IAEA
International Atomic Energy Agency
Atoms for Peace and Development

INFN
Istituto Nazionale di Fisica Nucleare

SPES
exotic beams for science

“IAEA programs related to the application of radioisotopes in Medicine and Industry”

SPES Workshop
“Interdisciplinary aspects and applications related to the SPES project”
IUSS Istituto Universitario Studi Superiori, FERRARA
29-30 January 2019

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RPRT/NAPC/NA/IAEA
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The IAEA Mandate
"The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose."

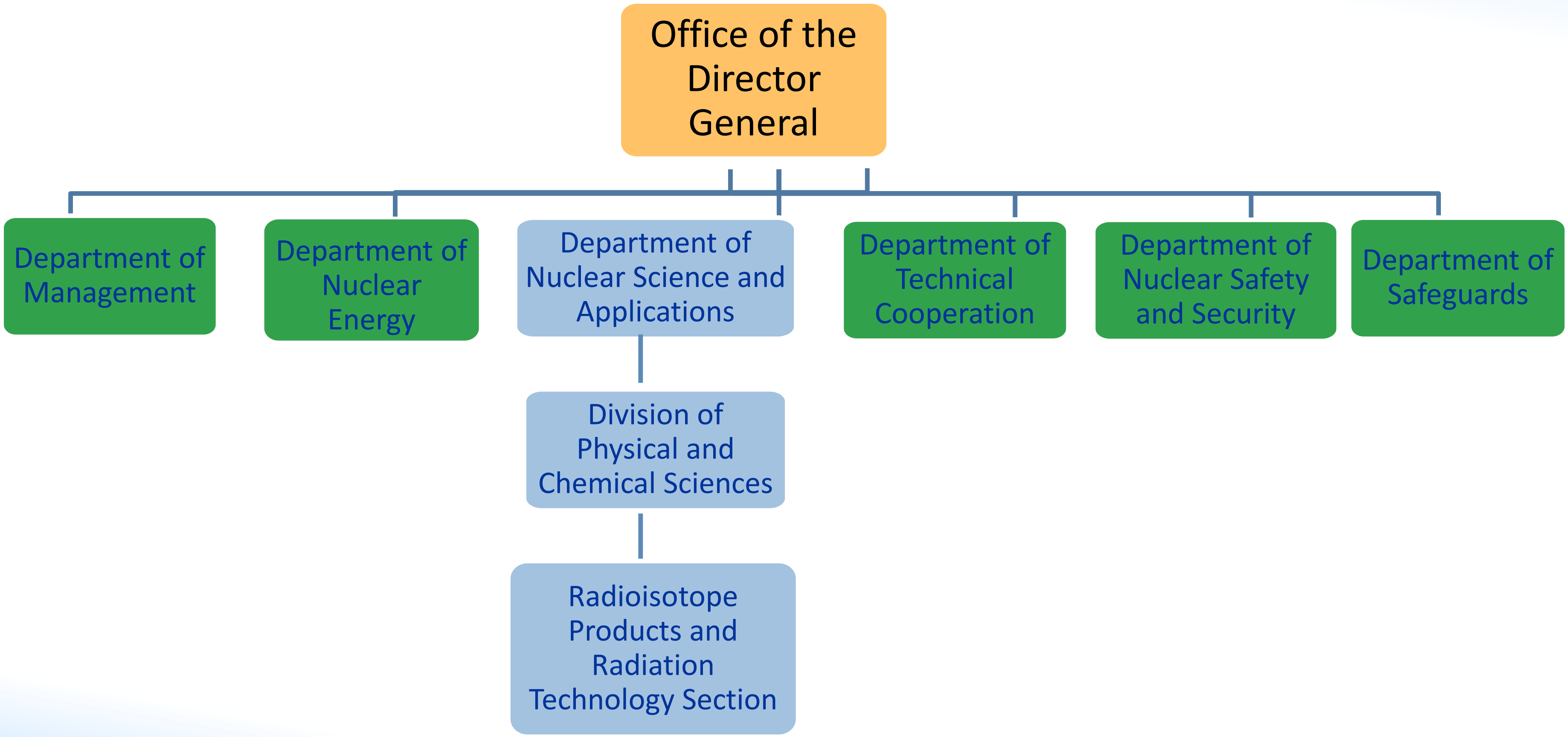
The “Three Pillars” of the IAEA

Safeguards
&
Verification

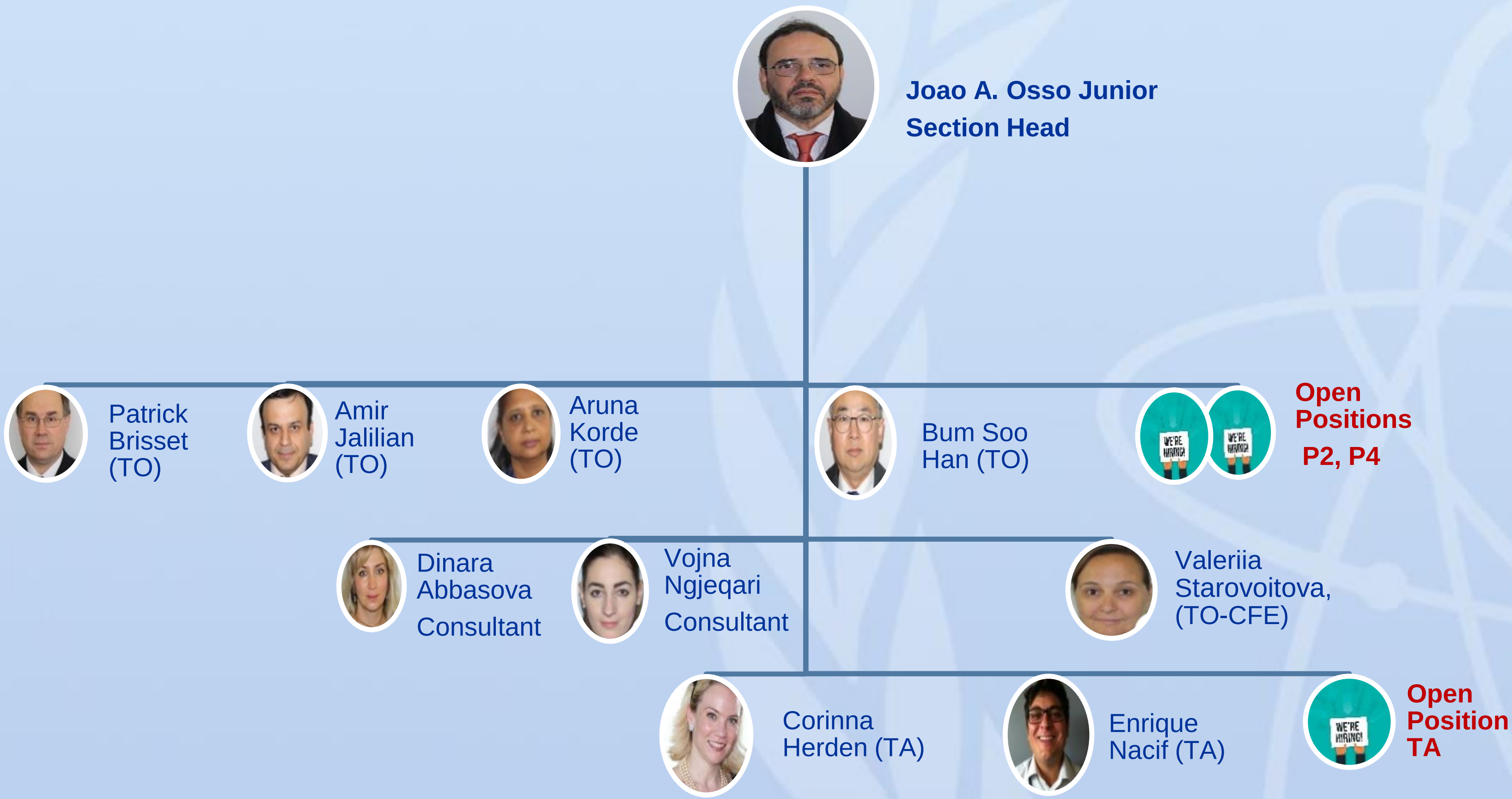
Safety
&
Security

Science
&
Technology

IAEA Organization – RPRT Section



RPRT SECTION - STAFF



IAEA Projects: RPRT Section

- Coordinated Research Projects (R&D) 15
- Technical Cooperation Projects (implementation) 160
- Regular program activities

Participation in complimentary international activities

Networks & coalitions

Publications

Collaborating Centres 8

Missions

General Conference side-events and Scientific Forum

Meetings / Conferences

Radiotracers, sealed sources, NDT

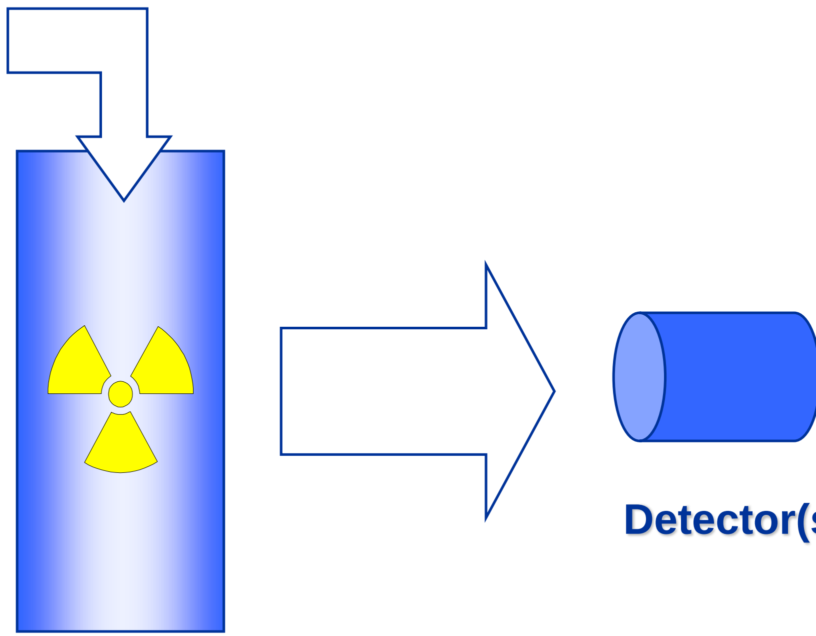
Radiotracers – General principle

Measurement of flow dynamics inside process reactors

from RTD to emission tomography

Radioisotope

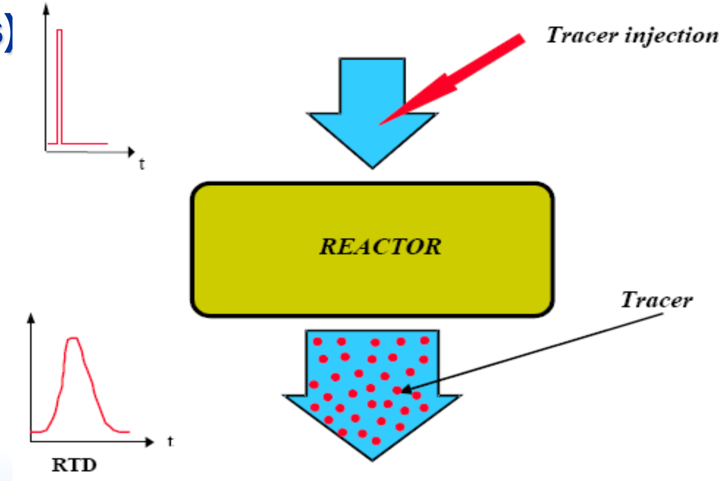
(γ radiation)



Detector(s)

Process, system,

sample, …



Diagnosis of Sludge Digester and Clarifier in WWTP

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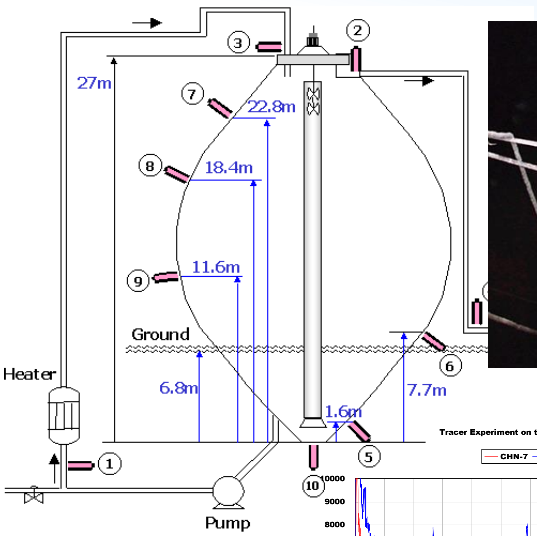
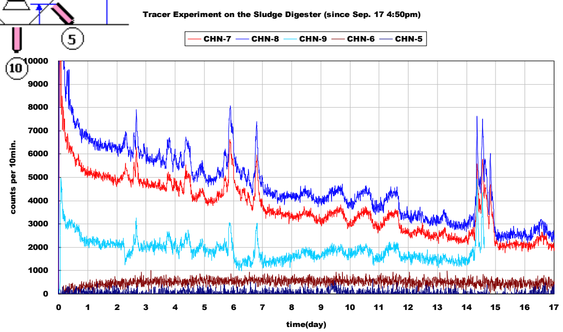
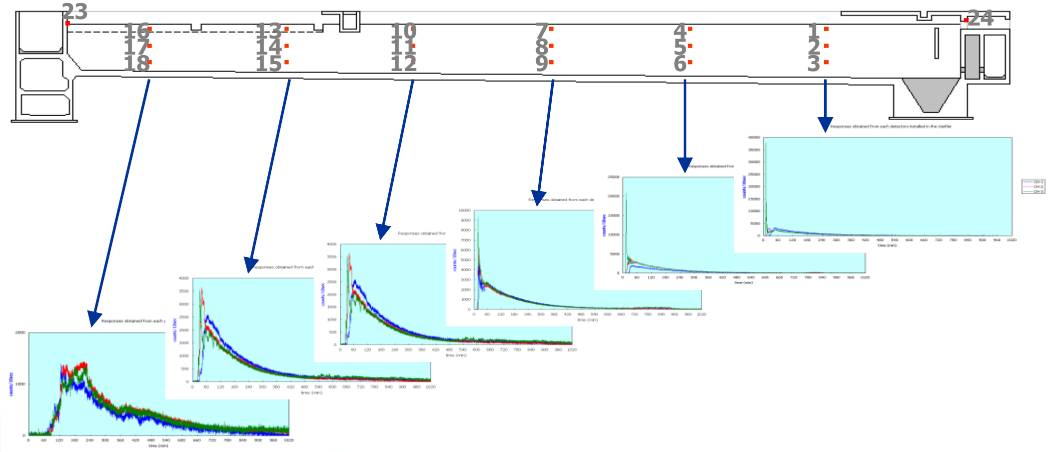


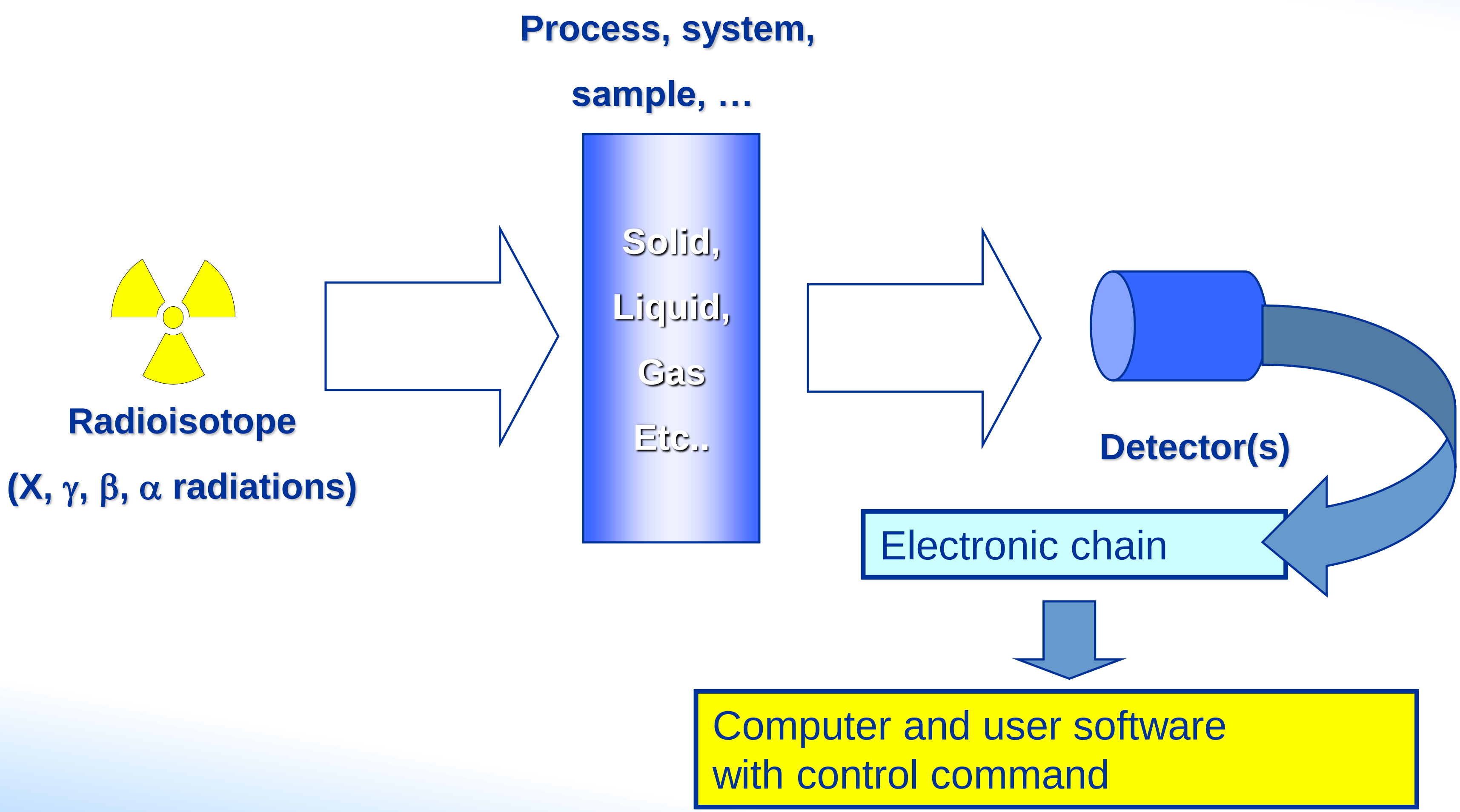




Sealed sources / NCS : general principle

Measurement of physical property of an object using ionising radiation

from gauge to transmission tomography



Food industry

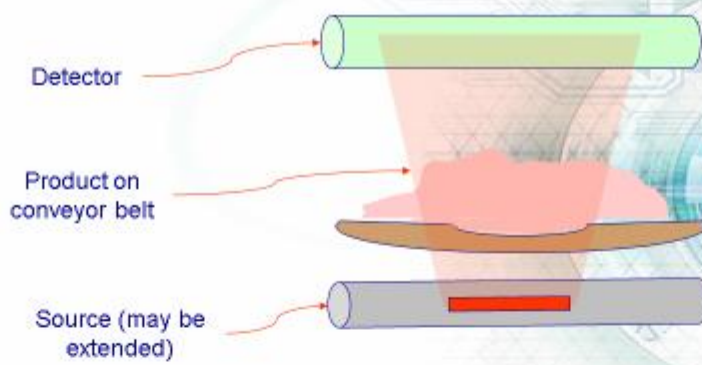
For small containers e.g. drink cans, low energy gamma radiation may be used (^{241}Am) or electrically generated X-rays.

241Am level gauge

Beverage Level

X-ray (100 kV) level gauge

Mining Industry



Belt weighing gauge

Mineral Weight

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Non Destructive Testing (NDT) – General principle

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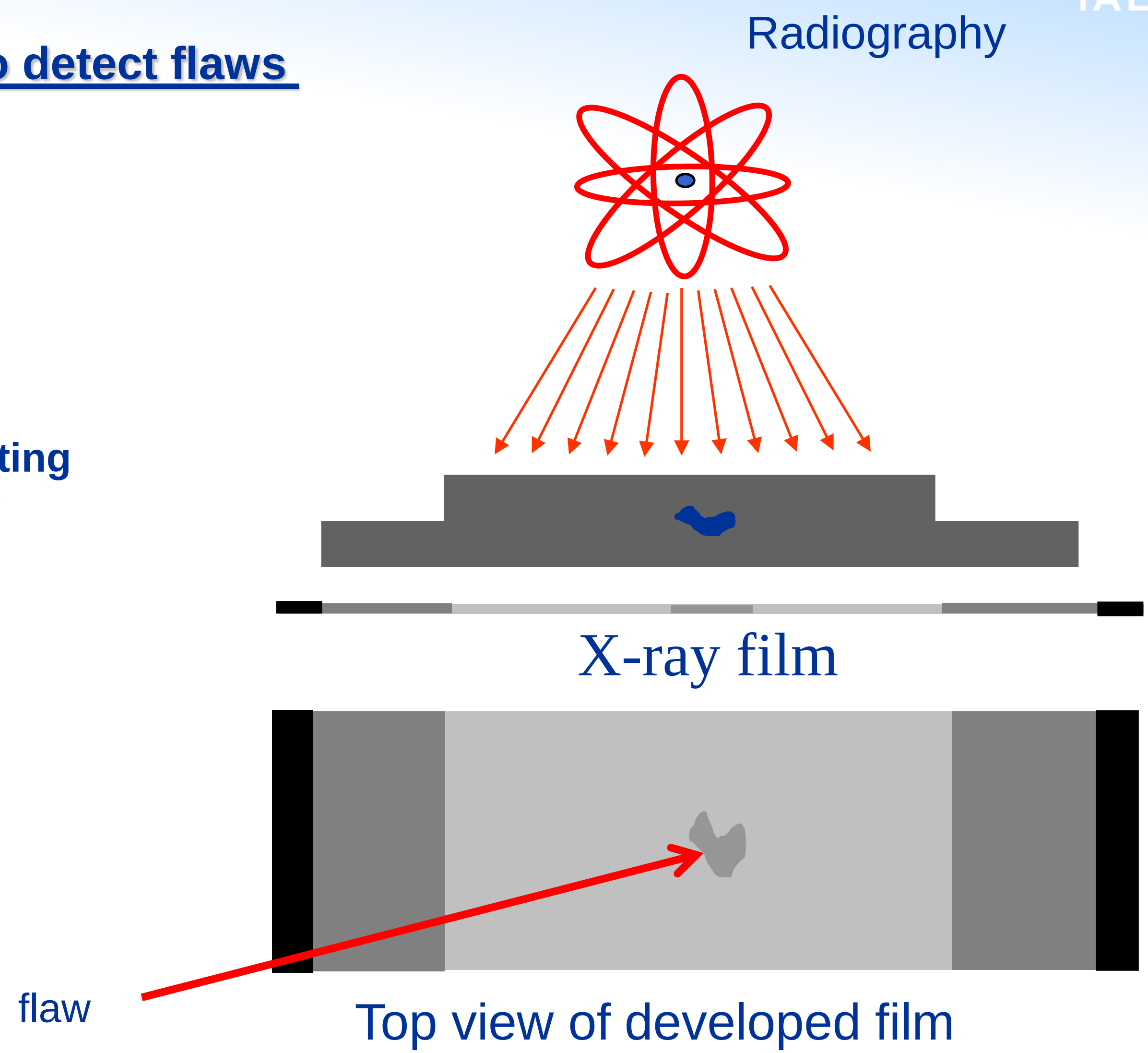
Inspection of objects to detect flaws

Main methods:

- Radiography testing
- Ultrasonic testing
- Visual testing
- Magnetic testing
- Liquid penetrant testing
- Eddy current testing
- Etc…



Non destructive Testing

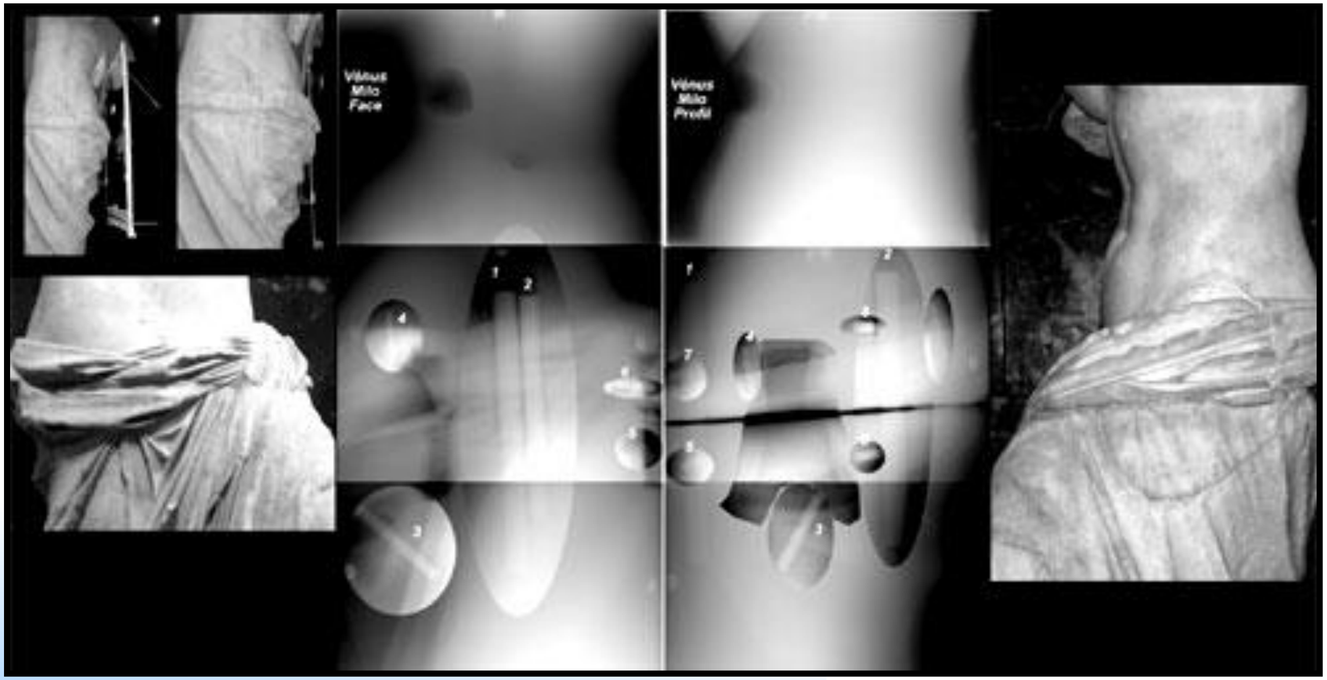
Why NDT ?

- To **improve** (to **assure**) the **quality** of industrial goods and services, **safety** of operation and **protecting** human lives.
- NDT plays an important role in the overall **quality assurance** (QA) programmes and indispensable for the survival in the long run, national and international levels.
- Typical applications of NDT is very large: power plant, aerospace, transport (road, rail, sea and air); oil- and gas, refineries, buildings, **roads and bridges**, electronics, defense and many more areas and applications - all to assure the quality and safety.
- Salient features of the NDT is the establishment of NDT infrastructure for training, certification and NDT services to the international standards to assure sustainability.

NDT for cultural heritage

Venus de Milo
Louvre Museum
Gammagraphy
Cobalt 60

Central hole and metallic inserts



Industrial Process control and safety
(radiotracers, sealed sources and nucleonic gauges)

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Tracers for water

Isotope	^{137m}Ba	^{113m}In	^{99m}Tc	^{82}Br	^{198}Au
Half-life	2.6 min	100 min	6.02 hours	1.5 days	2.7 days
Energy (keV)	662	410	140	Approx. 700	410
Activity	1 to 200 mCi 37 to 7400 MBq	1 to 200 mCi 37 to 7400 MBq	1 mCi to 10 Ci 37 MBq to 370 GBq	1 to 200 mCi 37 to 7400 MBq	1 mCi to 9 Ci 37 MBq to 333 GBq
Obtention	Generator ^{137}Cs-^{137m}Ba	Generator ^{113}Sn-^{113m}In	Generator ^{99}Mo-^{99m}Tc	Reactor activation	Reactor activation
Preparation	None	EDTA Complexation	None	None	Complexation

Industrial Process control and safety
(radiotracers, sealed sources and nucleonic gauges)

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Sealed sources for gauges

Isotope	^{60}Co	^{137}Cs	^{241}Am	^{241}Am-Be	^{252}Cf
Half-life	5.271 years	30.1 years	432 years	432 years	2.6 years
Energy	1.17 MeV 1.33 Mev	662 keV	60 keV	Neutrons 2 – 10 MeV	Neutrons 2 MeV
Activity	< 200 mCi < 7.4 GBq	< 200 mCi < 7.4 GBq	< 1 Ci < 37 GBq	< 10 Ci < 370 GBq	

Sealed sources for NDT

Isotope	^{60}Co	^{75}Se	^{192}Ir
Half-life	5.271 years	120 days	74 days
Energy	1.17 MeV 1.33 MeV	120 to 400 keV	296 to 468 keV
Activity	< 50 Ci < 1850 GBq	< 100 Ci < 3700 GBq	< 100 Ci < 3700 GBq

Industrial Process control and safety
(radiotracers, sealed sources and nucleonic gauges)

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Main issues

- Reactor time for irradiation
- Some generators have been discontinued

IAEA activities
(radiotracers, sealed sources and nucleonic gauges)

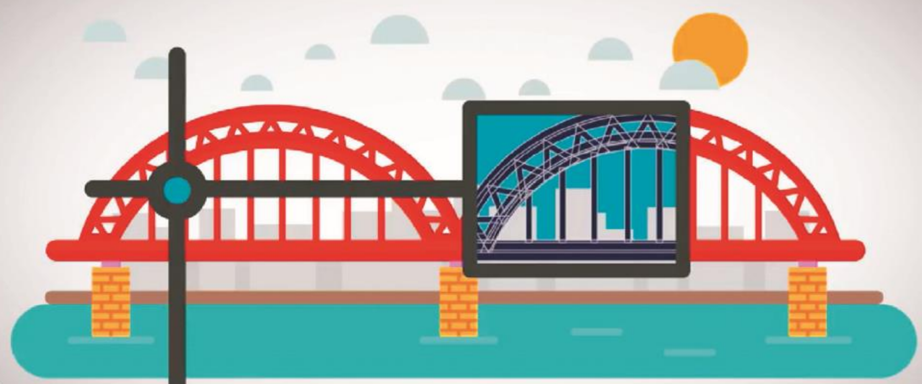
- New laboratory in Seisberdorf: neutron lab,2 neutron sources (D-D procurement, D-T donation):
  - ❖ Experiments in Nuclear Physics
  - ❖ Training on the poduction of radiotracers in industry
- CRPs:
  - ❖ Development of radiometric methods and modelling for measurement of sediment transport and dispersion of particles and pollutants from outfalls
  - ❖ Radiometric Methods for Exploration and Process Optimization in Mining and Mineral industries
  - ❖ Imaging Technologies for Process Investigation and Components' Testing
- Training courses in Seisberdorf and CCs: radiotracers, certification with ISTRA
- Support to more than 40 TC projects

IAEA activities

SIDE EVENT

Non-Destructive Testing

Methods and techniques for testing civil structures in pre- and post-management of natural disasters



20 September 2018, Thursday
11:00-12:30, M-Building, M6

Non-Destructive Testing

Natural disasters can kill thousands of people and wreak vast economic and infrastructural damage. Non-destructive methods, including radiography and radiotracers, can identify structural defects that may be imperceptible to traditional testing methods and assess the integrity of important buried distribution systems, such as gas and water networks. The side event will discuss key nuclear techniques that are integral to non-destructive testing.

Keynote speakers

Mr Dario Foppoli, Tecchnical Director, Foppoli Moretta e Associati Consulting Engineers, Italy

Mr Mykola Kurylchyk, Programme Management Officer, IAEA

Mr Mani ram Gelal, Director General, Department of Urban Development and Building Construction, Ministry of Urban Development, Nepal

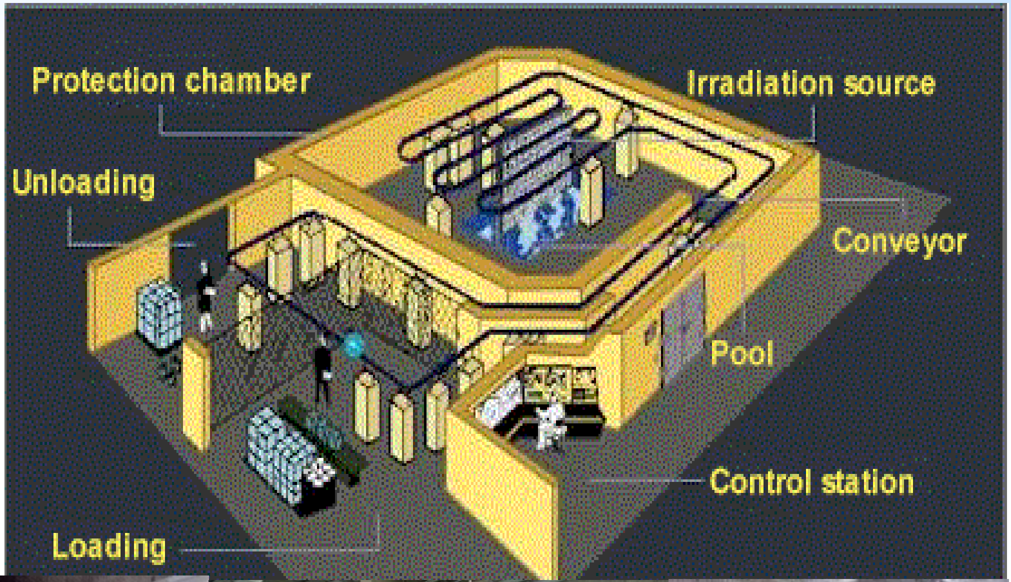
Mr Eduardo Robles Piedras, Departamento de Tecnología de Materiales, Instituto Nacional de Investigaciones Nucleares Estado de Mexico, Mexico

Radiation processing

Sources for Radiation Processing in Industrial Scale Operations

Gamma radiation sources:

- High intensity ^{60}Co sources from 0.1MCi to >5MCi (> 200 facilities worldwide)



Electron Accelerator (EB):

<u>Energy:</u>

low (300-700keV),
medium (2-3MeV)
high (5-10MeV)

<u>Power:</u>

Medium (20-100kW)
High (0.5-1MW)
Electron mode
X-ray mode
(>2000 worldwide)

RADIATION STERILIZATION

- Medical devices
- Packaging
- Labware
- Raw materials
- Some cosmetics and pharmaceutical goods
- Blood irradiation
- Preserving heritage

Radiation Technology Applications towards Protection of the Environment

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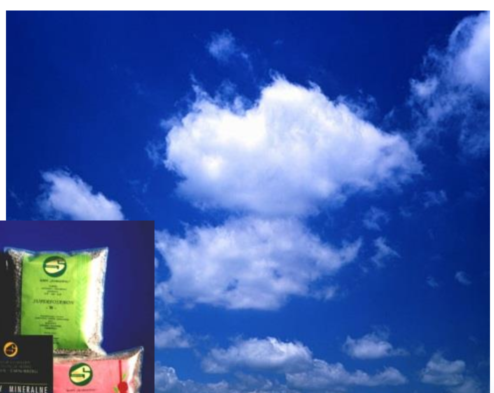
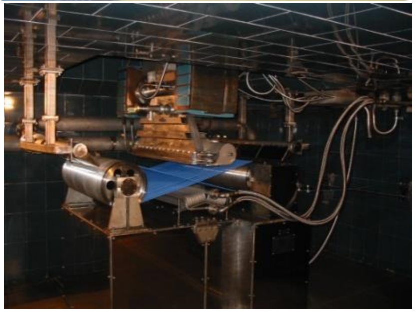
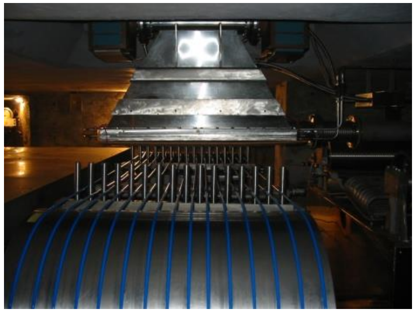
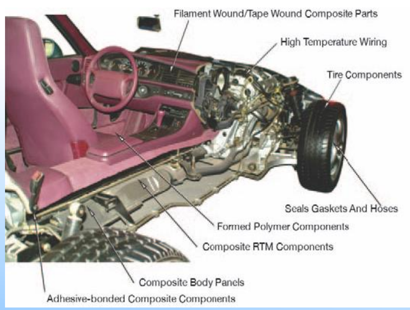
Flue gas Purification | **Wastewater Treatment** | **Sludge Hygienization**





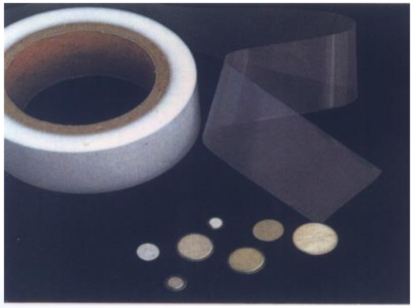
Material modification

Cable & wires

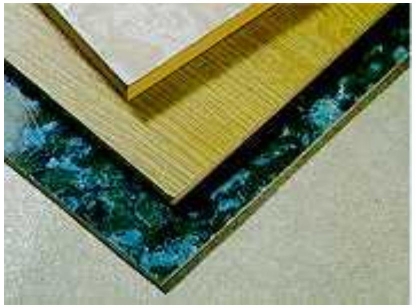





Heat Shrinkables, Foams and Food Packaging

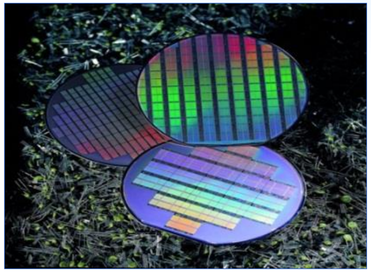




Curing/Coatings



Semiconductor etc.



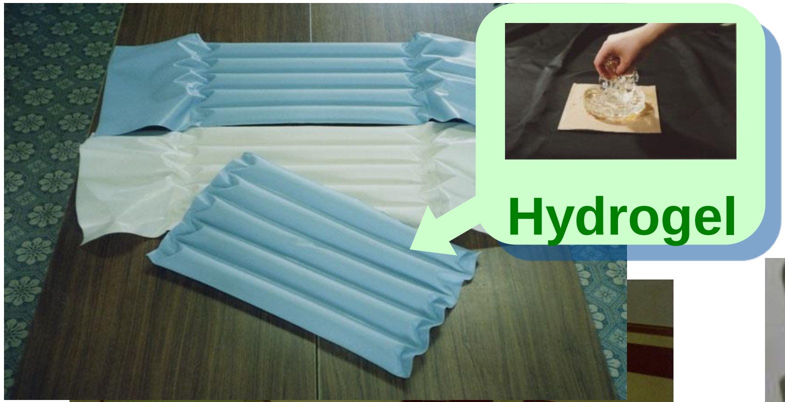
Radiation-processed hydrogels

Cross linking + sterilization in one step

Cost effective process

Technology development in many Member States through IAEA initiatives

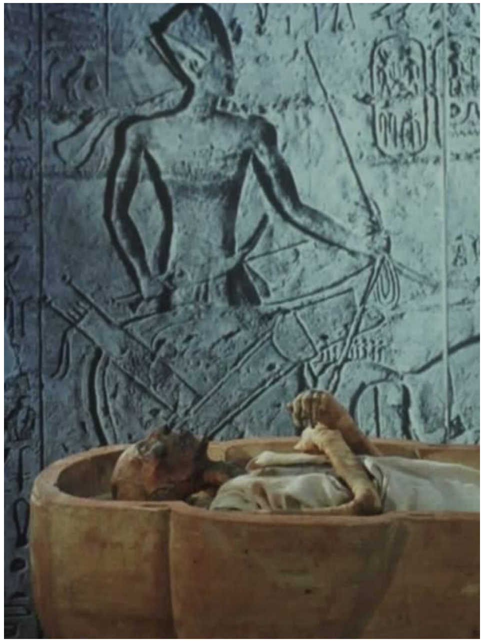
Wound dressing:
Sterile cover
Cooling effect
Regulates O_2 supply
Healing progress fast
Less or no scar formation



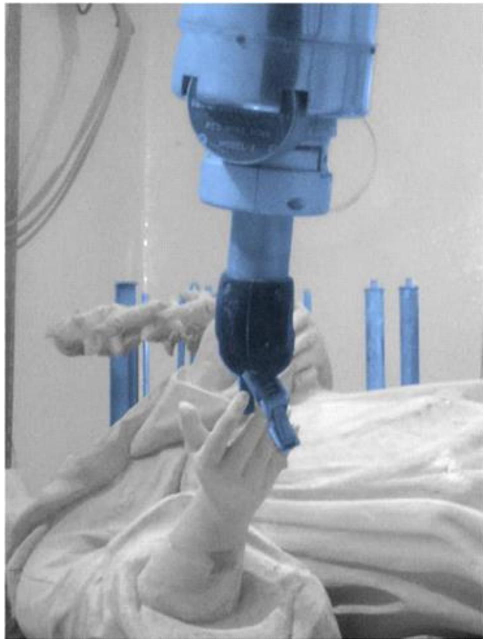
Non-bedsore mat:
Keeps body temperature
Disperses body pressure
Nontoxic (natural polymer)

Coolants
Non-toxic natural polymer

Gamma irradiation for conservation of cultural heritage artifacts



Ramses II mummy in Musée de l'Homme, Paris 1977



Sculpture in the irradiation chamber, 2000

Frozen baby mammoth Siberia, 2010

Disinfestation

FIG. 3. Photographic paper, black and white, silver salts, turn sepia and coloured by hand dating from the 1920s: a) not irradiated; b) irradiated at 90kGy [45].

Cobalt-60 irradiators for different applications

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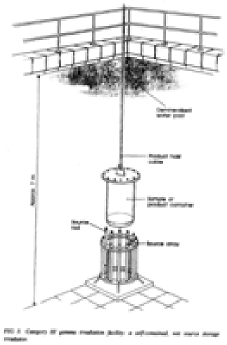
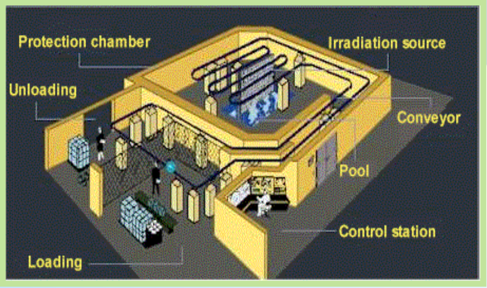
$^{59}Co(n,\gamma)^{60}Co$

S.No.	Type	Typical Cobalt-60 Source strength (Curie)	Application area
1	Gamma Cell with irradiation volume of 1-5 litres	1,000-20,000	R&D at laboratory scale Blood irradiation Irradiation of seeds etc. for mutation breeding
2	Panoramic Batch Irradiators	30,000-100,000	Pilot scale studies Semi-commercial operations for sterilization of medical products Food irradiation requiring low dose irradiation such as irradiation of onions, potatoes, mangoes etc.
3	Commercial Gamma radiation plants	100,000-5,000,000	Sterilization of medical products Food irradiation requiring high doses such as hygienization of spices





Issues regarding supply of Cobalt-60

- **The current supply of Co-60 meets the demand and IAEA has been able to procure and ensure the supply for some Member States, though the transportation across the continents poses a few challenges**
- **Co-60 is produced in CANDU and RBMK power reactors in Canada, Russia, China, Argentina and India. CANDU reactors have a 25-year life span and much of the installed reactors will reach this milestone over the next decade.**
- **Many CANDUs are being refurbished extending their life by an additional 25-30 years.**
- **Canada, major distributor of Co-60 using multiple reactor, may face distribution issues in the near future.**

Radiation Processsing: IAEA activities

- CRPs:
  - ❖ Enhancing the Beneficial Effects of Radiation Processing in Nanotechnology
  - ❖ Development of Radiation-Grafted Membranes for Cleaner and Sustainable Energy
  - ❖ Instructive Surfaces and Scaffolds for Tissue Engineering Using Radiation Technology
  - ❖ Developing Radiation Treatment Methodologies and New Resin Formulations for Consolidation and Preservation of Archived Materials and Cultural Heritage Artefacts
  - ❖ Removal of Emerging Organic Pollutants
  - ❖ Radiation Inactivation of Bio-hazards using High Powered Electron Beam Accelerators
- Several hands-on training courses and summer schools
- Focus on replacing radioactive sources by machine-generation radiation
- Support to more than 60 TC projects

IAEA role in Medicine

Radioisotopes for Medicine

Teletherapy

Isotope	^{60}Co	^{137}Cs
Half-life	5.271 years	30.1 years
Energy	1.17 MeV 1.33 MeV	662 keV
Activity	< 13,000 Ci < 500 TBq	
Production	$^{59}Co(n,\gamma)^{60}Co$	Fission product

Radioisotopes for Medicine

Braquitherapy

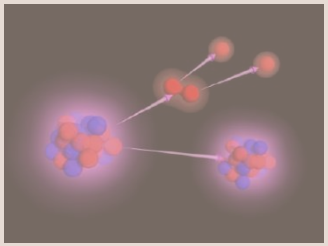
Isotope	^{192}Ir	^{125}I	^{103}Pd
Half-life	74 days	60 days	74 days
Photon average energy	380 keV	28 keV	21 keV
Production	$^{191}Ir(n,\gamma)^{192}Ir$	$^{124}Xe(n,\gamma)^{125}Xe$ $^{125}Xe \rightarrow ^{125}I$ Enriched target	$^{102}Pd(n,\gamma)^{103}Pd$ Enriched target $^{103}Rh(p,n)^{103}Pd$

Brachytherapy classification with respect to dose rate:

- Low dose rate (LDR) (0.4 – 2 Gy/h)
- Medium dose rate (MDR) (2 – 12 Gy/h)
- High dose rate (HDR) (> 12 Gy/h) < 10 Ci/pellet

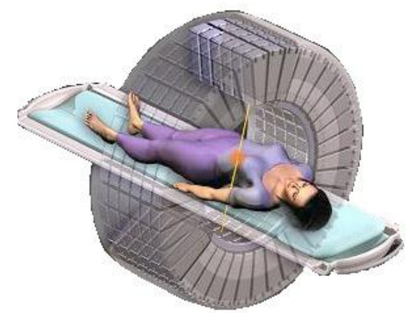
IAEA role in the development of radiopharmaceuticals

Nuclear Medicine Procedure



Radioisotope production

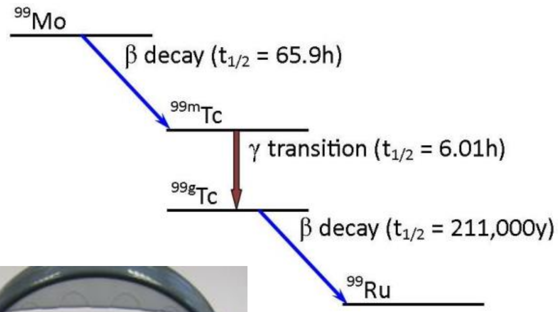
Radiopharmaceutical production



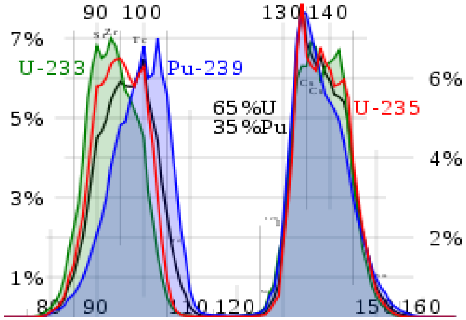
Diagnostic or therapeutic application

Cyclotrons / Accelerators

Production of radioisotopes



Radionuclide generator

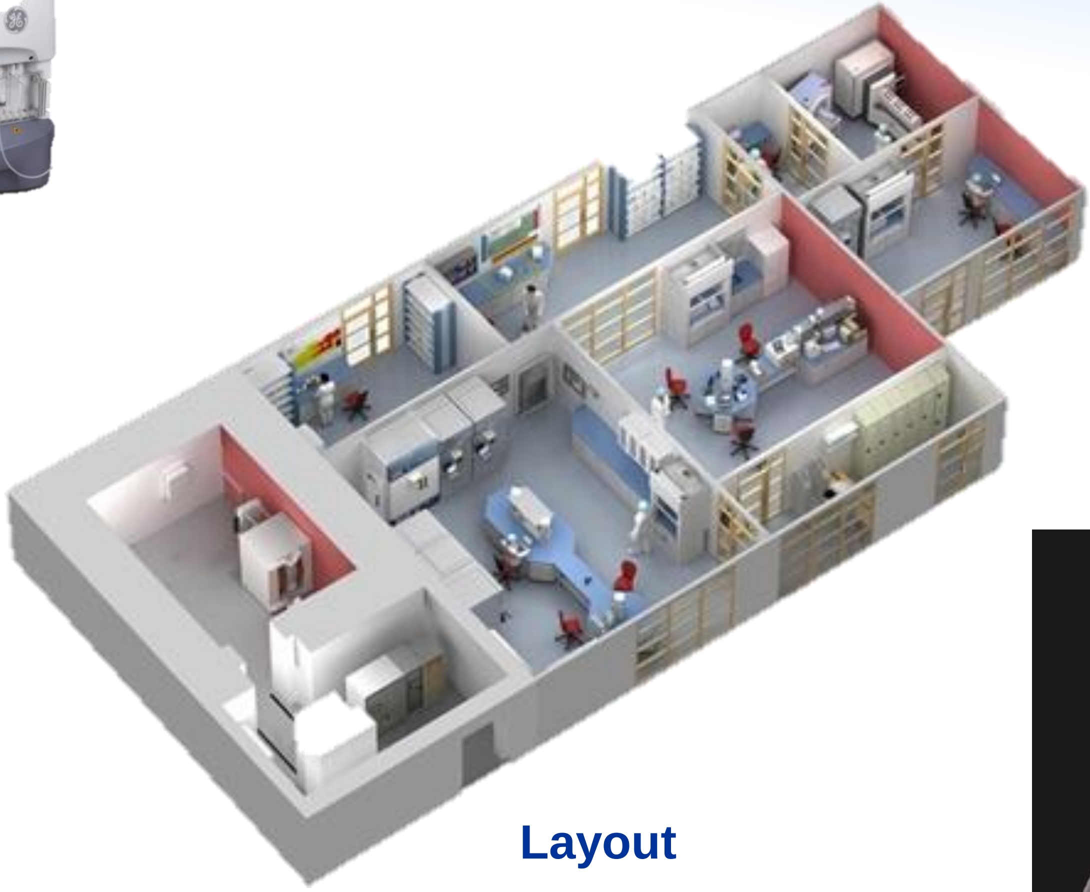


Research Reactor

Mo-99 and Ac-225

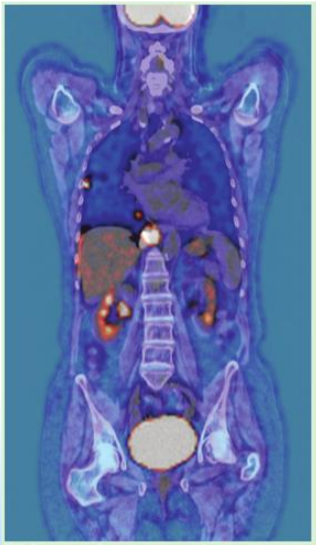
Production of radiopharmaceuticals

Synthesis module



Layout

Hot cell



FDG scan of a cancer patient with metastatic diseases

PET/CT

SPECT/CT bone

Radioisotopes for Nuclear Medicine - Diagnostic

PET (Cyclotron)

Isotope	^{11}C	^{13}N	^{15}O	^{18}F
Half-life	20 min	10 min	2 min	110 min
Production	$^{14}N(p,\alpha)^{11}C$	$^{16}O(p,\alpha)^{13}N$	$^{15}N(p,n)^{15}O$	$^{18}O(p,n)^{18}F$ enriched

Isotope	^{64}Cu	^{68}Ga	^{82}Rb	^{89}Zr
Half-life	12.7 h	68 min	1.25 min	78.4 h
Production	$^{64}Ni(p,n)^{64}Cu$ enriched	Generator (^{68}Ge-^{68}Ga) $^{nat}Ga(p,xn)^{68}Ge$ High energy Cyclotron	Generator (^{82}Sr-^{82}Rb) $^{85}Rb(p,4n)^{82}Sr$ High energy Cyclotron	$^{89}Y(p,n)^{89}Zr$

Radioisotopes for Nuclear Medicine - Diagnostic

SPECT

Isotope	^{67}Ga	^{99m}Tc	^{111}In	^{123}I	^{201}Tl
Half-life	78.3 h	6 h	67.2 h	13 h	73 h
Production	$^{68}Zn(p,2n)^{67}Ga$ enriched	Generator (^{99}Mo-^{99m}Tc)	$^{112}Cd(p,2n)^{111}In$ enriched	$^{124}Xe(p,2n)^{123}Cs$ $^{123}Cs \rightarrow ^{123}Xe \rightarrow ^{123}I$ enriched	$^{203}Xe(p,3n)^{201}Pb$ $^{201}Pb \rightarrow ^{201}Tl$ enriched

Radioisotopes for Nuclear Medicine - Therapy

IAEA

B^- emitters

Isotope	^{32}P	^{90}Y	^{153}Sm	^{131}I	^{177}Lu
Half-life	14.3 d	2.7 d	46.3 h	8 d	6.7 d
Production	$^{32}S(n,p)^{32}P$	Generator (^{90}Sr-^{90}Y) $^{89}Sr(n,\gamma)^{90}Y$ Fission product	$^{152}Sm(n,\gamma)^{153}Sm$ enriched	$^{130}Te(n,\gamma)^{131}Te$ $^{131}Te \rightarrow {}^{131}I$ Fission product	$^{176}Lu(n,\gamma)^{177}Lu$ $^{176}Yb(n,\gamma)^{177}Yb$ $^{177}Yb \rightarrow {}^{177}Lu$ enriched

Radioisotopes for Nuclear Medicine - Therapy

IAEA

α emitters

Isotope	Daughter isotopes	Physical half-life	Emission (%)
^{211}At	– ^{211}Po	7.2 h 516 ms	α (41.8%) α (100%)
^{225}Ac	– ^{221}Fr ^{217}At ^{213}Bi ^{213}Po	10 d 4.9 min 32.3 ms 45.6 min 4.2 µs	α (100%) α (100%) α (99.98%)/β (0.01%) α (2.2%)/β (97.8%) α (100%)
^{213}Bi	– ^{213}Po	45.6 min 4.2 µs	α (2.2%)/β (97.8%) α (100%)
^{212}Bi	– ^{212}Po	61 min 298 ns	α (36%)/β (64%) α (100%)
^{212}Pb	– ^{212}Bi ^{212}Po	10.64 h 61 min 0.3 µs	β (100%) α (36%)/β (64%) α (100%)
^{223}Ra	– ^{219}Rn ^{215}Po ^{211}Bi	11.4 d 4 s 1.8 ms 2.14 min	α (100%) α (100%) α (100%) α (99.7%)/β (0.3%)
^{227}Th	– ^{223}Ra ^{219}Rn ^{215}Po ^{211}Bi	18.72 d 11.4 d 4 s 1.8 ms 2.14 min	α (100%) α (100%) α (100%) α (100%) α (99.7%)/β (0.3%)

Radioisotopes for Nuclear Medicine

Issues

- Mo-99
- I-131 supply could be affected by Mo-99 crisis
- The only alpha emitter radiopharmaceutical, Xofigo, has been discontinued due to lack of Ra-223
- Enriched targets of Lu-176 and/or Yb-176, Ni-64, Mo-98, Mo-100
- Potential new β^- emitters: Cu-67, Re-186, Sc-47
- New Theranostic

Main activities

1. Production of radioisotopes

2. Quality control and assurance

3. Meetings, workshops, conferences

4. Production of radiopharmaceuticals

5. Education (e-learning, training modules, sylabus for Universities)

6. Regulatory issues: Due to the increasing complexity of radiopharmaceutical preparations and the mandatory requirement of patient's safety, there exists a widespread demand to support regulators and preparation of guidelines of Good Manufacturing Practice (GMP)

7. Publications: CRPs, guidelines

8. International Pharmacopeia in cooperation with WHO

Radioisotope production technologies

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CRPs

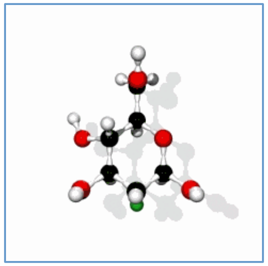
- Production and utilization of Emerging Positron Emitters for Medical Applications with an Emphasis on Cu-64 and I-124 (2010-2014)
- Accelerator-based Alternatives to Non-HEU production of Mo-99/Tc-99m (2011-2015)
- Sharing and Developing Protocols to Further Minimize Radioactive Gaseous Releases to the Environment in the Manufacture of Medical Radioisotopes, as Good Manufacturing Practice (August 2015)
- Therapeutic Radiopharmaceuticals Labelled with New Emerging Radionuclides (^{67}Cu, ^{186}Re, ^{47}Sc) – Started in 2016 – 3rd RCM in 2019
- New Ways of Producing Tc-99m and Tc-99m Generators – new 2017 – 2nd RCM in 2019

Radiopharmaceuticals: production, quality aspects and clinical use

IAEA

CRPs

- Development of Ga-68 based PET-Radiopharmaceuticals for Management of Cancer and other Chronic Diseases (2010-2015)
- Development and preclinical evaluations of therapeutic radiopharmaceuticals based on Lu-177 and Y-90 labeled monoclonal antibodies and peptides (2011-2015)
- Nanotheranostic: Nanosized delivery systems for radiopharmaceuticals (2014-2019) 4th RCM in 2019
- Cu-64 Radiopharmaceuticals for Theranostic Applications – November 2016
- Production of Zr-89 and Development of Zr-89 Radiopharmaceuticals – new 2019 – 1st RCM 2019

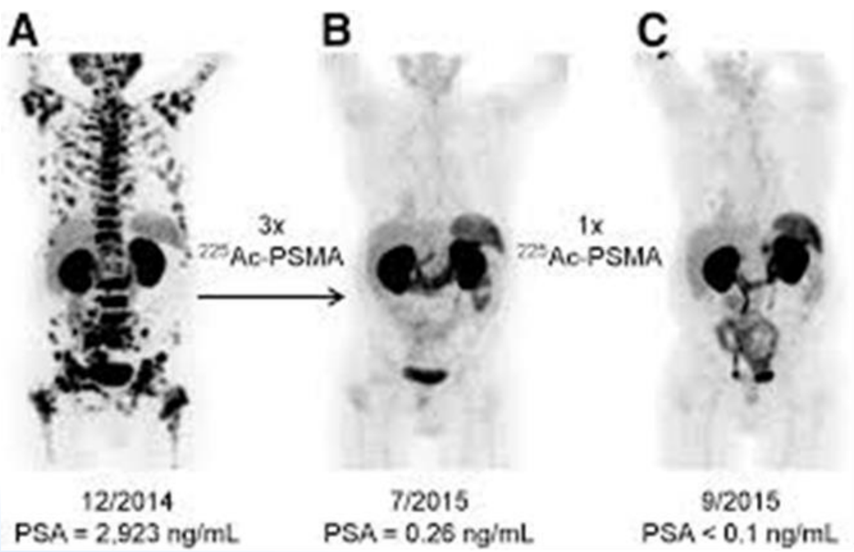


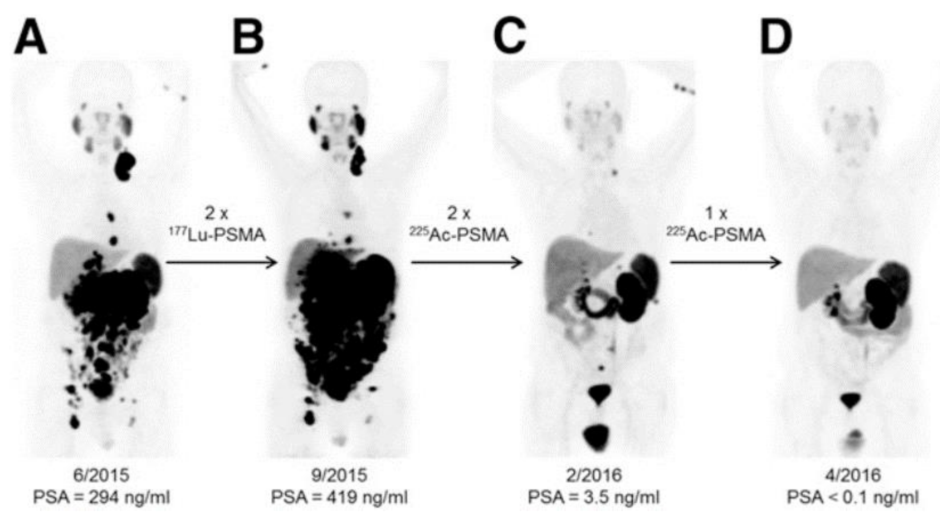
TC Projects

- ***More than 60 projects***
- ***Capacity Building : FE, SV, NTC, Experts***
- ***Setting up facilities through TC projects***
  - ✓ Technetium-99m Generator Production facility;
  - ✓ Cyclotron facility for PET radiopharmaceuticals and RPHs;
  - ✓ Ga-68 generators and RPHs
  - ✓ Production of therapeutic radiopharmaceuticals

Workshop on Supply of Ac-225

- 09-10 October 2018; IAEA HQ; 80 participants, 17 MSs
- In collaboration with EC-JRC
- Trends in global demand and supply for Ac-225
- Motivation: excellent clinical trials results of Ac-225-PSMA
- Report being finalized

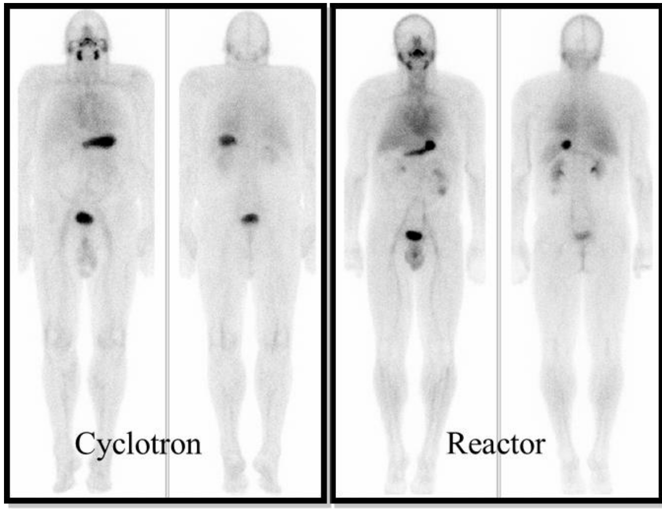




J Nucl Med December 1, 2016 vol. 57 no. 12 1941-1944

Accelerator-based Alternatives to Non-HEU production of Mo-99/Tc-99m

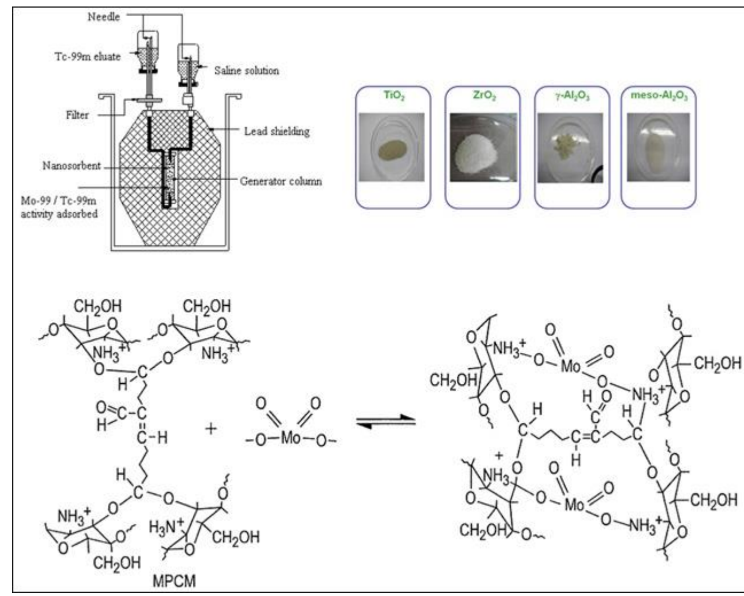
- 2011-2015
- 18 participants from 16 Member States
- Production of Tc-99m in cyclotron - very successful
- Technology to produce several (>30) Ci Tc-99m per run in medical cyclotrons of energies below 24 MeV proven; clinical trials under way; regulatory approvals sought
- Monograph approved in Europe
- Self-sufficiency in hospitals/towns/country
- Good option for hospital or radiopharmacy; local productions
- Target specifications; reuse of targets etc. need consideration



Comparison of cyclotron- and reactor-based Tc-99m pertechnetate for the Univ. of Alberta Clinical Trial (cancer thyroid patients imaged post-thyroidectomy)

New CRP: New Ways of Producing Tc-99m and Tc-99m Generators

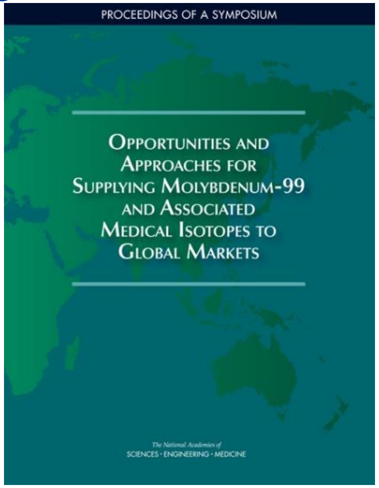
- First Meeting: 11-15 December 2017
- 18 approved proposals
- Recommendation from Technical Meeting on same topic (March 2016)
- Aimed as use of low specific activity Mo-99 for generator preparation and accelerator production of Mo-99 (Mo-100 (γ,n) reaction)



- https://www.iaea.org/newscenter/news/new-crp-new-ways-of-producing-tc-99m-and-tc-99m-generators

Symposium on Opportunities and Approaches for Supplying Molybdenum-99 and Associated Medical Isotopes to Global Markets

- 17-19 July 2017; IAEA HQ; 100 participants
- Co-hosted by the US National Academies of Sciences, Engineering, and Medicine and the Russian Academy of Sciences and held in cooperation with the International Atomic Energy Agency. Sponsored by the U.S. Department of Energy's National Nuclear Security Administration.
- Trends in global demand and supply for Mo-99 and associated medical isotopes.
- Prospects and approaches for developing new global supplies of Mo-99 and associated medical isotopes.
- Technical, regulatory, economic, and policy considerations for producing Mo-99 and associated medical isotopes for global markets using uranium-fission and other processes.



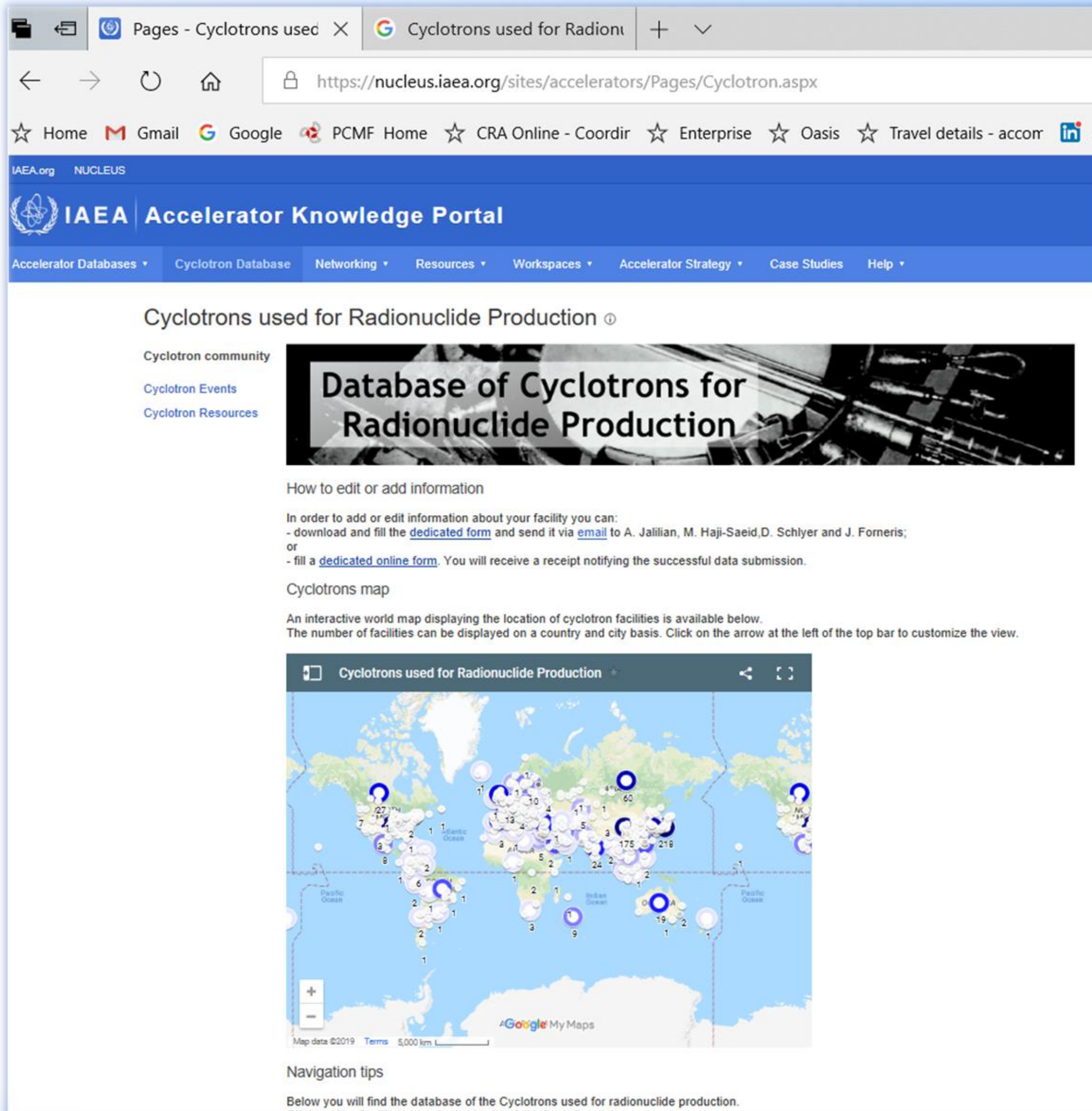
Recent Publications – Section

Database: Cyclotrons used for Radionuclide Production

IAEA

- >1350 cyclotrons
- 89 MSs
- Online data inquiry
- World-wide map
- Continuous data acquisition
- Live and streaming
- List of products
- Contact info
- Still in completion process

Cancer Centre (VCCC)						
No Title	...	Australia	Perth	IBA	CYCLONE 18	18
No Title	...	Australia	St. Lucia QLD 4072	IBA	CYCLONE 18	18
CycloPET Pty Ltd	...	Australia	Sydney	GE	PETtrace	16
Liverpool Hospital	...	Australia	Sydney	GE	PETtrace	16
No Title	...	Australia	Sydney	IBA	CYCLONE 30	30
No Title	...	Australia	Sydney	Siemens	ECLIPSE	11
No Title	...	Australia	Sydney	Siemens	ECLIPSE	11
Princess Alexandra Hospital	...	Australia	Woolloongabba	GE	PETtrace	16
Argos Zyklotron Klagenfurt	...	Austria	Klagenfurt	GE	PETtrace	16
Argos Zyklotron Linz	...	Austria	Linz	GE	PETtrace	16
Seibersdorf Laboratories	...	Austria	Seibersdorf	GE	PETtrace	16
AKH Wien	...	Austria	Wien	GE	PETtrace	16
No Title	...	Azerbaijan	Baku	IBA	CYCLONE 18	18
King Hamad Univ. Hospital	...	Bahrain	Manama	GE	PETtrace	16
Masihe Daneshavari Hospital	...	Bangladesh	Dhaka	GE	MiniTrace	10



https://nucleus.iaea.org/sites/accelerators/Pages/Cyclotron.aspx

Conference in 2019

International Symposium on Trends in Radiopharmaceuticals (ISTR-2019)

28 October–1 November 2019, Vienna, Austria

Trends in Radiopharmaceuticals (ISTR-2019)

Home

› News

Progress in nuclear medicine has been always tightly linked to the development of new radiopharmaceuticals and efficient production of relevant radioisotopes. The use of radiopharmaceuticals is an important tool for better understanding of human diseases and developing effective treatments. The availability of new radioisotopes and radiopharmaceuticals may generate unprecedented solutions to clinical problems by providing better diagnosis and more efficient therapies.

Impressive progress has been made recently in the radioisotope production technologies owing to the introduction of high-energy and high-current cyclotrons and the growing interest in the use of linear accelerators for radioisotope production. This has allowed broader access to several new radionuclides, including gallium-68, copper-64 and

Live
Video Stream

Conference App

Related resources

Online Pre-Registration

Announcement and Call for Papers

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Thanks!
Grazie Mille!!