International Atomic Energy Agency

Project 2.5.2.1
Radioisotopes Applications in Industry

Patrick BRISSET

Radiosotopes Products and Radiation Technologies Section, NAPC

Department of Nuclear Sciences and Applications

Presentation by Dr Rubens MOREIRA, CDTN

IAEA

International Atomic Energy Agency

Promotion of Nuclear Technology by IAEA

Objectives of the Project

To strengthen the national capabilities of developing MSs:

- to effectively use radioisotope and radiation techniques,
- for supporting cleaner and safer industrial process management.

Technologies for the Project

- Radiotracer
- Sealed Source
- Nucleonic Control System
- Non Destructive Testing

IAEA

IMPLEMENTATION OF THE PROJECT

Coordination of Research & Development

- 4 Coordinated Research Projects
- 10 Technical Meetings
- 3 Conferences
- 17 IAEA Publications

Supporting Technical Cooperation

- 14 Regional TC Projects since 2000
- 30 National TC Projects since 2000

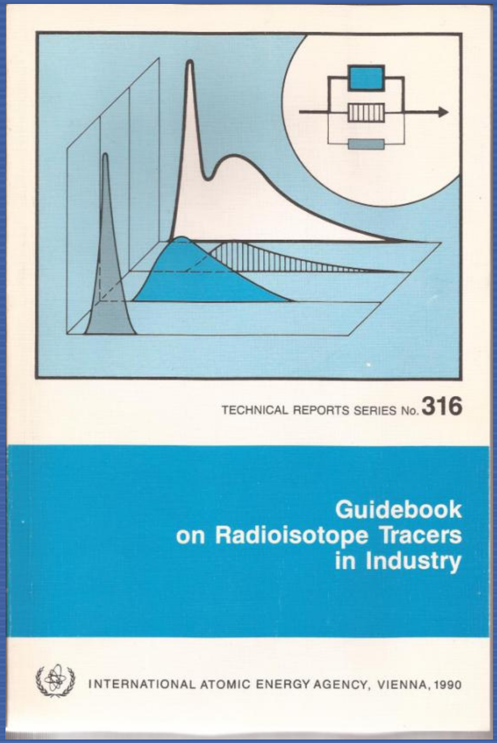
CRPs on Radiotracer Technology since 2000

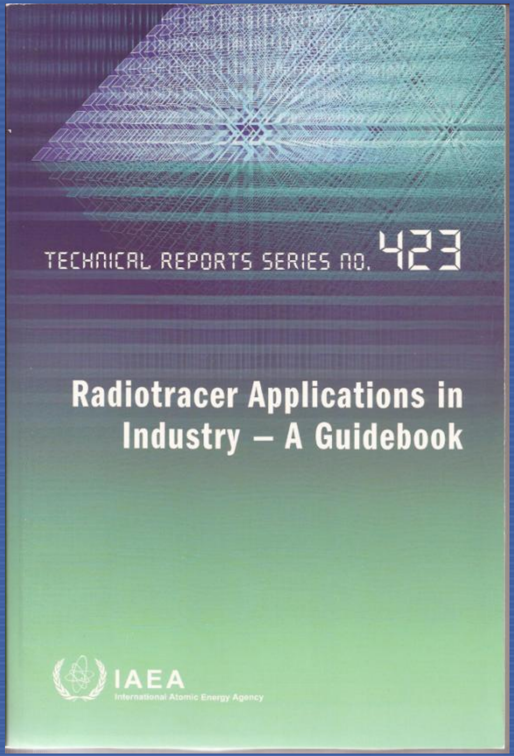
(5 Finished:, 1 On-going)

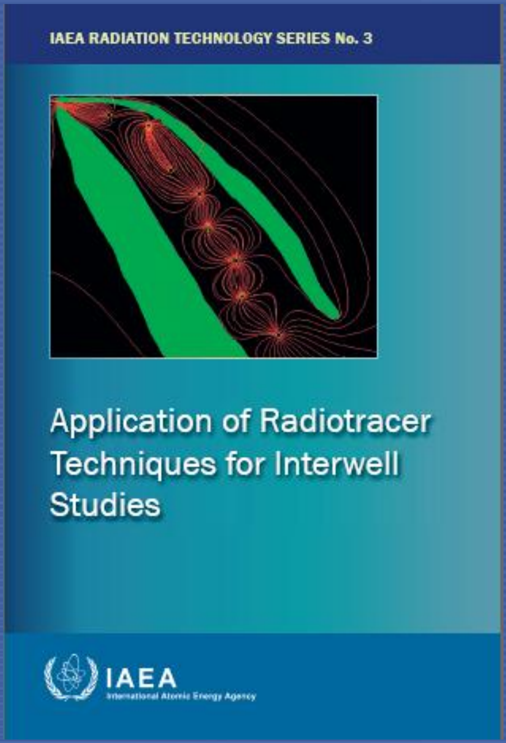
- Integration of RTD Tracing with CFD Simulation for Industrial Process Visualization and Optimization *(2001 -2003)*
- Industrial Process Gamma Tomography *(2003-2006)*
- Validation of Tracers and Software for Inter-well Investigations *(2004-2008)*
- Evaluation and validation of radionuclide generator-based radiotracers for industrial applications *(2007-2011)*
- Radiometric methods for measuring and modelling multiphase systems towards industrial processes (2012- 2015)

IAEA

IAEA Main Publications on Radiotracer & Sealed Source Technology

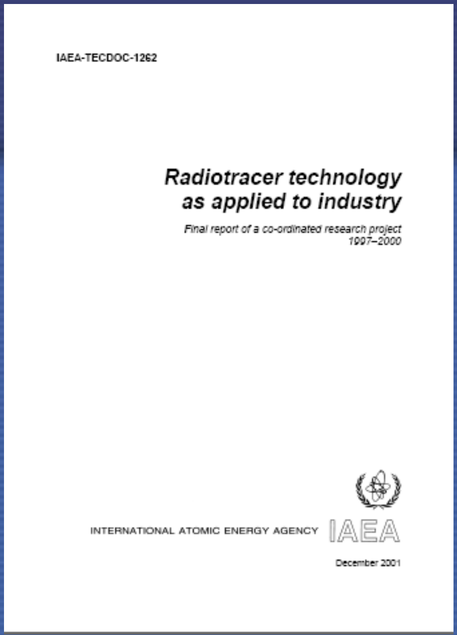


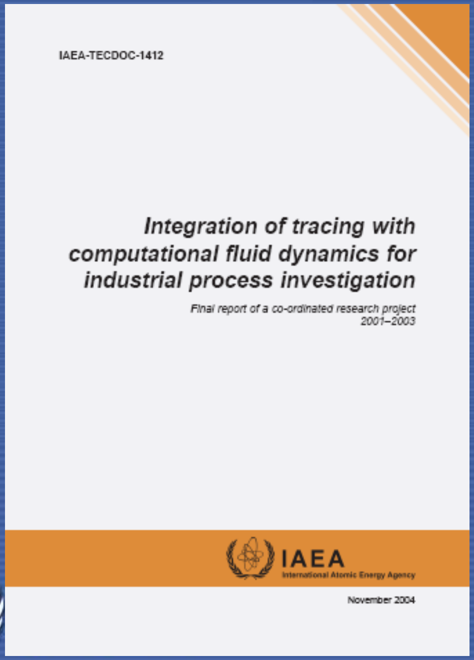


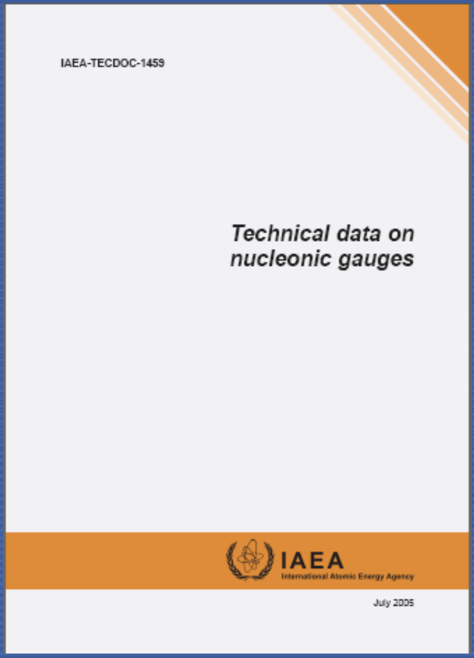


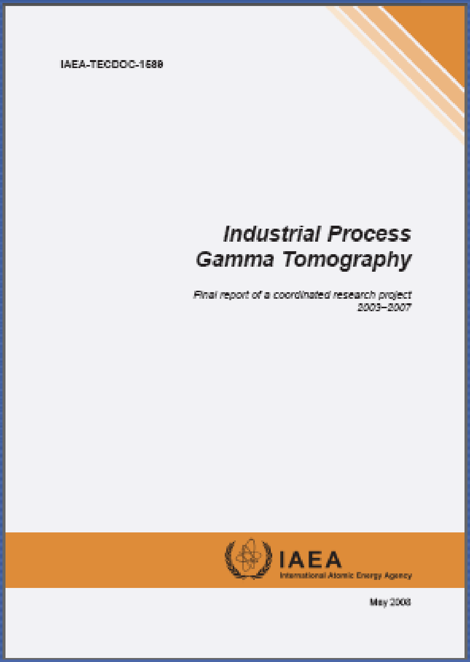
IAEA

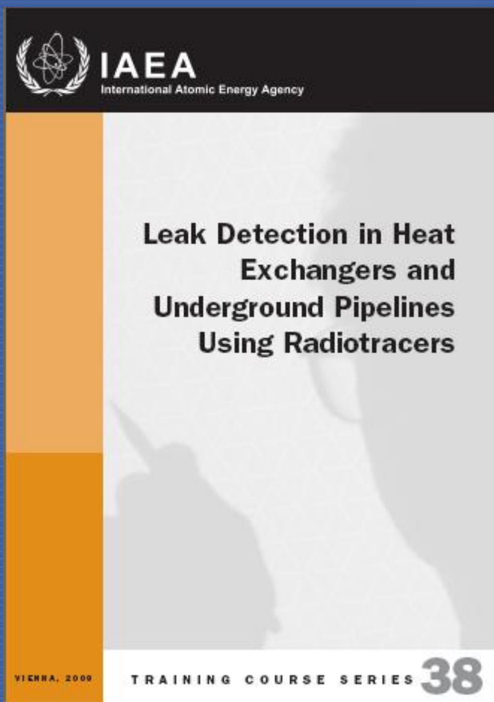

IAEA-TECDOC-1142
Emerging new applications of nucleonic control systems in industry
Report of an Advisory Group meeting held in Vienna, 5–8 May 1998
INTERNATIONAL ATOMIC ENERGY AGENCY
IAEA
March 2000

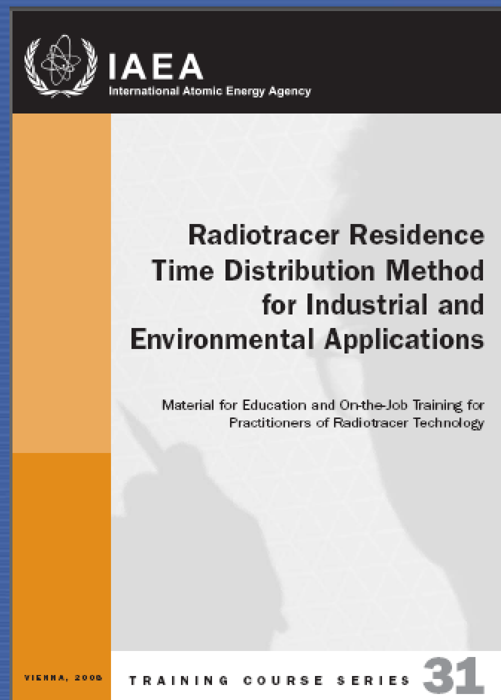

IAEA-TECDOC-1262
Radiotracer technology as applied to industry
Final report of a co-ordinated research project 1997–2000
INTERNATIONAL ATOMIC ENERGY AGENCY
IAEA
December 2001

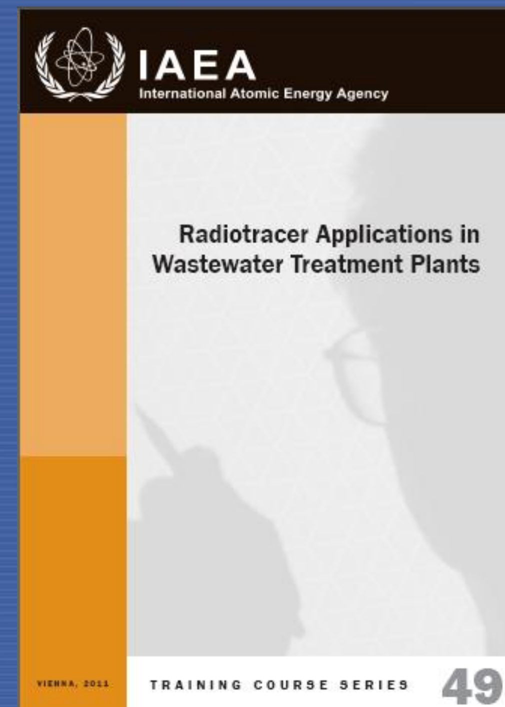

IAEA-TECDOC-1412
Integration of tracing with computational fluid dynamics for industrial process investigation
Final report of a co-ordinated research project 2001–2003
IAEA
International Atomic Energy Agency
November 2004


IAEA-TECDOC-1459
Technical data on nucleonic gauges
IAEA
International Atomic Energy Agency
July 2005

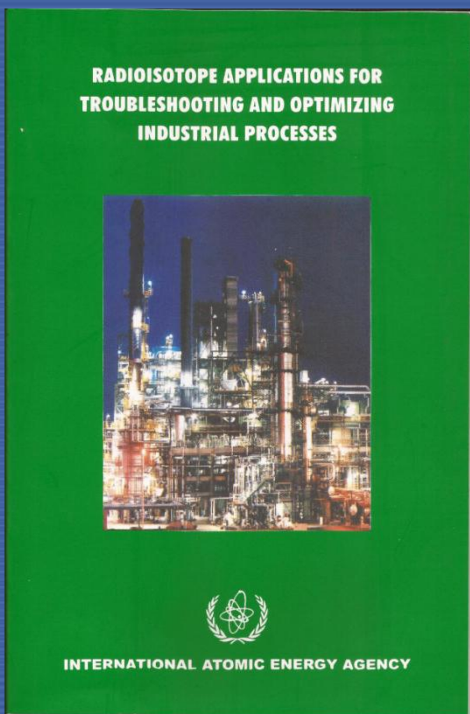

IAEA-TECDOC-1589
Industrial Process Gamma Tomography
Final report of a coordinated research project 2003–2007
IAEA
International Atomic Energy Agency
May 2008

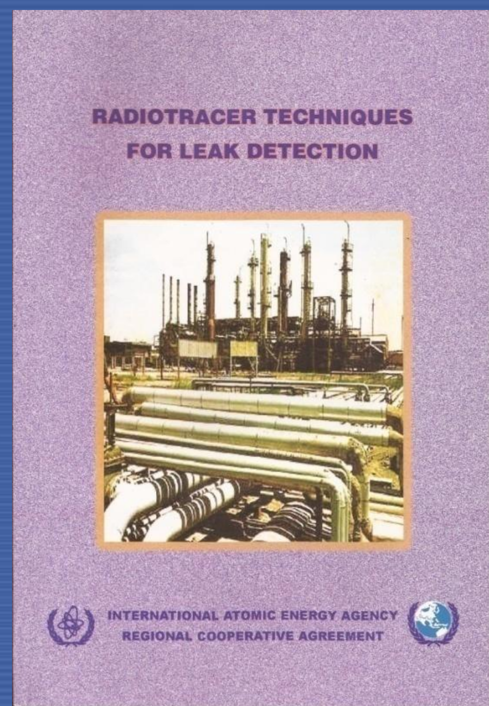

IAEA
International Atomic Energy Agency
Leak Detection in Heat Exchangers and Underground Pipelines Using Radiotracers
TRAINING COURSE SERIES 38

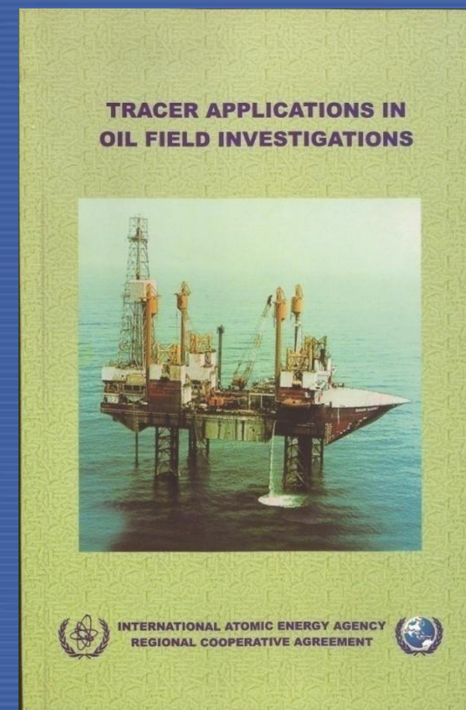

IAEA
International Atomic Energy Agency
Radiotracer Residence Time Distribution Method for Industrial and Environmental Applications
Material for Education and On-the-Job Training for Practitioners of Radiotracer Technology
TRAINING COURSE SERIES 31


IAEA
International Atomic Energy Agency
Radiotracer Applications in Wastewater Treatment Plants
TRAINING COURSE SERIES 49

IAEA


RADIOISOTOPE APPLICATIONS FOR
TROUBLESHOOTING AND OPTIMIZING
INDUSTRIAL PROCESSES
INTERNATIONAL ATOMIC ENERGY AGENCY


RADIOTRACER TECHNIQUES
FOR LEAK DETECTION
INTERNATIONAL ATOMIC ENERGY AGENCY
REGIONAL COOPERATIVE AGREEMENT


TRACER APPLICATIONS IN
OIL FIELD INVESTIGATIONS
INTERNATIONAL ATOMIC ENERGY AGENCY
REGIONAL COOPERATIVE AGREEMENT

Trends in Radiosiotopes applications

1. Technical trends
   - Tracers technologies
   - NCS technologies
   - Imaging technologies
2. Standards, protocols, good practices
3. Training and certification, International Society

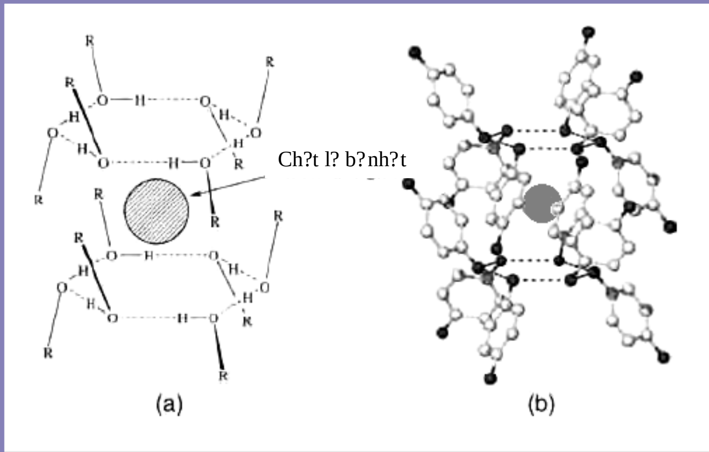
IAEA

Topic 1 : Conventional tracers but new methods of production

Developments in CANTI - Vietnam

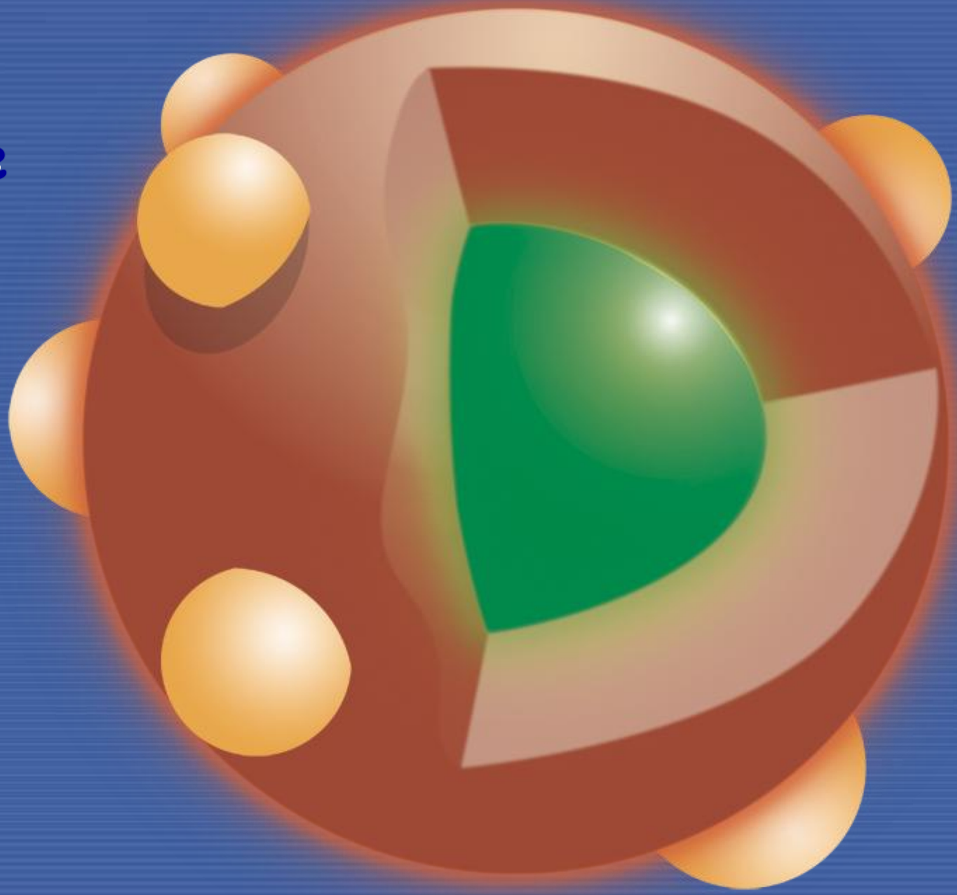
- Ar-41 produced by **hydroquinol clathrate**
  - Ar inside Molecular Cage of Hydroquinol $(C_6H_4(OH)_2)3.xAr$ – 1,4 dihydroxybenzen
  - Ar saturation solution with hydroquinol
  - Allow to form the crystal of β – structure to keep Ar inside the cage.
  - Drying hydroquinol
  - Melting temperature: 170^0C.
  - Ar starts release at 135^0C.
  - Ar can stay in clathrate long time.

Next : Krypton 79



Topic 2: Nanoparticle tracers
Objective : high selectivity and stability of the tracer

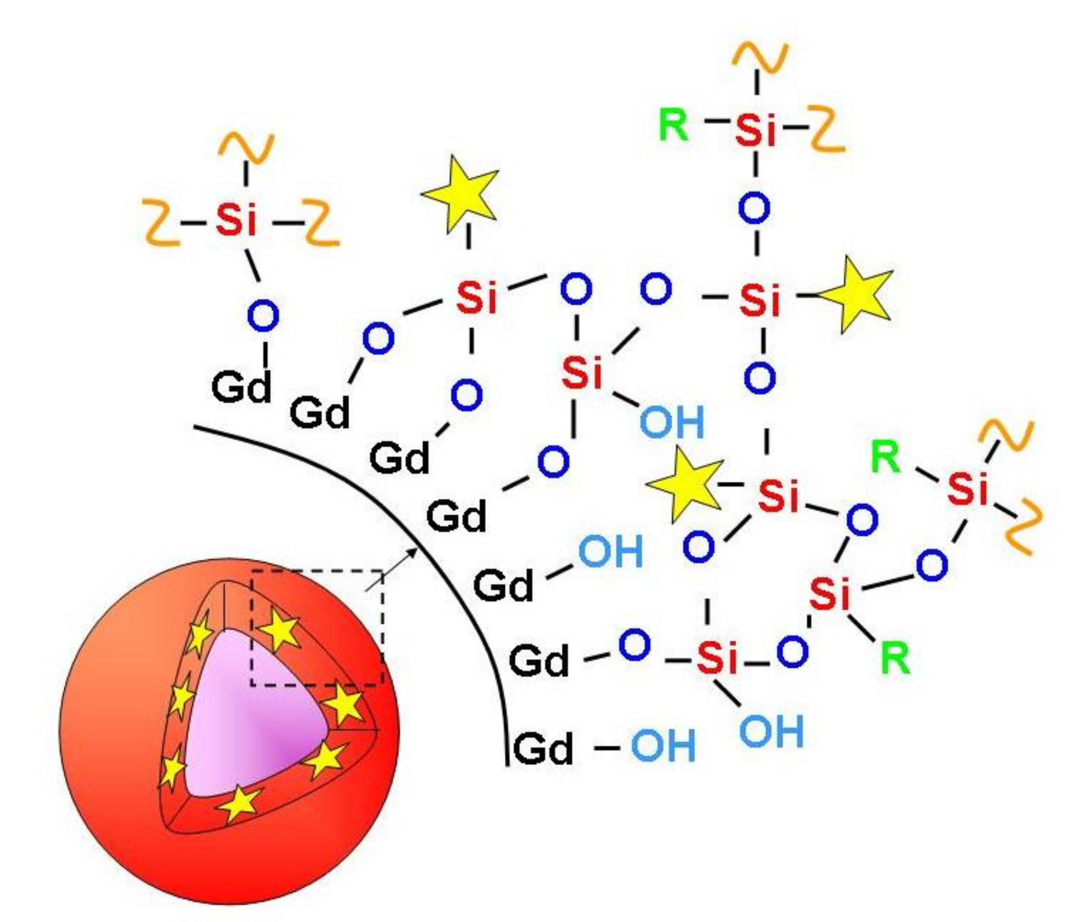
Principle structure of nano-particle with inner core and functionalized surface layer



From T. Bjornstadt IFE Norway

Functionalized particle surfaces

Nanoparticle with Gd_2O_3-core and siloxane surface coating which again is functionalized with additional molecules

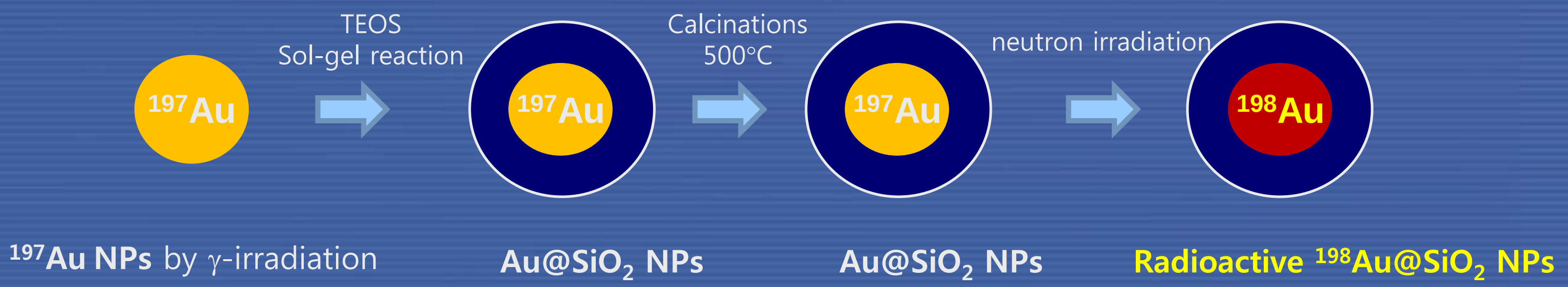


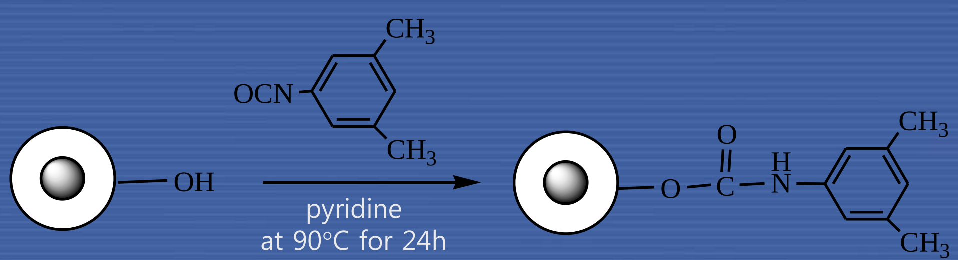
From T. Bjornstadt IFE Norway

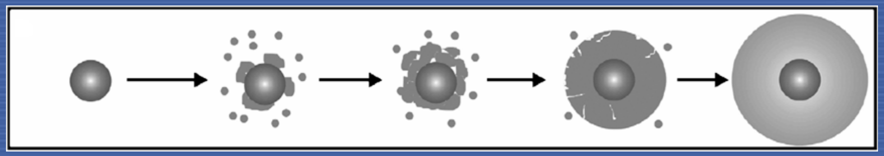
Tracers technologies – nanoparticle tracers

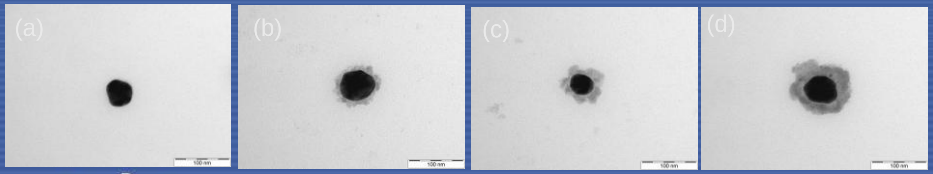
Objective : high selectivity and stability of the tracer

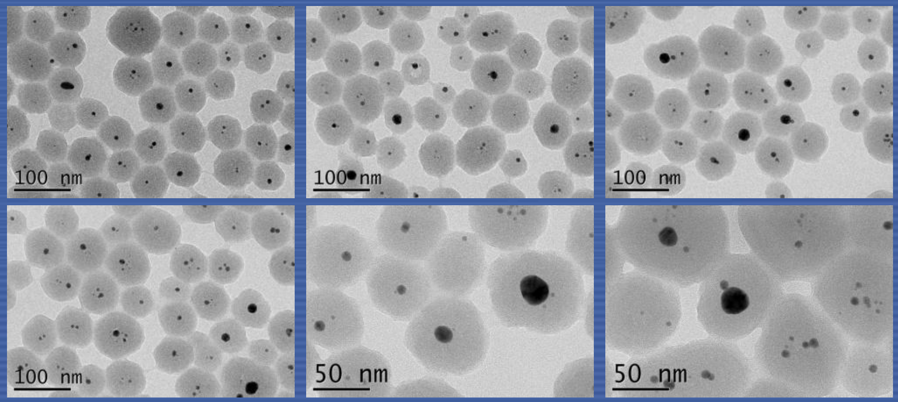
Developments in KAERI- Korea









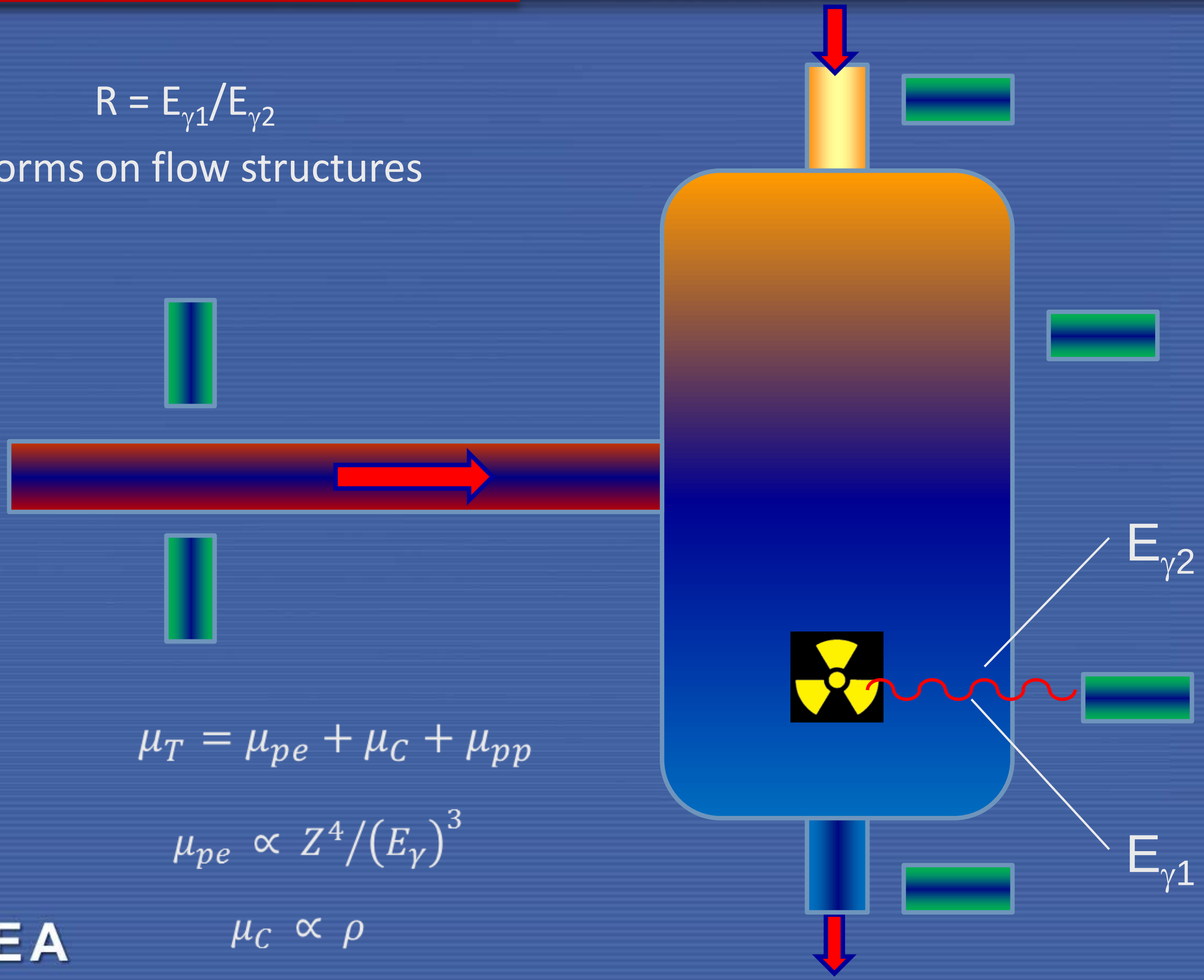


Sung-Hee Jung et al., 2010, Preparation of radioactive core-shell type $^{198}Au@SiO_2$ nanoparticles as a radiotracer for industrial process applications. Applied Radiation and Isotopes 68, 1025-1029.

Topic 4: Multi-gamma RTD with full spectroscopy information, including the Comptons scaterring

$R = E_{\gamma 1}/E_{\gamma 2}$

informs on flow structures



$$\mu_T = \mu_{pe} + \mu_C + \mu_{pp}$$

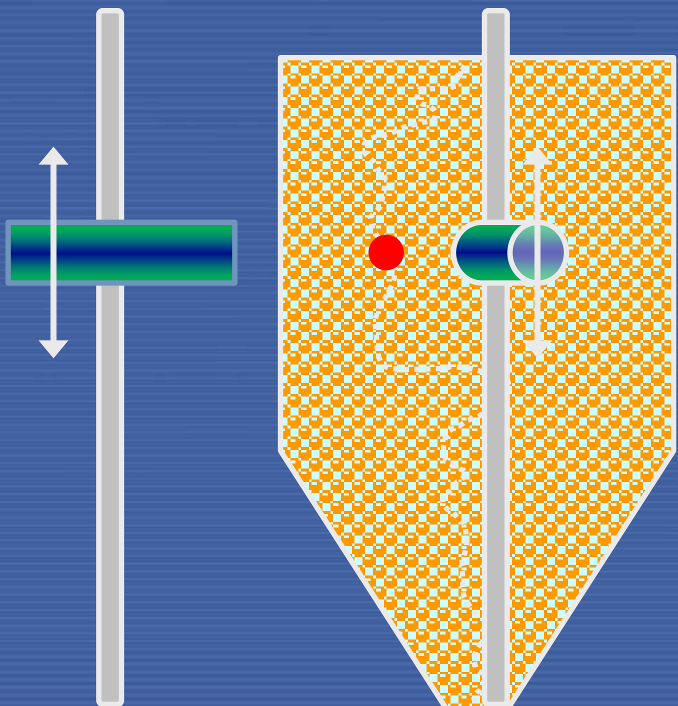
$$\mu_{pe} \propto Z^4/(E_\gamma)^3$$

$$\mu_C \propto \rho$$

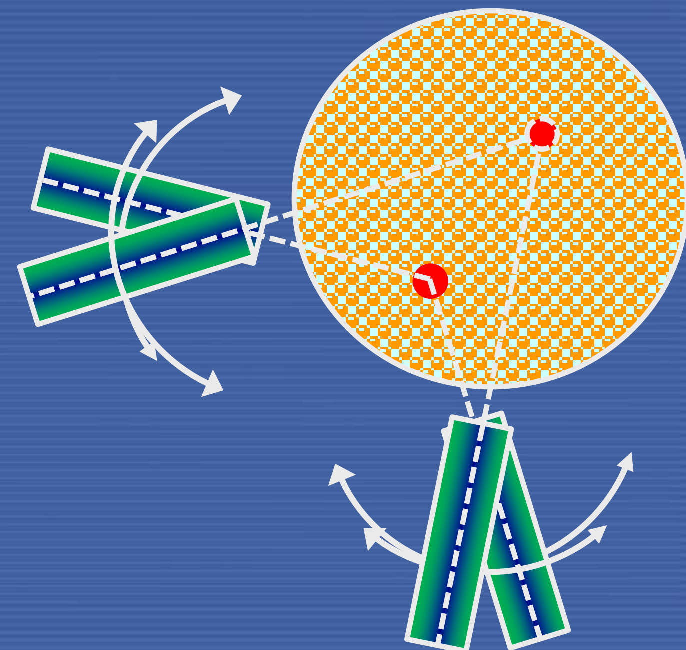
IAEA

Angle and height optimization of detector response

Vertical position

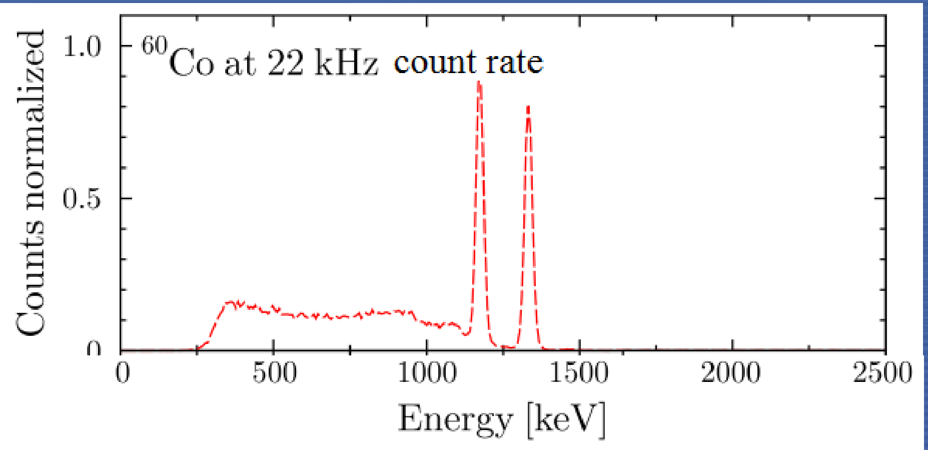


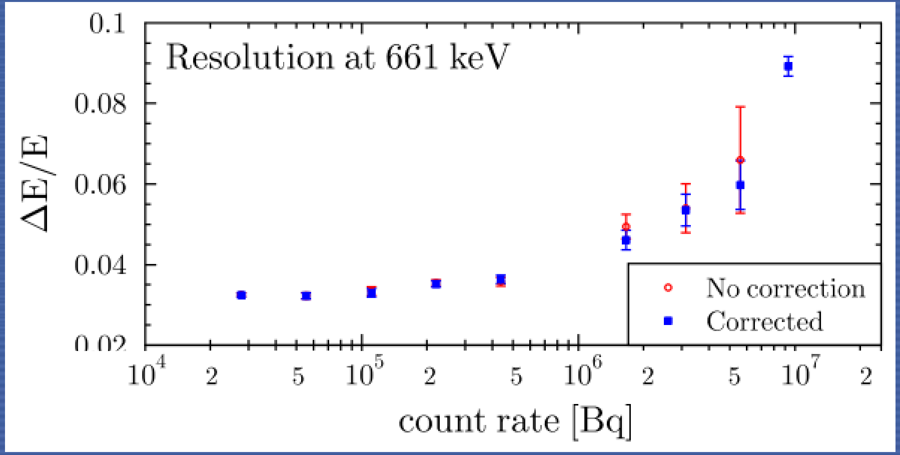
Horizontal position



$LaBr_3$(Ce)-detectors

- Approximately half the FWHM of comparable sized NaI(Tl) detectors above 350 keV
- Higher efficiency than similarly sized NaI(Tl) detectors – 1.2-1.65 times above 350 keV
- Fast emission, excellent temperature and linearity characteristics
- Directly compatible with traditional scintillation detector electronics and multi-channel analyzers





Topic 5: On-site activation of short half-life radionuclides

Radiotracers of industrial interest are more and more dificult to obtain because of the lack of research reactors.
Administrative rules.
Thus the idea is to study the possibility for tracer teams to produce tracer on-site

- Examples are:
  - **81Br-** + n_{th} $\rightarrow$ ^{82}**Br**$^{-}$
  - ^{59}**Co**$(CN)_6^{3-}$ + n_{th} $\rightarrow$ ^{60}**Co**$(CN)_6^{3-}$
  - ^{45}**Sc**-$EDTA^{-}$ + n_{th} $\rightarrow$ ^{46}**Sc**-$EDTA^{-}$
  - ^{50}**Cr**-$EDTA^{-}$ + n_{th} $\rightarrow$ ^{51}**Cr**-$EDTA^{-}$
  - ^{139}**La**-$DOTP^{-}$ + n_{th} $\rightarrow$ ^{140}**La**-$DOTP^{-}$
  - ^{16}**O** (in H_2O) + $n_{14\ MeV}$ $\rightarrow$ ^{16}**N**

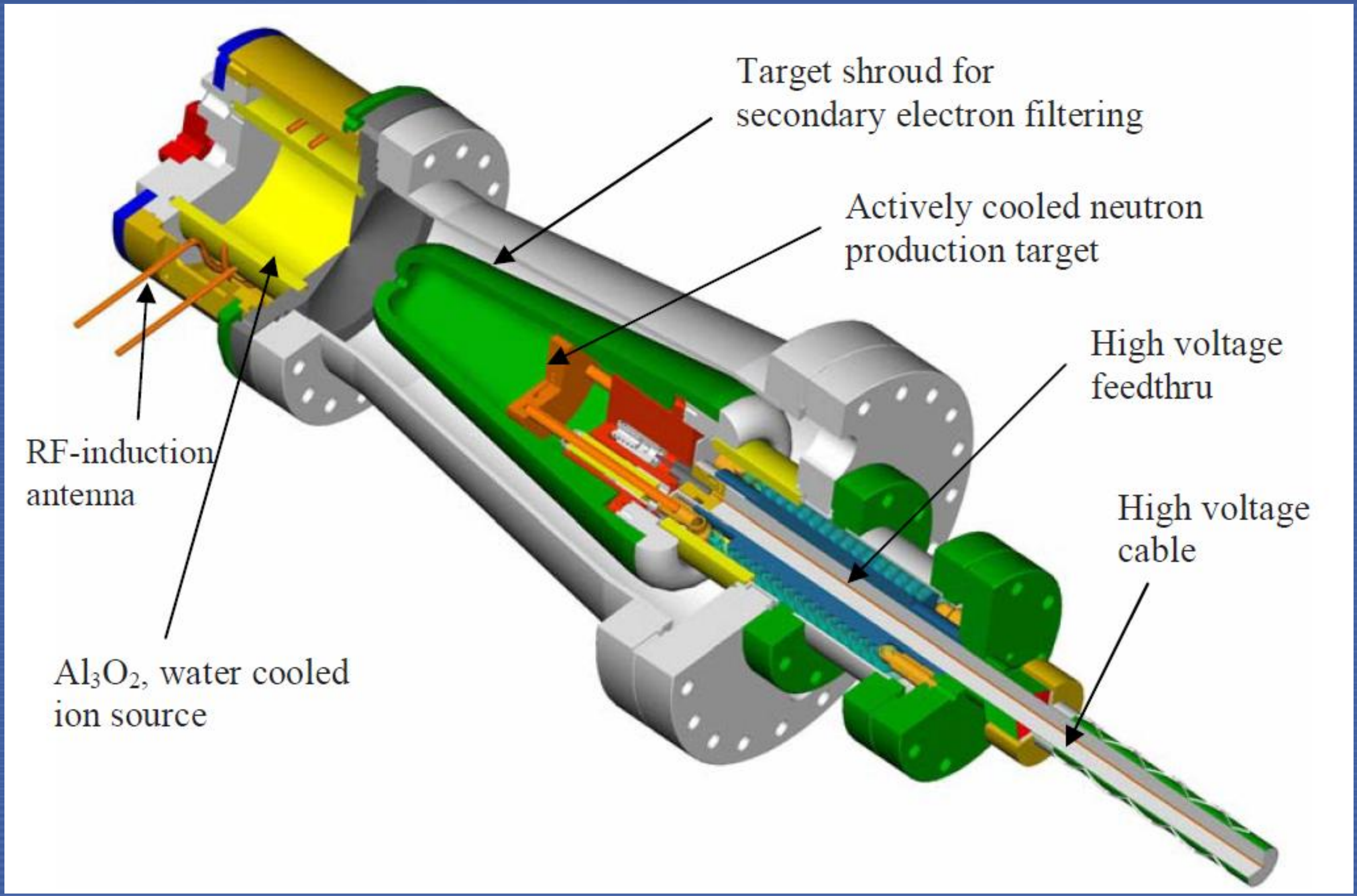
IAEA

Neutron generators

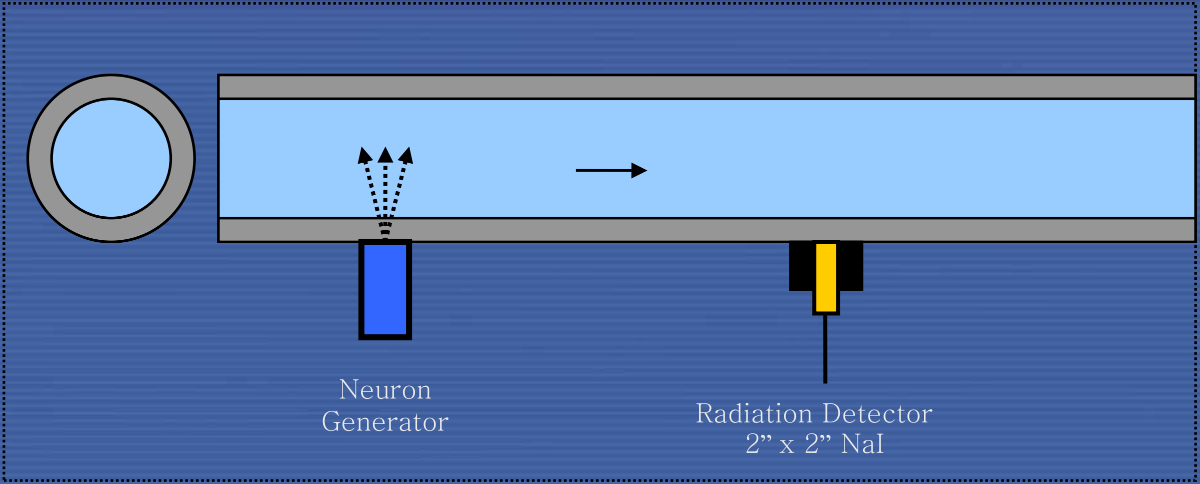
- Small neutron generators using the deuterium (D) and tritium (T) fusion reactions.
- Neutrons are produced by creating ions of D, T, or D + T and accelerating these into a hydride target loaded with D, T, or D + T.
- The DT reaction is used more than the DD reaction because the yield of the DT reaction is 50–100 times higher than that of the DD reaction.
  - $D + T \rightarrow n + {}^{4}He$ $E_n = 14.1$ MeV
  - $D + D \rightarrow n + {}^{3}He$ $E_n = 2.5$ MeV

IAEA

DT neutron generator design



Idea 1 : Direct activation of water in process



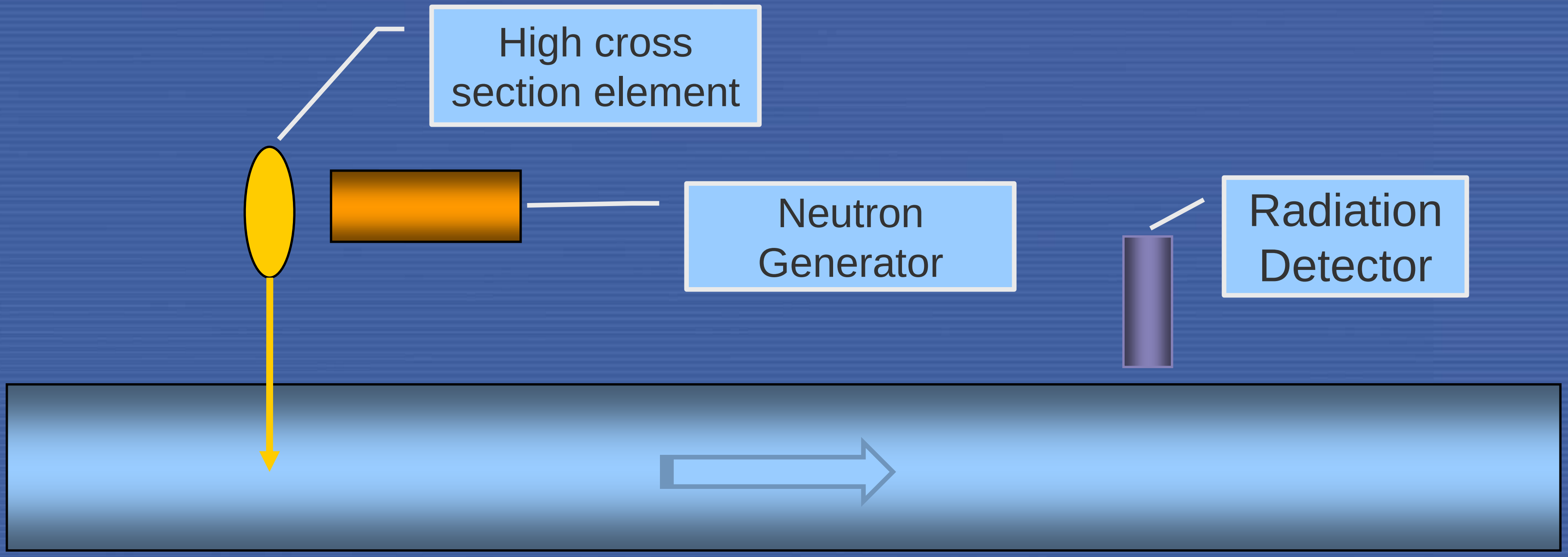
- Steel Pipe dia.: 30 cm, Wall thickness: 0.5 cm
- Fluid: water (O), Velocity: 6 or 60 m/min
- Neutron Generator: D-T,
  - Pulse=10 ns,
  - Flux= 10^{10} n/pulse
- Detector: 2" x 2" NaI(Tl)

- Simulation with MOCA code
  - Oxygen activation: ^{16}O (n,p) ^{16}N
  - Gamma ray emitted: 510 keV
  - Half life: 7.73 sec.

- Result: The expected radiation count measured by the detector is 14300 or 1430 impulses according as the velocity is 6 or 60 m/min.

Simulations : J.H. Jin

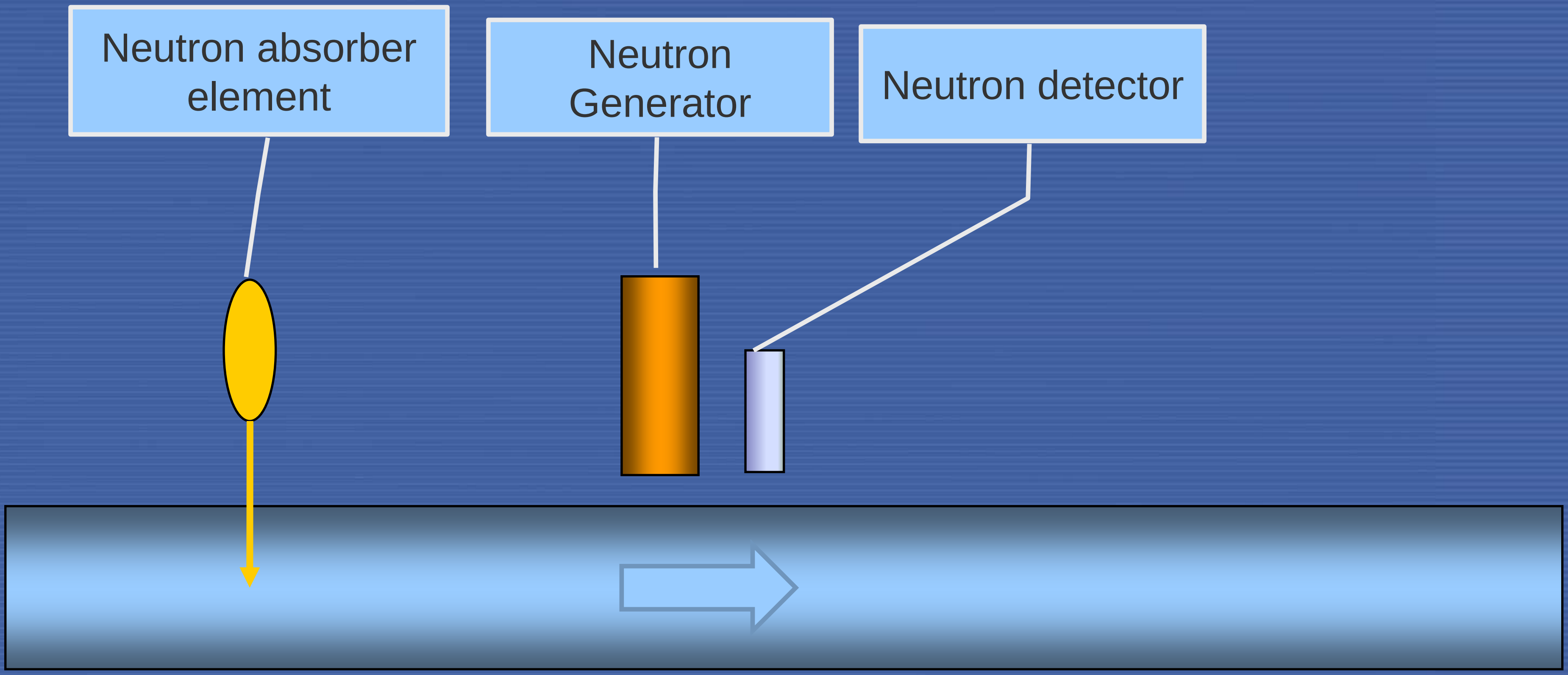
Idea 2 : Activation prior to injection



Idea 3 :

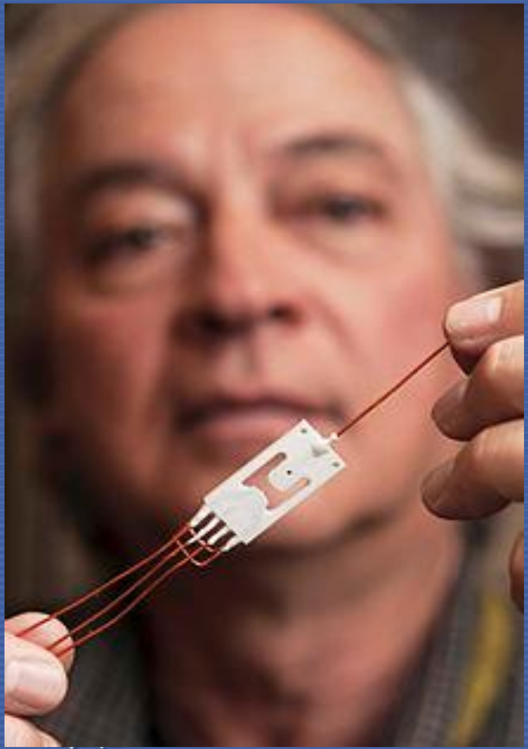
- Injection of an activable tracer in the pipe
- then activation within the pipe as described in Idea 1

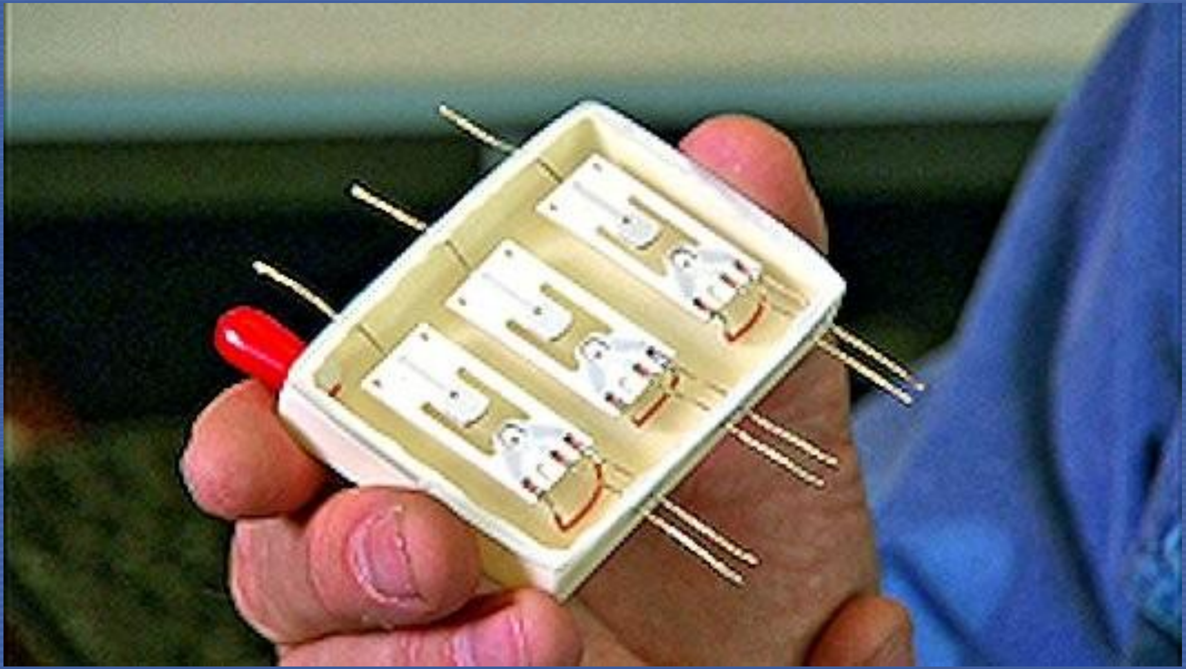
Idea 4 : Concentration measurement by neutron backscatter

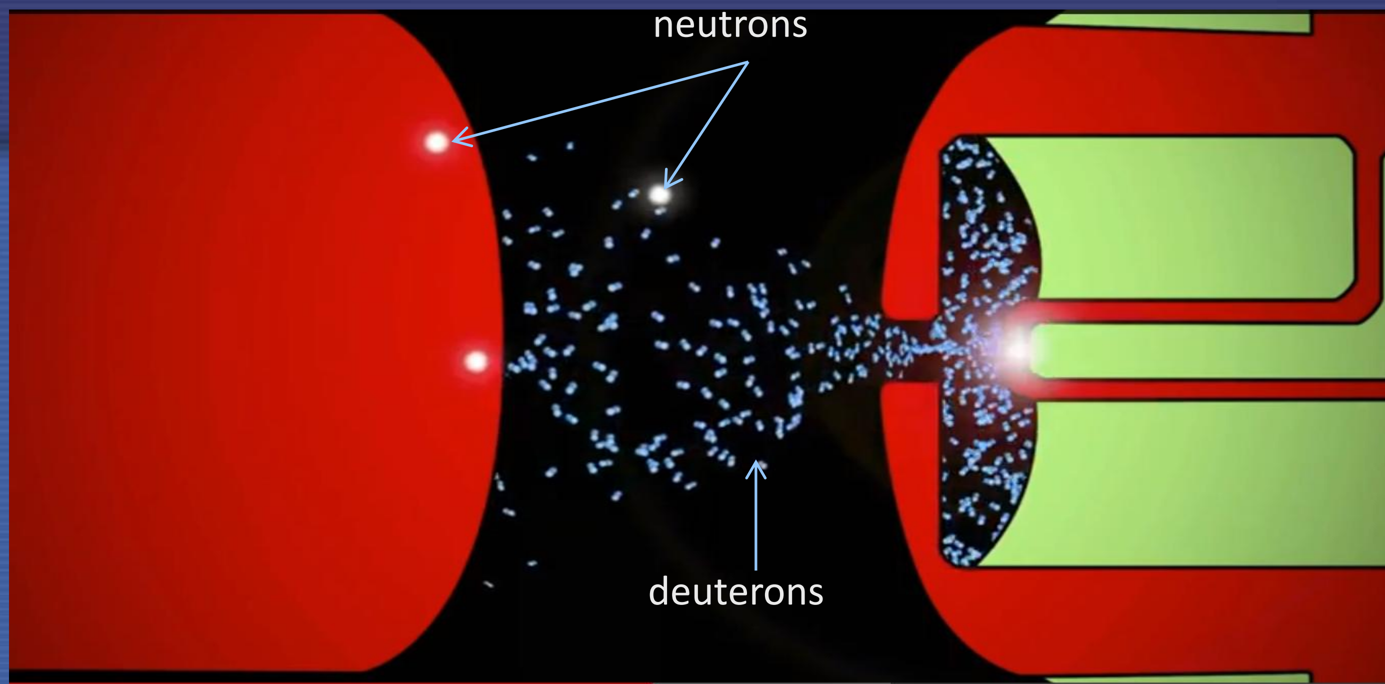


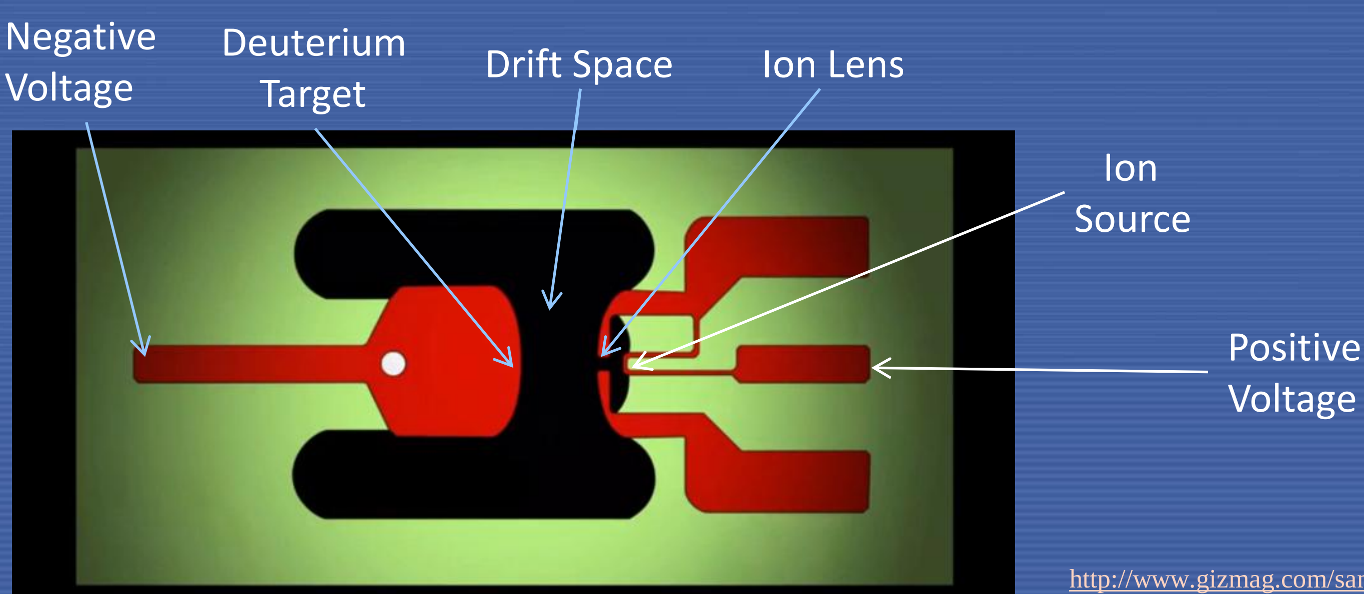
IAEA

Developments in neutron generators





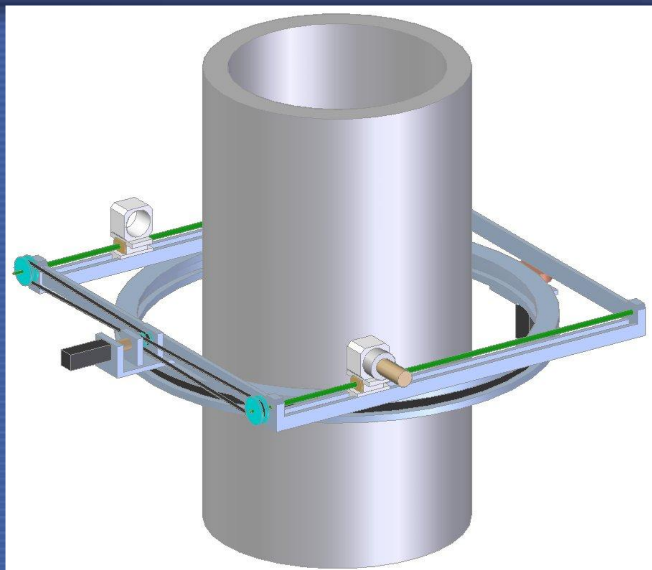


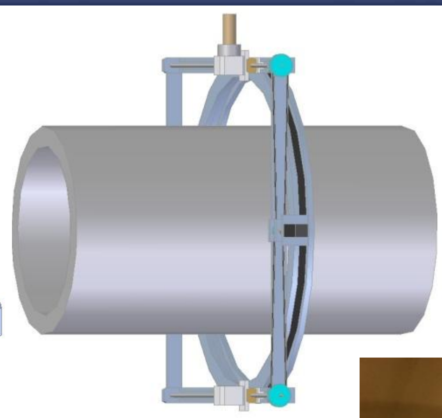


http://www.gizmag.com/sandia-neutristor-neutron-generator-chip/23856

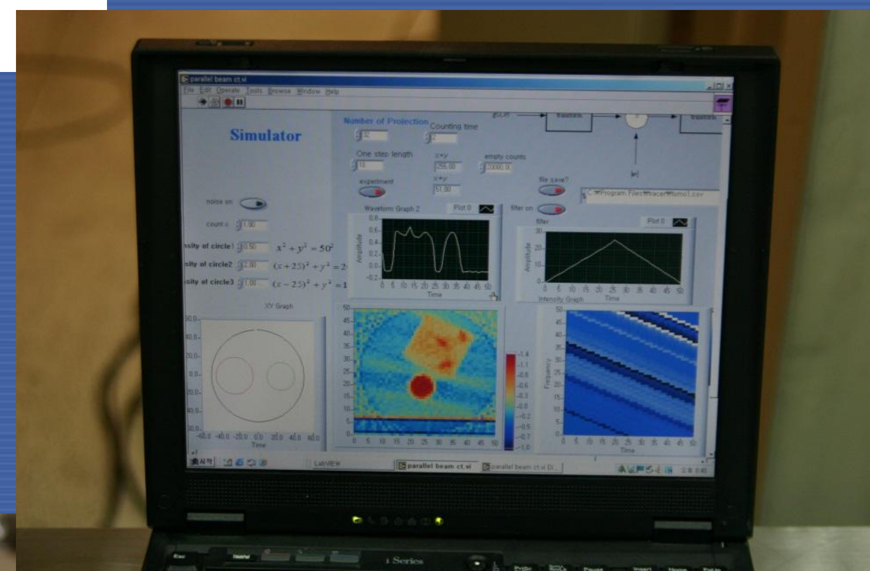
Topic 6 : Imaging technologies

Industrial Process Gamma Tomography : generation 1 portable low-cost

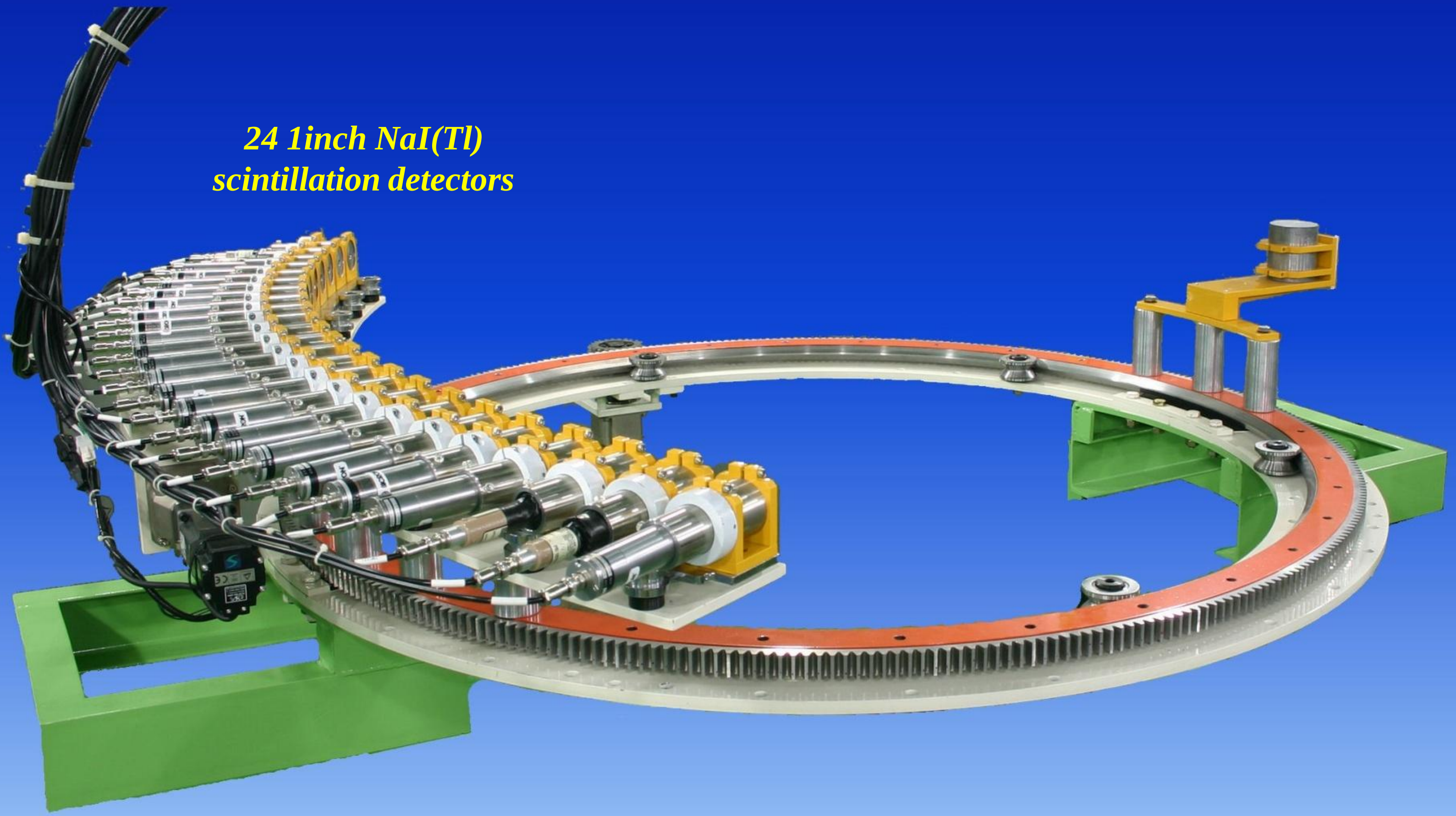




Korea, Malaysia, Vietnam



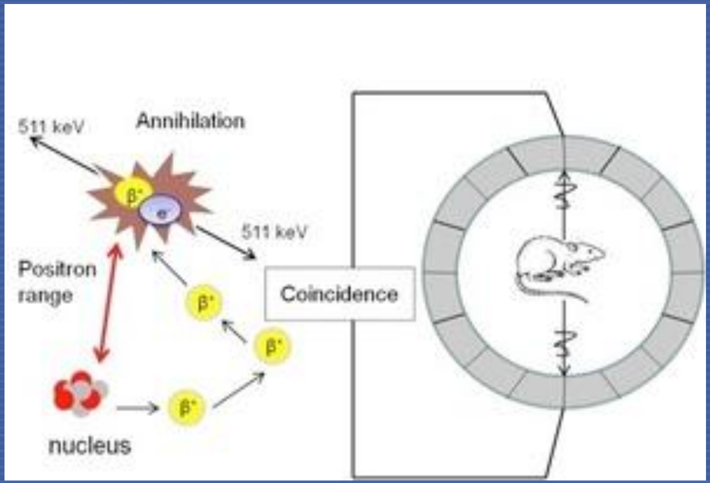
Industrial Process Diagnosis Gamma Tomography

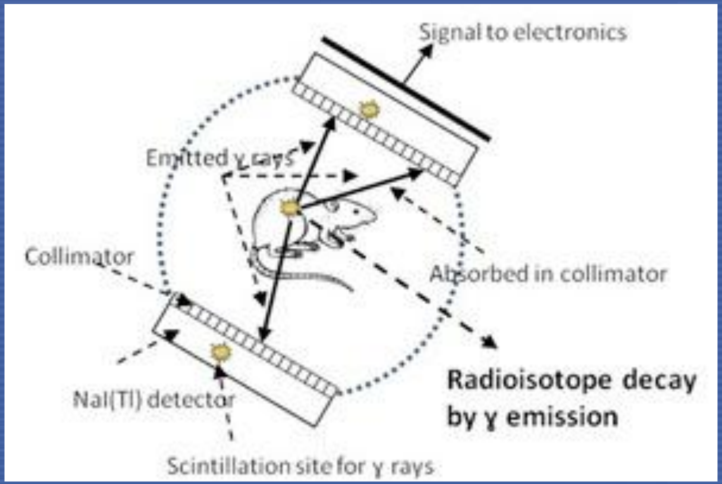


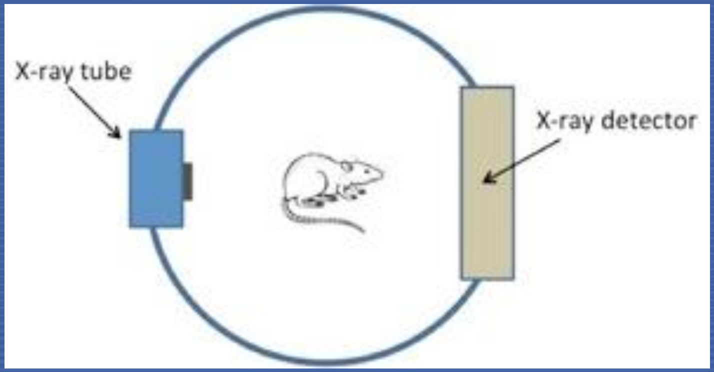
24 1inch NaI(Tl)
scintillation detectors

Korea, India, France, Malaysia, etc…

- **PET, SPECT, CT, CARPT**





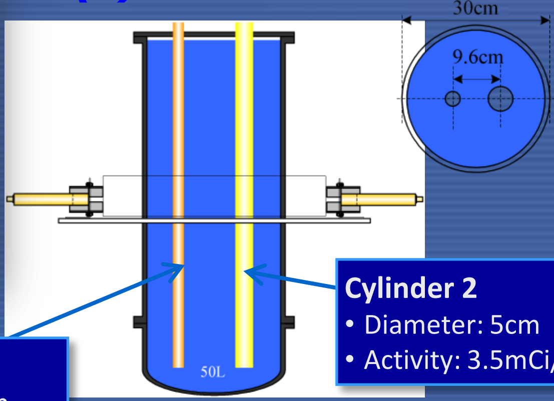


IAEA

Industrial SPECT for tracer distribution measurement

RI injection for dynamic flow

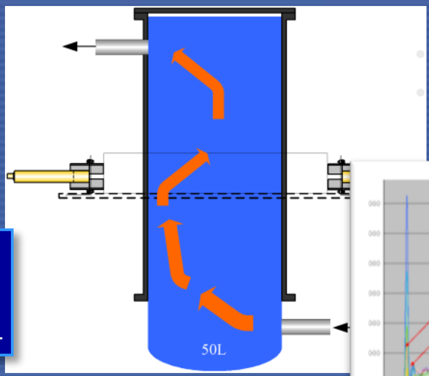
(1) Static condition



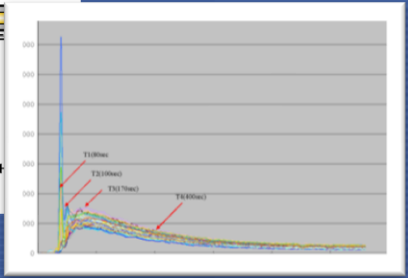
Cylinder 1
- Diameter: 3cm
- Activity: 10.3mCi/L

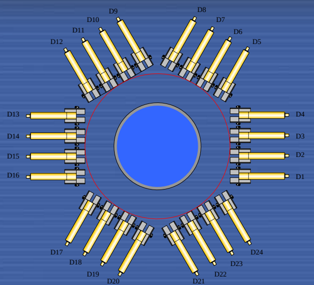
Cylinder 2
- Diameter: 5cm
- Activity: 3.5mCi/L

(2) Flow condition

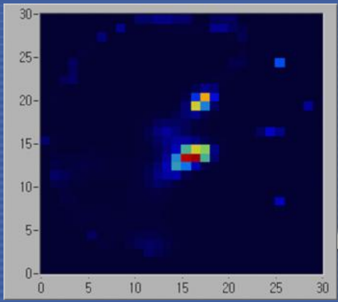


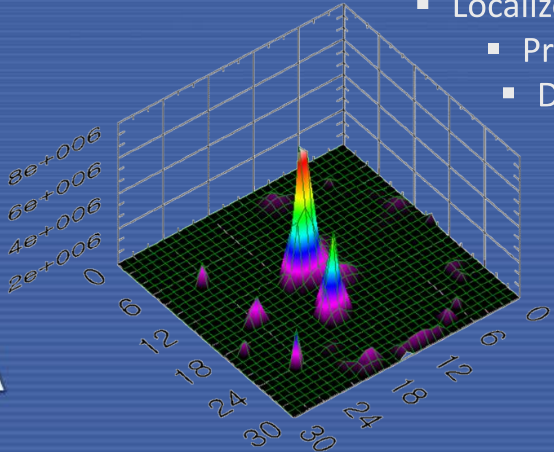
Flow rate: 6 L/min
Activity: 21mCi

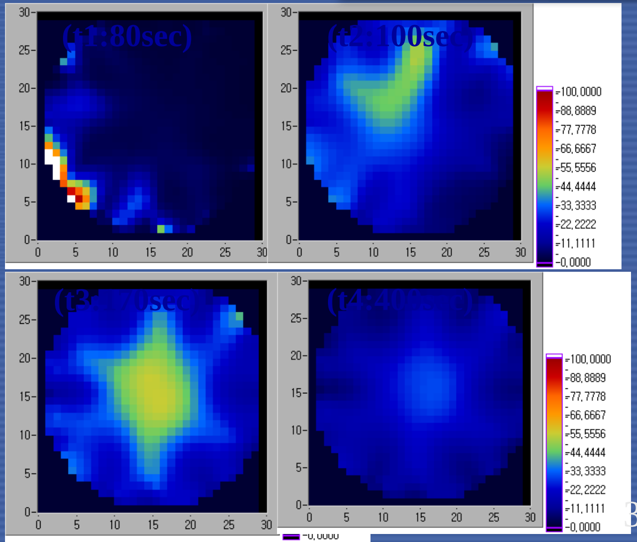




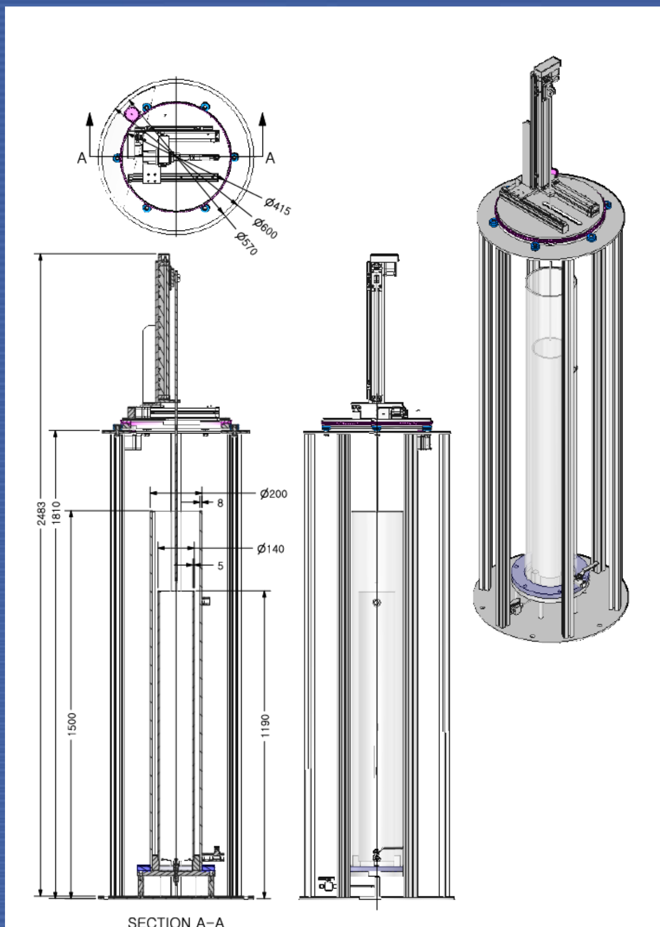
- By-pass
- Localized distribution
- Preferential flow
- Dilution/Mixing



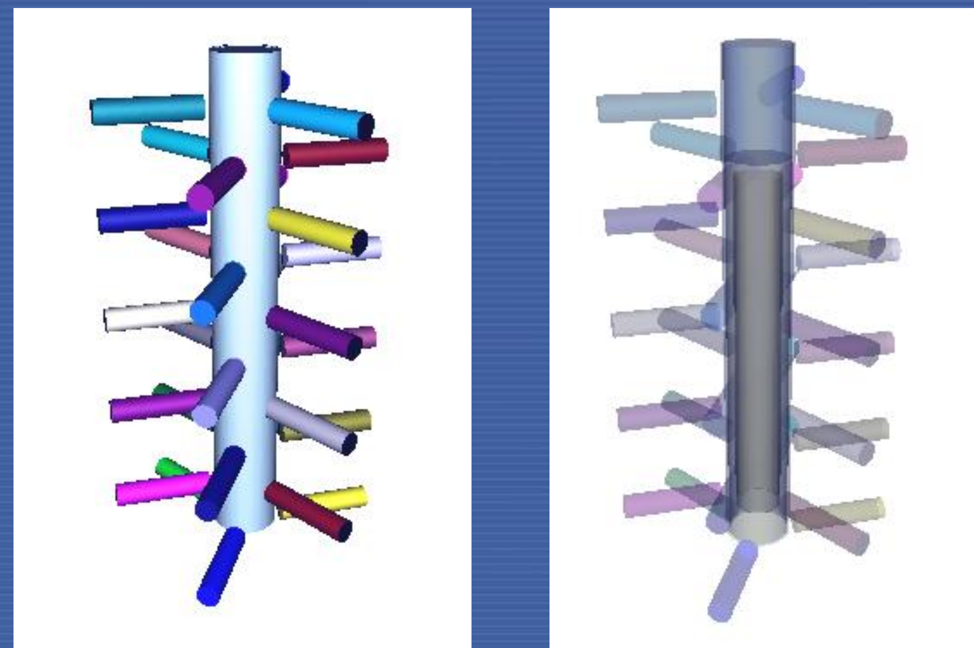




Geometry setup for radioactive particle tracking tecnique



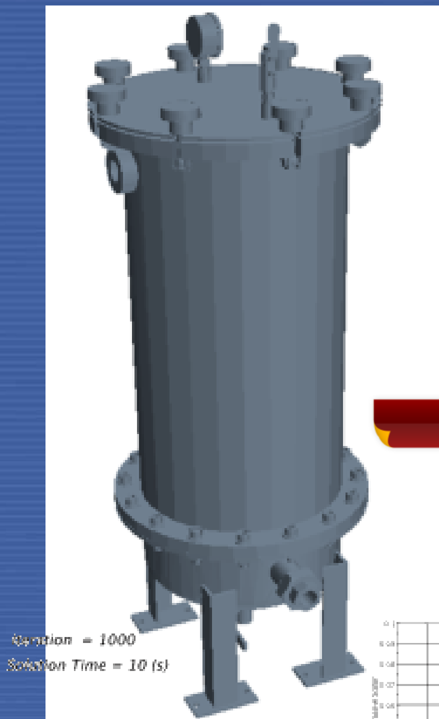
Column for RPT

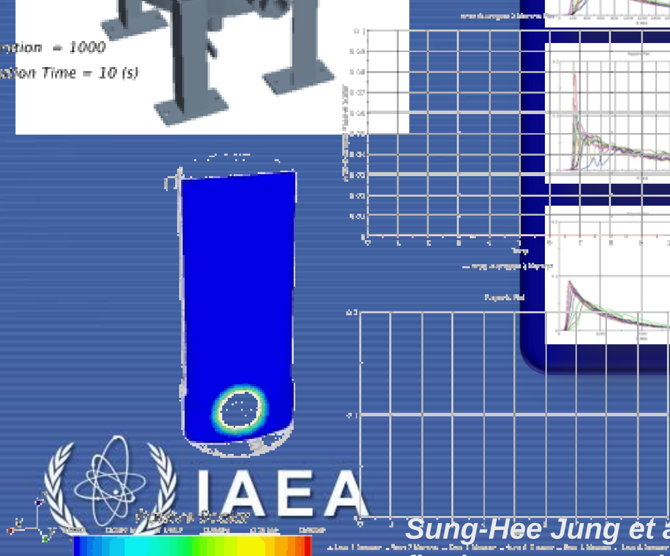


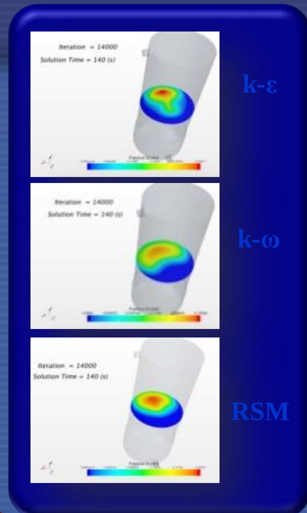
Simulation setup

CFD/SPECT/RTD + CT + CARPT

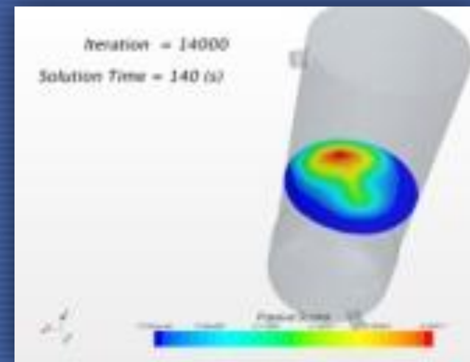
CFD modeling



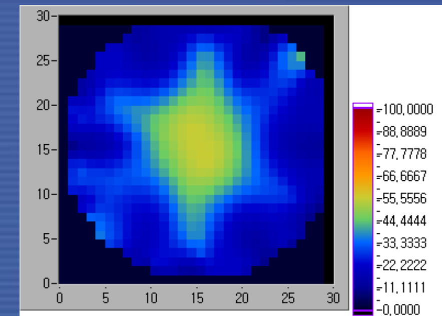


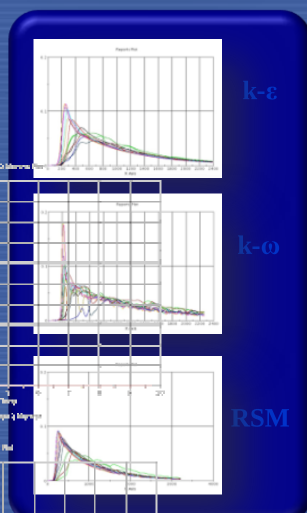


C(x,y,t)

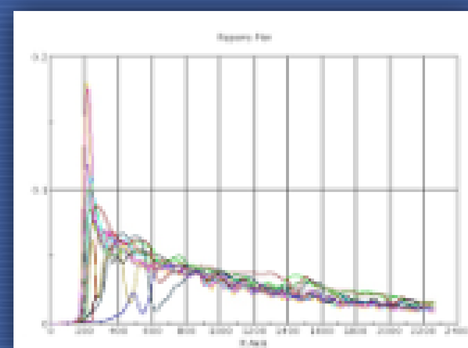


SPECT

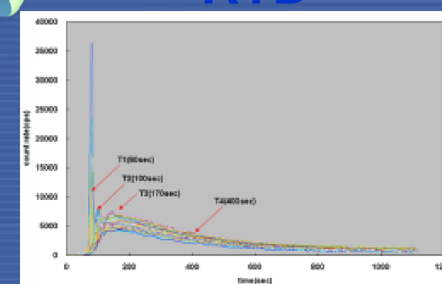


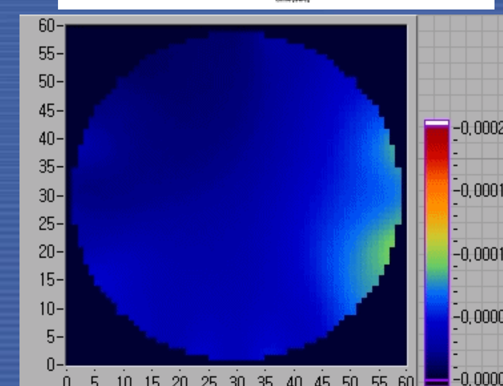


C(t)



RTD





IAEA

Sung-Hee Jung et al., 2012, Study on the validation of the Computer Fluid Dynamics modeling for a continuously flowing water vessel with the Industrial SPECT using a radiotracer. Applied Radiation and Isotopes.

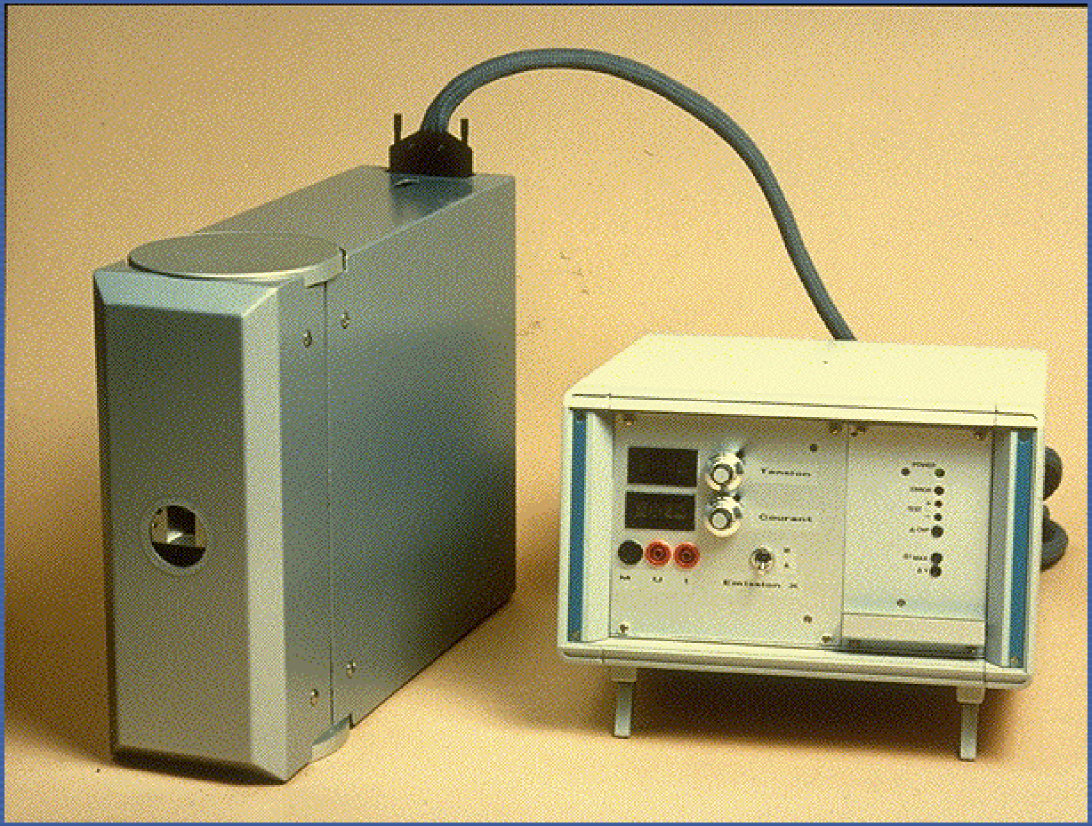
Nuclear Control System (NCS) Technologies

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

The main objective is to replace radioactive sources because of regulations weight, transportation issues, limited availabilty of some sources, etc..

- Gamma sources > X-ray generators
- Neutron sources > Neutron generators

Instrumentation X Ray generator 90 kV and 160 kV



APPLICATIONS

Nucleonic control system (thickness, density, level, void fraction measurement)

On line process measurement

X-ray non destructive testing

X-ray fluorescence

Industrial Computed Tomography

Medical imaging

Component Irradiation

France

IAEA

Some observed trends and new developments in NCS

- Use of low activity sources;
- Replacement of radioactive sources with radiation generators;
- Development of new detectors with higher efficiency and better resolution;
- Development of high count rate nuclear electronics;
- Development of next generation nuclear analyzers for multi-elemental analysis;
- Enhancement of software programmes for data acquisition and processing, including multivariate analysis for calibration and 3-D visualization software packages;
- Use of Monte Carlo simulation for design optimization, calibration and data processing;
- Introduction of expert systems for the NCS field;
- Extending the use of the spectral data that is available from multichannel spectrometric measurements;

IAEA

ISO standards, protocols, etc…

- ISO 2975-3:1976 Measurement of water flow in closed conduits - Tracer methods - Part 3: Constant rate injection method using radioactive tracers
- ISO 2975-7:1977 Measurement of water flow in closed conduits -- Tracer methods -- Part 7: Transit time method using radioactive tracers
- ISO 4053-4:1978 Measurement of gas flow in conduits -- Tracer methods -- Part 4: Transit time method using radioactive tracers
- ISO 555-3:1982 Liquid flow measurement in open channels -- Dilution methods for measurement of steady flow -- Part 3: Constant rate injection method and integration method using radioactive tracers

> There is a clear need to develop new standards or at least protocols for good practices to strenghthen the technology

International Society on tracers and tracing methods
(Nota : exact name to be defined later)

- General objective : to create an international structure to federate and represent the tracer technologies activities and teams around the world.
- To establish a training system on the model of NDT with 2-3 levels of training and associated responsabilities.
- To develop training system according to syllabus, hours of training.
- To be the certification body certifying the traning of tracer. operators complying with the syllabus, etc. accepted by all under a certification betwen peers system.

Objective : To promulgate the society during the TRACER 7 Conference - Marrakech October 2014

IAEA


Thank You