MIRION Connect 21

Annual Users' Conference

Mirion's CAAS Solutions

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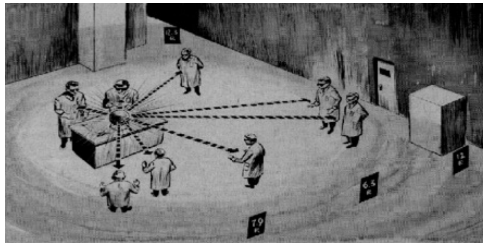
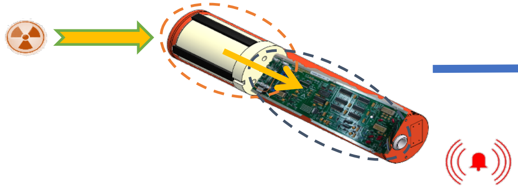
Outline



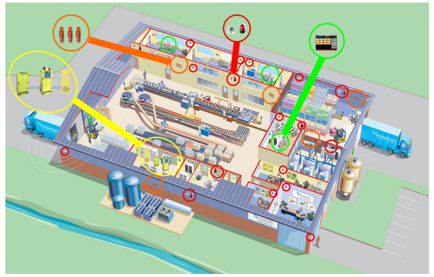
Historical perspective

CAAS-3S



Detector Options

Alarms



Maintenance

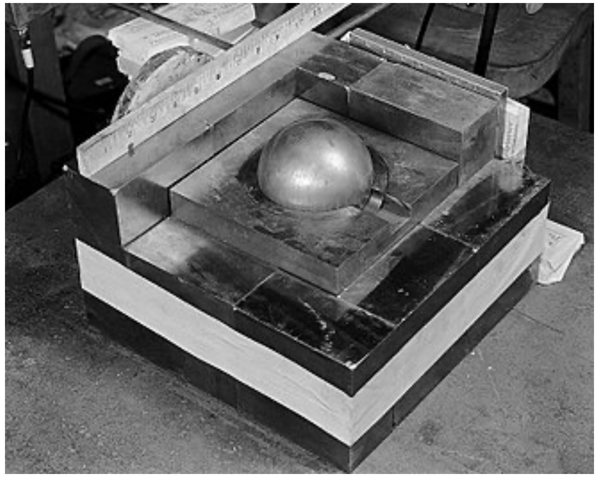
Historical Perspective

- Historical perspective on the need for a criticality system
- Standard and definition for CAAS – Key design criteria
- Mirion (formerly Canberra) history of CAAS

Criticality Accidents / History

- Criticality Accident – Unintended accumulation or arrangement of a critical mass of fissile material resulting in an uncontrolled fission reaction

<u>First known fatality caused by a criticality accident</u>
August 21, 1945 - (Harry) Daghlian, Jr. accidentally dropped a tungsten carbide brick onto a plutonium core while stacking the bricks around the core to build a neutron reflector.

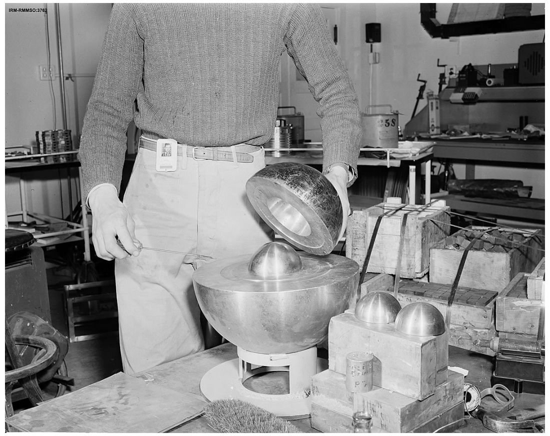


- The core was <u>near</u> critical; the brick made it <u>prompt</u> critical (yield ~10^{16} fissions)
- Daghlian received an estimated dose of > 500 rem (5 Sv) resulting in severe radiation poisoning
- He died 25 days later

Criticality Accidents / History

- As a consequence – Safety procedures were revamped
- One new requirement – Use of at least two instruments monitoring neutron intensities with audible alerts
- This also set in motion plans for remote controlled devices for testing (early planning for Godiva pulsed reactor)
- But on May 21, 1946…

- Same core, different reflector – Beryllium hemispheres separated by shims. Slotin used a screwdriver momentarily which slipped
- Most of the dose was due to neutron radiation, which could not be measured by dosimetry at the time
- Slotin's estimated dose was ~10 Gy (n) + 1 Gy (γ)
- He died 9 days later with what was described as agonizing symptoms in that period



The Demon Core

Criticality Accidents/History → Where are CAAS systems required?

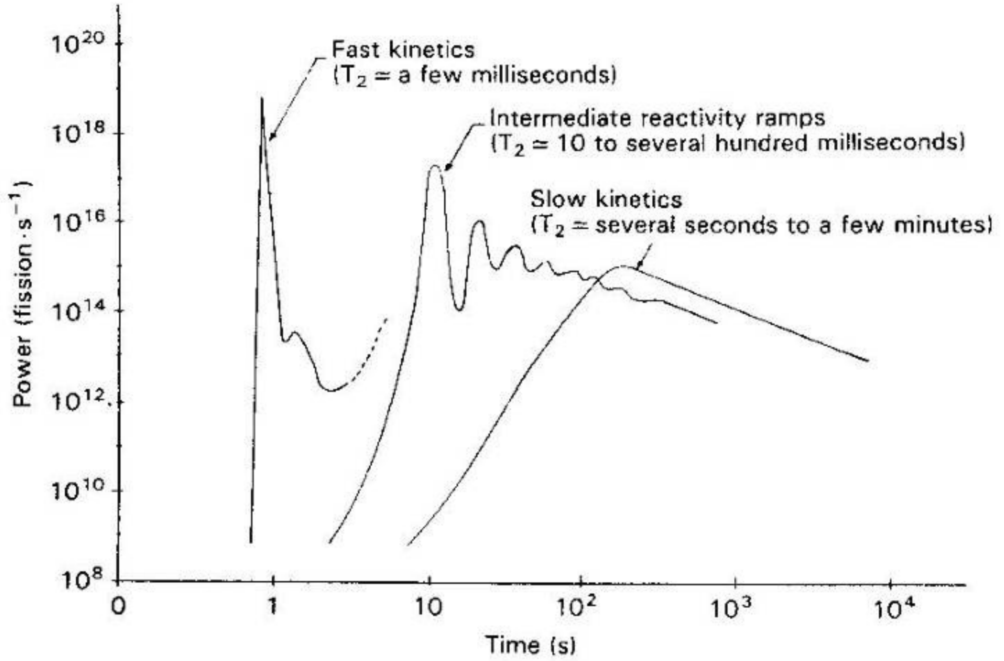
- Sixty known/recorded criticality accidents since 1945
- 22 Process Accidents - 21 occurred with the fissile material in solutions or slurries
- 38 Reactor Accidents and critical experiments – 5 occurred in working reactors; 33 occurred in critical experiments where the properties of the assembly itself was being studied

Criticality Accident Radiation

- **Characteristics of the criticality accident radiation depend on several factors:**
  - Physical form of the fissile material (metal, liquid, powder)
  - Geometrical configuration (diameter, material, shielding)

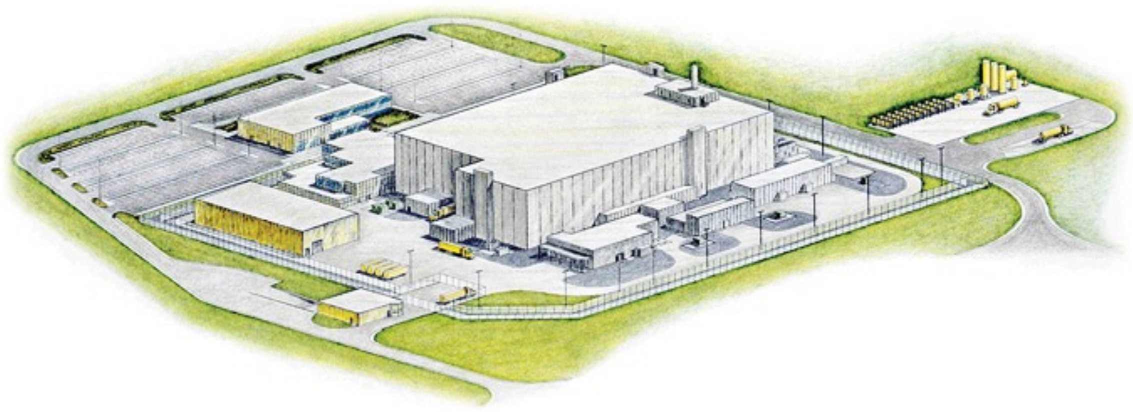
► The ratio of neutron to gamma radiation can vary considerably depending on the type of accident.

► Correlation between total number of fissions and the total neutron and gamma dose is highly variable



CAAS Standard & Definition

- Definition of Criticality Accident Alarm System (CAAS)
  - An alarm system for prompt evacuation of personnel in the event of a criticality event
  - Should be located in areas where personnel would be exposed to an excessive radiation dose



- **ANSI/ANS-8.3-1997 (R2017)**

This standard is applicable to all operations involving fissionable materials in which inadvertent criticality can occur and cause personnel to receive unacceptable exposure to radiation

- **Key Criteria for Design –**
  - Meet the criticality standards
  - Response time (per standard)
  - Reliability
  - Fault/Failure warning
  - Minimization of false alarms
  - Seismic tolerance

Mirion - Over 40 Years of Experience with CAAS Systems

- **More than 75 Systems installed globally over 40 years**

1976
EDAC-1

1990
EDAC-2

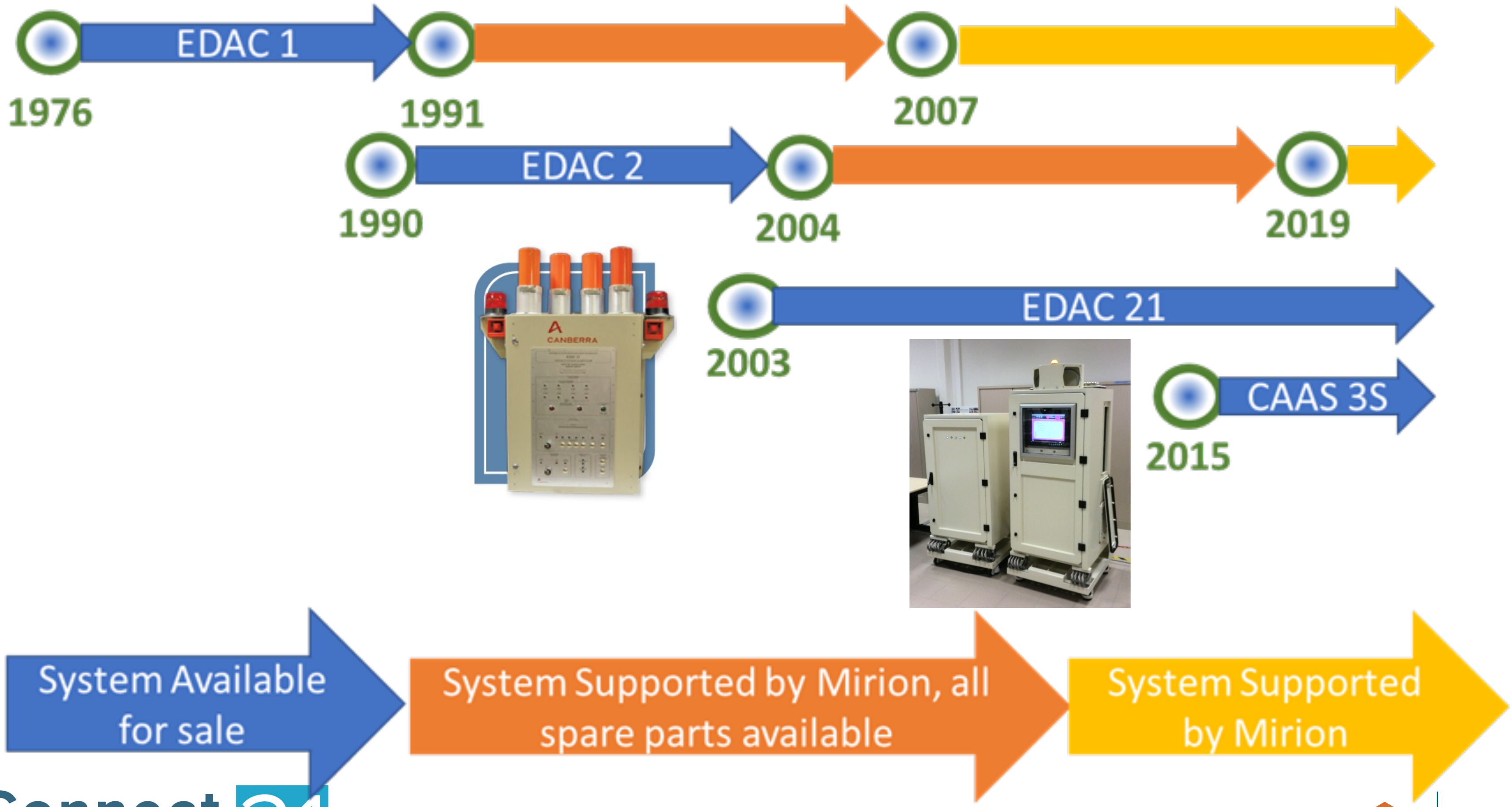
2003
EDAC-21

2015
CAAS-3S

- Experience with over a 1000 neutron & gamma probes
- New designs based on highly reliable analog signal chain used in the probe design for the previous products
- Successful safety record and very low false alarm rates over 40 years

Mirion - Over 40 Years of System Support

- **Continued support through life of the system**

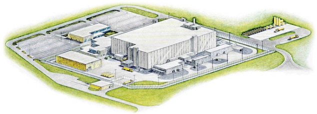


CAAS-3S System Timeline

2013
Industrialization
& Qualification

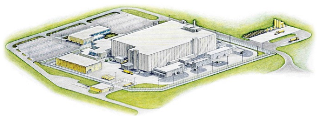
New n_h probe
development
2014

2015
Product
release



1^{st} go-live
system
2017

2018
2^{nd} go-live
system



New γ_h probe
development
2020

2021
CAAS-3S
Cabinet rad
testing

CAAS-3S System & Components

- Overview
- Probes
- Processing Cabinet
- Software Supervision
- System Qualifications

Mirion’s CAAS-3S

CAAS-3S

The CAAS-3S is intended for wide-area coverage of multiple zones within large buildings and across a facility.

- **Key Criteria for Design –**
  - Reliability
  - Fault/Failure warning
  - Minimization of false alarms
  - Seismic tolerance
- **Minimum impact on facility operation**
  - Testing, Maintenance, Repair, and Training

CAAS-3S Overview

- 8 zones with 4 probes per zone,

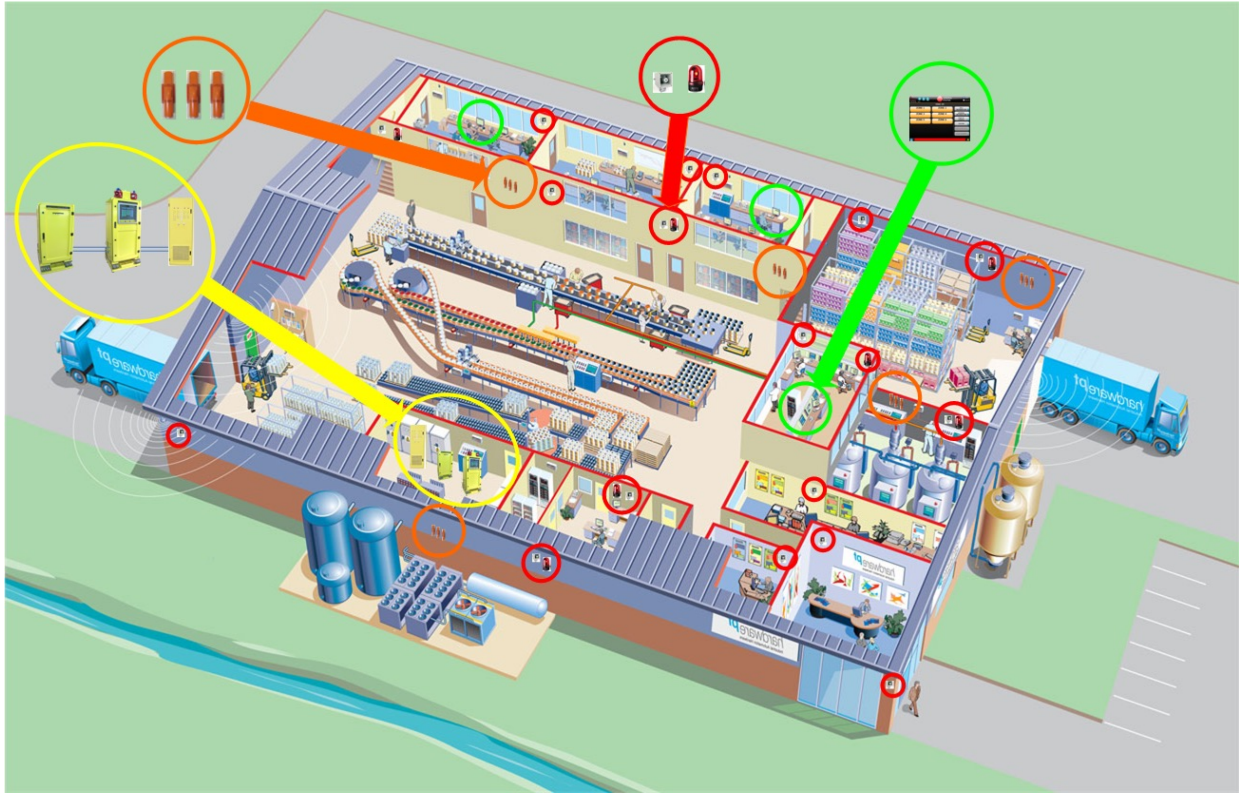
or

- 10 zones with 3 probes per zone

CAAS-3S Sample Layout

- Probes are placed in groups of three or four in each criticality zone
- The processing unit is typically located in a control room or other central area outside a criticality zone

- The power-supply cabinet is co-located with the processing cabinet
- The processing unit can be connected to an alarm network via safe ethernet
- The processing unit can be monitored remotely using supervision software

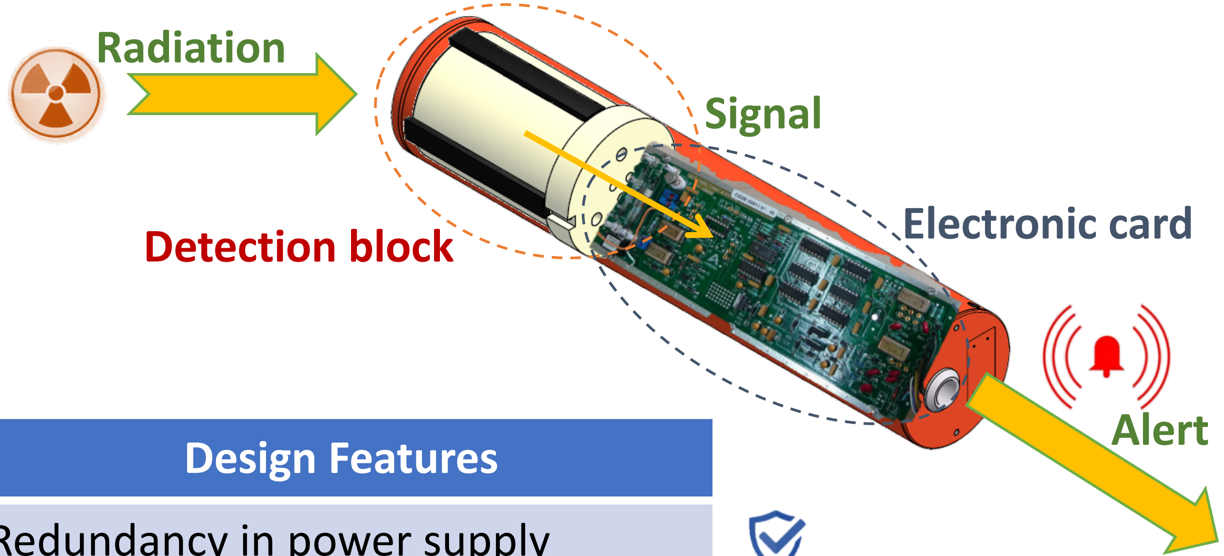


Detector Choices and Sensitivities for CAAS-3S

Probe Type	Set Point (rad/hr)	mrad/hr	mGy/r
CAAS-3S (γ+n)	2	2000	20
CAAS-3S (γ+n)	0.1	100	1
CAAS-3S (n)	0.1	100	1
CAAS-3S (γ)	0.05	50	0.5
CAAS-3S high sensitivity (n)	0.008	8	0.08

- All detector types have the same probe housing and electronics
- Different zones may have different types of probes
- Maximum cable length from probe to processing cabinet: 1000 meters (~3300 ft)
- Included in SIL-2 readiness

CAAS-3S Probes – Smart Probes



Probe Functionality	Design Features
Power supplied by cabinet	Redundancy in power supply
Signal is processed inside the probe • Status voltage • State of health (SOH)	Watchdog circuitry (continuous)
Response to radiation above threshold is an 'Alert'	Alert – Simple 0 or 1 Separate from the SOH signal chain

Processing Cabinet

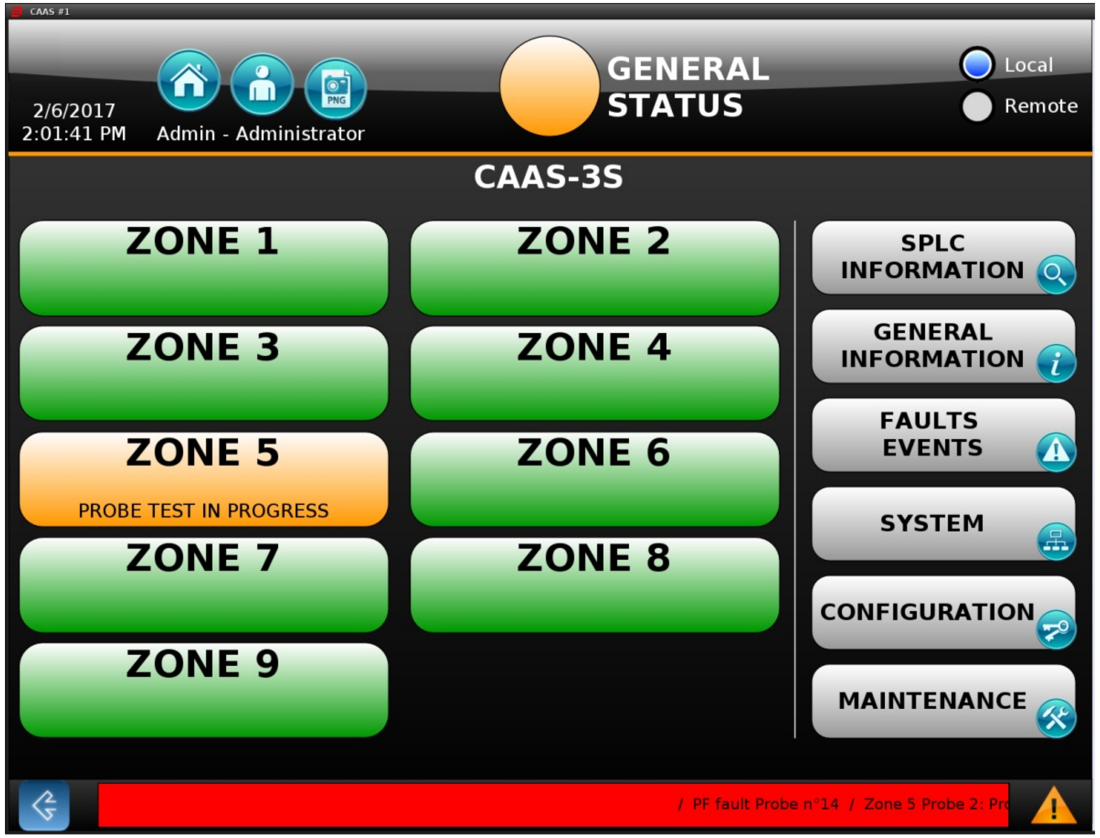
- Up to ten zones can be monitored simultaneously
- 3 or 4 detectors per zone depending on the selected voting logic (2oo3 or 2oo4)
- Different detector types (neutron vs gamma) can be in different zones
- Detector to cabinet distance up to 1000m (3300 feet) – with dedicated (and qualified) cable
- Processing unit is designed to be situated outside the zone (typically in a control room)

Processing Cabinet Features

- Alarming
  - Managed by the safety channels of the system (safety PLCs, Fail safe communications)
  - Activates external alarms through relay contact outputs (to alarm cabinet)
  - Activates local horn and beacon
  - On-screen visual alarms and optional remote display for visual alarm
- Monitoring
  - Automatic diagnostics of all functions in the system
  - Includes monitoring of the Power Supply cabinet as well
  - Automatic switchover to redundant circuits in the event of a fault
- Testing
  - Single probe ("alert") testing using built-in LED
  - General zone alarm testing
  - Programmable automatic probe testing
- User Interaction
  - On-board touch-panel interface for all controls

Supervision Software

Main Screen – All Zones



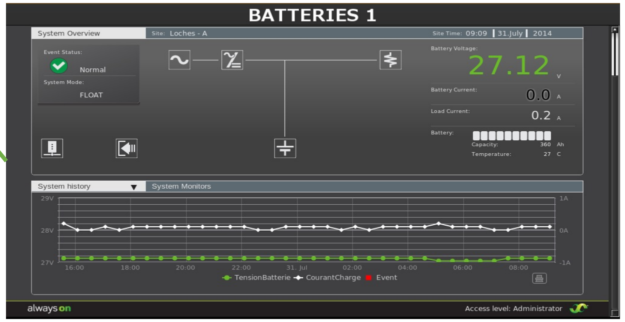
- Independent of the alarm (safety) signal chain
- On-board built-in touch screen
- The same MMI can be installed on remote computers
- User management with password restrictions
- Some customization possible

Software Supervision – Extended Capabilities

Detailed probe information by zone

Fault information & logging

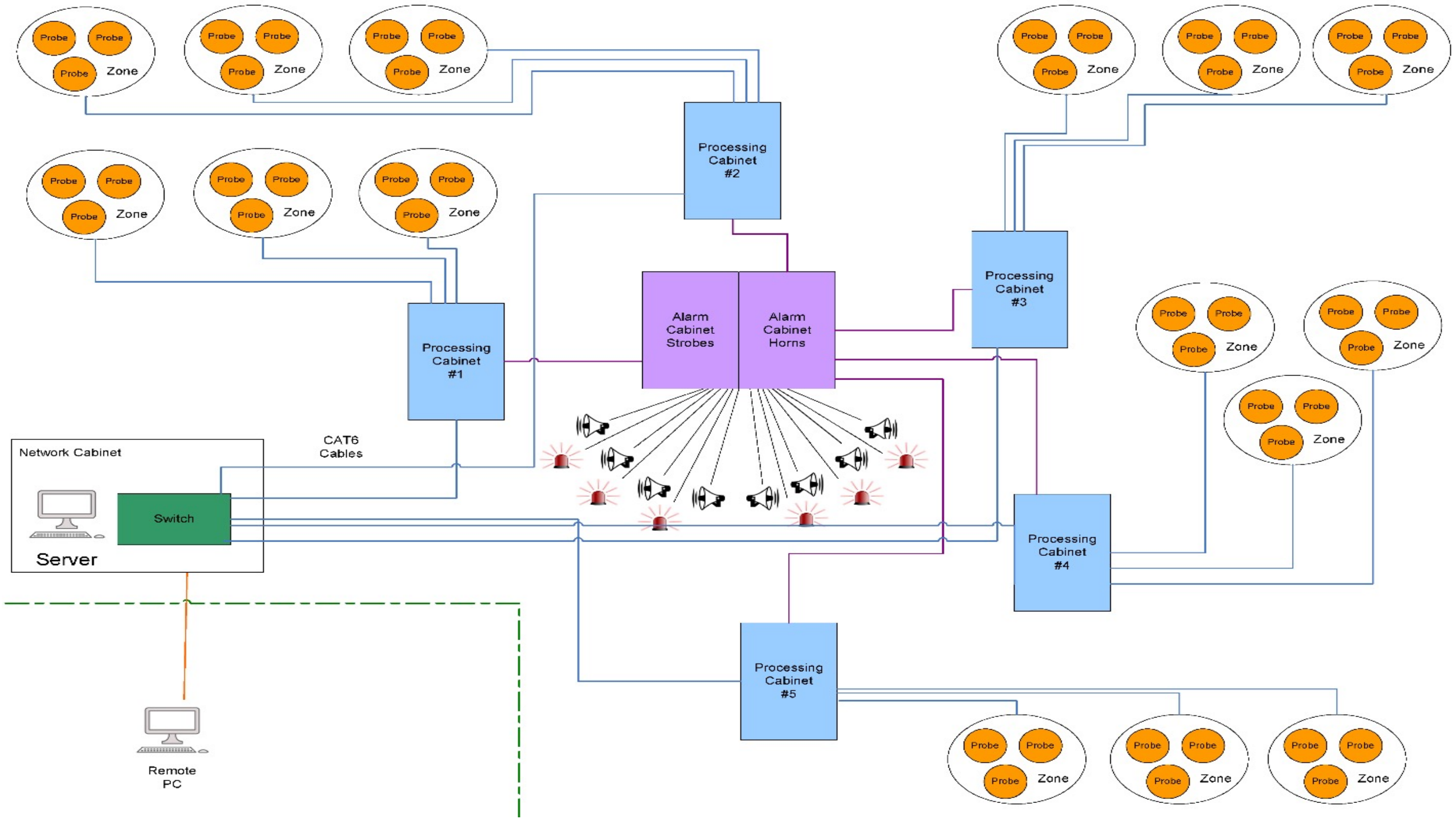
Battery Status



Alarm history

Global Supervision for Multiple Processing Cabinets

- Multiple processing cabinets and alarm cabinets networked together with the capability to be monitored simultaneously



Power Supply Unit

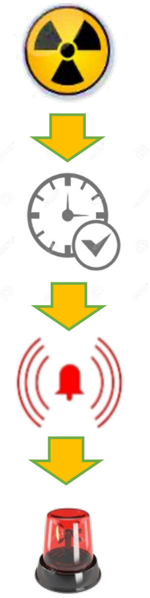
- Converts facility “mains” power supply to 24V DC
- Provides 24V DC to CAAS-3S processing cabinet (also for probes)
- Supply: 110V AC 50/60 Hz US / 230VAC 50/60 Hz International
- Ensures continuous operation of the system, even in case of power outage (battery backup)
- The 24V supply is from the converter or batteries with redundancy (2 cables)
- All power components (rectifiers, batteries) are hot swappable

Power Supply Unit – Battery Backup

- Two sets (Redundant) of battery packs made by different vendors
- 16 hours of normal monitoring, followed by
- 30 minutes of alarm state
  - Sound alarm is automatically acknowledged after 10 minutes (Evacuation phase) at Processing Cabinet (latched optional at Alarm Cabinet)
  - Visual alarm persists (Re-entry warning)

Criticality ALARM Sequence

- A carefully monitored sequence of steps is used to minimize false alarms and only alarm on an actual criticality event
- After the criticality accident occurs:
  - Check of dose-rate & integrated dose criteria
  - Confirmation of crossing the alert threshold after 20 ms time delay
  - Activation of the ALERT signal inside the probe
  - Registering of the ALERT status in Processing cabinet
  - Confirmation of ALERT status with the other probes in the same zone by the hardware logic inside the processing unit confirms the ALARM



System Qualifications

CAAS-3S Probes – Qualification

- Probes submitted to various criticality shots
  - From 60 µs pulses to 500 s doubling time
  - Dose rate up to more than 10^6 Gy/h

- Probes never failed to alarm
  - ISO 7753 and IEC 60860-2014 requirements are met
    - 1 ms transient
    - 1000 Gy/h
  - Alert triggered by the probe within less than 35 ms

- Various n/γ & shielding configurations have been tested
  - No shielding
  - 20 cm or 40 cm concrete
  - 10 cm HDPE, with and without 1.2 mm Cd

Qualification to Criticality Standards

- Probes & System are tested and certified to criticality standards:
  - ANSI/ANS-8.3 1997 Criticality Accident Alarm System – Published by the American Nuclear Society and approved by the American National Standards Institute
  - IEC 860 1987 – Warning Equipment for Criticality Accidents
  - ISO 7753 1987 – Performance and Testing Requirements for Criticality Detection and Alarm Systems
  - IEC 61511 - SIL2 – 99% to 99.9% availability standard for the process control sector.
    - CAAS-3S only – Readiness applies to probes, processing cabinet, power supply cabinet.
    - Can be applied to select alarm cabinet as well as an option

Qualification Summary

- Probe testing in criticality reactors:
  - Pulsed reactor
  - Delayed critical state and continuous power reactor
  - CAAS-3S - Certified by the Atomic Energy Commission in France (CEA) with formal report available

- Other qualifications include: Environmental, vibration, shock, and seismic

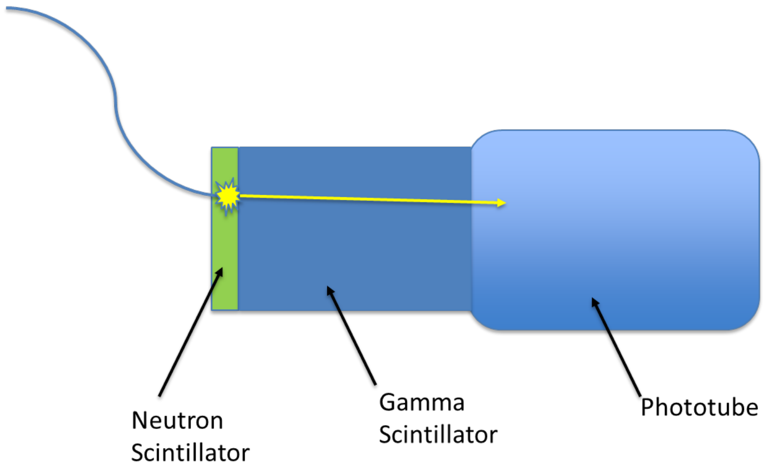
- NQA-1 – Consult with Mirion for evaluation to this standard.

CAAS-3S Probes

- Probe options – gamma vs neutron

Detector Design

- All of the CAAS-3S probes are based on scintillator technology
  - Lower susceptibility to false alarms
  - Source-free testing can be automated
  - Follows dose levels and does not saturate



Detector Choices and Sensitivities for CAAS-3S

Probe Type	Set Point (rad/hr)	mrad/hr	mGy/r
γ + n	2	2000	20
γ + n	0.1	100	1
n-only	0.1	100	1
γ-only	0.05	50	0.5
High sensitivity n-only	0.008	8	0.08
High sensitivity γ-only (prototype)	~0.01	~10	~0.1
Low sensitivity γ-only (concept)	~1	~1000	~10

- All detector types have the same probe housing and electronics
- All probe types have the same all-analog signal circuitry
- A processing cabinet can accommodate different types of probes in different zones

Gamma + Neutron Detection Capability

- Detection sensitivity to the combined gamma plus neutron dose in whatever proportion it occurs, offers the most versatile and sensitive means to detect any criticality accident that may occur

- In some cases gamma-only or neutron-only may be advantageous:
  - Significant shielding (heavy equipment or substantial concrete walls) can reduce ability to detect gamma signal;
  - High gamma background can cause excessive false alarms;
  - High neutron background areas may call for Gamma only detection.

Detector setpoint and Area Coverage

Probe Type	Set Point (Rad/hr)	Total Range (m)	n range (m)
CAAS-3S (γ+n)	0.1	230	124
CAAS-3S (n)	0.1	124	124
CAAS-3S (γ)	0.05	270	0
CAAS-3S high sensitivity (n)	0.008	~400	~400

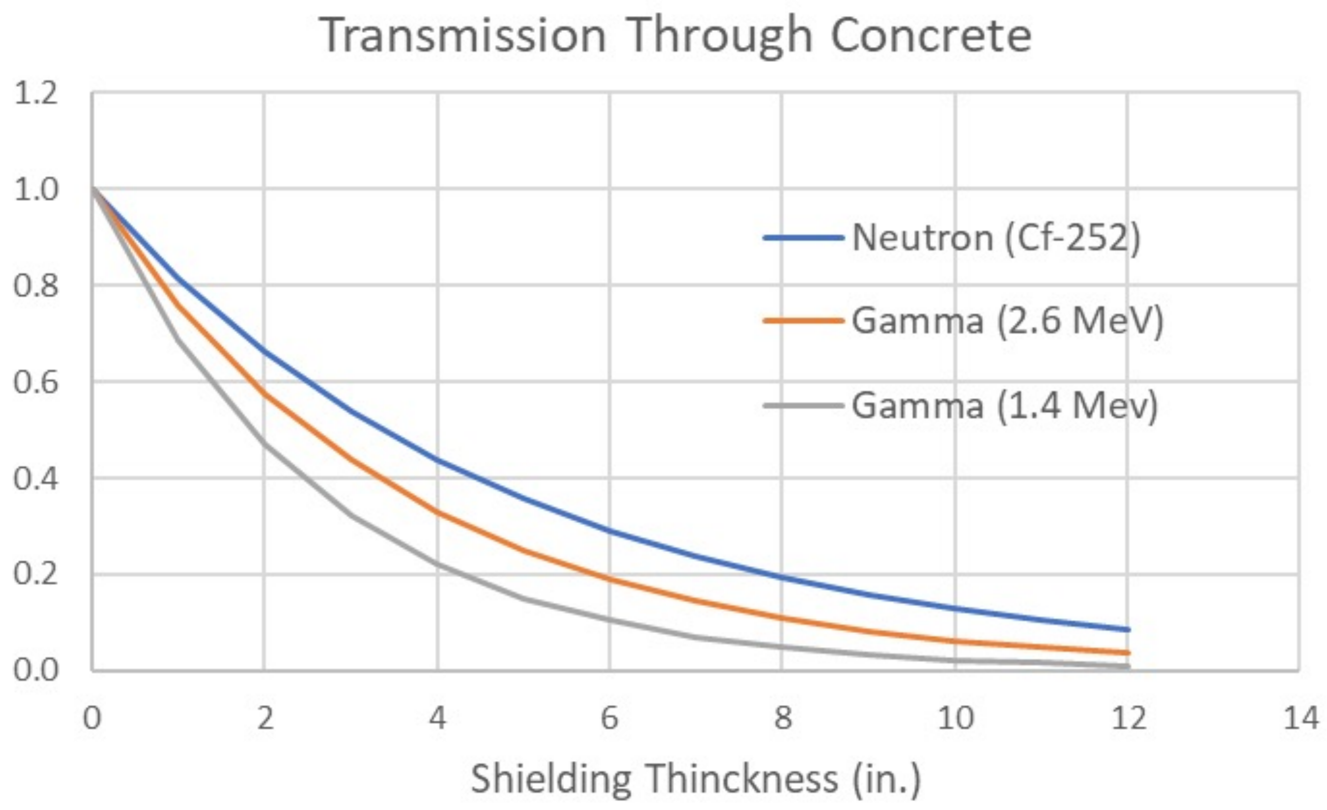
Neutron to gamma dose ratio = 0.3

- A range of approximately 200 meters (656 feet) in air, corresponds to a circular coverage area of 40,000 square meters (430,000 sq. ft).
- With attenuation, the gamma sensitivity can reduce rapidly and the range is most safely treated in terms of the neutron detection of approximately 100 m (328 ft).

Neutron Detection

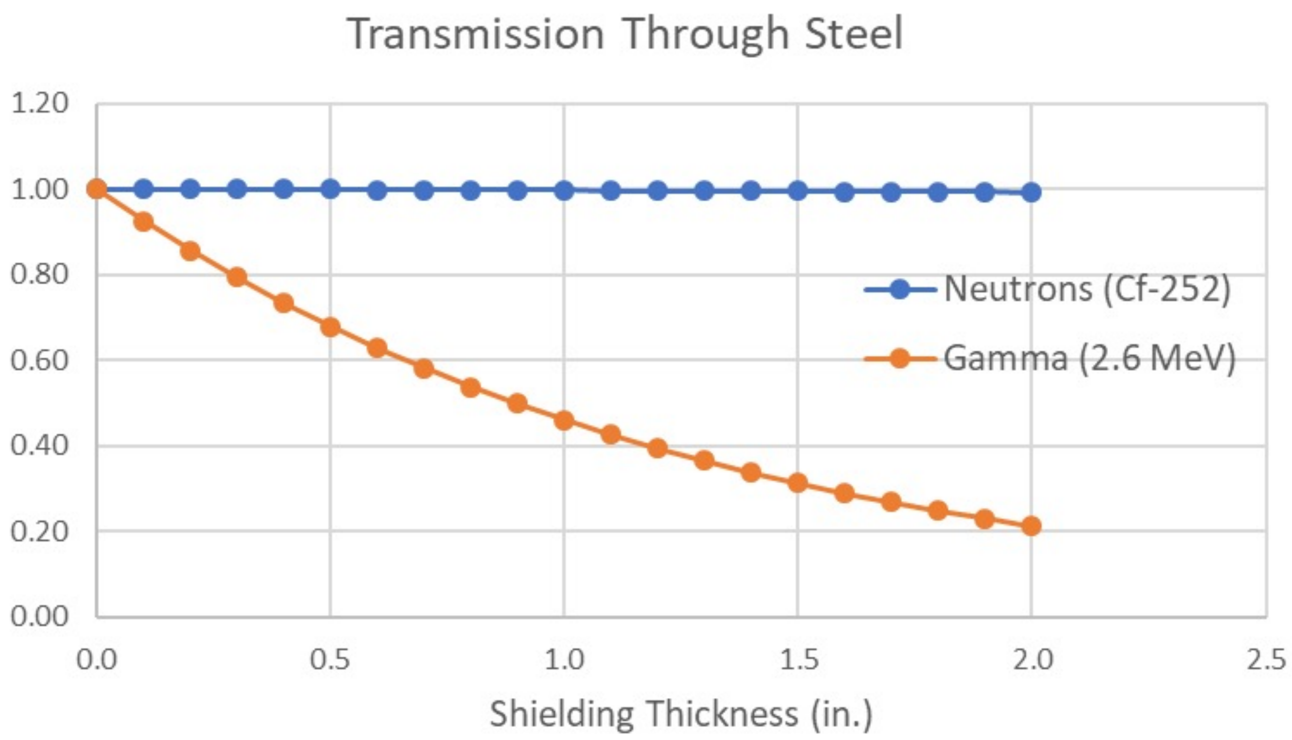
- Neutrons are generally less attenuated than gamma rays by typical construction materials like concrete

- Neutrons have 50% more transmission through 6" concrete than 2.6 MeV gamma



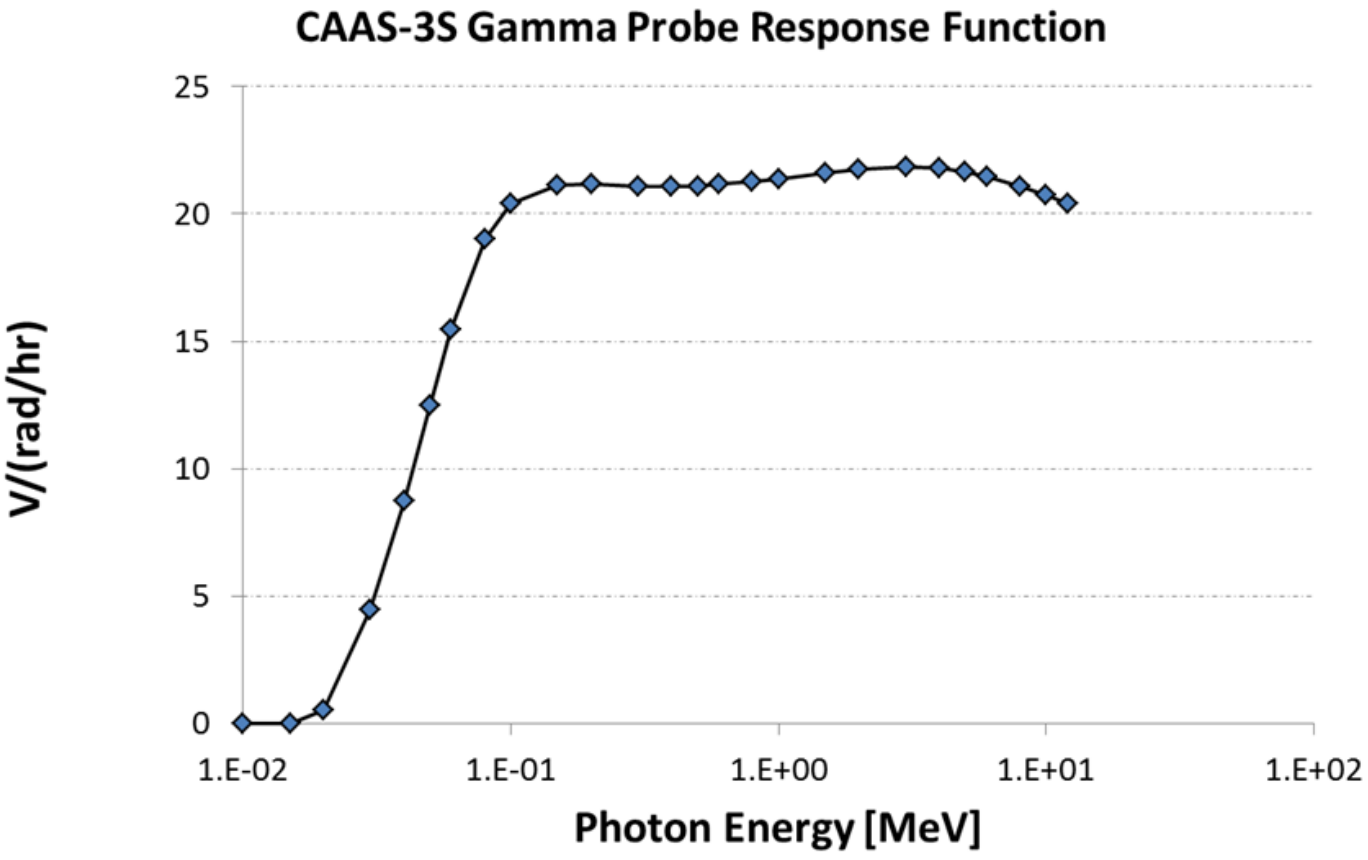
Neutron Detection

- Neutrons have 99.2% transmission through 2” of steel shielding – detection range virtually unaffected
- 2.6 MeV gamma rays are attenuated to ~20% intensity – detection range reduced to <50%



Detector Response Functions

- Detector response functions, modeled in MCNP and benchmarked to laboratory measurements with gamma and neutron sources, can be used for detector placement and coverage demonstration studies



Alarm Options

- Alarm Configurations & Options

Alarm Options and Considerations

- The choice of an alarm system is very dependent on the facility layout and needs

- Either interface with existing facility horns/beacons or to be supplied with new horns/beacons

- Multiple or single network loops of horns/beacons

- Number of horns and/or beacons that must be supported

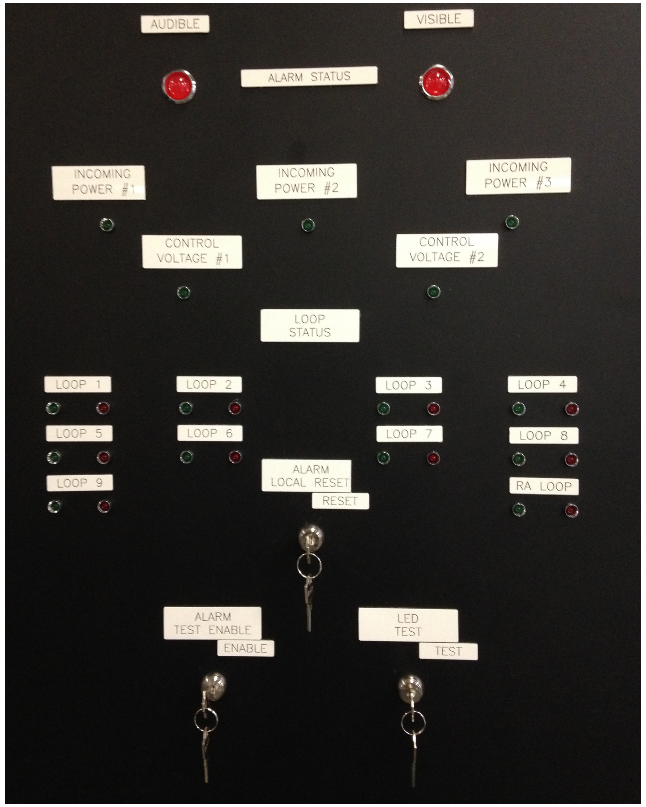
Alarm Cabinet Considerations

- There are three basic components of the alarm network:

- Power (VA) requirements to drive devices
  - Depends on number of devices that must be supported
- Multiple alarm cabinets can be networked together

Alarm Cabinet Considerations

- Level of fault indication & redundancy
  - Additional continuity loops to determine if there are physical breaks in the circuit
  - Duplicate systems and power supplies
  - Mechanical or software-based monitoring of the alarm cabinet
  - Notification or monitoring of processing cabinet operational status



CAAS-3S Alarm Relay Enclosure
Front Panel Indicators & Switches

Horns and Beacons

- If horns and/or beacons are required, Canberra will evaluate the following:
  - Horns - volume, tone
  - Beacons - Color, brightness
  - Number and location - Site/building layout with planned location of all the sensors, light and horn alarms, processing cabinet, alarm cabinet, and cable lengths
  - Site-specific standards – Note that IEC 860 only specifies horns to be above background noise level and loudness to be mutually agreed upon between parties

Testing & Maintenance

Types of Tests

Probe Functionality	Alarm Test (No source)	Alarm Test (With source)
• Signal chain • Gain processor • Threshold dose rate /voltage	• Any combination of probes • Alert logic • Voting logic • Horn • Lights • Evacuation Alarm	• Any combination of probes • Alert logic, horn, light, and evacuation alarm verified • Probe scintillator operation and threshold verified

Testing Control

- Local tests
  - Local tests are performed on the processing unit front panel
- Remote tests
  - Remote tests can be performed on any supervisor computer
- Automated tests
  - Can be programmed to run on a pre-defined schedule (nightly system checks)
- All tests require username and password

Routine Testing

- Recommended testing includes:
  - Monthly electronic testing of probes, processing cabinets, and power supplies
  - Radioactive source is not needed to test full electronic signal chain
  - Yearly radiation testing of probes with Gamma or Neutron sources

- Calibration check of probes suggested every 5-10 years

CAAS-3S Summary

Probe Highlights

Minimization of false alarms	Reliability	Maintenance
• Scintillator technology less susceptible to environmental & industrial triggers • Circuit logic less susceptible to stray radiation sources	• Analog detection chain based on 30-year install base	• No source required to test full signal chain • Probes are hot swappable

- Gamma and/or neutron detection

- Probes do not saturate - Post accident monitoring

System Highlights

Reliability

- Full redundancy through the entire signal chain
- Redundancy is automatically enabled upon fault detection

Maintenance

- Any single point of failure provides a warning
- Push button periodic testing
- Components are hot swappable

- Ease of Extension - Additional zones (and cabinets)

- Different zones can have different probe types

Summary – Canberra CAAS Systems

- **High reliability**
  - Through choice of technology and components
  - Redundant circuits through the complete signal chain
  - Qualified to meet criticality standards
  - Seismic tolerance
- **Low False Alarms**
  - Scintillator-based detection
  - Built-in alarm logic
  - Dose-rate & integrated dose based alarm
- **Ease of maintenance**
  - Testing without interruption of the monitoring
  - Testing without radioactive sources
  - Maintenance activity from remote PC
  - Fault/Failure warning