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Application of nuclear techniques in industry and environment and their impact on the economy of developed and developing countries

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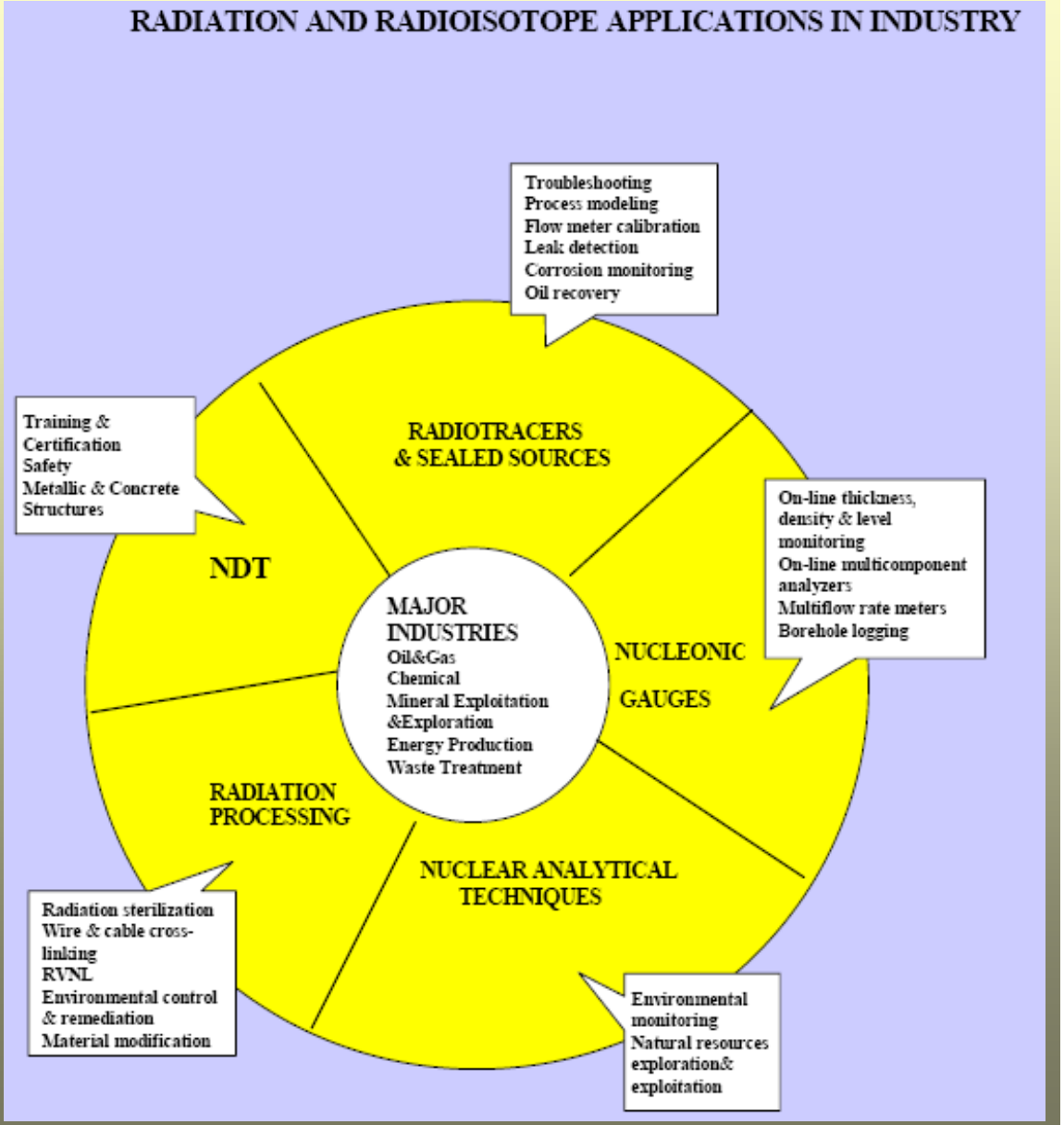
Major targets

- **Chemical & Petrochemical industries**
- **Mineral processing industry and metallurgy**
- **Cement industry**
- **Wastewater purification installations.**



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***Benefits to cost ratios of radiotracers, sealed sources and nucleonic gauges applications are considerably high: between 10:1 and 4000:1**

***Major techniques are now in routine service to industry to optimize processes, solve problems, improve product quality, save energy and reduce pollution.**

***Number of services for troubleshooting carried out worldwide per year is in excess of tens of thousands (out of them > 5000 are gamma scans).**

***The number of nucleonic gauges worldwide could be estimated > 250 000.**

***Estimation of benefits from radioisotope applications in industry gives figures of around US$ 5 billion/yr.**

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R&D in radioisotope methodology:

1. ***Modeling complex processes using experimental tracer residence time distribution (RTD) and computer fluid dynamics (CFD) codes,***

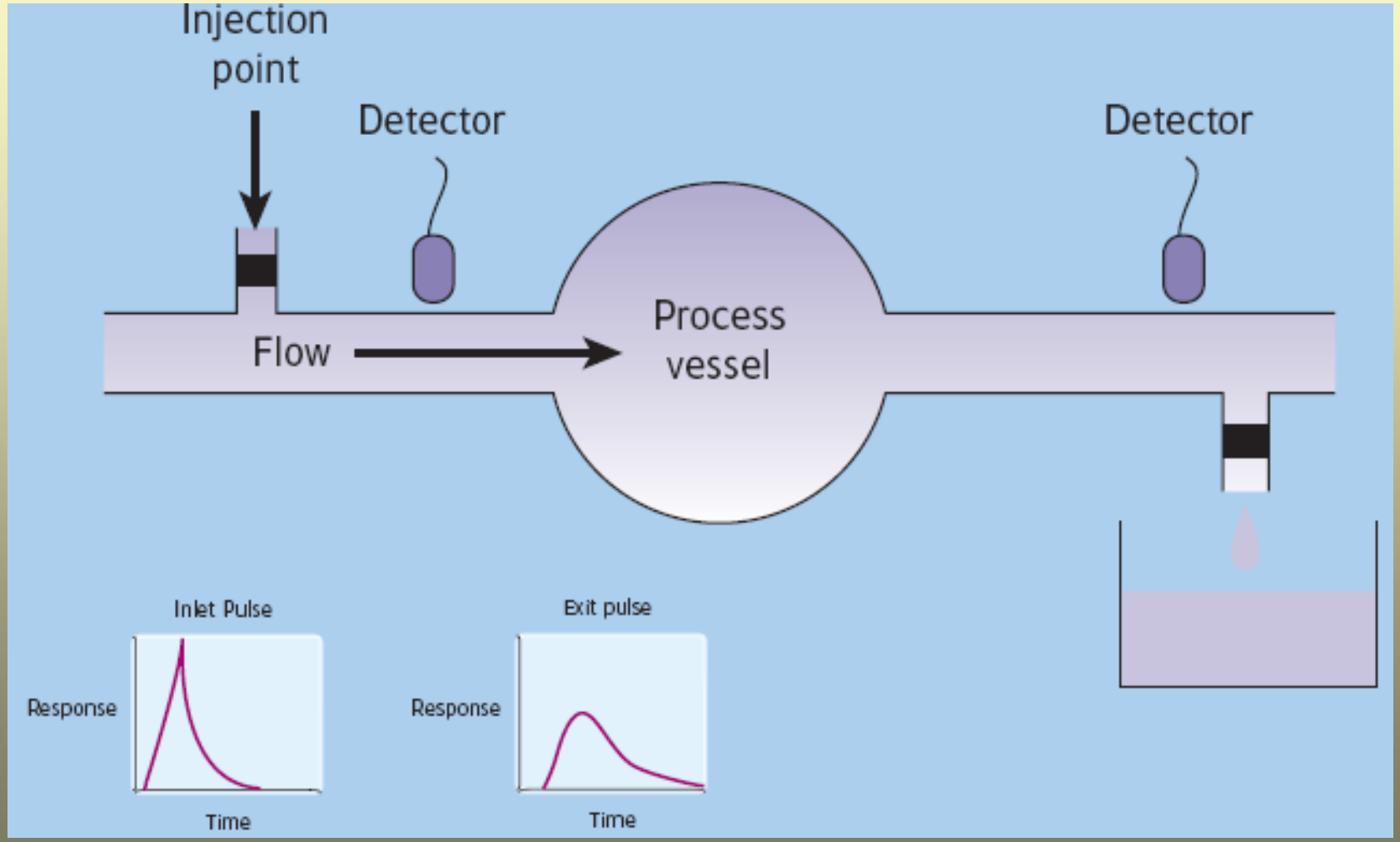
2. Developing gamma computer tomography (GCT) and single particle tracking methods for 2D and 3D imaging of opaque multiflows.

****RTD is fundamental to reactor design. CFD simulation provides detailed spatial insight of a process. Trend is to combine experimental and numerical approaches to obtain reliable quantitative results for processing units to improve and optimize their design and efficiency.***

*****Gamma computer tomography (CT) and radioactive particle tracking (RPT) methods are better suited for flow visualization in opaque multiphase systems. They provide reliable insight regarding phase distributions, mixing and flow patterns making them powerful tools for troubleshooting of industrial processes.***

Principle of Residence Time Distribution (RTD) method

RTD animation.avi



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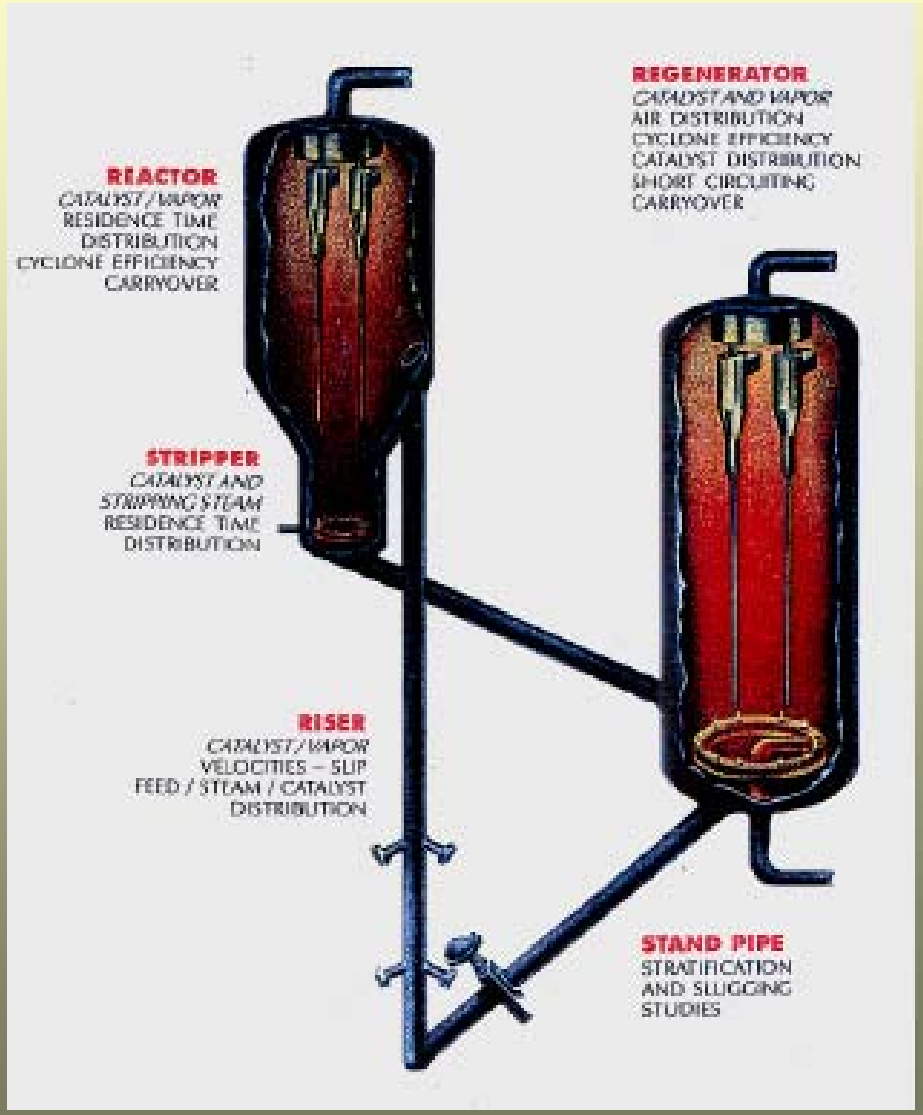
Radiotracers in FCCU



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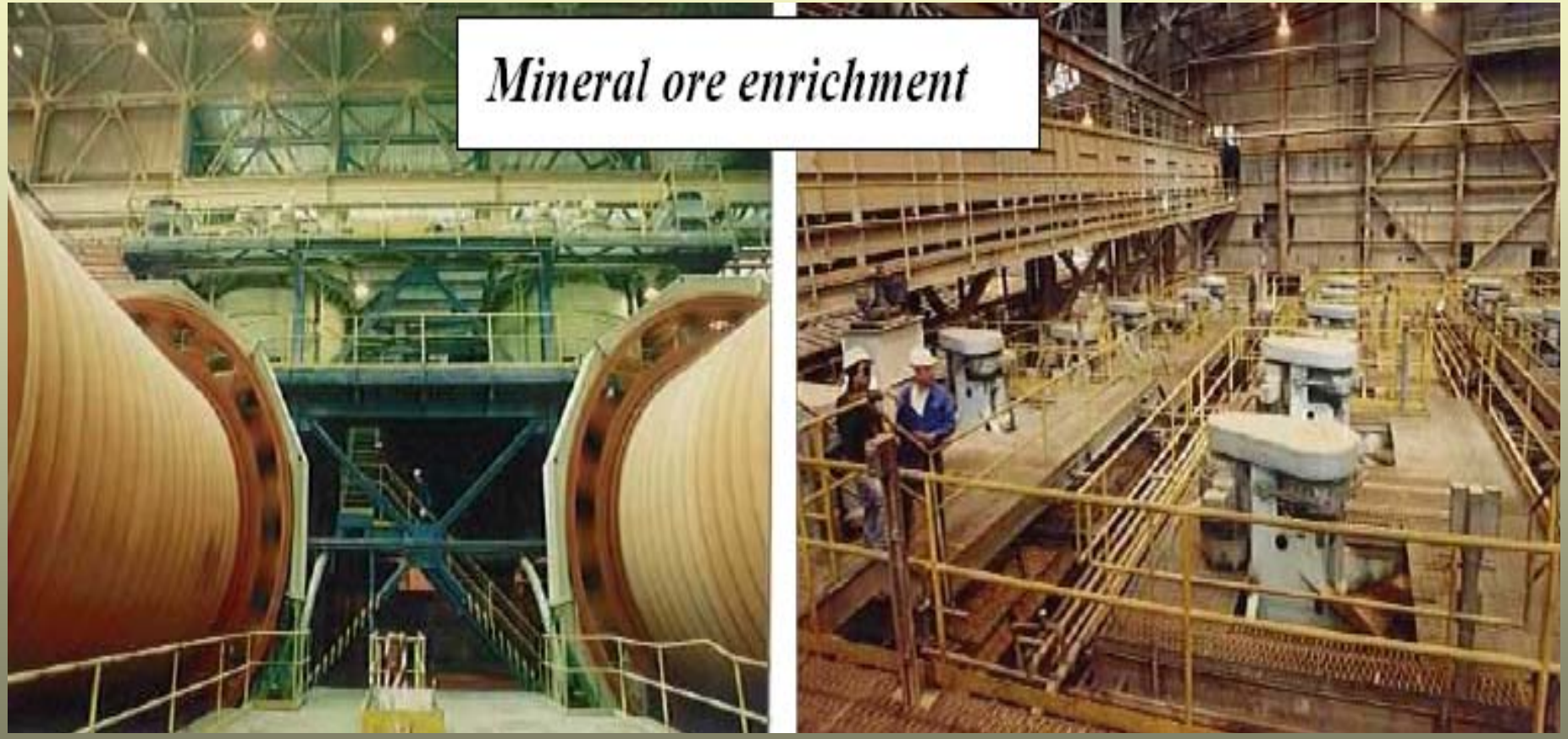

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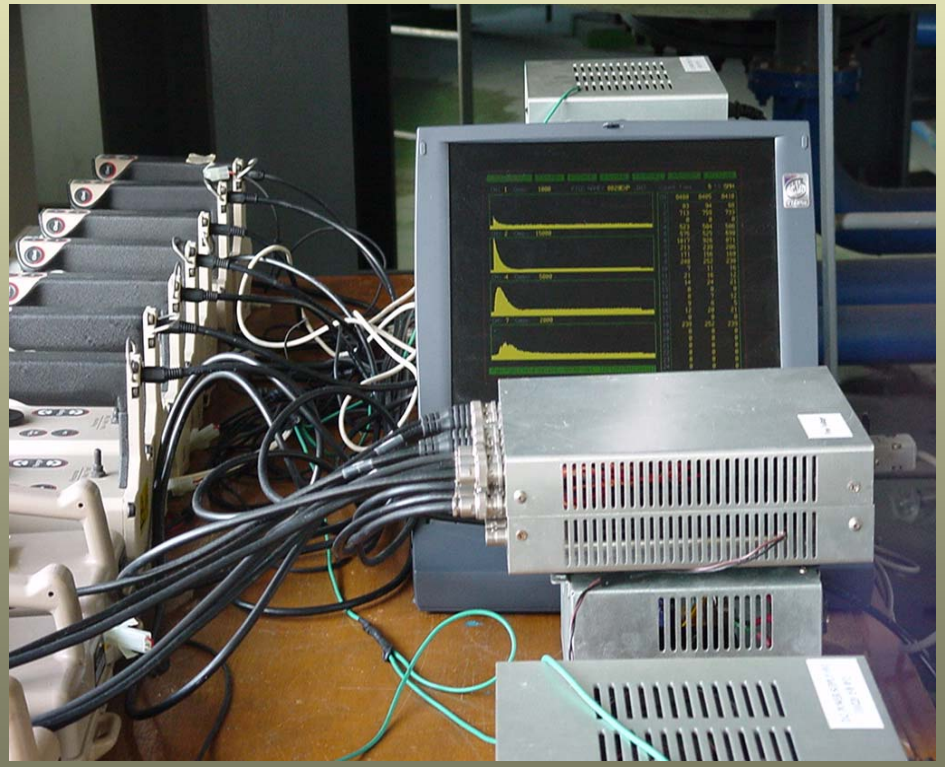
Radiotracer applications in wastewater installations

(diagnose efficiency of water purification)



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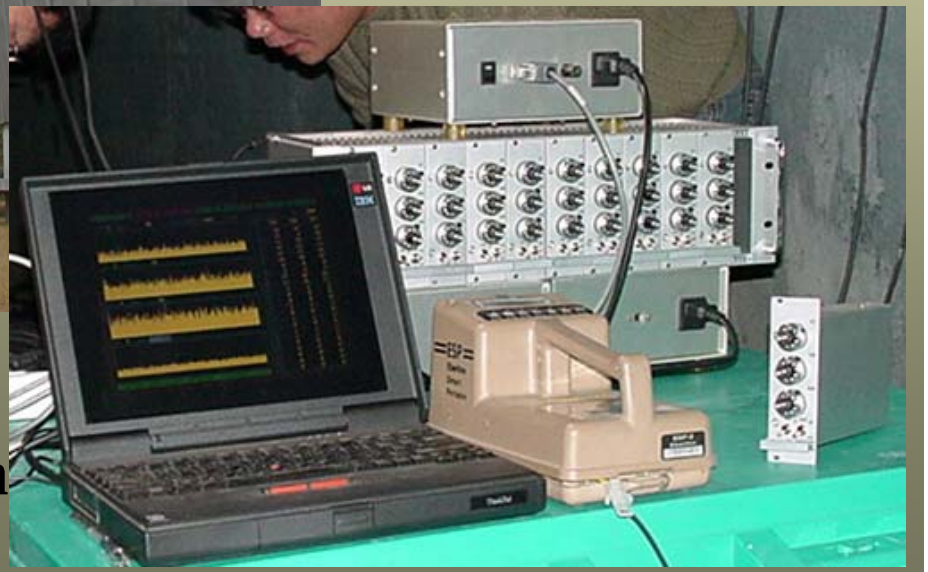
Sludge Digester

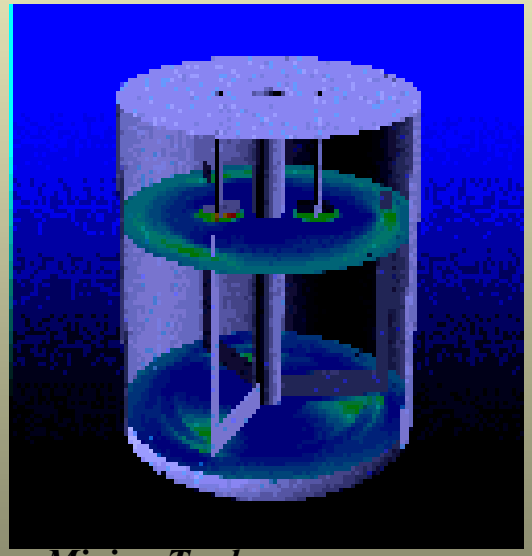
Top View of Mixer Pipe



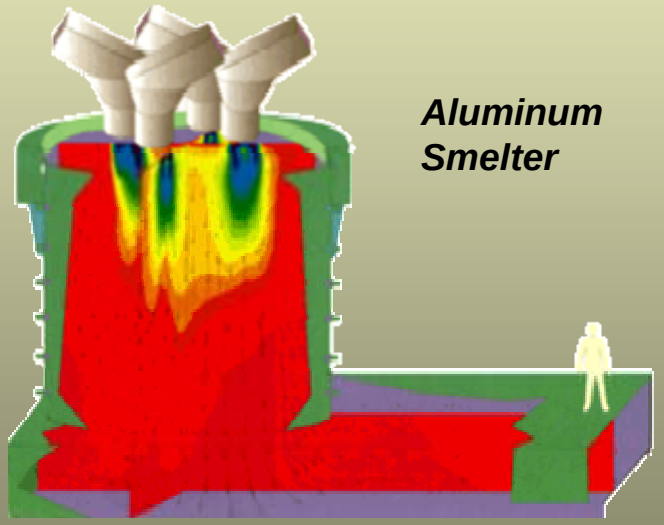
Data Acquisition System

CFD – RTD integration for accurate process visualization, modeling and optimization

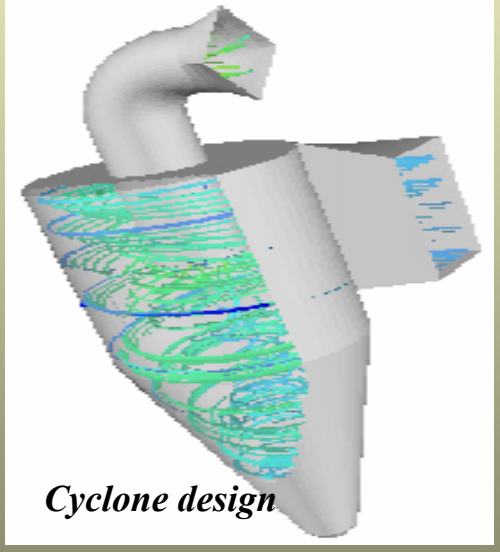
CFD results are being questioned by industries about reliability of their models due to lack of experimental techniques for model verification and validation



Mixing Tanker



Aluminum Smelter



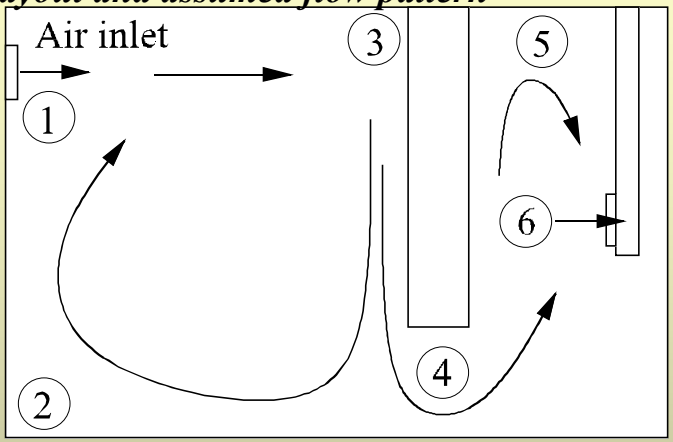
Cyclone design

Are these CFD simulations (flow and velocity maps modeling) correct? Only tracer experiments can confirm and validate them.

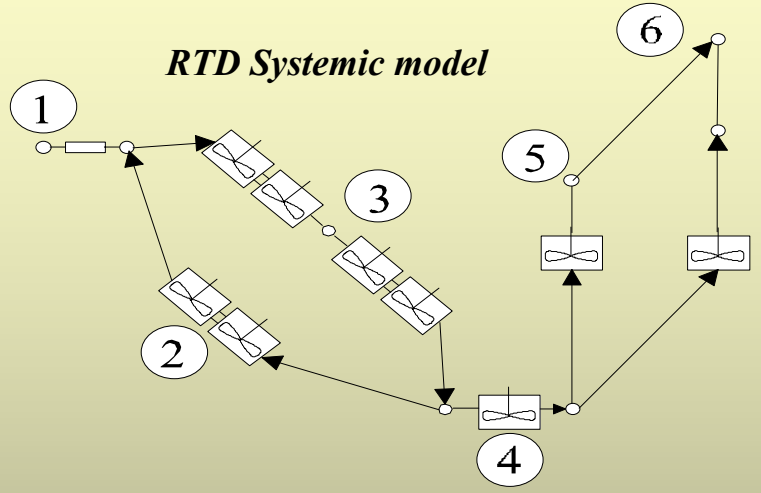
Systemic RTD and CFD modelling

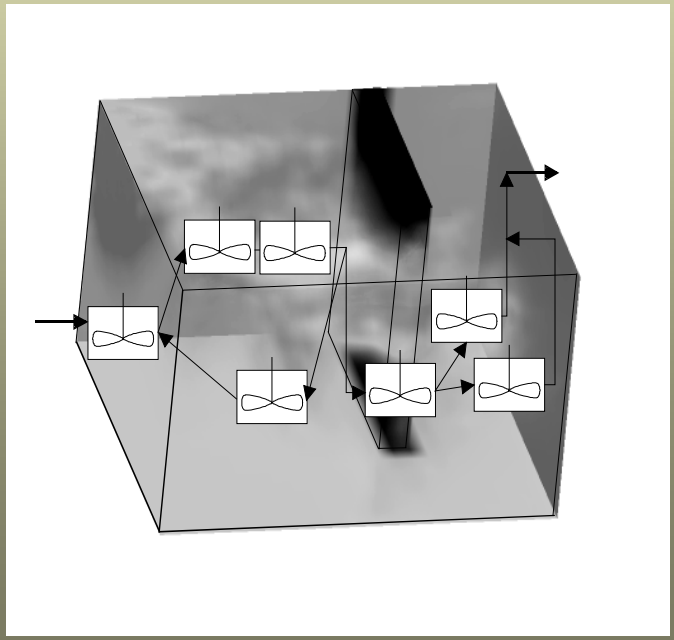
(of room ventilation)

Room layout and assumed flow pattern

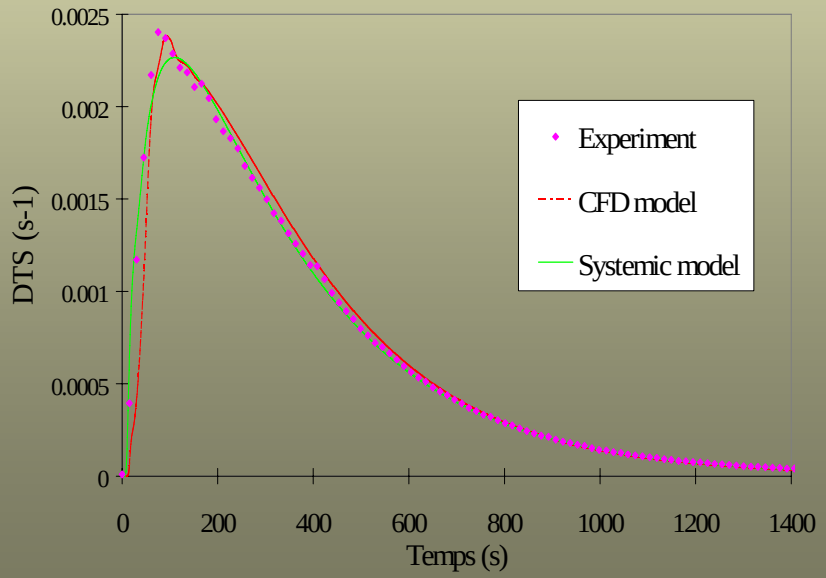


RTD Systemic model





CFD Concentration field and RTD systemic model



Comparison of exp. RTD with RTD from CFD

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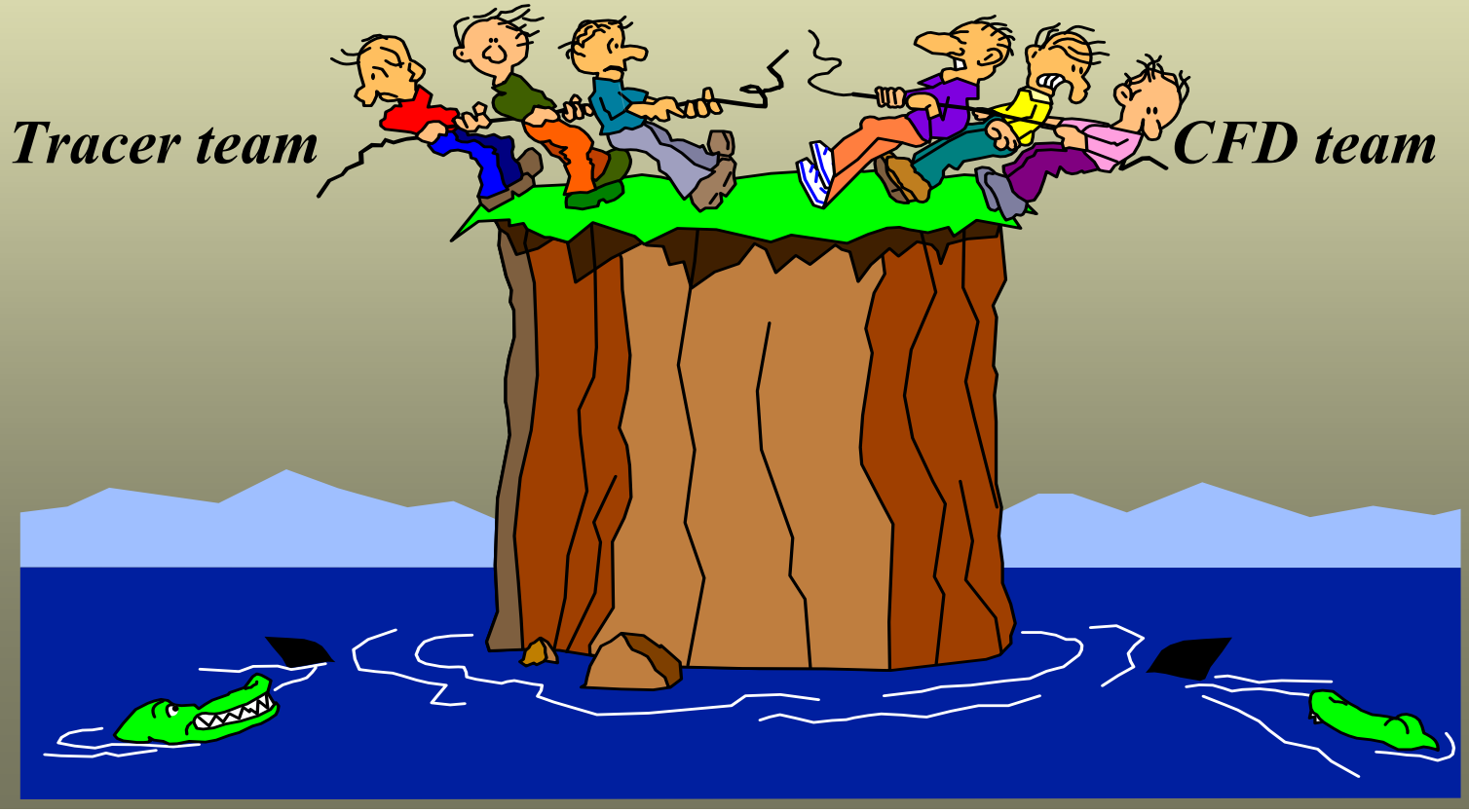
Tracer experiments - a way to validate Computational Fluid Dynamic (CFD) simulations

CFD Simulations and Tracing methods: Two complementary tools to improve knowledge about process insight.



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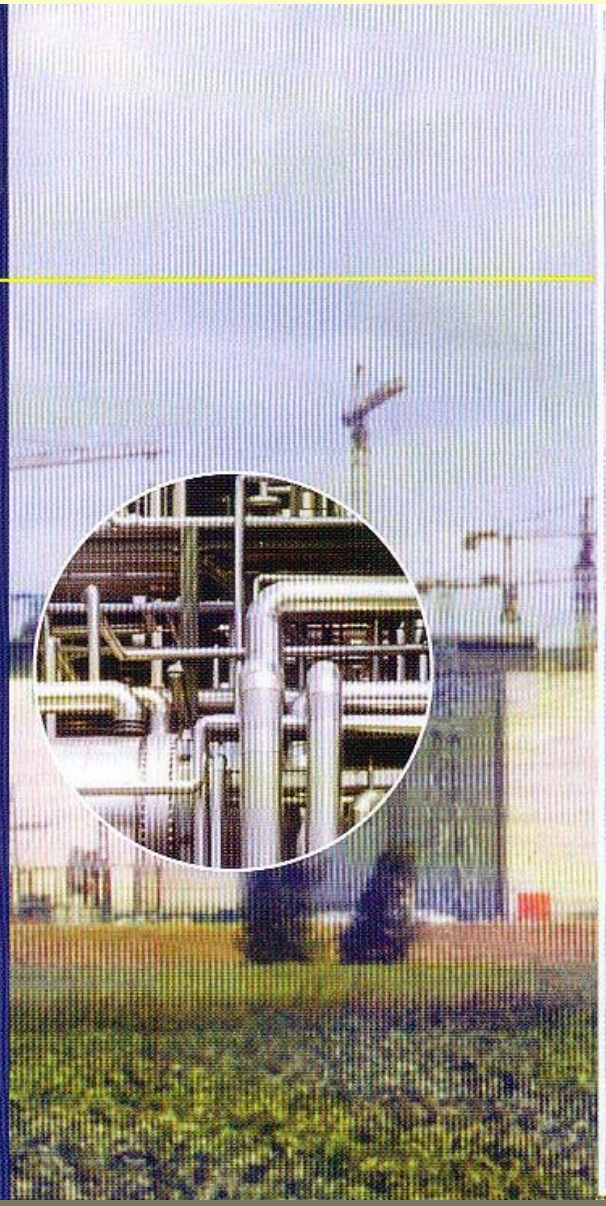
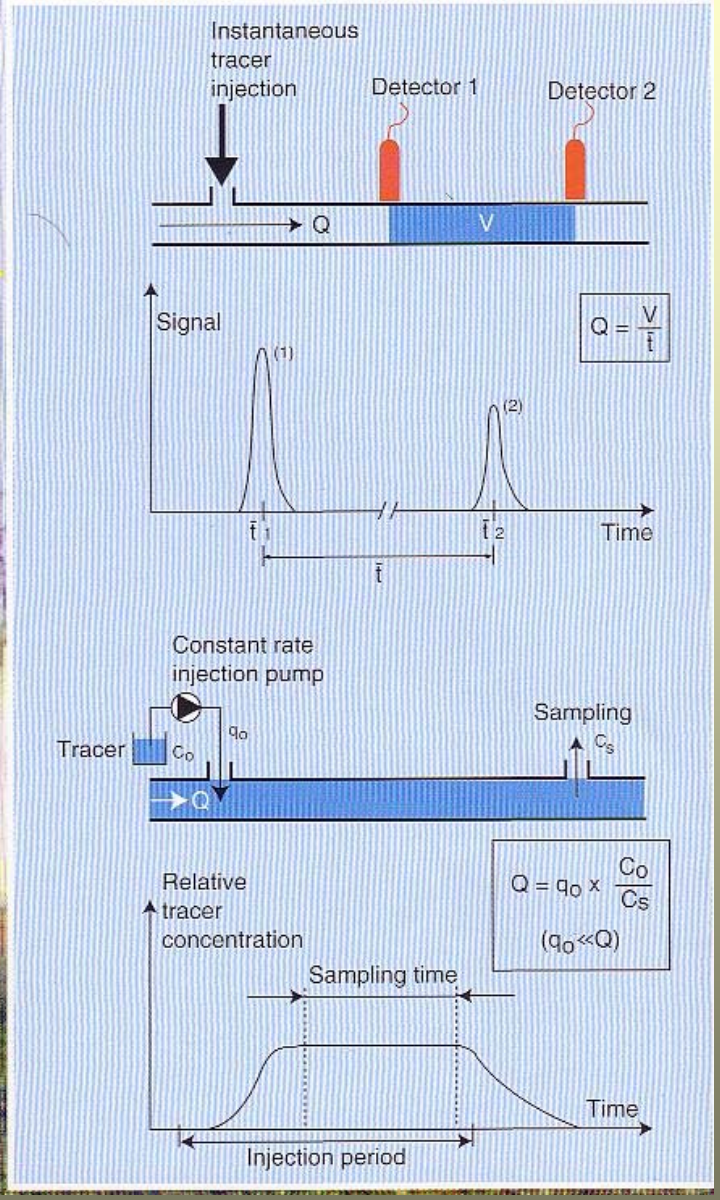
Flow measurement

The two methods available for flow measurement are pulse transit time, which gives velocity directly and the dilution method which gives mass flow rate directly.

Measurement procedures are based on the application of the ISO norms (4093 for gas and 2975 for liquid). Better than 2% accuracy is achievable

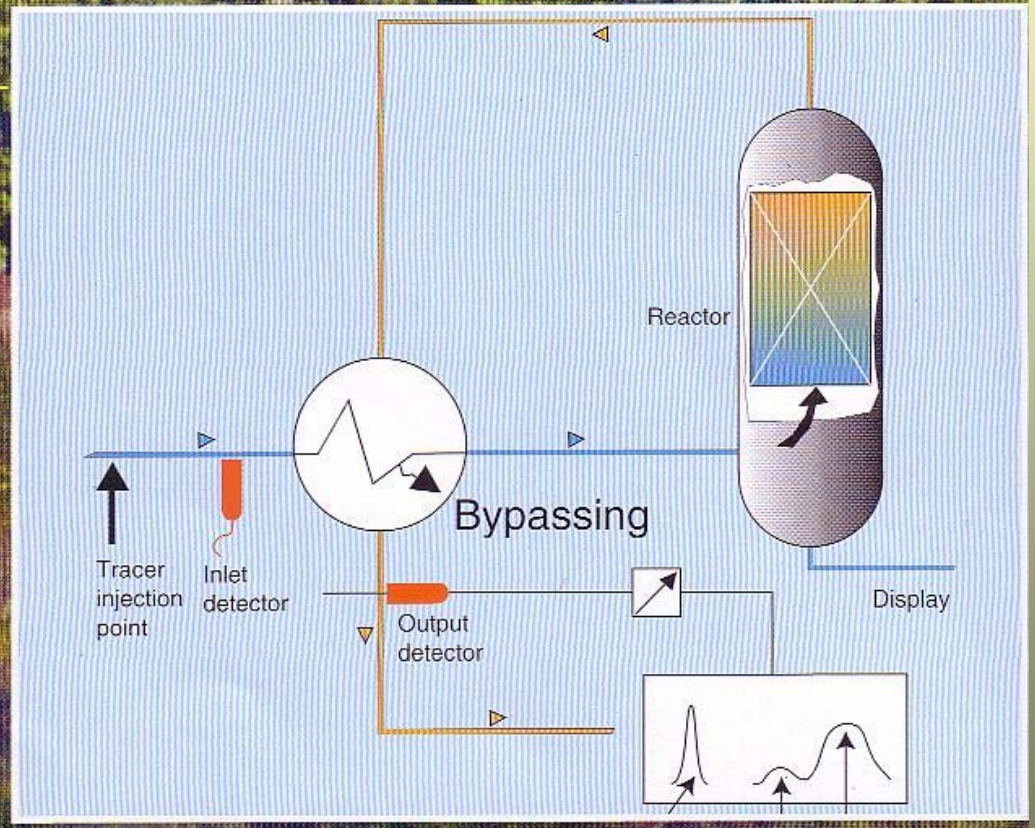




Leak detection in Heat exchanger

Leak detection

Difficult to locate, internal process leaks often cause serious problems... Tracer techniques offer an effective response to this problem. Typical detection threshold is between 1% and 0.1%, but lower levels are obtainable in some cases.



Gamma scan method

Gamma scanning provides the clearest picture of online conditions inside a process vessel.

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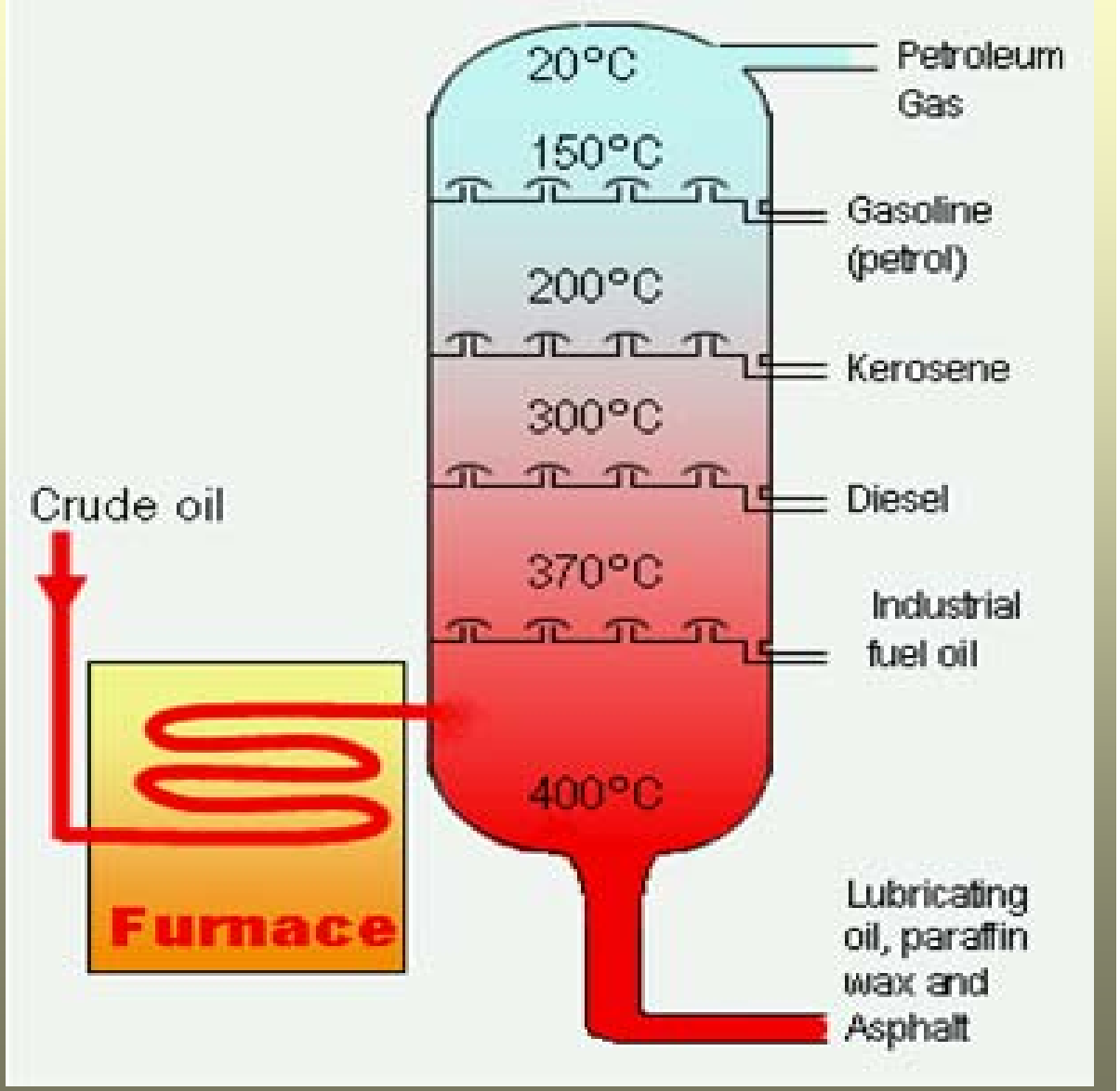
Column scan: Fractional distillation column of crude oil in refinery

distillation.exe

Gamma scan of trayed columns, finds:

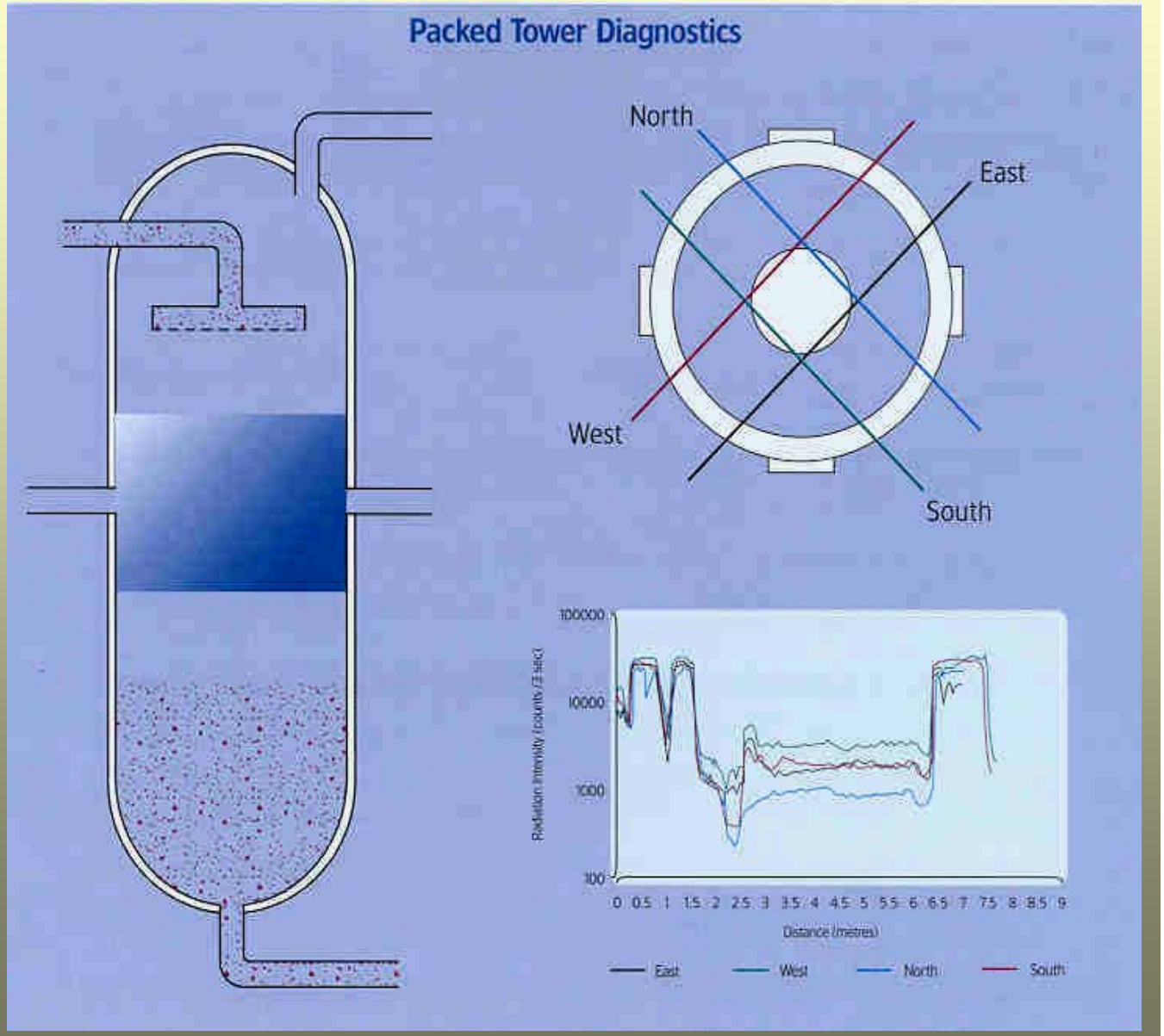
- ***location of damaged and/or missing trays***
- ***severity and extent of flooding, entrainment, foaming, or weeping***
- ***depth and relative densities of the aerated liquid on the trays, and the liquid level in the base of the column***
- ***preventing unnecessary shutdowns***



Gamma scan – Tower scan

Scan on a packed bed tower determines:

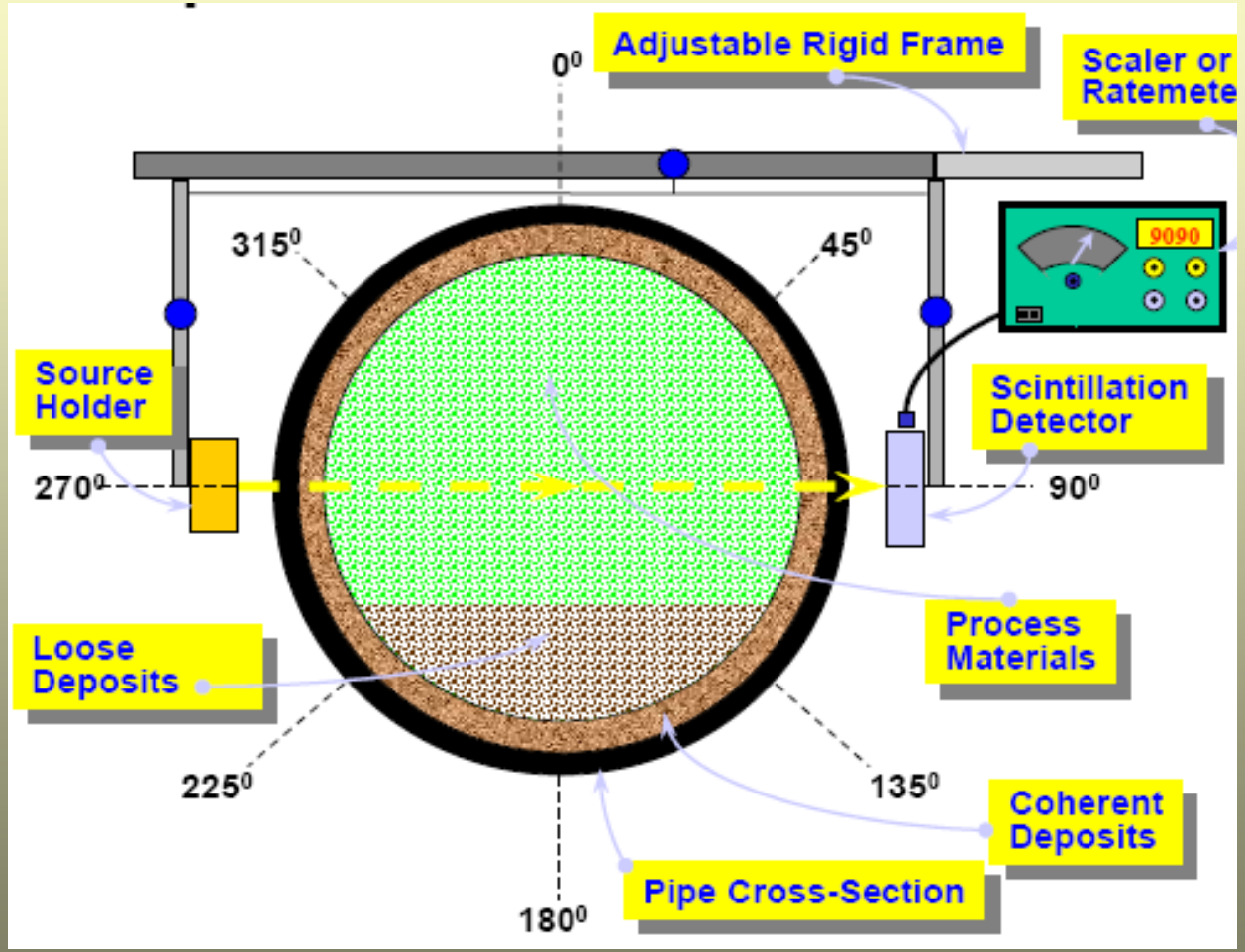
- ***whether all packed beds are present in the column***
- ***if beds have experienced any damage or settling of packing***
- ***liquid level on chimney and collector trays***
- ***if any of beds have experienced flooding or fouling***
- ***whether demister pads and distributors are at their proper elevations***



Pipe scanning

By applying gamma scan technique to piping, can quickly:

- *Locate blockages*
- *Locate scale or coke buildup*
- *Locate liquid in vapor lines*
- *Locate areas of lost refractory or lining*
- *Measure flowing densities*
- *Evaluate the fluidizations of catalyst*



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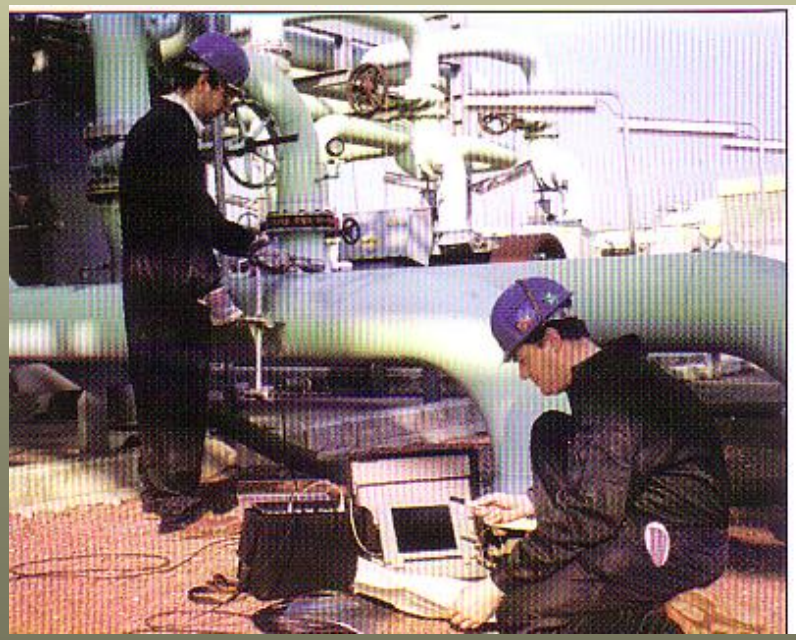
Pipe scanning



Nucleonic gauges or Nucleonic control systems (NCS):

"Instrumental measurement for control and analysis as based on the interaction between ionizing radiation and matter".

There are several ways of applying the NCS, among them:

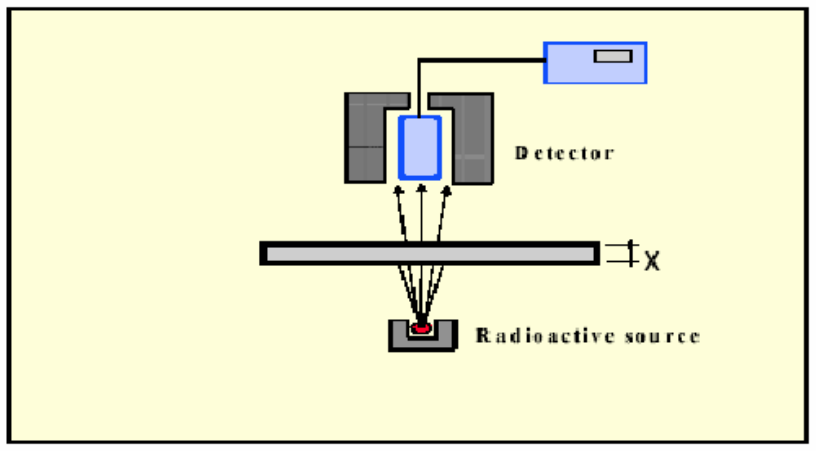
- ***On-line (process),***
- ***Off-line (process),***
- ***In-situ (well logging),***
- ***Used in laboratory (on samples), and***
- ***Portable, for site measurements***

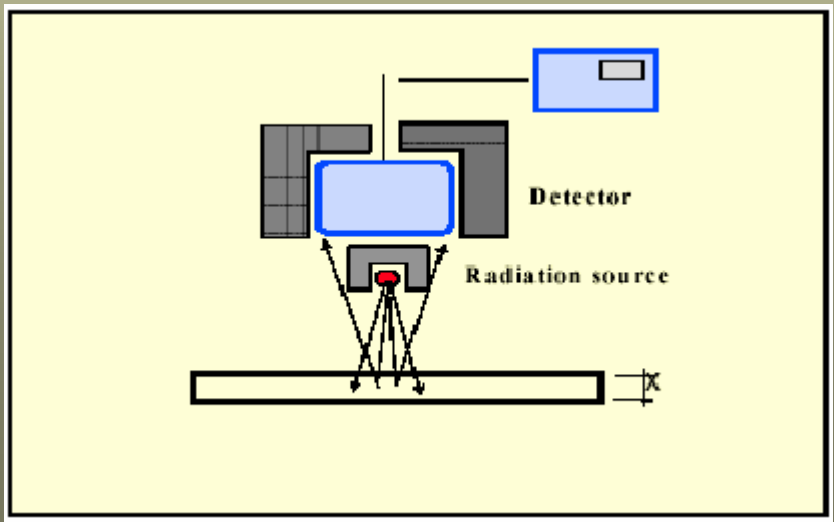
Relevant target areas are defined in international priority industrial sectors, where the benefit is enormous and the technology competes well with conventional techniques:

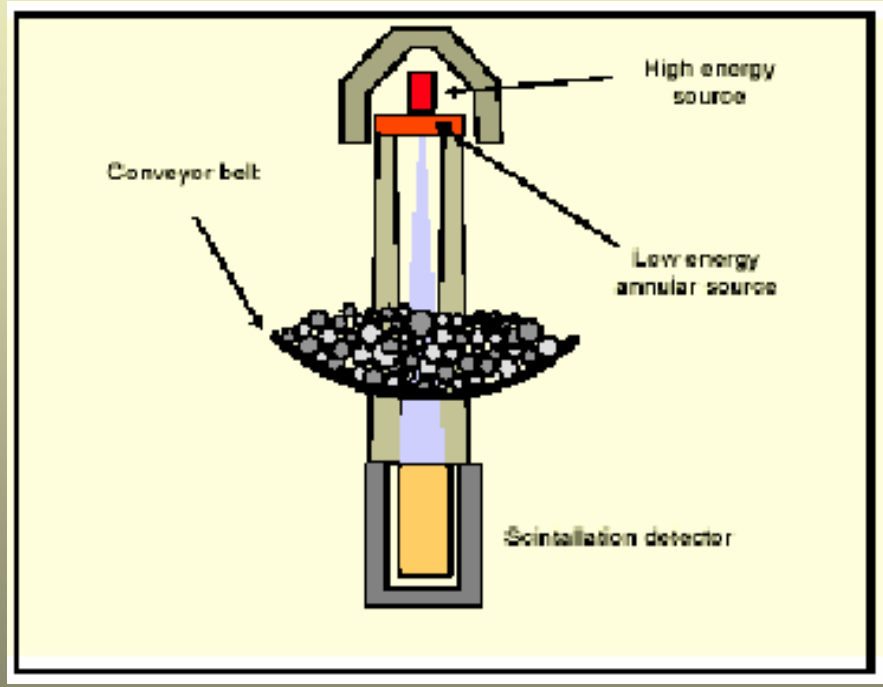
- ***oil and gas production,***
- ***mining and mineral ore processing,***
- ***paper and plastics industries,***
- ***cement and civil engineering industries***

Principles of nucleonic gauges

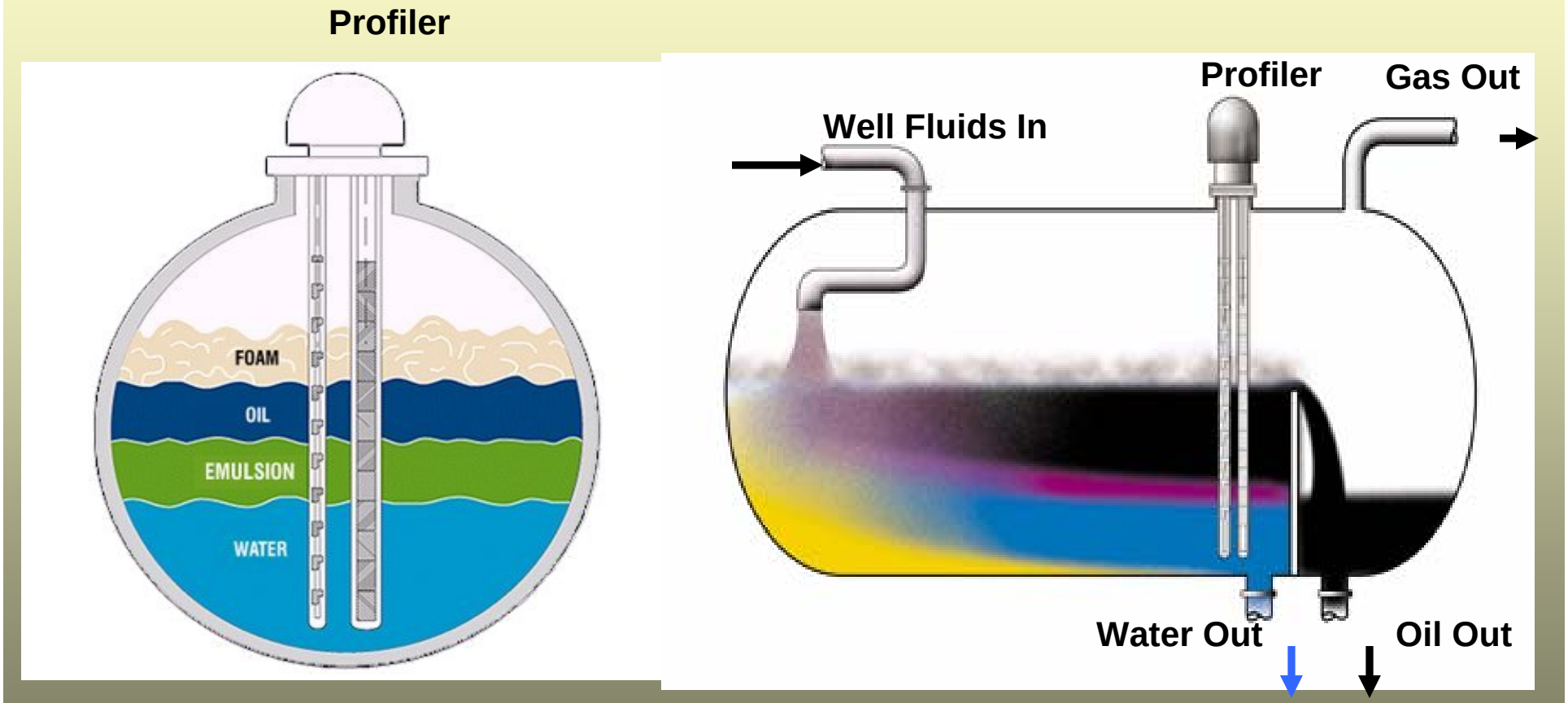
using gamma &beta radioisotopes







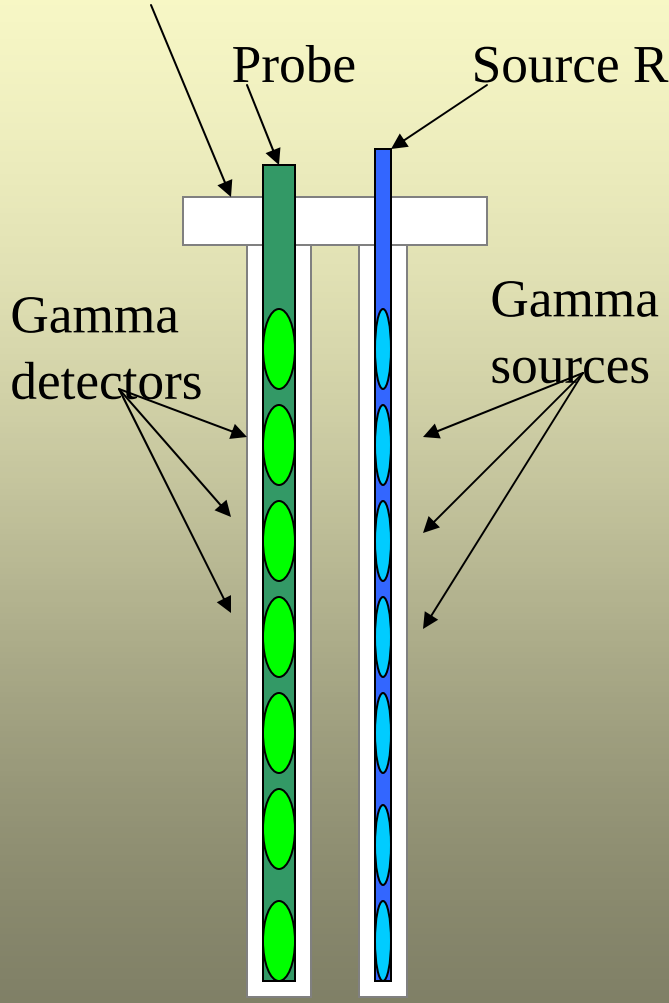
Density Profiler Installed in an Oil Separator



Density profiler

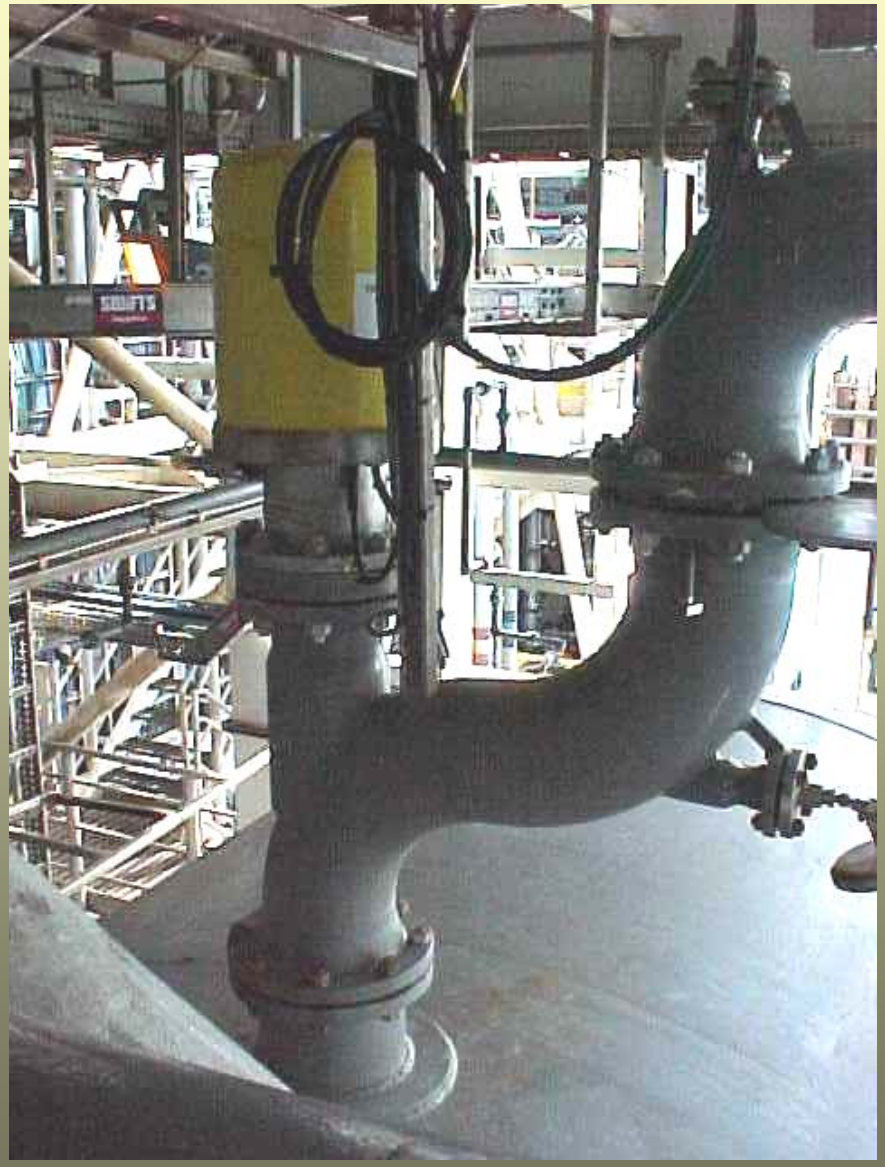
Source Detector Arrangement

Titanium dip pipes (similar to flanged thermo-wells)



Each source / detector gives an individual density reading at 28mm resolution. Counts vary due to different absorption coefficient and density of materials.

Photograph of a model of the Tracerco Profiler™



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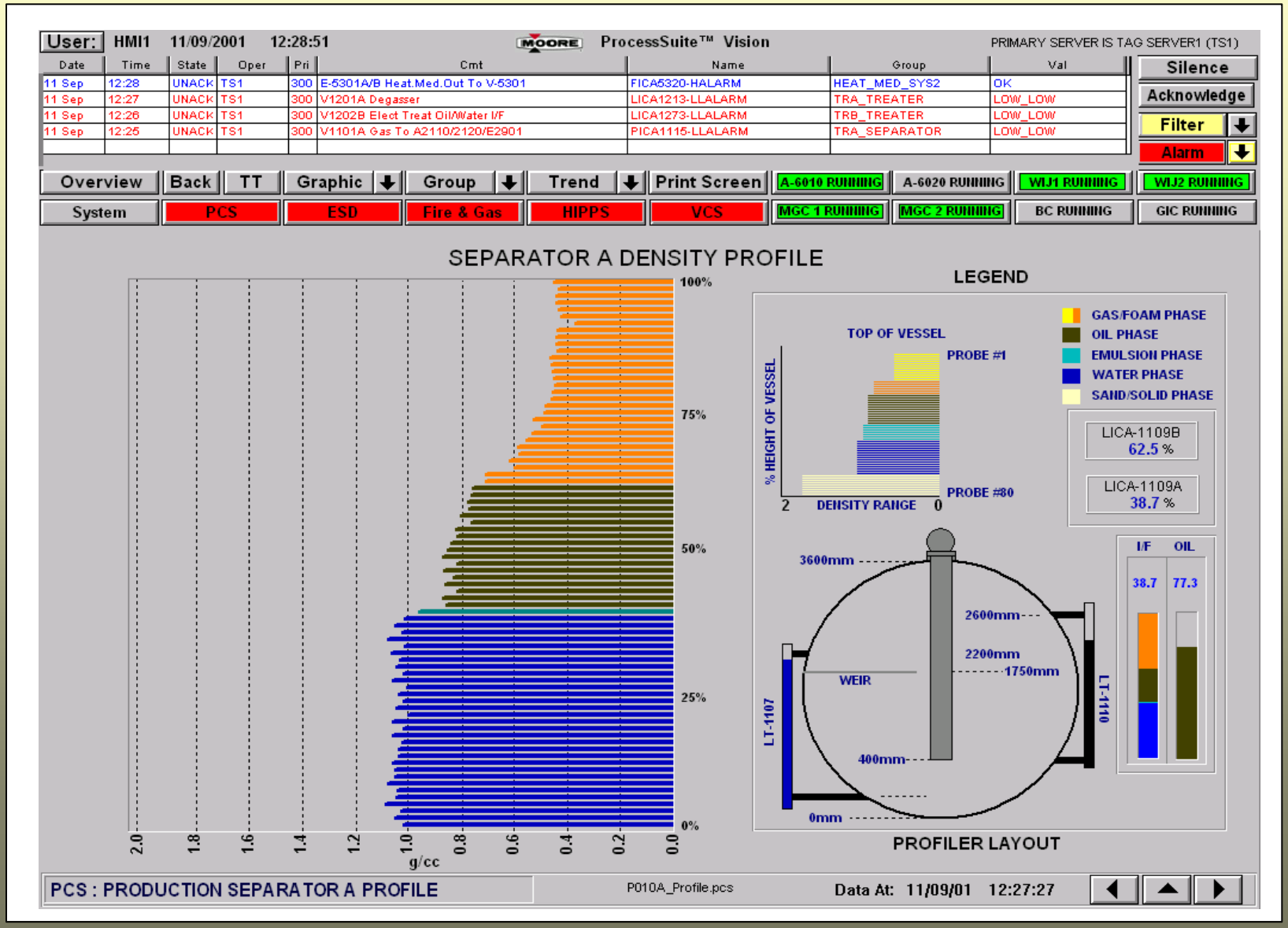
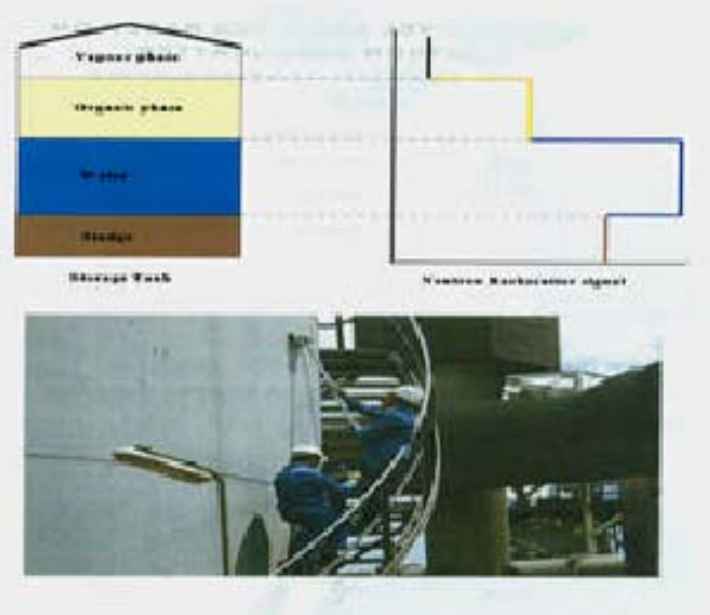
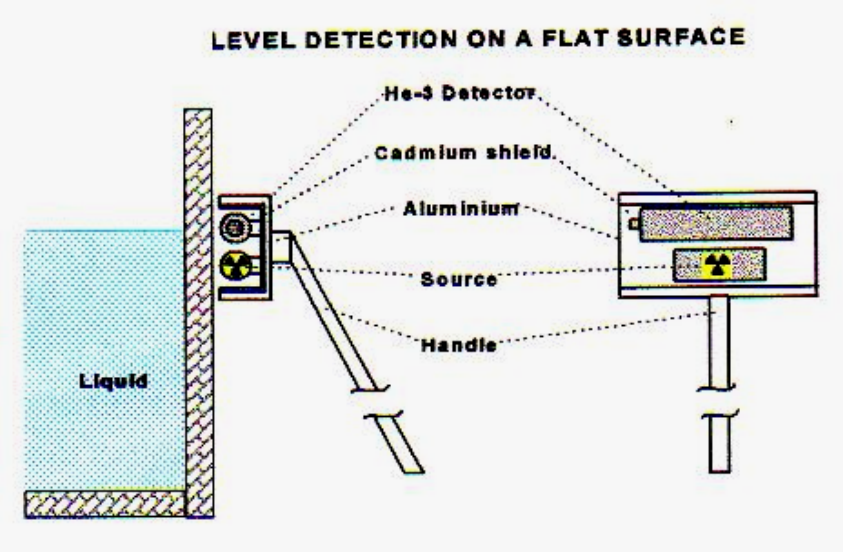
Tracerco Profiler™ in Operation Offshore Angola. Screen-shot 2.



Neutron backscatter technique





Typical neutron backscatter gauge equipment

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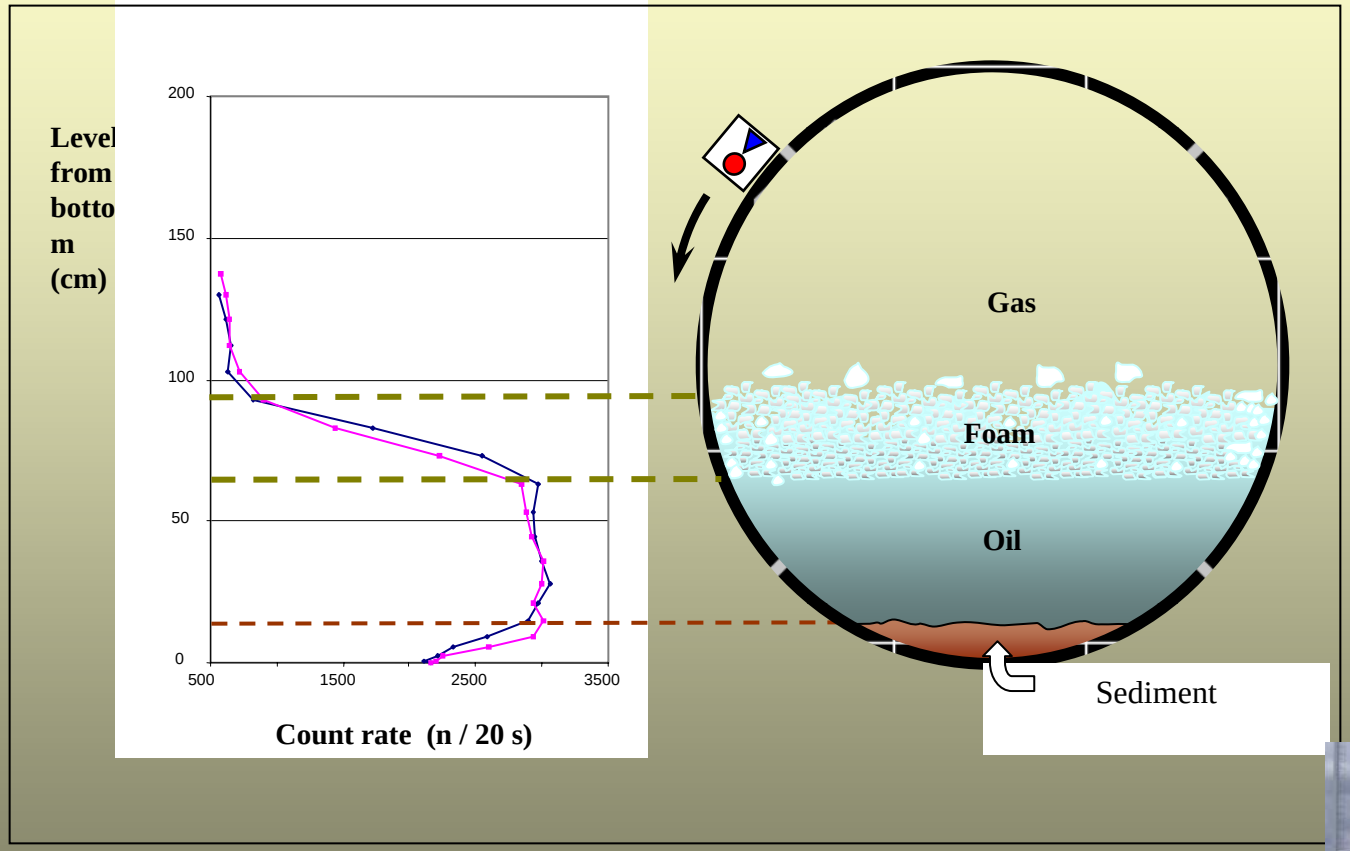
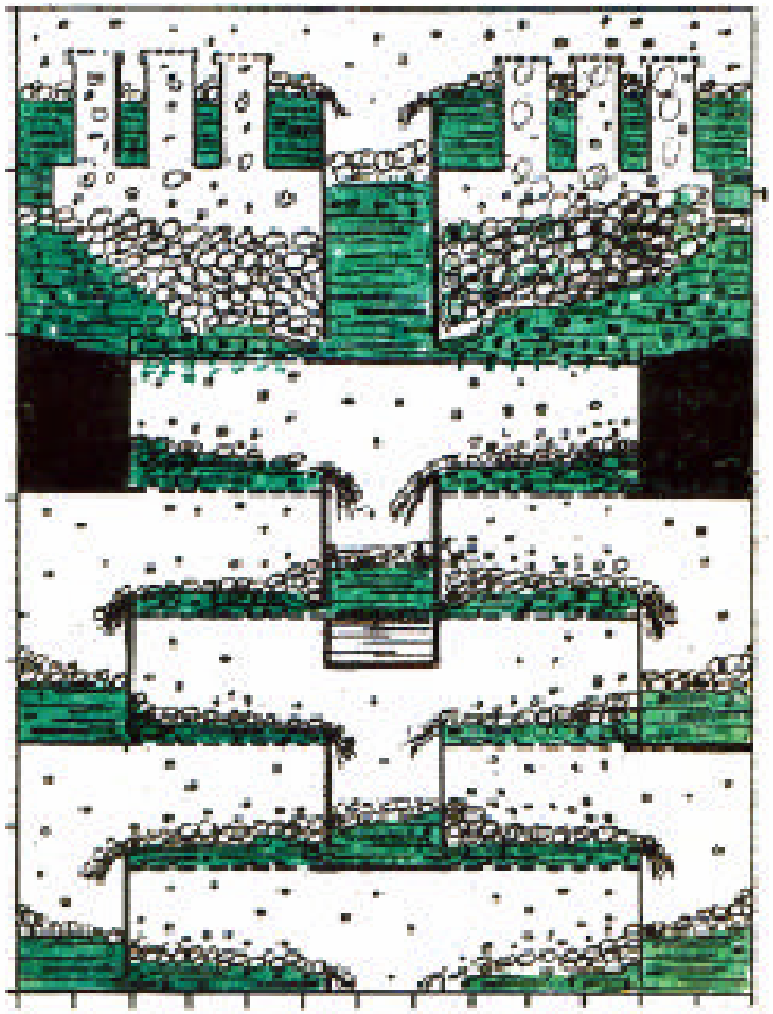
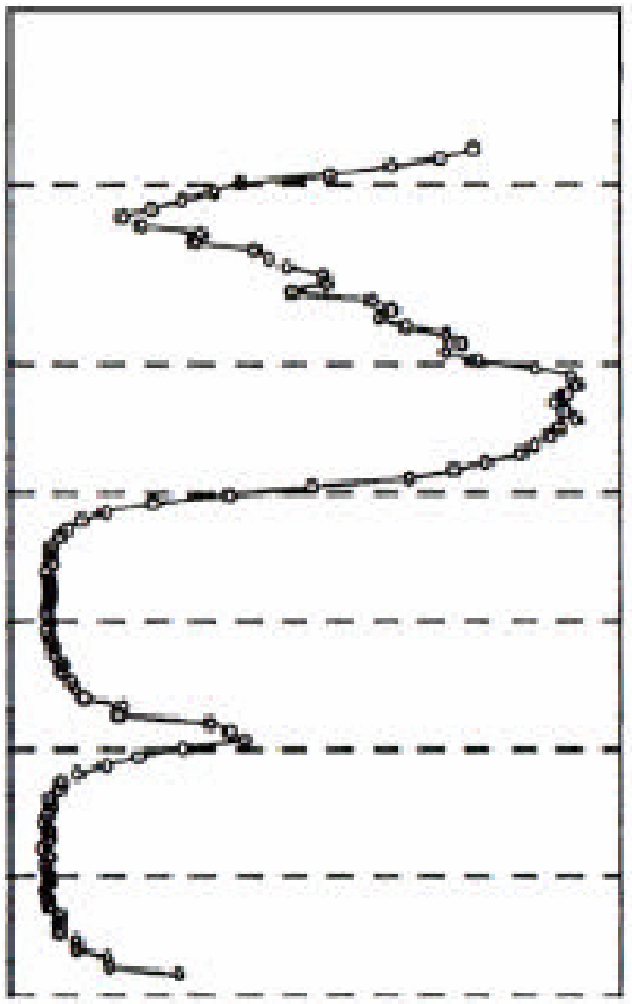
Measurement of Oil, Water, Vapour and Sand Layers in Oil Separator using a Neutron backscatter technique



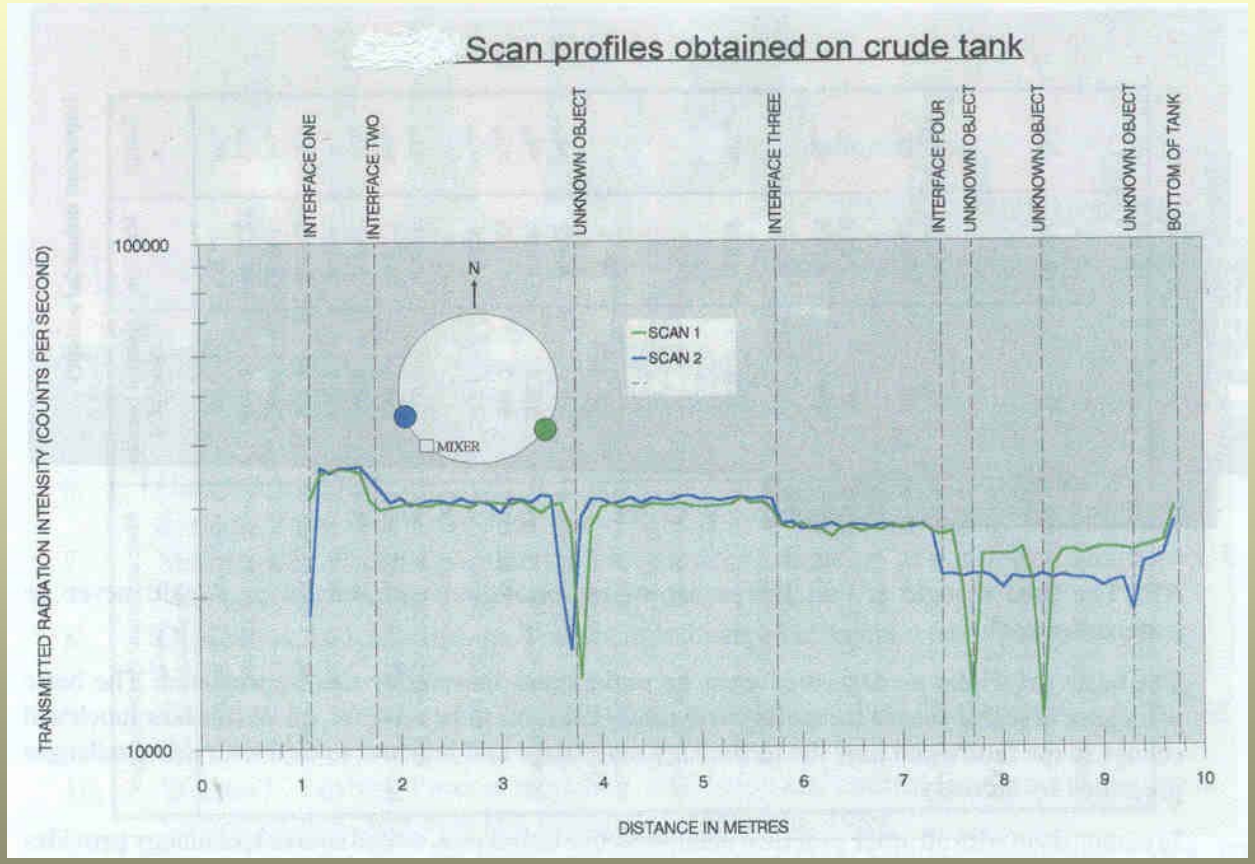
Neutron profile

On the try 6 there is a blockage by coke formation





Interface levels in a crude tar tank



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NCS techniques for mining and mineral processing

TABLE I. NCS APPLIED TO THE EXPLORATION, EXPLOITATION AND PROCESSING OF NATURAL RESOURCE

Techniques	FIELDS OF APPLICATION					
	OIL & GAS	LOGGING		MINERAL PROCESSING		
	Fluid Flow	Delineation of deposit	In-situ Assaying	On & Off Belt Analysis	Slurry Analysis	Density, Weight, Level/Fill
Natural γ Radiation		X	X	X	X	X
γ-Ray Transmission	X			X	X	X
γ-Ray Backscatter		X	X	X	X	X
PGNAA & DGNAA		X	X	X		
XRF analysis			X		X	

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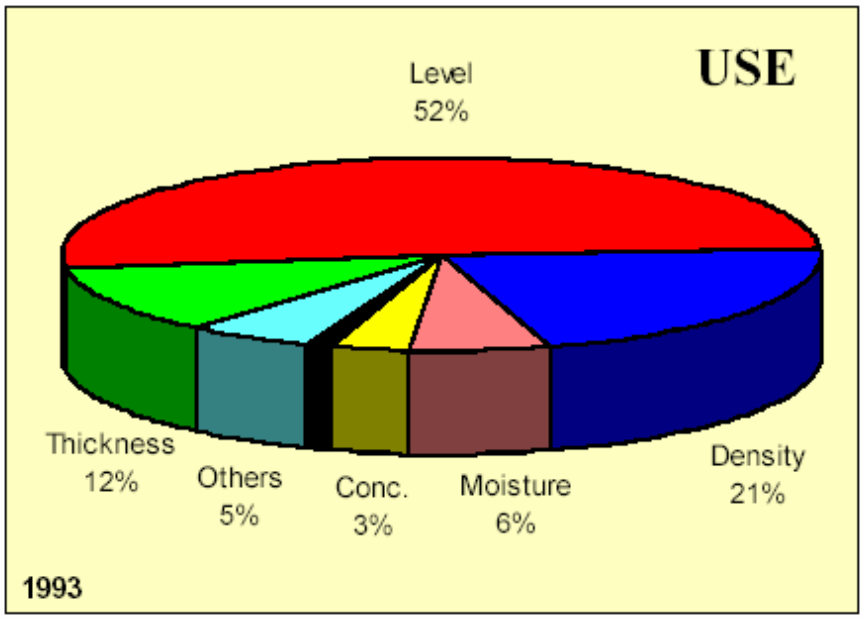
TABLE II. NCS USED IN MANUFACTURING INDUSTRIES

Applications	Techniques	FIELDS OF APPLICATION						
		Civil Engineering	Packaging	Plastic, Paper & Pulp	Metal Processing	Chemical & Petrochemical	Safety	Miscellaneous
Level / Fill	γ Transmission		x	X	x	x		x
	N Backscatter			X		x		
Thickness and Area Weight	γ Transmission				x			
	β Transmission			X	x		x	
	γ Backscatter			X				
	β Backscatter			X	x			x
	XRF				x			x
Density	γ Transmission	x	x	X				x
	γ Backscatter	x						x
Bulk Weight	γ Transmission	x						
Fluid Flow	γ Transmission Single + Multi-energy					x		x
Moisture	γ Transmission	x						
	N Transmission	x						x
	N Moderation	x						x
Analysis	PGNAA	x						x
	γ Transmission	x					x	x
	XRF				X	x	x	x
	Ionisation						x	
	ECD					x	x	

Kind of applications of nucleonic gauges in industry



Total 500

Typical for a developing country

Japan

Kind of Instruments	*1991*	*2000*
Thickness gauges (Total)	*2,565*	*2,726*
▪ Beta-gauges for paper & pulp	*796*	*956*
▪ Beta-gauges for others	*914*	*953*
▪ Gamma-gauges for steel plate	*646*	*592*
▪ Others	*209*	*225*
Level gauges	*1,553*	*1,218*
Density gauges	*761*	*814*
Sulfur meters	*371*	*243*
Moisture gauges	*181*	*127*
All the NCS in industry	*6,751*	*6,254*

Typical for a developed country

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Nucleonic gauges worldwide
(statistics of 2000)

- *USA: more than 100 000 nucleonic gauges*
- *EU: more than 50 000 nucleonic gauges*
- *China: around 50 000 nucleonic gauges*
- *Asia (without China): around 20 000 nucleonic gauges*
- *Latin America: 5000 nucleonic gauges*
- *Africa: 2000-3000 nucleonic gauges*
- *Russia: (not known) around 50 000 nucleonic gauges*

Total :
around 250 000 – 300 000 nucleonic gauges worldwide

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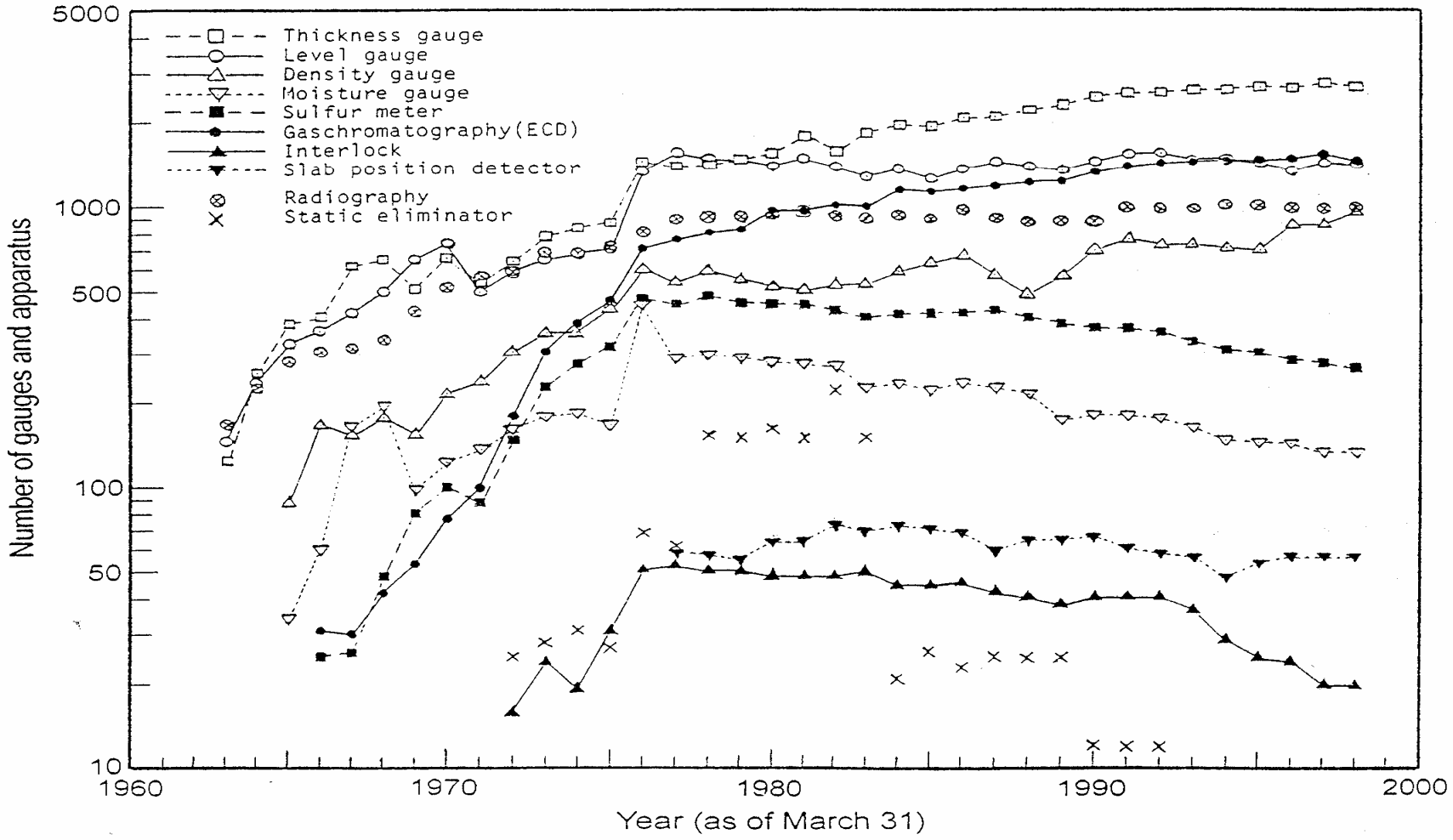
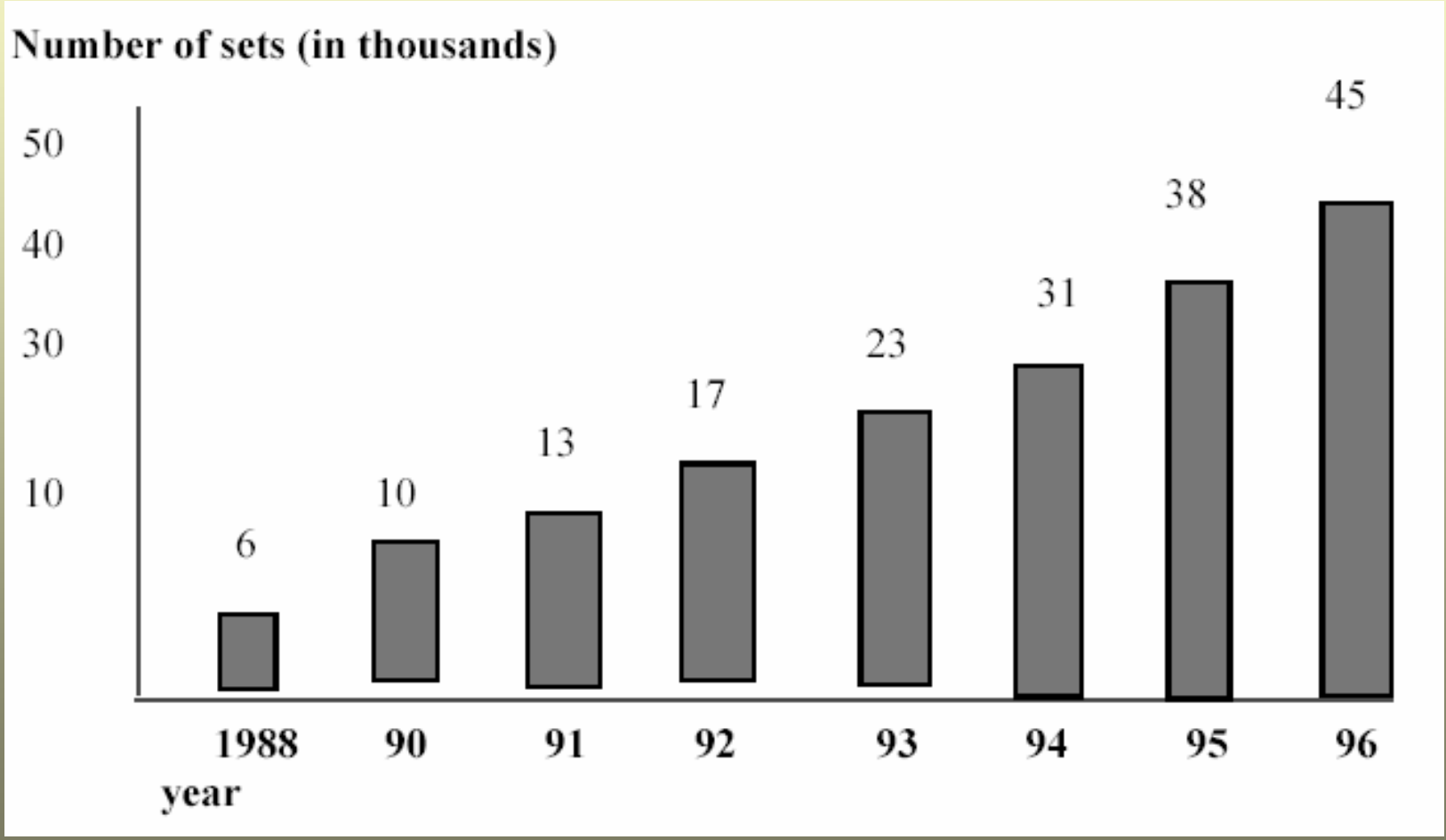
Trends in NCS progress in developed countries (Japan) (almost saturation)



Changes with the year in the number of radioisotope-equipped gauges and apparatus in use in industrial firms except research institutions.
(Fig.1)

Trends in NCS progress in China

(exceptional incresing)



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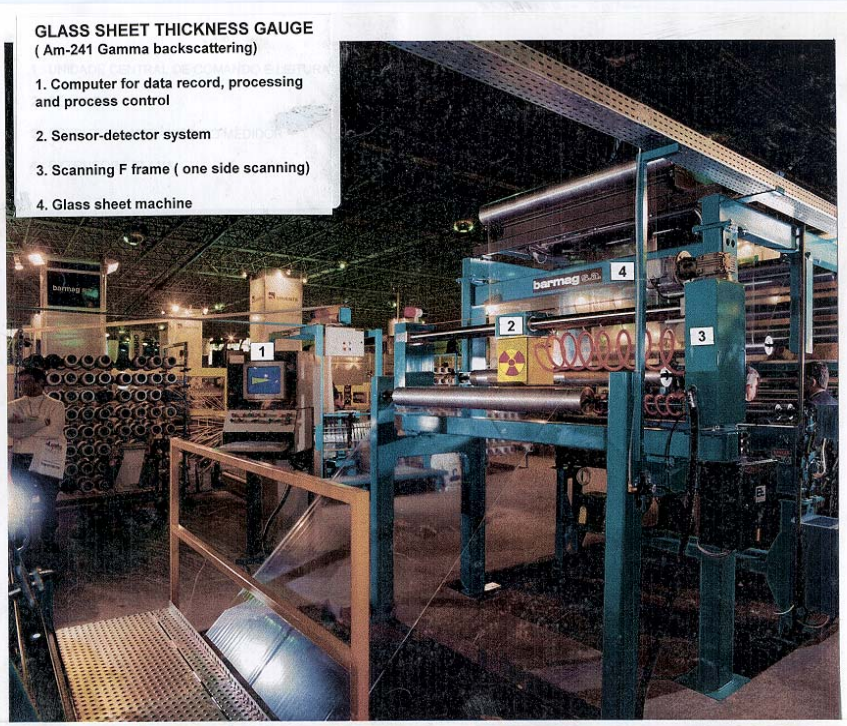
NCS for basis weight measurement



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Installing a nucleonic gauge for on-line density measurement inside a pipe

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Dust pollution monitor
Airborne dust concentration gauge

Principle: Dust mass deposited on a filter is measured by attenuation of beta radiation of Pm-147.

It works 24 hours nonstop and it can be part of meteorological stacions in urban areas

Measuring range	5-5000 µg/m^3 in 7 subranges
Sensitivity of measurement	2 µg/m^3 for 24 h measuring cycle
Wind measurements	16 discrete directions 0-60 m/s
Radiation source	Pm-147, 100 MBq
Air flow	1 m^3/h ± 2%
Dust deposition time	30 min ÷ 24 h
Air filter	fiber glass band 40 m long
Digital port	CENTRONICS, RS232C

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Neutron gauge for online measurement of H_2SO_4 concentration

Measuring range	90% - 99.9% H_2SO_4 in any subrange with the span 5% wide
Exploitation accuracy	0.2% H_2SO_4
Concentration indication	in % of H_2SO_4, digital display

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COAL ASH MONITOR LB 420

Coal selection in 1985

- On-conveyor belt analysis of coal thickness of ~100-600 mm
- Accuracy better than 0.2 - 0.6 wt.% ash
- Analysis times of <5-10 minutes
- Accuracy unaffected by segregation & profile variation
- Measure a large proportion of the coal stream
- Cost < annual savings (often ~US$0.5 million/year/gauge)
- Rugged, little maintenance & infrequent calibration

Coal selection in 1965

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Coalscan 3500 dual energy gamma ray transmission ash analyser installed in a coal washery.

Gamma ray sources Am-241 and Cs-137 are located under the conveyor belt and detector is located above the belt.

Oil-Water-Gas flow meter

- Americium-241 with emissions at 13.9, 17.8, 21.5, 26.3, and 59.5 keV is a suitable source.

- Barium-133 source (30 and 360 keV) or

- Combination of Am-241 and Caesium-137 sources (60 keV and 660 keV)

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Gamma transmition gauge for sediment concentration measurement in rivers

LOW ACTIVITY NUCLEONIC GAUGES

- Many states defined 3.7 MBq (100 µCi) as the minimum activity of a gamma-ray source requiring a License for Possession, Use and Transport of Radioactive Substances.

- Low Radioactivity Coal Face Analyzer employs a ^{133}Ba source of activity 1.8 MBq (50 µCi) and for gain stabilization a ^{137}Cs source of activity 0.37 MBq.

- Stockpile Probe uses either ^{133}Ba source of activity 1.8 MBq (50 µCi) and for gain stabilization a ^{137}Cs source of activity 0.37 MBq, or a ^{137}Cs source of activity 1.8 MBq.

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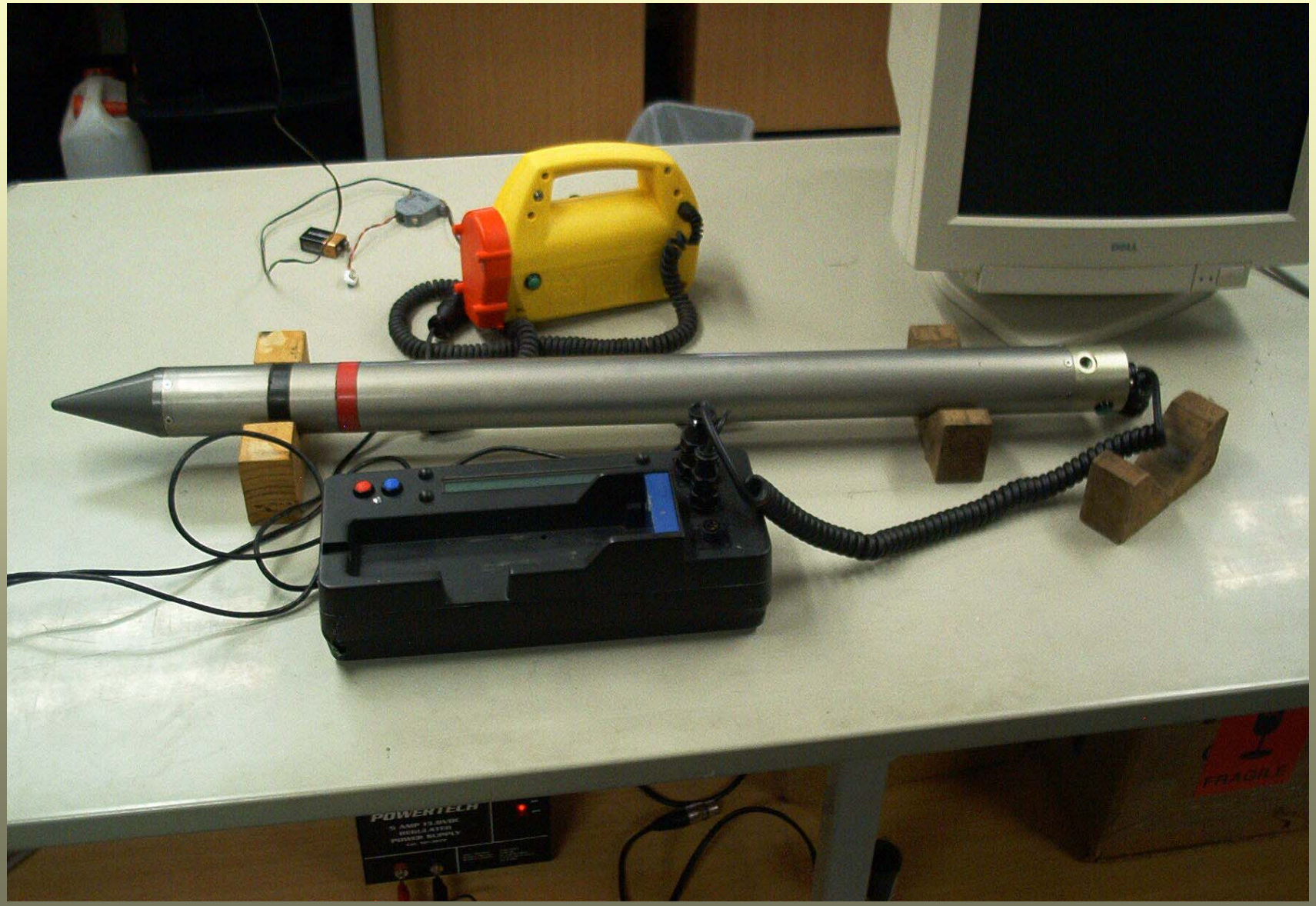
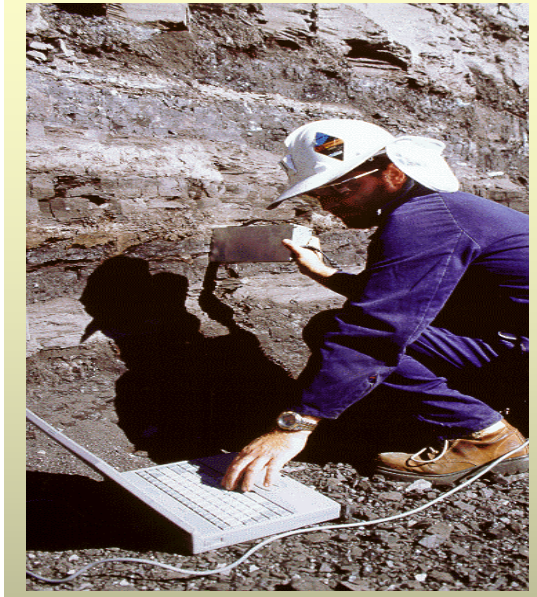
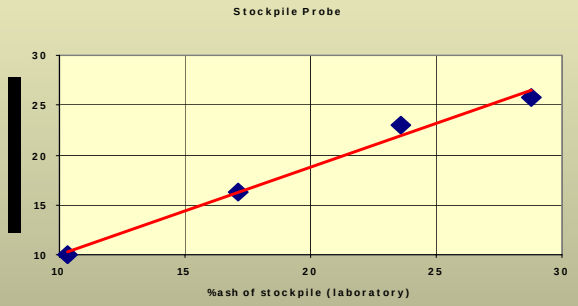
Coal Face Analyser, Stockpile Probe and Base Unit

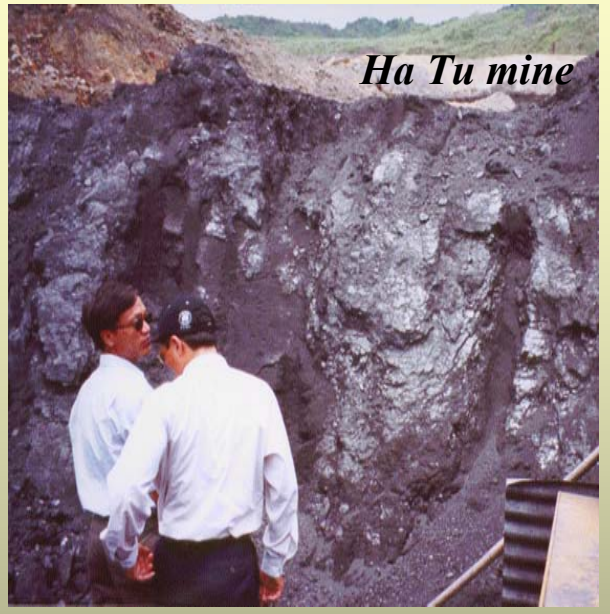


Low activity nucleonic gauge – coal face and stockpile analyser for ash content

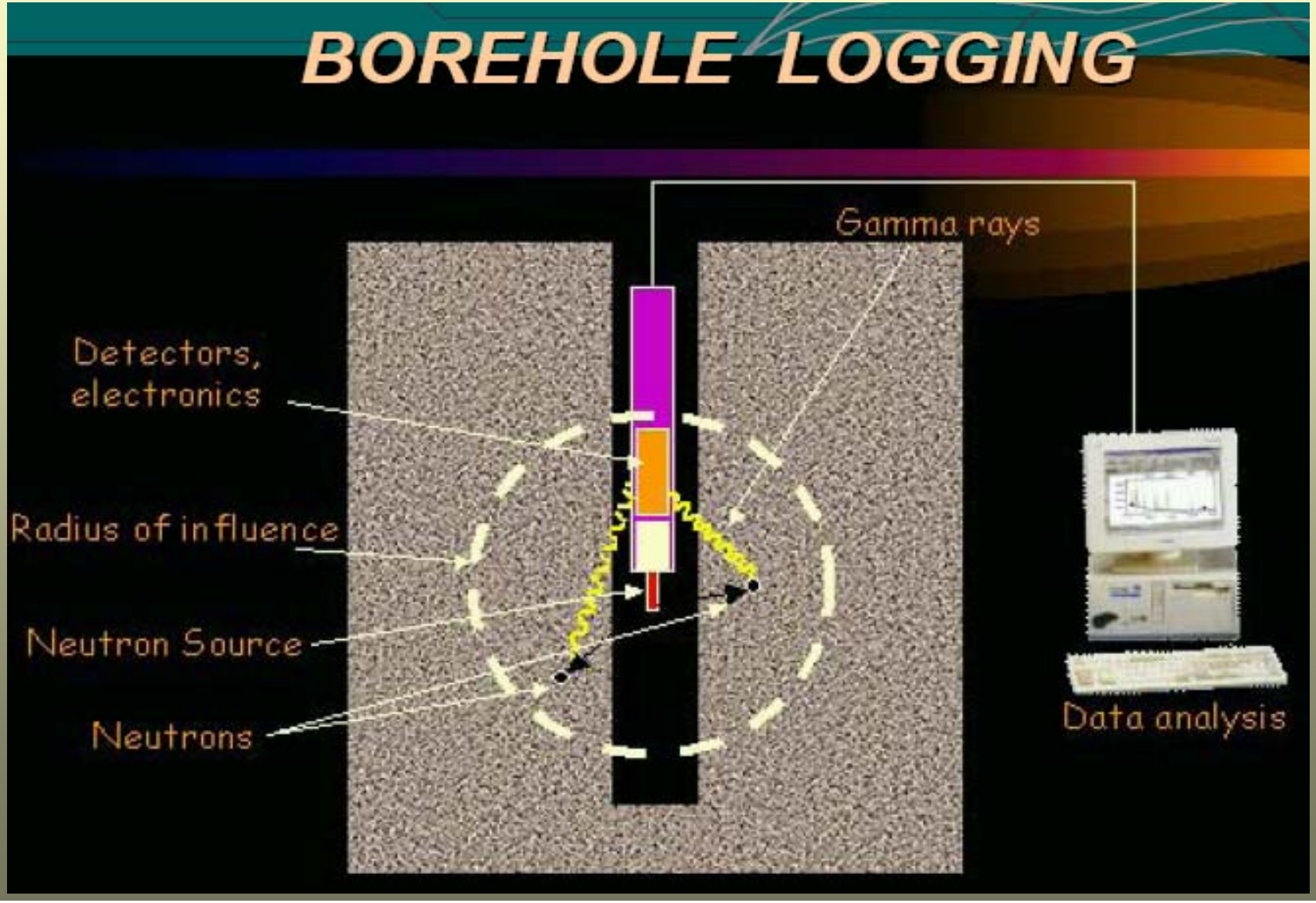


Low activity portable coal face ash analyser for differentiating coal and look alike sediments. The use of quantitative face ash analyser permits selective mining and is applicable to the production phase in open-cut pits and underground mines. The analyser works as a backscatter gamma ray type gauge.





NUCLEAR TECHNIQUES FOR MINING AND LOGGING



Logging operations (PGNAA) at Chuquicamata copper mine in Chile

Bottom – up logging

Major gamma and neutron techniques

GAMMA RAY

- *Am-241 backscatter*
- *Dual energy gamma ray transmission (^{137}Cs-^{241}Am)*
- *Pair production*
- *Natural gamma*
- *Compton profile analysis*

NEUTRON / GAMMA

- *Neutron-induced gamma rays (Prompt Neutron – Gamma Techniques)*
  - *Thermal neutron capture (0.025 eV)*
  - *Inelastic scatter (> 2 MeV)*
- *Neutron activation (Delayed Neutron – Gamma Technique)*
- *Sources*
  - *^{252}Cf*
  - *^{241}Am-Be*
  - *Neutron generator*
- *Detectors*
  - *NaI(Tl)*
  - *BGO*

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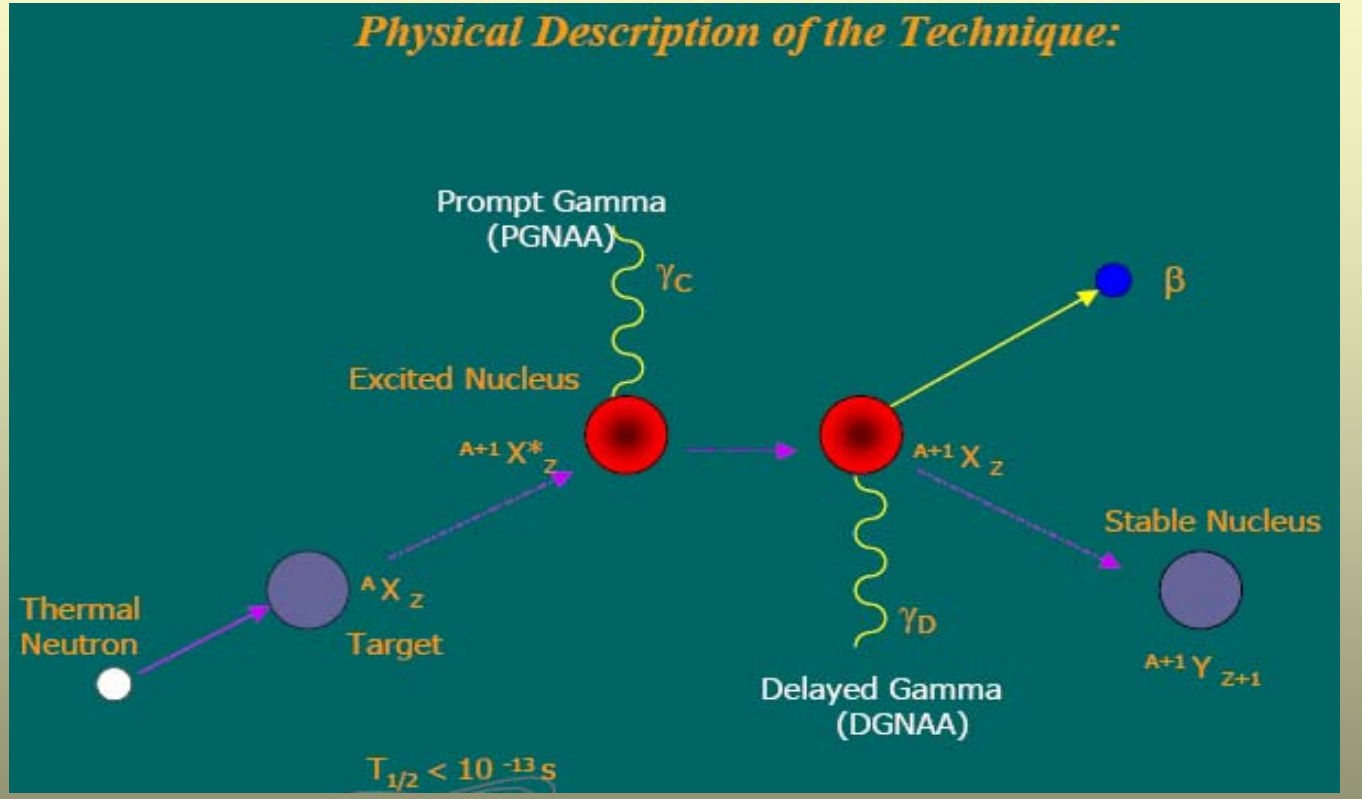
Prompt Gamma Neutron Activation Analysis

PGNAA

PGNAA technique is using a ^{252}Cf neutron source and scintillation detectors to determine elemental composition based on thermal neutron capture gamma rays.



The technique was initially developed for by-line applications but recently has been used for on-conveyor belt analysis and borehole logging

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Components of the portable PGNAA logging system

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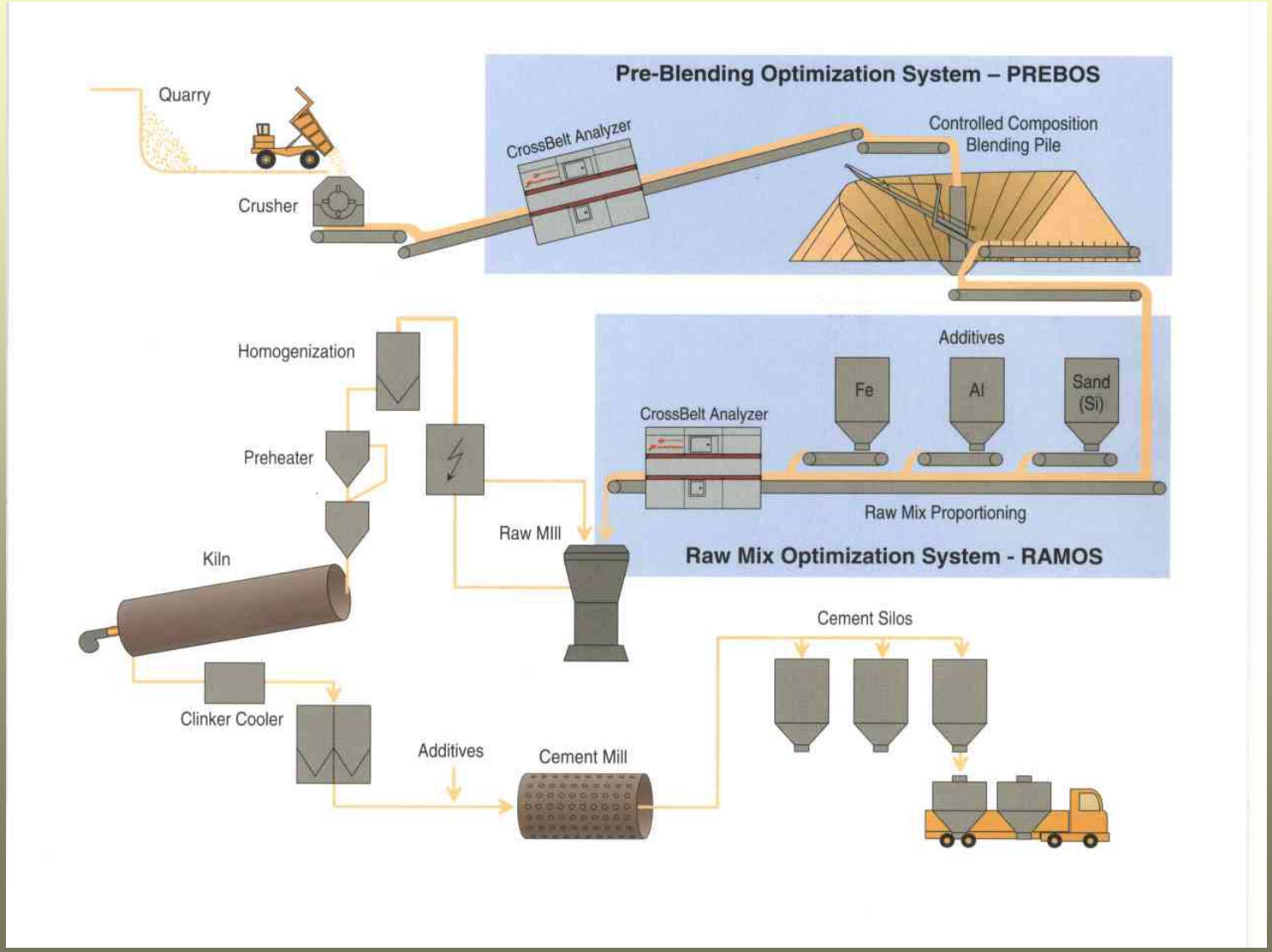
The Cross-Belt Analyzer, *uses the Prompt Gamma Neutron Activation Analysis (PGNAA) technique is the most precise on-line elemental analyzer for bulk materials ever made.*

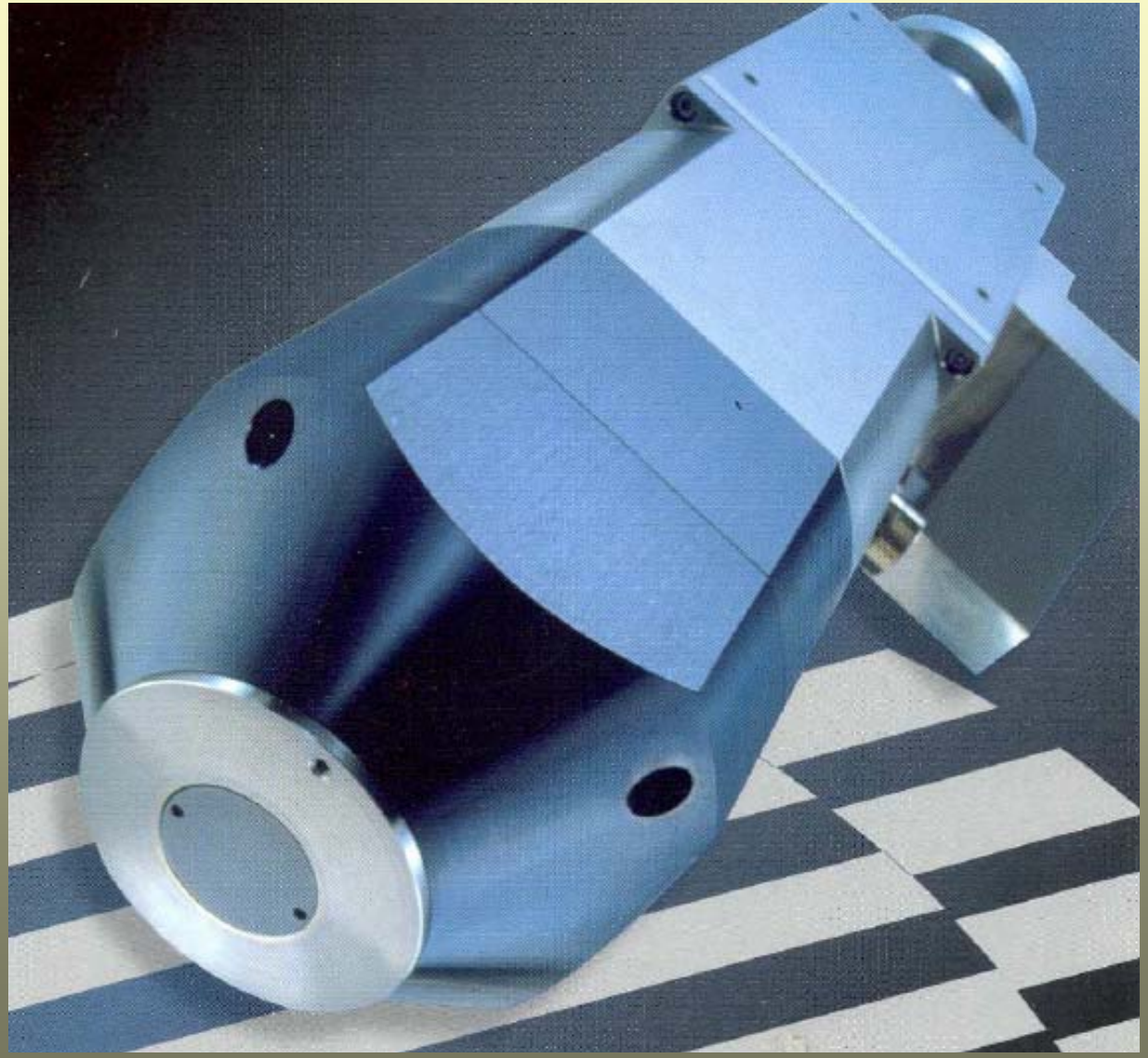
PGNAA in cement industry: *Raw Mix Optimization System (RAMOS)"*



Microfocus X ray generator

Focus < 1 µm (150 nm for 20 kV)

160 kV – 9 W



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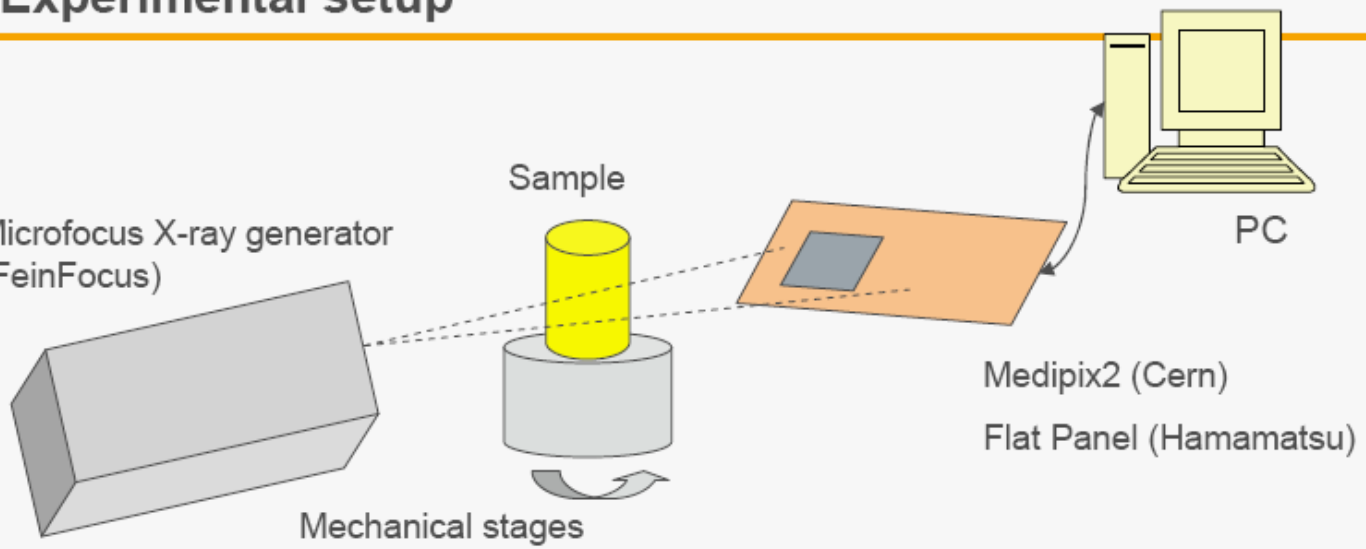
Experimental setup

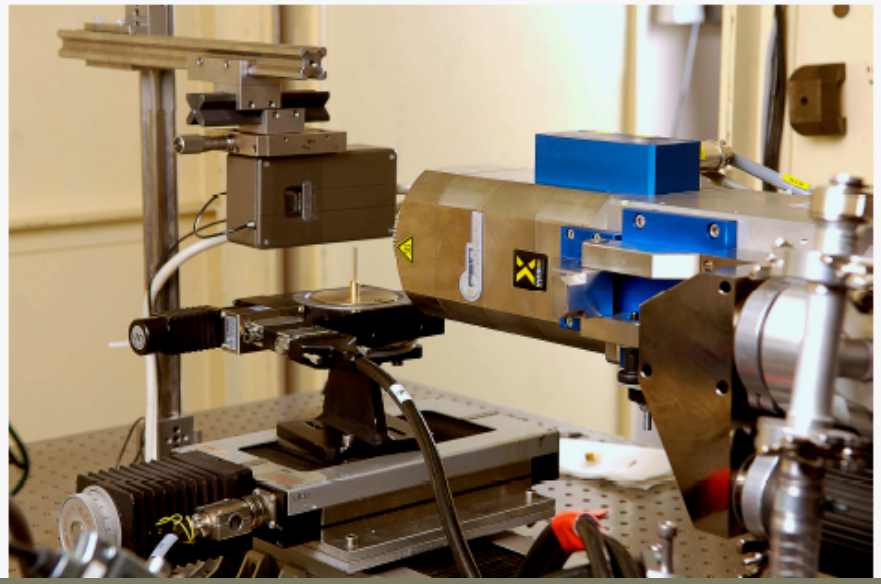


2400 x 2400 pixels

300 µm CsI

12 bits

$FTM_{50\%}$ 150µm



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Recent Compact Neutron Generator

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GAMMA COMPUTER TOMOGRAPHY (GCT)

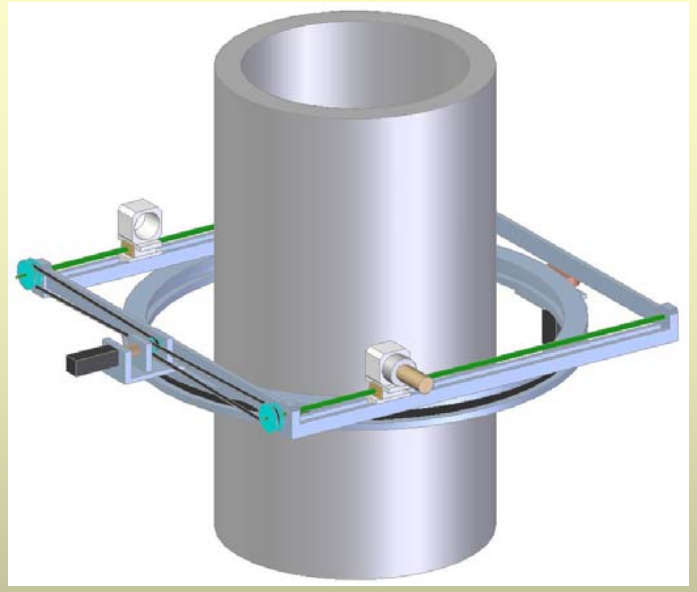
Gamma Transmission (Active) CT

Gamma transmission tomography uses the differences in density of the medium to obtain the structural images inside the processing vessel.

Gamma Emission (Passive) CT

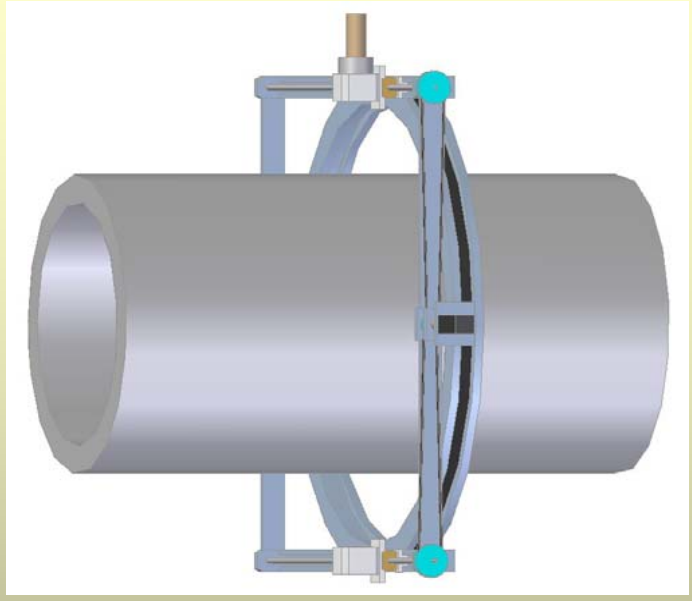
To investigate flow dynamics in multiphase flows, with or without density variations, gamma emission tomography is a method of choice. A multidetector set up installed around a cross section of the processing pipe provides the tomographic image, which gives the phase distribution, transport and mixing. This technique is known as the Single Photon Emission Computed Tomography (SPECT) method, which is largely used in nuclear medicine.

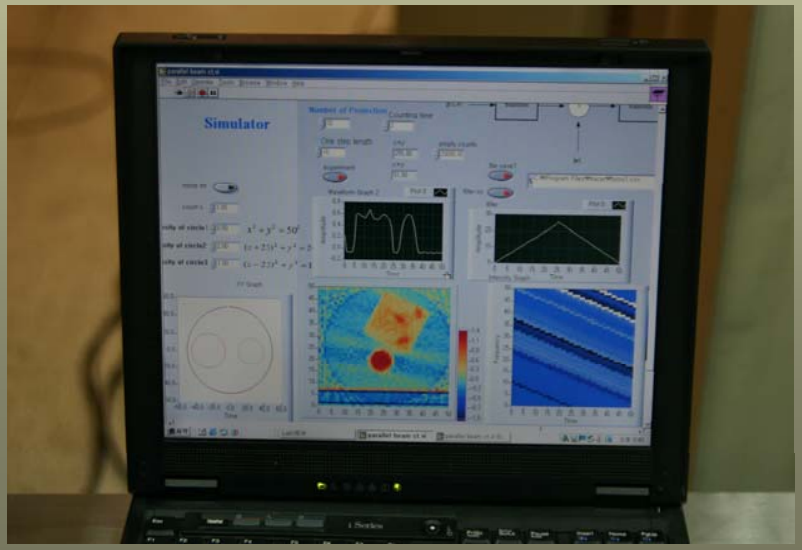
Industrial Process Gamma Transmission CT



1 S – 1 D

parallel, or pencil beam,





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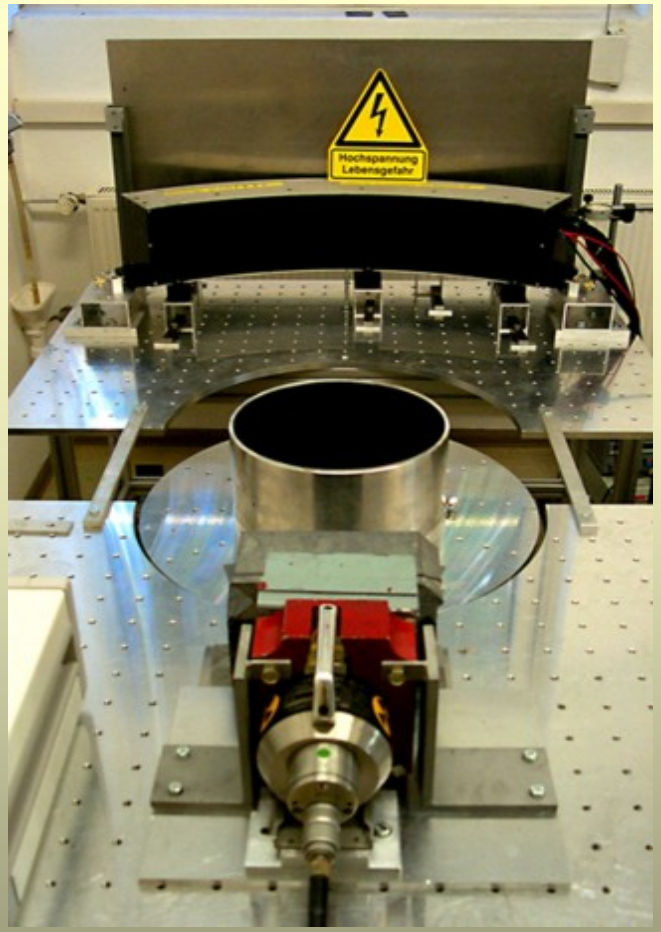
Gamma Transmission Tomograph:

1 Source – Multi-detectors

Fan beam measurement mode



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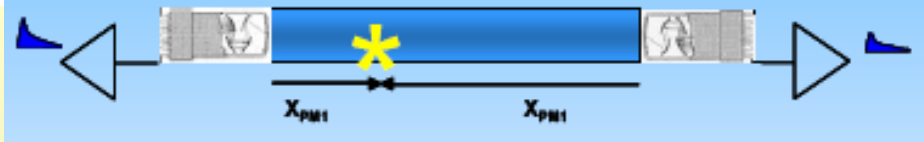
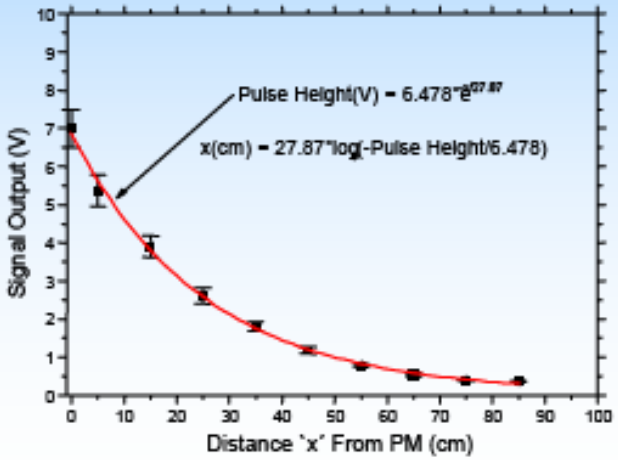
Gamma transmission tomograph:

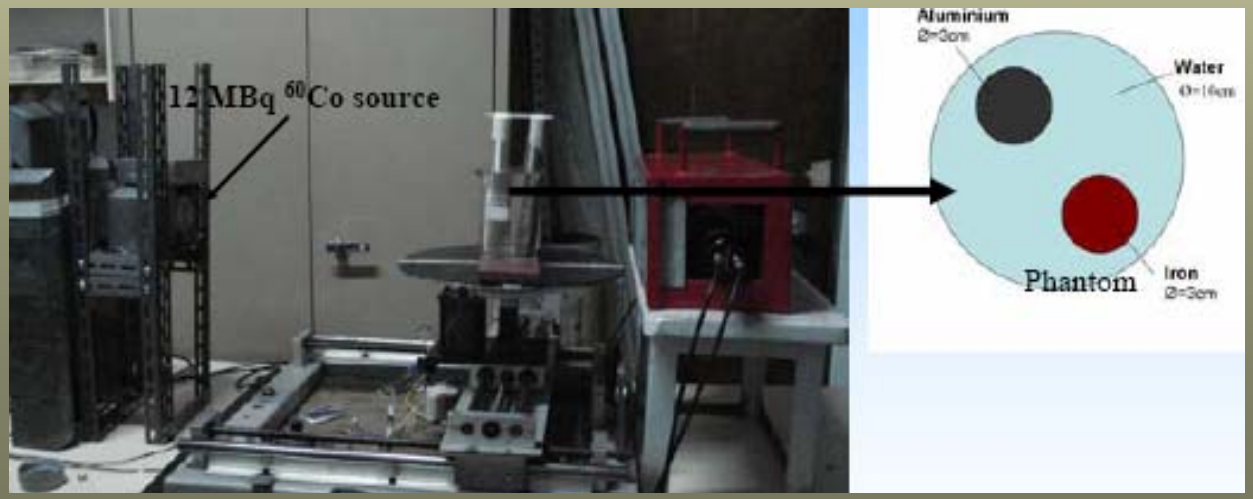
1 Source - 1 Plastic detector



A plastic scintillator cylinder of 4 cm diameter and 100 cm high was prepared

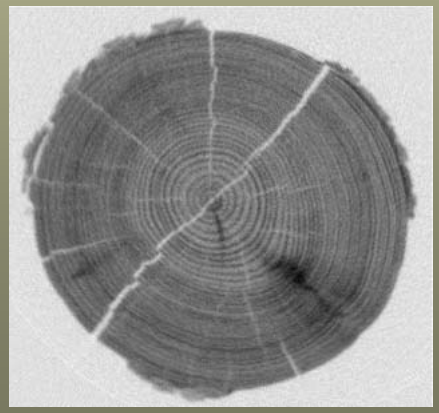


The plastic scintillator cylinder can be used up to 80 cm in order to work suitably as a position sensitive detector.



Portable Transmission Gamma CT

A portable GCT for routine examination of wooden power poles to detect rot and internal defects.
A full image takes up to 8 minutes for a 300 mm diameter pole.
In a comparative evaluation with other techniques this was found to be the most reliable.



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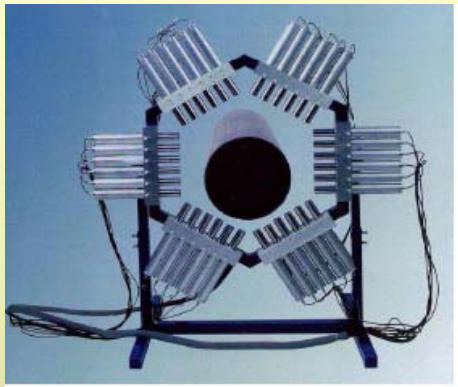
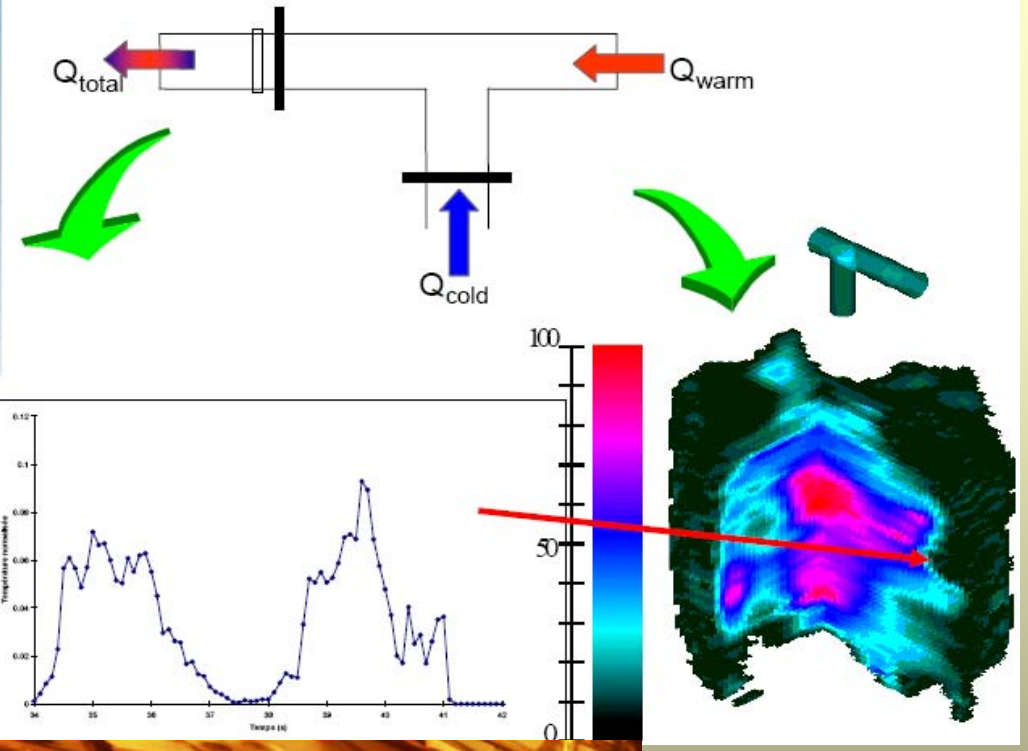
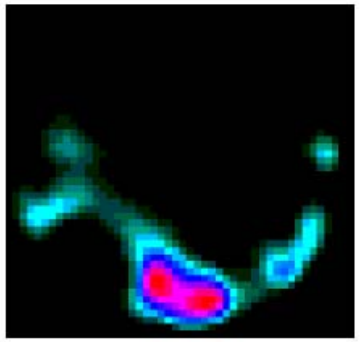
Industrial Process Gamma Emission CT







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CARGO INSPECTION

Today: slow, very costly (>US$20M/unit), complex

Trend: -Combines neutrons & gamma-rays to provide shape, density and composition information

- ***Uses commercially available neutron and gamma-ray sources***
- ***Rapid imaging***
- ***Good radiation safety***
- ***Relatively low cost***

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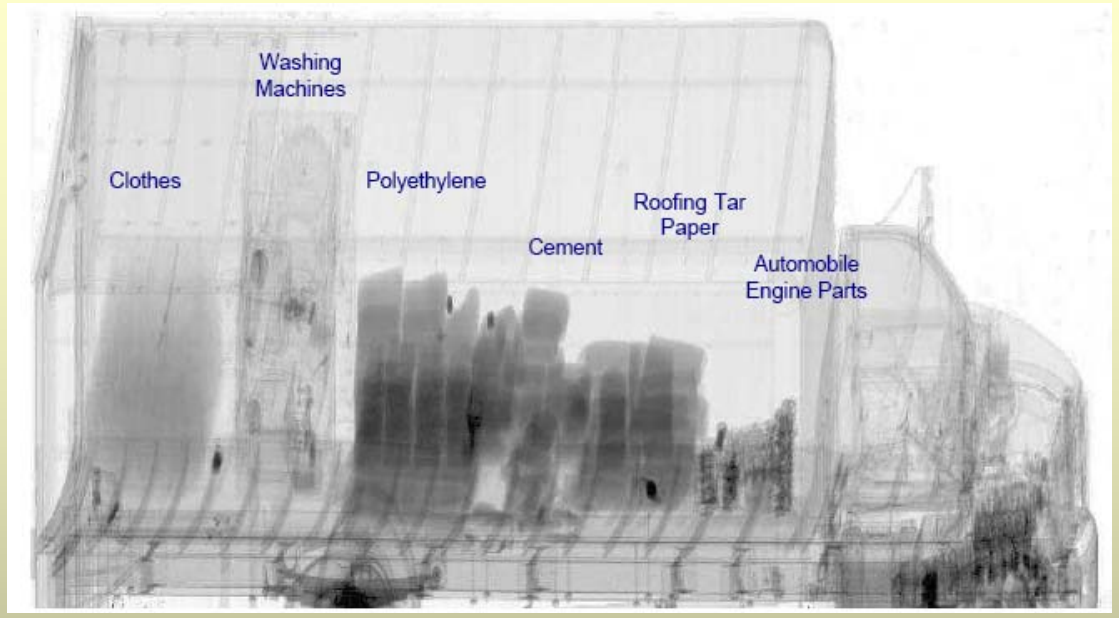

Cocaine hidden near rear window well and quarter panel

Stowaways hidden amongst cargo

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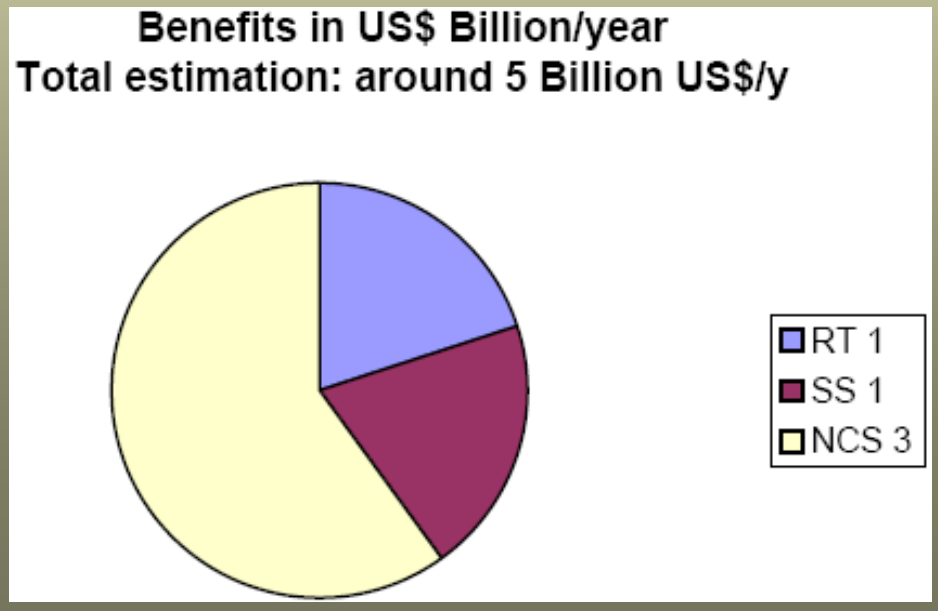
Benefits from the industrial use of radioisotopes (million/yr) (IAEA survey early l960's)

24 countries (1961-63)		*Total*
NCS	*26.7 - 43.4*	*162 - 194*
Radiography	*12.1 - 28.9*	*38 - 58*
Radiotracers	*10 - 40*	*95 - 146*
Total	*49 - 104*	*296 - 400*



Benefits estimation in 2000

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The US report titled: "The Untold Story: Economic and Employment Benefits of the Use of radioactive Materials" estimates that (excluding nuclear power) approximately $ 250 B production or 4% of the US GDP is associated in some way with the use of radioisotopes, in medicine, agriculture, industry, resources development and research. This report does indicate that we are dealing with very important issues.