HSE
Radiation Protection

Radiation Monitoring - Requirements

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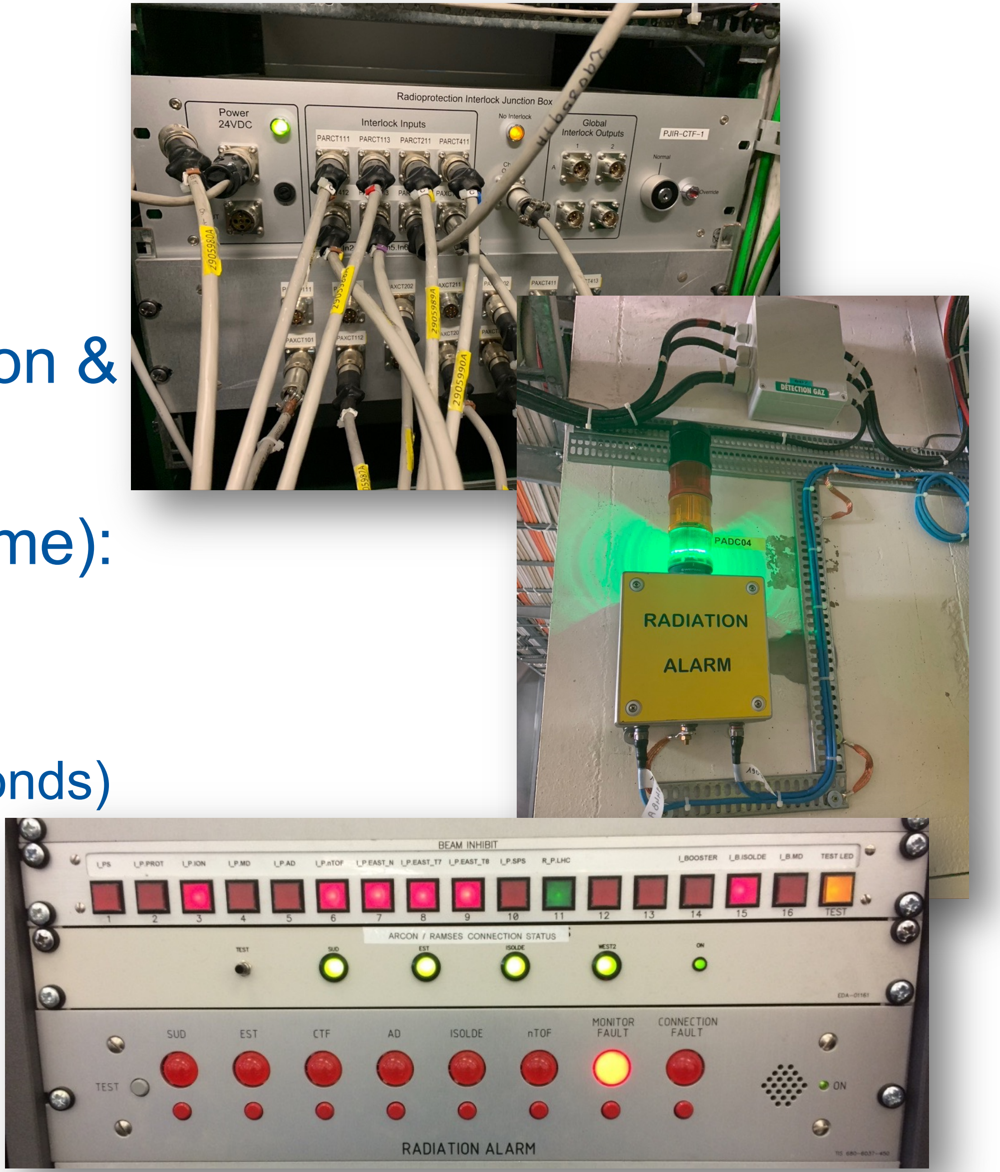
EDMS 2804019

Radiation from accelerator operation

- High energy particle accelerators produce stray radiation
  → ideally contained by passive shielding
- Full containment of radiation in any situation is **technically challenging** or **not economical**
- Radiation levels may potentially exceed legal limits in some operation situations → need for active mitigation to limit impact
- Critical locations:
  - Potential or high beam loss rates
  - Access points
  - Ducts (ventilation or cabling)
  - High occupancy areas
  - Known weak shielding spots
- Equally for areas with:
  - Other modulated radiation sources (e.g. X ray generating devices)
  - Movement of highly radioactive objects

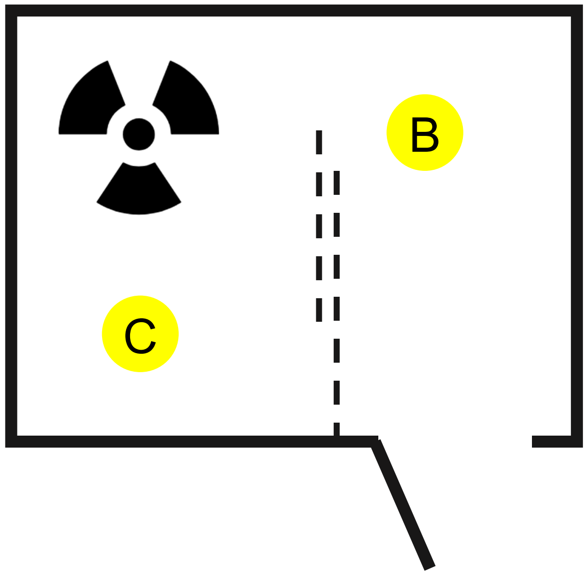
Radiation monitoring

- **Active radiation monitoring**
- Monitoring = (Dose) measurement & Alarm function & Logging
- Depending on risk level (and expected reaction time):
  - Local alarm signalisation (~ hours)
  - Alarm transmission to accelerator operator (~ minutes)
  - Automatic interlock of potential radiation source (~ seconds)
- Considering external conditions via status input information
- Reliability for safety <u>and</u> operation



Monitoring configurations & external conditions

A **Unconditional “Always accessible”**: Alarms are generated



Conditional “Monitor when access”
- SAFE FOR ACCESS: Alarms are generated
- SAFE FOR OPERATION: Alarms are inhibited

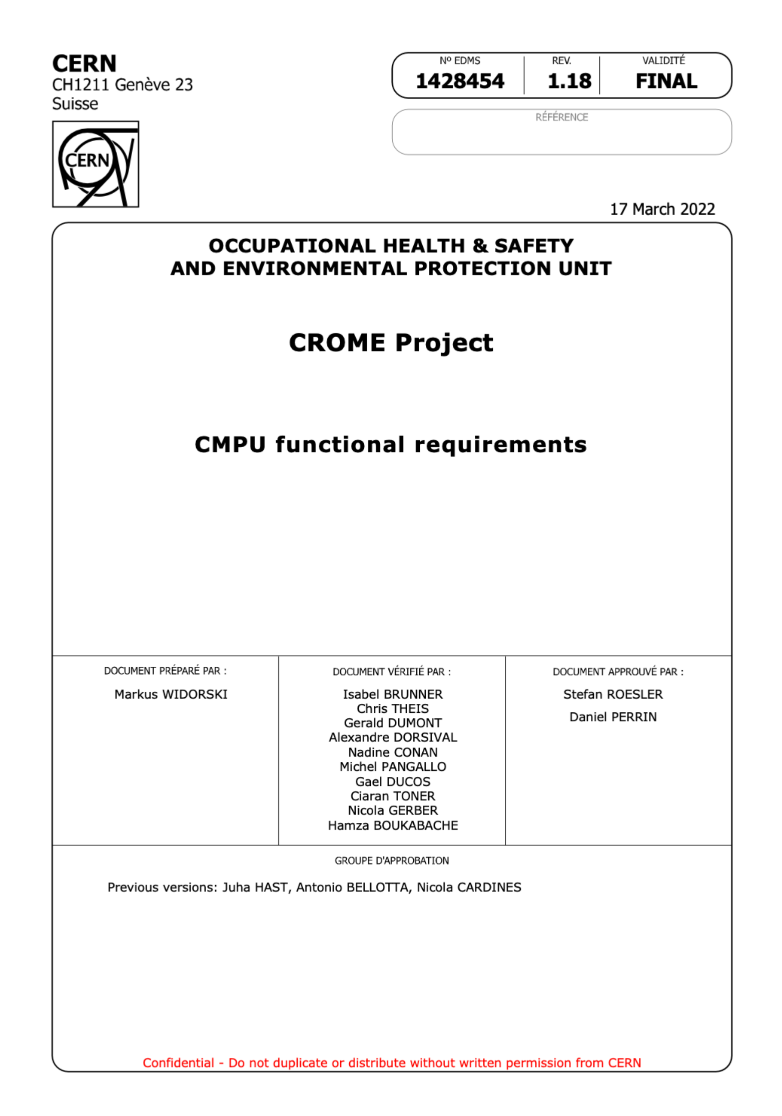
Conditional “Prevent access”
- SAFE FOR ACCESS: Below threshold (no alarm)
- SAFE FOR OPERATION: Any level permitted

Some common configurations for radiation monitors requiring external inputs or outputs from/to other systems

Functional requirements

- “CMPU Functional Requirements (EDMS 1428454)
- **Inputs:**
  - Measurement signal: current / pulses
  - Status information (via potential-free relay contacts)
  - Parametrisation via Ethernet (REMUS or other application)
- **Processing**
  - Operation modes
  - Measurement value calculation
  - Integration and averaging of values
  - Alarm and event generation
  - Fault diagnostics
  - Input/output operations & logics
- **Outputs**
  - Local alarm displays
  - Status information (via relays)
  - Data transfer via Ethernet (REMUS or other application)

→ Discover all implemented functionalities on Wednesday in the CROME hands-on training session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1428454	1.18	FINAL

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CROME Project

CMPU functional requirements

DOCUMENT PRÉPARÉ PAR :	DOCUMENT VÉRIFIÉ PAR :	DOCUMENT APPROUVÉ PAR :
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GROUPE D'APPROBATION

Previous versions: Juha HAST, Antonio BELLOTTA, Nicola CARDINES

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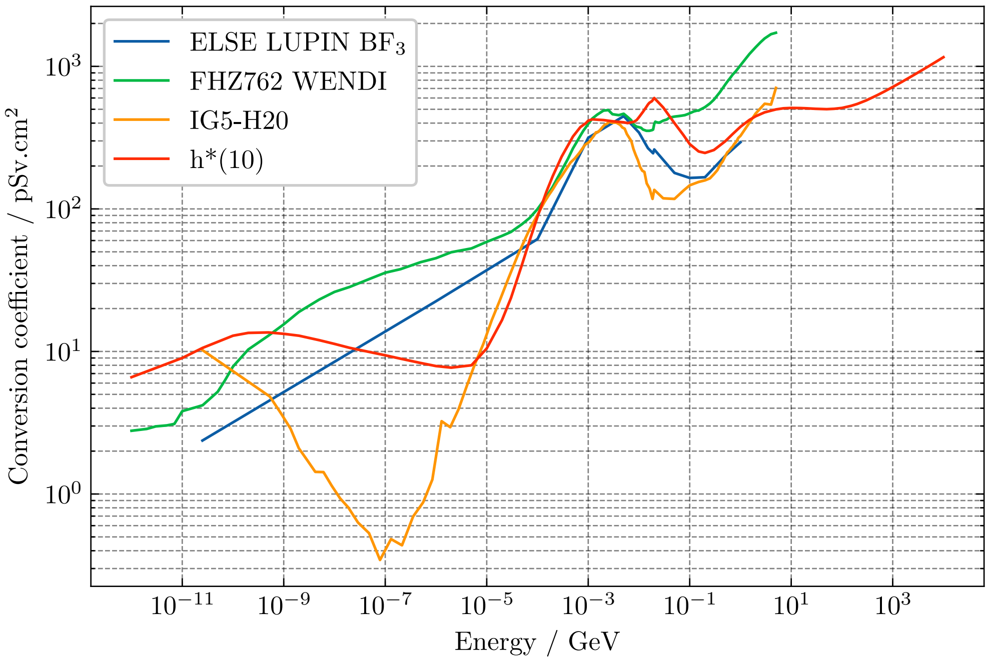
Measurement parameters

- Measurement quantity: Ambient dose equivalent H*(10) (usually referenced to ^{137}Cs or AmBe)
- Specific challenges in accelerator environments
  - mixed particle spectra → field or correction factor
  - dynamic radiation fields (pulsed radiation, low duty cycle)
- Timing
  - Account for varying radiation levels over time, periodicity and low signals
  - Averaging at accelerators: Typically using a simple moving average over a few super cycles and matching basic accelerator cycle.
- Alarm thresholds
  - For radiation protection: The dose is of interest !
  - Dose-based values so far rarely used (not available in RAMSES, but in CROME), usually reasoning in dose rate.



Example: Energy dependent neutron conversion coefficients for various detectors

Ideal detector:
- Response function that models h*(10) for any particle at any energy
- Independent of any time structure of the radiation field

Dose (rate) limits and alarm thresholds

Applicable for the lower measurement range limit		
Requirement/Justification	**Dose**	**Derived dose rate**
Below this threshold, doses to non-occupationally exposed workers are considered to be optimised	10 µSv / year (based on 2000 h) [2]	0.005 µSv/h
Below this threshold, doses to occupationally exposed workers are considered to be optimised	100 µSv / year (based on 2000 h) [2]	0.05 µSv/h
Delimitation between non-designated and radiation areas	1 mSv / year (based on 2000 h)[2]	0.5 µSv/h
A potential alarm or interlock level based on integrated dose	2 µSv over 4 hours[3]	0.5 µSv/h
Delimitation between non-designated and radiation areas	20 µSv per week (based on 40 hours) [4]	0.5 µSv/h
Delimitation between non-designated and radiation areas with low occupancy	20 µSv per week (based on 8 hours)[4]	2.5 µSv/h
Delimitation between Supervised and Controlled Radiation Areas	6 mSv / year (based on 2000 h) [2]	3 µSv/h
Delimitation between Simple Controlled and Limited Stay Controlled Radiation Areas	20 mSv / year (based on 2000 h) [2]	10 µSv/h

EDMS 1314879

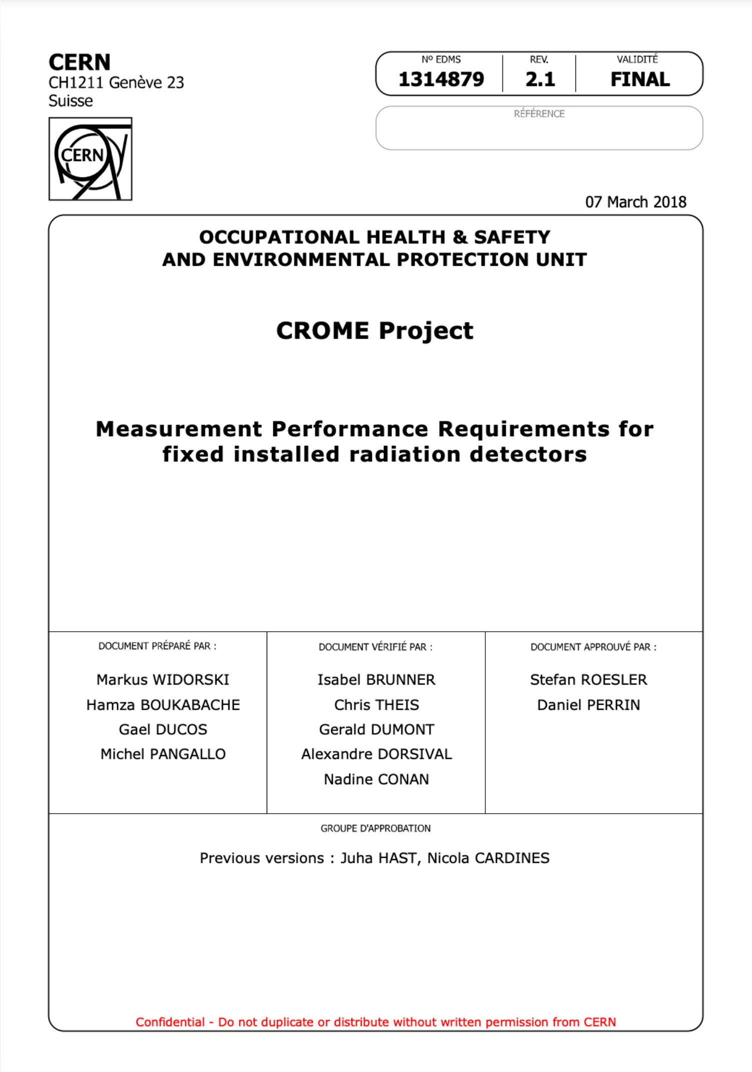
- General alarm thresholds
- May be adapted to local requirements (extrapolation)

EDMS 1376031

Area classification			**Permanent workplaces**		**Low-occupancy**	
			Warning	Action	Warning	Action
Non-designated Area			0.5 µSv/h	1 µSv/h	2.5 µSv/h	5 µSv/h
Radiation Area	Supervised Radiation Area		3 µSv/h	6 µSv/h	15 µSv/h	30 µSv/h
	Controlled Radiation Area	Simple Controlled Radiation Area	10 µSv/h	20 µSv/h	50 µSv/h	100 µSv/h
		Limited Stay Area	-	-	not predefined	
		High Radiation Area	-	-	not predefined	
		Prohibited Area	-	-	not predefined	

Measurement performance requirements

- “Measurement Performance Requirements for fixed installed radiation detectors” EDMS 1314879
- Input derived from CERN-SC-2004-007-RP-TN (A. Muller, Réponse des chambres d‘ionisation dans des champs de radiations pulsées intenses)
- Measurement ranges:
  - 50 nSv/h – 100 mSv/h (accessible area monitoring)
  - 0.5 uSv/h – 10 Sv/h (tunnel monitoring)
- Determines the minimum and maximum measurable charge to the measurement electronics
- The document defines:
  - accuracy and precision criteria
  - stability criteria
  - environmental parameters for operation conditions
- Specific to the set of ionisation chambers used by RP at CERN



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CROME Project

Measurement Performance Requirements for fixed installed radiation detectors

DOCUMENT PRÉPARÉ PAR :	DOCUMENT VÉRIFIÉ PAR :	DOCUMENT APPROUVÉ PAR :
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Standard ionisation chamber types used by RP at CERN

Monitor type	Detector model	Measurement range	Typical conversion factor [A/Sv/h]	Output current range	Pulse charge at 90% saturation[7] (nominal HV)
AGM	CENTRONIC IG5-A20	50 nSv/h – 0.1 Sv/h	γ: 1.6 10^{-6}	80 fA – 160 nA	100 nC
AMF	CENTRONIC IG5-H20	**50** nSv/h[8] – 0.1 Sv/h	γ: 1.13 10^{-7} n: 4.0 10^{-8}	5.7 fA – 11.3 nA **2** fA – 4 nA	< 30 nC
XRM	CENTRONIC IG5T-A15	50 nSv/h – 0.1 Sv/h	γ: 1.2 10^{-6}	60 fA – 120 nA	unknown
	CENTRONIC IG5T-N15	50 nSv/h – 0.1 Sv/h	γ: 6.83 10^{-7}	34 fA – 68 nA	unknown
	PTW T32006	0.5 μSv/h – **10** Sv/h	γ: 2.5 10^{-8}	12.5 fA – **250** nA	5 nC
TGM[9]	CENTRONIC IG5-A20	1 μSv/h – 0.1 Sv/h	γ: 1.6 10^{-6}	1.6 pA – 160 nA	100 nC
	CENTRONIC IG32-A3.1	1 μSv /h – 1 Sv/h	γ: 1.13 10^{-7}	113 fA – 113 nA	**500** nC
TMF[9]	CENTRONIC IG5-H20	1 μSv/h – 1 Sv/h	γ: 1.13 10^{-7} n: 4.0 10^{-8}	113 fA – 113 nA 40 fA – 40 nA	< 30 nC
IAM[9]	PTW T32006	1 μSv/h – **10** Sv/h	γ: 2.5 10^{-8}	25 fA – **250** nA	5 nC

- (High-pressure) ionisation chambers used since > 60 years by RP at CERN
- Same detector – different readout electronics
- Reliable design and known response to high-energy mixed radiation fields (→ see Helmut Vincke's talk coming next)

→ Interfaced with charge measurement electronics: Now CROME

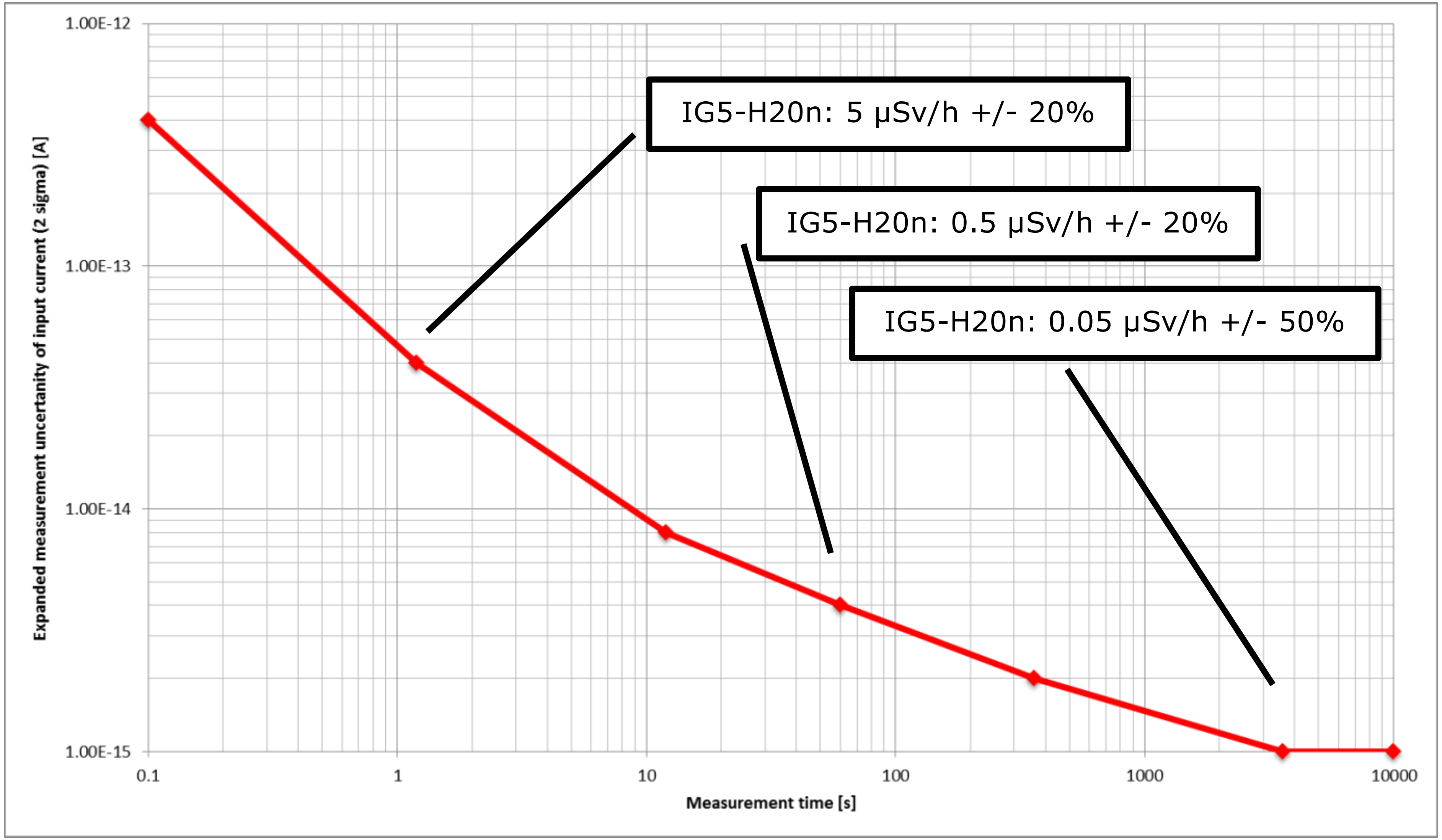
Parameter	Range/Value (elect. Units)	Remark
Measurement range (Dose rate)	2 fA[10] to 250 nA[11]	Input current range (8 decades); within this range the specified accuracy and precision requirements are fulfilled.
Measurement range (Dose)	up to 500 nC / pulse	The charge/discharge characteristic is determined by the chamber capacitance and output/input impedance. A sharp rising pulse with a time constant of less than a millisecond is followed by an exponential decay with a time constant usually in the order of milliseconds.
Resolution	1 fA / 60 fC[12]	Smallest change of the input current which causes change in the indication; smallest digitizable charge unit
Accuracy (Linearity over measurement range)	± (1 fA + 5% of the reading) See Figure 2	Closeness of the agreement between the measurement and the conventionally true value of the measurement quantity over the full measuring range. To confirm the specified accuracy, the precision of the measurement must be sufficient; the averaging time needs to be set appropriately.
Precision (Statistical fluctuation)	± (1 fA[13] + 5%[14] of the reading) See Figure 1 and Figure 2	Reached precision expressed by the expanded measurement uncertainty and as a function of the averaging time
Operational temperature range	10 °C to 40 °C	Temperature range to permit inside (and outside) use; within this range the specified accuracy and precision requirements are fulfilled.

Parameter	Range/Value (elect. Units)	Remark
	(-15 °C to 55 °C)[15]	
Max. temperature gradient	≤ 5 °C/h	With temperature gradients equal or smaller than this value, the specified accuracy and precision requirements are fulfilled.
Operational humidity range	5 to 95 %	Relative humidity; within this range the specified accuracy and precision requirements are fulfilled.
DC Power supply variations	Variations applied between [22V 30V]	No effect on measurement; according to IEC532 device shall declare power supply failure before variations affect measurements.
AC Power supply variations	Variations applied between [150kHz 30MHz]	No effect on measurement; according to IEC532 device shall declare power supply failure before variations affect measurements.
Mechanical impact variations (Microphony)	Variations applied according IEC532	Measurement remains within specified accuracy and precision requirements.

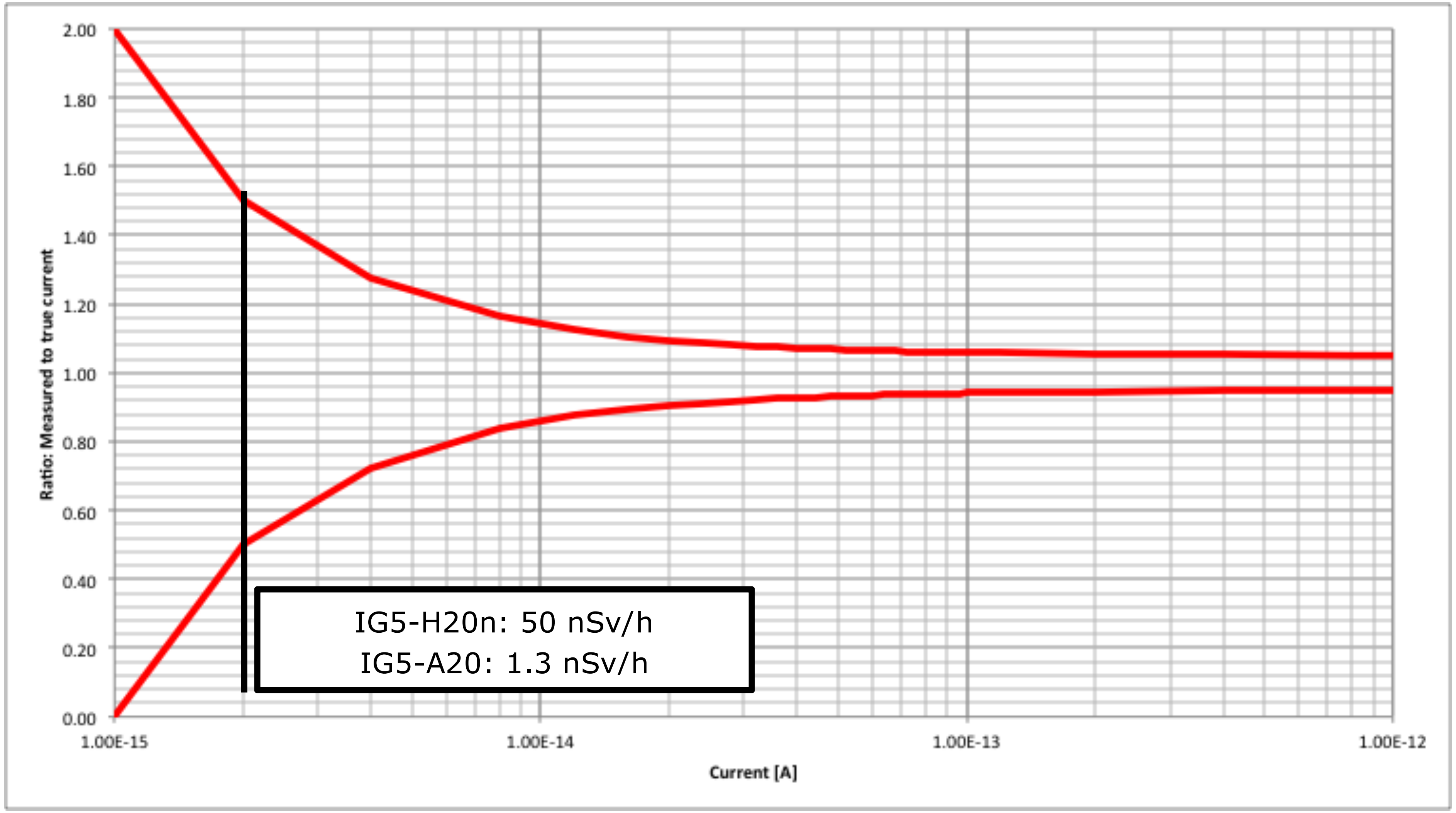
Parameter	Range/Value (elect. Units)	Remark
Overload characteristics	Up to 10 x of the maximum dose or dose rate, no irreversible effect on the readout circuit	Above 10 x of the upper range value, overload exposure shall be indicated as system failure, where the instrument requires verification.
Warm-up time	≤ 1 hour	After this time all the performance requirements must be fulfilled.
Response time	≥ 1 sec (with a resolution of 0.1 sec[16])	This value defines the minimum time interval between basic measurement values. The final response time depends on the used algorithm and averaging parameters. This is defined at a higher level in the data treatment.
Radiation type	Detector dependent	
Energy range	Detector dependent	
Angular response	Detector dependent	

Parameter	Range/Value (elect. Units)	Remark
EMC	Variations applied according to IEC 61000-4 [8]	Measurement remains within specified criterions A[17] or B[18].
	Immunity to common mode RF on the cables	Acceptance criterion A[17]. Level as defined by CEI 61326-1: 3V from 150kHz to 80MHz, 80% AM (1kHz).
	Immunity to common mode RF on the enclosure	Acceptance criterion A[17]. levels as defined by IEC 61326-1 [9] on an industrial environment : ➔ 10V/m de 80MHz to 1000MHz, 80% AM (1kHz) ➔ 3V/m from 1.4GHz to 2.0GHz, 80% AM (1kHz) ➔ 1V/m from 2.0GHz to 2.7GHz, 80% AM (1kHz)
	Immunity to burst	Acceptance criterion B[18]. Level as defined by IEC 61326-1 [9] on an industrial environment: ±1kV on signal lines.
	Immunity to surge waves	Acceptance criterion B. Level as defined by IEC 61326-1 [9] on an industrial environment: ±1kV (1,2/50µs) signal line to earth.
	Immunity to electrostatic discharges on the enclosure	Acceptance criterion B. Level as defined by IEC 61326-1 [9]: ➔ ±4kV on contact ➔ ±8kV in the air

Measurement precision as a function of measurement time



Measurement accuracy as function of input current



Summary

Active radiation monitoring required for radiation protection in varying radiation fields

Specific challenges in accelerator environments

Monitoring requires flexible input/output functions

Measurement performance criteria: A set of parameters defined for readout electronics, based on ionisation chambers types used in RP at CERN.

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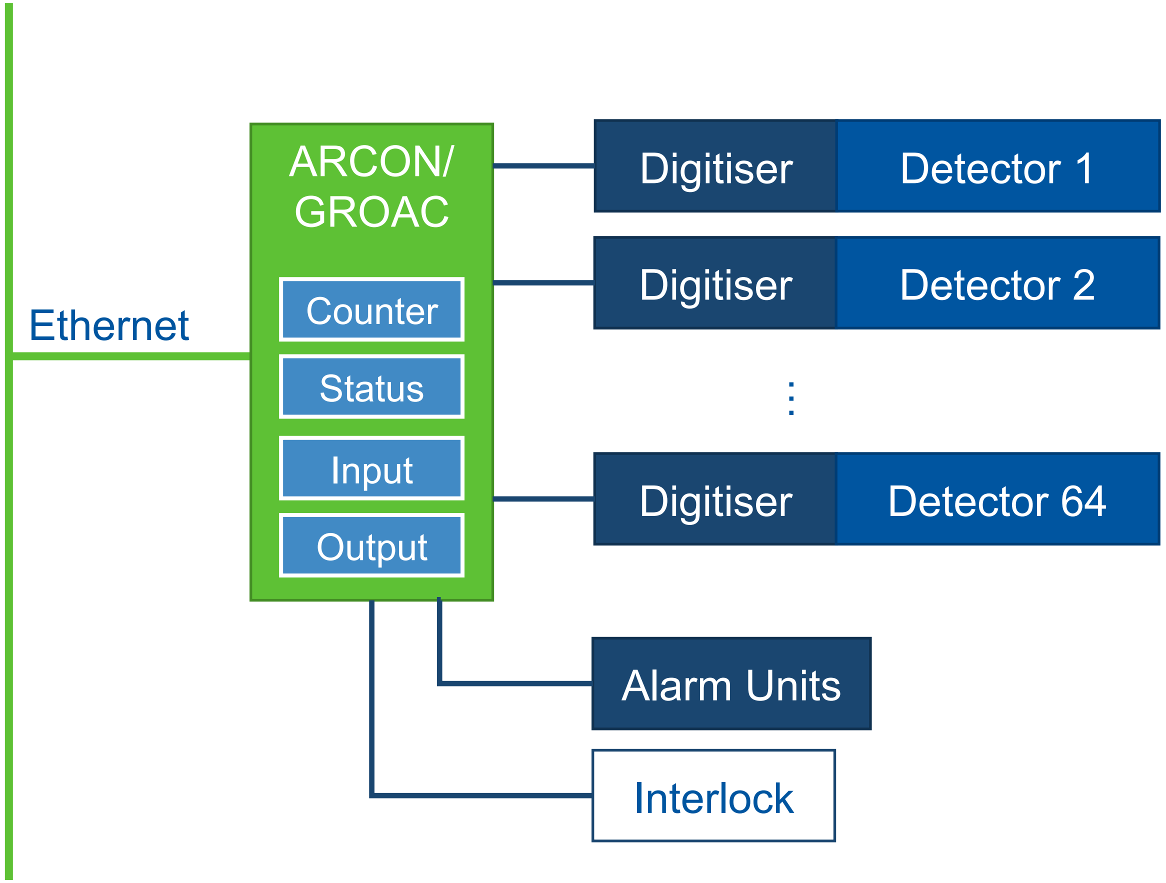
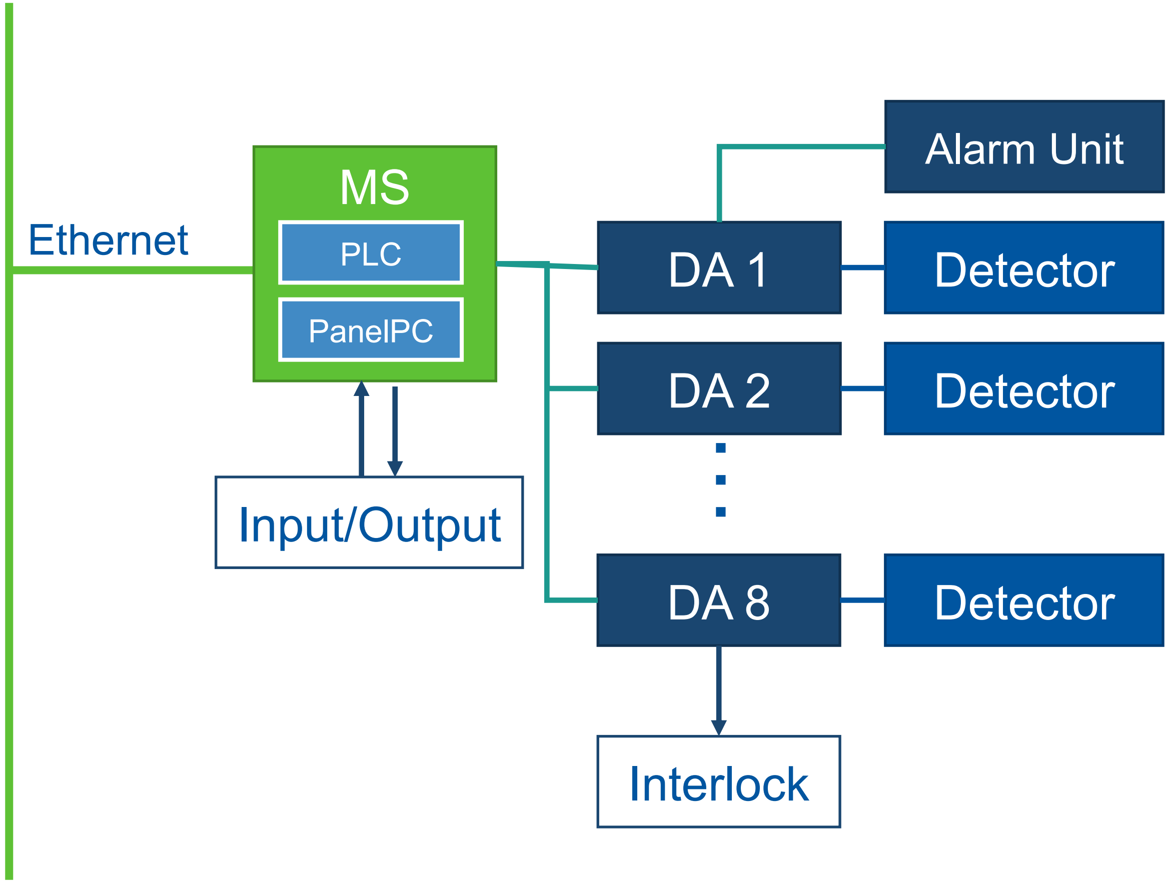
Backup slides

ARCON (LEP era monitoring)



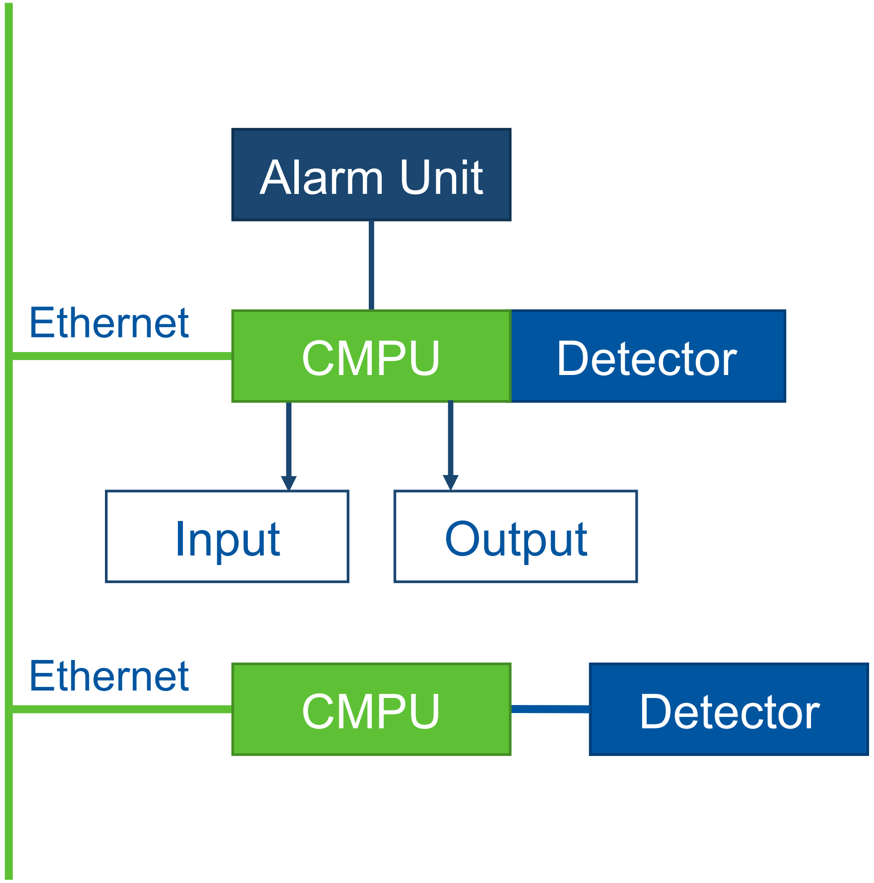
- central processing unit
- flexible input/output logic
- simple processing functions
- low functional safety and low reliability (aging)

RAMSES (LHC era monitoring)



- standard industrial design and components (and dependencies)
- little flexibility for input/output signals
- complex system layout and configuration

CROME (HL-LHC era monitoring)



- Fully decentralised concept
- Requires cabled network and 230V power supply for each monitor
- Flexible and performant input / output logics → but high level of complexity
- Initial objectives:
  - More flexible and faster installation
  - Scalability
  - Reduced cost
  - Reduction of system failure overall impact
- High level of functional safety by design