MISSOURI
S&T
University of
Science & Technology

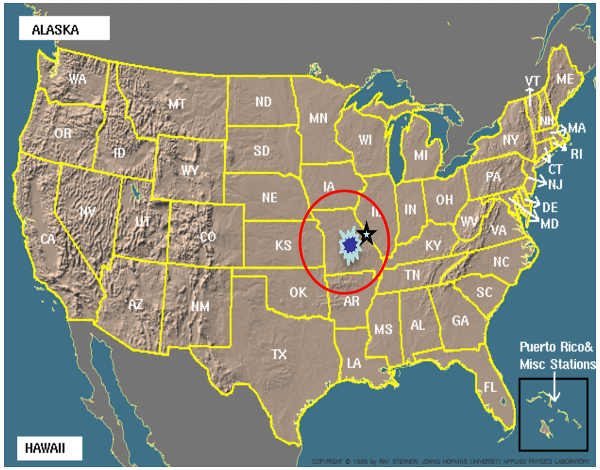
Industrial Process Tomography and Visualization Using Nuclear Technology

Advancing Excellence

Professor Muthanna H. AL-Dahhan
Chairman & Professor of Chemical & Biological Engineering
Professor of Nuclear Engineering

Department of Chemical & Biological Engineering

Missouri S&T

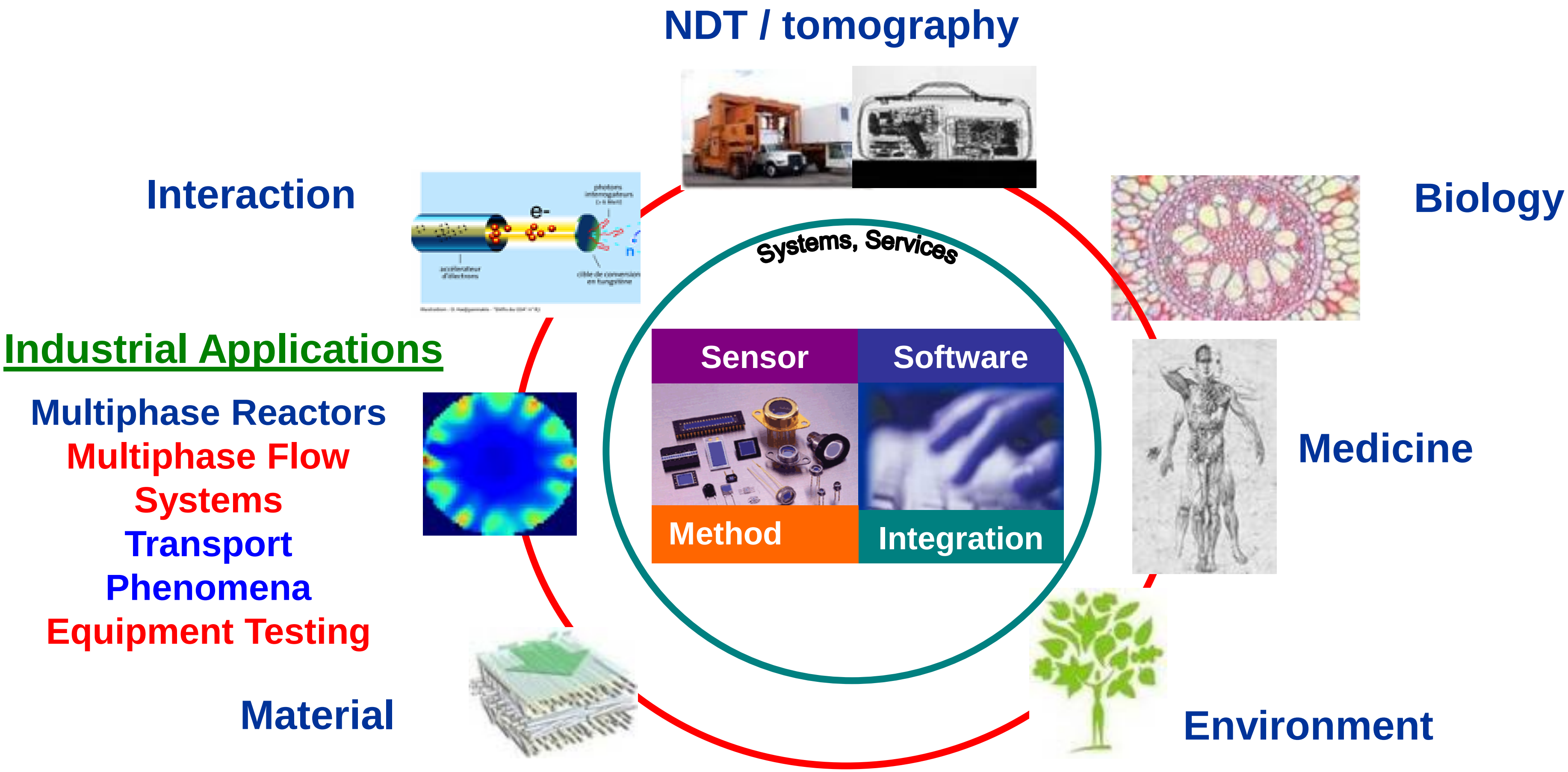


INAC - XI ENAN
Recife, Brazil
November 24-29, 2013

PRESENTATION OUTLINE

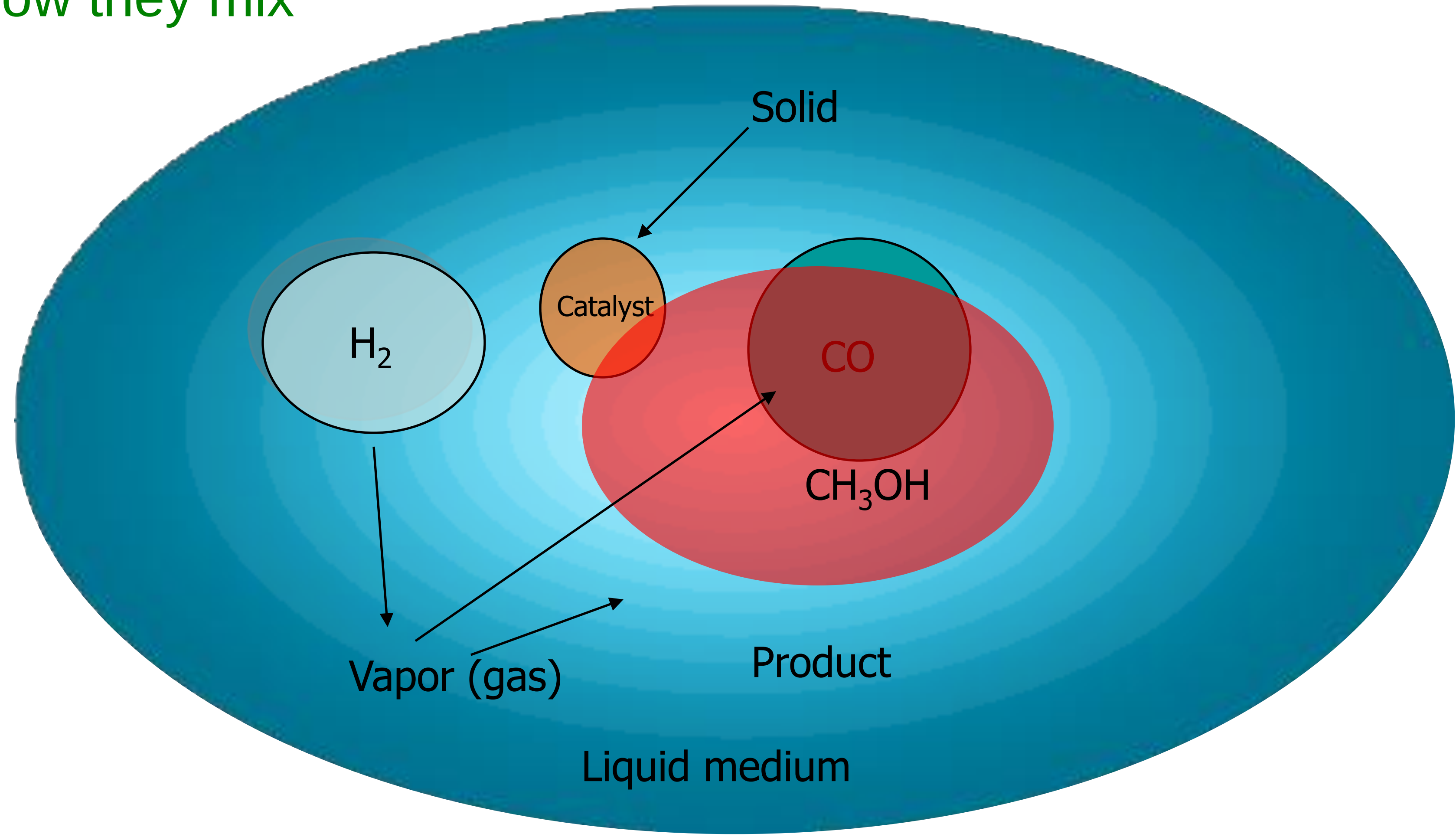
- Introduction & the needs
- Nuclear Technology Applications – Selected Examples
  - Laboratory and pilot plant scales for research
  - Commercial scales for troubleshooting and monitoring
- Remarks

Service « Systems and Technology for measurement »



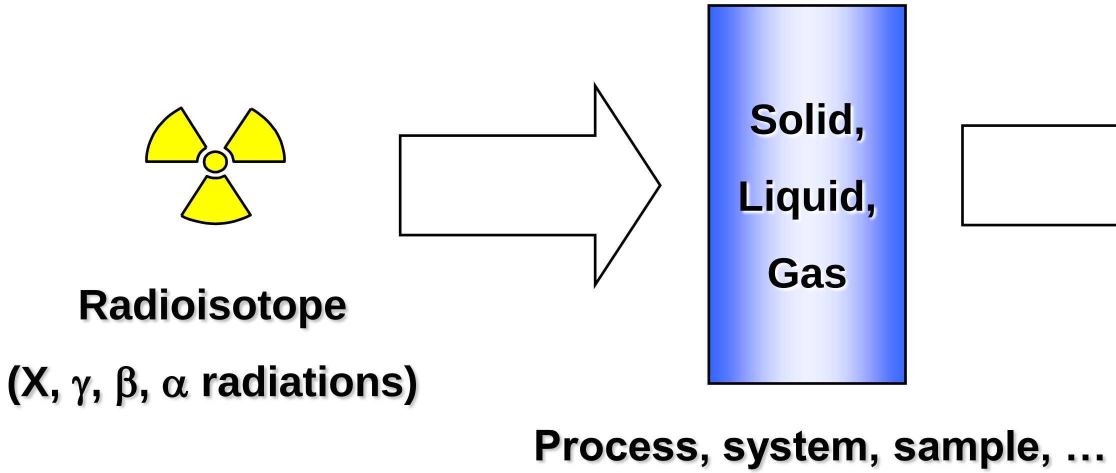
S. Legoupil
CEA-France

- These transformations require contacting of reactants and catalysts in different phases
- Successful operation and transfer of lab scale information to the industrial process requires knowledge of how the phases flow and how they mix



Radioisotope Based Techniques Are the Techniques of Choice Since, industrial multiphase systems are opaque.

- For these systems high energy gamma ray photons are required, because they can penetrate them to provide information about phase distributions, flow, and mixing.
- Many radioisotopes can be used in industrial applications in the form of sealed and open sources (tracer) such as Scandium-46, Cesium-137, Cobalt-60 and 58, Selenium-75, Americium-241, Gold, Sodium-22, Manganese-54, Oxide on Manganese-56, Yttrium-88, Ziconimu-95, Niobium-95, Ruthenium-103, etc.
- Various radioisotope based techniques have been developed and used for **research at the laboratory scale** and **pilot plant scales** and **for site applications in industrial processes** for equipment integrity testing, process investigations and troubleshooting, monitoring, control, inspection, modeling validation, optimization, and many other purposes.



S. Legoupil, cea, Fr

THE DESIRABLE CHARACTERISTICS IN ANY EXPERIMENTAL DIAGNOSTIC AND MEASUREMENT TECHNIQUES

- **Good spatial and temporal resolution in both velocity and volume fraction (holdup measurements),**
- **Capability to provide instantaneous (snapshot) measurements so that one could, in principle, be able to quantify the turbulent and dynamic flow structure,**
- **Ability to probe opaque systems in which the dispersed phase volume fractions are high,**
- **Statistically reproducible results obtainable in a finite time,**
- **Amenability to automation, so as to minimize human involvement in the data collection process,**
- **Portability of the technique to and its applicability on larger units, such as pilot plant and industrial units,**
- **Affordable cost,**
- **Safety of the personnel involved in the experimentation,**
- **Etc.**

- **At present, no single experimental technique satisfies all these characteristics.**
- **However, research in the direction of the long term goal to achieve the above requirements is constantly in progress.**

Applications of Nuclear Technology for Research
Laboratory and Pilot Plant Scales

Selected Examples

- **Gamma Ray & X Ray Computed Tomography (CT)**
- **Gamma Ray Densitometry (GRD)**
- **Radioactive Particle Tracking**
- **Residence Time Distribution – Radiotracer & radioactive particles**
- **X Ray – PIV Radiography – Velocimetry**
- **Positron Emission Particle Tracking**

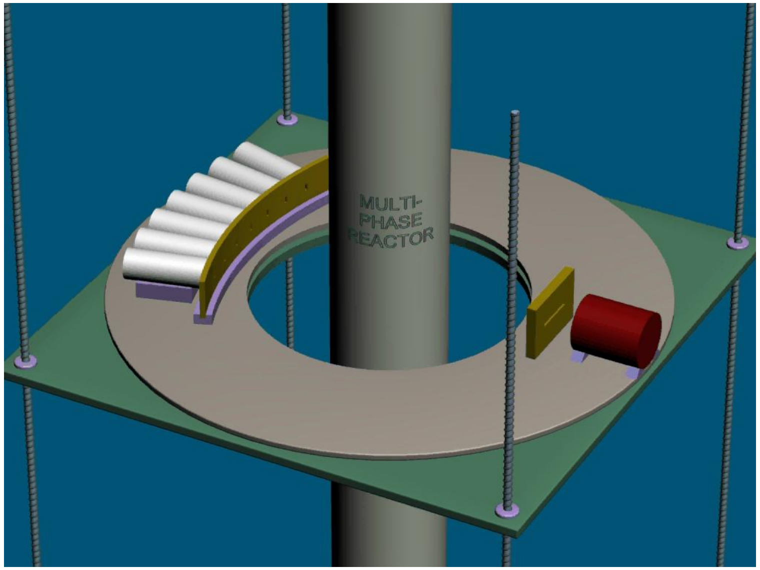
Dual Source Computed Tomography (DSCT/CT) – Missouri S&T

For Phases Distribution Measurements

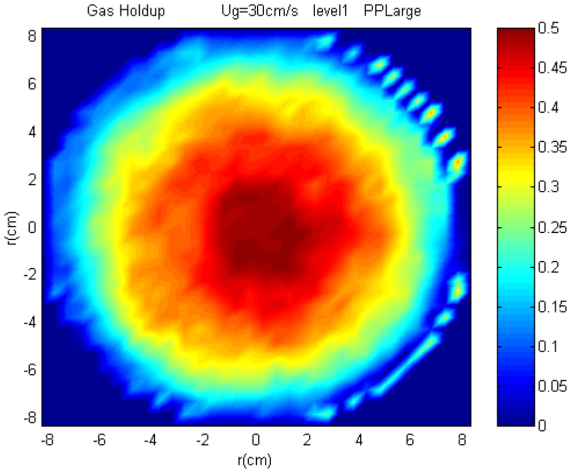
CT is a technique for measurement of the cross-sectional density distribution of two/three phase distribution by measuring the attenuation distribution in **multiphase** phase systems (e.g. G-L, …).

$$A = -\ln\frac{I}{I_0} = \sum_{l} (\rho\mu)_{eff,ij}\, l_{ij}$$

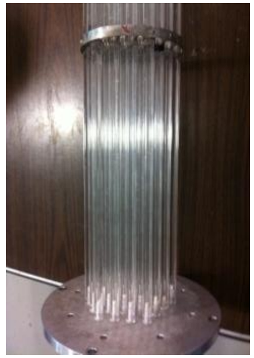
$$(\rho\mu)_{eff,ij} = \sum_{K} (\rho\mu)_{K,ij}\, \varepsilon_{K,ij}$$

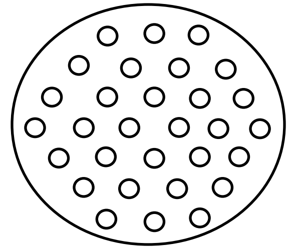


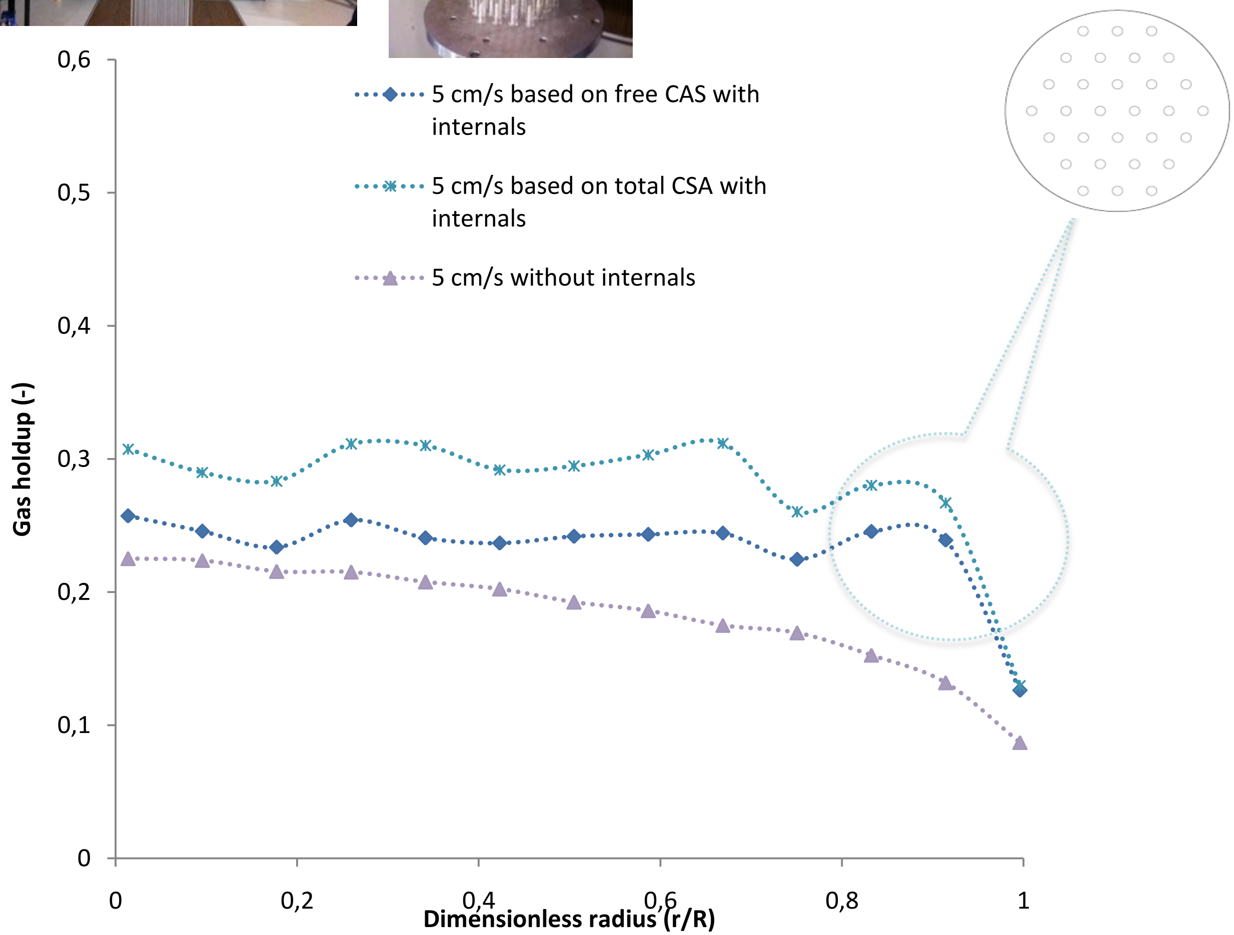
Experimental Result

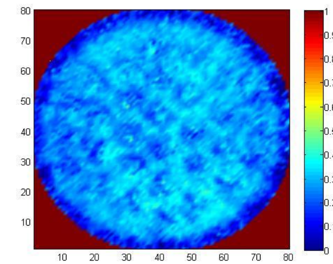


Effect of Internals on the Radial Profiles of Gas Holdup

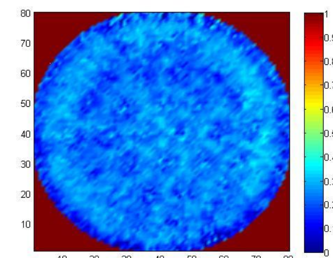




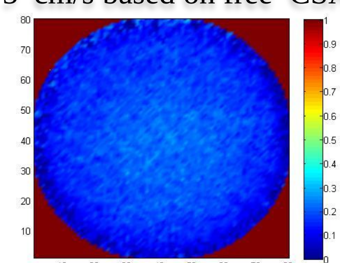




5 cm/s based on total CSA



5 cm/s based on free CSA

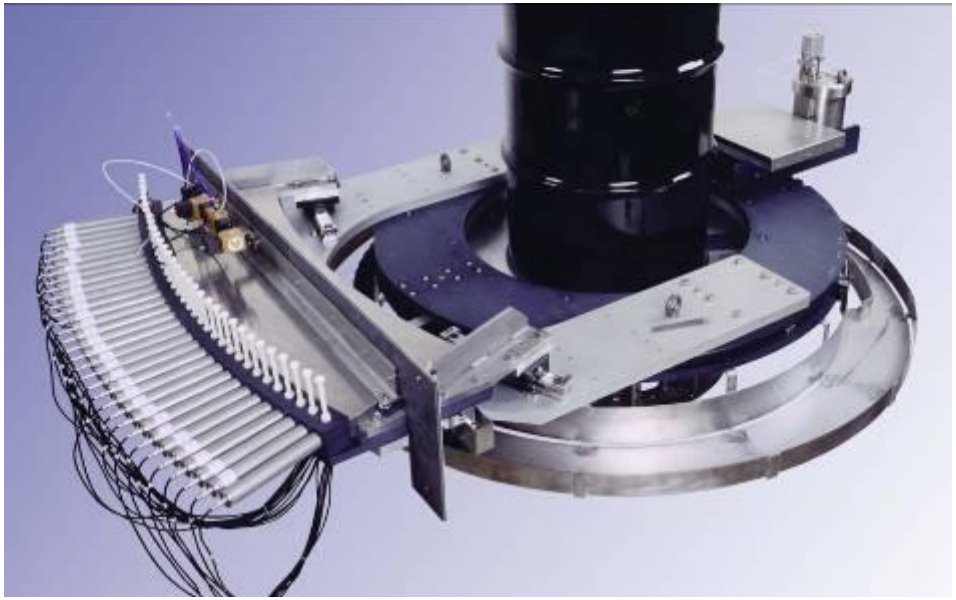


5 cm/s without internals

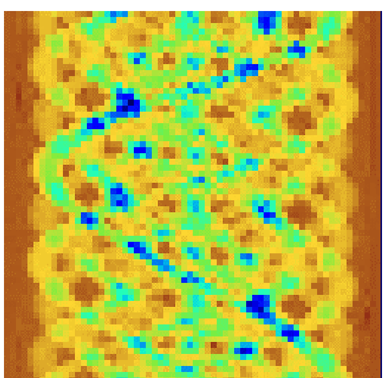
At 5 cm/s, the internals have noticeable effect on the redial gas holdup profile

Gamma CT in a fixed bed reactor

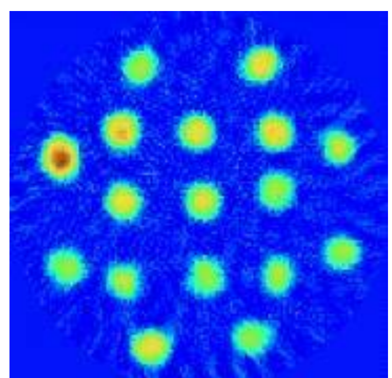
Hydrodynamics in reactor - IFP, Fr



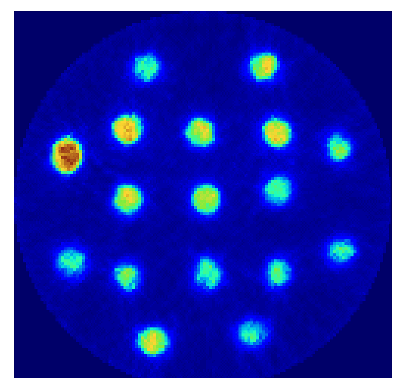
- Density of catalyst
- Porosities
- Void fraction



Sinogram



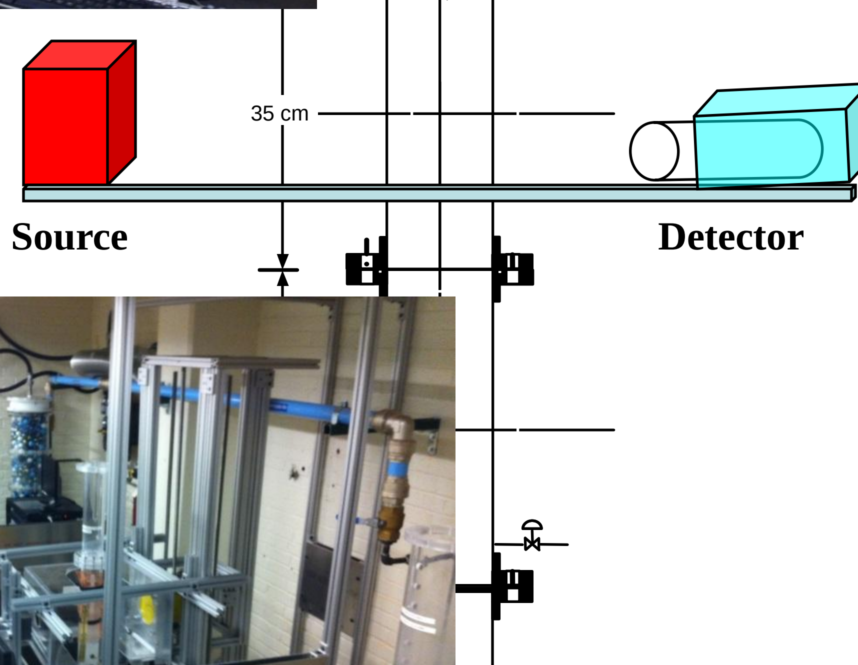
FBP



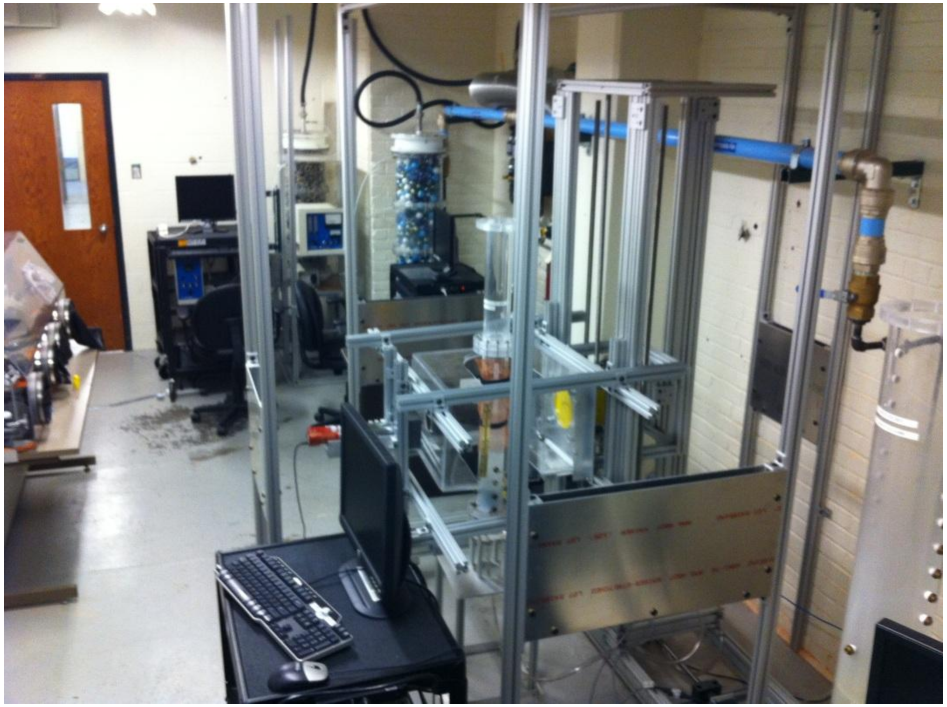
MAP-EM

S. Legoupil
CEA-France

A Novel On-line Technique Using NGD as Gamma Ray Densitometry (GRD) for Pinpointing Flow Pattern (Regime), Radial/Diameter Profile of Phases' Holdups & Reduced Tomography



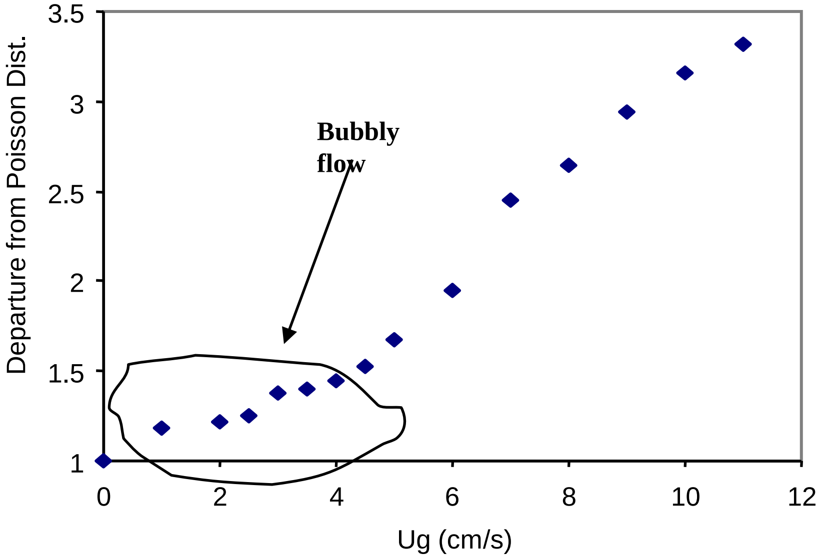
Gamma Ray Densitometry (GRD)



Flow Regime Indicators developed using GRD – Bubble Column

Departure from Poisson Distribution (D_P)

$$\text{Coefficient of Departure, } D_P = \frac{Variance@Ug}{(Variance@Ug)_{Poisson}}$$

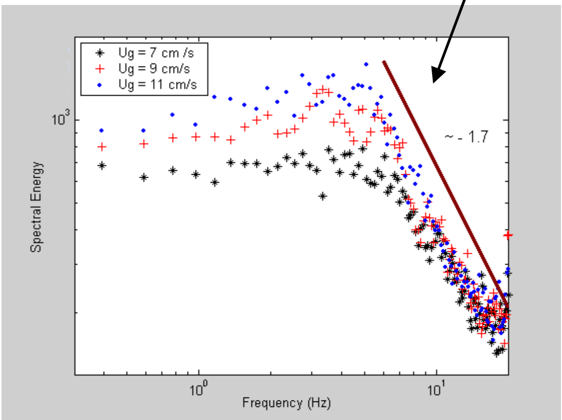


Heterogeneous Regime: $D_P > 3/2$ [$Ug > 4$ cm/s]

Found to be valid in steel column at low as well as high pressure

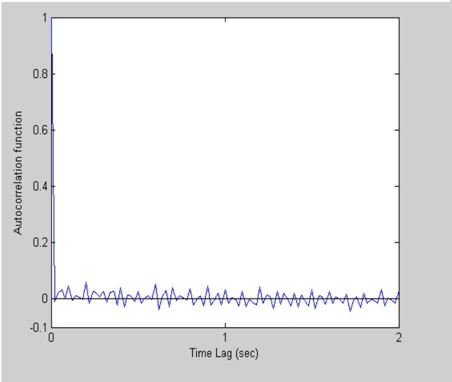
Spectral Analysis:

Kolomogorov's –5/3 law
in churn-turbulent flow

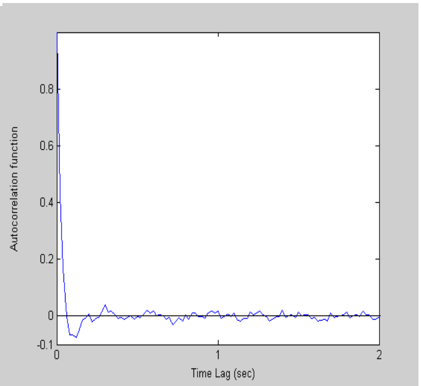


Autocorrelation Analysis:

Bubbly flow

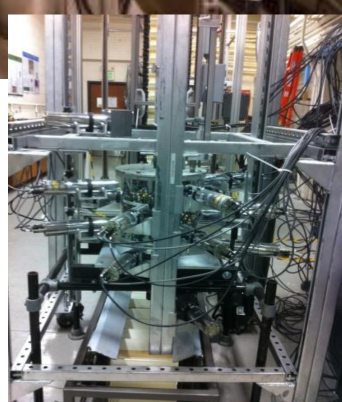


Churn-turbulent flow

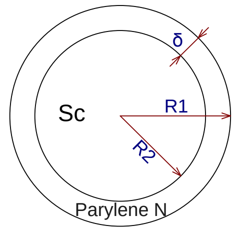


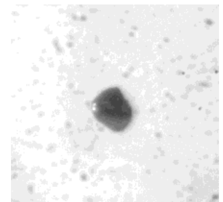
Applied on bubble columns, Fluidized beds, spouted beds, packed beds

Radioactive Particle Tracking (RPT)

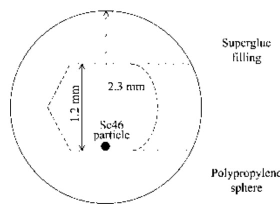


Radioactive Tracer Particles

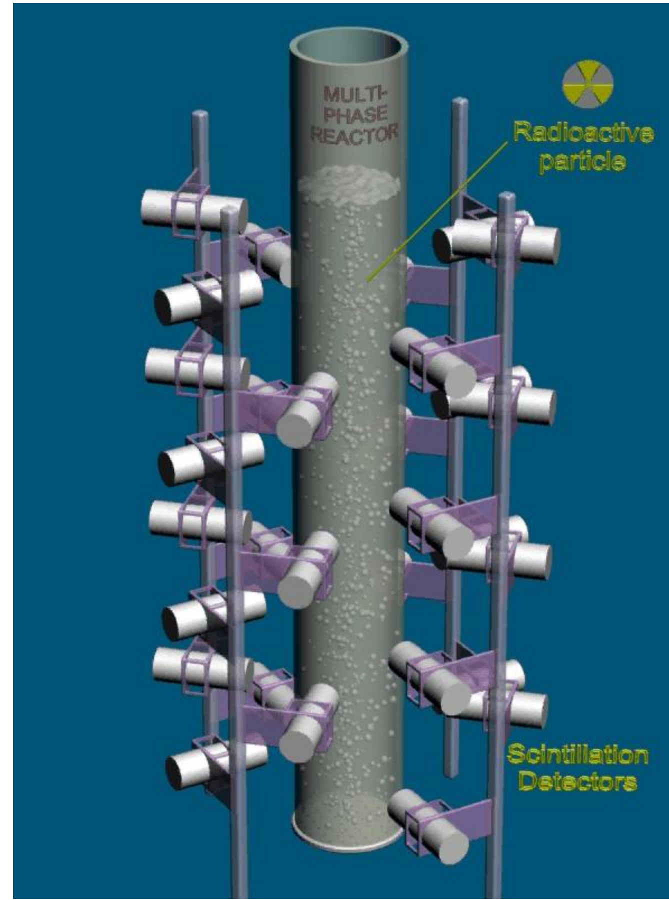


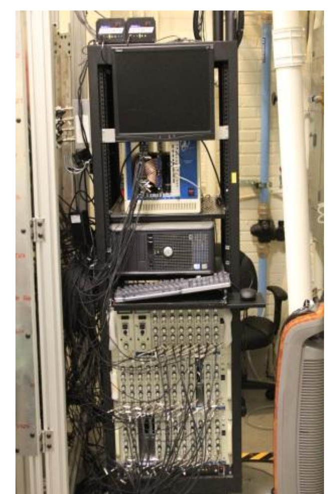


Sc^{46} particle coated with parylene-N, tracking solids



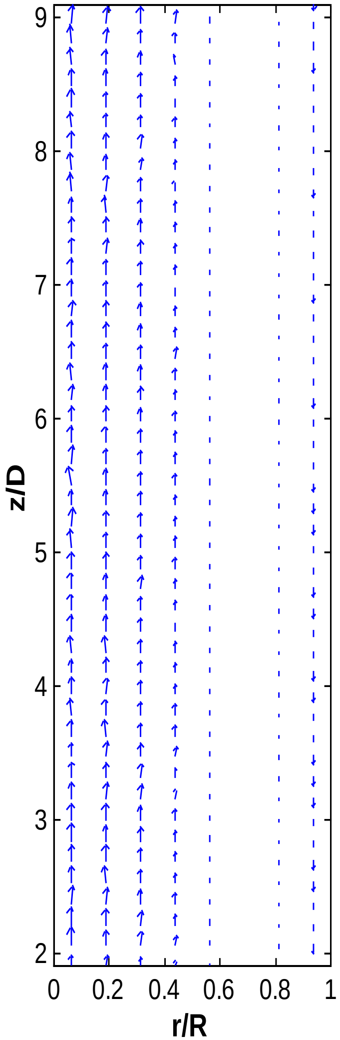
Co-60, Sc^{46} particle in polypropylene ball, tracking liquid

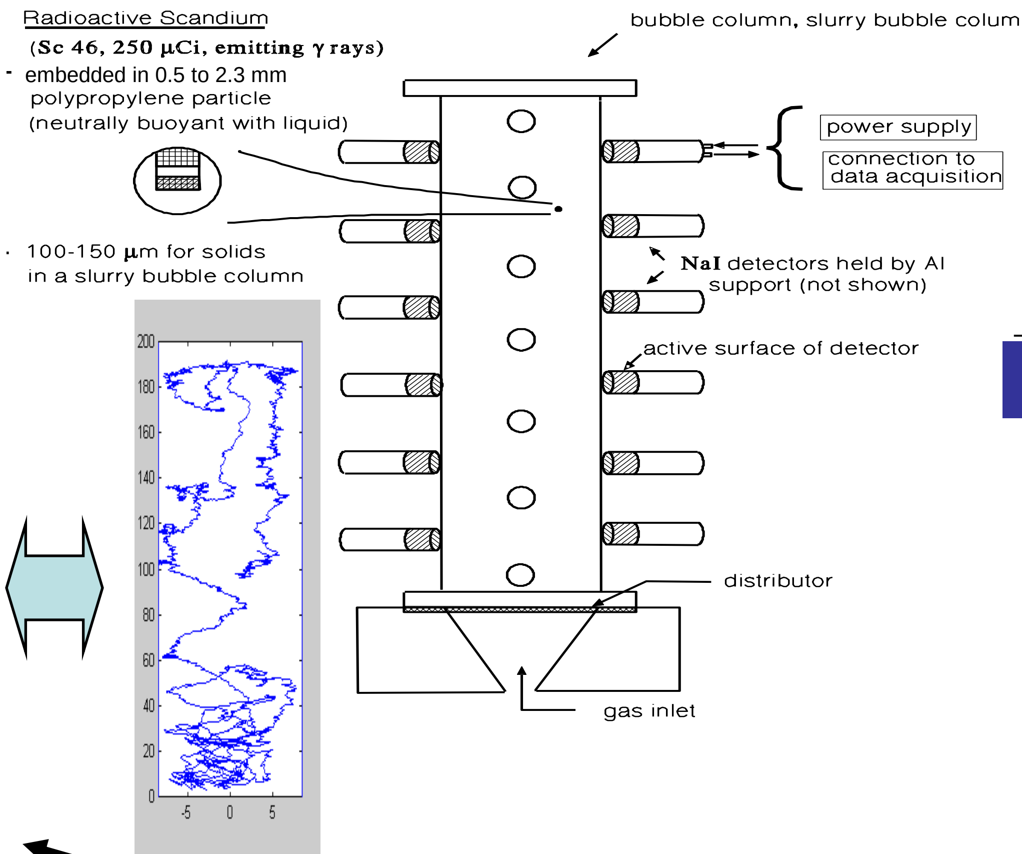




Radioactive Particle Tracking (RPT)

1.In-situ calibration 2. Particle Tracking





2D velocity vector plot

Counts from Detectors (*t*) + Distance - Count Map

↓

Regression / Monte-Carlo Search

↓

Instantaneous Positions (*x, y, z, t*)

↓

Filter

↓

Filtered Instantaneous Positions (*x, y, z, t*)

↓

Time-Difference Between Successive Locations

↓

Instantaneous Velocities (*x, y, z, t*)

↓

Ensemble (Time) Average

↓

Mean Velocities (*x, y, z*)

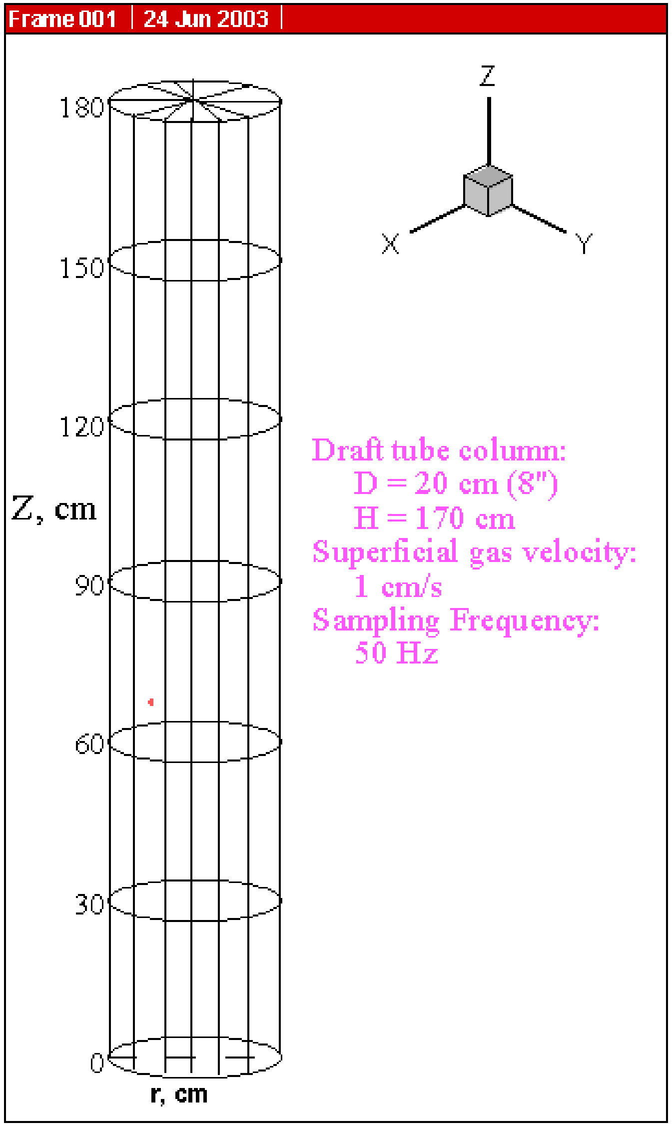
↓

Fluctuating Velocities (*x, y, z, t*)

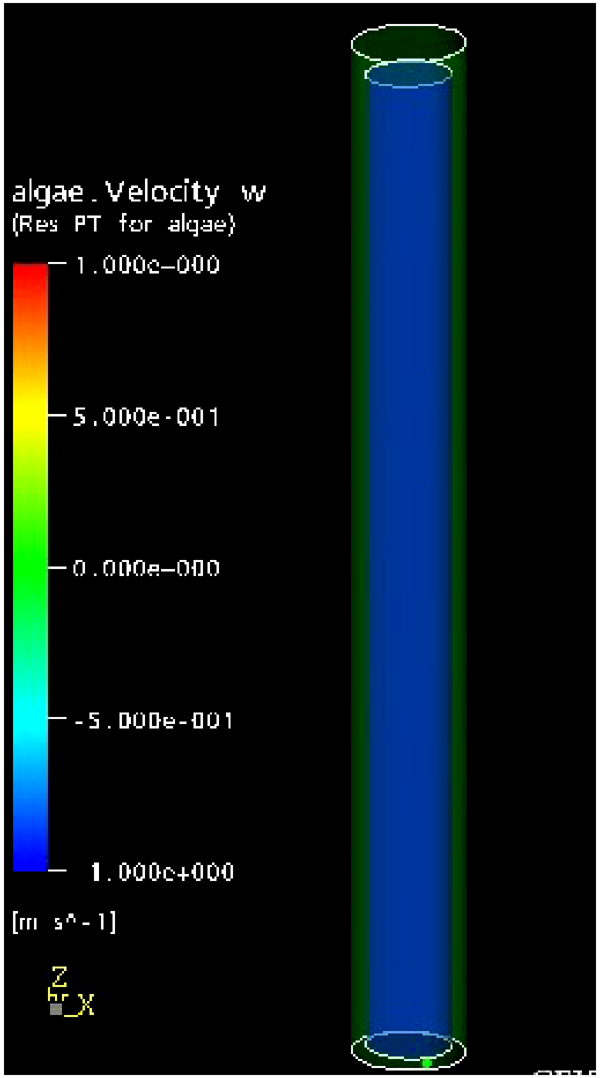
↓

Turbulent Parameters, Reynolds Stresses, TKE, Eddy diffusivities, etc.

Liquid or Solids Phases Tracking



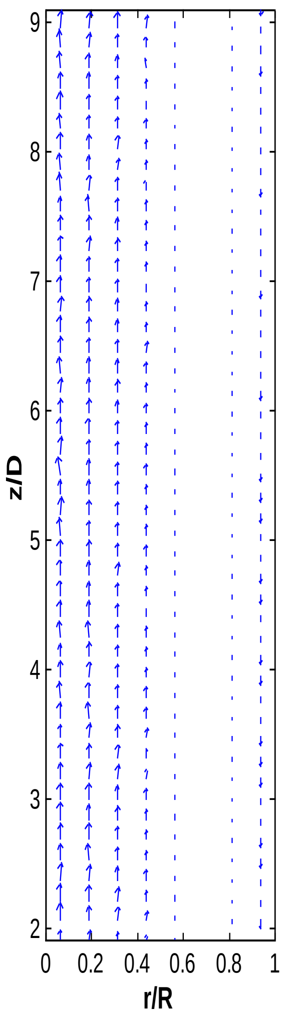
RPT vs. CFD



Hydrodynamics Similarity in Bubble Columns

A NEW SCALE-UP APPROACH

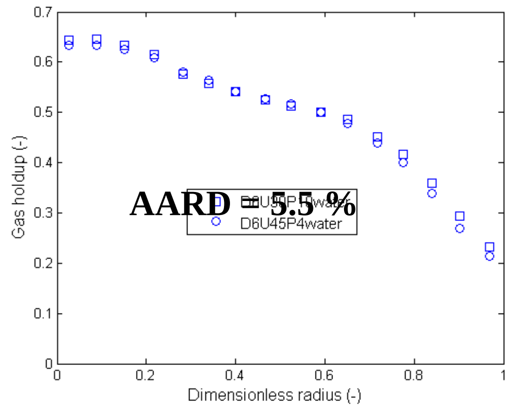
10 bar, 30 cm/s, air-water



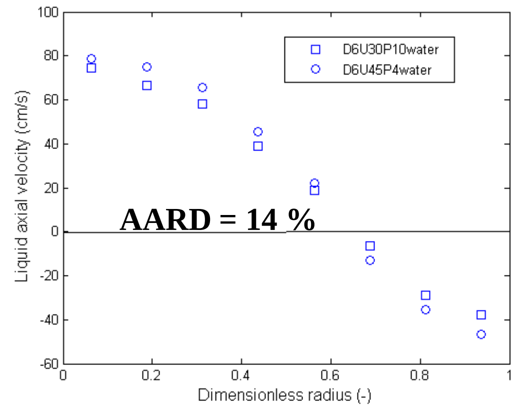
$\bar{u}_{rec} = 52.5\ cm.s^{-1}$

Overall gas holdup = 0.41

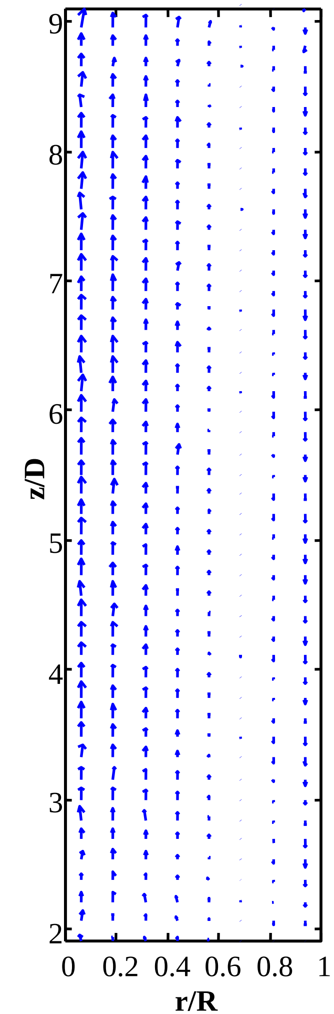
Gas holdup profile



Axial velocity profile



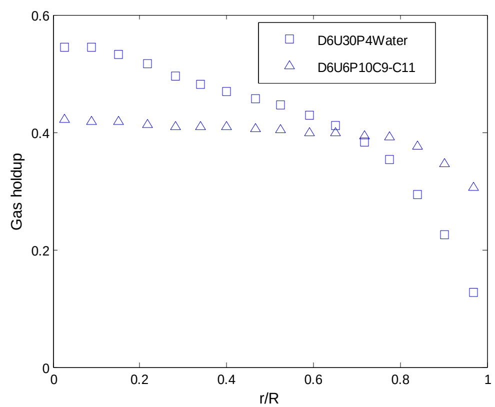
4 bar, 45 cm/s, air-water



$\bar{u}_{rec} = 55\ cm.s^{-1}$

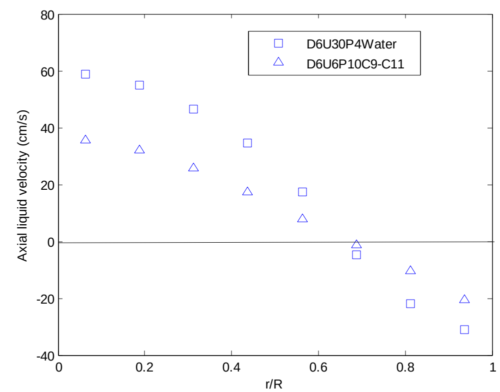
Overall gas holdup = 0.35

Gas holdup profile



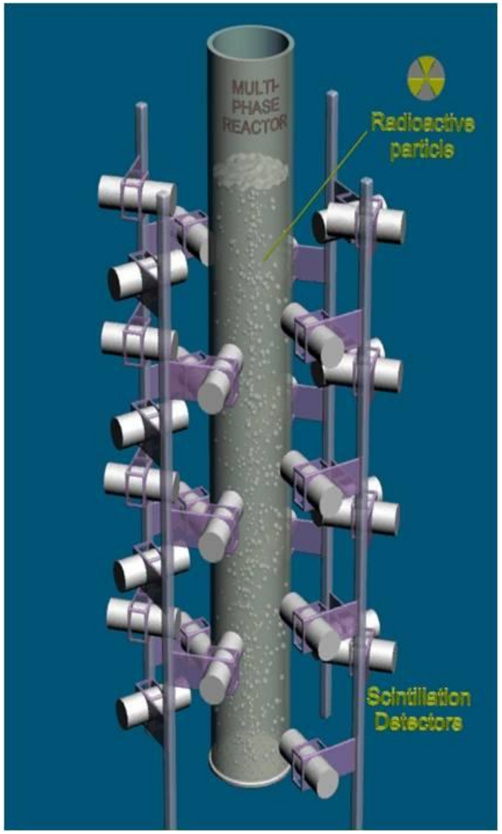
$\bar{u}_{rec} = 42\ cm.s^{-1}$

Axial velocity profile



$\bar{u}_{rec} = 22\ cm.s^{-1}$

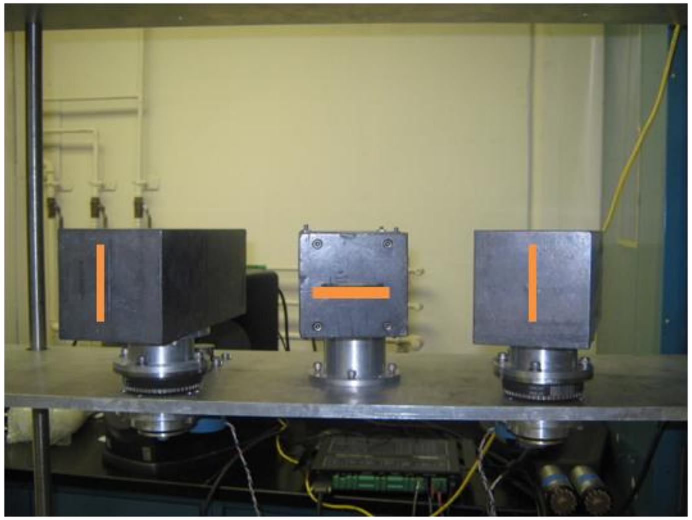
Novel dynamic In-Situ calibration Technique

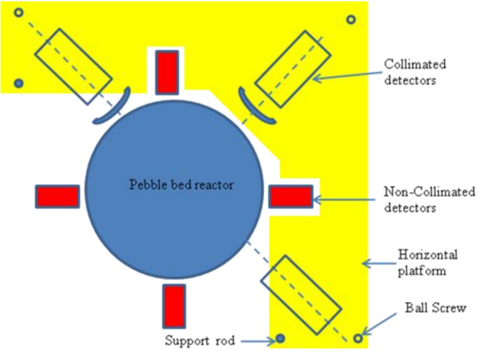


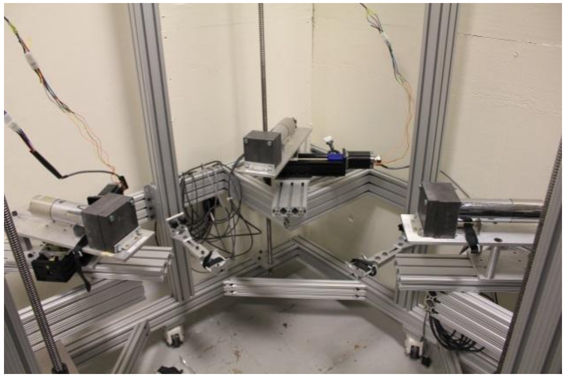
Conventional RPT

ADVANTAGES

LIMITATIONS


Collimated detector based RPT

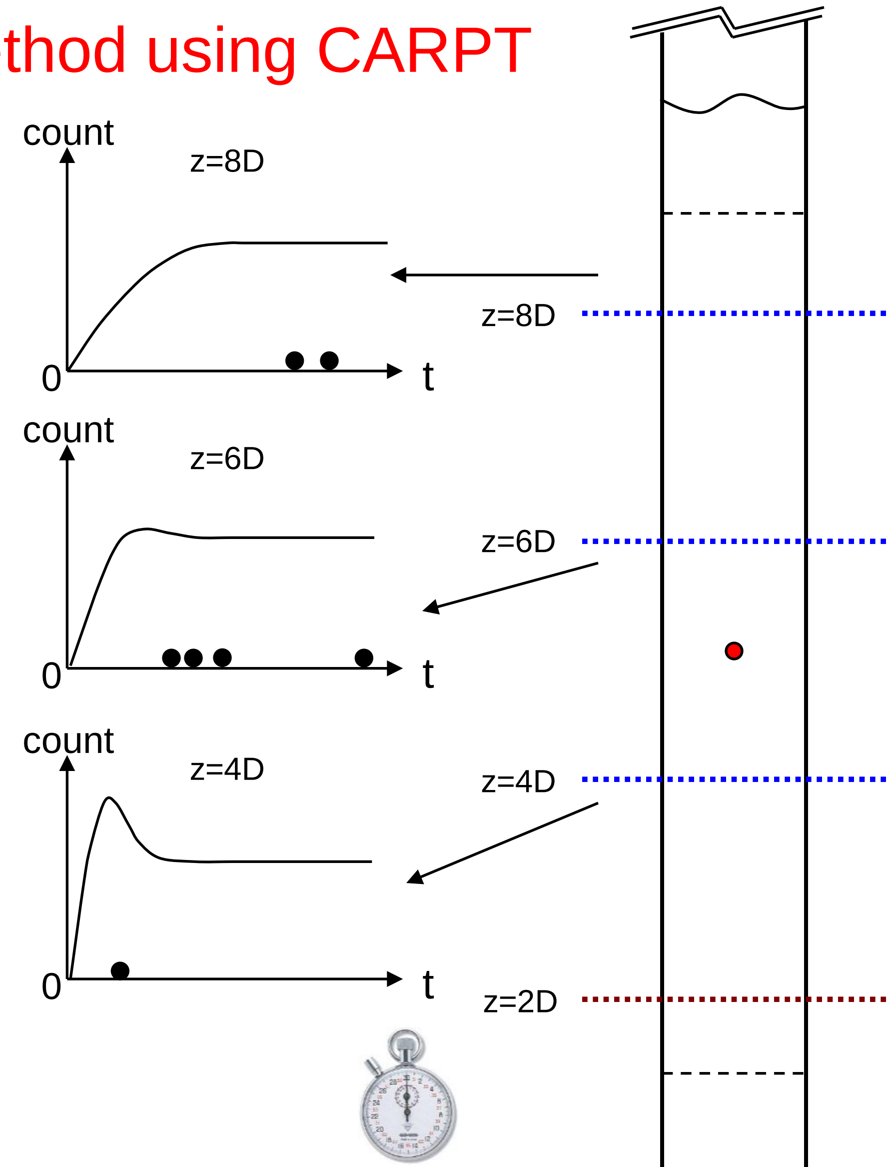




Liquid/Solids phase mixing
Novel virtual tracer response method using CARPT

- -Virtual response curves
- -Injected tracer is almost ideally distributed in time and space
- -Small axial variation of fitted D_l values in fully developed zone
- -Injection and sampling can be designed anyway within the CARPT experiment zone.

Liquid response curves, fitted with ADM



Particle counting process

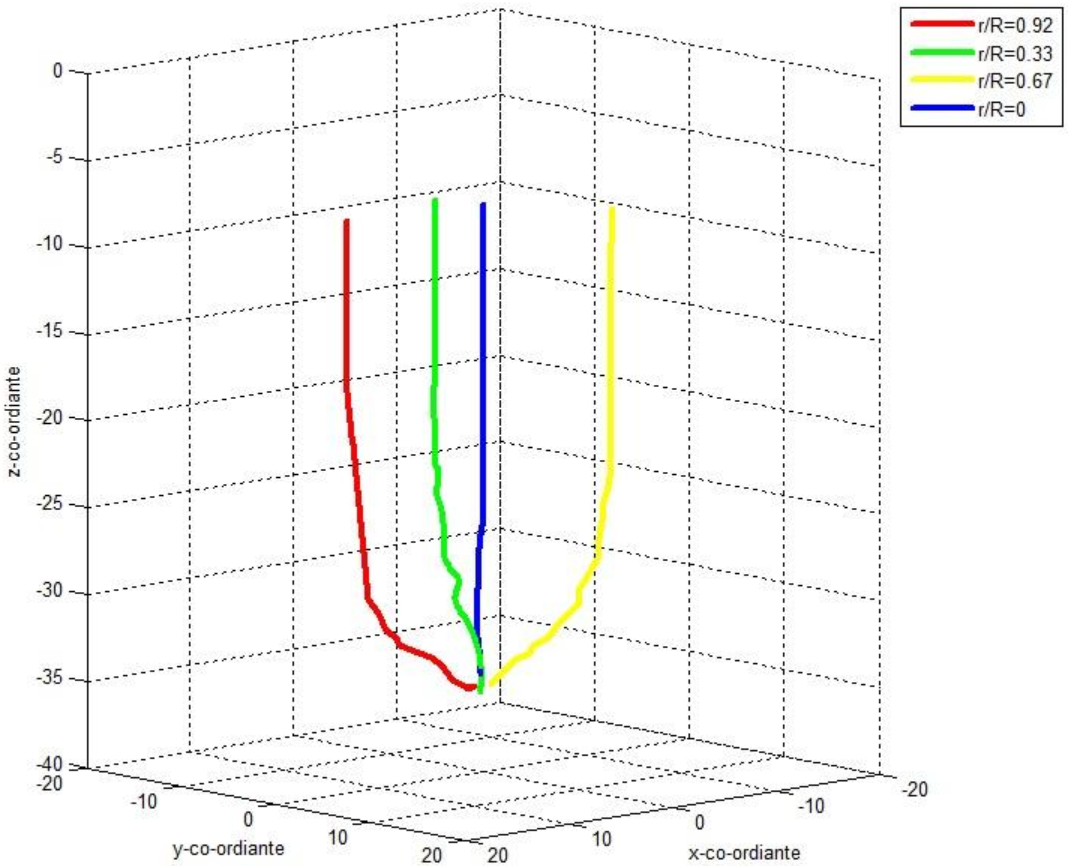
Experimental and Computational Study of Pebble Bed Reactor Technology

- Design and development of Continuous pebbles recirculation experimental set-up at Missouri S&T, to mimic the flow of pebbles in the pebble bed reactor.
- Features:
  - having ***control over pebbles exit flow rate***
  - **capability to place returned pebble at different radial positions**
- Implementation of RPT, Solids RTD and GRD technique to study pebbles dynamics
- Computational study involving application of EDEM (Discrete Element method (DEM) based code)

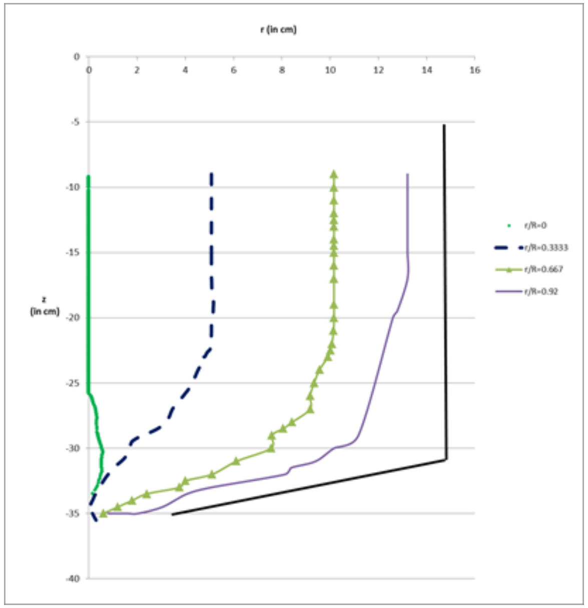
Continuous pebbles recirculation exp. set-up

RPT –Radioactive Particle Tracking , GRD-Gamma Ray Densitometry RTD – Residence Time Distribution

2-D/3-D pebble trajectories



3-D trajectories

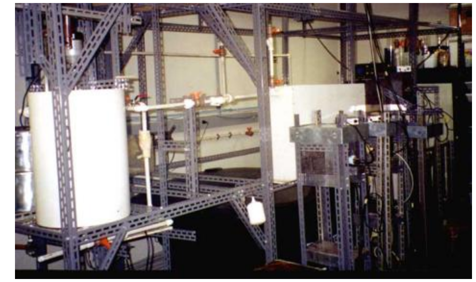


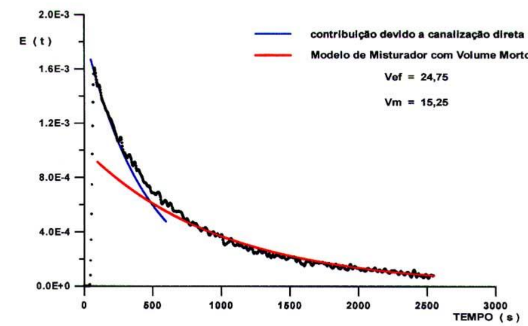
2-D trajectories

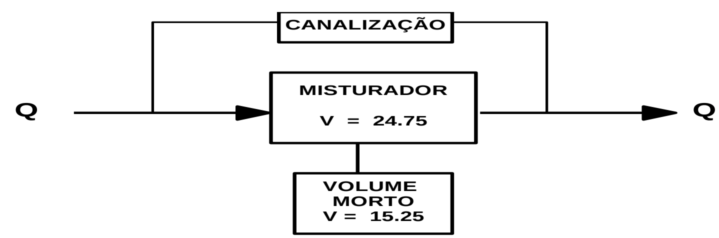
- Plug type flow in the uppermost portion of cylinder whereas converging flow exists towards exit opening

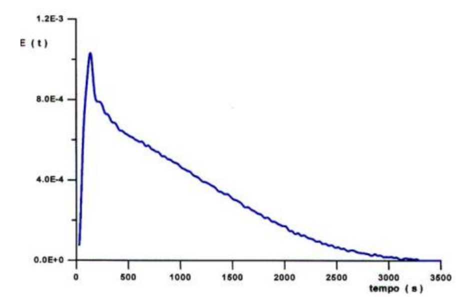
L. Brandão, ien, Brazil

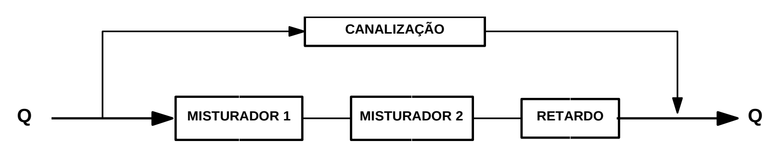
Lab Scale Radioactive Tracer Experiment







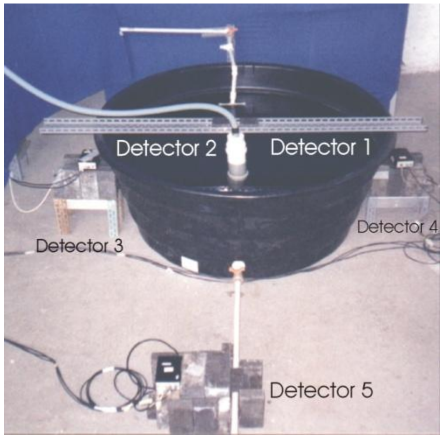




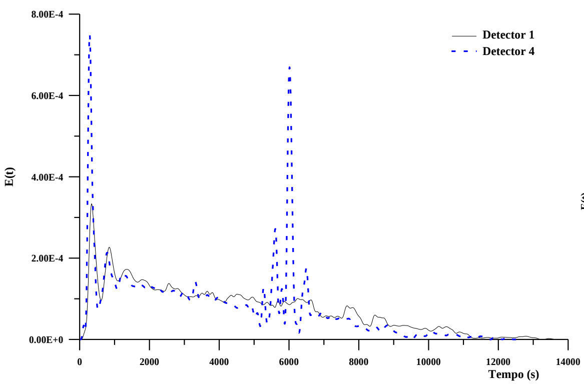
Large Scale (2000 L), Detectors are inside

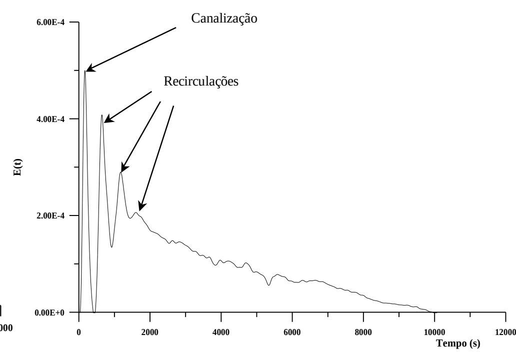
Non-Ideal Mixing

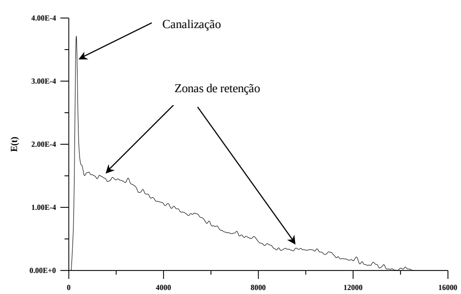
Mal-distributing flow



Injection: I-132

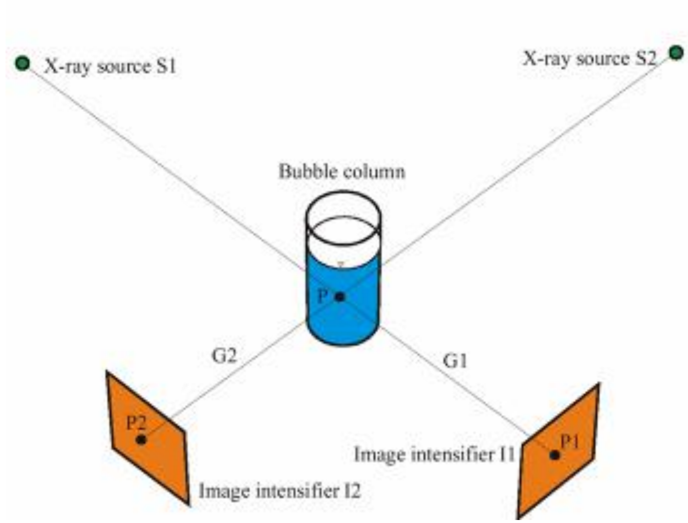


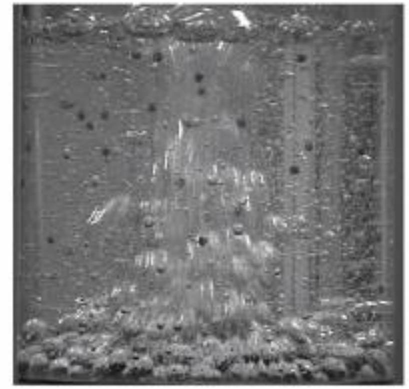


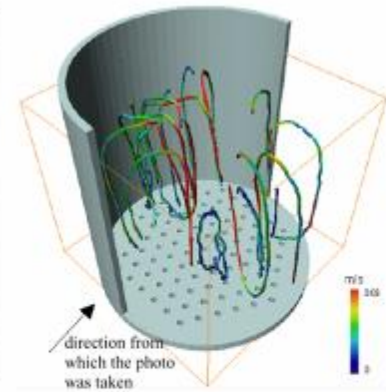


X-Particle Tracknih Velocimetry

Measurement system

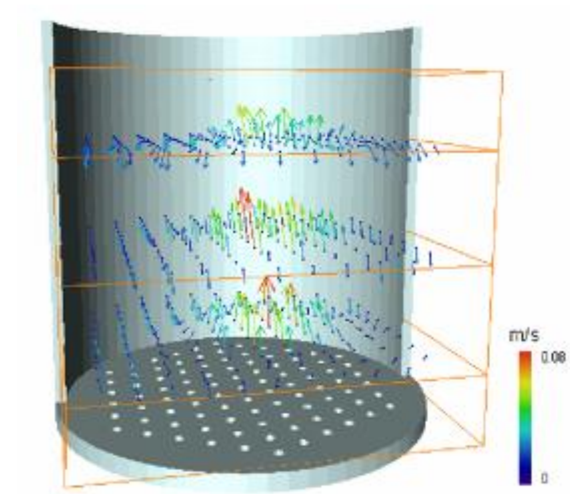






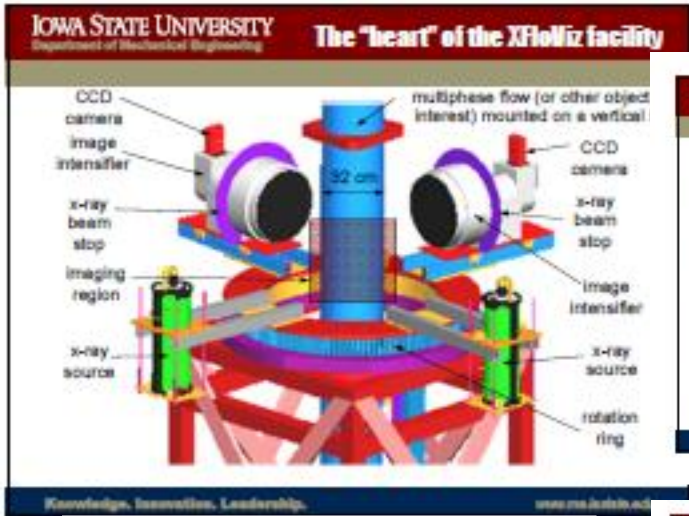
Method :

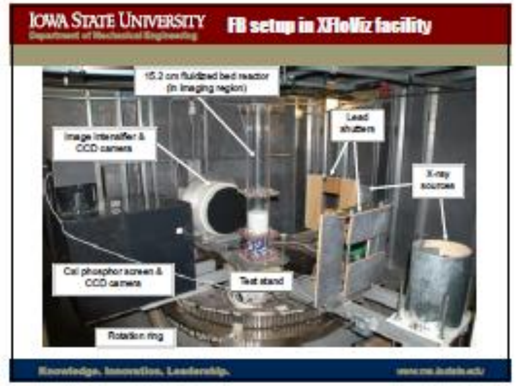
- Tiny solid opaque particle to flow label
- Particles localisation : P(x,y,z,t)
- particles trajectories reconstruction
- velocities reconstruction

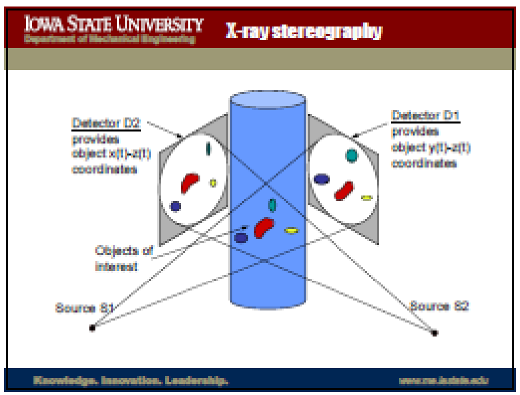


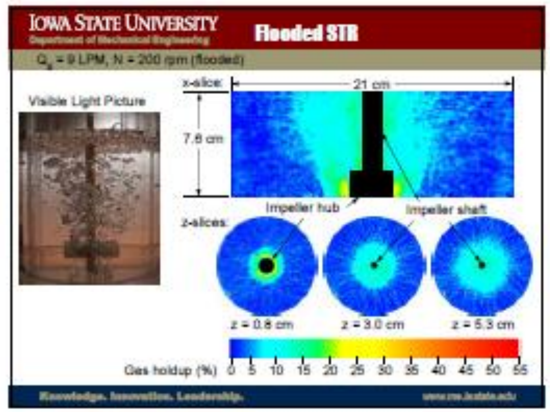
Cf Seeger et al.

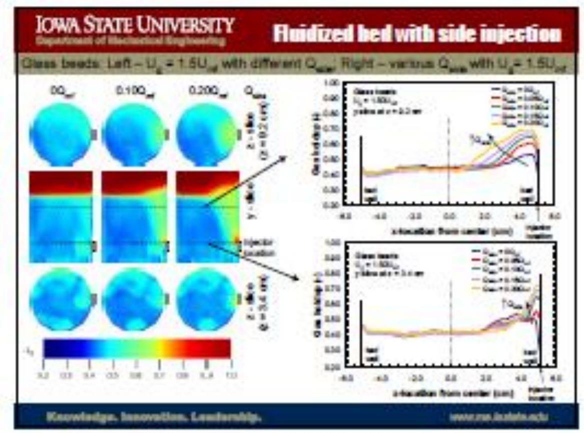
S. Legoupil
CEA-France

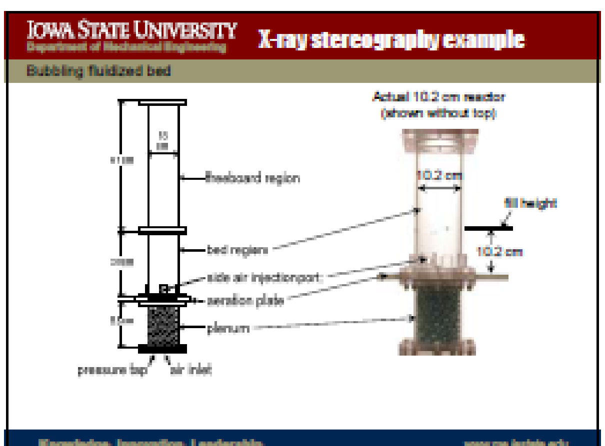












Professor Heindel's
x-ray Lab
Iowa State University

Solids Blenders

Introduction

Experimental

Numerical

Experimental Results

Numerical Results

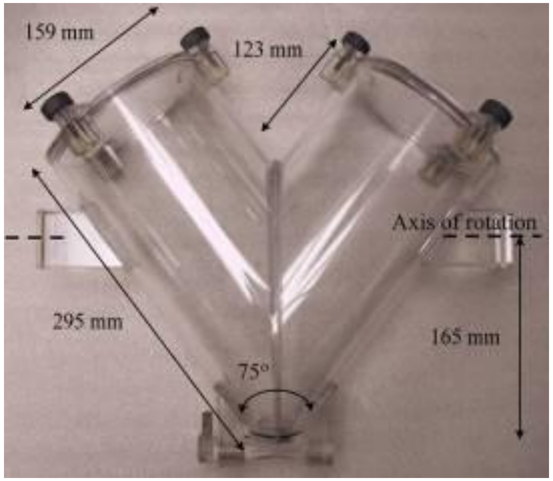
Conclusion

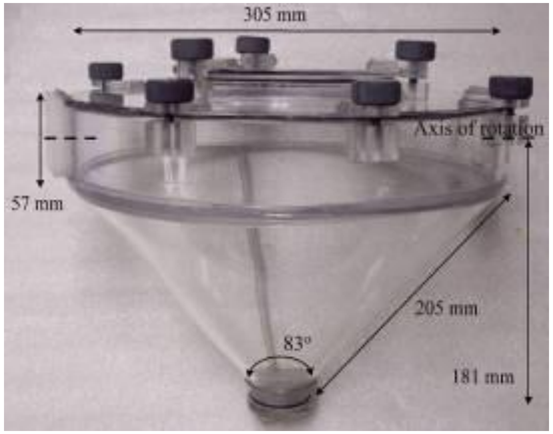
Industrial scale

Geometrical scale-down

7.5x

Lab scale (8-qt.)

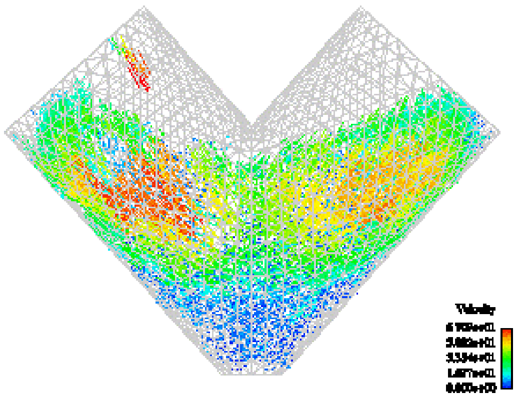




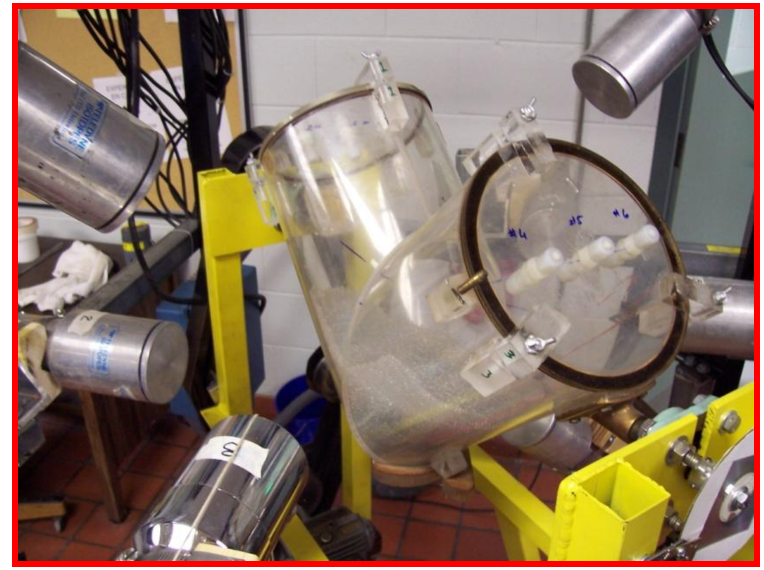
J. Chaouki, Ecole Polytechnique Montreal, Canada

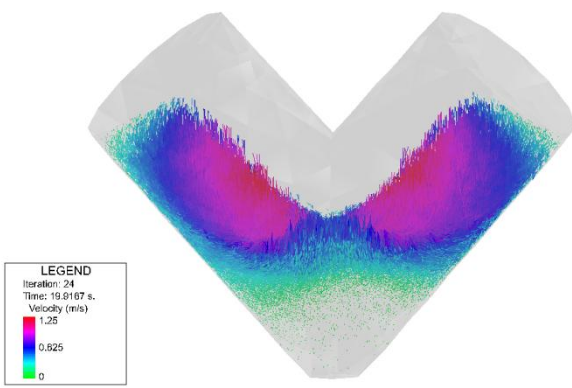
Radioactive Particle Tracking (RPT) in Particles Blending

225 000 3-mm particles (30 rpm)

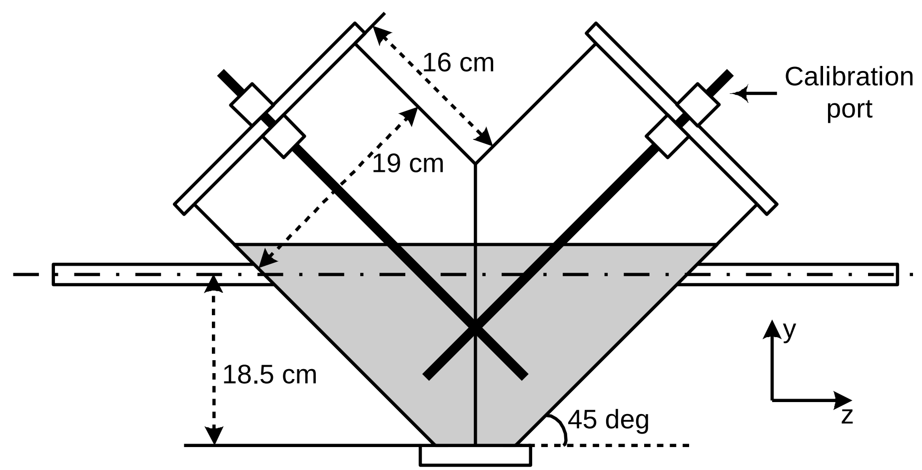


Experimental results from RPT measurements





Numerical results from DEM



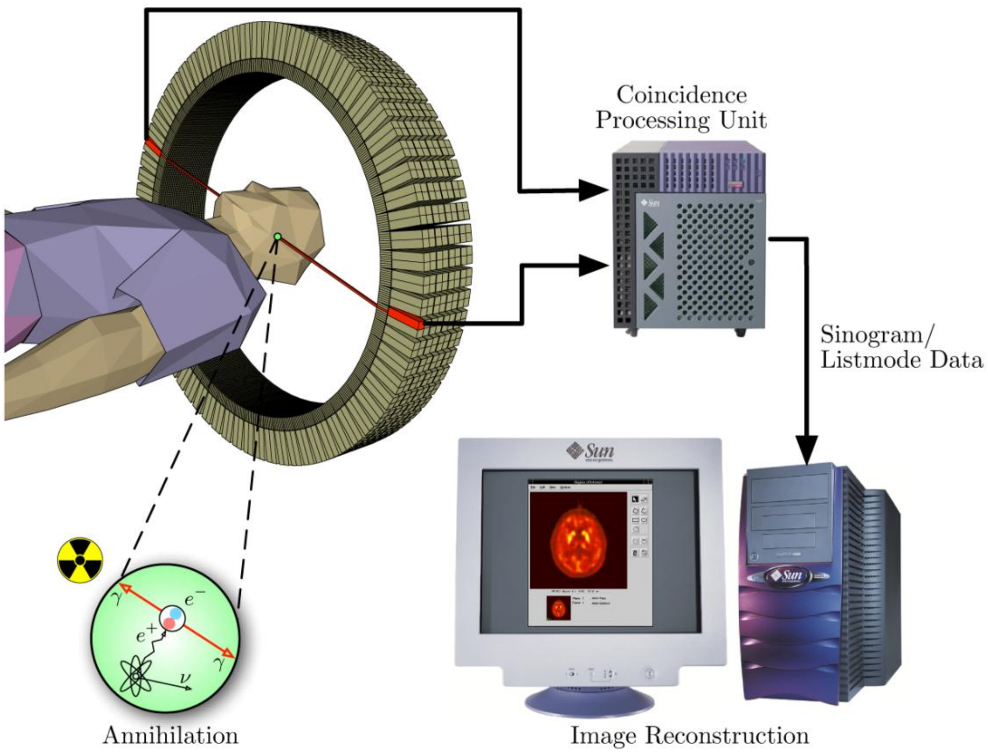
J. Chaouki, Ecole Polytechnique Montreal, Canada

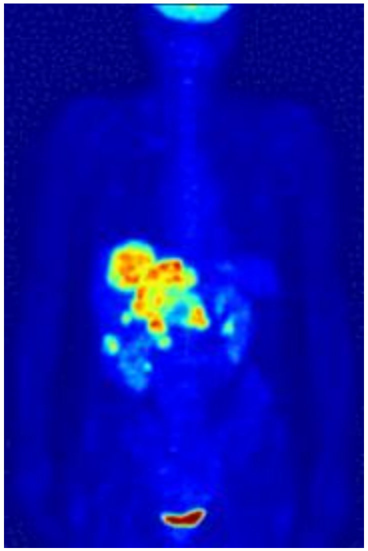
Positron emission tomography (PET):

Mapping concentration of radioactively-labelled fluid

PET scanner consists of rings of many small detectors, operating in coincidence to detect the pairs of back-to-back γ-rays from positron annihilation.

After detecting millions of such events a 3D tomographic map of tracer concentration can be reconstructed

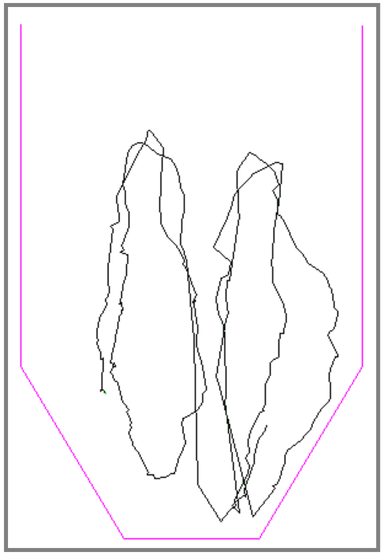




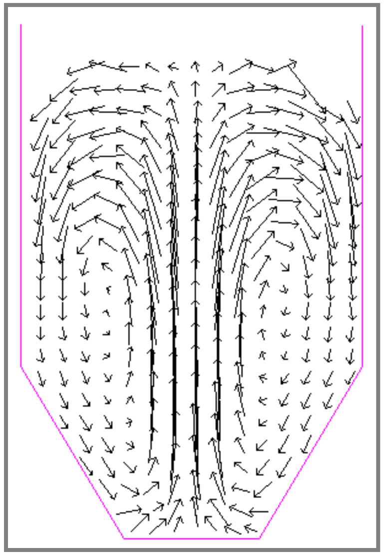
David Parker, University of Birmingham

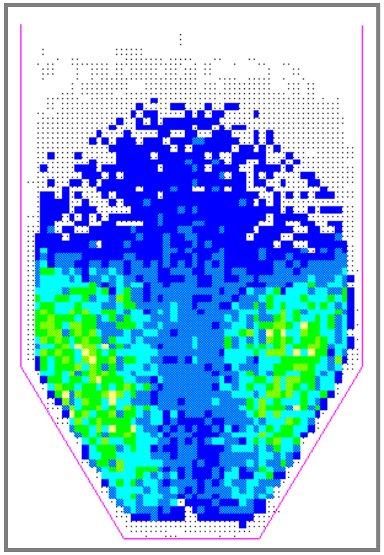
Positron Emission Particle Tracking (PEPT) Application in a Spouted Fluidized Bed

5s



Velocity field





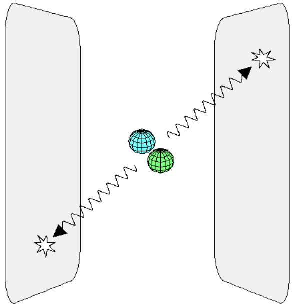
Bulk density by time spent and *occupancy*

Fluidised bed

David Parker,

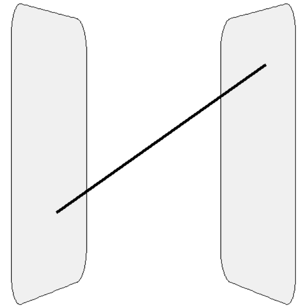
University of Birmingham

PEPT Principles & Industrial Applications



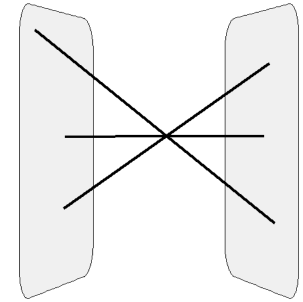
Detection

Detection of gamma rays using two large position sensitive detectors.



Reconstruction

Two rays detected in coincidence define line along which particle lies.

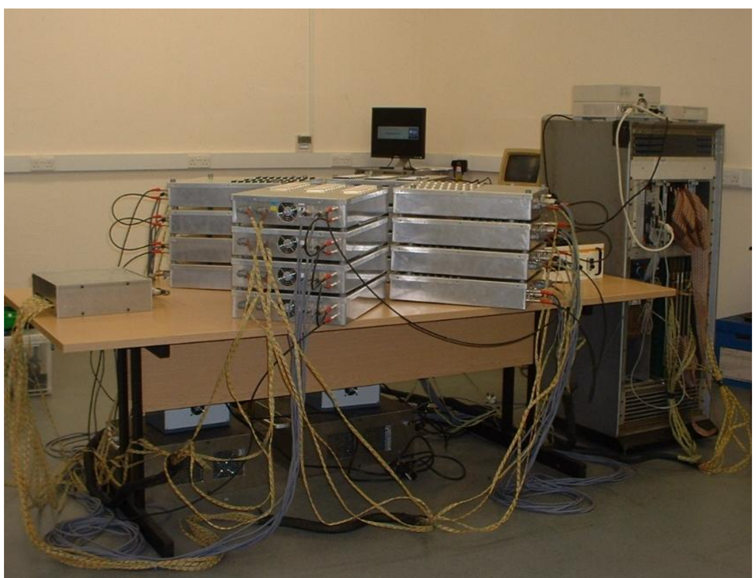


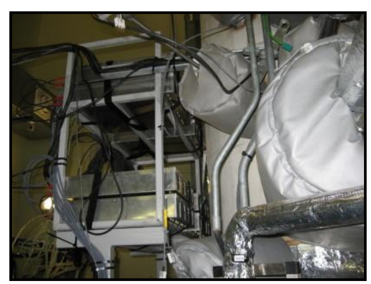
Particle Location

After several events, tracer can be located via triangulation.

Transportable Modular Positron Camera for PEPT

16 detector modules (extendable to 32)





David Parker, University of Birmingham

Applications of Nuclear Technology for Industrial Applications
Commercial Plant Applications

- ***Due to the size of process equipment and the safety measures, the nuclear technology has limited applications yet they are essential for process troubleshooting and equipment integrity testing***

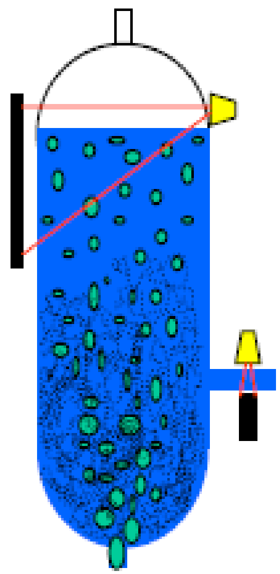
Selected Examples

- **Nuclear Gauge Densitometry for level measurement and control**
- **Fast Neutron Back scattering for phases levels and volume measurements**
- **Radioactive Tracer (open source) for residence time distribution, flow measurements**
- **Gamma Ray Densitometry for troubleshooting, equipment integrity testing, density measurement**
- **Industrial Process Tomography for imaging**
- **Emission Tomography for imging**

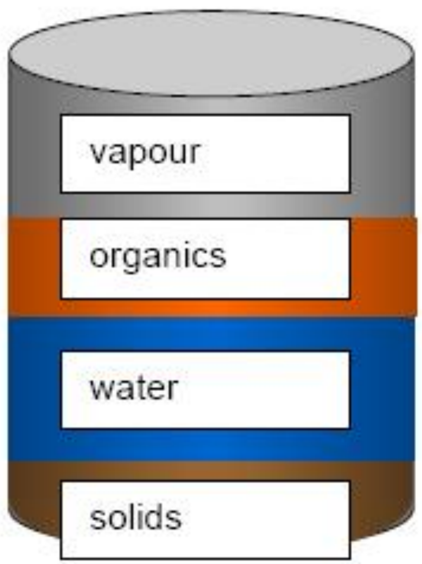
Liquid Level Measurement and Foam Detection (Tracerco, UK)

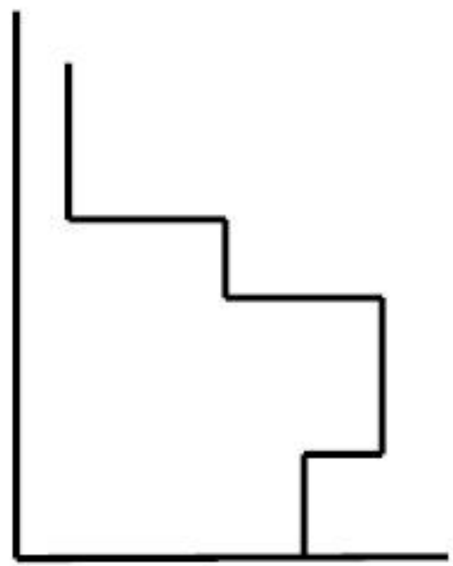
Sealed Source-Detector

- Sealed radioactive sources have been used for detection and measurement of liquid levels in hostile process environments or in critical systems.
- Same method has been used to detect foaming or carryover (catalyst/liquid) into the free gas space above the liquid/slurry level.



Fast Neutron Backscattering

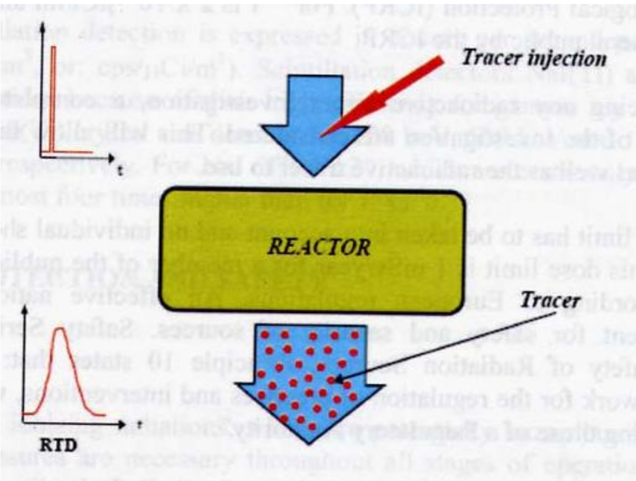




Backscatter response

Radiotracer method for the measurement of the residence time distribution (RTD) and for trouble shooting and diagnostics

- RTD (Tracerco)

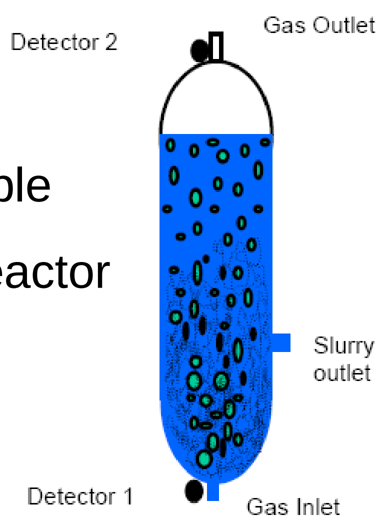


GTL: Natural gas to liquid fuels and chemicals

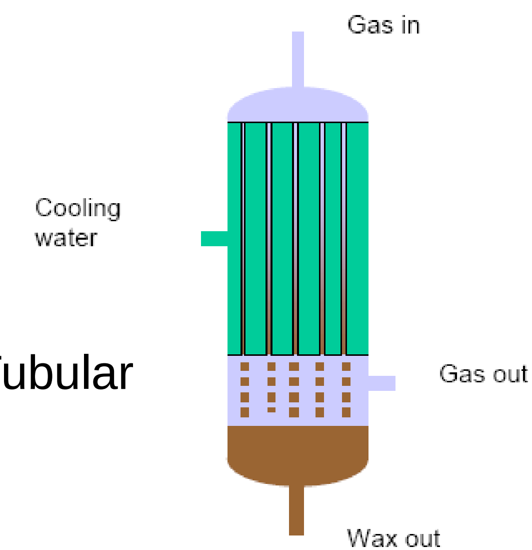
GTL Reactors

Slurry Bubble

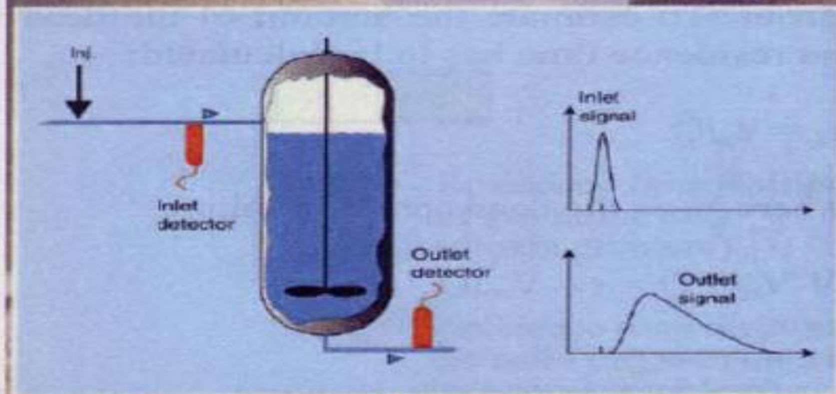
Column Reactor



Packed Bed Tubular Reactors

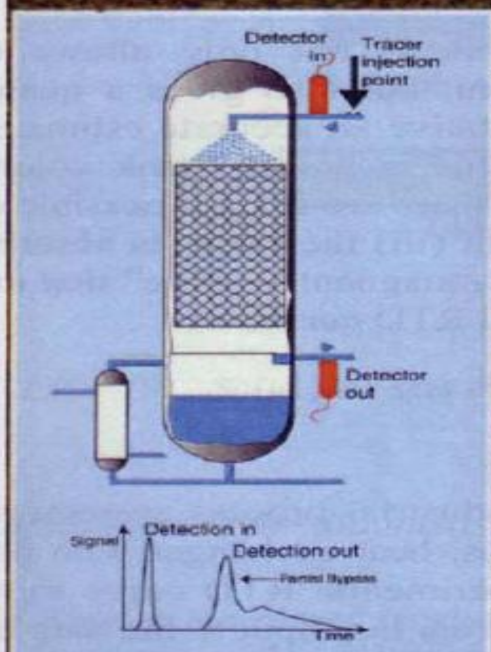


RTD & Trouble Shooting



Residence time analysis

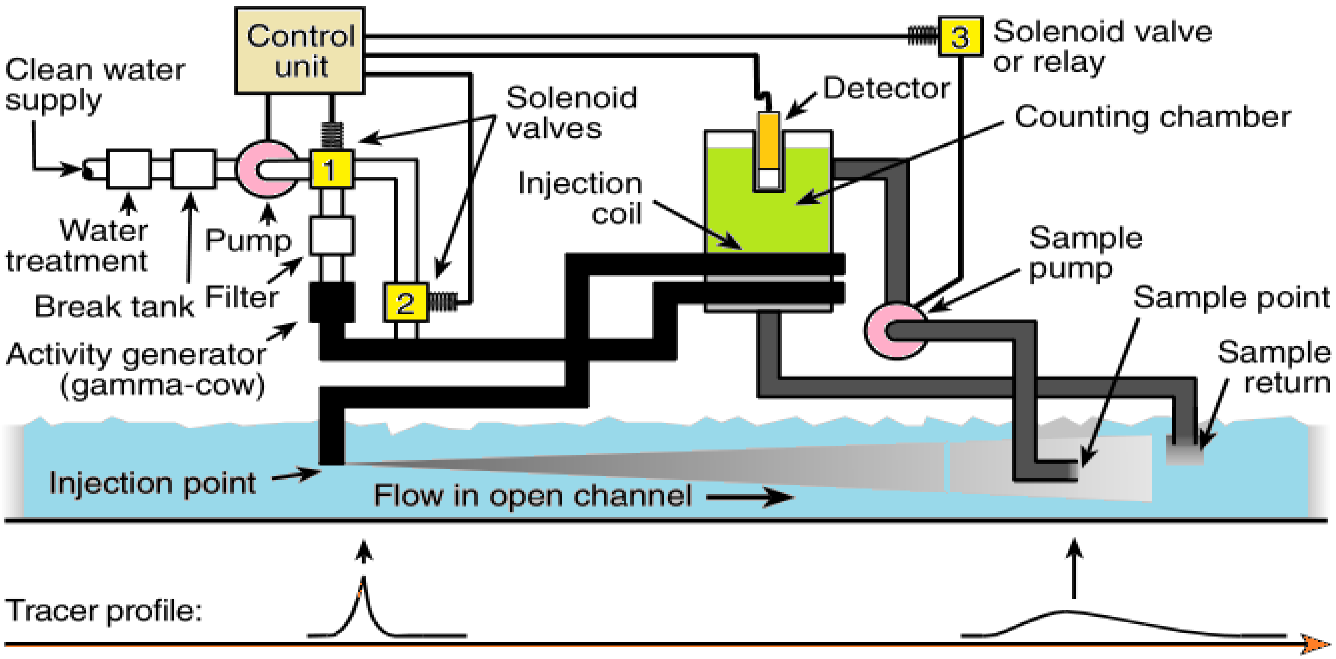
The best way to improve vessel design is to understand what is happening internally. Residence time analysis by tracers derives important information from the process units, such as flow pattern, back mixing, bypassing etc...



Trouble shooting

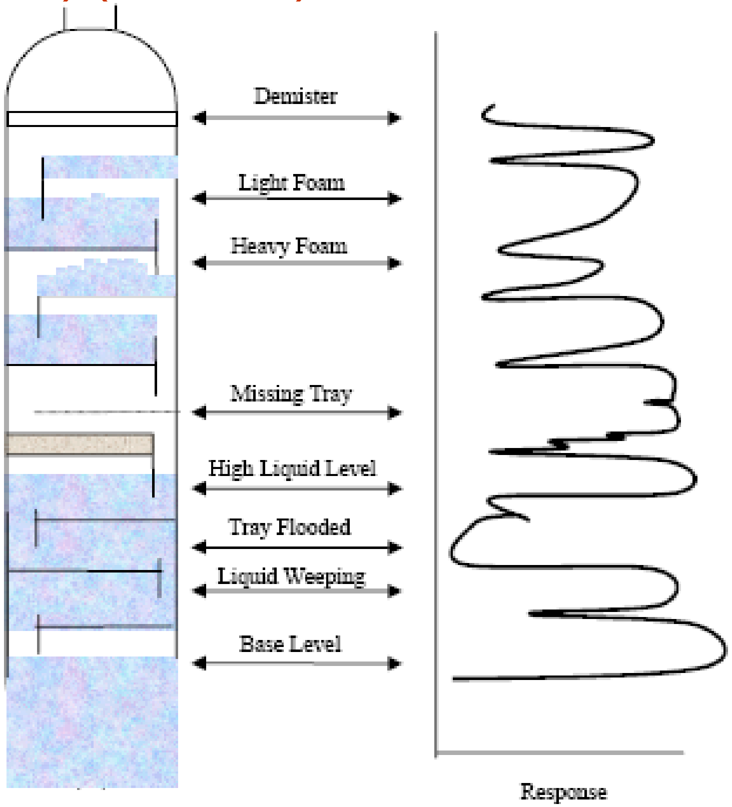
Tracer technology can shorten diagnosis time during trouble shooting. It quickly provides observable, reliable data : flow rates, bypass, entrainment etc... at many process points where no instrumentation is available.

- Multi-Phase Flow Metering
- Tracer Dilution Method



General arrangement of an isotope dilution flowmeter using a gamma-cow. Under computer control the injection pump produces a pulse of ^{137m}Ba, which is measured by the detector and then flushed into the stream with water. The sample pump delivers a constant sample from the stream back to the same counter where the count-rate in the stream sample is assayed

Distillation Column: Examining the column for mechanical conditions (e.g., missing or damaged trays, etc.) and process conditions (e.g., foaming, weeping, flooding, etc.) (Tracerco)

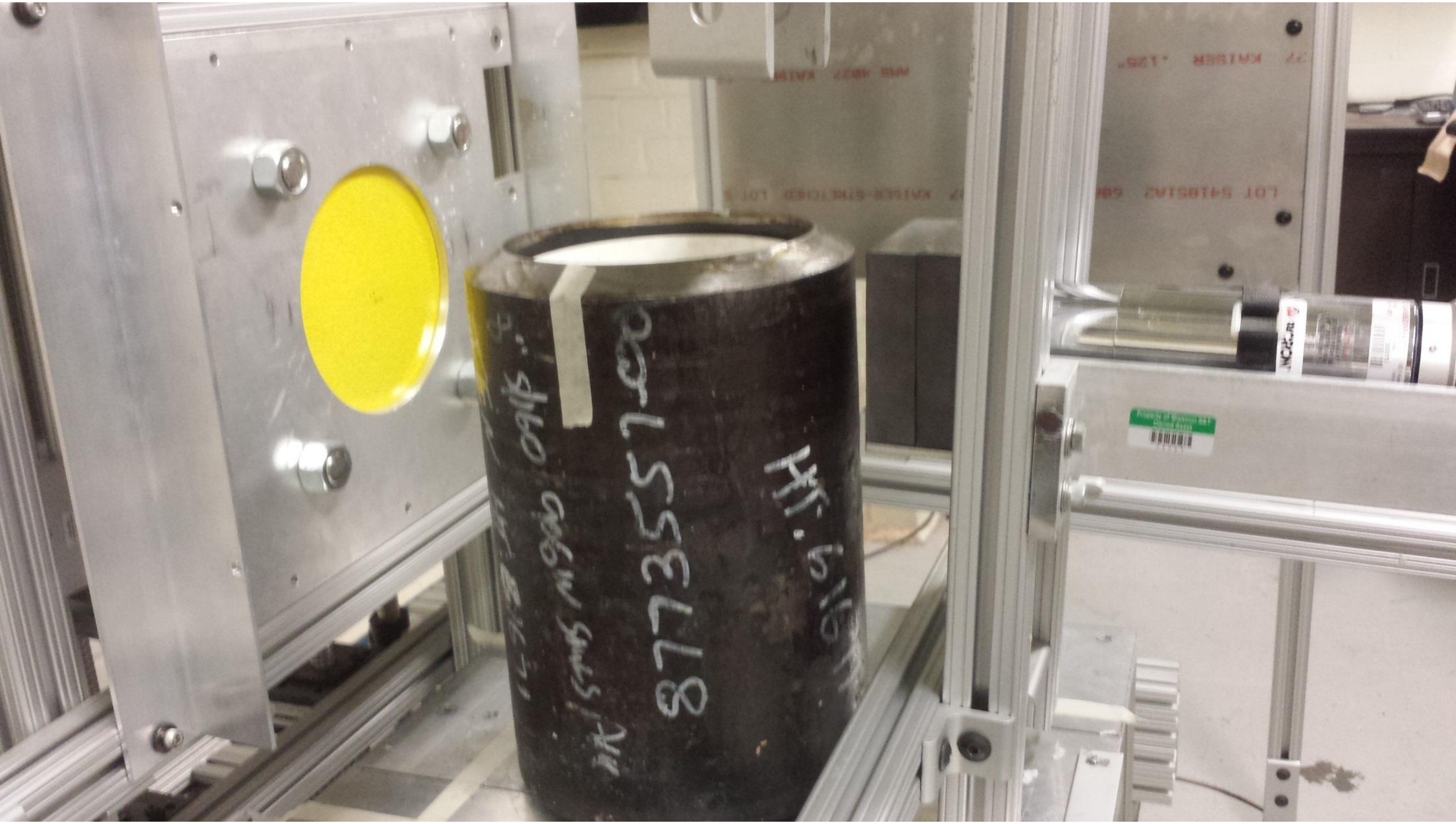


Other Applications for Radioactive Tracer method (Tracerco)

Carryover, Maldistribution, Leaks, Bubble Rise velocity, Flow rate, etc.

Pinpoint heat exchangers & boilers leaks, finding control or bypass valves leaks, characterizing relief valves that are passing, etc.

Pipe Testing

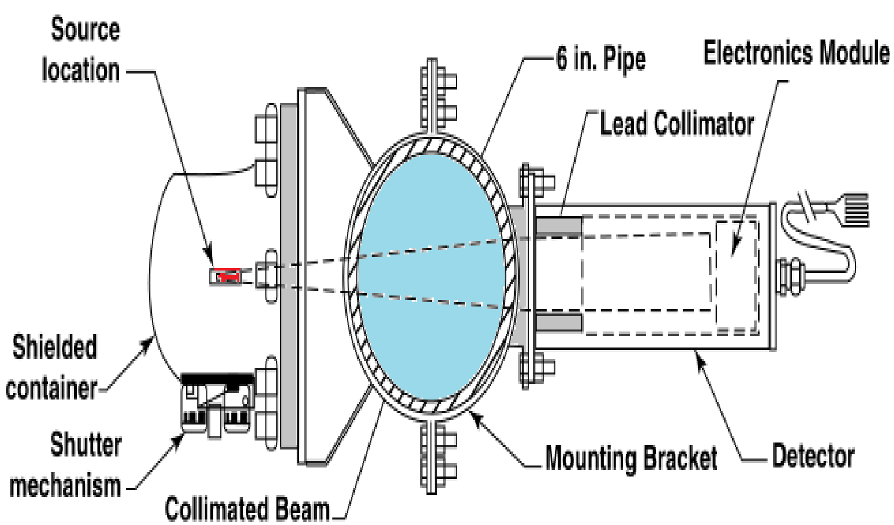


1- DENSITY MEASUREMENT

Radioisotope Gauges for Industrial Process Measurements. Geir Anton Johansen and Peter Jackson.
(2004) John Wiley & Sons, Ltd. ISBN 0-471-48999-9.

- The gamma-Ray Densitometer

A gamma densitometer is used to measure the density inside a medium with fixed dimensions. This gauge is often used as a meter on pipes where the density of the flow varies with time.



Cross section of a typical density gauge with mounting bracket for 6 in. diameter pipe. The specified sensitivity of this gauge is 0.001 g/cm^3. Courtesy of Tracerco

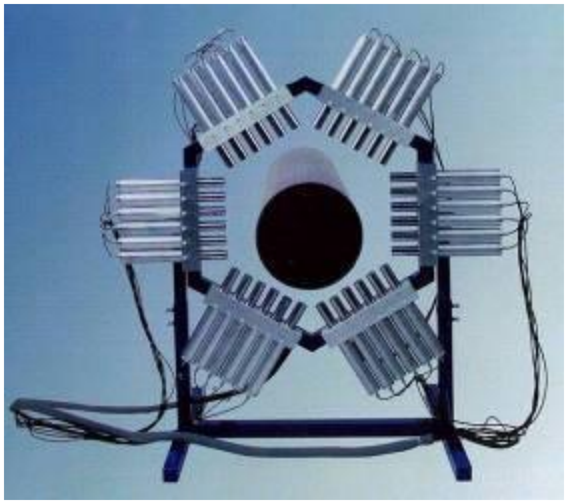
Typical applications of this meter are

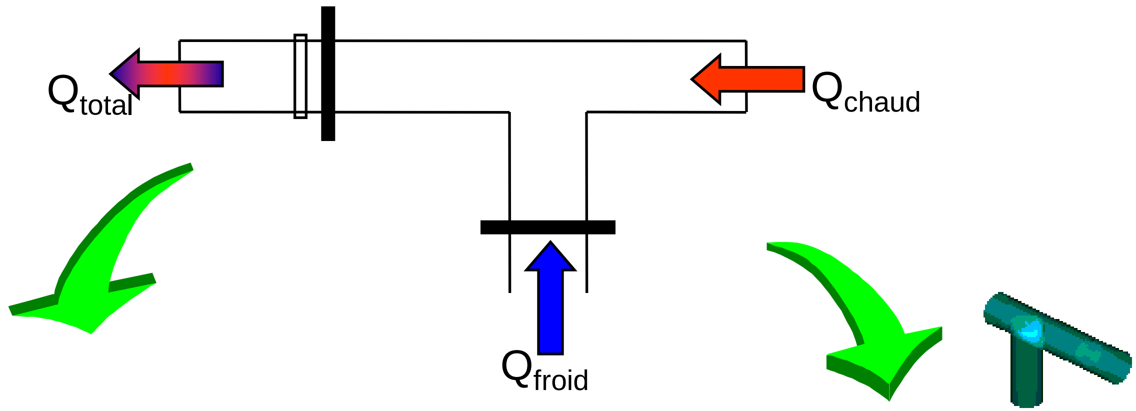
- mining and metallurgical industries,
- pulp and paper,
- food and animal feed processing,
- chemical and petrochemical industries and
- offshore drilling fluid/mud applications.

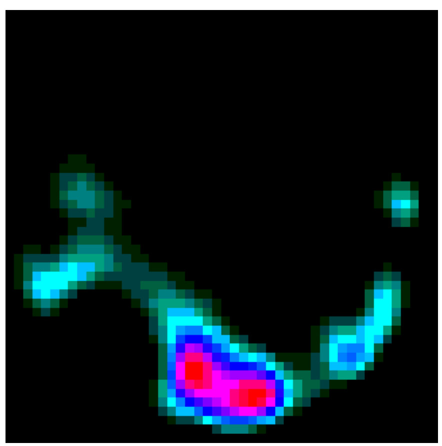
Charlton, J. S. (Ed.) (1986). Radioisotope Techniques for Problem-Solving in Indus-trial Plants, Leonard Hill, London.

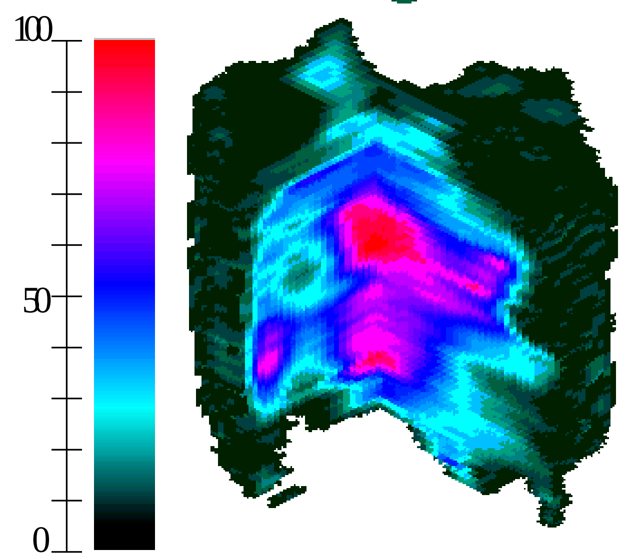
Industrial SPECT tomography (Emission Tomography)

Flow in a T mixer



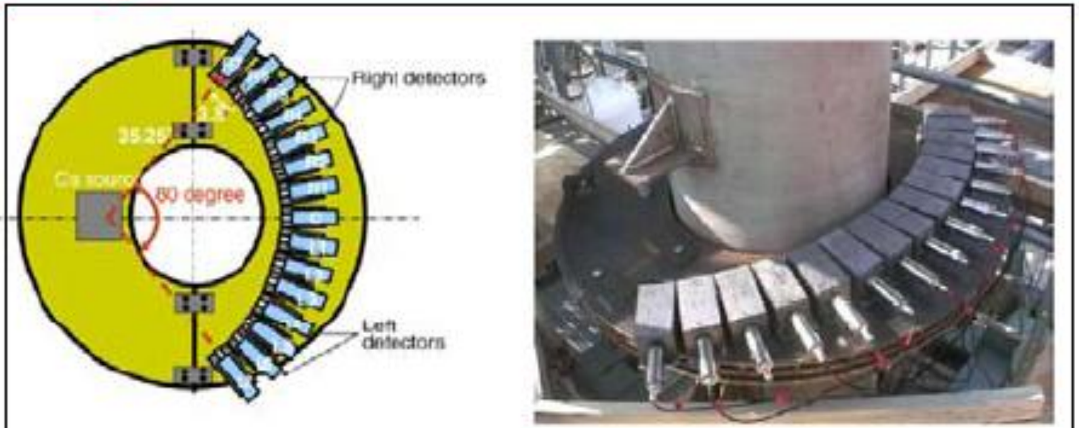




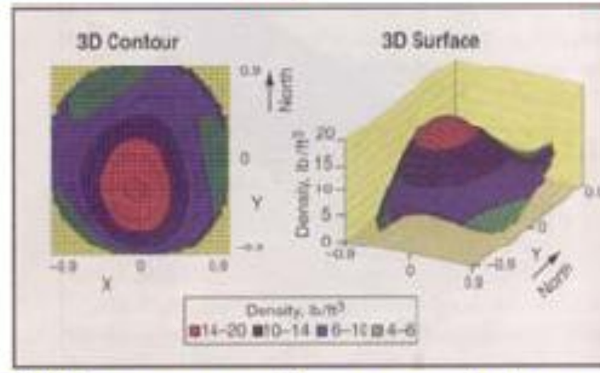


S. Legoupil, cea, Fr

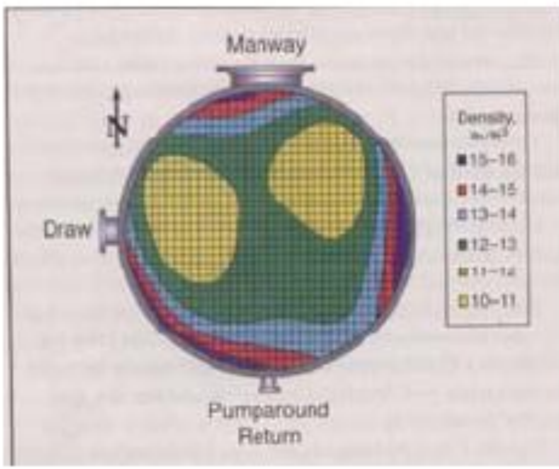
Diagnostics of Maldistribution in Industrial Equipment



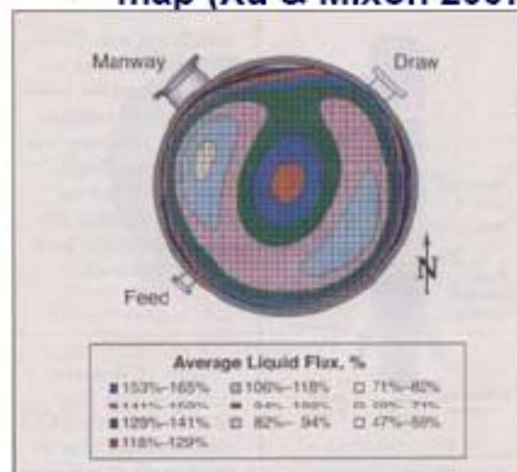
Industrial Tomography Scanner (Al-Dahhan et al. 2007)



CAT-scan results presented as a 3D contour map or 3D surface map (Xu & Mixon 2007)

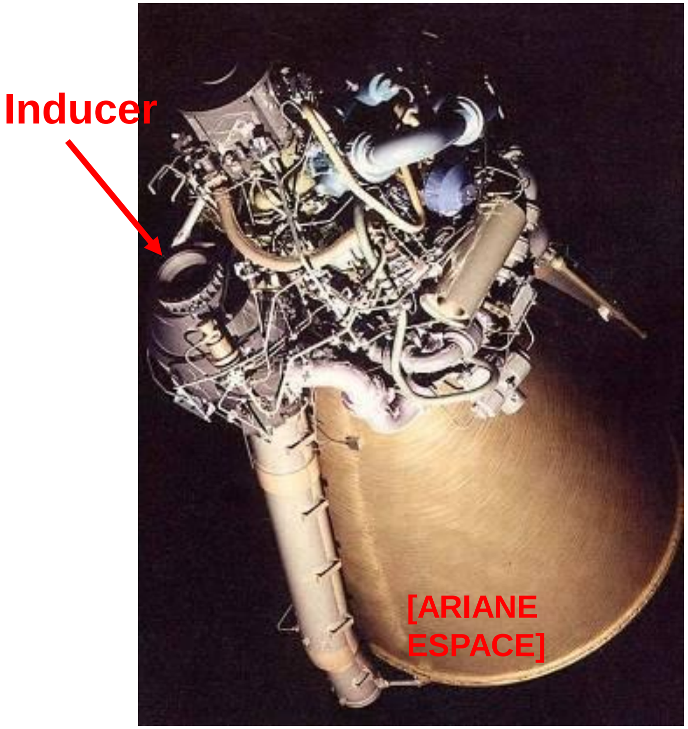


CAT-scan of the top fractionation bed identified two dry spots (Xu & Mixon 2007)



CAT-scan shows more liquid channeling down the center of the revamped packed bed (Xu & Mixon 2007)

- High speed CT for cavitation study



ALL THE NEWS WITHOUT FEAR OR FAVOR

The Japan Times ONLINE

Weekend SCENE ONLINE

KLM

Site Map

Sunday, April 16, 2000

CLASSIFIED ADS | WEEKEND SCENE | SUBSCRIBE | BULLETIN BOARD | SHUKAN ST | WEEKLY | BOOK

SPORTS | LIFE | MOVIES | MUSIC

Printer friendly | E-mail this article.

Advanced search

Bubbles in fuel caused crash of H-II rocket, experts claim

Government investigators looking into the crash of an H-II rocket last November said Friday they have determined that the crash was caused by stress caused to a critical engine pump by bubbles in the rocket's fuel.

Officials of the Space Activities Commission's technical assessment panel say they are compiling a report on the crash and will present it shortly to the government-appointed commission.

- Subscribe

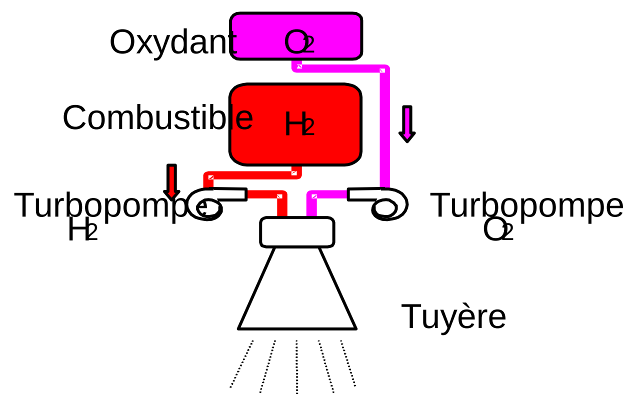
Home
News
Business

Market Moves 5 p.m. Mon. in Tokyo

Yen per dollar
118.04-07 (-0.23 from Fri.)

Nikkei average
14,116.04 (-35.02)

TOPIX
1,480.42 (-14.14)



Validation of CFD codes for H2 et O2 in cavitating flows

S. Legoupil
CEA-France

Cavitating flow imaging

System

- X-ray generator : 160 kV, 30 mA.
- 11 Detectors (NaI) functioning in current mode.

Measurement conditions

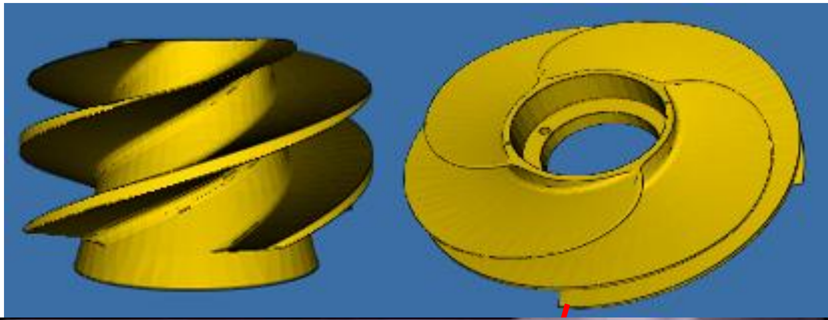
- Cavitation cycles : q/qn = 0.9, 1.0, 1.1.
- Pressure : 1.04 bar → 0.480 bar (10 pts).

Parameters

- Rotation speed: 4000 rpm.
- Angular resolution: 4.8 degrees
- Measurement time: 200 µsec.

0211_0241.mpg

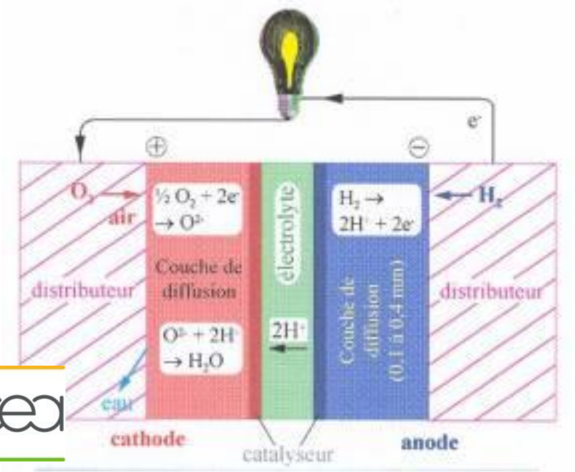
Inducer B22



S. Legoupil
CEA-France

Micro flow imaging

- Nickel foams are used in PEMFC as gaz diffusion layers (O_2 / H_2) :
  - conductor material
  - good surface to volume ratio



- Water condensation in pores
  - head loss increases

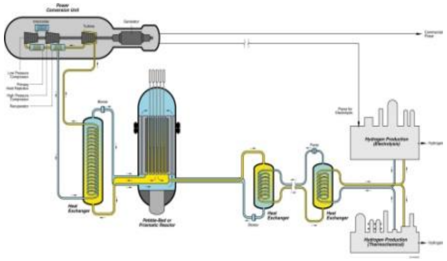
- Necessity to measure fluid fixation vs time

- Nowadays, optical techniques are employed
  - but limitation to obtain a quantitative result
  - not applicable for opaque medias
  - no 3D measurement

- Test and implementation of a X-ray technique

S. Legoupil
CEA-France

Six Generation IV technology concepts

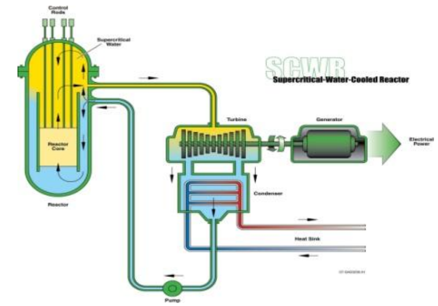


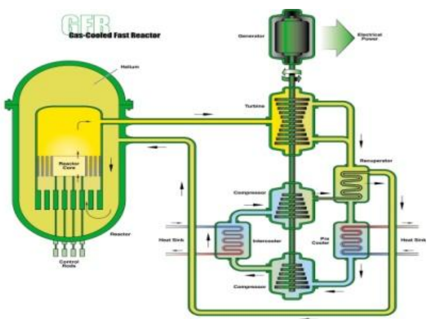
1.Very-High-Temperature Reactor (VHTR):

- graphite-moderated
- helium-cooled
- once-through uranium fuel cycle

2. Supercritical-Water-Cooled Reactor (SCWR):

- high-temperature
- high-pressure water-cooled
- operates above the thermodynamic critical point of water



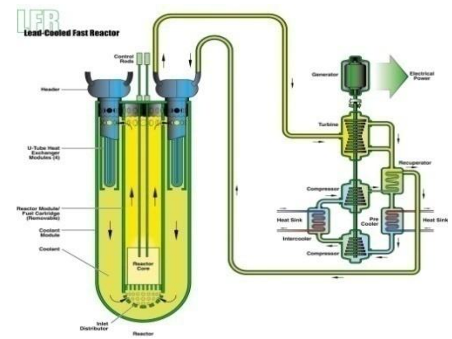


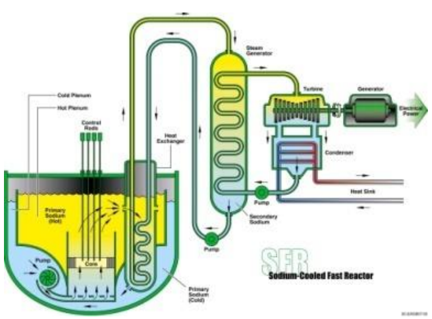
3. Gas-Cooled Fast Reactor (GFR):

- features a fast-neutron-spectrum
- helium-cooled
- closed fuel cycle

4. Lead-Cooled Fast Reactor (LFR):

- features a fast-spectrum lead of lead/bismuth eutectic liquid
- metal-cooled
- closed fuel cycle for efficient conversion of fertile uranium and management of actinides



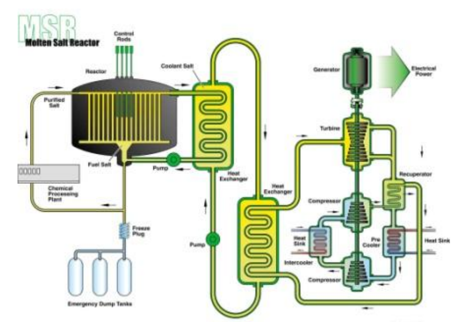


5. Sodium-Cooled Fast Reactor (SFR):

- features a fast-spectrum
- sodium-cooled
- closed fuel cycle for efficient management of actinides and conversion of fertile uranium

6. Molten Salt Reactor (MSR):

- produces fission power in a circulating molten salt fuel mixture
- an epithermal-spectrum reactor
- full actinide recycle fuel cycle



Laboratory for Advancing Multiphase Reaction Engineering

For
Sustainable Energy & Environment

Professor M. Al-Dahhan

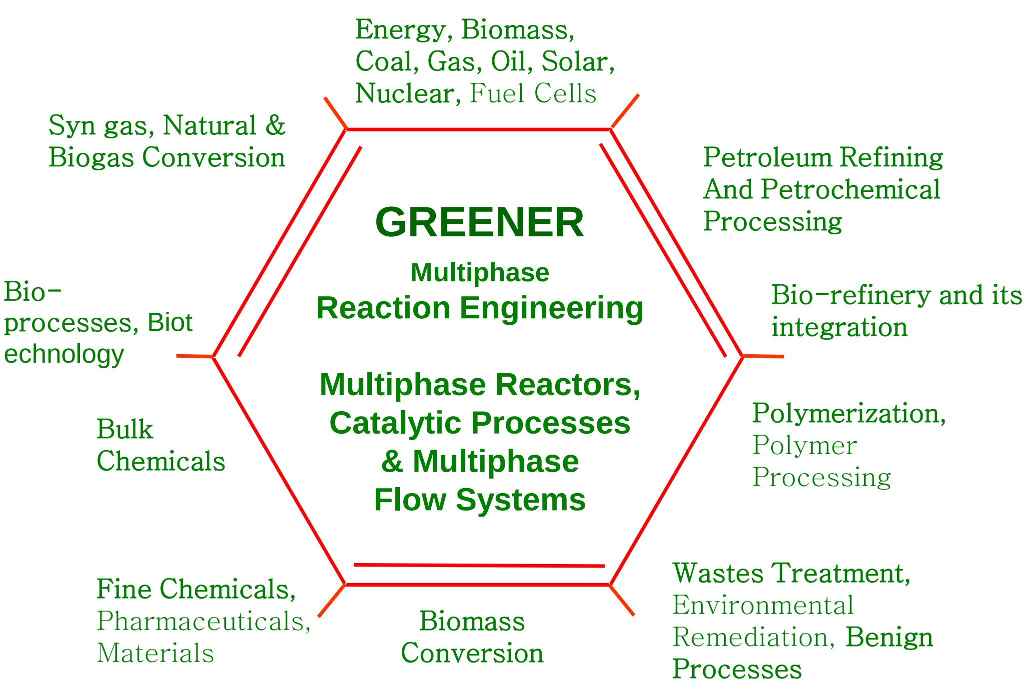
Development & Implementation of Advanced Techniques and Facilities

MRPT, RPT, DSCT, CT, NGD, ECT, Optical Probes, Mass Transfer, Heat Transfer, Gas Dynamics & RTD, Particle/liquid RTD, Conductivity probes, Hot Wire, Room conditions multiphase flow facilities, High ressure and temperature multiphase flow facilities, Kinetics measurement facilities, Mini-Micro reactors, On line measurements, Analytical equipment, etc.

Multi-Scale Modeling & Quantification of Kinetic-transport Interactions

Mechanistic Reactor Scale Models, Apparent and Intrinsic Kinetic Models, ANN, CFD and Closures Evaluation and Development, Integration of Mechanistic models and CFD, etc.

Green & Sustainable Processes



Multiphase Flow systems

- BUBBLE COLUMN (GAS-LIQUID INTERACTION)
- SLURRY BUBBLE COLUMN (GAS-LIQUID-FINE SOLIDS INTERACTION)
- GAS-SOLID FLUIDIZATION & CIRCULATING FLUIDIZATION (GAS-SOLIDS INTERACTION)
- LIQUID-SOLID RISER AND FLUIDIZATION (LIQUID-SOLIDS INTERACTION)
- EBULLATED BED (GAS-LIQUID-CATALYST SOLIDS INTERACTION)
- PACKED BEDS AND STRUCTURED PACKING/MONOLITH BEDS (GAS-SOLIDS, LIQUID-SOLIDS AND GAS-LIQUID-SOLIDS INTERACTIONS)
- STIRRED TANKS (GAS-LIQUID, LIQUID-SOLIDS AND GAS-LIQUID-SOLIDS INTERACTIONS)
- AIRLIFT COLUMNS (GAS-LIQUID AND GAS-LIUQID-SOLIDS INTERACTIONS)
- BIOREACTORS, DIGESTERS
- ETC.

Remarks

- While significant progress on nuclear technology applications in research and industry, further development and advancement are still needed
- Improving both temporal (dynamic) and spatial resolutions are needed
- Hybrid techniques that combine both nuclear technology and non-nuclear techniques are recommended to be developed and implemented to obtain more information
- Continuing development on overcoming the limitations of nuclear technology in industry is required

Thank You