MIRION Connect 25

Annual Users' Conference

INNOVATION AT WORK

Connecting Visionaries in Radiation Safety, Science and Industry

Conrad Orlando Resort, FL –July 28th – August 1st

MIRION TECHNOLOGIES

Detectors in RMS Applications

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Mirion Connect | Annual Users' Conference 2025

Orlando, Florida

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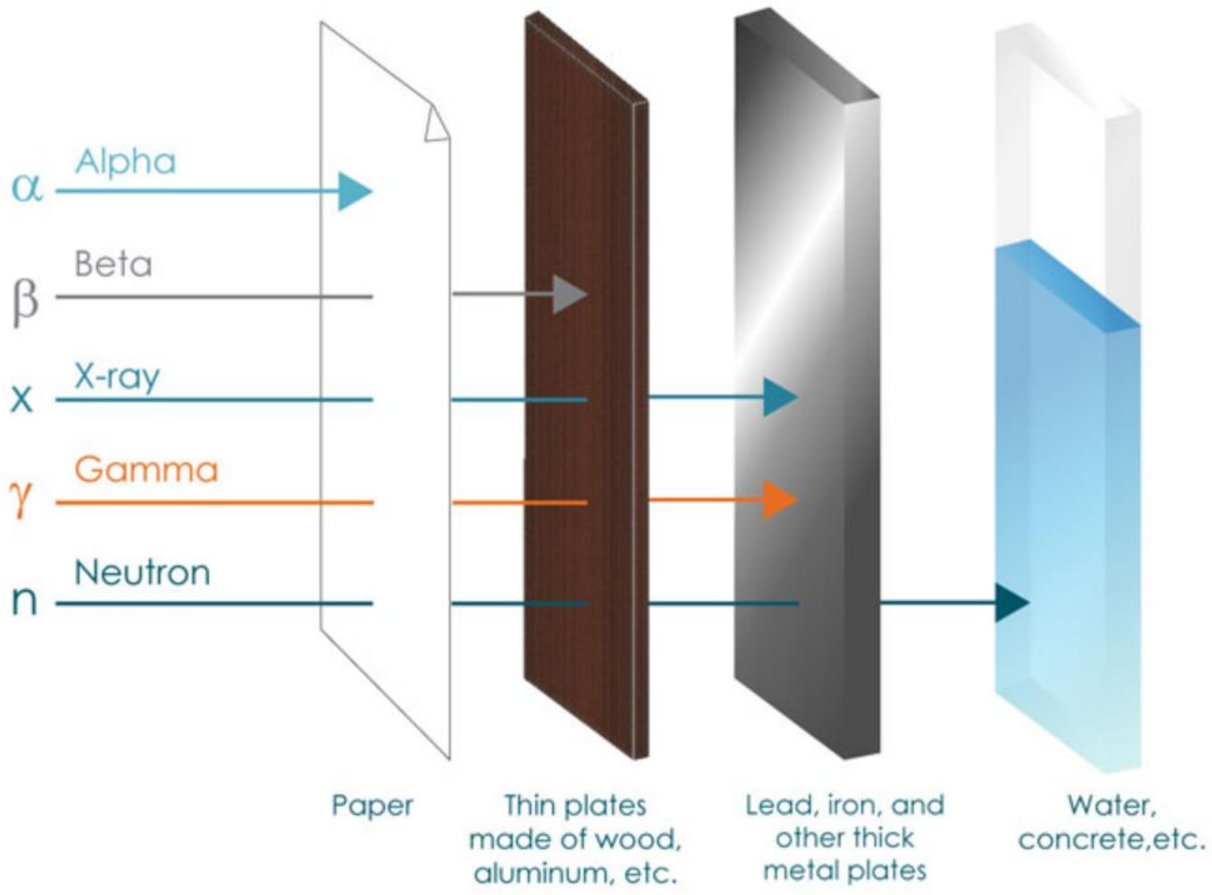
Overview

- Focus on installed Radiation Monitoring System (RMS) detectors
- Types of radiation and their sources in NPPs
- Types of detectors and their applications in RMS

Types of Ionizing Radiation



- **Alpha Particles**
  - High mass (4 amu) & high charge (+2) (helium nucleus)
  - Travel 1-2 inches in air
  - Stopped by paper, skin

- **Beta Particles**
  - Low mass (0.0005 amu) & low charge (+ or -1) (electron)
  - Travel 10 -20 feet in air
  - Stopped by book, cardboard, wood, plastic, etc.

- **Gamma Rays**
  - Electromagnetic waves produced in the nucleus
  - No mass & no charge
  - Travel many feet in air
  - Lead or steel used as shielding

- **X-Rays**
  - Same characteristics as gamma rays but originate in the electron cloud, not the nucleus
  - Typically lower energy vs. gamma rays

- **Neutrons**
  - Moderate mass (1 amu) & no charge
  - Travel many feet in air
  - Stopped by hydrogen, other low Z material (water, concrete)

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Dose Rate (Area Monitoring) Terms & Units

Roentgen

- Unit used to measure exposure to x-rays or gamma rays
- Measure of charge created in dry air
- Typical units: mR, mR/hr (SI: no equivalent)

Rad

- Unit used to measure a quantity of absorbed dose (Radiation Absorbed Dose)
- Measure of energy deposited in dry air
- Typical units: mrad, mrad/hr (SI: mGy, mGy/hr)

Rem

- Used to measure a quantity called equivalent dose;
- Measure of the absorbed dose (energy deposited) in human tissue to quantify the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose.
- Typical units: mrem, mrem/hr (SI: mSv, mSv/hr)

Common misconception: R = rad = rem; as seen above, these are different physical quantities

- 1 R = 0.877 rad
- Rad/Rem relationship is energy dependent; 1 rad Cs-137 = 1.21 rem; 1 rad Co-60 = 1.17 rem; etc.*

Process Monitoring Terms & Units

Volumetric activity

- Measure of normalized (per unit volume) activity in gas or liquid
- Typical units: µCi/cc, pCi/l, Bq/m3

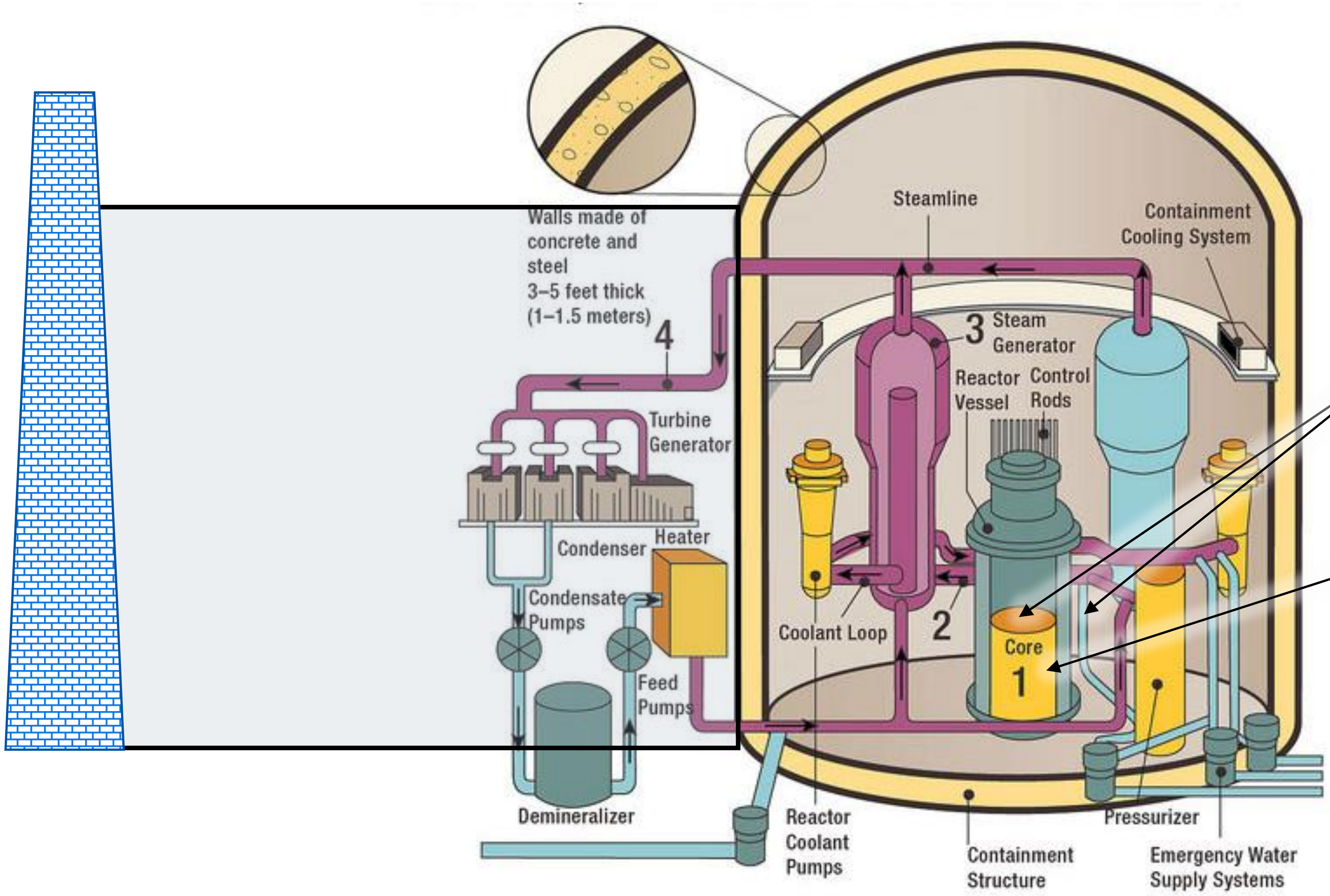
Minimum Detectable Activity (MDA) (also Minimum Detectable Concentration, MDC)

- Smallest amount of activity that can be detected in specified measurement conditions: background, measurement time, confidence level
- Typical units are those of the parent system, e.g. µCi, µCi/cc, Bq, Bq/m3, etc.
- In many plant documents, MDA or MDC is often referred to as “Sensitivity” (see below)

Sensitivity

- Response factor that correlates the raw output of a detector (e.g. CPM or amps) to the quantity of interest. Determined empirically by primary calibration, or by modeling
- Typical units: CPM/µCi, CPM/(µCi/cc), CPM/(mrad/hr), amp/(mrad)/hr, etc.
- Caution: as mentioned above, sometimes “Sensitivity” is used in referenced to MDA

Sources of Radiation (PWR Example)



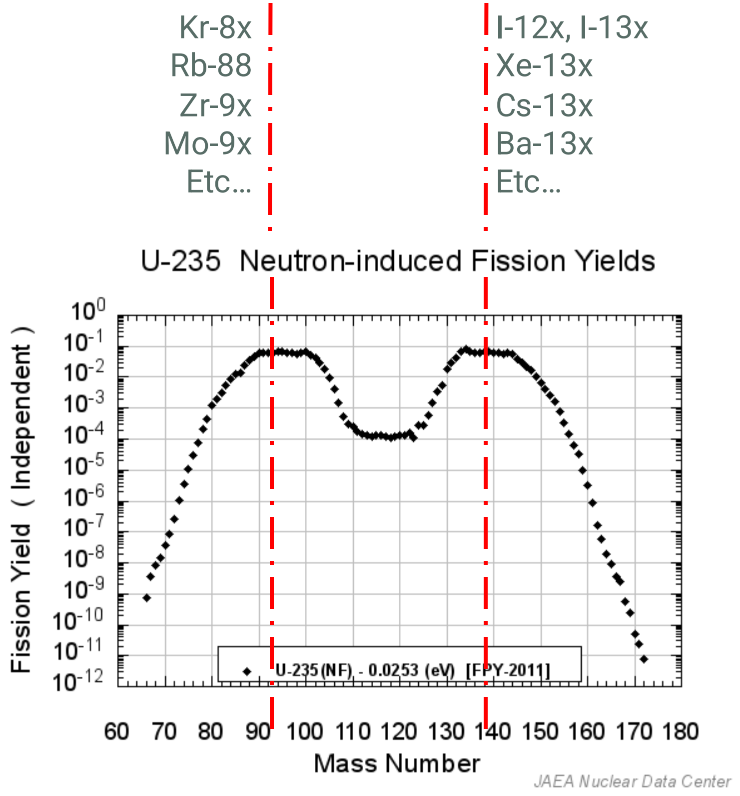
Activation products created in and around the reactor

Fission products created in the fuel

(nrc.gov/reactors/pwrs.html)

Sources of Radiation

Fission Products are the direct byproducts of nuclear fission. They are confined to the fuel pins, unless the pins are leaking.



Activation Products are created by neutrons interacting with materials in and around the reactor.

- Coolant → ^{13}N, ^{16}N, ^{18}F from water; ^{41}Ar from argon entrained in water, etc.
- Vessel & internal structures → ^{51}Cr, ^{54}Mn, ^{58}Co, ^{59}Fe, ^{60}Co …
- Around the reactor: ^{41}Ar from Argon in air (interferes with containment atmosphere monitoring)
- Advanced reactor designs may have differing activation products specific to their coolant and materials used in the vessel & internal structures. For example, sodium coolant under neutron flux will generate ^{24}Na, which emits 1.37 MeV and 2.75 MeV gammas

Radiation Monitoring Examples (PWR Example)

Effluent release points (e.g. plant vent, fuel pool vent, containment purge) are monitored for airborne activity.
Activity release results in offsite dose to the public which must be quantified
The activity can consist of both fission and activation products

In a PWR, activity in the steam line indicates a primary-secondary leak

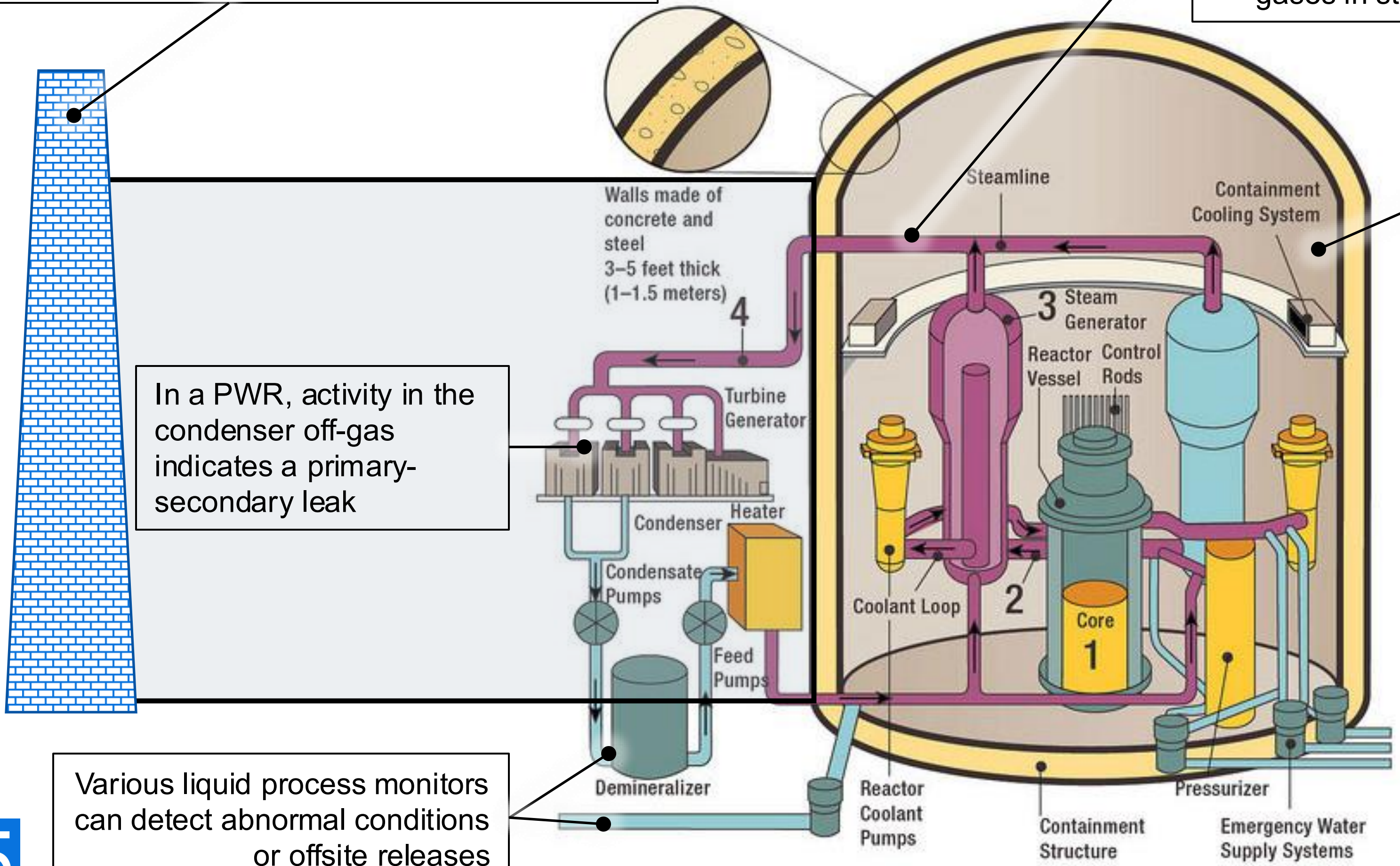
- N16 detectors can identify a small leak
- Area monitors adjacent to the steam line quantify a catastrophic leak / environmental release (mixed noble gases in steam line)

A sample drawn from containment can be monitored for airborne radioactivity to detect a small primary coolant leak

- Typ. Rb-88 or Cs-137 particulate
- Typ. Kr-85, Xe-133 noble gas

In a PWR, activity in the condenser off-gas indicates a primary-secondary leak

Various liquid process monitors can detect abnormal conditions or offsite releases

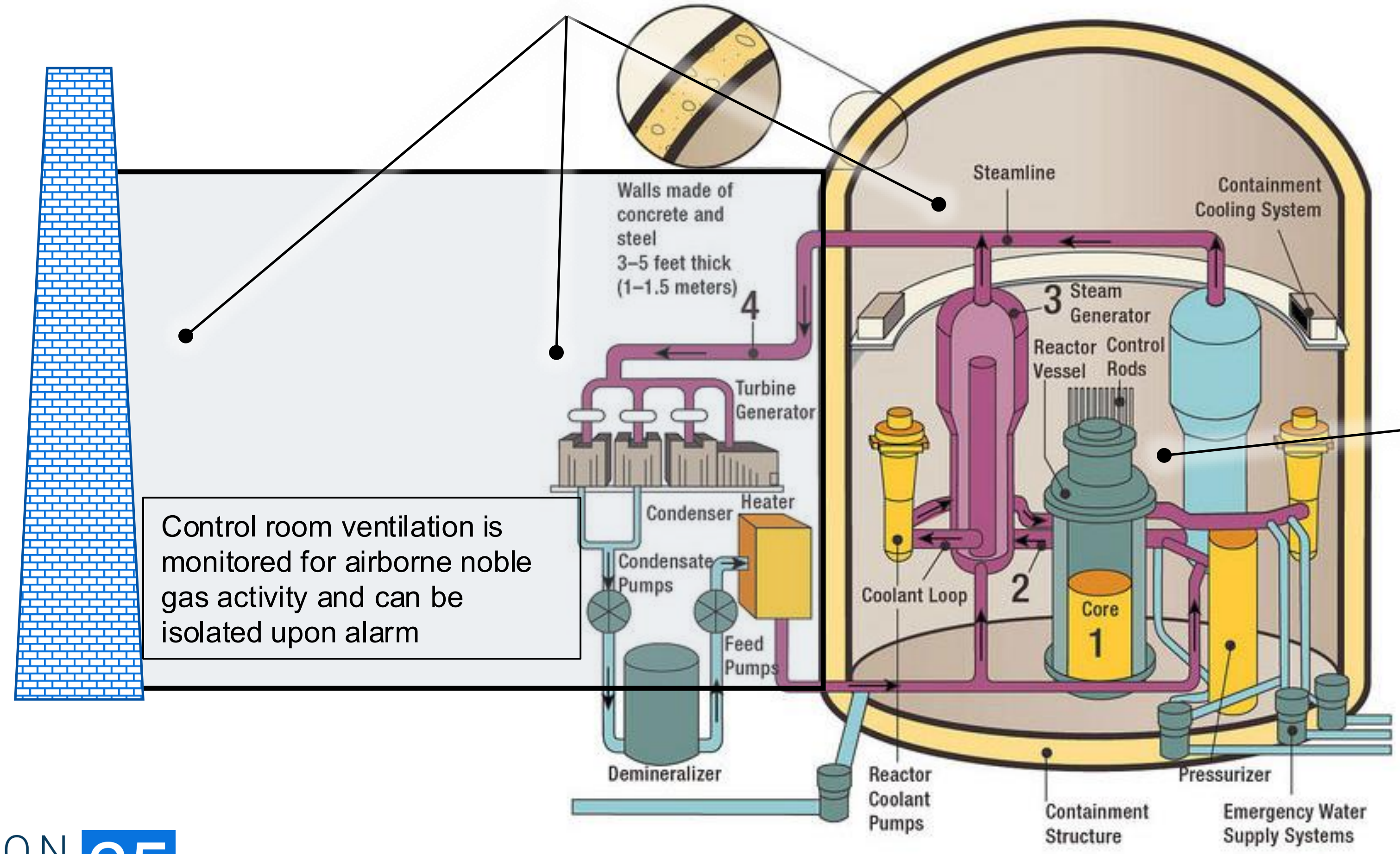


(nrc.gov/reactors/pwrs.html)

Radiation Monitoring Examples (PWR Example) (cont'd)

Gamma area monitors placed throughout the plant, including in containment, alert operators to high dose rates

Area and/or airborne monitors at the plant boundary provide an indication of release to the environment and surrounding public
(typically a separate system from the RMS)



During a severe accident, a LOCA-qualified gamma detector inside containment is used to track the magnitude of the accident
(this is not a personnel protection ARM)

Control room ventilation is monitored for airborne noble gas activity and can be isolated upon alarm

(nrc.gov/reactors/pwrs.html)

Measuring Radiation

	Sources	How measured – airborne
Alpha emitters	Fuel (^{235}U, ^{238}U)	N/A
	Radon daughters	N/A -- but can interfere with beta particulate detectors
Beta and/or Gamma/x-ray emitters	Noble gas fission & activation products e.g. Kr-85, Xe-133	Normal range: Offline monitor with sample chamber viewed by beta scintillation detector, or beta GM tube, or PIPS detector Accident range: GM tube or ion chamber adjacent to sample chamber, or flow-through ion chamber
	Particulate fission & activation products e.g. Co-60, Cs-137, Rb-88	Offline monitor with filter paper viewed by beta scintillation detector, or beta GM tube, or PIPS detector
	Gaseous or molecular iodine (activation product)	Gamma scintillation detector viewing offline sample cartridge
	Radon daughters (particulates)	Naturally occurring but interferes with beta particulate measurement – can be compensated with alpha (PIPS) detector

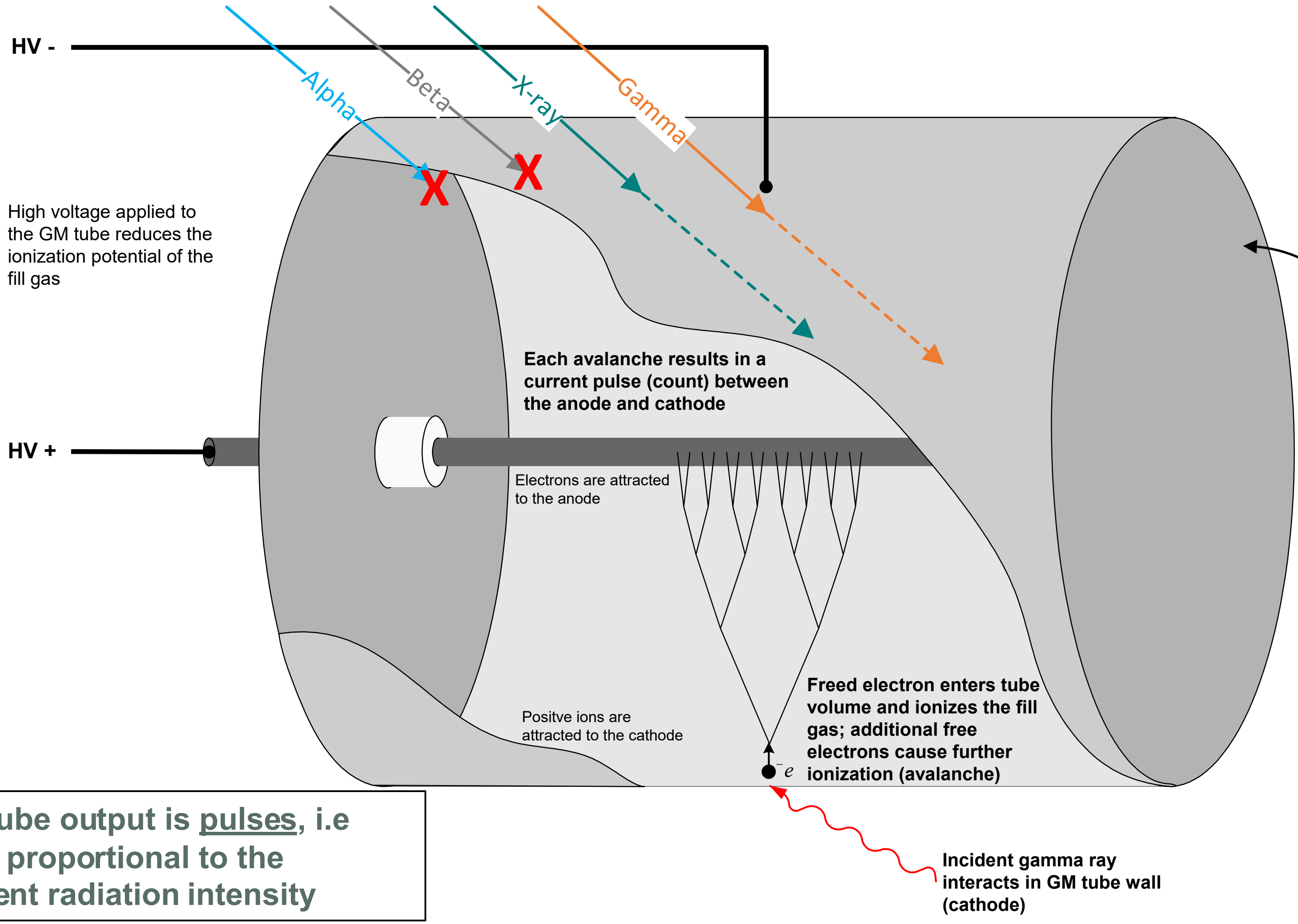
Measuring Radiation (cont'd)

	Sources	How measured – entrained in process
Alpha emitters	Fuel (^{235}U, ^{238}U)	N/A
	Radon daughters	N/A
Beta and/or Gamma/x-ray emitters	Noble gas fission & activation products	In steam line: Adjacent to line area monitor (GM tube, Ion chamber, scintillation detector) In liquid process: N/A – low entrainment of NG in water
	Particulate fission & activation products	Adjacent to line gamma scintillation detector
	Gaseous or molecular iodine (activation product) e.g. I-131, I-135	Adjacent to line gamma scintillation detector
	Radon daughters (particulates)	N/A

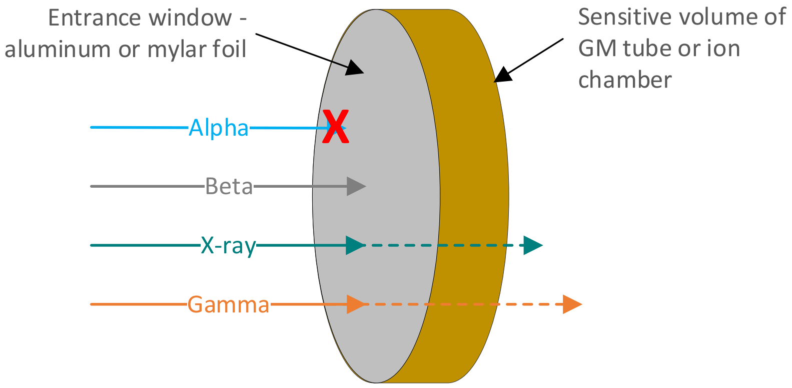
Measuring Radiation (cont'd)

	Sources	How measured – gamma dose rate
Gamma/x-ray dose rate	Contaminated process streams, filter banks, etc; reactor, RCS, steam lines	GM Tubes Ion chambers Si diode detectors

Geiger Mueller Tube Detection Principle



A thin entrance window, e.g. aluminum or mylar, will allow beta detection ("pancake GM tube")



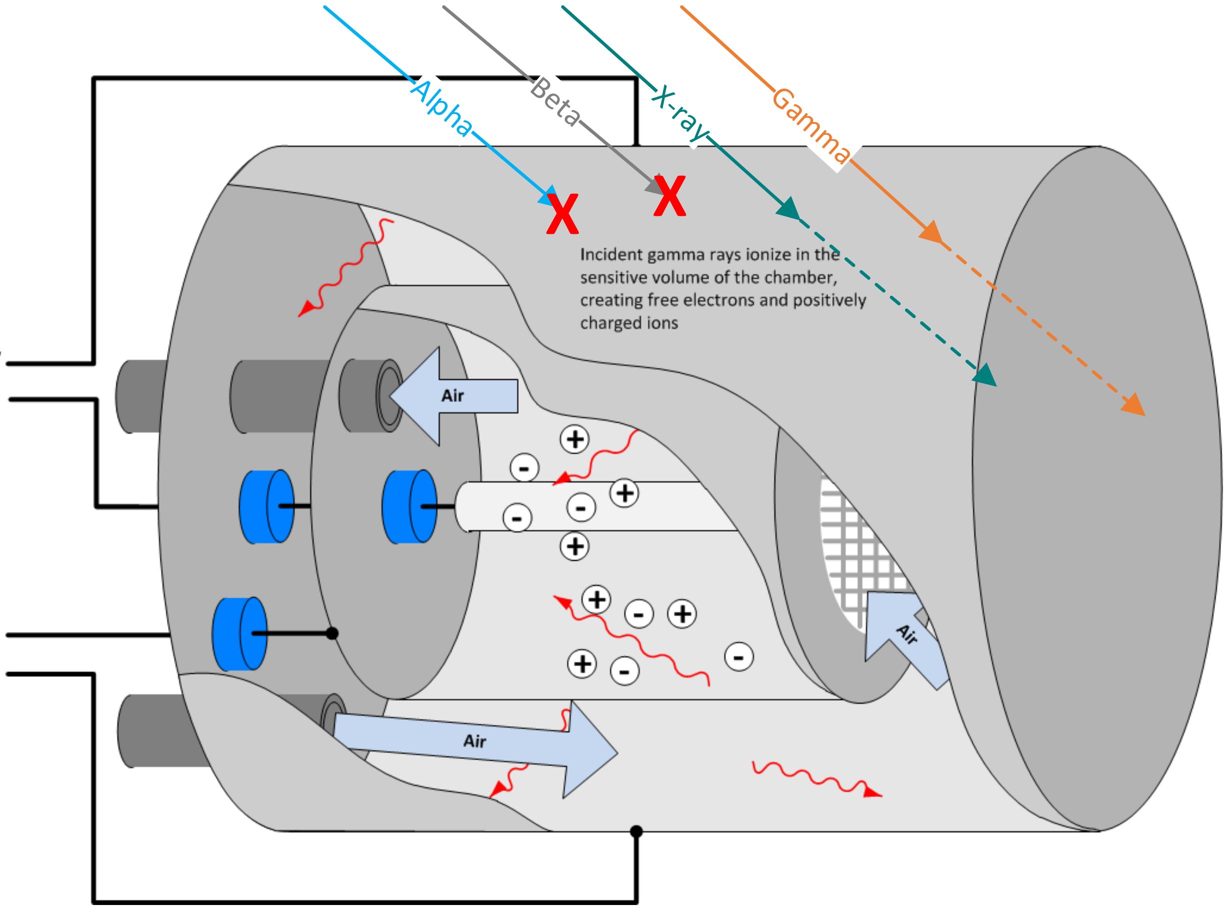
Thin-window GM tube or ion chamber

- GM Tube output is pulses, i.e CPM, proportional to the incident radiation intensity

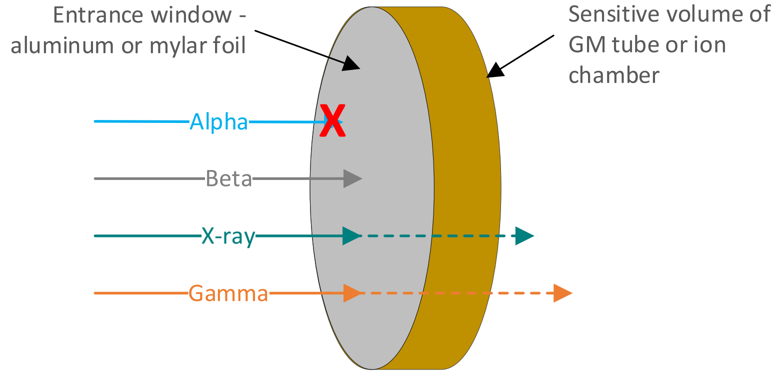
Ionization Chamber Detection Principle

The current measured by the processing unit is proportional to the intensity (amount) of radiation – i.e. proportional to the dose rate at the detector location and to the amount of activity in the pipe being monitored.

High voltage is applied to the ionization chamber, drawing electrons to the anode and positive ions to the cathode.



Flow-through ion chamber shown; sealed chamber is conceptually similar except all radiation originates from the outside.

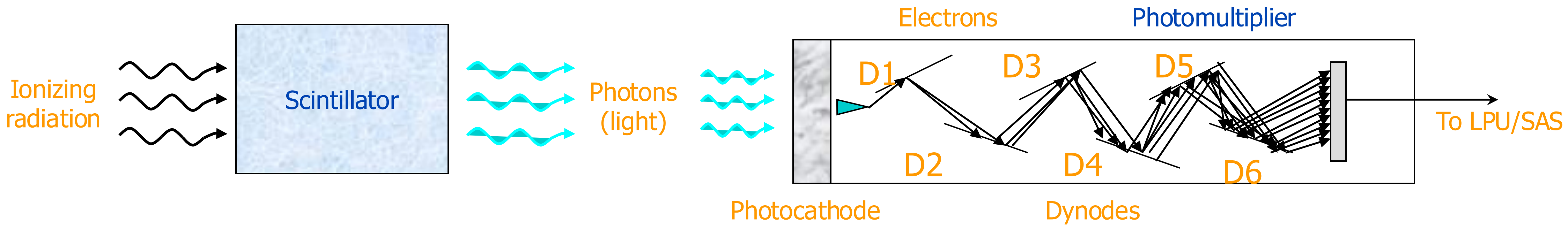


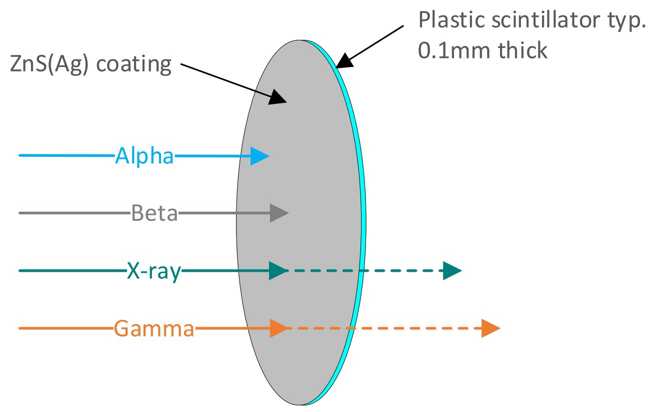
Thin-window GM tube or ion chamber

- **Ion chamber output is current, i.e Amps, proportional to the incident radiation intensity**

Scintillation Detection Principle

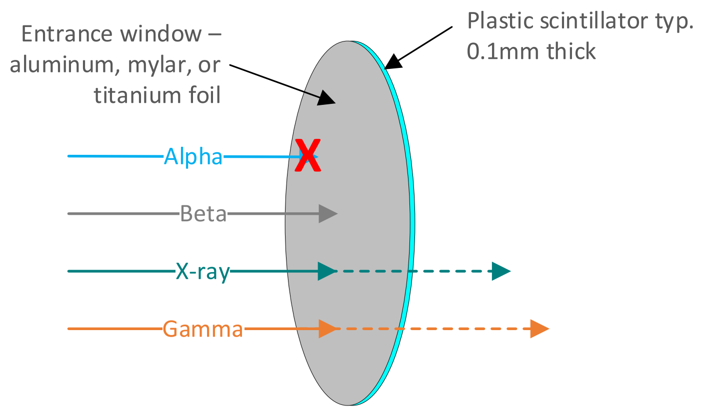
- Scintillation detector output is <u>pulses</u>, i.e <u>CPM</u>, proportional to the incident radiation intensity
- Additionally, pulse amplitude is proportional to the radiation energy



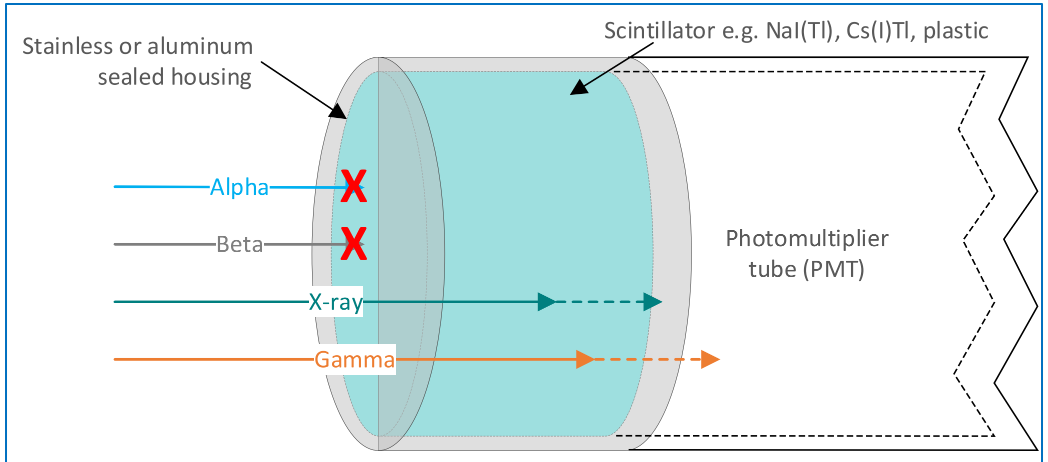


Alpha/Beta plastic scintillation detector

(not commonly used in RMS applications)



Beta plastic scintillation detector

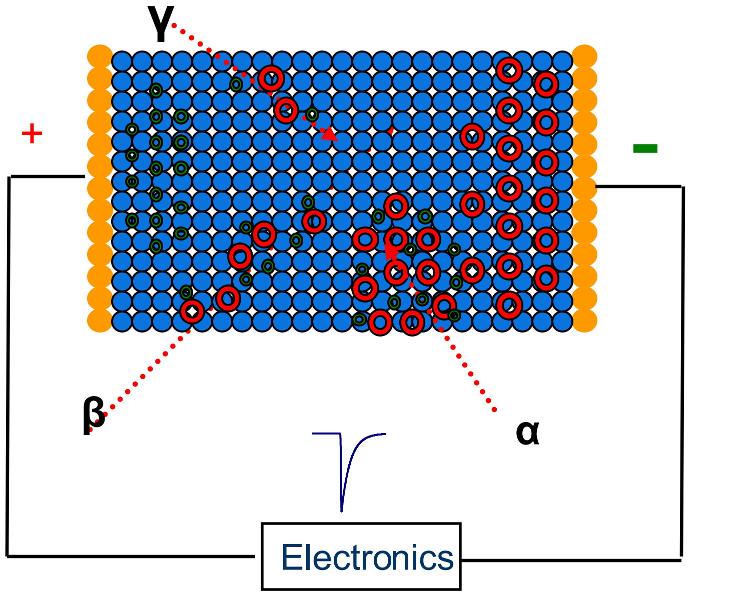


Gamma scintillation detector

PIPS Detection Principle

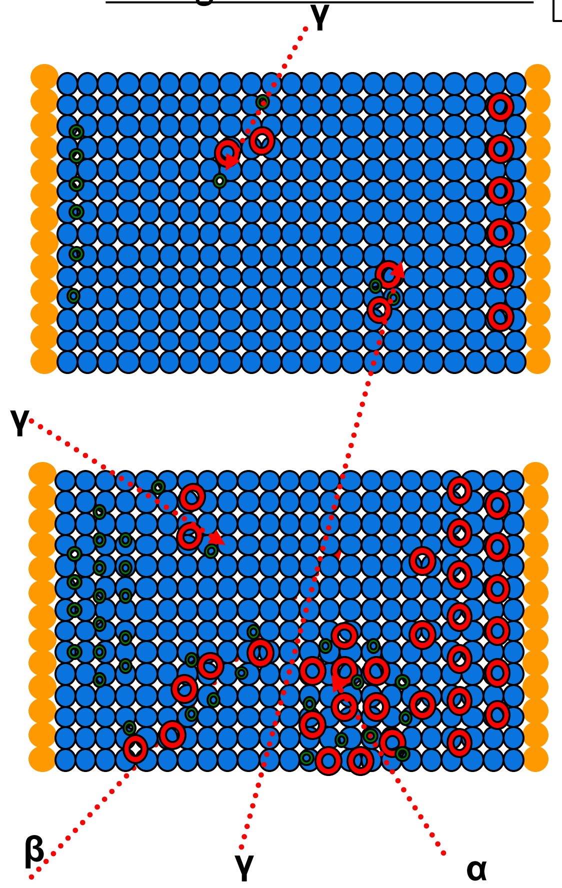
- PIPS detector output is pulses, i.e CPM, proportional to the incident radiation intensity
- Additionally, pulse amplitude is proportional to the radiation energy

PIPS Solid State Silicon Diode:
(PIPS = Passivated Implanted Planar Silicon)

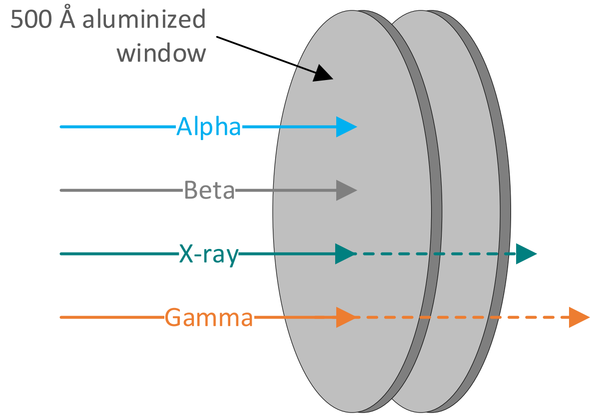


Ionizing radiation entering the PIPS diode creates free electrons and corresponding "holes" in the diode.
A bias voltage (~80 V) is applied to the diode to collect the electrons and holes, generating a pulse (count).
Because the active layer of the diode is thin and not very dense, the diode is more sensitive to charged particles (alpha & beta) than to photons (gamma).

Background Subtraction:



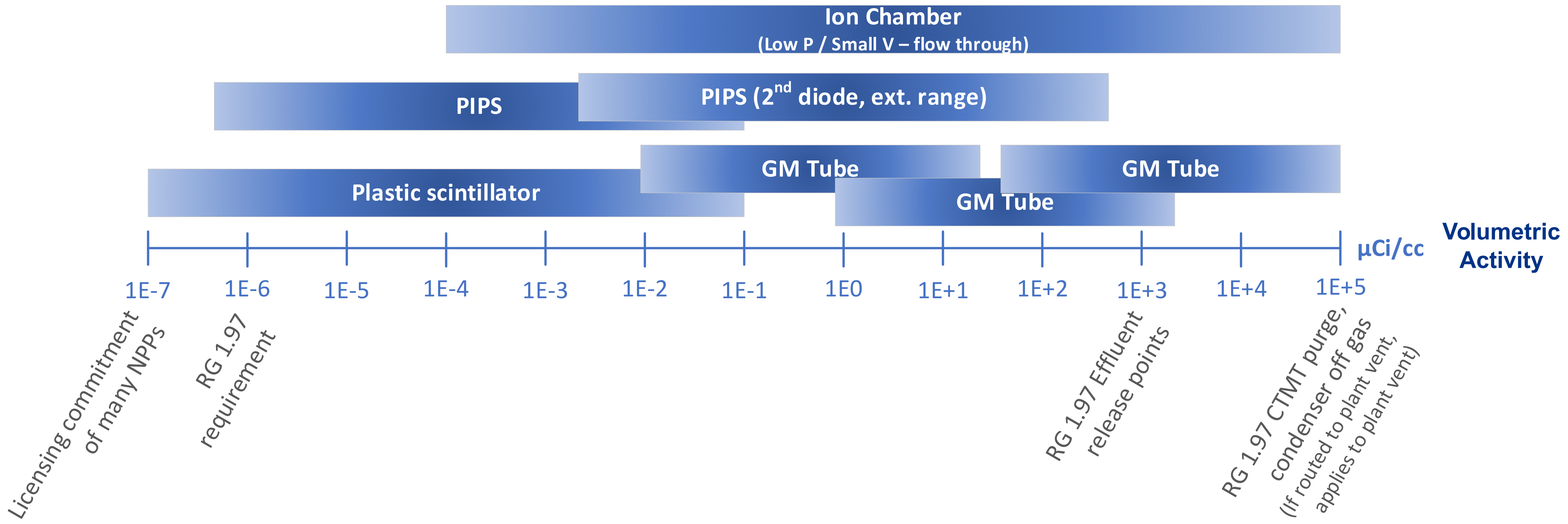
By "stacking" two PIPS diodes together, the 2nd diode is shielded from alpha & beta radiation. Both diodes will detect gamma radiation.
The response of the 2nd diode is subtracted from that of the 1st diode for gamma compensation.



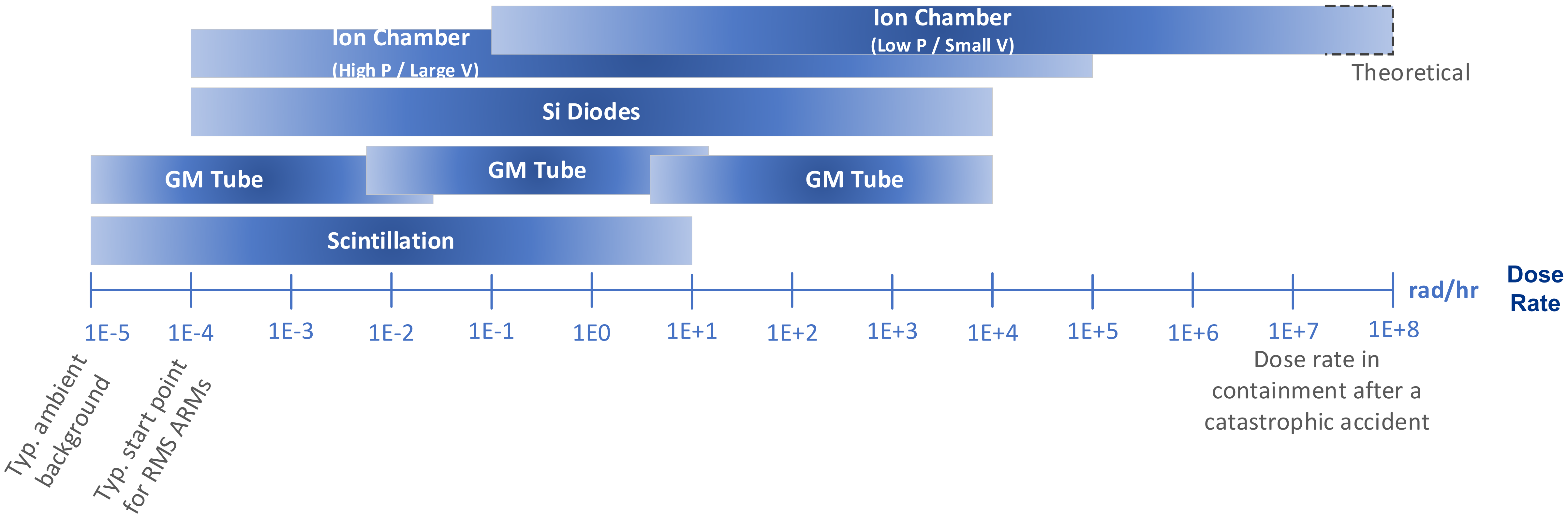
PIPS Diodes
(2X stacked configuration)

Detector Selection – process monitoring

Scale shown below for noble gas since it is always monitored, including accident range:



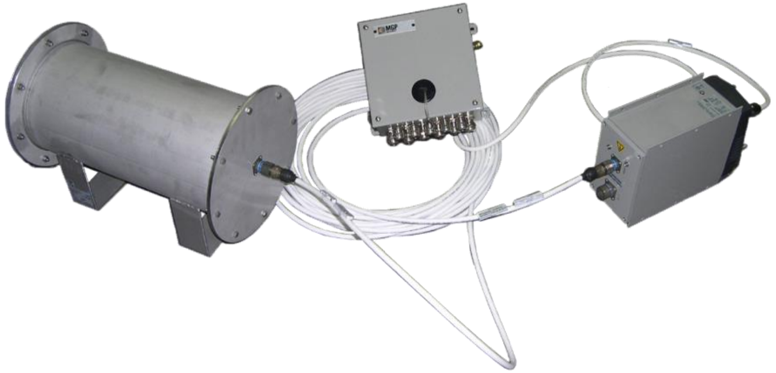
Detector Selection – area monitoring



Area & Process Monitors

Ion Chamber Detector with Local Processing & Display Unit (LPDU) field unit

N16 detector with Local Processing Unit (LPU) field unit & signal junction box



Si Diode Detector & LPDU field unit

Adjacent to line (ATL) shielded liquid process monitor

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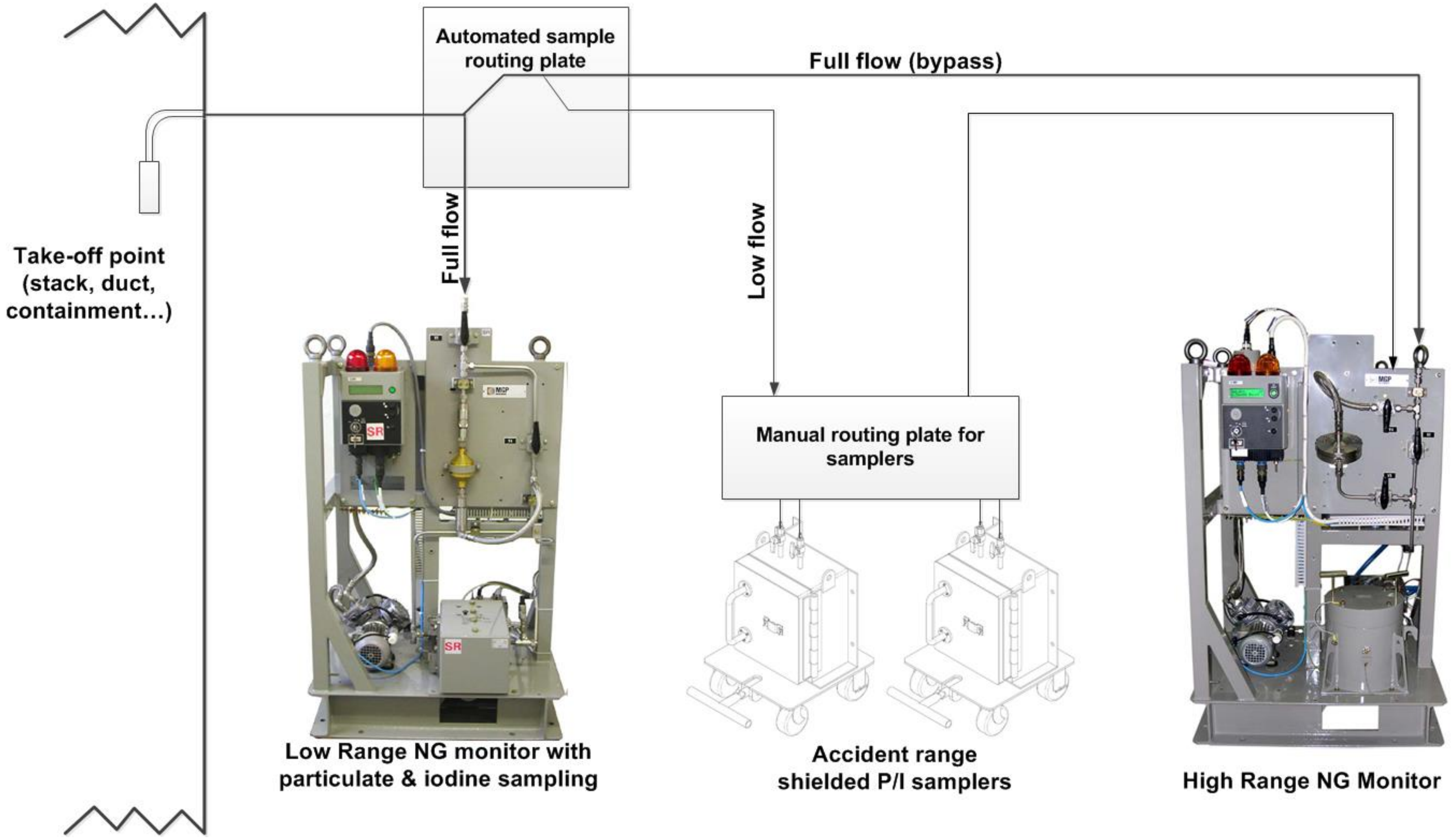
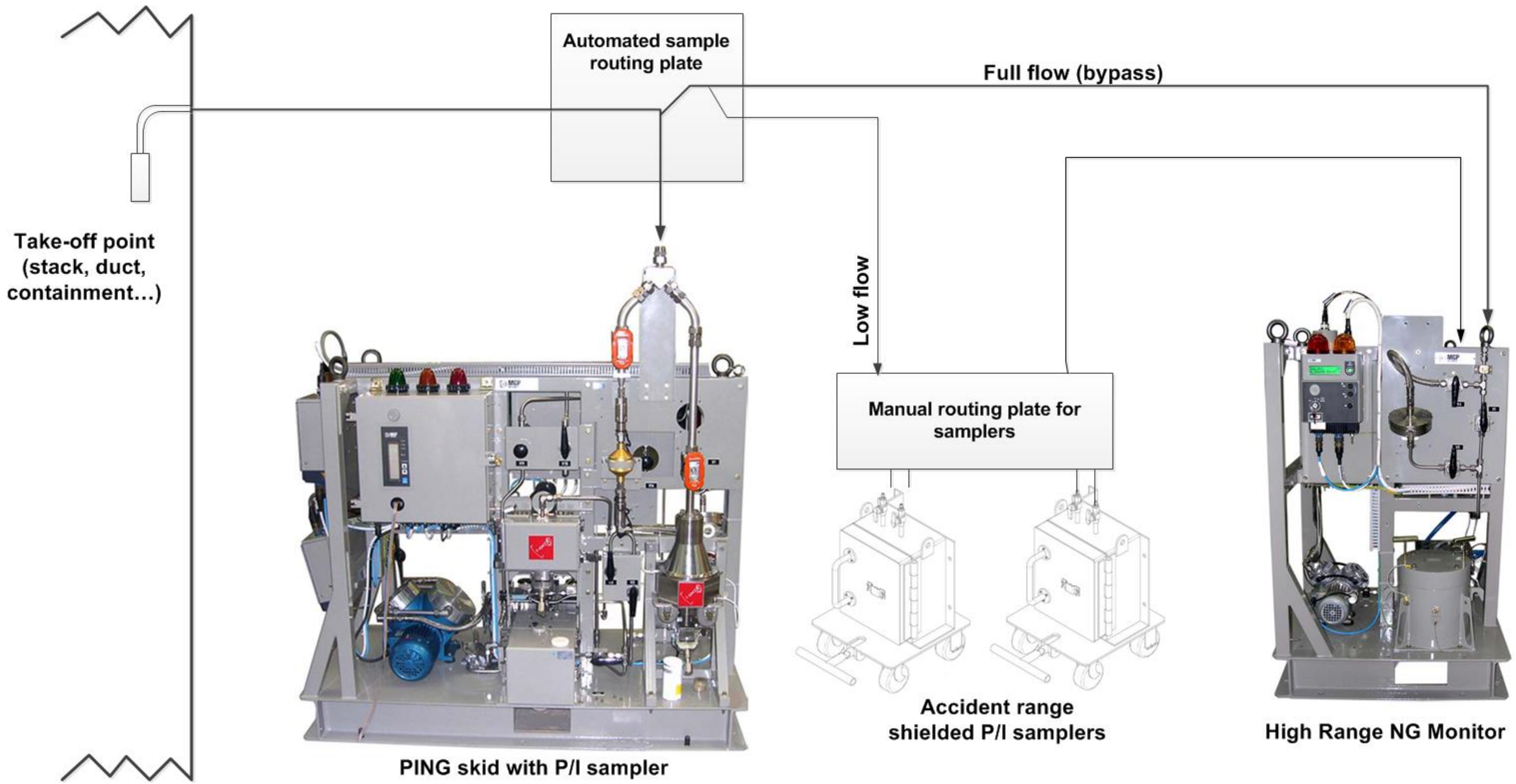
Typical Offline Airborne Monitoring System



- Simple normal + accident range configuration
- Normal and accident range NG *monitoring sampling*

“Complete” Offline Airborne Monitoring System

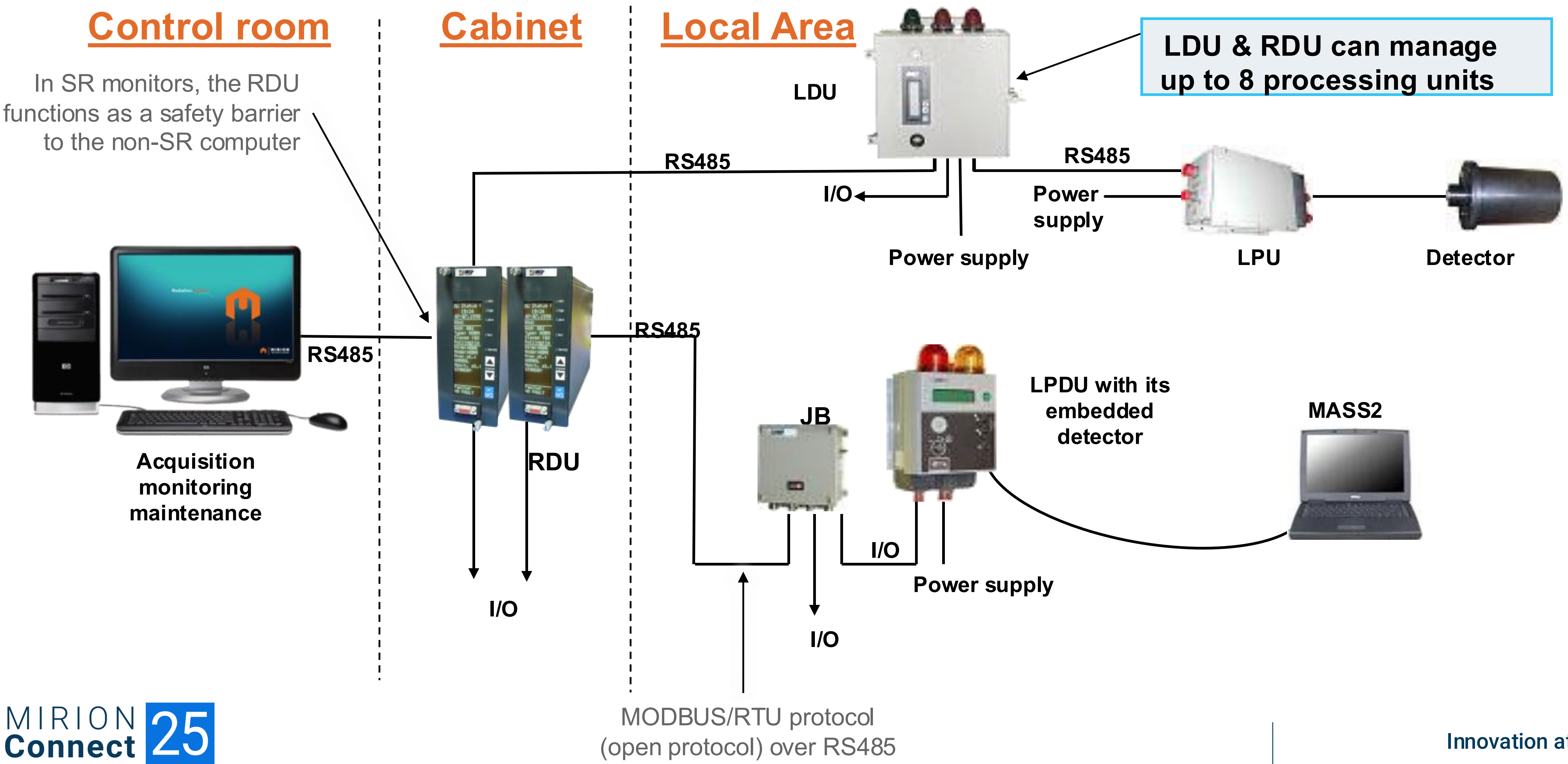


- Normal range PING skid + high range noble gas monitor & samplers
- Presence or absence of P&I detectors determined by plant licensing docs – regs only require sampling

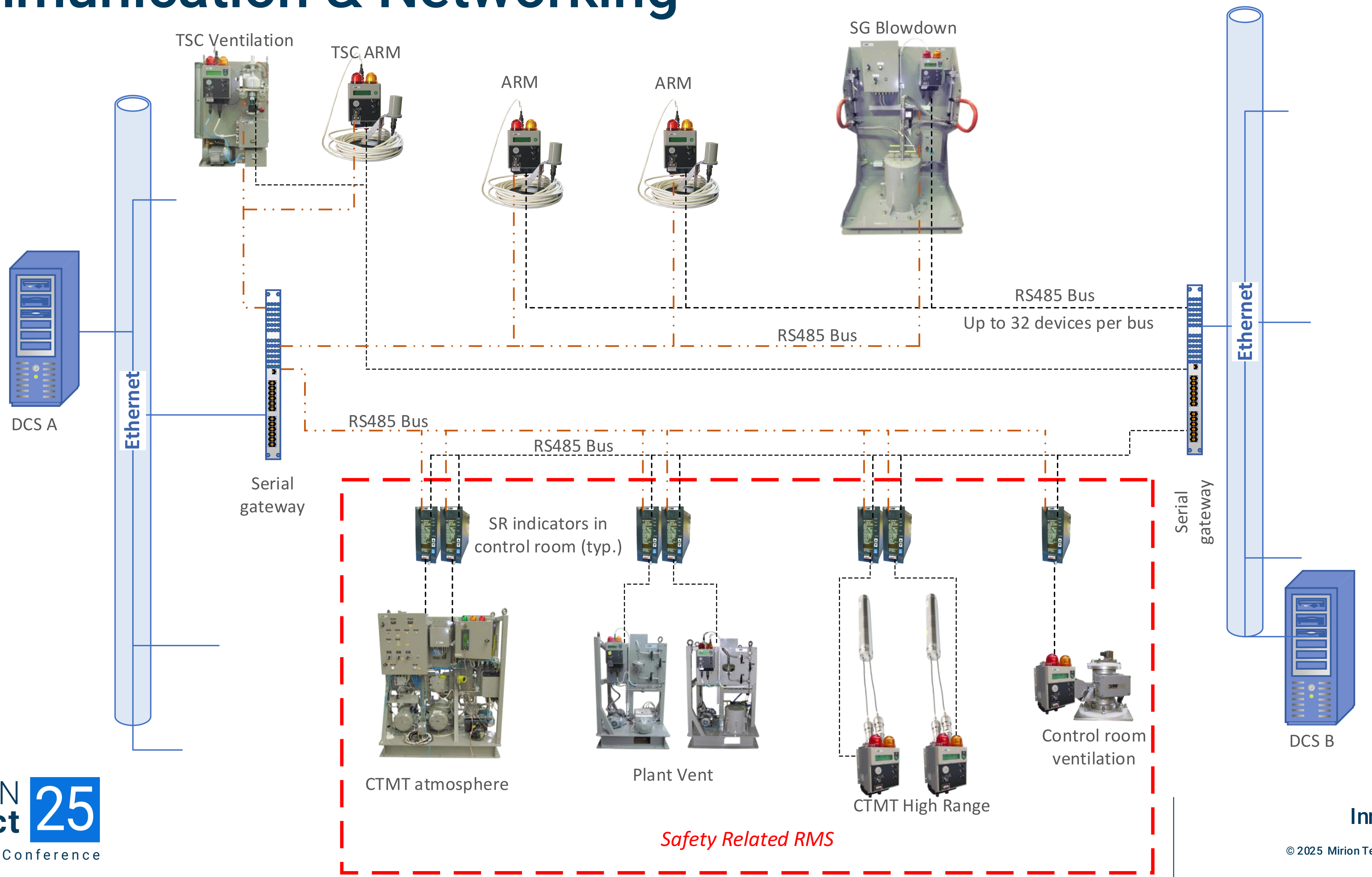
A note about offline sampling

- To effectively sample or monitor particulate, the particulate reaching the sample collector or detector must be representative of what was drawn in at the sample point.
- Particle size can range from 0.002 to 100 µm
- Examples: Dust, cloud, fume, haze, fog, smog, smoke, spray, etc…
- **The main challenge in particulate monitoring is to ensure that the aerosol distribution / concentration at the source (i.e. stack) does not change by the time it gets to the monitor.**
- This requires:
  - Specific flow regime (Reynolds number between laminar and turbulent)
  - Vertical line with very smooth transitions / bends
  - Shortest possible sample line, specifically shortest possible horizontal runs
- Otherwise, the majority of the particulate / aerosol may deposit on the inner surfaces of the sample lines and the measurement is rendered irrelevant.
- Similar concepts apply to transport of radioiodine.
- Requirements:
  - Operating NPPs: ANSI N13.1-1969
  - New non-NPP facilities: ANSI N13.1-1999 or 2011

Communication & Networking



Communication & Networking



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Useful References

- Glenn F. Knoll, *Radiation Detection & Measurement*
- *Area and Process Radiation Monitoring System Guide, Rev. 3*, EPRI, Dec. 2017
- *Calibration of Radiation Monitors at Nuclear Power Plants: Revision 2 of TR-102644*, EPRI, Dec. 2017
- *Instrumentation For Light-water-cooled Nuclear Power Plants To Assess Plant And Environs Conditions During And Following An Accident,* Regulatory Guide 1.97, Rev. 2 or Rev. 3 for US NPPs
- *Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities*, ANSI N13.1, 1969 (US NPPs), 1999/2011 (new non-NPP facilities)

Questions?

Thank you