# MIRION Connect 26 AMERICAS

## Annual Users' Conference

## ADVANCING RADIATION SAFETY. EMPOWERING PROGRESS.

*M Resort, Henderson, NV | June 15 – June 18*

MIRION TECHNOLOGIES

# *Safeguarding the Advanced Reactor Nuclear Fuel Cycle*

## *New Challenges and Solutions*

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*Deputy Business Lead, Systems (MSS) Business Line*

*Mirion Connect | Annual Users' Conference 2026*

*Henderson, NV*



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*Empowering Progress.*

# Scan QR code to log your attendance for today's (Thursday, June 18th ) breakout session

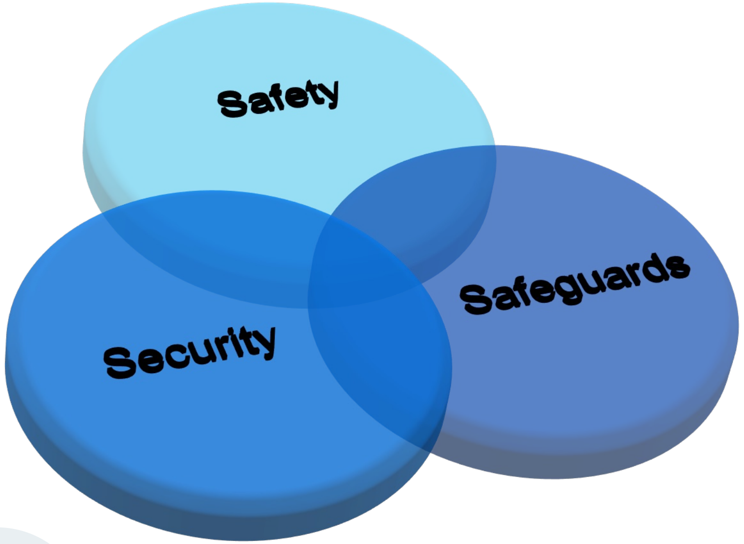
# OUTLINE

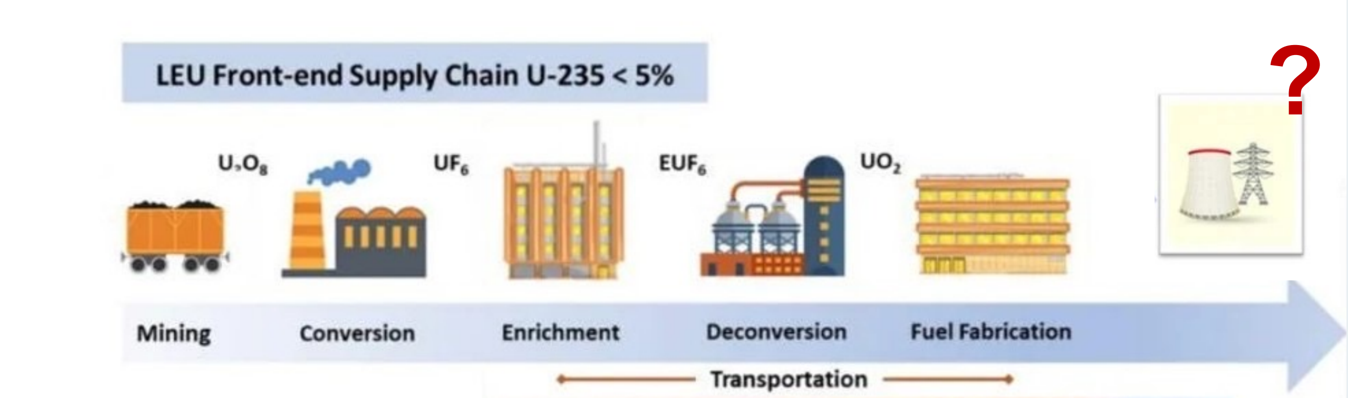
- *INTRODUCTION*
- *CRITICALITY ACCIDENT ALARM SYSTEM (CAAS)*
- *MATERIAL CONTROL AND ACCOUNTABILITY (MC&A)*
- *CLOSING*

# *Introduction*

# 3S Overview

- *Safety – Criticality safety*
- *Safeguards – Protecting special nuclear material (SNM)*
- *Security – Physical & Cyber*




**HALEU Front-end Supply Chain U-235 (5 – 20%)**



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# *WHAT IS HALEU?*

## **Advanced Fuel - High Assay Low Enriched Uranium**

- *Uranium enriched to 5–20% U-235 — above conventional LEU (< 5%), below HEU (> 20% )*
- *Required by most advanced reactors — SMRs and microreactors*

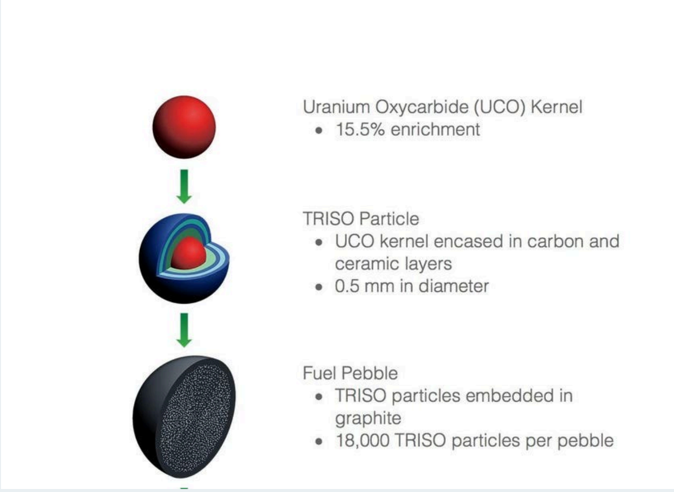



Image credit:
https://www.forbes.com/sites/jamesconca/2021/09/08/supplying-new-types-of-nuclear-fuel-with-haleu-is-not-a-problem/

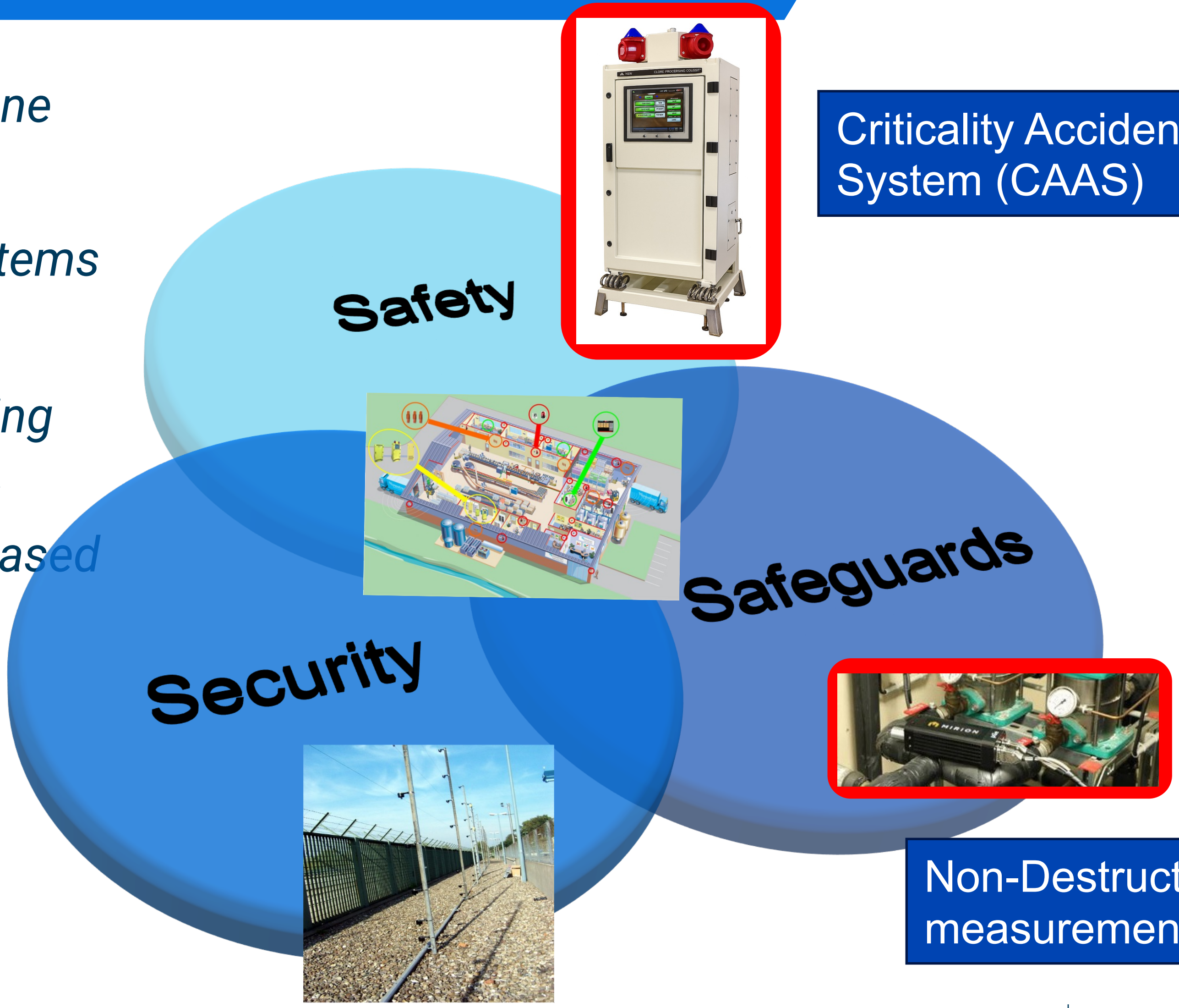
# **WHY IT MATTERS**

- *Higher enrichment, smaller cores*
- *Longer fuel cycles, fewer refuelings*
- *Greater power density*
- *Enables advanced reactor designs*
- *Domestic supply still scaling up*

**A key enabler of advanced reactors**

# 3S Interdependence

- *Interdependence - Actions in one domain affect the others*
- *Conflict - Gaps arise when systems are not jointly planned*
- *Integrate 3S requirements during early design, not retroactively - Enable predictable, evidence-based regulatory reviews.*

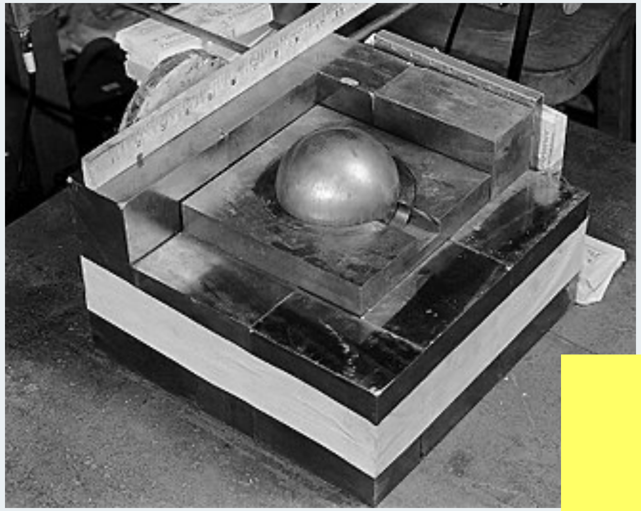



Criticality Accident Alarm System (CAAS)

Non-Destructive Assay (NDA) measurement systems

# *Criticality Accident Alarm System (CAAS)*

# Criticality Accidents / History



The Demon Core

*CRITICALITY ACCIDENT – An uncontrolled fission reaction resulting from an unintended accumulation or arrangement of a critical mass of fissile material*

- *First known fatality caused by a criticality accident – Harry Daghlian, 1945*
  - *The core was near critical; the brick made it prompt critical (yield ~$10^{16}$ fissions)*
  - *Daghlian received an estimated dose of > 500 rem (5 Sv) resulting in severe radiation poisoning*
  - *He died 25 days later*
- *As a consequence – Safety procedures were revamped*
  - *One new requirement – Use of at least two instruments monitoring neutron intensities with audible alerts*

# CAAS Standards & Guidance

| | |
|---|---|
| **10 CFR 70.24** | *Sets the* **legal** *requirements. Based on quantity of special nuclear material.* |
| **REGULATORY GUIDE 8.12** | *Provides* **guidance** *for meeting 10 CFR 70.24 requirements. Explicitly discusses ANSI/ANS 8.3* |
| **ANSI/ANS 8.3 2022** | *This is a* **consensus** *standard. Applies to operations with fissionable materials in which inadvertent criticality could produce a radiation dose immediately dangerous to life and health* |
| **ISO 7753:2023** | **International** *standard similar to ANSI/ANS 8.3 with recent changes to title and focus on* **operations**. |
| **IEC 60860:2014** | ***Equipment*** *standard for criticality accident warning equipment – Outlines detector/alarm performance, EMC, environmental requirements.* |

MIRION TECHNOLOGIES

*Protect What's Next™*

# *CAAS – When?*

## NRC requires CAAS under 10 CFR 70.24

- *For licensees authorized to possess* ***special nuclear material*** *in excess of specified thresholds*
- *Criticality needs to be credible*
- *Any facility that processes, handles, or stores fissile material*

## APPLICABLE FACILITIES

- *Enrichment facilities*
- *Fissile material processing plants*
- *Fuel fabrication plants*
- *Fuel cycle R&D laboratories*
- *Some research or industrial facilities with large fissile inventories*
- *Reprocessing facilities*
- *Storage areas where critical configurations could occur*

Picture credit: https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment

# *What is different about Advanced Nuclear?*

## HALEU

- *Requirement defaults to the low mass limit of 700g for U-235*
- *Compared to LEU – Criticality with smaller masses & more compact geometries, and more sensitive to changes in moderation.*

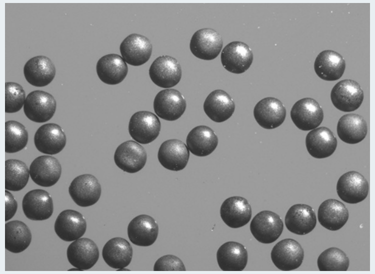


Image credit: https://www.energy.gov/ne/articles/triso-particles-most-robust-nuclear-fuel-earth

## ACTIVITIES REQUIRING MORE SCRUTINY

- *Powder processing*
- *Fuel particle production*
- *Batch transfer*
- *Storage in dense arrays*
- *Accident scenarios involving water intrusion*

**More operations become "credible criticality scenarios"**

# HALEU Impact on CAAS Needs

## IMPACT

*Detector placement – Consideration of both gamma and neutron channels*

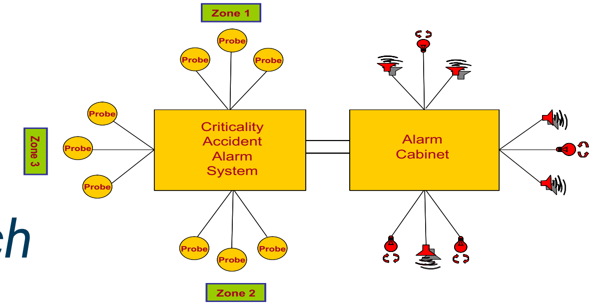
*Facility zoning – Smaller criticality volumes could mean more zones for coverage*

*Operations*

## CAAS-3S OFFERINGS

*Detector placement studies & other facility and site planning support*

*Expansion capability with star network approach*




- *Reduced footprint approach*
- *Existing features that lend themselves to automation – testing, fault warning,*
- *Remote monitoring*

# CAAS – Criticality Accident Alarm System


## An alarm system for the prompt evacuation of personnel in case of a criticality event

*Key Criteria for Design –*

- *Adhere to criticality standards*
- *Response time (per standard)*
- *Reliability*
- *Fault/Failure warning*
- *Minimization of false alarms*
- *Seismic tolerance*



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# CAAS Experience: Global Footprint, Consistent Performance

**50**
YEARS' EXPERIENCE

**100+**
SYSTEMS INSTALLED GLOBALLY

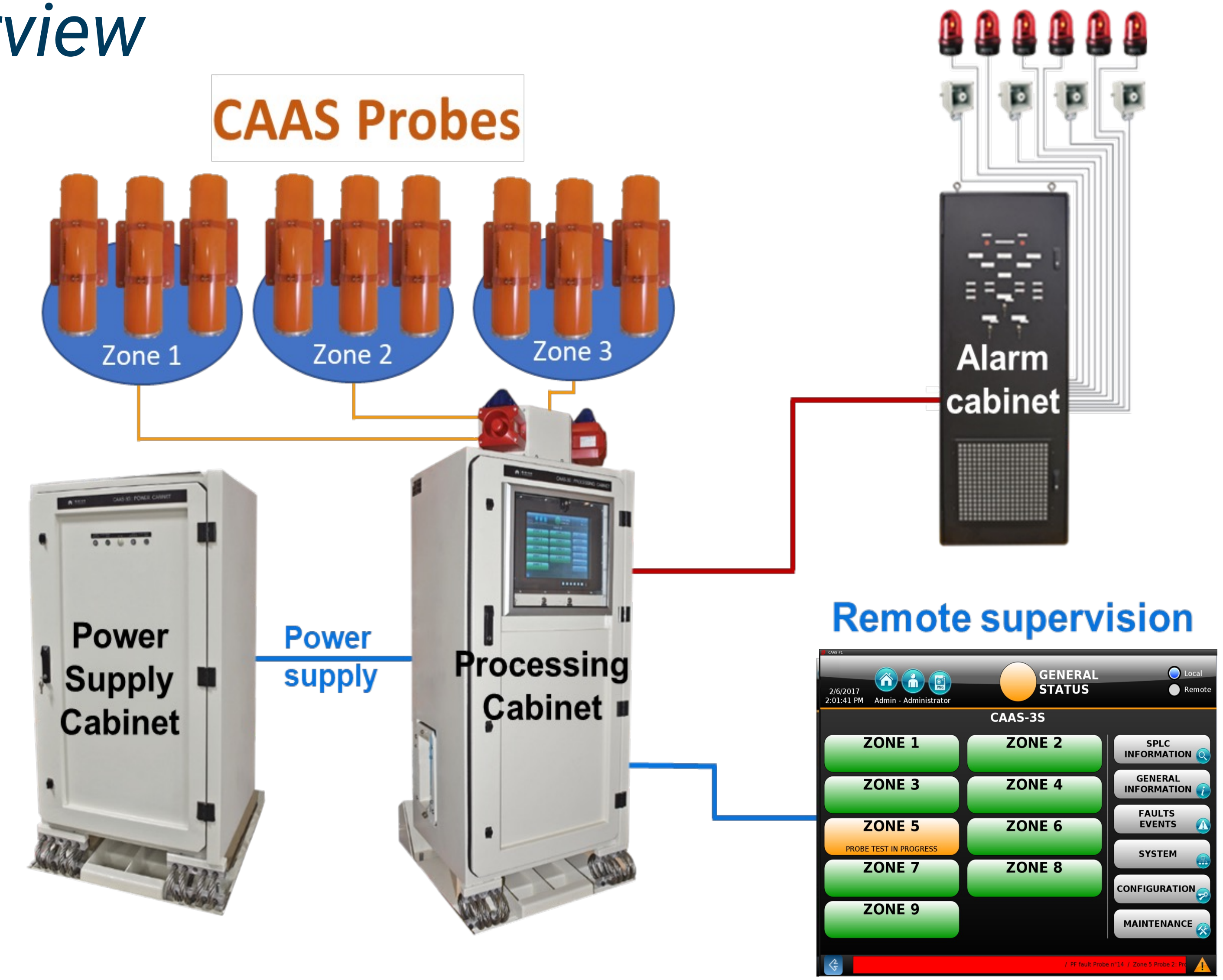
IN 50 YEARS
**<10**
RECORDED FALSE ALARMS

**1,000+**
NEUTRON & GAMMA DETECTORS DEPLOYED

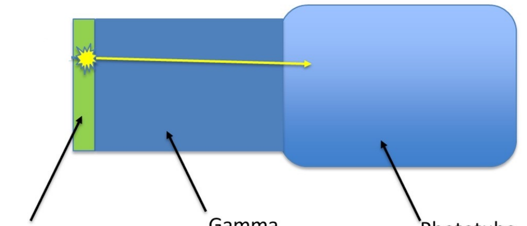
PROVEN, RELIABLE
*Analog Signal Chain*

# CAAS-3S™ System Overview

- Detection
- Processing
- Power Supply
- Alarms
- Supervision



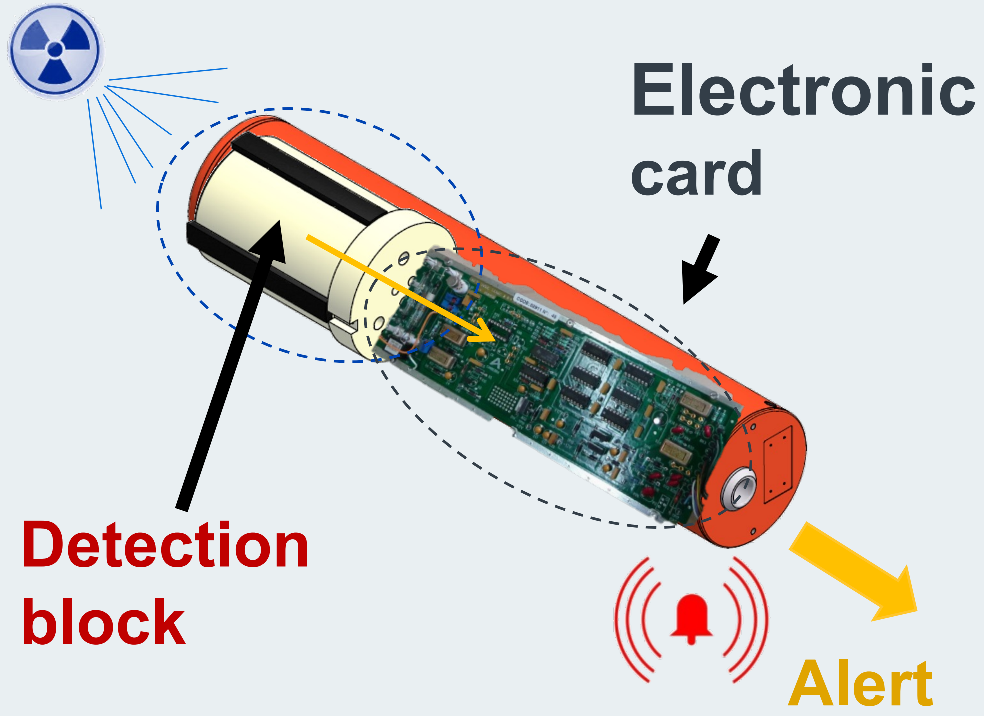
# CAAS-3S Smart Probes




## CAAS-3S DETECTORS USE SCINTILLATOR TECHNOLOGY

- *Lower susceptibility to false alarms*
- *Follows dose levels and re-scales dynamic range to extend measurement range*
- *Will recover readout even though upper limit has been crossed (no saturation)*
- *Source-free testing can be automated*

# CAAS-3S Probes – Smart Probes




- Redundant power supply
- Watchdog circuitry (continuous)
- Alert – Simple 0 or 1

## DETECTOR KEY FEATURES

- *Signal processing local to the probe*
- *Alert triggered on a preset voltage threshold (correlated with dose rate)*
- *Independent alert (no dependency on other probes)*
- *Other non-safety information: status, voltage, temperature*

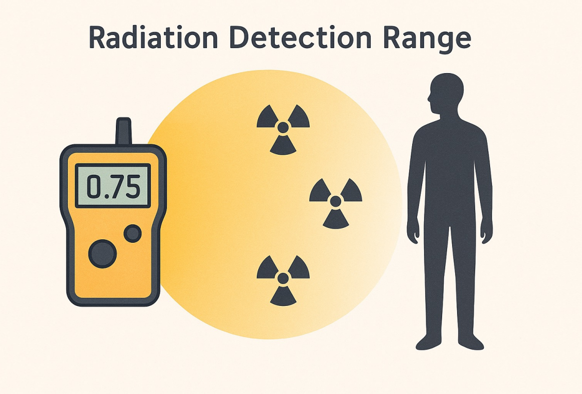
# Detector Setpoints and Coverage Ranges

- *Same housing and electronics in each probe*
- *Combined gamma/neutron = most versatile*
- *Gamma-only or neutron-only may be advantageous in some cases*

| Probe Type | Set Point (mrad/hr) | Total Range (m) | n range (m) |
|---|---|---|---|
| CAAS-3S (γ+n) | 100 | 230 | 124 |
| CAAS-3S (n) | 100 | 124 | 124 |
| CAAS-3S (γ) | 50 | 270 | 0 |
| CAAS-3S high sensitivity (n) | 8 | ~400 | ~400 |

*Neutron to gamma dose ratio = 0.3;*

*Other probes not listed: Gamma low-sensitivity, gamma high-sensitivity*




*With attenuation, the gamma sensitivity can reduce rapidly and the range can be conservatively treated in terms of neutron detection.*

# Processing Unit

- 10 zones (2oo3)
- 1000 m detector distance

# PROCESSING UNIT KEY FEATURES

- *Zones can be added sequentially*
- *Different zones can have different detector types – Expansion can be tailored to different operations*
- *Automatic diagnostics, fault warning, and switchover for redundancy*
- *Probe testing (can be automated)*
- *Relay contacts for external alarms*



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# Power Supply Unit


## POWER UNIT KEY FEATURES

- *Converts facility "mains" power to 24V DC (cabinet & probes)*
- *Battery backup – Minimum 16 hours of monitoring and 30 minutes alarming*
- *Two different vendor battery packs for redundancy*

# Supervision Software


# SUPERVISION KEY FEATURES

- *Independent of the alarm (safety) signal chain*
- *On-board display replicated on remote monitoring stations*
- *User management with password authentication*

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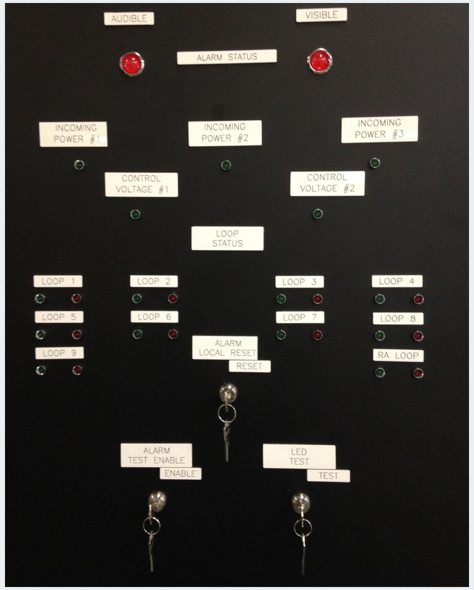
# Alarm System

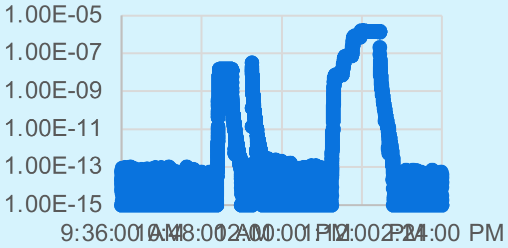


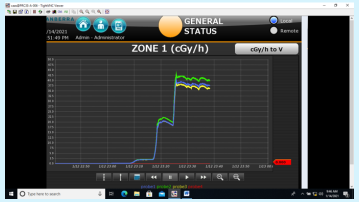

## ALARM UNIT KEY FEATURES

- *Tailored to facility layout and needs*
- *Existing facility horns/beacons or Mirion supplied devices*
- *Fault indication & redundancy*

# CAAS-3S Qualifications

**National Criticality Experiments Research Center (NCERC) – Godiva reactor**


**White Sands – Radiation exposure**

## QUALIFIED TO ANSI/ANS-8.3, IEC 60860, & ISO 7753

- *Detector response*
- *Environmental*
- *Electromagnetic*
- *Mechanical*

- *Expanded testing (2020 – 2022)*
  - *High-rad limits for the cabinets (instantaneous dose-rate & integrated dose)*
  - *Expanded seismic testing*
  - *Expanded temperature testing*



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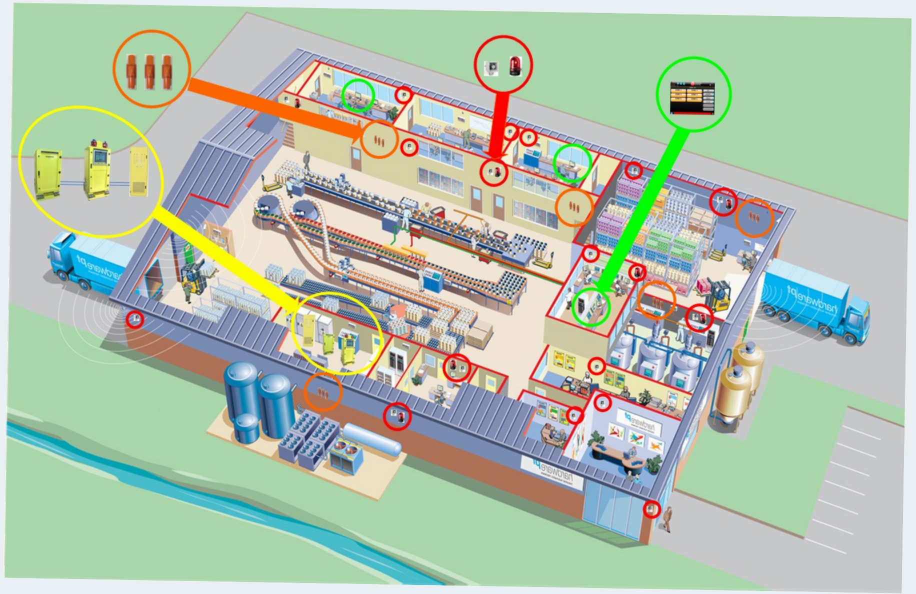
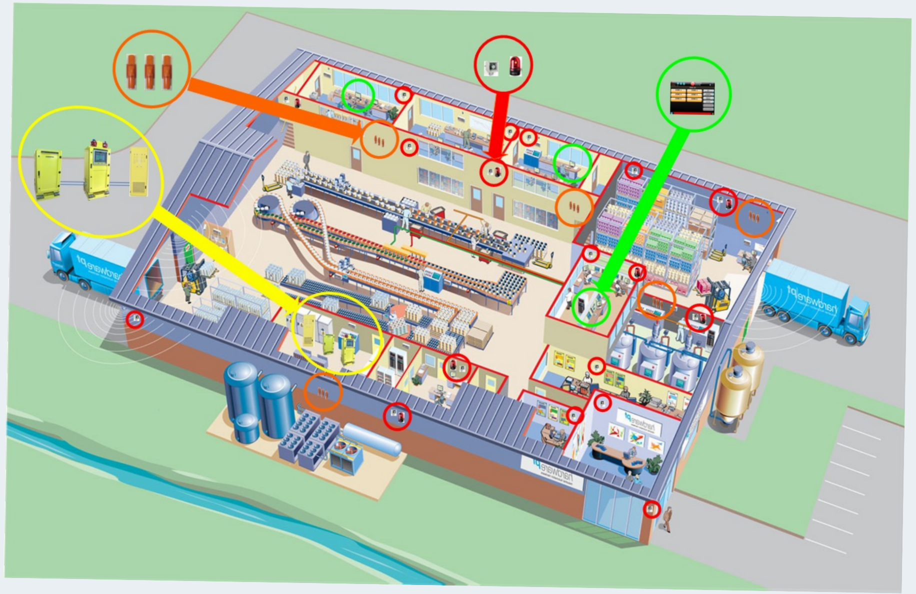
# CAAS Design & Operational Support



## DESIGN SUPPORT

- *Probe positioning study*
- *Probe type, placement, and number of zones*
- *Future expansion considerations*
- *By building or zone*
- *Equipment location*
- *Cable pathways and routing*
- *Horn/beacon needs and placement (volume, tone, color, brightness)*

# CAAS Design & Operational Support



## OPERATIONAL SUPPORT

- *Site installation*
- *Lifetime maintenance –*
  - *Regular testing*
  - *Probe re-calibrations*
  - *Obsolescence notice and upgrades*
  - *Spare parts*



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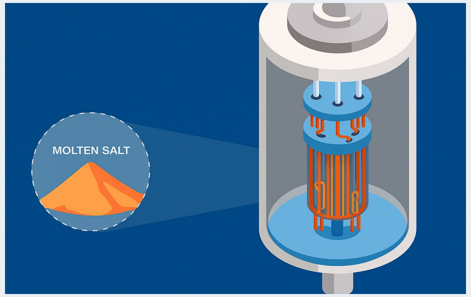
# *Material Control & Accountability (MC&A)*

# *MC&A Standards & Guidance*

| | |
|---|---|
| **10 CFR 74** | *Sets the* ***legal*** *requirements. NRC regulatory requirements for the control and accounting of SNM at licensed facilities. Written primarily for LWR fuel assumptions.* |
| **ANSI/INMM N-15 STANDARDS** | *A series of standards that define requirements for MC&A with* ***emphasis on measurement, calibration, and quality of measurements****. N15.36 and N15.56 provide requirements for NDA holdup & in-situ measurements.* |
| **DOE ORDER 474.2A** | *Requirements for developing, implementing, and maintaining a nuclear MC&A program within the U.S. Department of Energy* |
| **DOE STD 1194 2011** | *DOE technical standard that defines MC&A practices and used by DOE reviewers to assess licensing adequacy. Drives* ***measurement quality objectives****.* |

# Advanced Nuclear MC&A Needs



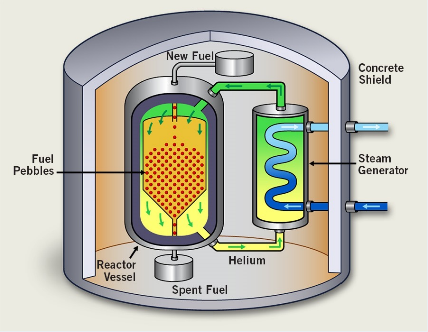




Image courtesy of IAEA

Image courtesy of Neutron Bytes

- **Reference to 10 CFR 70**
- **'Significant quantity' ≥10 kg or more of U-235 enriched 10% to 20%**

## HALEU INCREASES MATERIAL ATTRACTIVENESS

- *Pushes facilities into Category II - Requires tighter accounting*
- *Re-evaluation of KMPs and MBAs - Safeguards by design*
- *Fuel form impacts approach – Item counting versus bulk, hybrid approaches*
- *Additional physical protection*
- *International safeguards? Exporting reactor technology*

# *Impact on Measurement & Measurement Control Programs*

- *High accuracy, low uncertainty, more statistical reliance (1000s of pebbles)*
- *Holdup significance increases*
- *Potentially near-real-time accountancy*
- *Enhanced digital impact for continuity-of-knowledge*
  - *Electronic logs*
  - *Secure access to data*
- ***NDA capability is a core MC&A risk mitigator** — more so than for conventional LEU fabrication*

Verification of spent nuclear fuel stored in cooling ponds
Source: IAEA photo gallery

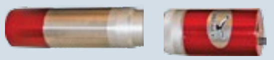
# Core NDA Capabilities Required for HALEU MC&A

| NDA TECHNIQUES | REASON |
| --- | --- |
| *High accuracy gamma spectrometry for U-235 quantification* | *Increased U-235 → increased self-absorption and matrix attenuation corrections (and reduced U-238)* |
| *Neutron NDA (passive and possibly active)* | *Higher (α,n) and spontaneous fission neutrons, but background and moderation sensitive* |
| *Hybrid gamma/neutron* | *NDA for enriched $UF_6$ cylinders* |
| *Segmented scanning NDA capabilities for heterogeneity* | *Heterogeneity in samples, if not accounted for, forces larger uncertainties and conservative assumptions* |

# *Continuous Spectroscopy Monitoring Applications*

- *Inline enrichment monitoring*
- *Survey trending for process equipment*
- *Continuous holdup*
- *Burnup monitoring*

**Scintillators**



**NaI, LaBr, CeBr** **Osprey® unit**

**High Purity Germanium (HPGe)**

# Data Analyst™ CSM Platform

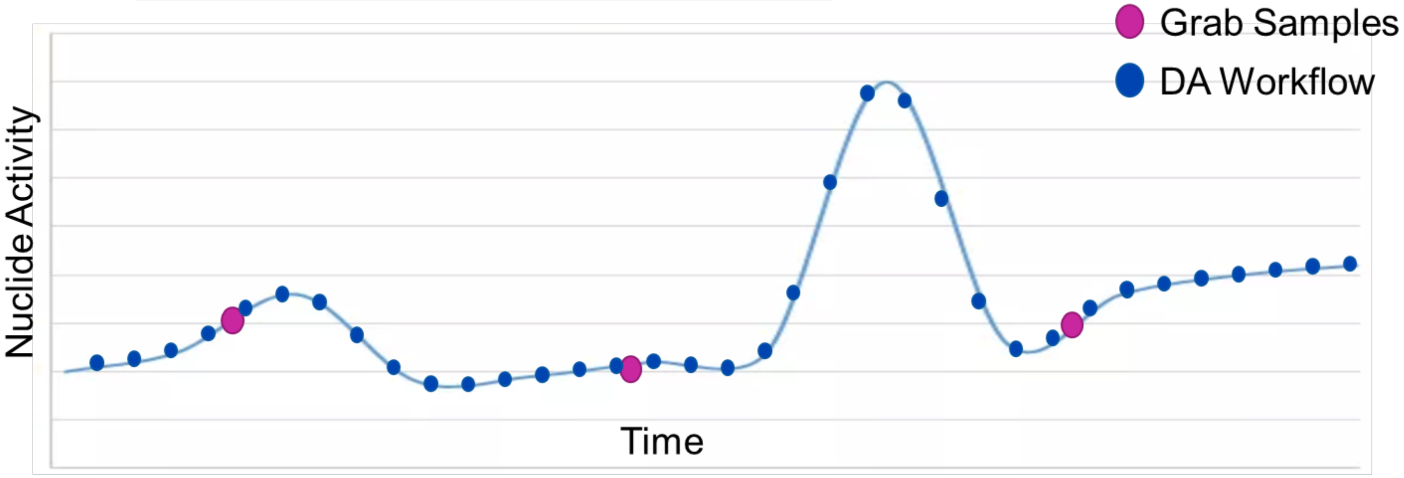
**(Embedded Software)**

*Autonomous Operation*

**Data Analyst Web UI**

- *Automated and triggered counting and analysis at defined intervals*
- *Enabled by the Data Analyst platform*

*NPP in-situ CZT system*



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# Compact Gamma Spectrometers

- Holdup Applications
  - Pipes, Traps, Glove Boxes
  - Bulk powders
- Holdup Measurement Support
  - Portable, lightweight
  - Shielded and collimated detector
  - High sensitivity
  - Accurate and reproducible
  - Rugged and reliable
  - Various measurement geometries
  - Easy data collection and analysis


- GR1 compact CZT (1 cm3)
- 25 x 25 x 63 mm, 60 g
- Power consumption <250 mW
- Generic ISOCS characterization

Image credit: David Davis, CNS Y-12, Holdup Workshop 2019


- MicroGe – Electrically cooled | 52.5 x 43.7 x 21.3 cm , 9.4 kg
- Can be cooled in 30 minutes | 1.2 keV at 122 keV, 1.7 at 661.7 keV



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# Neutron Counting Applications

- *Scenarios where gamma signature is heavily shielded or gamma background is 'too high'*
- *Complements gamma isotopics for fissile mass*
- *Holdup for metal or high-density oxide lines*
- *Transport/supply chain content verification*
- *Delayed neutrons from fission products in circulating salt*
- *Microreactors?*

**PSMC**
Plutonium Scrap Multiplicity Counter

- *High efficiency: >50%*
- *Sample Cavity 19.7 x 41 cm (7.8 x 16.1 in.) (Dia. x Height)*

**JCC-41™**
Neutron Coincidence Counter

- *Efficiency: >22%*
- *Motorized hoist*
- *Sample Cavity 24.4 x 50.0 cm (9.6 x 19.7 in) (Dia. x Height)*

**Portable Neutron Slab Counter (PNSC)**


- *Efficiency: 1.2 – 1.3% @30 cm*
- *Go/No-go measurements*

**WM3500**
Curved Slab Counter



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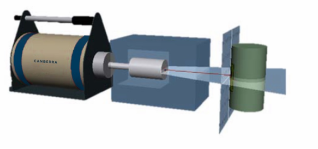
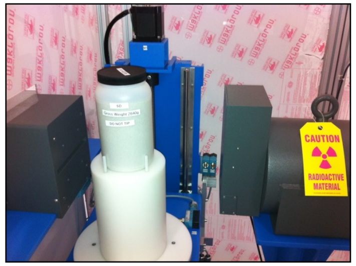
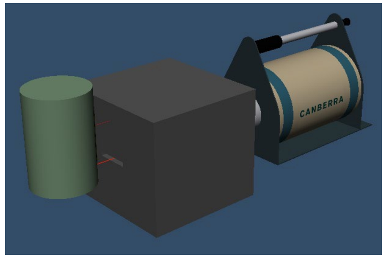
# Segmented Gamma Scanning Applications

- *For samples/applications with heterogeneous enrichment, material; non-uniform U-235 distributions*
- *Provides segment-by-segment U-235 activity*
- *For Category II HALEU forms*
  - *Tighter ID/SRD limits favor SGS/TGS*
- *Itemization of small containers at KMPs*
- *Shipper/receiver verification*
- *Satisfy ANSI/INMM N15-compliant measurement control*





*ISOCS software models for system collimators*



**CAN SGS**

**CAN TGS**

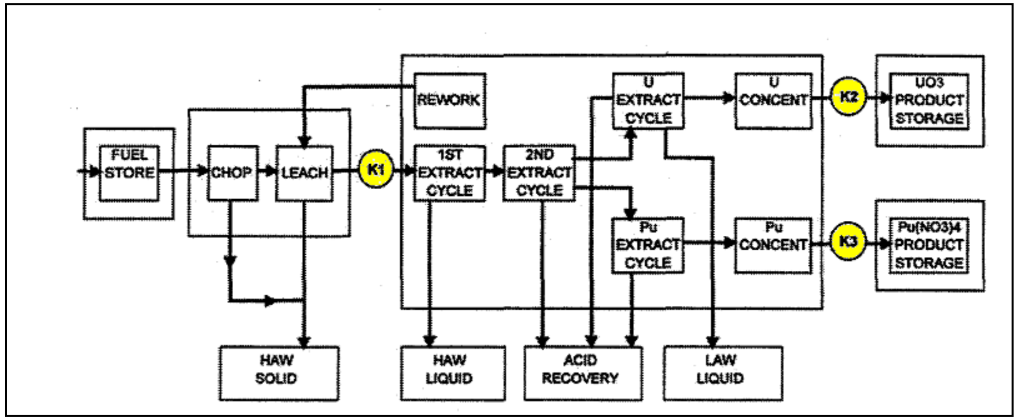
# Hybrid K-Edge/XRF Analysis Applications

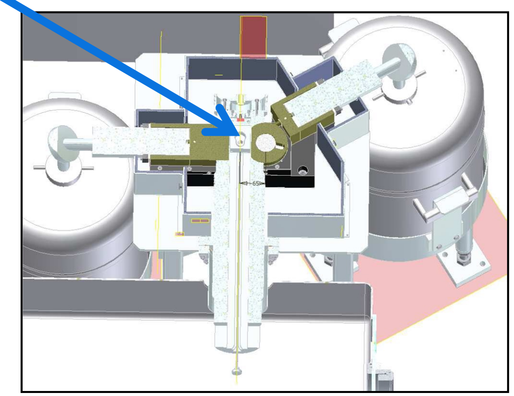
Non-destructive

Highly Accurate

Simultaneous

- MSR feed monitoring
  - U concentration
  - Fuel salts with multiple actinides (U/Pu, U/Th)
- Reprocessing – Solution samples



K1, K2, & K3: key measurement points
- K1: Measure dissolver solution
- K2, K3: Measure U and Pu product solutions

Determine material balance from these three measurement points

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# SUMMARY

- *The Advanced Reactor Nuclear Fuel Cycle creates new challenges*
- *In this session we focused on the needs driven by SNM, primarily HALEU*

**CAAS**

- *HALEU causes more operations to become credible criticality scenarios*
- *HALEU requires tighter criticality safety margins*
- *Having options of both gamma & neutron detection offers coverage flexibility*

**MC&A**

- *Requires higher accuracy*
- *Requires diversified NDA methods*
- *Continuous monitoring saves labor & costs*

*Mirion has the instrument portfolio and experience to provide new solutions*

*Survey for:*

# Safeguarding Advanced Reactor Nuclear Fuel Cycle: New Challenges & Solutions

*Please take a moment to fill out a short survey on this session.*

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# *Thank you*