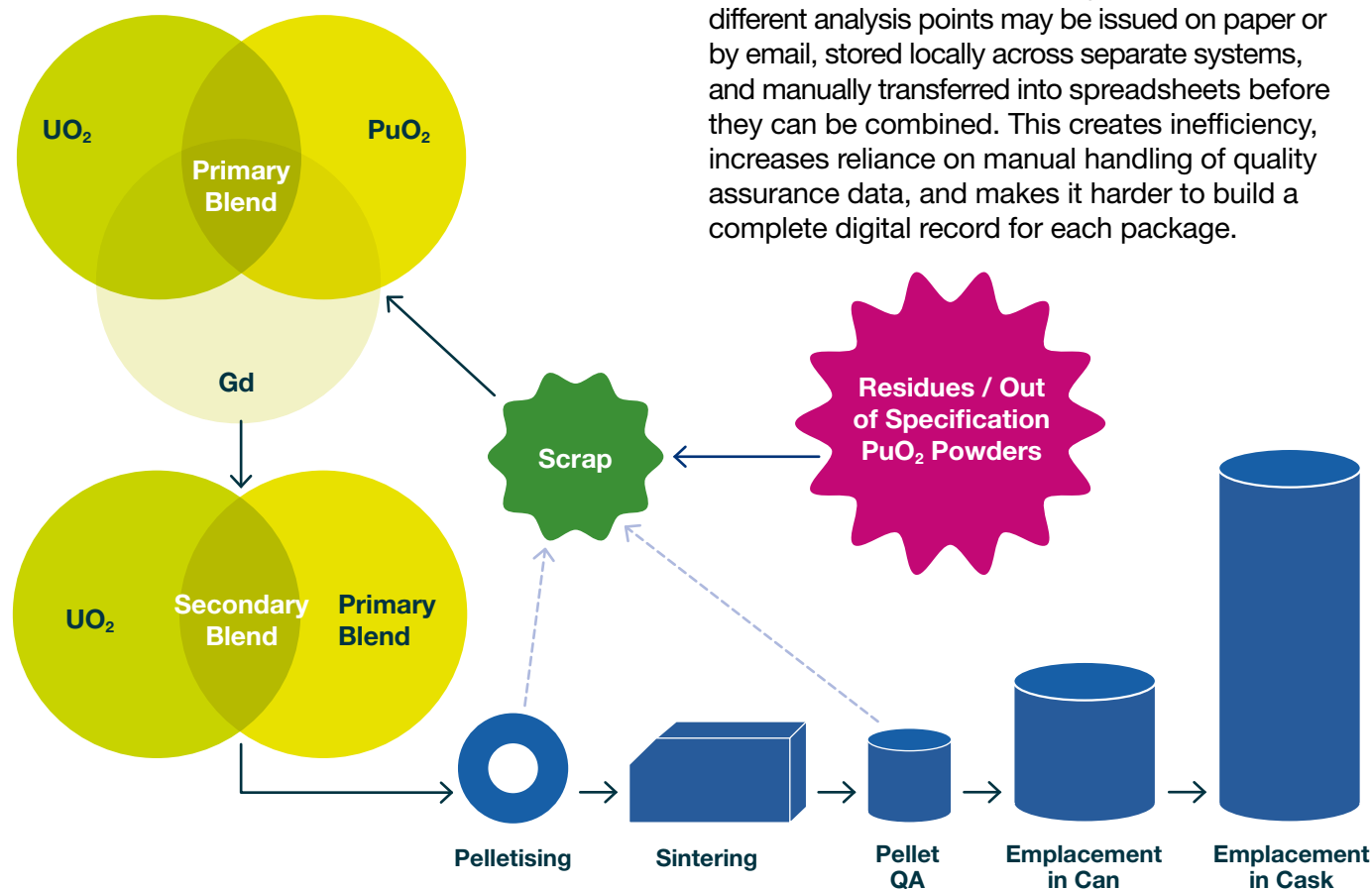


Figure 4: Overview of plutonium-bearing powder processing, pellet production and canning.

Table 1: Current approach and analysis methods for plutonium-bearing powder processing and pellet production.

Process Step	Current Approach	Analysis Method
Primary Blend	Remove 2g of the primary blend/mastermix powder	Powder sample to be measured for U, Pu & Gd content via ICP-MS
		Density
		PSD
	Whole batch	Mass measurement to determine pro-cess losses/hold up in vessels and safe-guards accounting
Secondary Blend	Remove 2g of the final blend powder	Powder sample to be measured for U, Pu & Gd content via ICP-MS
		Density
		PSD
	Whole batch	Mass measurement to determine pro-cess losses/hold up in vessels and safe-guards accounting
Final Pellets	Visible defects	Visual inspection
	Pellet geometry	Dimensional measurements
	Geometric density (all pellets)	Weighing and dimensions
	Immersion density (1 pellet per batch)	Weighing in air and in water
	Pu, U, Gd content	ICP MS
	Pu Gd distribution	Optical and electron microscopy
	Oxygen/metal ratio	TGA

Additional Techniques Throughout Process	Analysis Technique
Near Real Time Radiometric Nuclear Materials Accountancy	PIMS
Enrichment Monitoring	XRF
Rogue Pellet Detection	Passive neutron monitoring
Mass Based Materials Verification	Mass

Challenge Aims

The aim of this challenge is to identify technologies that can support the design of a future smart plutonium processing plant, where quality, safety and compliance checks can be carried out as close to the production process as possible.

The preferred outcome is to reduce reliance on sending samples to a laboratory for analysis by enabling inline or in-situ measurement at key stages of powder preparation, pellet production, canning and storage quality assurance. This would support a more automated approach, with fewer samples removed from the process and minimally direct human intervention.

A further aim is to enable data from different online analysis points to be brought together into a single digital quality assurance record for each package. This record should support traceability across the lifetime of the product, from production through storage and eventual disposal.

The challenge is not driven by an immediate need to replace current practice. Instead, it is linked to the opportunity to design future facilities and processes from the outset.

Benefits to Sellafield

Solutions to this challenge would provide clear benefits for Sellafield Ltd by improving safety, efficiency and confidence in future plutonium processing operations. Bringing analysis closer to the production process would reduce the need for people to handle and transport plutonium-bearing samples for offline laboratory testing.

Automated inline or in-situ analysis could also reduce reliance on costly laboratory testing, which can currently cost around £10,000 to £20,000 per sample. Over the anticipated 30-year operational life of the facility, analytical testing costs could exceed £270 million, presenting a substantial opportunity for cost savings through the deployment of advanced monitoring and analysis technologies. In addition to reducing costs, these technologies would enable more frequent process monitoring, shifting from periodic batch sampling towards near-continuous or high-frequency analysis.

For Sellafield Ltd, this would support better process understanding, stronger product confidence and more robust quality assurance records. It would also help ensure that monitoring and data integration are designed into the future facility from the outset, supporting a safer, more efficient and more digitally enabled plutonium processing plant.

Constraints

The proposed solutions will need to operate within a bulk plutonium processing environment and must be compatible with the associated security, radiological and containment requirements. The following constraints should be considered:

- The solution must be suitable for operation within an active plutonium environment and be compatible with multiple layers of containment, radiological protection measures and nuclear security controls. Prior to sintering, processes are likely to operate under a nitrogen blanket until the can is sealed
- The solution must operate without reliance on Wi-Fi or external wireless communications. Any data transfer or system integration approach must be compatible with secure, controlled nuclear facility environments
- Power supplies are expected to be available. The solution must be reliable, low-maintenance, and capable of long-term operation in a nuclear environment, ideally for several years without recalibration or breaking containment
- The solution may be required to operate in elevated-temperature areas, particularly near powder handling operations and furnace systems
- Furnace operations may involve very high temperatures (~1750°C) and may require monitoring of furnace temperature, gas composition and off-gas conditions
- Solutions must accommodate sample sizes: cylindrical pellet (12mm diameter by 15mm height)

- Non-destructive analysis is preferred but not essential
- Secondary waste generation should be minimised. The use of liquids should be avoided wherever possible, and any solid waste generated should be capable of safe handling and disposal
- Materials used within the system should be compatible with the intended disposal route. The use of plastics should be minimised and PVC should not be used
- The use of corrosive chemicals, hydrogen-based processes, highly oxidising substances, and air or oxygen-based gases should be avoided unless essential to the measurement technique and appropriately justified
- Any gases required for operation must be capable of being safely contained within the process environment and should not introduce additional safety, criticality or disposal challenges
- AI/ML should only be included where it provides a clear operational benefit. This challenge is not looking for software-only solutions, but proposed solutions must be capable of integrating with existing software and data systems

Functional Requirements

- The solution should be compatible with a highly automated pellet production process in which powder is dispensed into a die, pressed into pellets and subsequently processed for long-term storage and disposal
- The solution should be suitable for use across relevant stages of the pellet production process, including powder handling, pressing, firing, pellet inspection, canning and storage quality assurance
- Solutions should characterise key chemical, radiometric and physical properties of the material, such as isotopic composition, blend verification, gadolinium content, sintering conditions, off-gas monitoring, pellet mass and geometry, can contents and can weld quality. Solutions may address one or more characterisation techniques
- Solutions should be capable of handling or assessing individual pellets of less than 100g, as well as powder batches typically in the range of 50–100kg
- Solutions should support remote or automated operation, reducing the need for direct operator intervention in active or constrained environments
- The solution should generate data that can be integrated into a wider digital quality assurance record, supporting traceability throughout the lifetime of the product and package
- Solutions should prioritise non-destructive testing wherever possible. Limited destructive testing may be acceptable where essential to achieve the required measurement or validation outcome
- The preferred route for data transfer is wired rather than relying on Wi-Fi or cloud-based services

Find Out More

Game Changers are hosting a workshop for this challenge where delegates will have the opportunity to meet challenge owners. Details are available on the Game Changers website www.gamechangers.technology.

If you have new ideas or innovations which can be applied to address this challenge, we invite you to join us. If you'd like more information about the funding available through the Game Changers programme, please visit [Our Funding Process](#).

The deadline for applications for this challenge is 3pm on Tuesday 3rd November 2026.

Designed and delivered by:



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