Nuclear Technologies Contributing to Sustainability
LAS-ANS Symposium 2022

Nuclear Technologies in Industry

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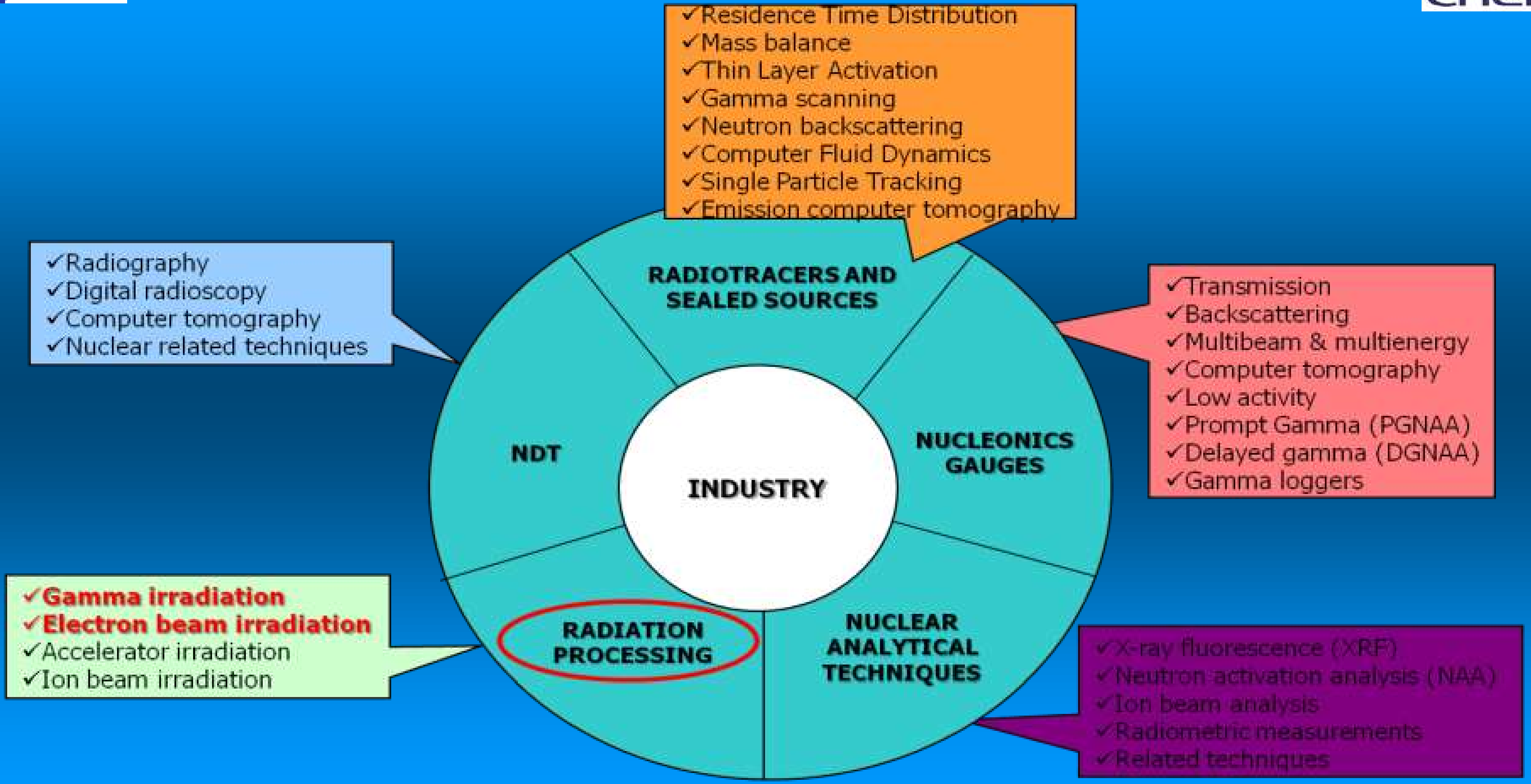
Nuclear and Energy Research Institute
National Nuclear Energy Commission - Brazil
IPEN/CNEN

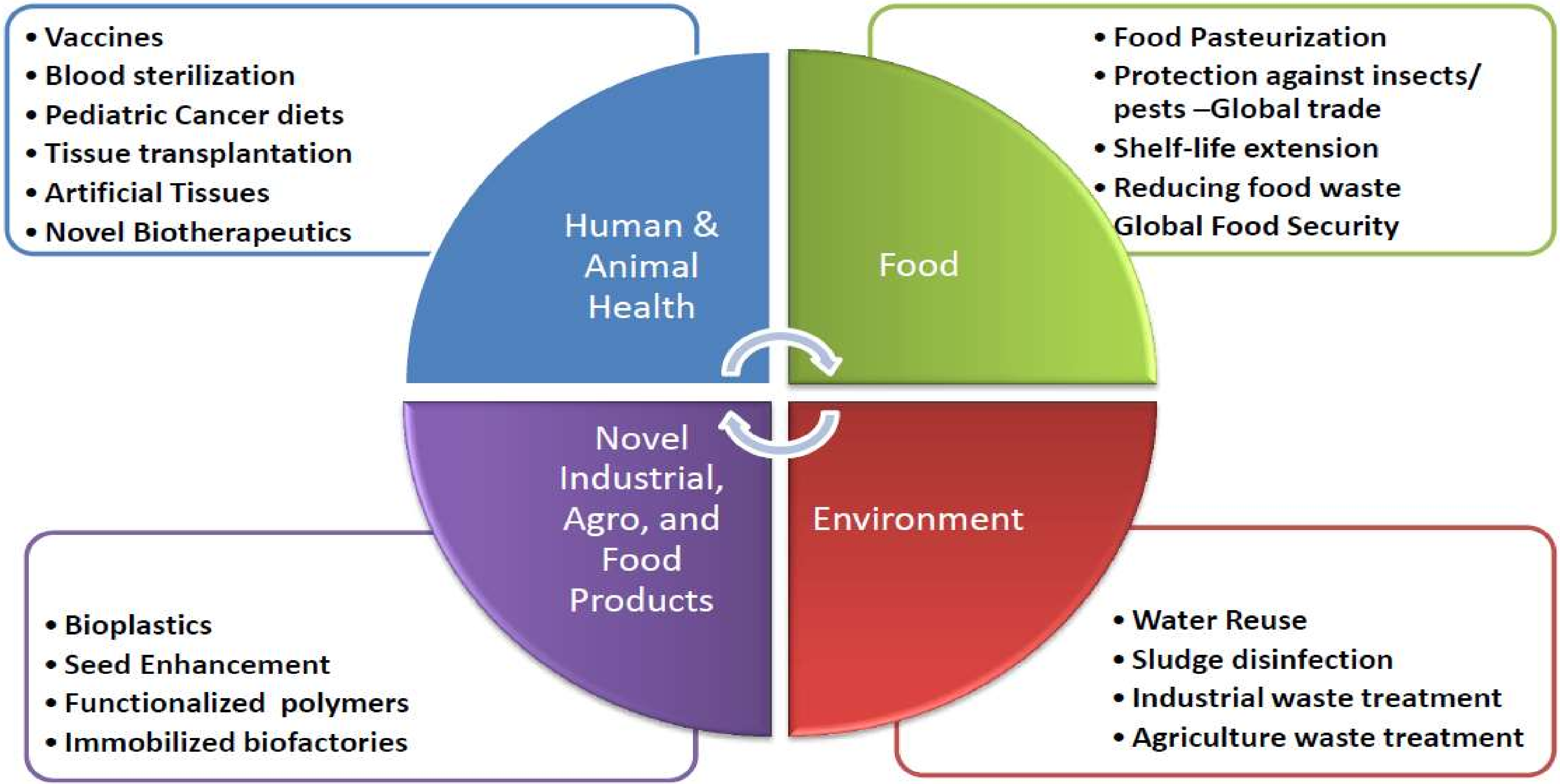
21st June, 2022

APPLICATIONS OF RADIATION AND RADIOISOTOPES TECHNIQUES IN INDUSTRY

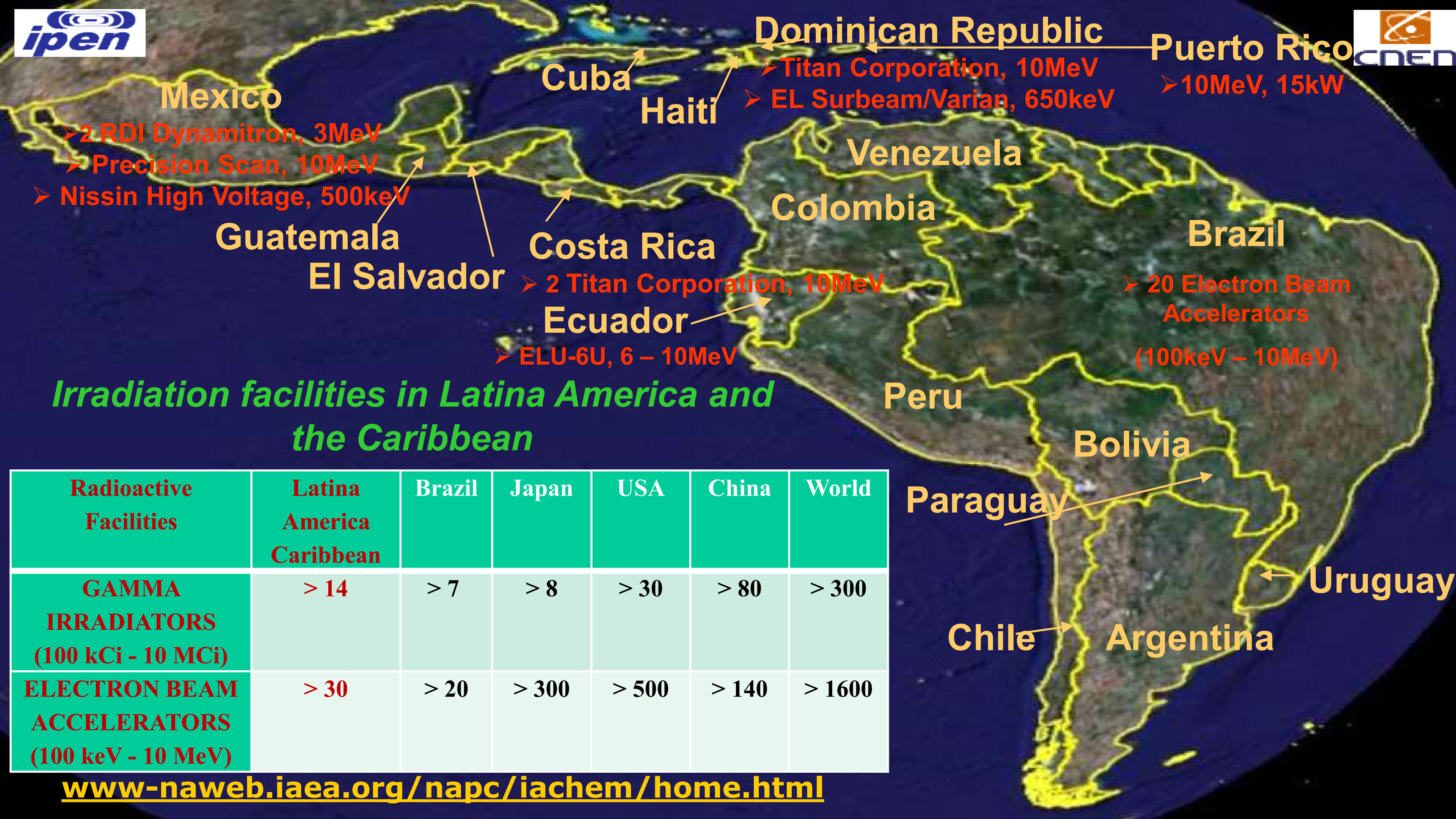


Source: IAEA

GAMMA RAYS AND ELECTRON BEAM TECHNOLOGY APPLICATIONS



Source: Texas A&M University



Irradiation facilities in Latina America and the Caribbean

Radioactive Facilities	Latina America Caribbean	Brazil	Japan	USA	China	World
GAMMA IRRADIATORS (100 kCi - 10 MCi)	> 14	> 7	> 8	> 30	> 80	> 300
ELECTRON BEAM ACCELERATORS (100 keV - 10 MeV)	> 30	> 20	> 300	> 500	> 140	> 1600

www-naweb.iaea.org/napc/iachem/home.html

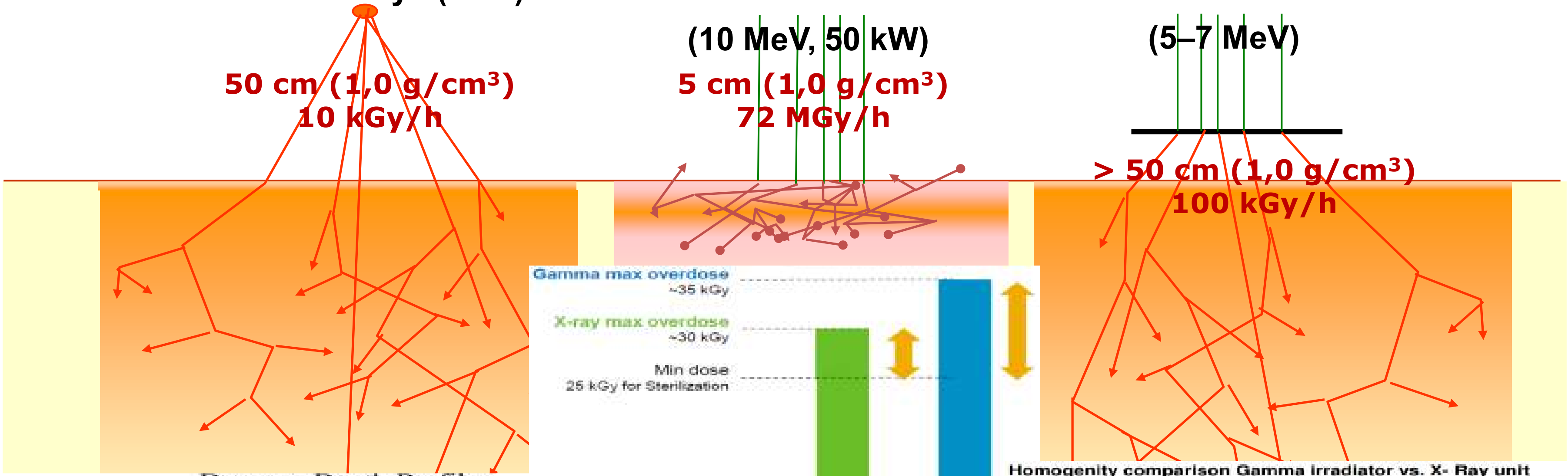
GAMMA IRRADIATOR (PALLET CONVEYOR)

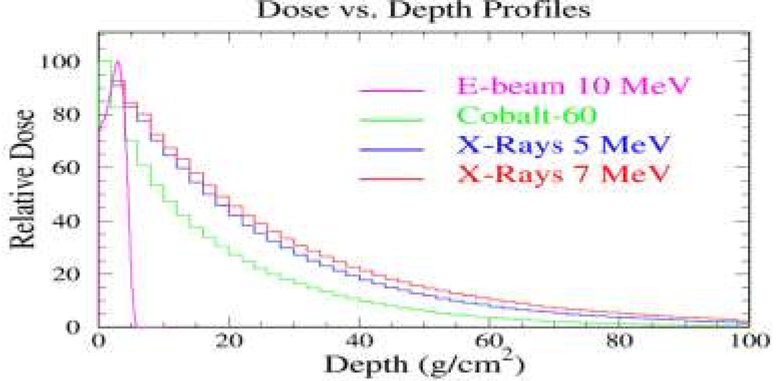
Brazilian Technology (3MCi)

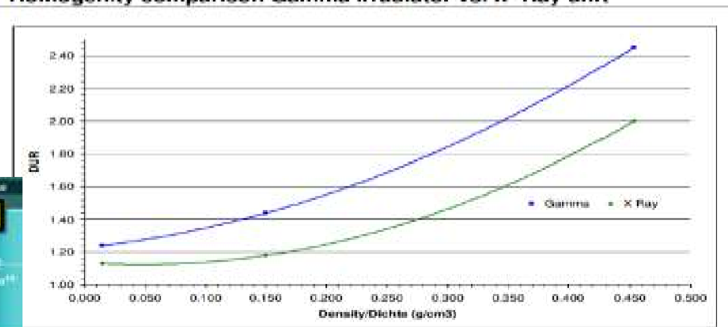
Source: Sterigenics

GAMMA RAYS, ELECTRON BEAM AND X-RAYS

Gamma Rays (^{60}Co) | Electron Beam (10 MeV, 50 kW) | X-Rays (5–7 MeV)







Source: IBA and IPEN/CNEN

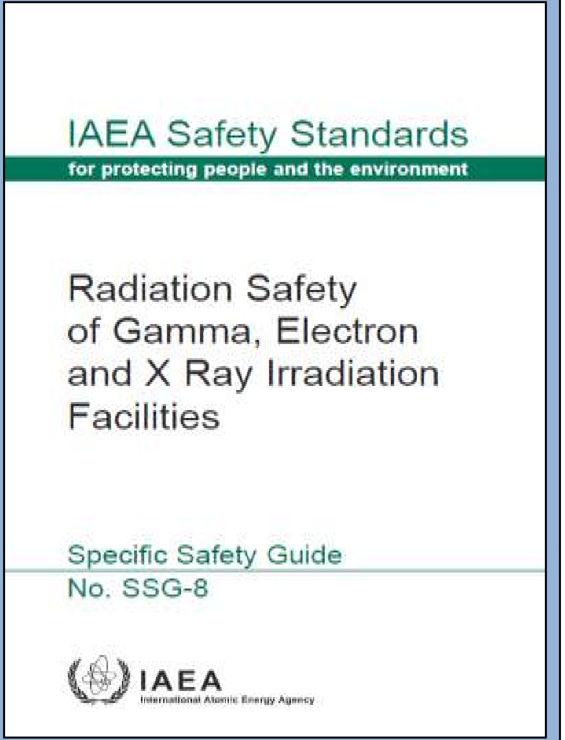
Safety Design, Construction and Operation

1. International Basic Safety Standards (BSS)
   - Protection against Ionizing Radiation
   - Safety of Radiation Sources

2. IAEA Safety Standards and Lessons Learned from Accidents in Industrial Irradiation Facilities

3. CNEN Safety Standards of the National Nuclear Energy Commission – Brazil

4. AAMI/ISO 11137 - Sterilization of Health Care Products – Requirements for Validation and Routine Control – Radiation Sterilization


IAEA Safety Standards
for protecting people and the environment

Radiation Safety of Gamma, Electron and X Ray Irradiation Facilities

Specific Safety Guide
No. SSG-8

IAEA
International Atomic Energy Agency

Source: IPEN/CNEN

Nuclear Technologies Contributing to Sustainability

AGRICULTURE

Food Irradiation
Treatment of Seeds

FOOD IRRADIATION

Current Production Volumes of Irradiated Food Stuffs

Region	Volumes (Metric tons)	Market Condition
USA	175,000	Flat
EU	198,000	Declining
Asia	450,000	Increasing

92% of food stuffs are treated with Cobalt-60. Only 8% is represented by E-beam

Latina America and Caribbean > 100,000 tons/year

Spices

Medicinal herbs

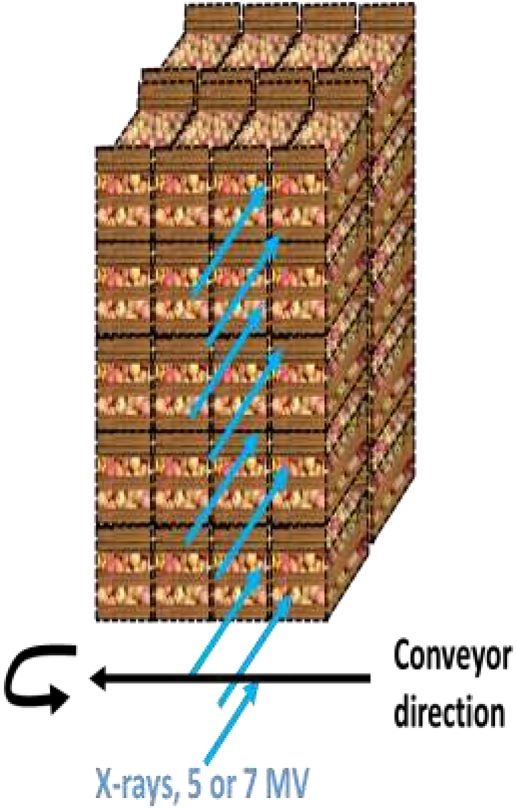
Mango (Mexico)

Food industry are looking for EB or X-ray machines:

- Lower capital cost
- Reliable
- Simple enough to operate
- Lower cost of operation
- Compact enough to integrate in existing
- Production in-line or a packing house space

Source: L3

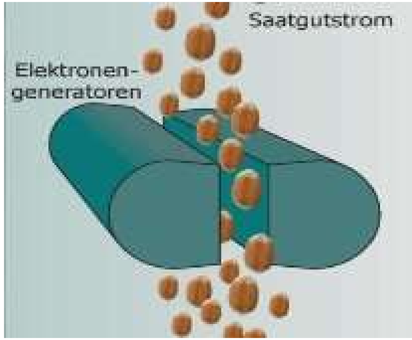
FOOD IRRADIATION (X-RAYS AND PALLET CONVEYOR)

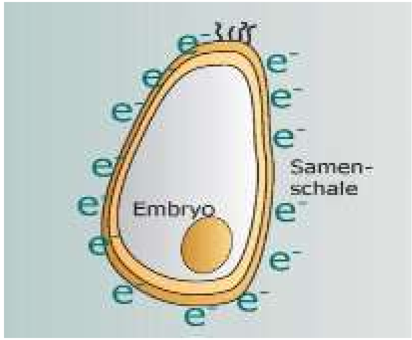


X Ray horn and pallet conveyor

Source: IBA/AERIAL

ELECTRON TREATMENT OF SEEDS





<u>IPEN/Fraunhofer</u>

Memorandum of understanding (MoU)

- **Penetration of episperm by electrons with precise depth control**
- **Embryo keeps untouched**

- **<u>Mobile treatment plant</u>**
  - ✓ **Continuous treatment on air**
  - ✓ **Throughput: 30 t/h**
  - ✓ **2 line emitting sources (150keV/30kW)**

<u>Source</u>: Fraunhofer Institut-FEP (<u>Seed-Health@fep.fraunhofer.de</u>)

Nuclear Technologies Contributing to Sustainability

INDUSTRY

Material Modification
Sterilization of Healthcare Products
Printing and Curing
Cultural Heritage

ELECTRON BEAM TECHNOLOGY APPLICATIONS

no Peroxides
less energy

better properties
less / no additives

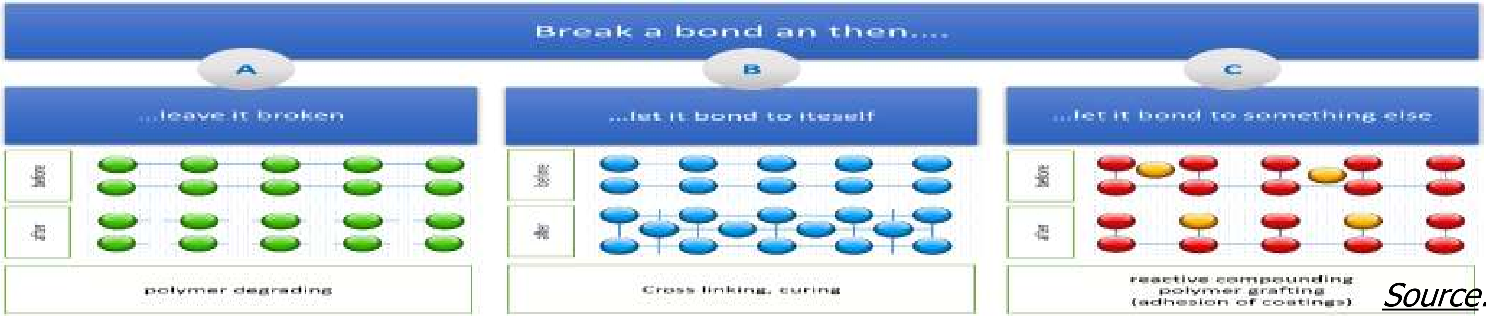
no UV-Initiators
less energy

better properties

no chemicals
less energy

no chemicals

processability
less material



Source: COMET Ebeam

STERILIZATION OF HEALTHCARE PRODUCTS

Sterigenics International

Science Driven • Healthcare Focused • Globally Trusted

Sterilized Medical Devices: 135.000 m^3/year

Source: Sterigenics

E-BEAM PRINTING AND CURING

RadTech South America

- Integrated shield roll design
  - With sealed e-beam Emitter
- Features
  - Energy: **80kV to 180kV**
  - Web width: **360mm**
  - Web speed **90m/min at 25kGy**
- Applications
  - Pilot / development lines
  - Narrow web printing presses
  - Presses for shrink sleeve labels

- no VOC (like thermal)
- no Photoinitiators (like UV)
- low substrate heating
- electrons are "colorblind"
- higher speed

e⁵

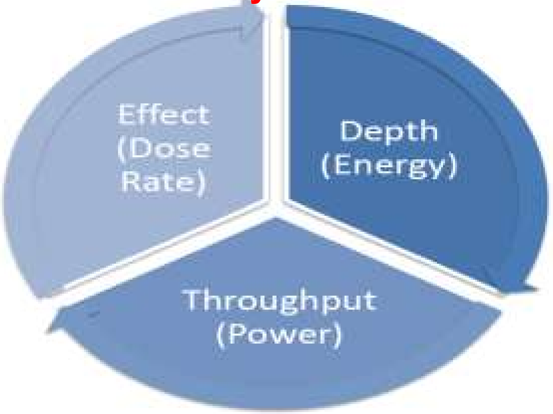
efficient

enabling

economical

energy savings

environmental friendly



Sources: RadTech and COMET Ebeam

- **Disinfestation and disinfection of cultural objects at IPEN/CNEN (books, furniture, sculptures and paintings)**

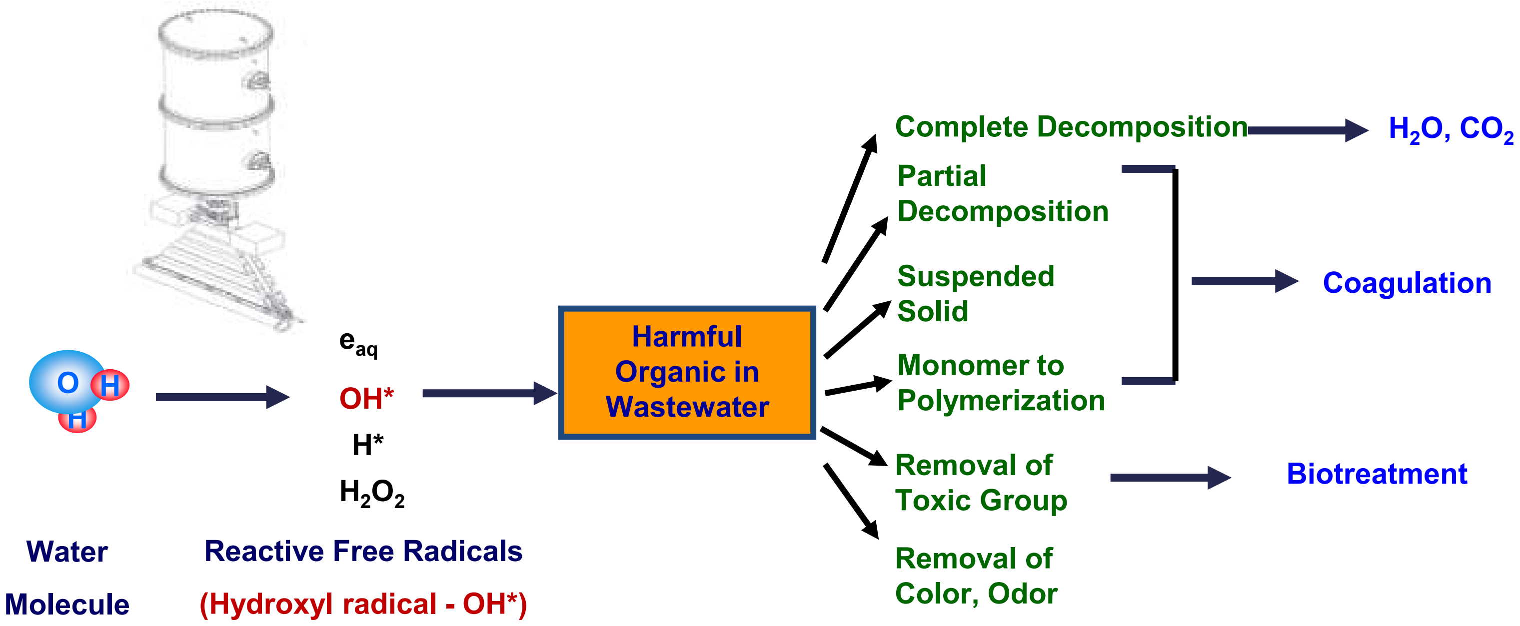
Source: IPEN/CNEN

Nuclear Technologies Contributing to Sustainability

ENVIRONMENTAL PROTECTION

Wastewater Treatment

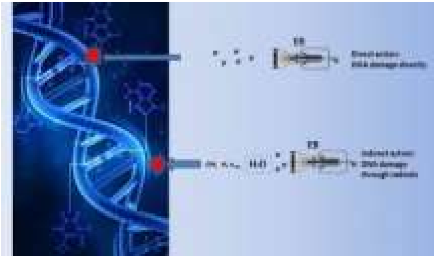
PRINCIPLES OF WASTEWATER TREATMENT WITH ELECTRON BEAM IRRADIATION



- **Removal of harmful impurities (COD, BOD, S/S)**
- **Removal of colour, odour and others**
- **Disinfection of microorganisms (Coliforms & pathogenic organisms)**
- **Destruction of endocrine disrupter and synthetic chemicals**

Source: IAEA

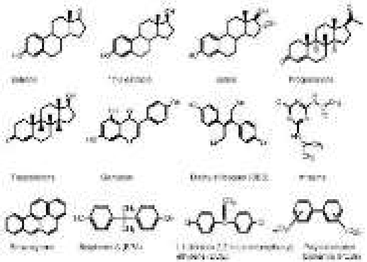
PARTICIPATION IN COORDINATED RESEARCH PROJECTS ON WASTEWATER AND SLUDGE TREATMENT



1) Radiation Inactivation of Bio-hazards Using High Powered Electron Beam Accelerators (2018 - 2022)

Objective: To enhance and strengthen use of EBA for treatment of biohazards of concern under changing conditions such as at high dose rates, different ambient conditions, and varying substrates in **applications such as radiation sterilization, hygienization of biosolids, sanitizing infectious hospital waste or toxic effluents and eliminating deliberate biohazards**

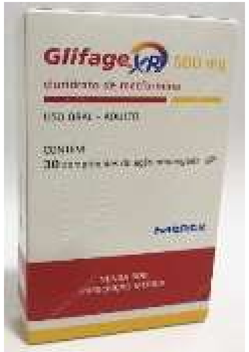
2) Removal of Emerging Organic Pollutants in the Wastes by Radiation (2019 - 2023)



Objective: To exploit the innovative methodologies and technologies **to remove the emerging pollutants such as endocrine disruptors, pharmaceutical residues, and other toxic pollutants in wastewater and sludge**

Source: IAEA, IPEN/CNEN

PHARMACEUTICALS AND WATER IMPACTS



- From humans and animals, pharmaceuticals going to several environmental matrices: water, sewage, soil, plants and food !!!

Green algea

Dafnids

Salmo trutta

- **Pharmaceuticals have been introduced into the food chain !!!**

<u>Source</u>: IPEN/CNEN

ELECTRON BEAM IRRADIATION OF PHARMACEUTICALS

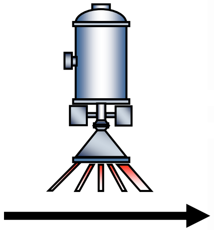
Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-020-11718-8

ADVANCED OXIDATION/REDUCTION TECHNOLOGIES: AN PERSPECTIVE FROM IBEROAMERICAN COUNTRIES

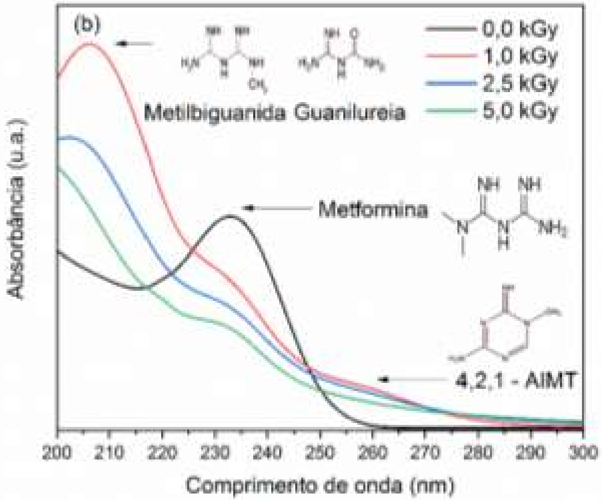
Is ionizing radiation effective in removing pharmaceuticals from wastewater?

Flávio Kiyoshi Tominaga[1] · Thalita Tieko Silva[1] · Nathalia Fonseca Boiani[1] · Juliana Mendonça Silva de Jesus[2] · Antonio Carlos Silva Costa Teixeira[2] · Sueli Ivone Borrely[1]

- **Fluoxetine – Prozac** (depression)
- **Amoxicilin; Ciprofloxacin; Sulfadiazine** (antibiotics)
- **Aspirin and Voltaren** (anti-inflamatory)
- **Propranolol** (blood pressure)
- **Metformin** (diabetics)



Degradation of Metformin Induced by EB Irradiation



Source: IPEN/CNEN

CHINA'S ELECTRON BEAM INDUSTRY OPENS WORLD'S LARGEST WASTEWATER TREATMENT FACILITY

- Capacity to treat 30 million liters of industrial wastewater/day
- Largest wastewater treatment facility using EB technology in the world
- Treatment process will save 4.5 billion liters of fresh water/year
- Enough to quench the thirst of 100,000 people/year

Guanhua Knitting Factory in southern China

Nuclear and Energy Technology Institute Tsinghua University

June 29th, 2020

Source: IAEA

IAEA TC PROJECT BRA1035 ON WASTEWATER TREATMENT

- **IAEA TC PROJECT BRA1035 - Establishing a Mobile Unit with an Electron Beam Accelerator to Treat Industrial Effluents for Reuse Purposes (2016 - 2020)**

- **INNOVATION AGREEMENT with Truckvan Industry**

Objective: To enlarge the national capacity to treat industrial effluents using electron beam accelerators, **the mobile unit treating effluents on site from 1 m^3/h up to 1,000 m^3/day**, **will provide an effective facility between a laboratory-scale plant to a large-scale plant with the objective to demonstrate the efficacy and transfer the technology**





Source: IPEN/CNEN

IAEA TC PROJECT BRA1035 ON WASTEWATER TREATMENT AT IPEN-CNEN

➢ Quantities of energy, treatment capacity and costs by type of effluent treated in the Mobile Unit

EFFLUENTS	Dose (kGy)	Amount (m^3/day)	Power (kW)	Capital cost (Million US$)	*Variable cost **(Variable and fixed costs) (US$)	Cost/m^3 of effluent treated (US$)
Removal of geosmine (GEO) and methilisoborneol (MIB) from drinking water	1	1,000	20	1.5	0.20 (0.38)	0.60 (1.14)
Removal of industrial textile dyeing from wastewater	2	500	20	1.5	0.20 (0.38)	1.20 (2.28)
Elimination of coliforms from raw sewage, secondary and chlorinated effluents	3	340	20	1.5	0.20 (0.38)	1.77 (3.36)
Removal of organic compounds from petroleum production water	20	50	20	1.5	0.20 (0.38)	12.0 (22.8)
Removal of PCB from transformers oils	50	20	20	1.5	0.20 (0.38)	30.1 (57.1)

* Variable cost only (maintenance, electricity and labor)
** Both variable and fixed costs (depreciation, bank interest and management)

Business Plan for the IAEA TC Project BRA1035:

a) Project Costs

➢ Capital Cost (Investment)
Initial investment costs of the Mobile Electron Accelerator: US$1,500,000.00

➢ Operating Costs
Operating costs (fixed and variable) of the Mobile Electron Accelerator: US$380,500.00/year

➢ Rental Price of the Mobile Facility
Rental price calculation of the Mobile Electron Accelerator: US$31,708.00/month or US$380,496.00/year

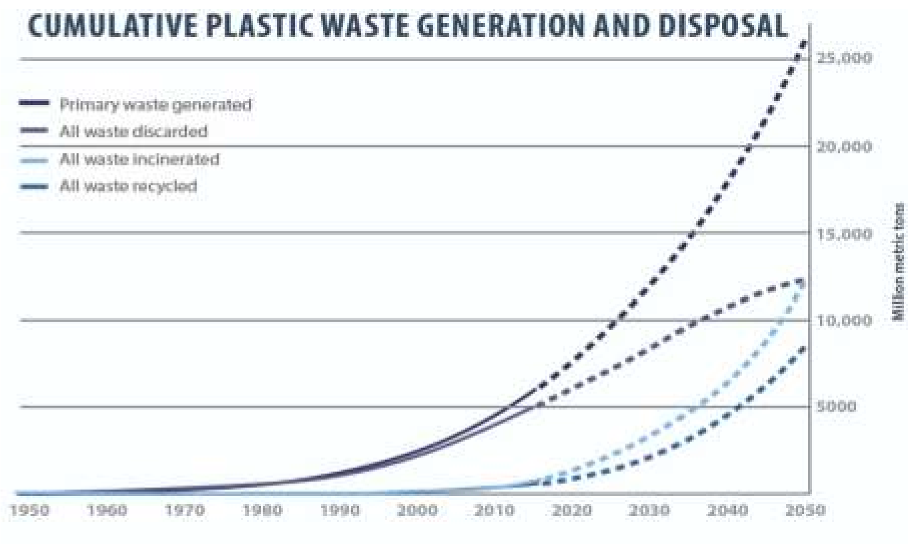
Source: IPEN/CNEN

Nuclear Technologies Contributing to Sustainability

ENVIRONMENTAL PROTECTION

NUTEC Plastics
Polymer Biodegradable

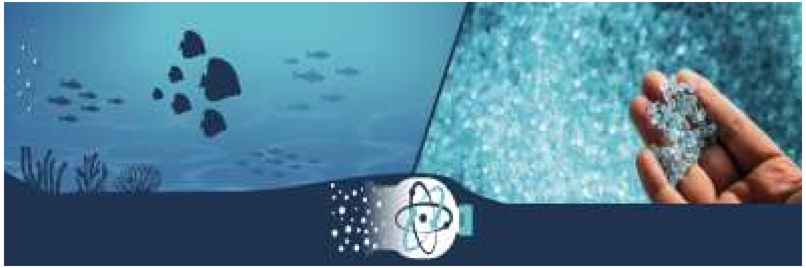
NUCLEAR TECHNOLOGY FOR CONTROLLING PLASTIC POLLUTION (NUTEC PLASTICS)



Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science advances, 3(7), e1700782.

- **IAEA's efforts to deal with plastic pollution through recycling using radiation technology and marine monitoring using isotopic tracing techniques**

It provides science-based evidence to characterize and assess marine microplastic pollution, while also demonstrating the use of ionizing radiation in plastic recycling, transforming plastic waste into reusable resources



Recycling with irradiation

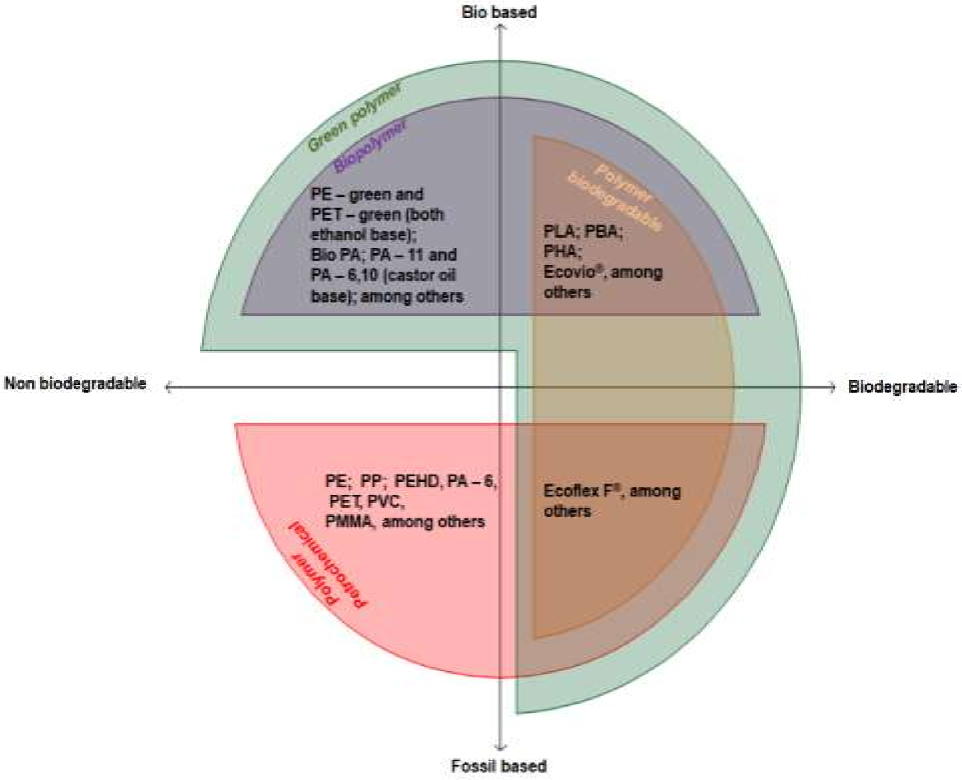
Using gamma and electron beam radiation technologies as a complement to traditional mechanical and chemical recycling methods, certain types of plastic waste can be modified and therefore reused or recycled. These technologies can complement existing recycling methods to:

- **Sort mechanically treated plastic waste according to polymer type.**
- **Breakdown plastic polymers into smaller components to be used as raw materials for new plastic products.**
- **Treat plastic so that it can be amalgamated with other material to make more durable products.**
- **Convert plastic into fuel and feedstock through radiolysis (irradiation + chemical recycling).**

- **Precise scientific data to inform plastic pollution policies**
- **Strengthened methodology to track plastics**
- **Effective and efficient technologies**
- **Scalable technology**

Source: IAEA

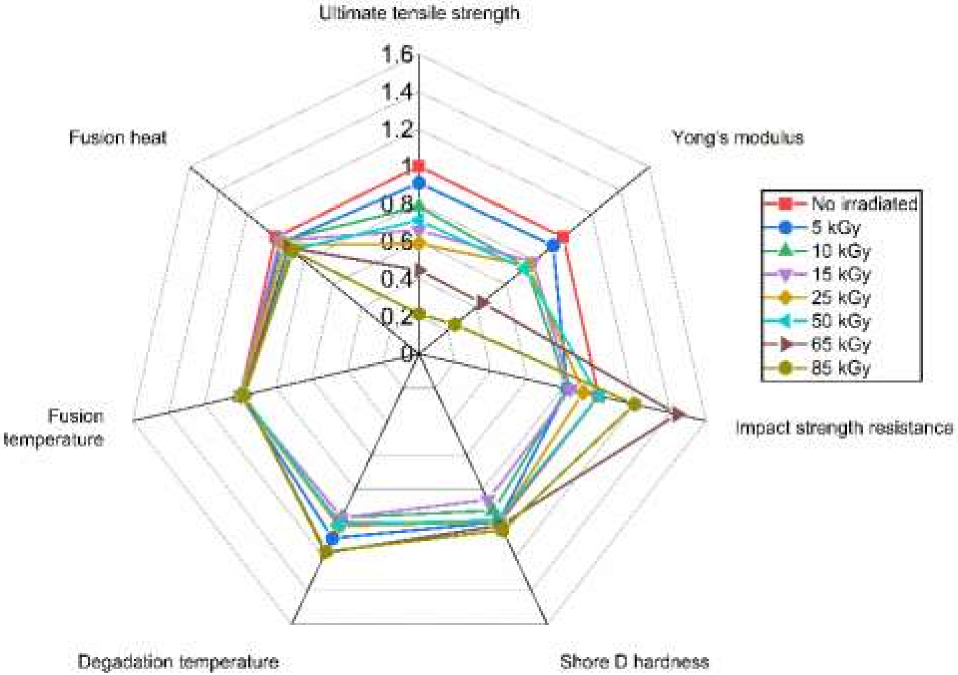
INFLUENCE OF ELECTRON BEAM IRRADIATION ON THE MECHANICAL AND THERMAL PROPERTIES OF PBAT/PLA POLYMERIC BLEND ECOVIO®



- **GREEN POLYMER - BIODEGRADABLE POLYMERIC BLEND ECOVIO® needs to be resistant to cross sectional demands, impact and thermal stability and should have an average lifetime of 1 to 5 years**
- **Then, for INJECTED PACKAGING, FILMS FOR TUBE PRODUCTION, PLASTIC BAGS, PACKAGING FOR COSMETICS AND FOOD, it is recommended to use the PBAT/PLA polymeric blend Ecovio® irradiated by EB with 65 kGy**
- **Industrial EBA (1.5 MeV, 25 mA, 37.5 kW) application on the PBAT/PLA polymeric blend Ecovio® was studied.**

Source: IPEN/CNEN

RESULTS OF MECHANICAL AND THERMAL ANALYZES OF THE PBAT/PLA POLYMERIC BLEND ECOVIO® AS A FUNCTION OF RADIATION DOSE



- **EB irradiation reduce only 2.4% the melting temperature of the PBAT/PLA polymeric blend with an absorbed dose of 80 kGy.**
- **A reduction of 78.6% was observed in relation to tensile strength at the highest radiation dose of 80 kGy.**
- **There was also a reduction of 80% in Yong's modulus at 80 kGy absorbed dose.**
- **A significant change in hardness was not observed at a dose of 65 kGy in relation to the non-irradiated material.**
- **With absorbed dose of 65 kGy , there was an increase of 43% in impact strength resistance and an increase of 17.4% in thermal stability of the polymeric blend**

Source: IPEN/CNEN

Nuclear Technologies Contributing to Sustainability

HEALTH

Radioisotope Production (Industry and Nuclear Medicine)
Brazilian Multipurpose Reactor

PRODUCTION OF RADIOPHARMACEUTICALS AT IPEN/CNEN

^{125}I, ^{131}I, ^{153}Sm, ^{192}Ir

RADIOISOTOPES

Material Test Reactors

Radiopharmaceuticals

Nuclear Medicine

Cyclotrons

Image Equipment

^{123}I, ^{18}F, ^{67}Ga, ^{201}Tl

- US$ 25 millions/year
- 460 hospitals and clinics
- 2 millions procedures/year

Source: IPEN/CNEN

PRODUCTION OF RADIOPHARMACEUTICALS AT IPEN/CNEN

$^{99}Mo/^{99m}Tc$ Generators

- 400 generators / week
- 450 Ci (^{99}Mo) / week
- 250 - 2000 mCi

Imported radioisotopes costs

- US$ 15 million/year (^{99}Mo)
- US$ 3 million/year (radioisotopes for NM)

Solution → RMB Tecnologia Nuclear a Serviço da Vida

Source: IPEN/CNEN

RMB
Tecnologia Nuclear
a Serviço da Vida

Nuclear Research and Production Areas

1 – NRPA Entrance
2 – Researchers Bld.
3 – Workshop Bld.
4 – Waste Processing and Storage Bld.
5 – Electrical Supply Bld.
6 – Cooling Towers
7 – Reactor Auxiliary Bld.
8 – Reactor Bld.
9 – Spent Fuel Bld.
10 – Post Irradiation Lab.
11 – Radioisotope Processing Bld.
12 – Radiochemistry Lab.
13 – Operator Support Bld.
14 – Neutron Beam Lab.

Source: IPEN/CNEN

RMB Tecnologia Nuclear a Serviço da Vida

Radioisotope Production (Industry and Health)

Application	Radioisotope	Target Irradiation	Frequency of Production (1)	Annual Production (2) (Ci)
Injectable Radiopharmaceuticals	Mo-99	U-235	W	54,000
	I-131	U-235	W	5,400
	I-131	Te-130	W	2,700
	Cr-51	Cr-50	B	5.4i
	Sm-153	Sm-152	B	108
	Lu-177	Lu-176	W	270
	Ho-166	Ho-165	W	5.4
	Y-90	Y-89	W	5.4
	W-188	W-186	M	1.2
	P-32	S-32	B	5.4
Brachytherapy	I-125	Xe-124	W	120
	Ir-192	Ir-191 (seeds)	W	12.000
	Ir-192	Ir-191 (wires)	M	20 wires
Radiotherapy	Co-60	Co-59	Y	15
Industry	Ir-192	Ir-191 (pellets)	B	30,000
	Co-60	Co-59	Q	2.5
	Se-75 (3)	Se-74	M	6,000
Radiotracers	Br-82	Br-81	Q	0.2
	Hg-203	Hg-202	Q	15
	I-131	Te-130	W	On demand

Source: IPEN/CNEN

(1) Production = W (Weekly), B (Biweekly), M (Mounthly), T (Quarterly) and Y (Yearly)

(2) 1 Ci = 3.7 x 10^{10} Bq (Becquerel)

Thank you very much for your attention!

Wilson Aparecido Parejo Calvo
wapcalvo@ipen.br

SÃO PAULO GOVERNO DO ESTADO ipen cnen MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÕES PÁTRIA AMADA BRASIL GOVERNO FEDERAL