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Feasibility Study for UAF application in NAA laboratory

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1. Introduction

Neutron Activation Analysis (NAA) is a highly precise technique for determining the elemental composition of materials. Conventional NAA facilities, however, depend heavily on manual operations—including sample handling, irradiation, decay timing, and measurement—which can limit throughput and introduce variability. The implementation of Unattended Analysis Facilities (UAFs) offers a transformative approach, enabling automated, continuously monitored, and remotely supervised NAA operations. By integrating advanced automation, robotics, and data management, UAFs enhance efficiency, ensure consistent data quality, and improve operational safety. With increasing demand for high-throughput, round-the-clock experimentation, UAFs represent a promising pathway to modernize and expand the capabilities of NAA facilities.

UAFs have emerged as a solution to automate and remotely monitor laboratory workflows [1]. UAFs minimize human involvement to system design, maintenance, and data interpretation, while routine operations—including sample preparation, instrument control, and data acquisition—are performed autonomously. Key characteristics of UAFs include robotic automation of repetitive tasks, integration of analytical instruments for queued operation, secure remote monitoring, automated data management through Laboratory Information Management Systems (LIMS) [2], and robust safety measures such as fail-safes and emergency shutdowns.

2. Methods and Results

This section describes the standard workflow of neutron activation analysis (NAA) and highlights the requirements for adapting NAA facilities to an Unattended Analysis Facility (UAF) framework. By analyzing each step of the workflow—from sample preparation to disposal—we identify where automation, remote monitoring, and data integration can be applied to enhance efficiency, reliability, and safety.

2.1 Workflow in NAA laboratory

The standard workflow of NAA consists of six main stages as shown in Fig.1.: sample preparation, sample irradiation, post-irradiation work, sample measurement, information recording, and sample disposal.

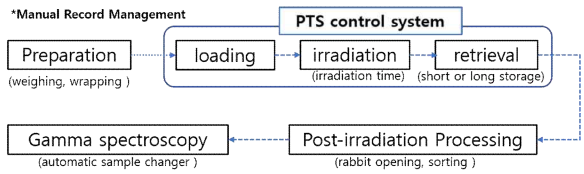

Fig. 1. Current workflow in NAA laboratory

Sample preparation: Samples are prepared for irradiation by sealing them in rabbit capsule suitable for transfer through the pneumatic transfer system (PTS).
Sample irradiation: Prepared samples are loaded into the PTS using an automated control system, irradiated in the reactor for a predefined period, and subsequently returned to the analysis laboratory.
Post-irradiation processing: Upon return, the rabbit capsule is opened, and samples are retrieved, classified, and prepared for measurement.
Sample gamma-ray measurement: After appropriate cooling, based on the half-lives of the induced radionuclides, samples are transferred to a gamma-ray spectrometer for measurement.
Record Management: Data such as sample identification, irradiation parameters, and gamma-ray spectra are typically recorded manually.
Sample disposal: Following measurement, samples are properly disposed of in compliance with radiation safety protocols.

2.2 Key requirements for UAF application

The adaptation of neutron activation analysis (NAA) facilities to an Unattended Analysis Facility (UAF) framework requires comprehensive integration of automation, data management, and safety systems.

Automated Sample tracking: Each sample requires a unique digital identifier, preferably linked to QR codes or RFID tags, to ensure traceability throughout the workflow—from preparation and irradiation to measurement and disposal.
Integrated Irradiation Control: Full automation of the Pneumatic Transfer System (PTS) is required, including scheduling, queuing, and precise control of irradiation timing. Remote supervision of reactor parameters and

sample tracking allows continuous monitoring without on-site personnel.

Post-Irradiation Automation: Mechanized systems are necessary for retrieval, classification, and controlled cooling of samples according to half-lives. Shielded robotic manipulators protect staff from radiation exposure during these processes.

Automated Measurement Systems: Integration of gamma-ray spectrometers with robotic sample changers enables scheduled measurements based on decay times, optimizing instrument utilization and throughput.

Data Integration and Management: All sample metadata, irradiation conditions, and measurement results should be automatically captured and managed within a Laboratory Information Management System (LIMS), ensuring structured storage, traceability, and efficient analysis.

Remote Monitoring and Supervision: Secure dashboards provide real-time visualization of workflows, instrumentation status, and alarms. Authorized operators can remotely intervene when necessary, maintaining operational control.

Safety and Compliance: The facility must include built-in fail-safes, radiation hazard detection, and automated emergency shutdowns. Full compliance with radiation safety standards and facility licensing requirements is essential to protect personnel, samples, and the environment.

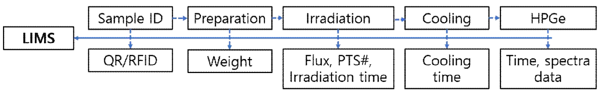

Fig. 2. Laboratory Information Management System of NAA workflow

The most important part is that the post-irradiation automation system ensures the safe and efficient handling of irradiated rabbit carriers. Within a shielded lead cell, a robotic system opens the carriers, sorts the encapsulated sample vials, and delivers them to designated gamma detectors strictly according to the LIMS-defined measurement schedule. All operations are performed in a fully unattended mode, minimizing personnel exposure and maximizing throughput

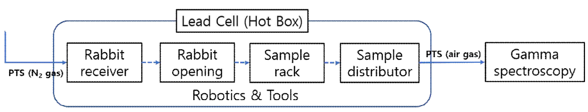

Fig. 3. Post-irradiation automation system

3. Conclusions

Unattended Analysis Facilities represent the future of research laboratories by combining automation, advanced analytics, and remote connectivity. They enable scientific discovery to proceed at a pace unachievable through conventional lab structures, while improving safety, reproducibility, and data quality. Though challenges such as cost and maintenance persist, the long-term benefits make UAFs a transformative investment for modern research institutions.

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