Complications, Compensations, Solutions

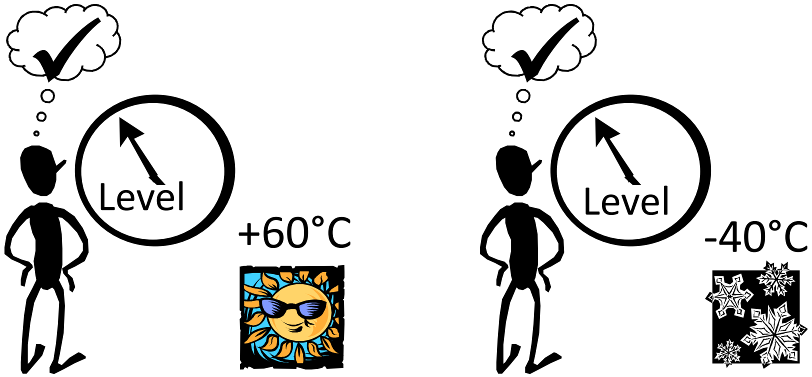
Understand the technical details

Dr. Jan Sielk 23.11.2016

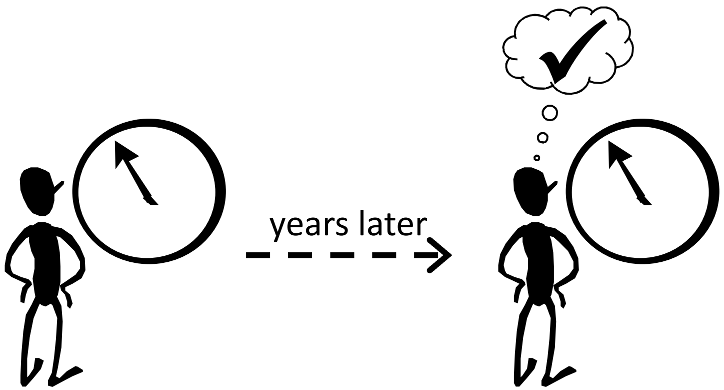
Long term stability

Thermal and aging effects

Temperature and Aging Compensation



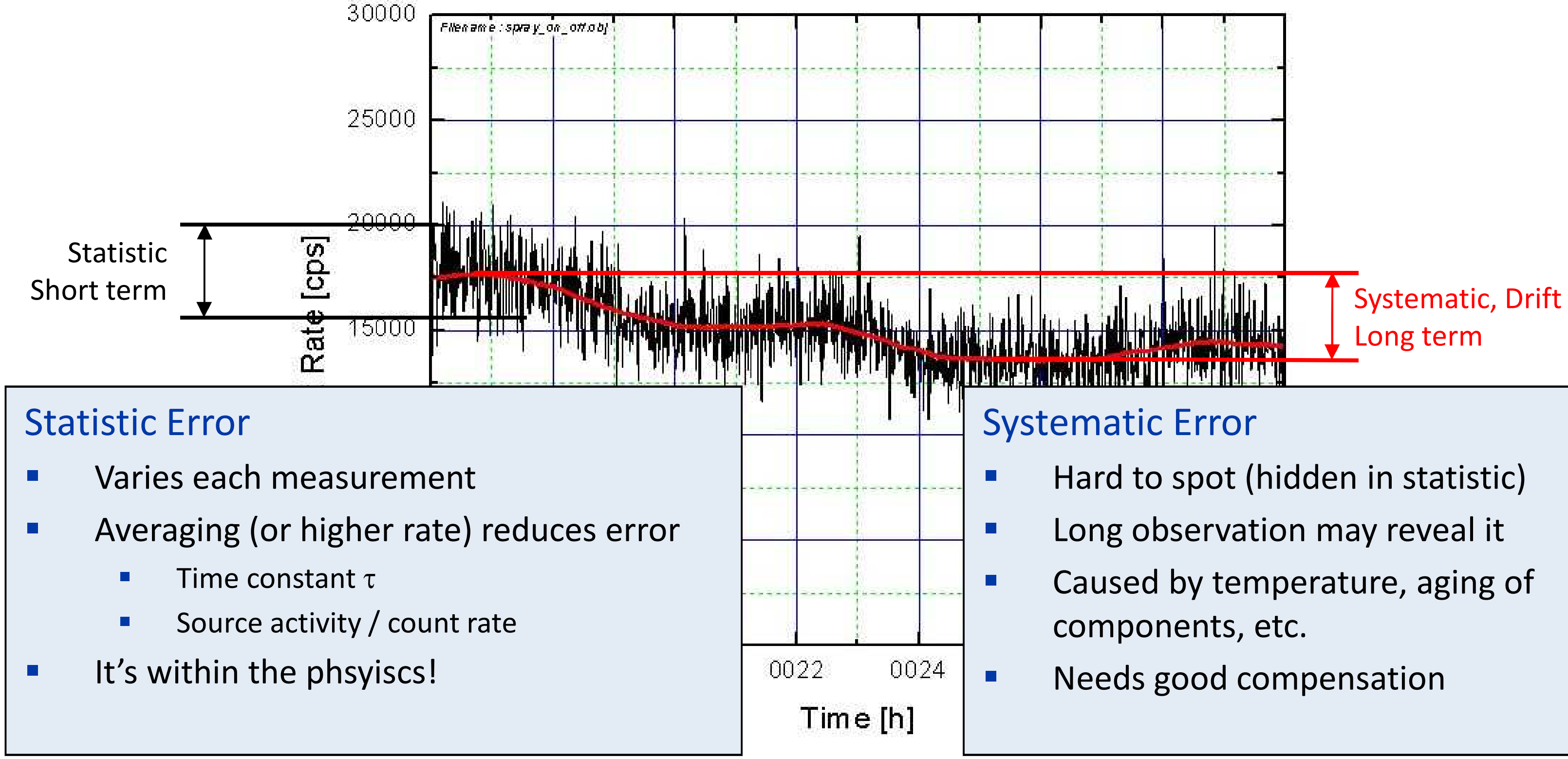
- Temperature Stability
  +/-0.1% at -40 … 60°C
  by a **patented** automatic gain control
- High repeatability



- Long-Time Stability
  by a **patented** automatic gain control
- No recalibrations!

Error: Short term vs. long term

- Put a source in front of a detector and change temperature
- Put a source in front of a detector and wait a few years



Statistic Error

- Varies each measurement
- Averaging (or higher rate) reduces error
  - Time constant τ
  - Source activity / count rate
- It's within the phsyiscs!

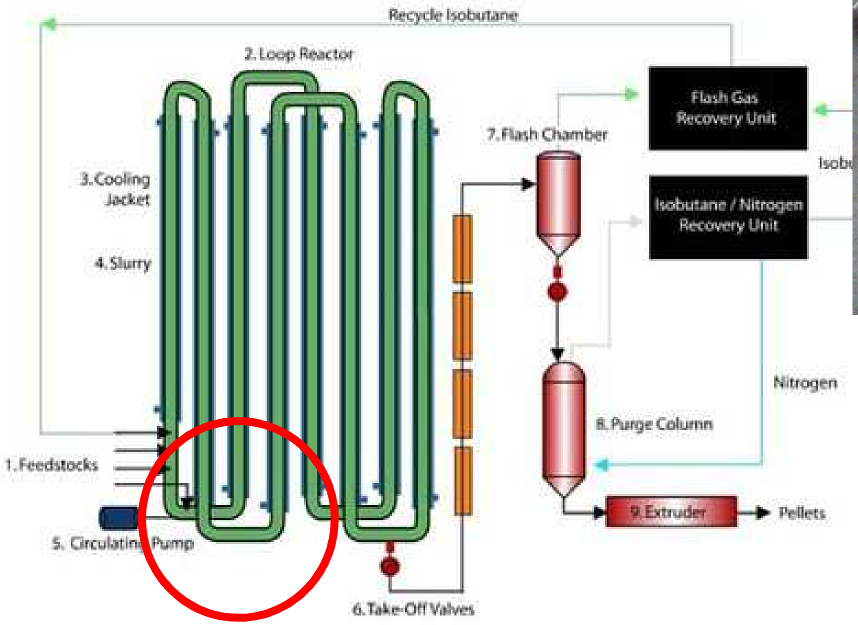
Systematic Error

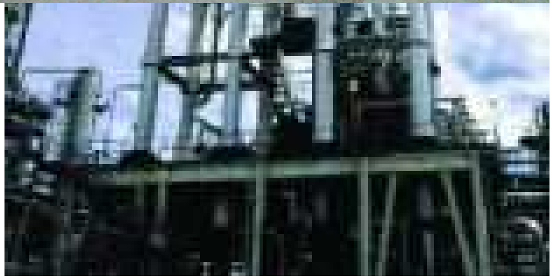
- Hard to spot (hidden in statistic)
- Long observation may reveal it
- Caused by temperature, aging of components, etc.
- Needs good compensation

Loop Reactor – Phillips Process

Loop Slurry PE Technology

- Highly critical PE loop reactor process
  Slurry from Ethylene + catalyst -> Polymer
- Produce close to density limit
- 3 density gauges – "democracy"





Long-term Stability

DATA FROM 'F' RX FOR 3 BERTHOLD DENSITY GAUGES
Data from 2 Dec 11, snapshots from 12:00 am to 7:30 am.

							Average Deviation and % of Span Error
Gauge 1	0.52203	0.52134	0.52145	0.52142	0.52132	0.52150	
Gauge 2	0.52188	0.52143	0.52140	0.52131	0.52086	0.52182	
Gauge 3	0.52180	0.52138	0.52104	0.52167	0.52126	0.52170	
Standard Deviation =	0.000116762	4.50925E-05	0.000223681	0.000184481	0.000250067	0.000161658	0.000163624
% of Span Error	0.0389%	0.0150%	0.0746%	0.0615%	0.0834%	0.0539%	0.0545%

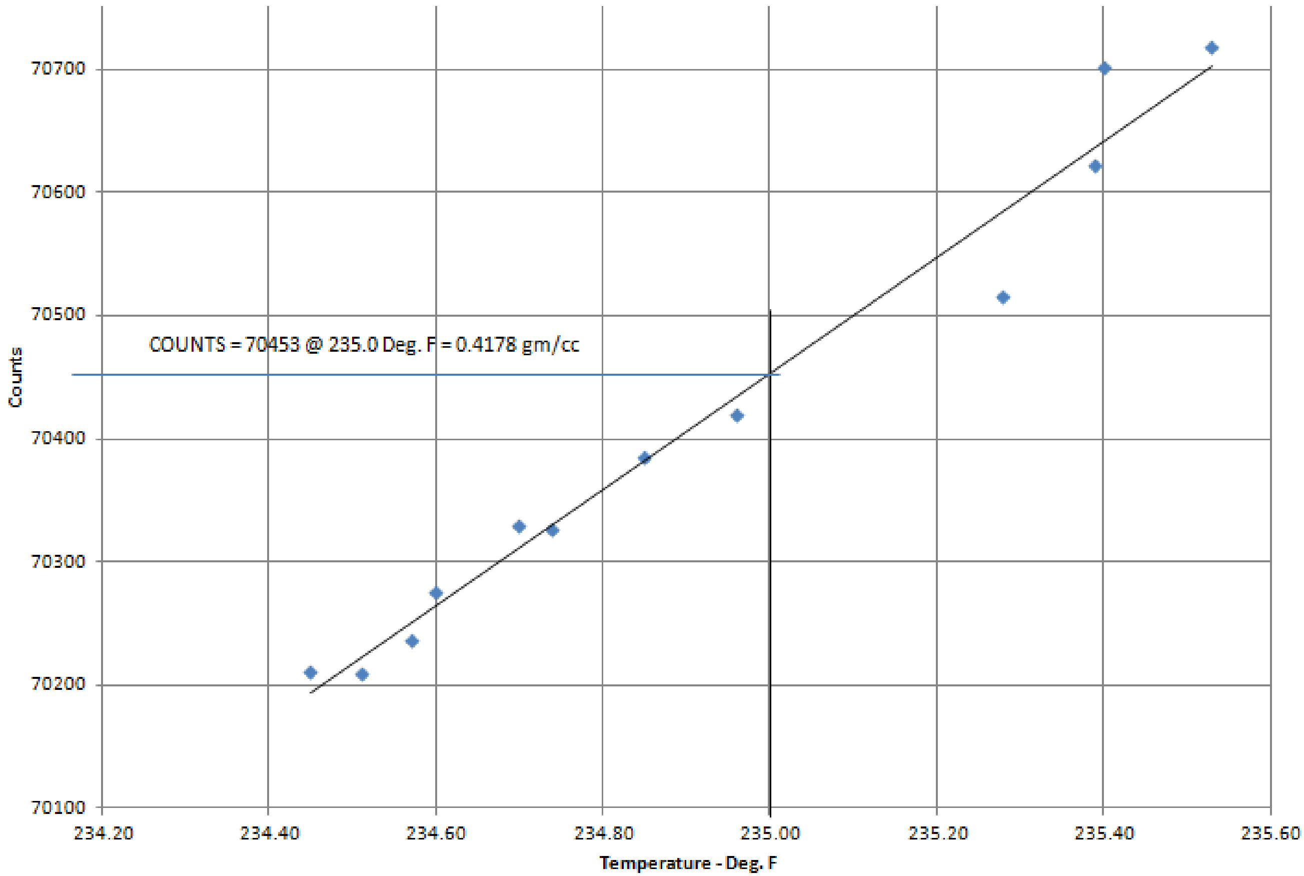
WORST ERROR SEEN → (0.0834%)

Max statistical error specified to Berthold for HDPE = 0.001 gm/cc
.001 gm/cc = 0.333% of Span Error

Worst error seen = (.0834/.333) = 25% of allowable error or four times better than required specification.

Average error = (.0545%/0.33%) = 16% of allowable error or six times better than

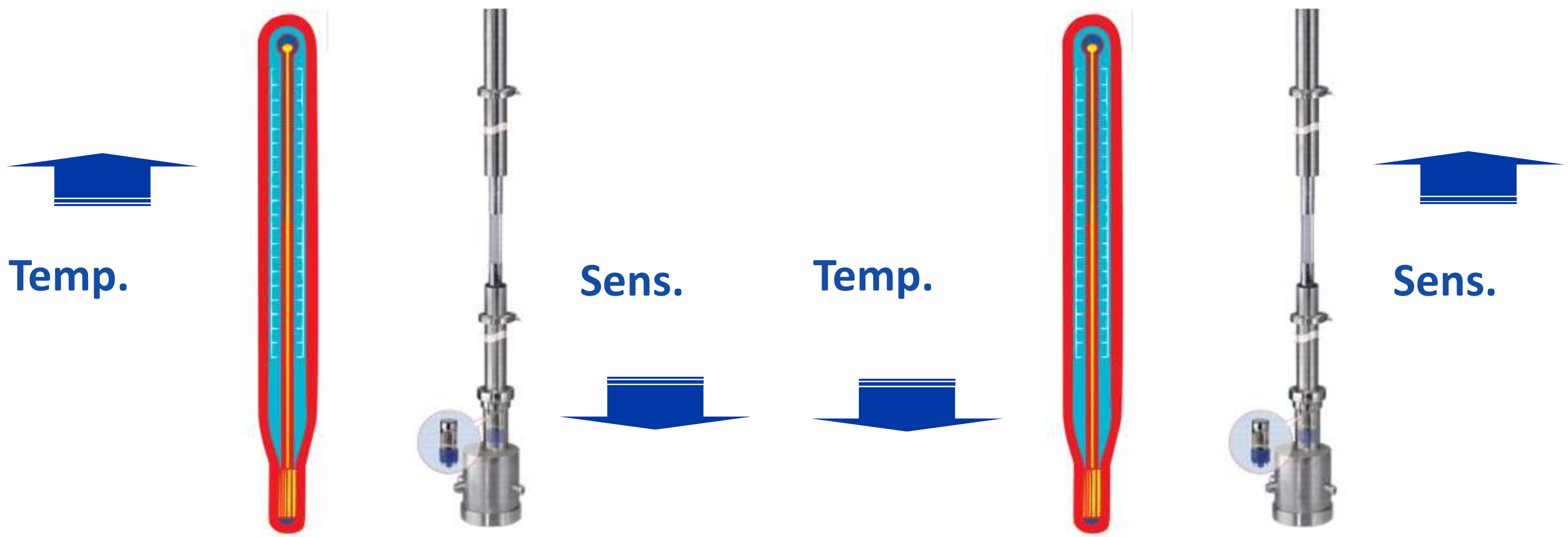
Long-term Stability



How do we achieve this?

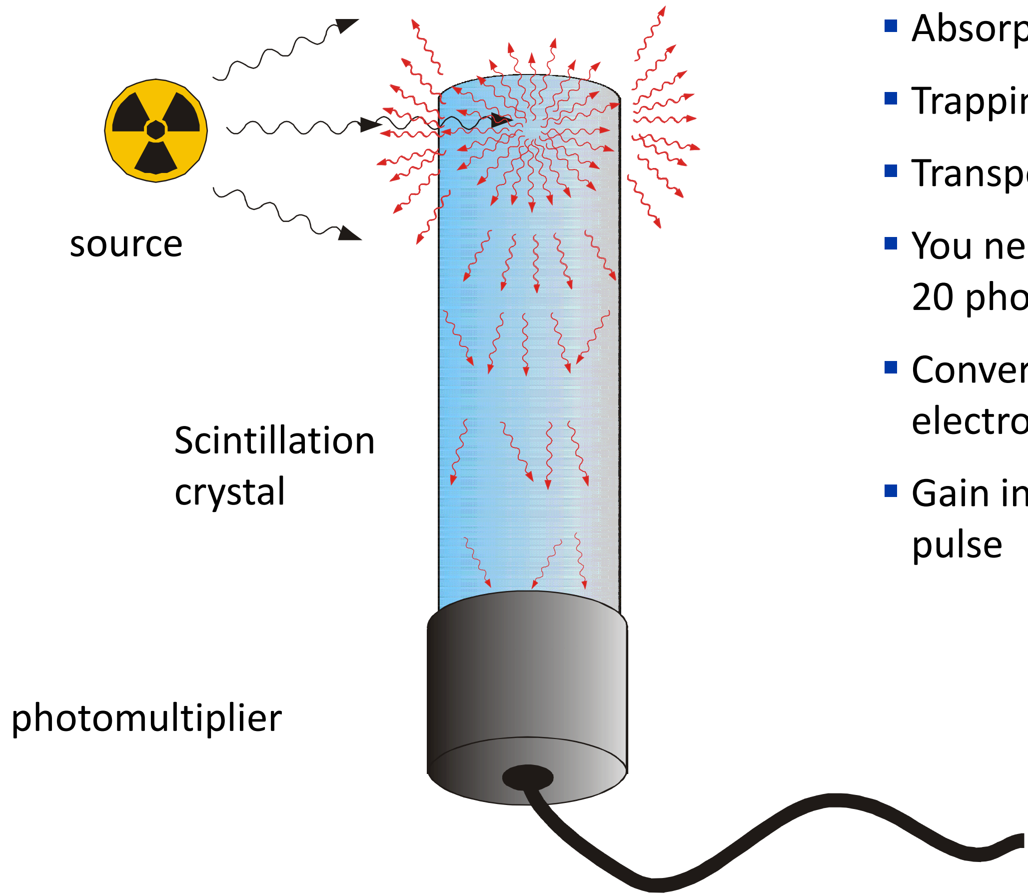
- Aim: Keep the sensitivity constant!
- Problem: E.g. temperature!

We need a lever!



Scintillation Detectors

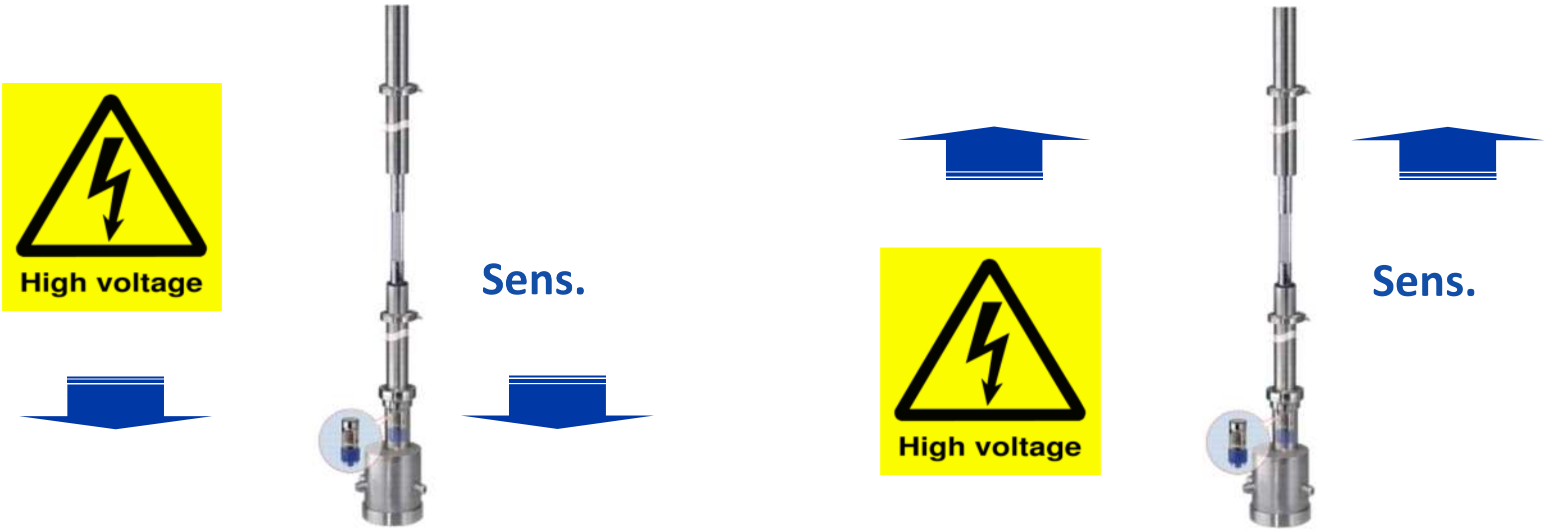
Make radiation visible!



- Absorption of the gamma ray
- Trapping of light
- Transport
- You need at least
  20 photons to detect
- Conversion of light to
  electrons
- Gain in photomultiplier generates voltage
  pulse

We have a lever…

Supply voltage of photo multiplier

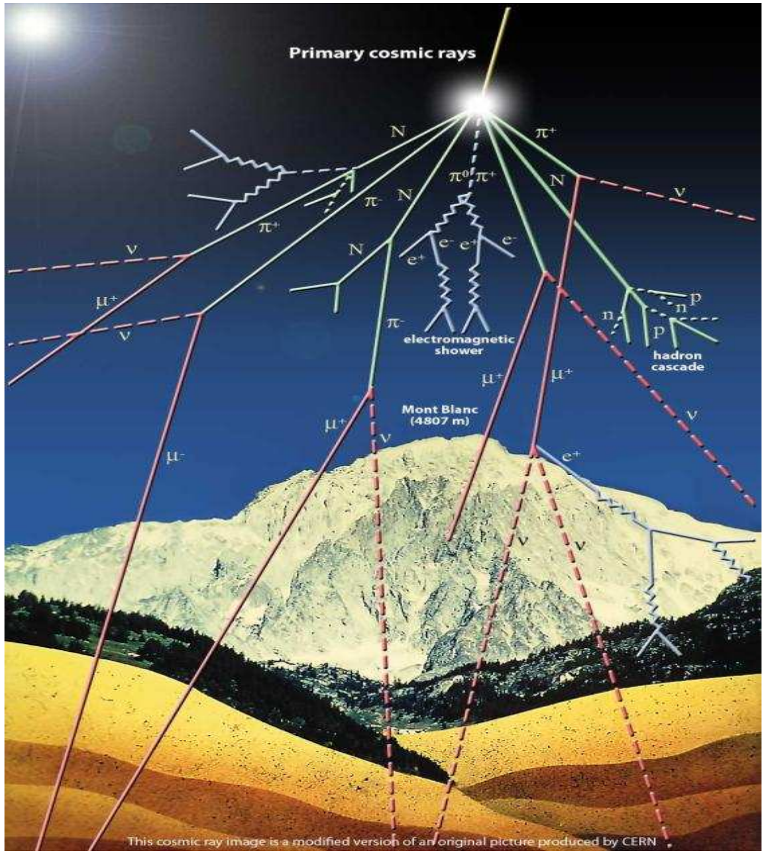


But by how much should we pull or push?

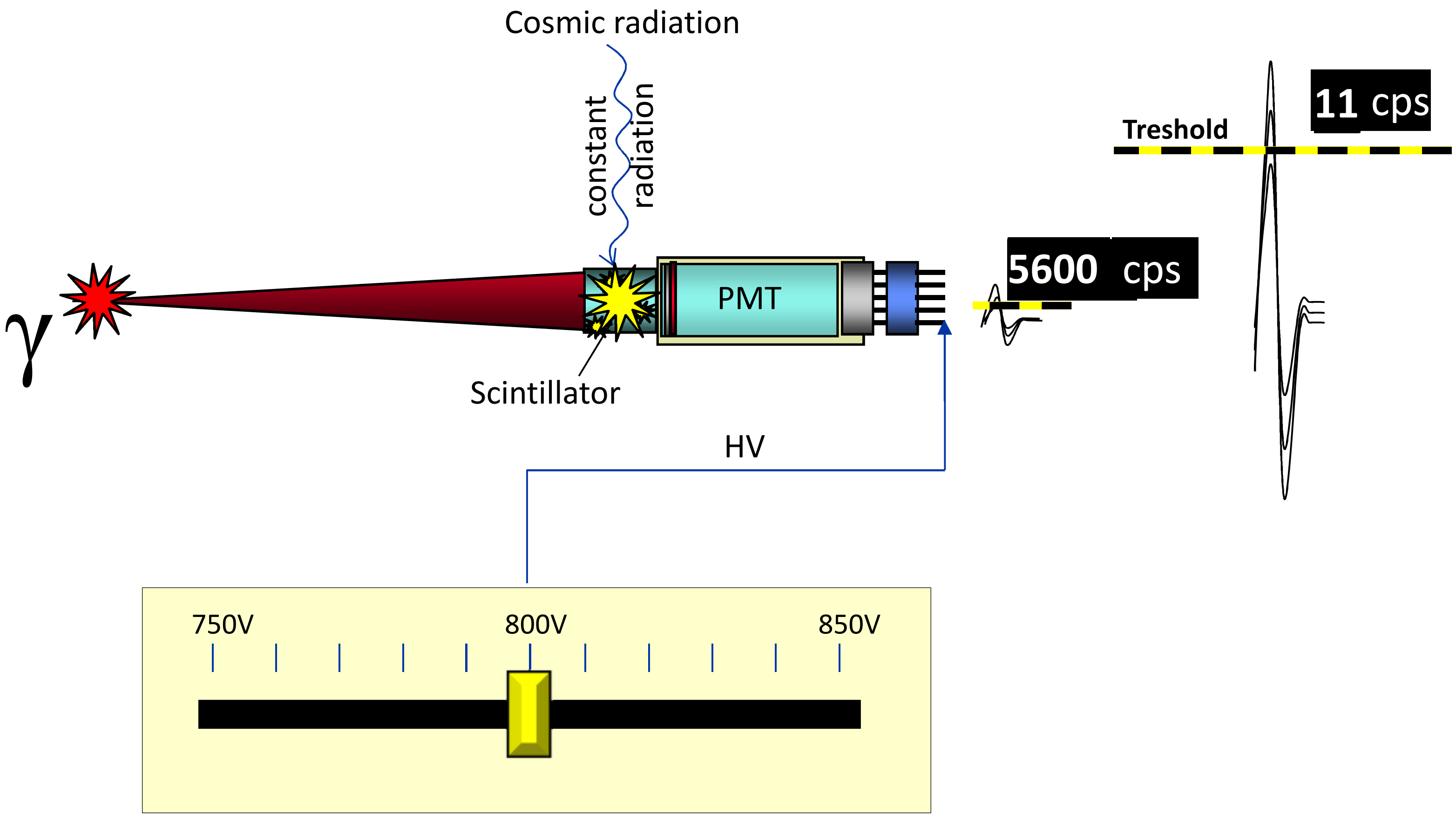
OR: How do we know the sensitivity changed?

How to monitor sensitivity?

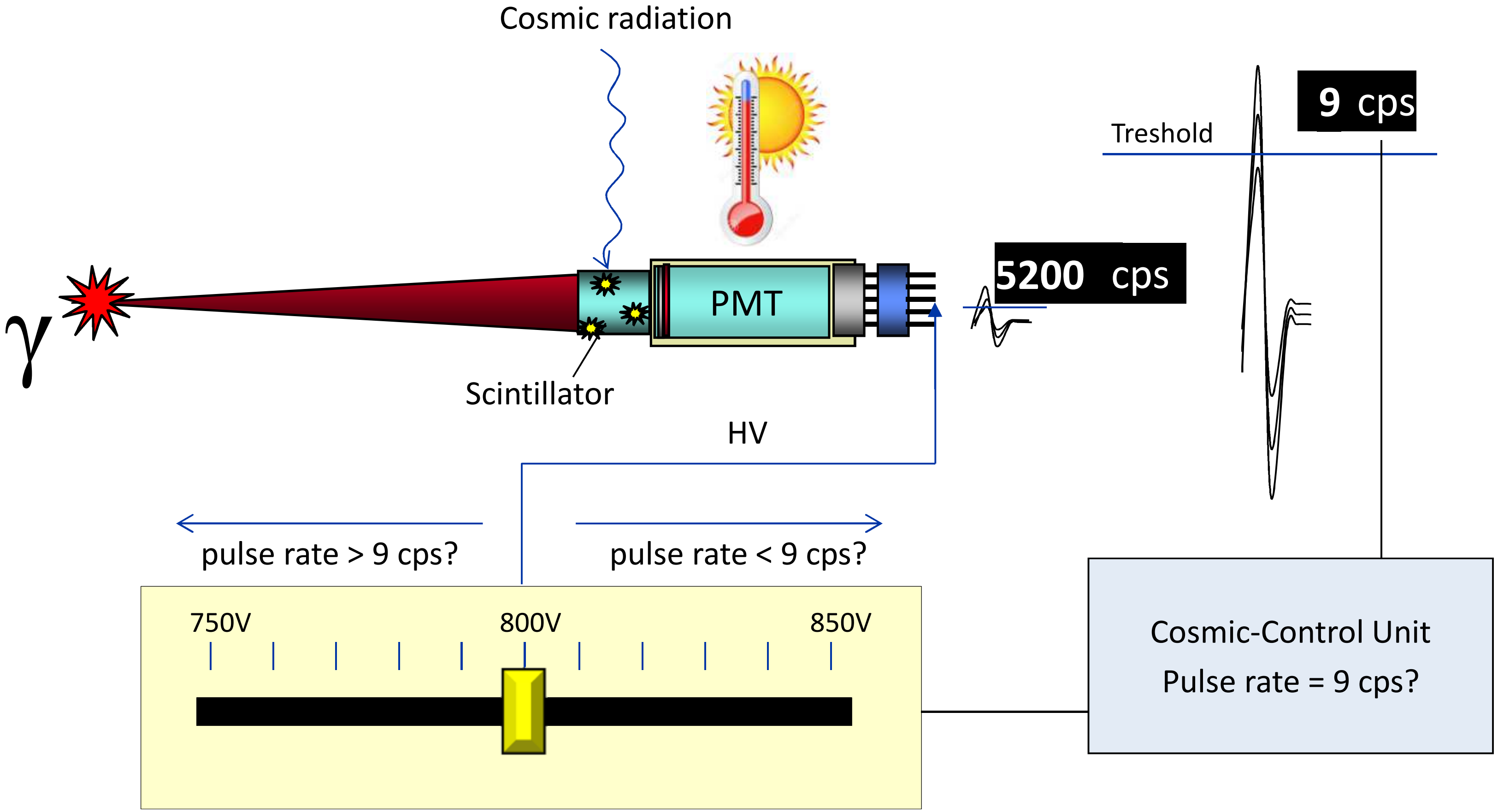
- Cosmic rays
  - H, He, … Fe
  - Converted to muons (big electrons)
  - From big bang
  - Start of the universe
  - Speed of light
- 1 per cm^2 and second
- Very constant rate
- Every person here is hit by 10 cosmics/second



Automatic Gain Control



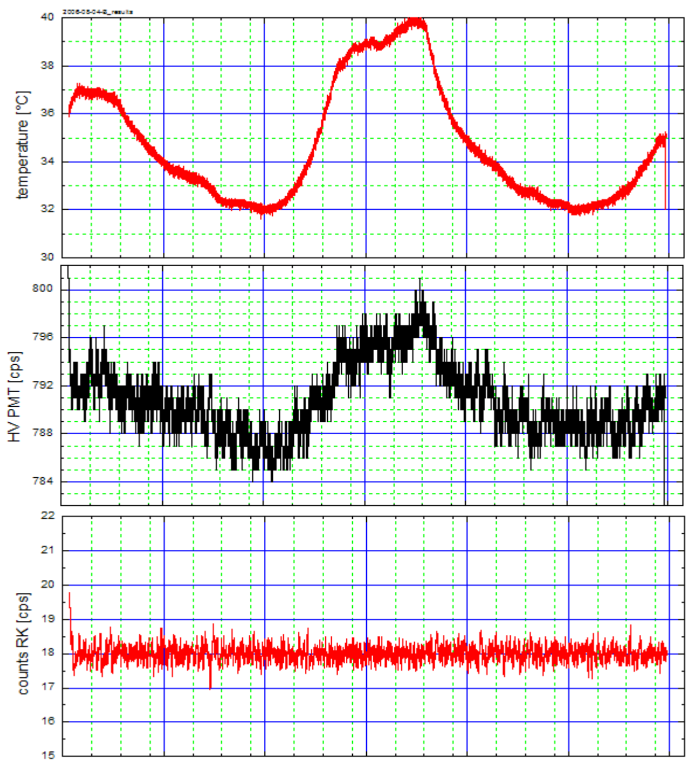
Automatic Gain Control



Cosmics: Back to the earth

- We have a very constant (and cheap!) source of pulses
- Very high energy (easily distinguished from gammas)
- Keeping their rate constant (HV)…
- …keeps the sensitivity constant!
- Corrects for temperature and aging
- Checks life-status of the detector

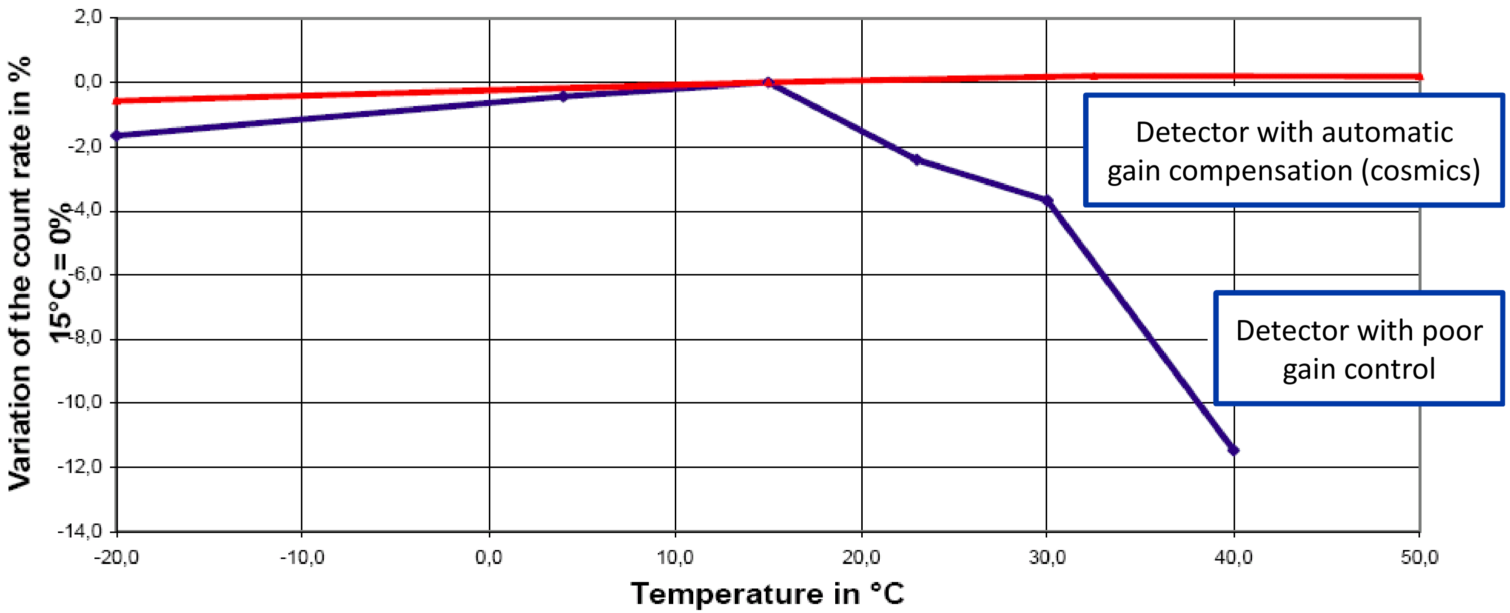
Cosmics are our reference object!



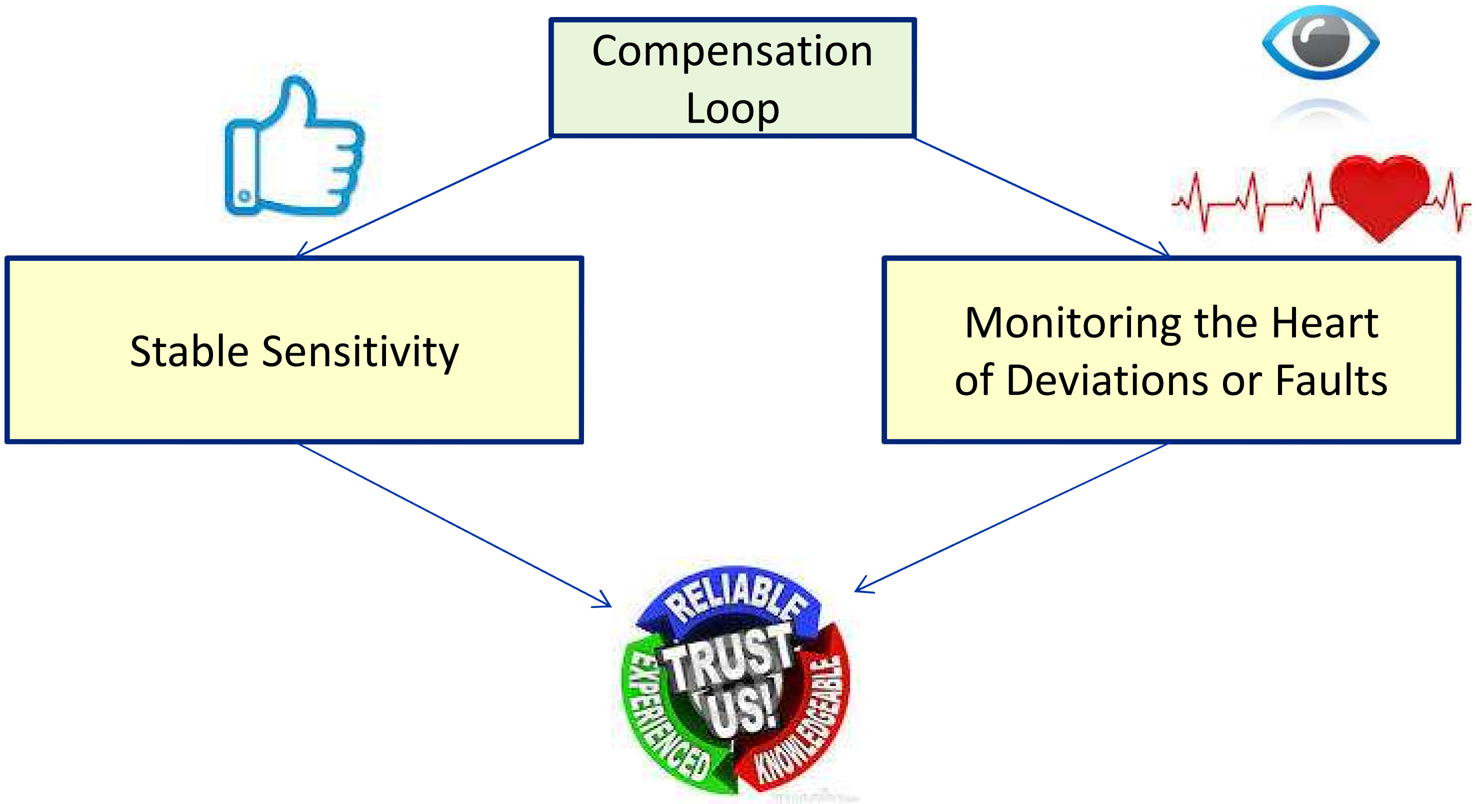
Fri / 7pm → Sun / 1pm

Investigation of temperature stability

- Constant radiation and changing temperature
- Berthold TowerSENS vs. other „long“ detector

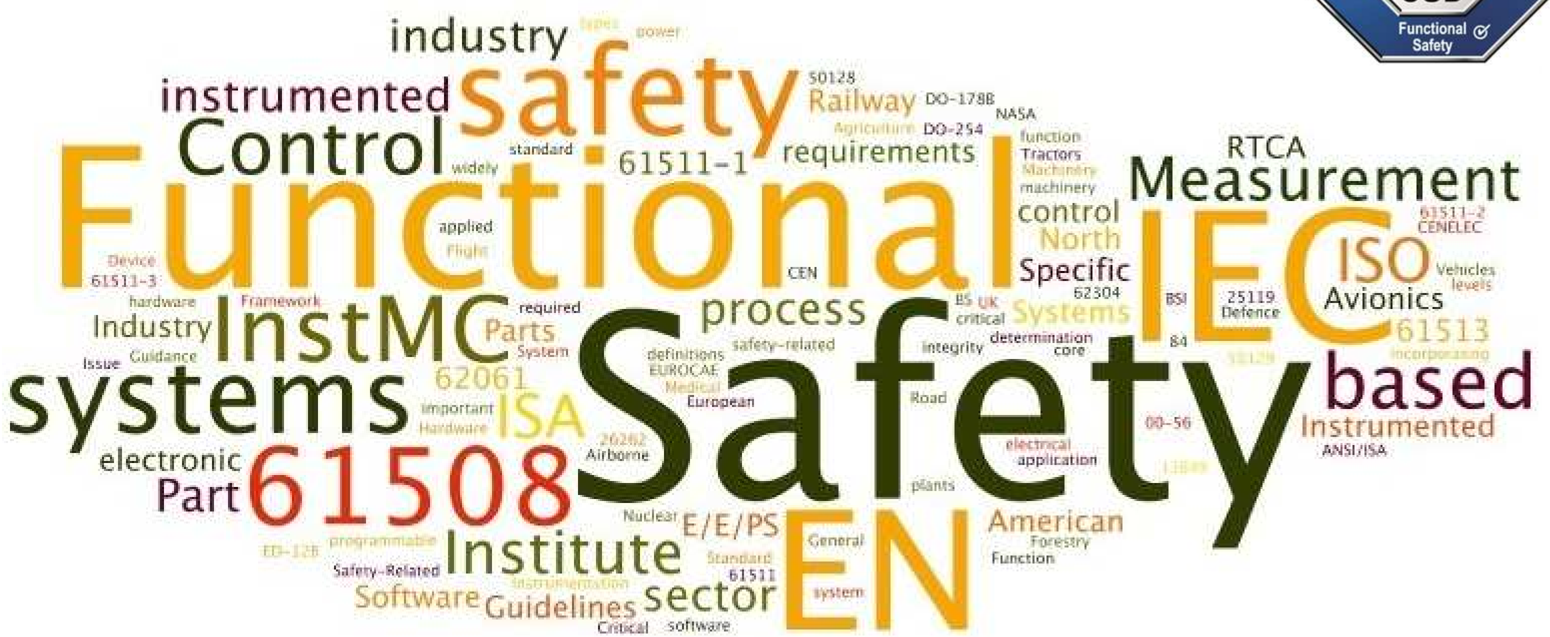


Compensation & SIL

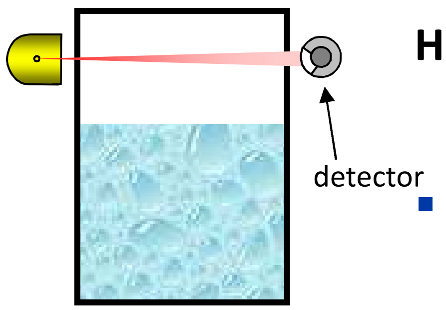


SIL

Saftey Integrety Level

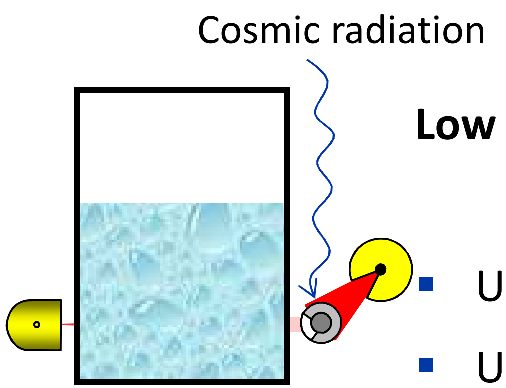


SIL for Level Switches



High Level Switch

- Always receives radiation in normal operating conditions



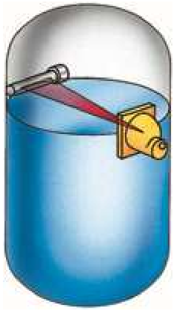
Low Level Switch

- Use additional external source to monitor life-status
- Use cosmic radiation as this source – simple and reliable

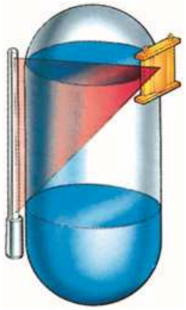
Whatever is measured

SIL 2 & SIL 3

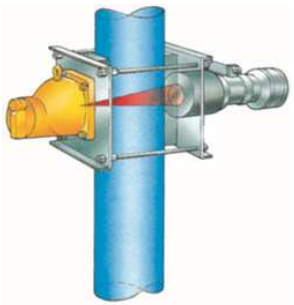
Level Switch



Level



Density



SIL2 / SIL3 certificate – How to achieve this?

- External reference source (Cosmic radiation) – Patented
- Monitored current output – Patented
- Aging compensation – Patented

- Others:
  - Mechanical stability
  - Date/Time and CPU Clock Monitoring
  - Program Flow Monitoring with Watch-Dog
  - Detector Temperature Monitoring
  - Improved HV-Limit Monitoring
  - Monitoring of the PMT Current
  - Continuous RAM + Flash-Memory Check

Influences of Product Properties

How do changing product properties affect the level reading?

- Aim:
  Measure the level in a vessel independent of changing product properties

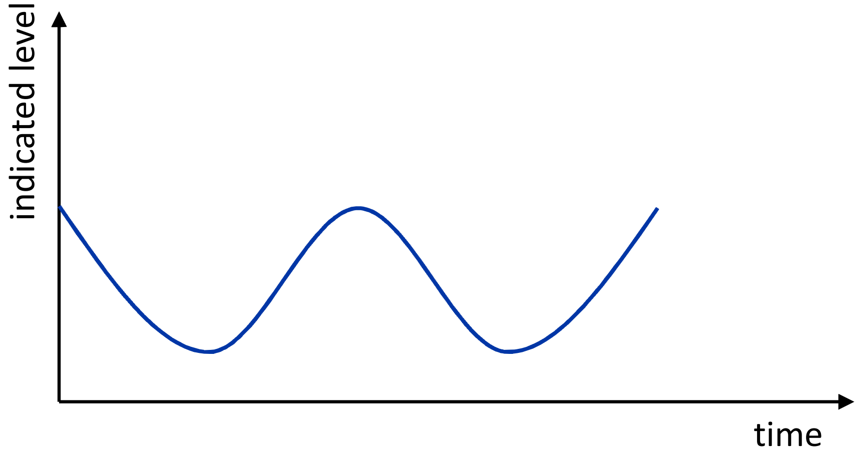
- Problem:
  Some properties affect the nuclear level measurement:
  - Varying gas density
  - Varying gas composition
  - Radioactive product
  - External radiation, e.g. from weld inspections

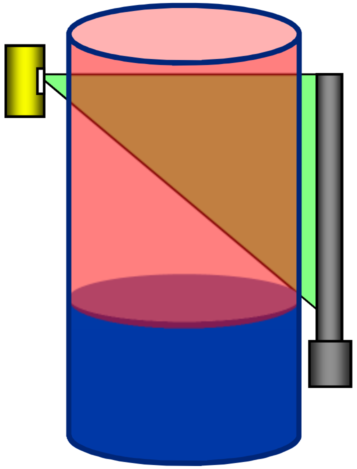
- Solution:
  Compensate effects!

Changing Gas Properties

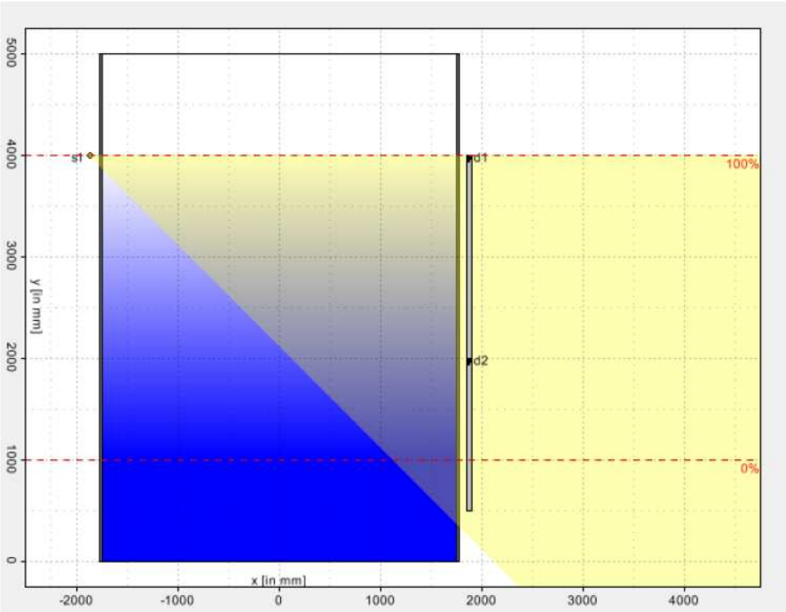
Why do we need to compensate these influences?

- Imagine constant level and changing gas density
- Changing gas properties have great influence on the accuracy of a level measurement.

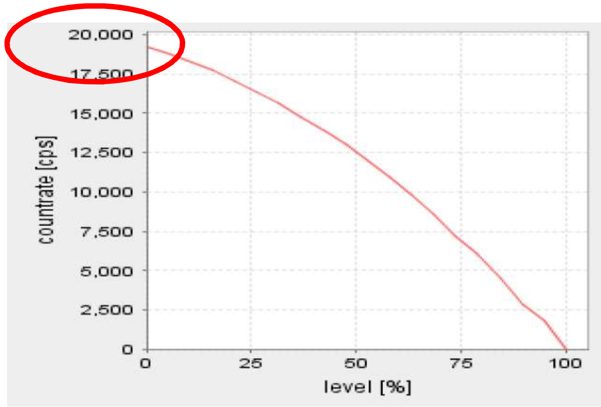




Example



- Increasing the gas density to 0.05 g/cm³ reduces the count rate by a factor of 3!



Gas @ atmospheric pressure

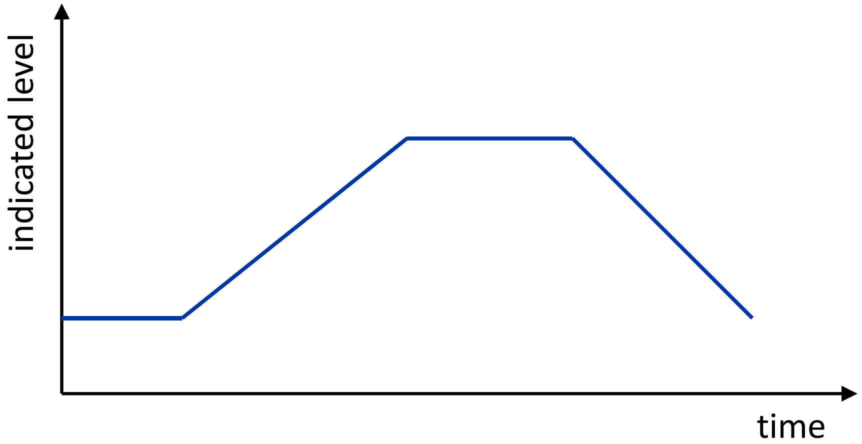
Gas density = 0.05 g/cm³

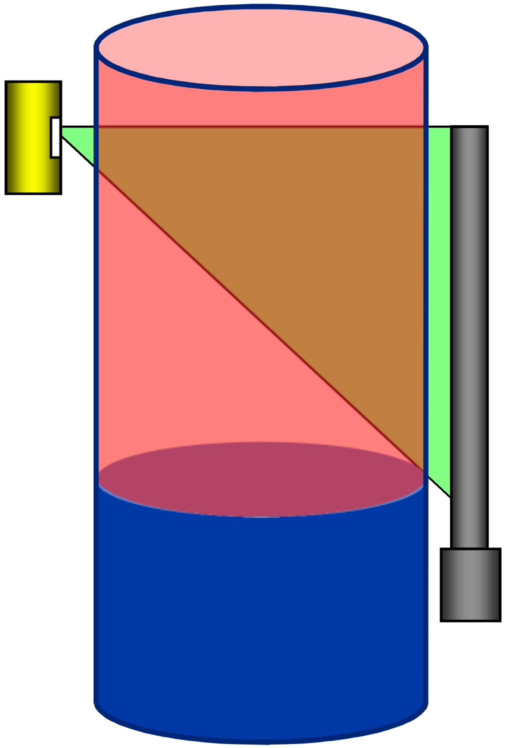
Gas Density

- Imagine constant level and changing gas density

$$I = I_0 \cdot e^{-\mu \cdot \rho \cdot d}$$

gas density



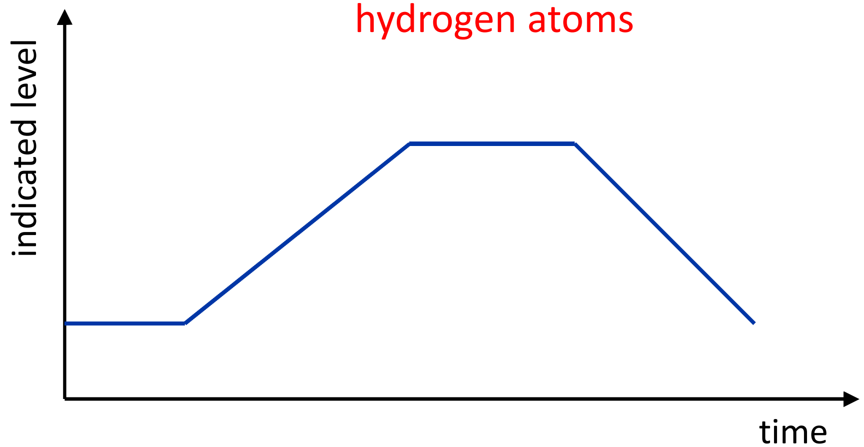


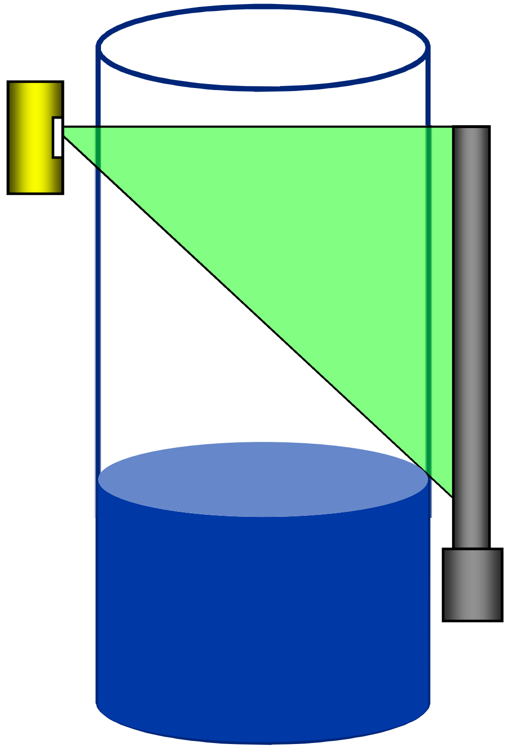
Hydrogen Content

- Imagine constant level and changing number of hydrogen atoms in the gas phase

$$I = I_0 \cdot e^{-\mu \cdot \rho \cdot d}$$

number of hydrogen atoms

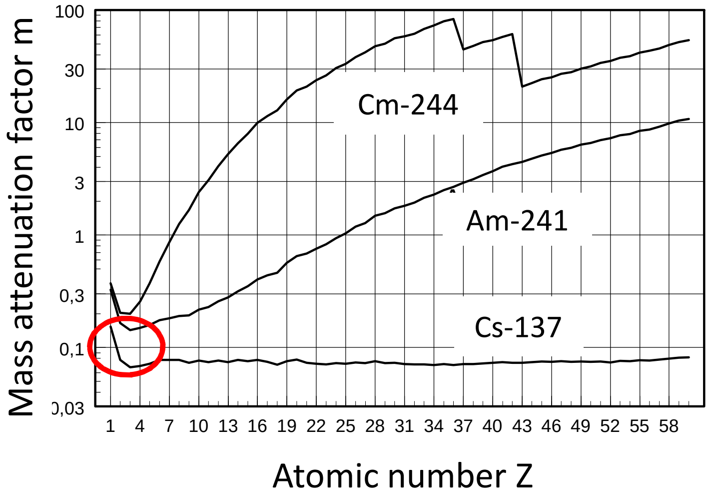




Generally μ is material dependent!

How does Hydrogen influence the level reading?

Mass attenuation factor μ

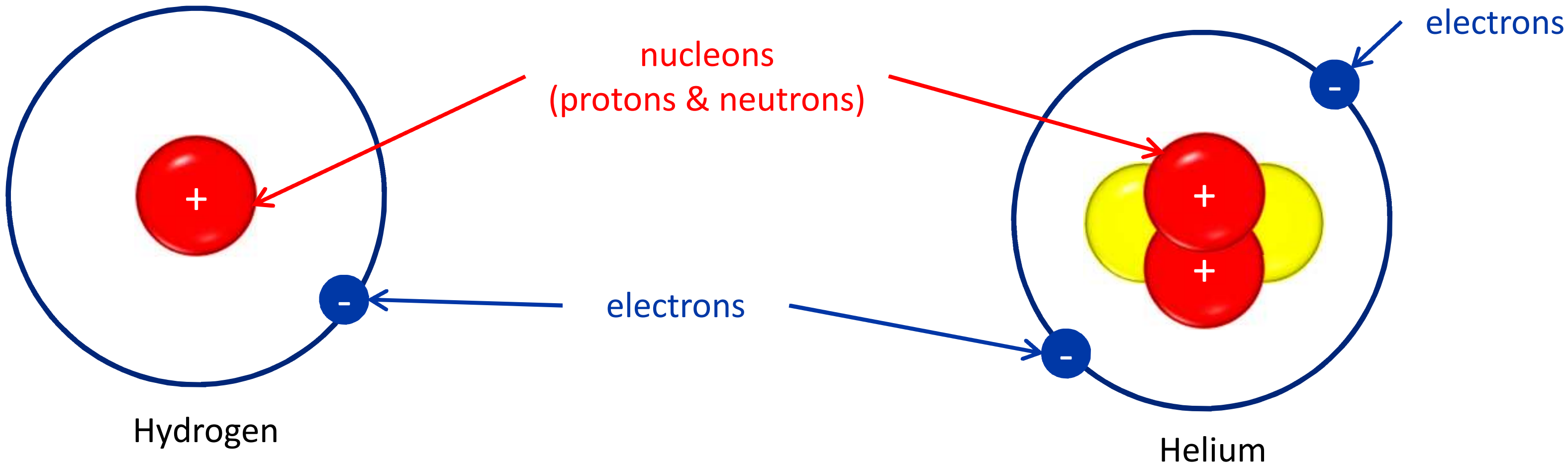


- Co-60 and Cs-137 have material *independent* μ
- This is why radiometric measurments are usually not affected by the material compostion but the density only
- But: Hydrogen atoms absorb twice as much!

- Am-241 and Cm-244 are used in special applications – Anaylsis of material composition

Hydrogen Content

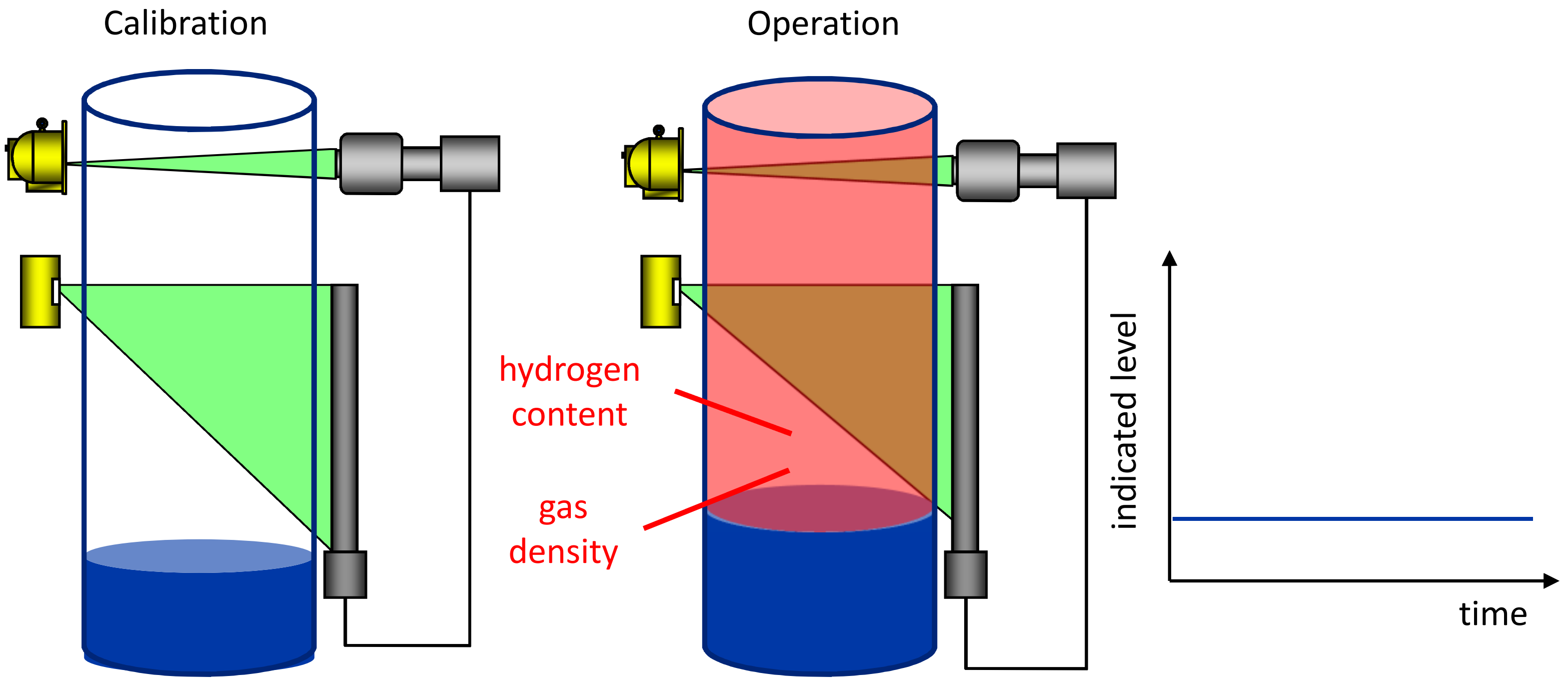
- The density depends on the mass of the atomic nucleus (number of nucleons)
- µ depends on the number of electrons
- The ratio of electrons and nucleons is twice as high for hydrogen as it is for other elements
- Hydrogen absorbs gamma radiation twice as good as you would expect based on it's mass.



Gas Properties Compensation

How do we do it

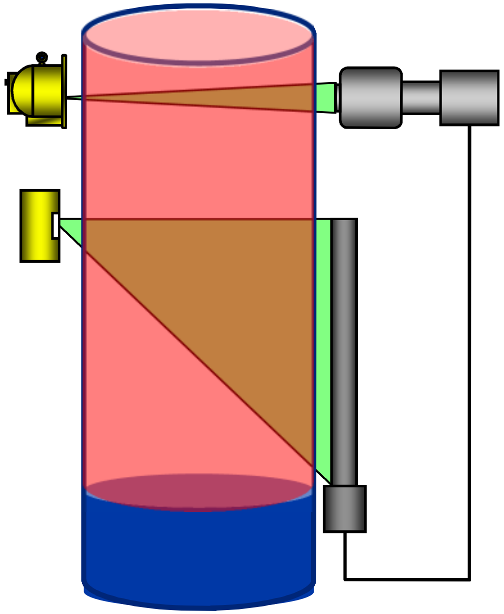
- Scenario: Gas density & hydrogen content are changing, but shall not influence the level reading
- Requirement: Additional measurement for compensation



Gas Properties Compensation

Basic Theory

Operation



- Record count rates at calibration
  - Density measurement: cps (ρ,ref), e.g. 1000 cps
  - Count rates for level calibration:

    0%, ref = e.g. 10.000 cps

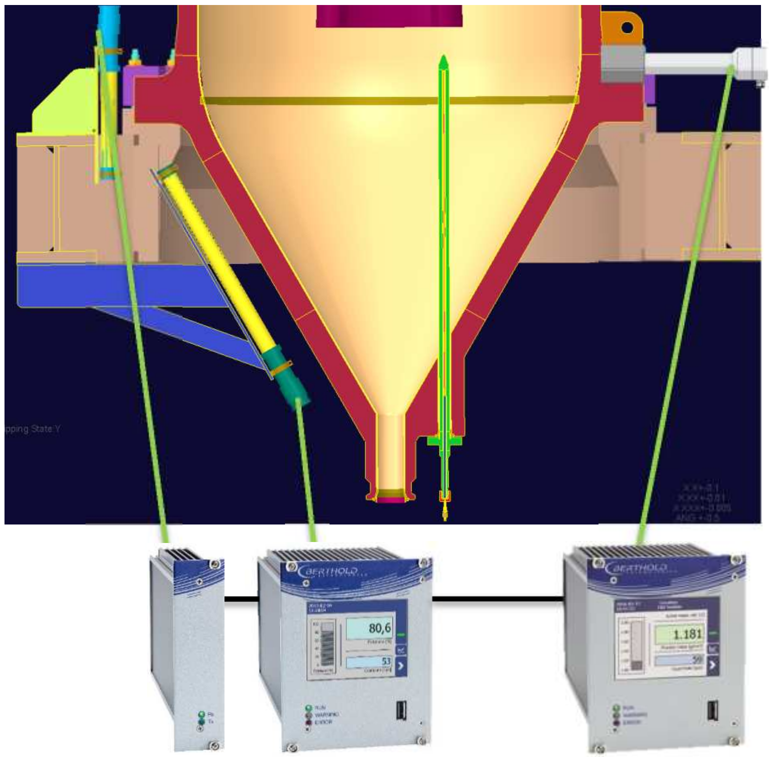
    100%, ref = e.g. 0 cps
- In operation: scale measured count rate by *K*
  - $K = \frac{cps\ (\rho, ref)}{cps\ (\rho)}$
  - $cps(\text{comp.}) = K \cdot cps(\text{meas.})$

- ATTENTION:
  Shown formulas neglect background count rate and fine tuning factors for simplicity.

Application Example

Multi-detector level measurement on HPS with GPC

- Product density (PE): 0.7 g/ccm
- Vapor density changing: 0.1-0.3 g/ccm
- 2 rod detector system for cascaded continuous level measurement
- 1 point detector system
  - Measures density in gas phase
  - 4…20mA process integration (density)
  - Relay output for high level switch
  - Input for GPC



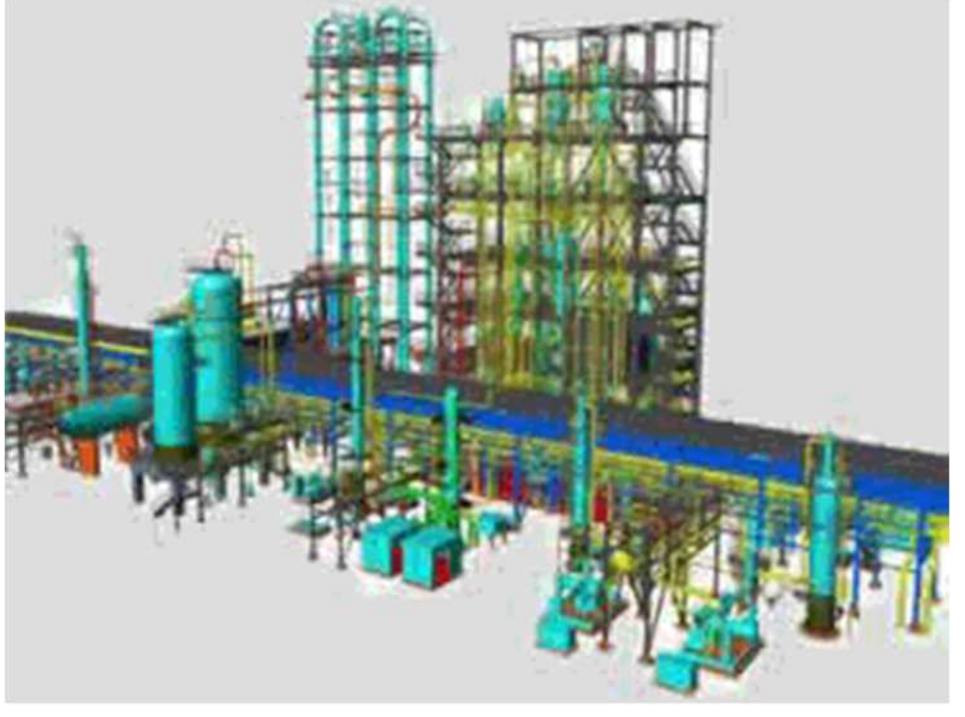
LB 470 „Slave“

LB 470 „Master“

LB 474 Density, Level Alarm, GPC detector

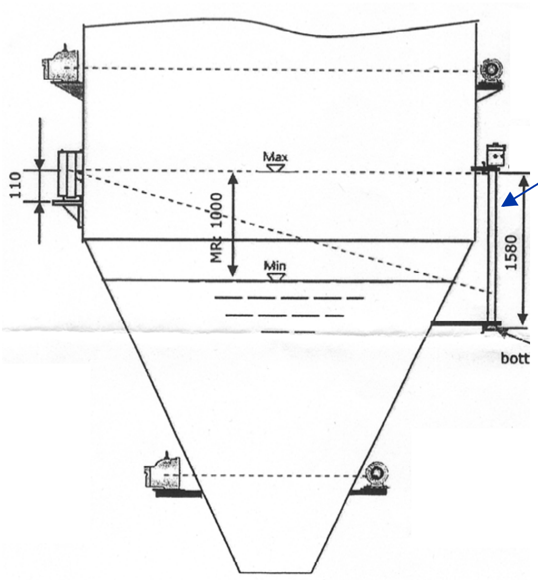
Egypt, Polypropylene production

Level gauge on vessels with radioactive product



Egypt, Polypropylene production

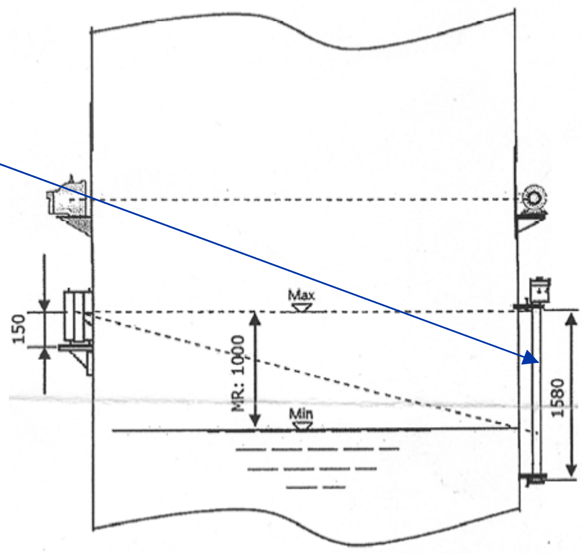
Original installation was running perfectly for 2 years.



In Sept. 2012 suddenly the Level readings went wrong.

After thorough investigation:

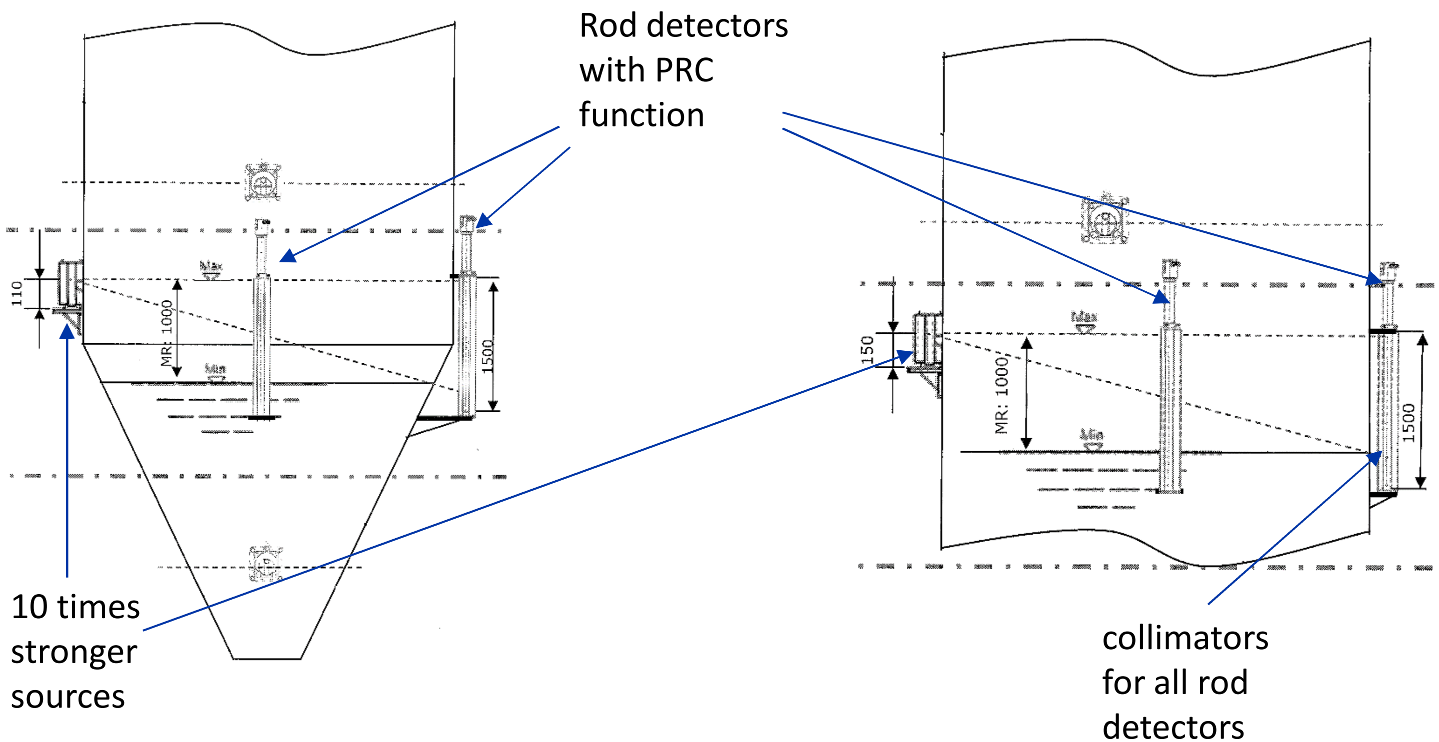
Radioactive product (Radon)



Product in both vessels: polypropylene powder

Egypt, Polypropylene production

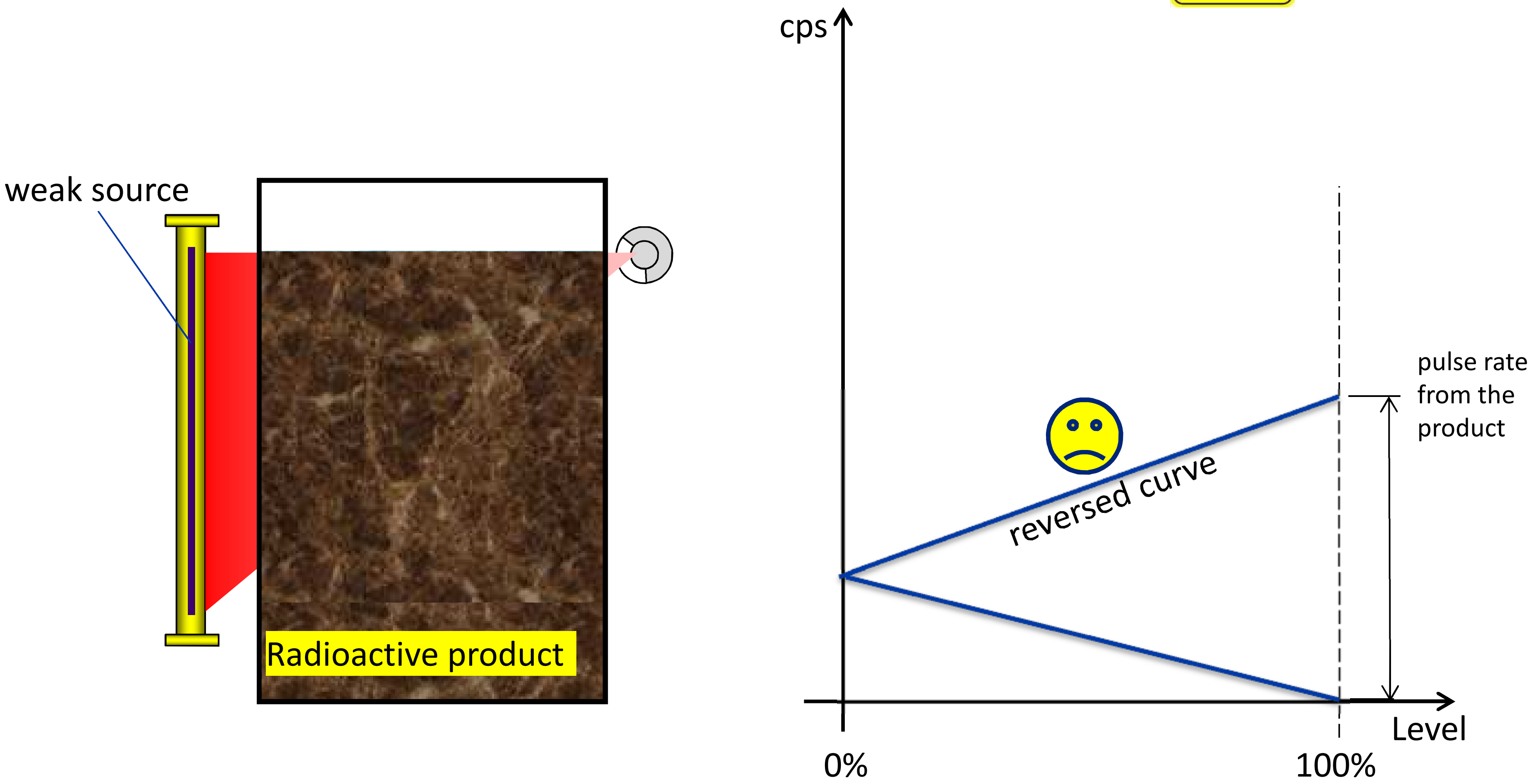
This was the suggested and delivered upgrade.



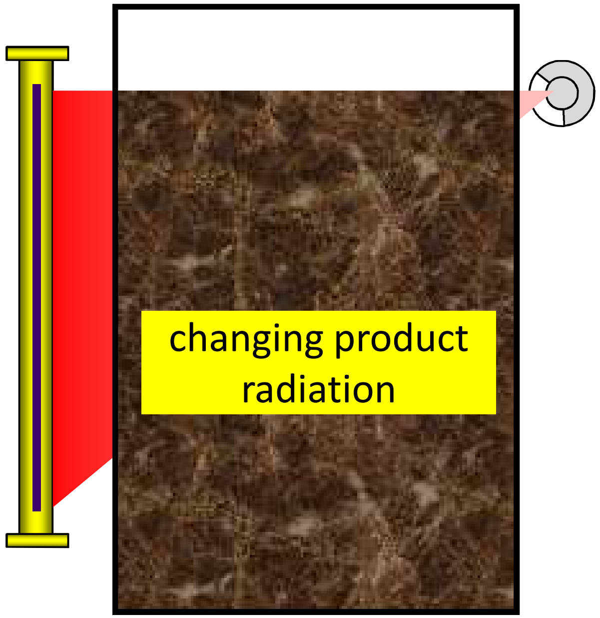
Egypt, Polypropylene production

Product with radioactivity

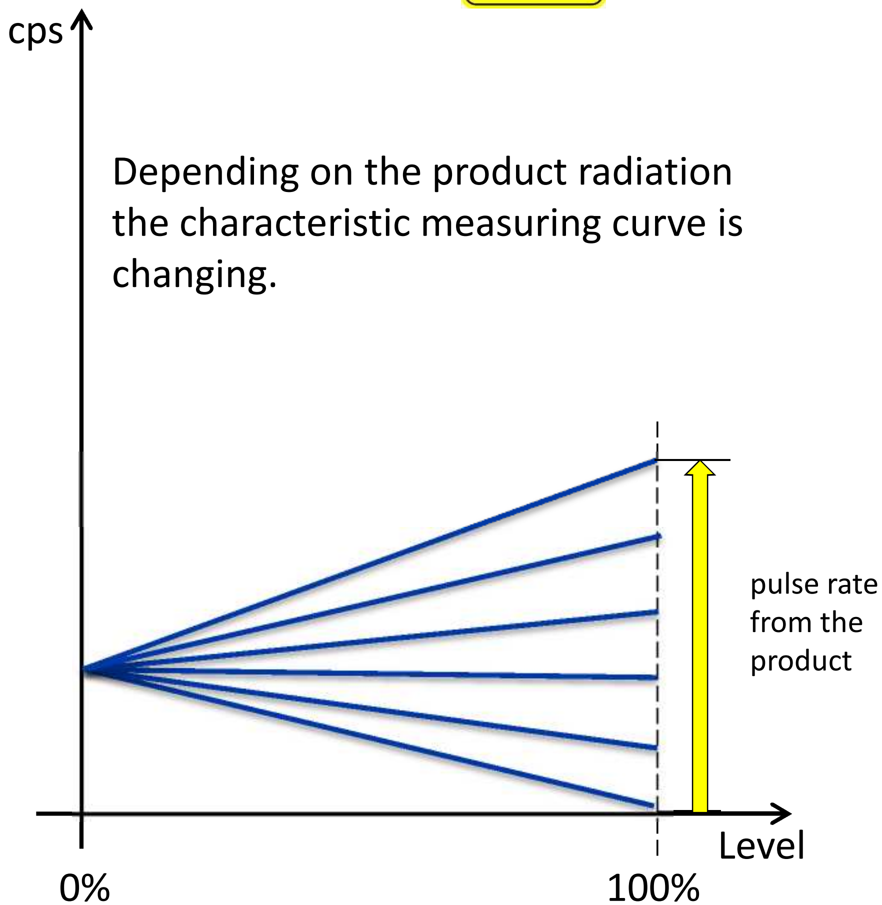
Behavior of the Pulse Rate



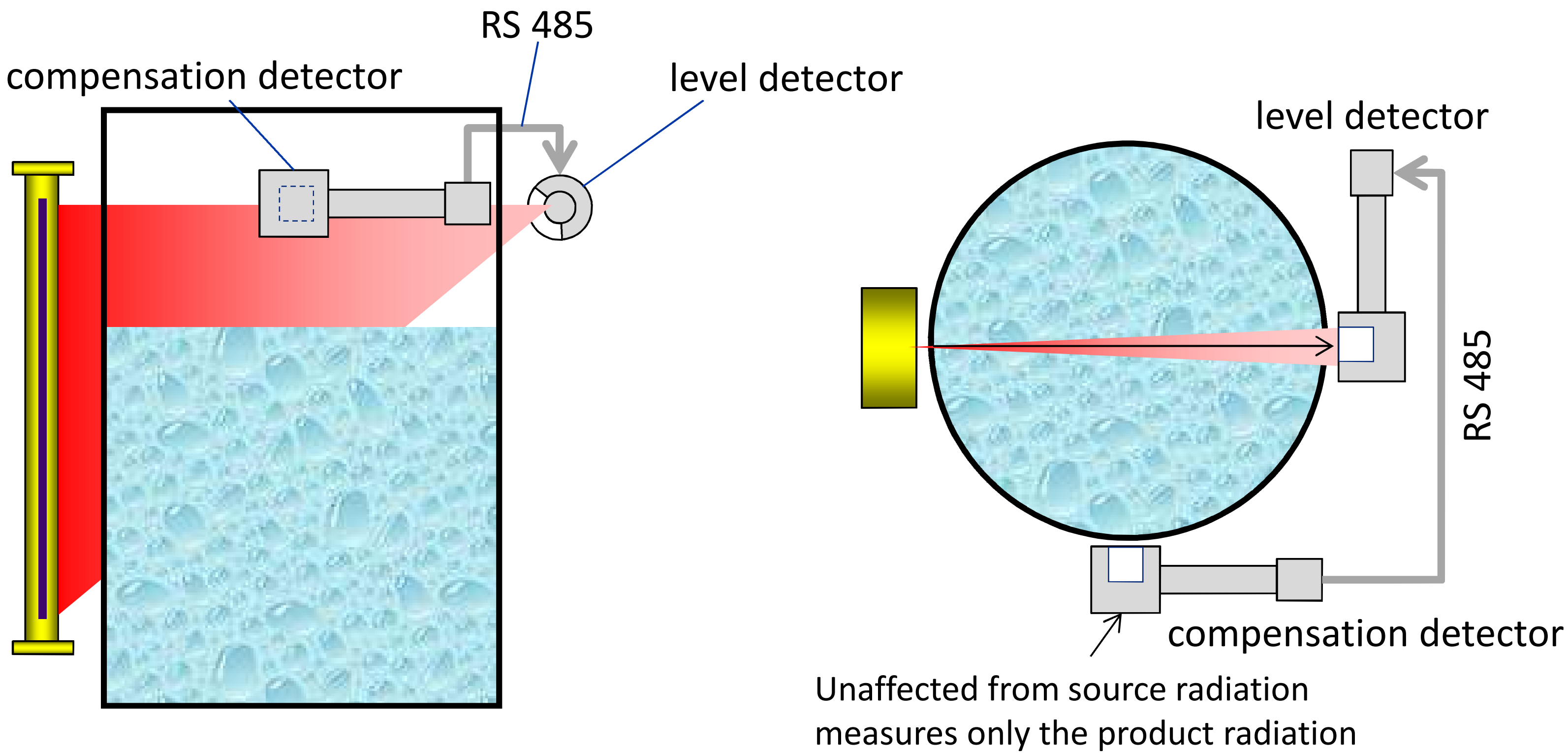
Changing Product Radiation



Depending on the product radiation the characteristic measuring curve is changing.



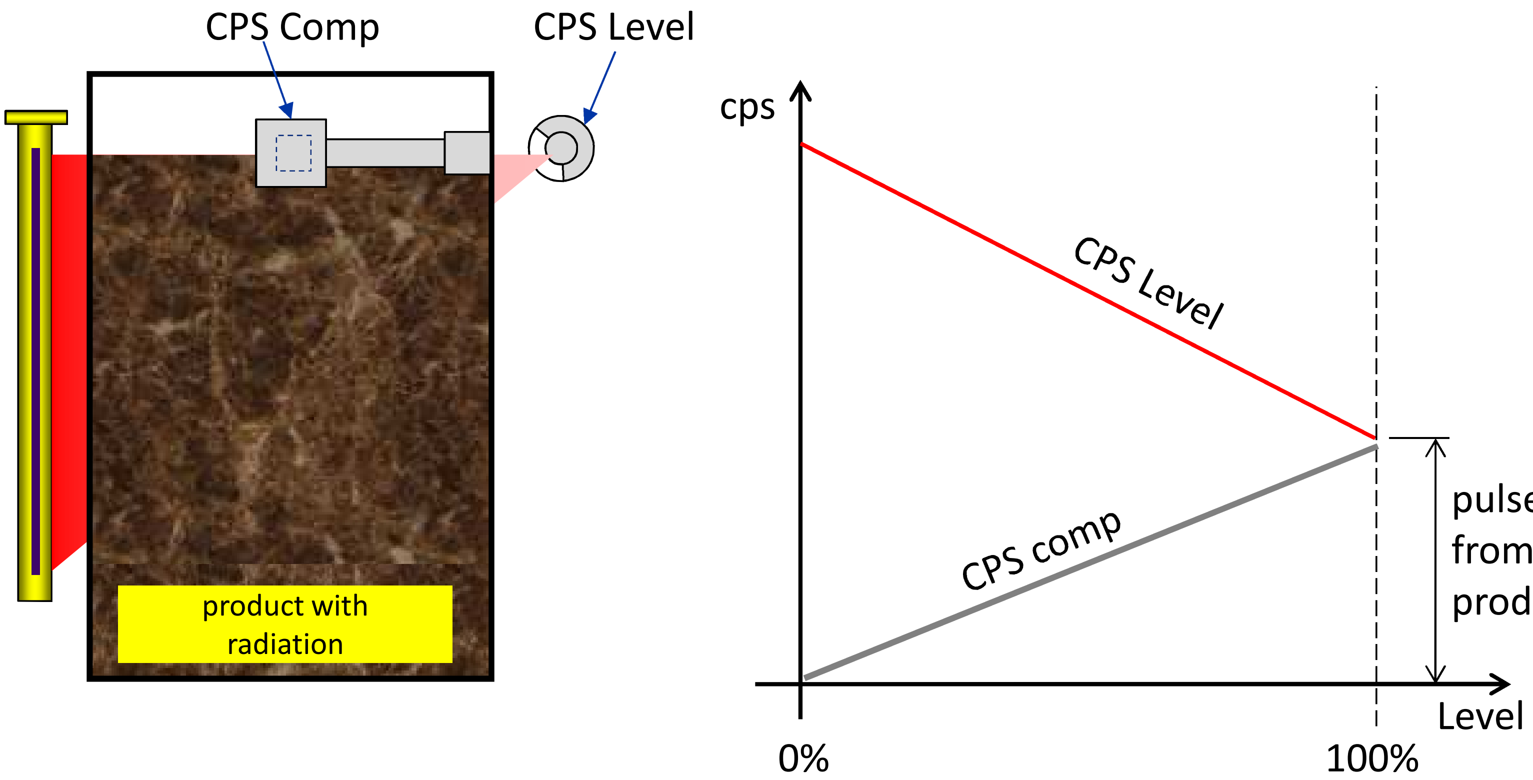
Basics to the PRC Function



Useable Count Rates = Level cps – Comp. cps

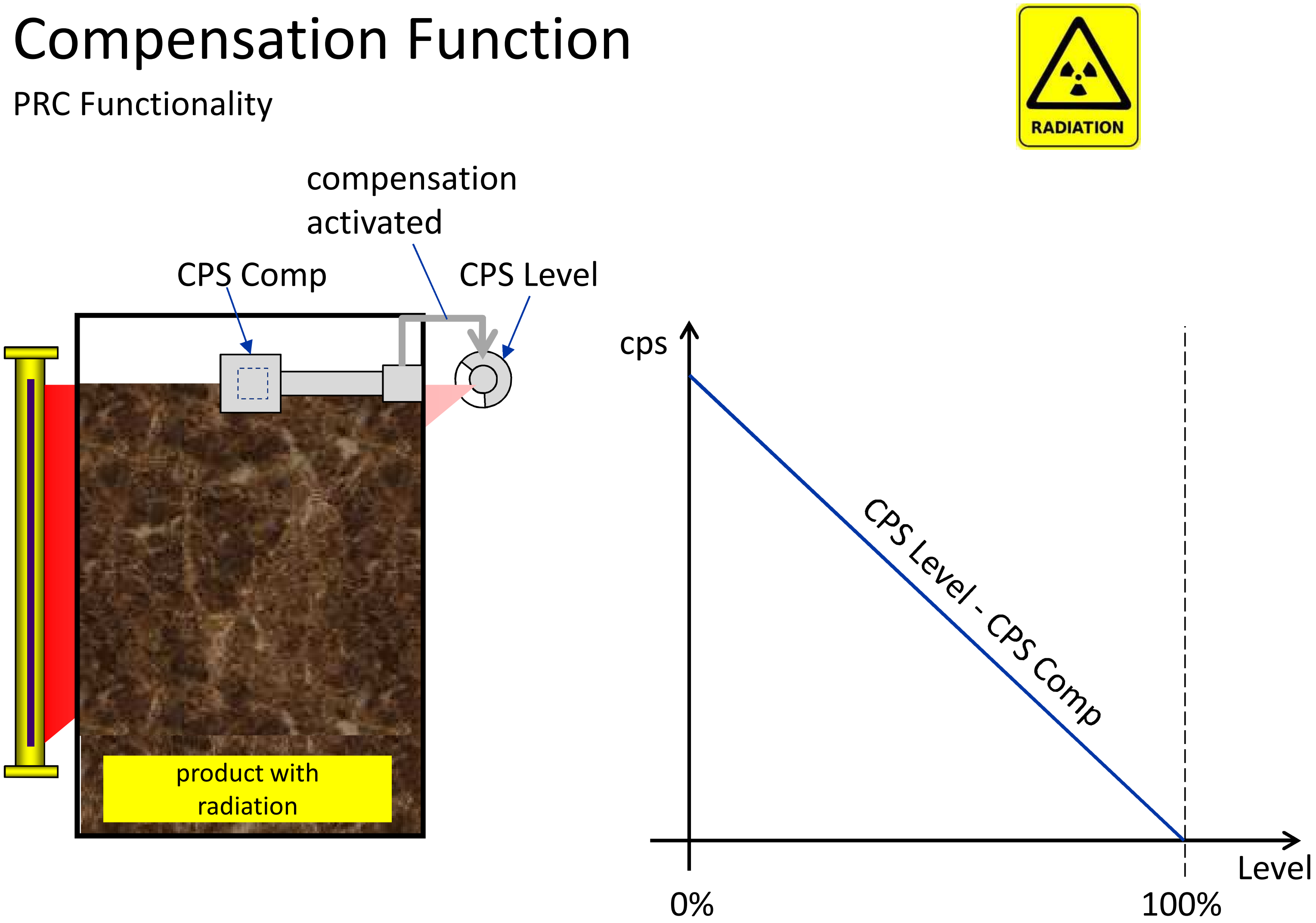
Pulse Rate **with** Product Radiation

PRC Functionality



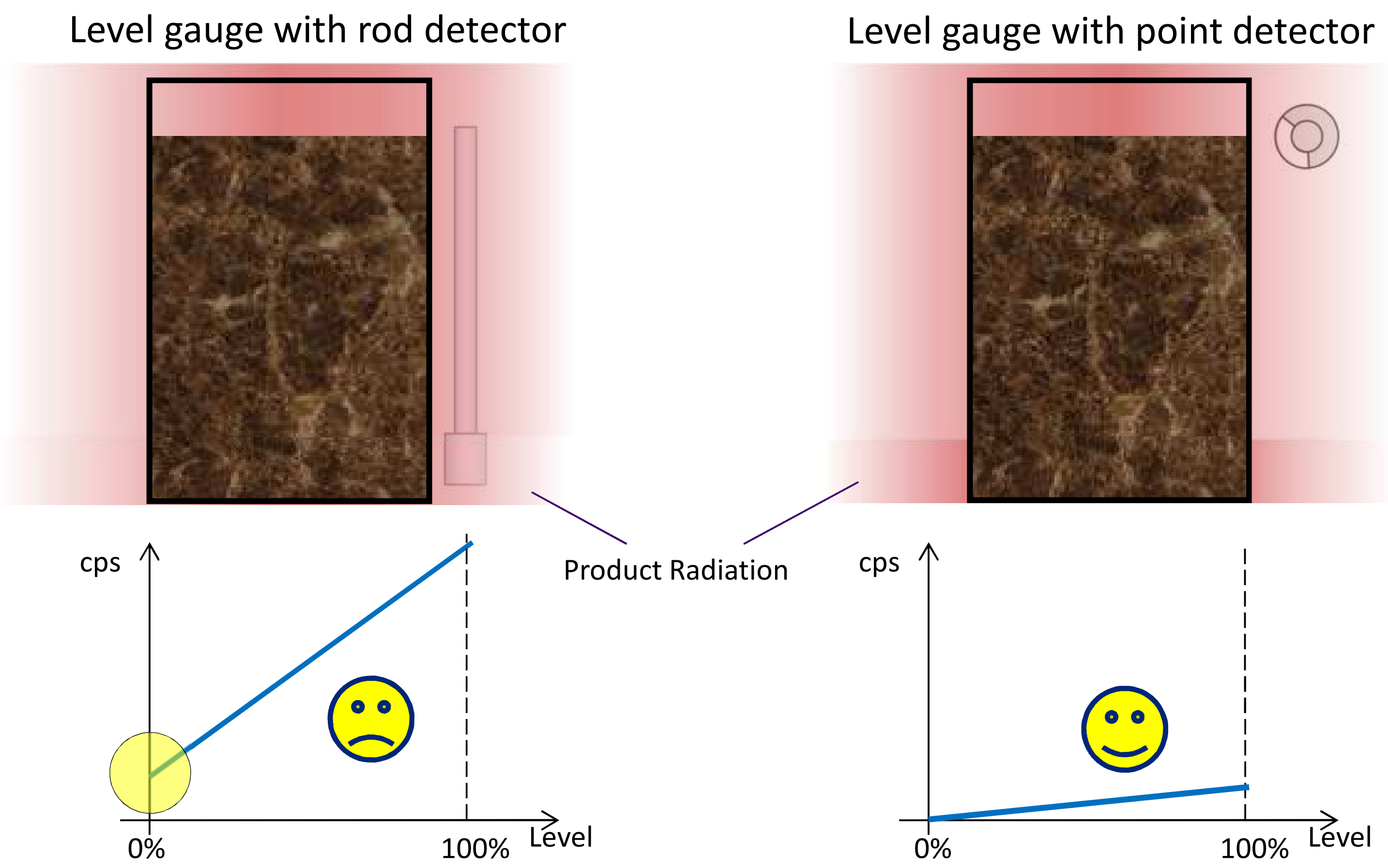
Compensation Function

PRC Functionality



Comparison between Rod and Point Detectors

PRC Functionality



Summary

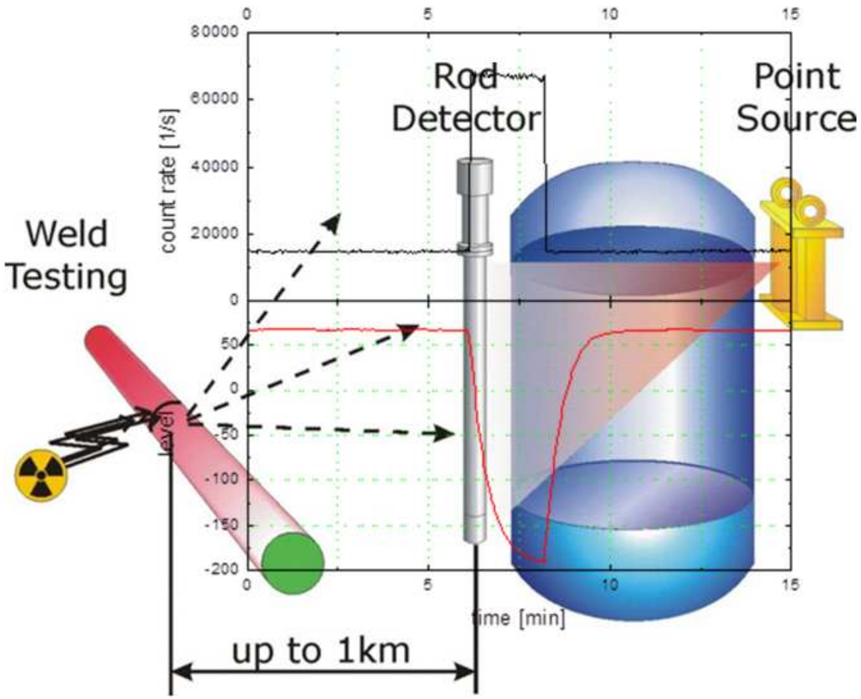
- Temperature and aging effects need to be compensated
  - Automated Gain Control for supply high voltage of photo multiplier
- Cosmic Radiation Gain Control makes SIL 2 / SIL 3 available also for Low Level Switch and Density measurement without additional cost
- Accuracy of level measurements is affected by gas properties changes
  - Gas density
  - Changing number of hydrogen atoms
- Level measurement with radioactive products

Thanks for your attention!

www.Berthold.com

Stable during weld inspections?

- Radiation interference from non-destructive testing



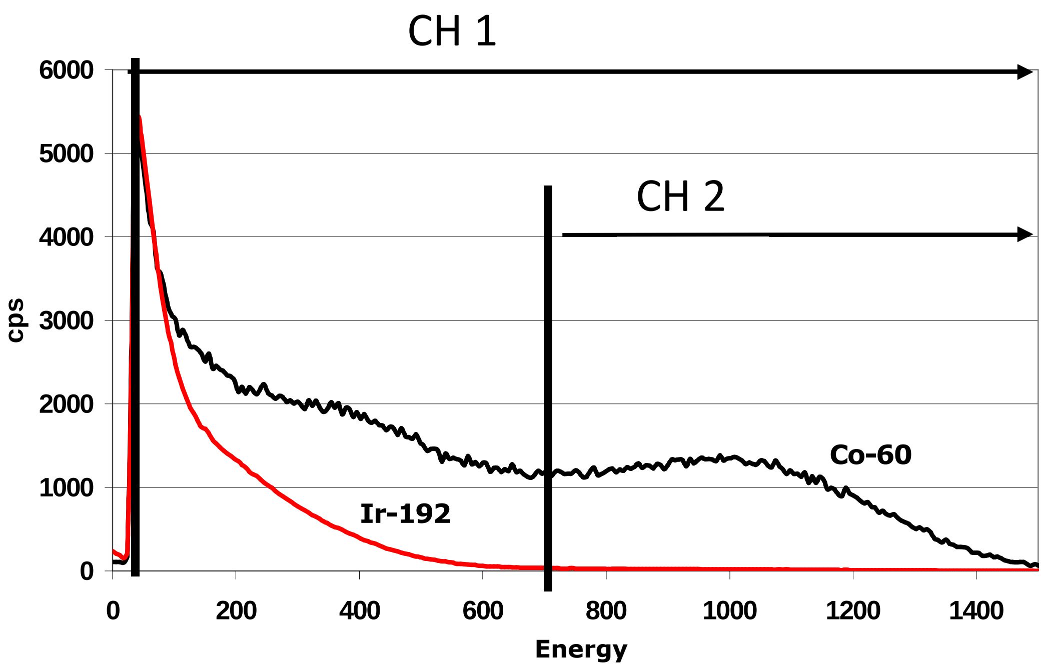
Use of high activity sources (3-80 Ci) mostly Ir-192

→ Wrong measurement due to excess count rate

→ Too low level is displayed

RID Discrimination of Radiation Interference

We can see the difference!



- 2nd measurement channel
  - Active when radiation interference is present
  - Counts from the inspection source are excluded

RID Example at BASF