



Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



INAC 2013

XI Meeting on Nuclear Applications (ENAN)

Trends of Radiation Technology in Industry and Environmental Applications

Wilson Aparecido Parejo Calvo
National Nuclear Energy Commission – Brazil
Nuclear and Energy Research Institute
Radiation Technology Center
IPEN-CNEN/SP

wapcalvo@ipen.br



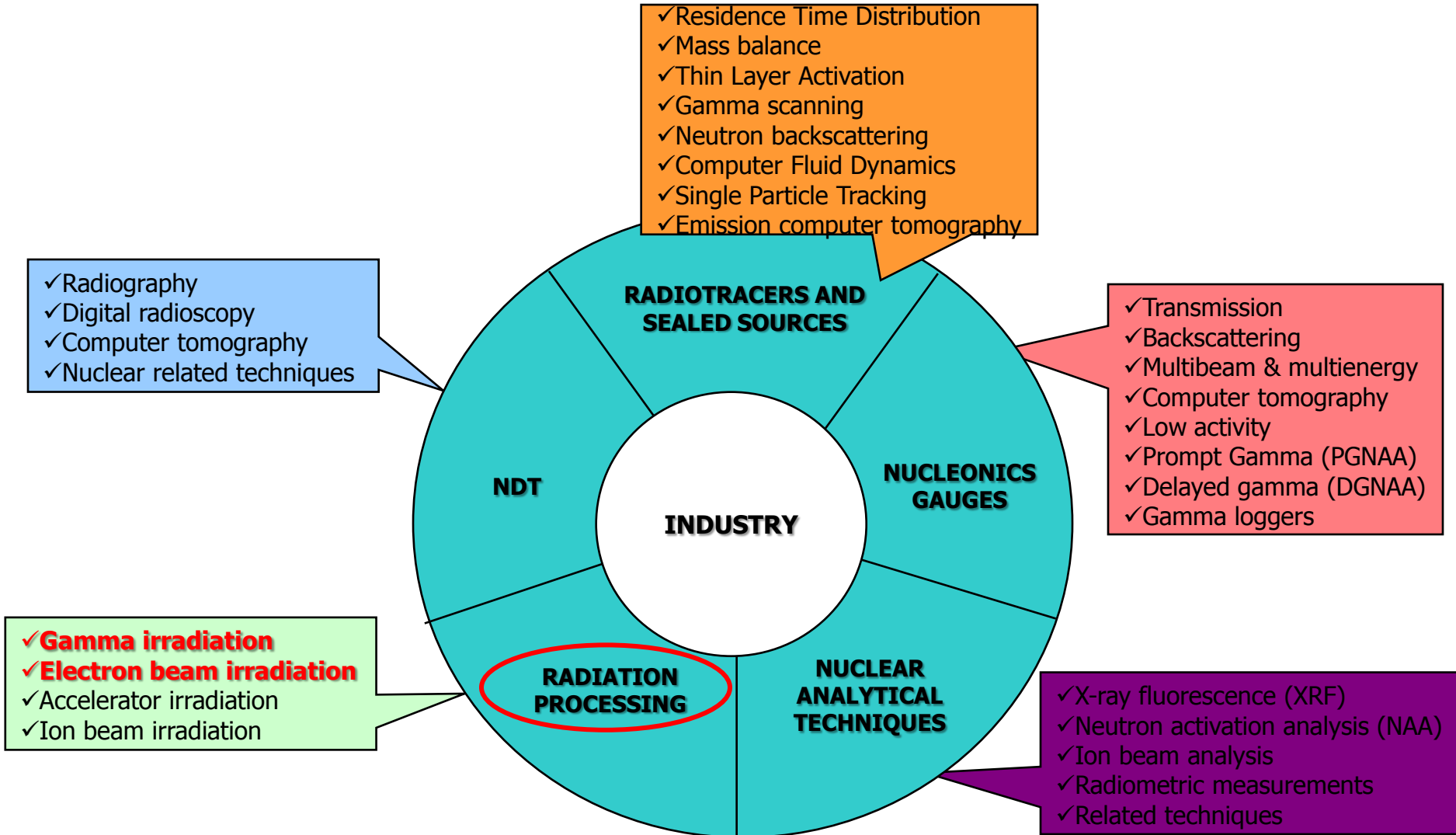
indc
2013
The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



APPLICATIONS OF RADIATION AND RADIOISOTOPES TECHNIQUES IN INDUSTRY



Source: IAEA

The UN Millennium Development Goals



Pillars of Sustainable Development



Gamma Rays, Electron Beam and X-Rays

Gamma Rays (^{60}Co)

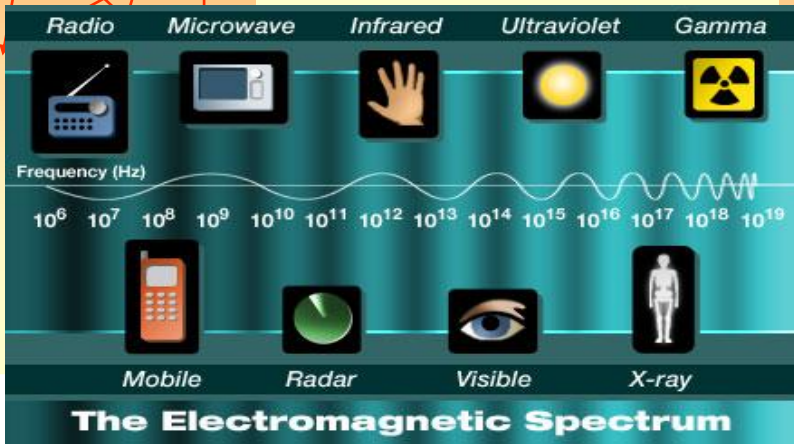
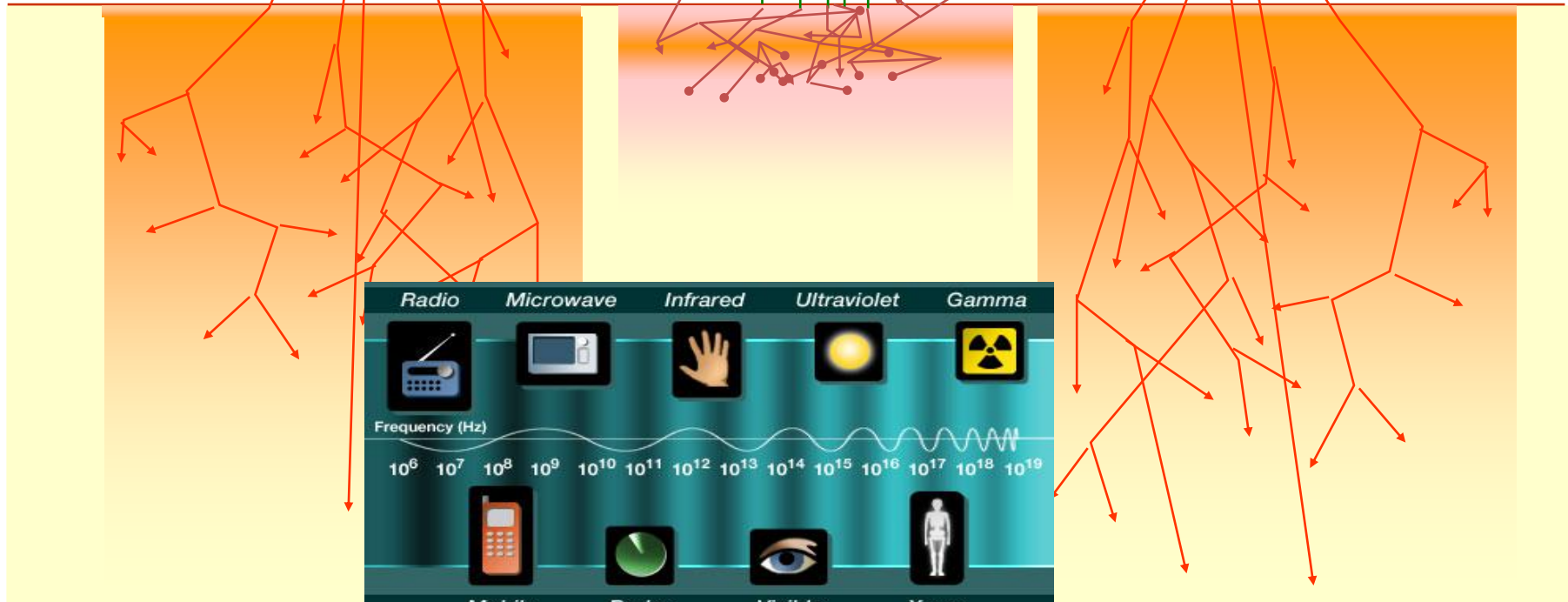
50 cm (1,0 g/cm³)
10 kGy/h

**Electron Beam
(10 MeV, 50 kW)**

5 cm (1,0 g/cm³)
72 MGy/h

X-Rays

(5–7 MeV)
> 50 cm (1,0 g/cm³)
100 kGy/h





Radioactive Facilities	South America	Brazil	Japan	USA	China	World
GAMMA IRRADIATORS (100 kCi - 10 MCi)	14	7	> 8	> 30	> 80	> 300
ELECTRON BEAM ACCELERATORS (200 keV - 10 MeV)	20	18	> 300	> 500	> 140	> 1500

Sources: IAEA, IPEN-CNEN/SP



2013
indc
International Nuclear Energy Agency

The Benefits of Nuclear
Technology for Social Inclusion

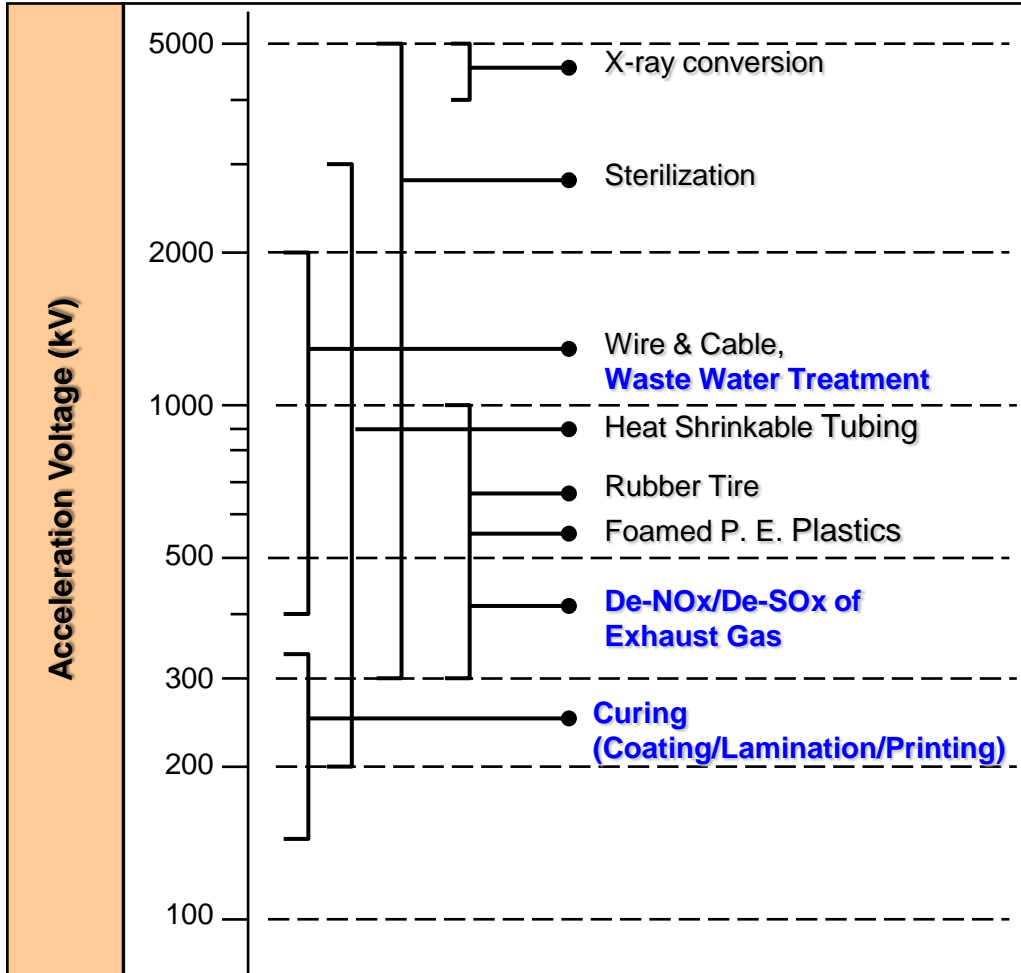
Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013

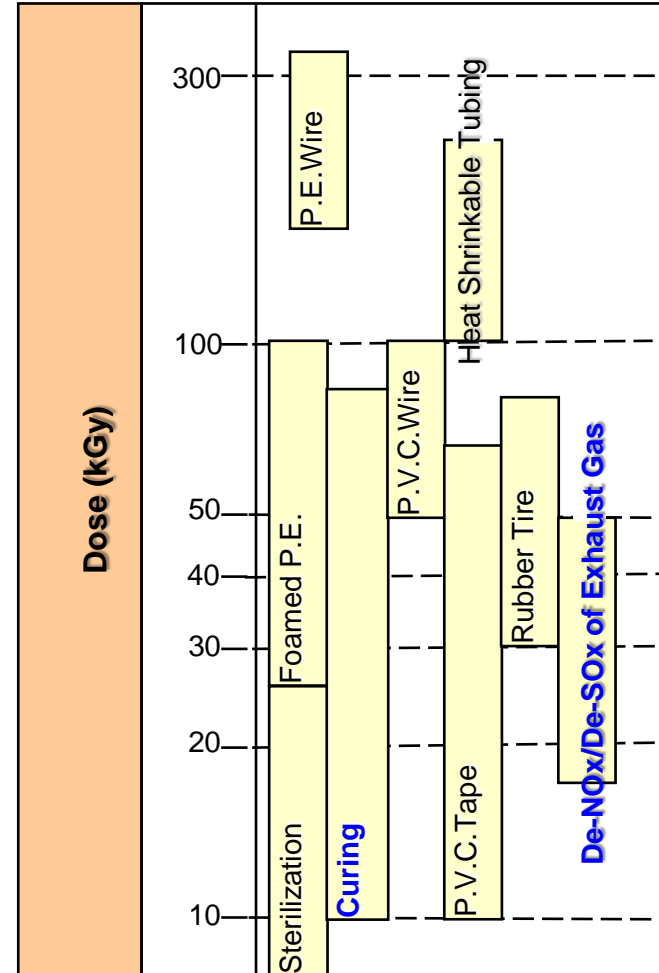


ELECTRON BEAM APPLICATIONS

Acceleration Voltage X Application



Dose X Application



ACELETRON INDUSTRIAL IRRADIATION





indc
Instituto Nacional de Desenvolvimento Científico e Tecnológico

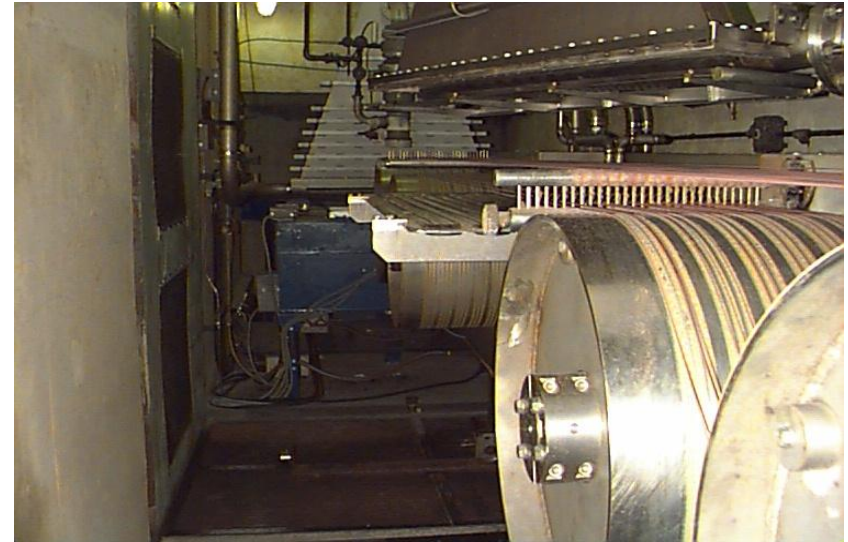
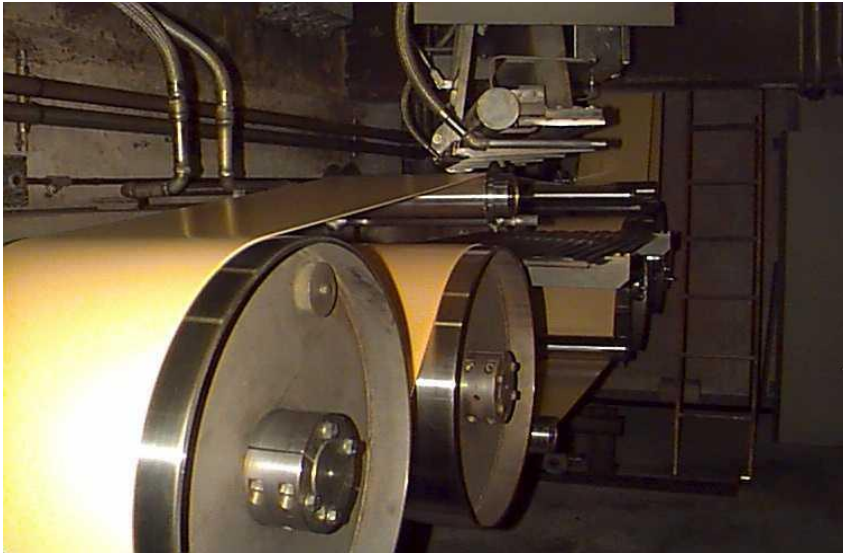
The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



IRRADIATION OF WIRE/ELECTRIC CABLES AND POLYETHYLENE FOAM



ACOME (Brazil) = 15,000 km/month

Source: IPEN-CNEN/SP



indc
International Nuclear Energy Research Institute

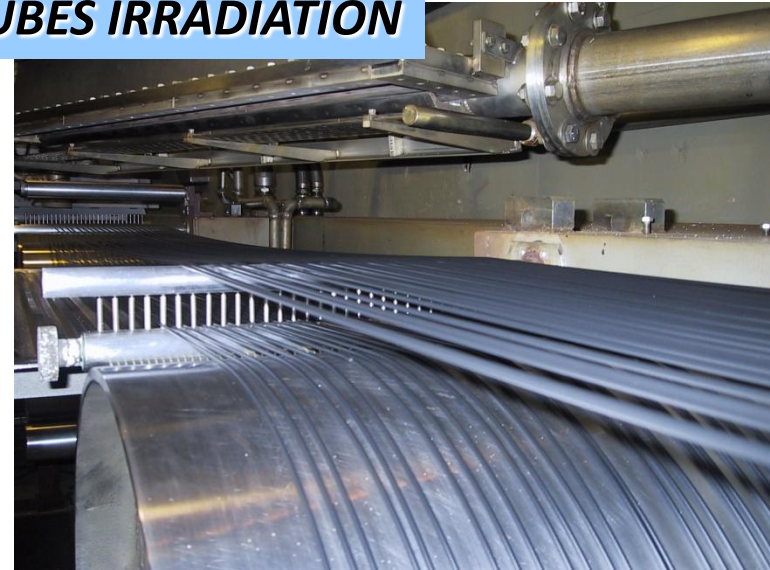
The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



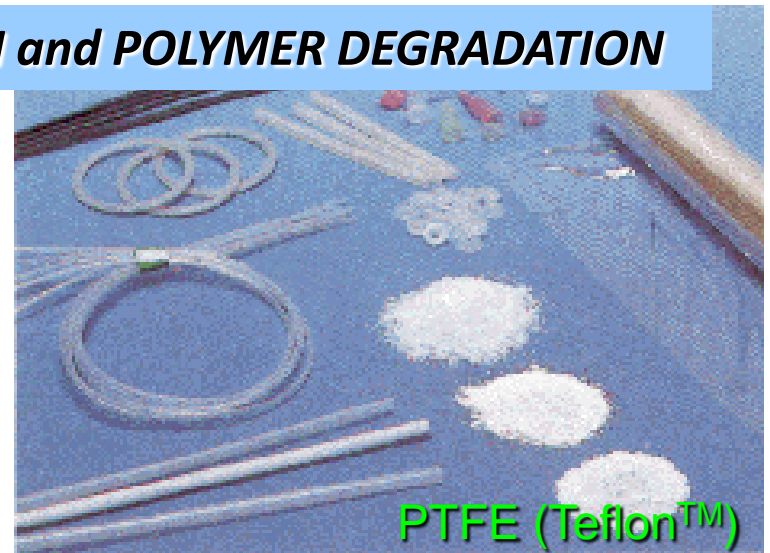
HEAT SHRINKABLE TUBES IRRADIATION



SEMICONDUCTORS IRRADIATION and POLYMER DEGRADATION



Powered
Diodes



PTFE (Teflon™)

Source: IAEA and IPEN-CNEN/SP



indc
International Nuclear and Environmental Technology Center

The Benefits of Nuclear
Technology for Social Inclusion

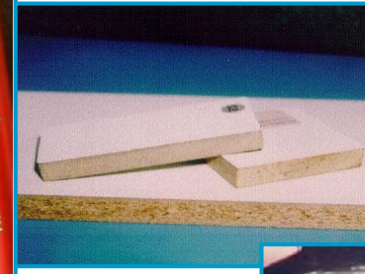
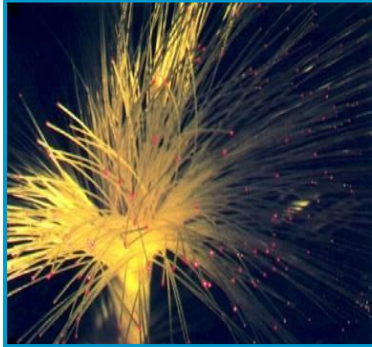
Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



UV/EB RADIATION CURING

e⁵
efficient
enabling
economical
energy savings
environmental friendly



Source: RadTech



indc
Instituto Nacional de Desenvolvimento Científico e Tecnológico

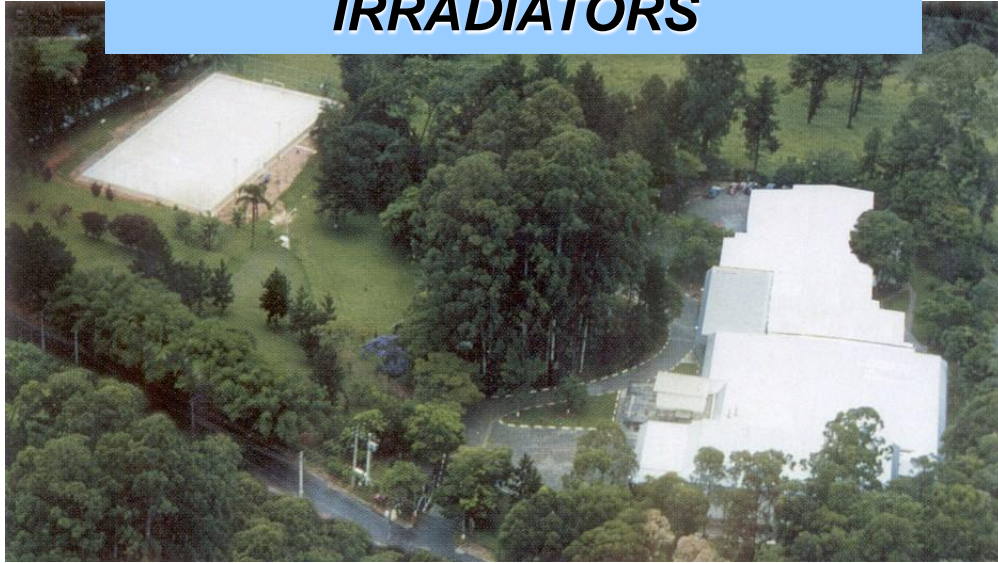
The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

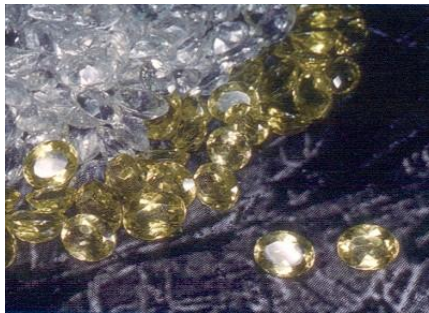
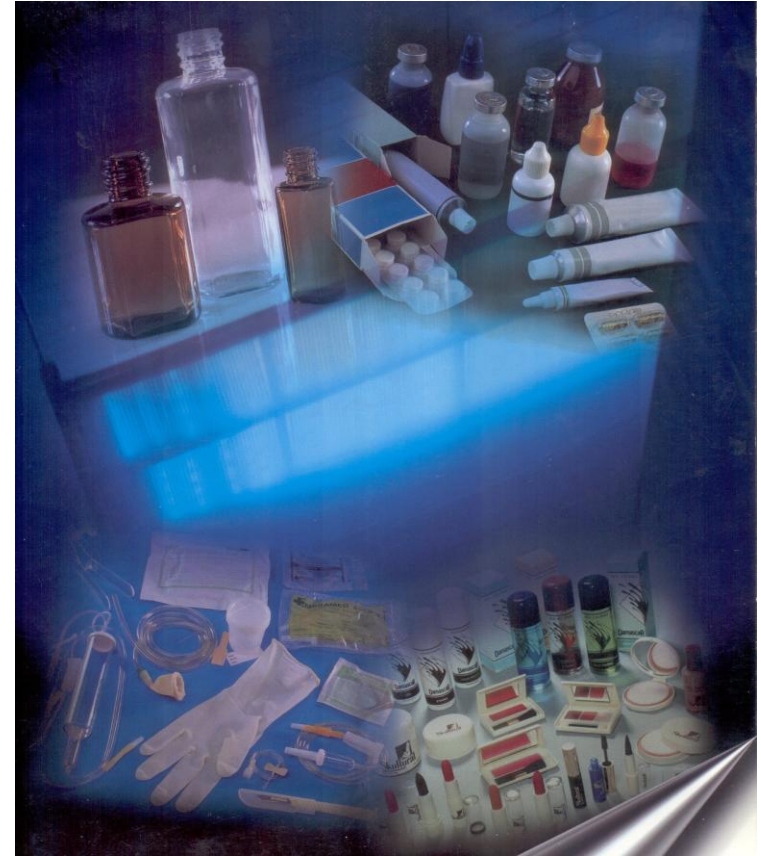
Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



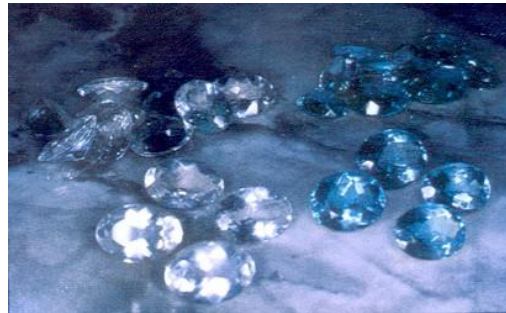
TOTE BOXES GAMMA IRRADIATORS



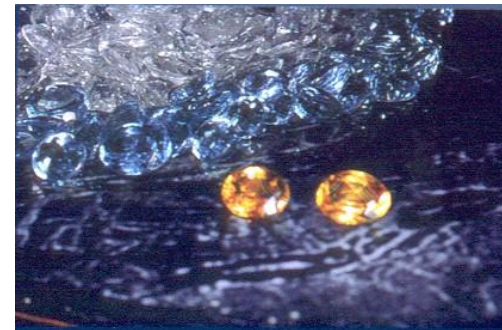
MDS Nordion Gamma Irradiators/Canada
(Categoria IV – AIEA)



White Quartz → Green Gold



Topaz



Blue Beryllium

Source: CBE



2013
indc
International Nuclear Energy Research Institute

The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



PALLET GAMMA IRRADIATOR



National Technology (3MCi)

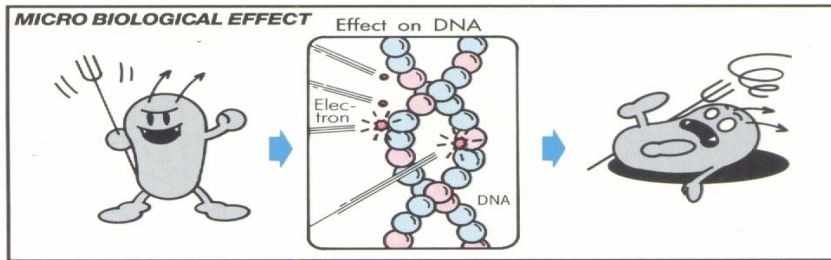


Source: CBE



STERILIZATION OF MEDICAL, PHARMACEUTICAL AND BIOLOGICAL PRODUCTS

World: ~60% (1500 electron beam accelerators)



STERILIZATION PROCESSES

NECESSARY CONTROLS	Gases	Liquids	Vapor	Filtration	Radiation
Time					
Temperature					
Package					
Pressure					
Humidity					
Concentration					
pH					



indc
Instituto Nacional de Desenvolvimento Científico e Tecnológico

The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



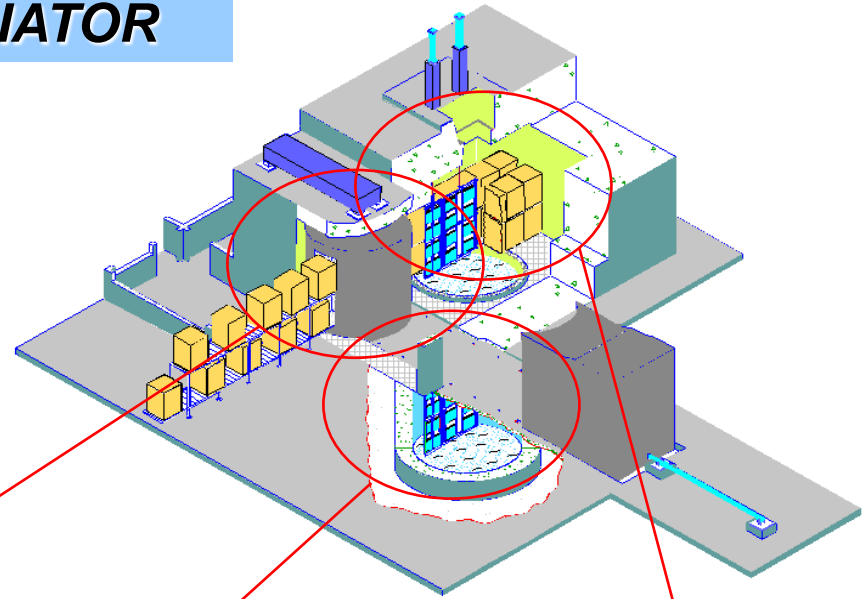
PANORAMIC GAMMA IRRADIATOR



MDS Nordion/Canada
(Category II – AIEA)

Source: CDTN-CNEN/MG

MULTIPURPOSE GAMMA IRRADIATOR



DUR / Efficiency:
 1,33 / 11,6% (0,09g/cm³)
 2,08 / 36,6% (0,49g/cm³)



Source: IPEN-CNEN/SP

RADIATION PROCESSING OF CULTURAL HERITAGE

Routine operations (semi-industrial scale)

- Disinfestation and disinfection of cultural objects (books, furniture, sculptures and paintings)





INDC
Instituto Nacional de Cultura

The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



RADIATION PROCESSING OF CULTURAL HERITAGE

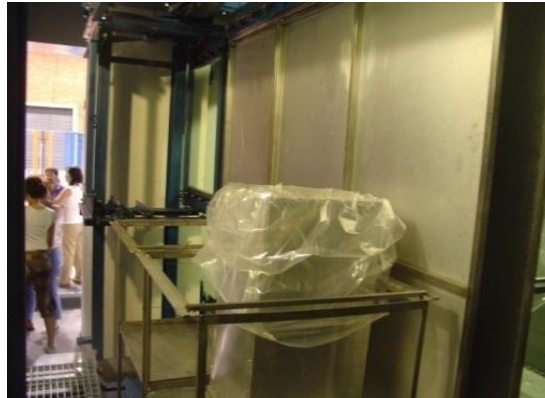
Extraordinary cultural objects irradiations



Source: IPEN-CNEN/SP

RADIATION PROCESSING OF CULTURAL HERITAGE

Floods and natural disasters recovery



Electron Beam Technology for Pollution Control



Flue gas Purification



Wastewater Treatment



Sludge Hygienization





indc
International Nuclear
Congress

The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013

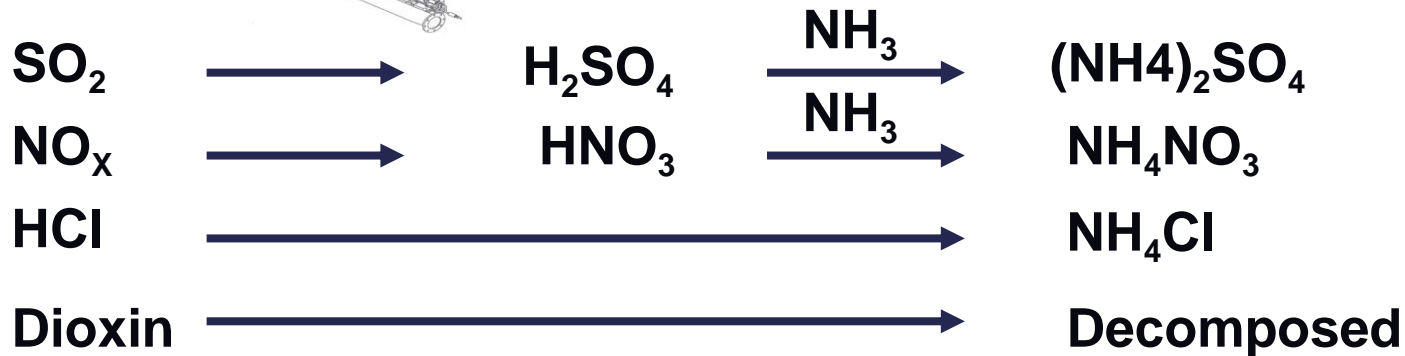
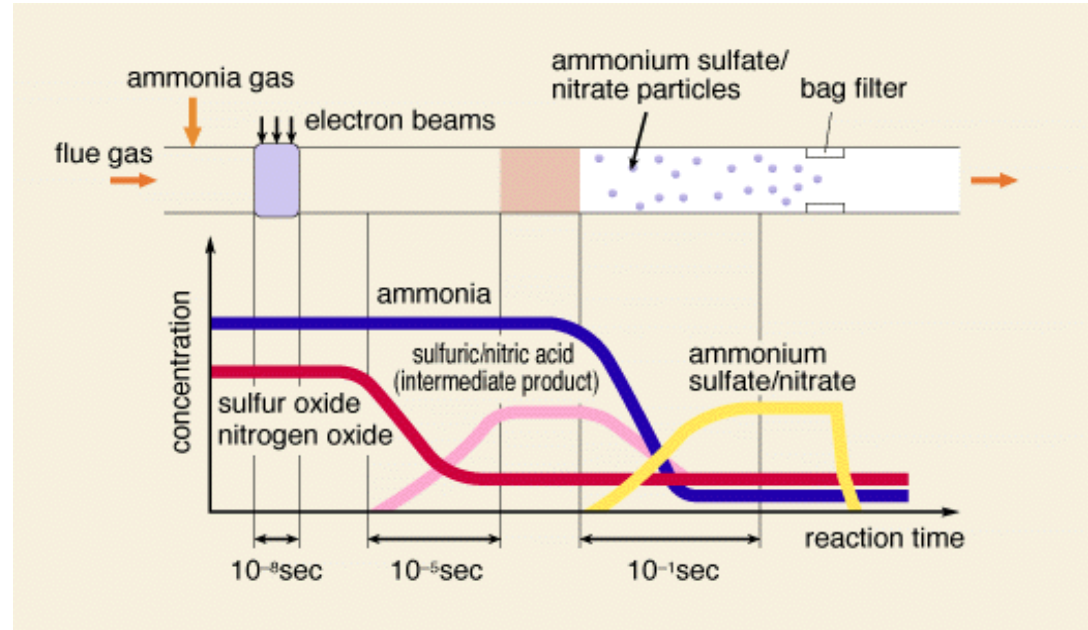
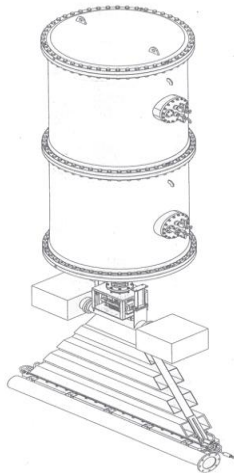


EPS Pomorzany – POLAND
(270,000 Nm³/h)

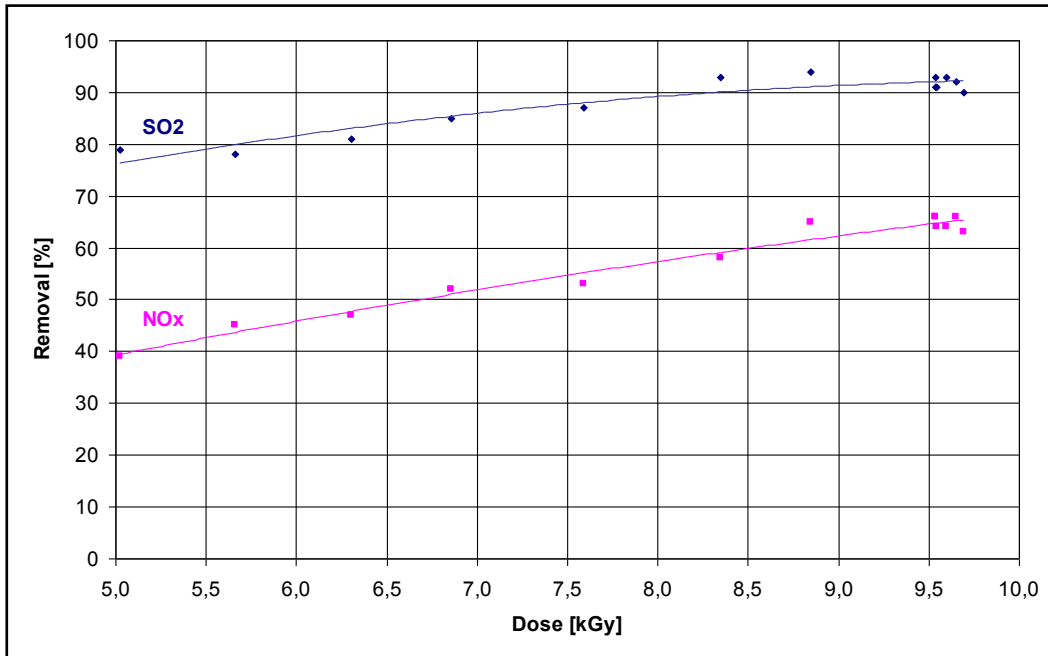


Source: INCT

Principles of Flue Gas Purification with Electron Beam



Dependence of SO₂ and NO_x removal efficiency on dose



E-BEAM FLUE GAS TREATMENT PROCESS (SO₂ AND NO_x REMOVAL)

By-Product Composition

(NH₄)₂SO₄ (45 - 60%)

NH₄NO₃ (22 - 30%)

NH₄Cl (10 - 20%)

Moisture (0,4 - 1%)

Water Insoluble Parts

(0,5 - 2%)



Pomorzany, Poland (IAEA/EPs/INCT)	1999
Flow gas flow (coal-fired)	270,000Nm³/h(130MW)
Flue gas temperature	130-150°C
SO ₂ /NO _x Conc.	1000~1500/400~600mg/Nm ³
SO₂/NO_x Removal Eff.	90%/70%
By-product production	200~300kg/h
NH ₃ consumption	100~150kg/h
Electron beam accelerator	800keV/4 × 300mA
Total power consumption	1MW



2013
indc
International Nuclear Document Centre

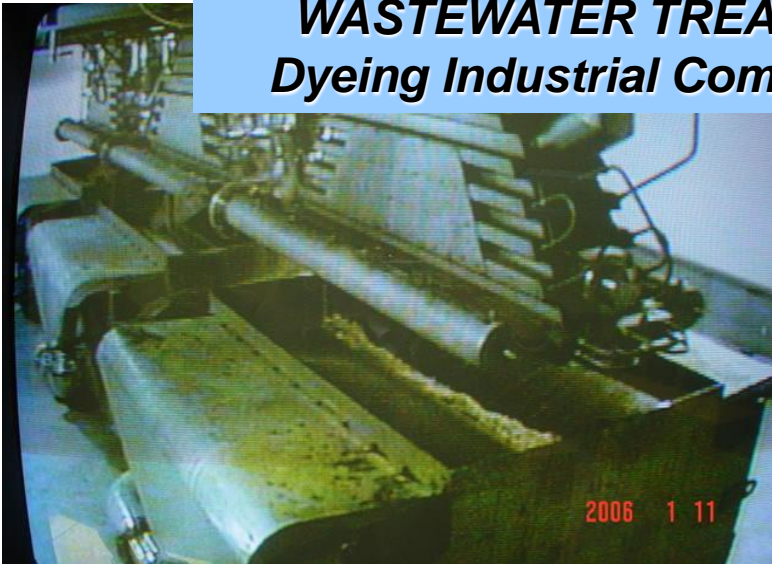
The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



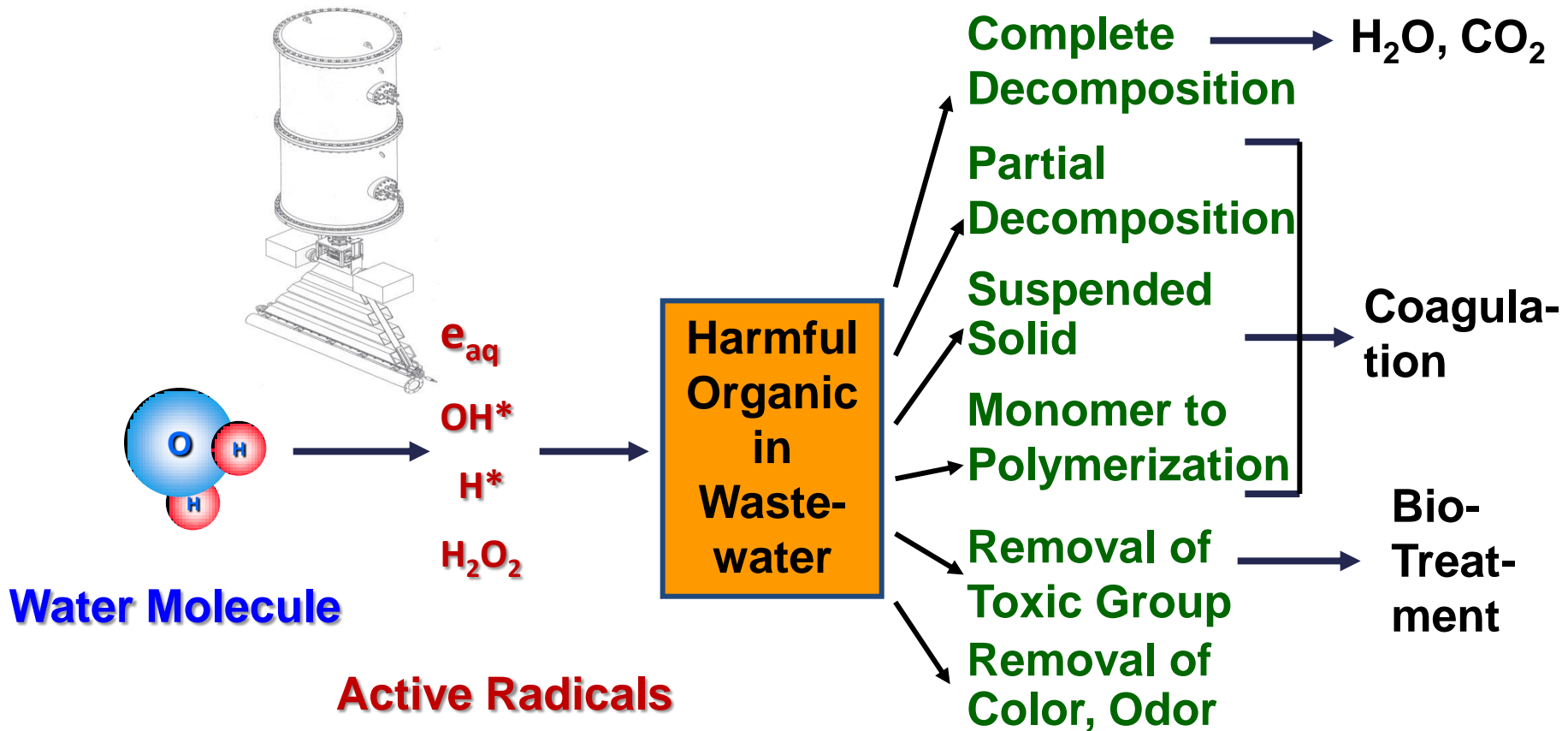
WASTEWATER TREATMENT PLANT BY E-BEAM Dyeing Industrial Complex/KOREA (10,000 m³/day)



⇒ **Electron Beam: 1MeV, 400kW**

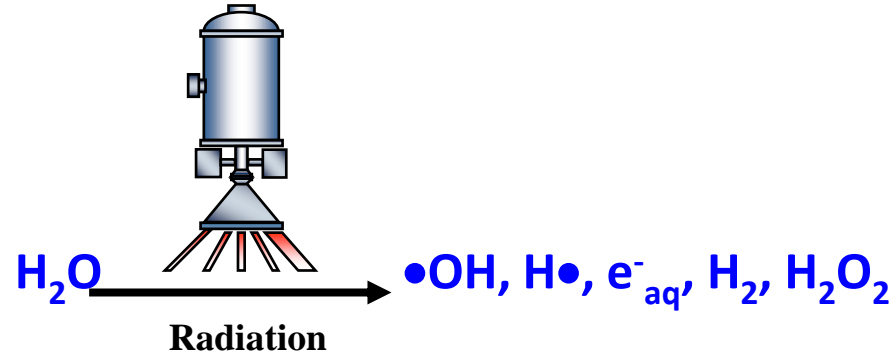
Source: IAEA

Principles of Wastewater Treatment with E-Beam



Principles of Sludge Treatment with E-Beam

Sludge Hygienization



$\bullet OH, H\bullet, e^-_{aq} + \text{DNA of microorganism} \rightarrow \text{Damage in DNA (no duplication)}$



Comparison of Flue Gas Purification, Wastewater & Sludge Treatment

	Flue Gas Purification	Wastewater Treatment	Sludge Hygenization
Contaminants to clear	SO ₂ , NO _x , (Dioxin)	Complex COD, BOD, other	Disinfection of microorganism
Cleaning process	Simple	Limitation in depth Combined with others	Limitation in depth Handling system
Competition with other processes	Superiority proved in commercial plant	Complicate to analyze	Many advantages over chemical processes
Technology	Fully developed	Laboratory to pilot scale	Laboratory to pilot scale
Economies	Proved through pilot & commercial plant	Complicate to analyze	Complicate to analyze
By-product	Useful for fertilizer	Wastewater (less toxic) Reuse	Useful for fertilizer or soil treatment



Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



Final Remarks

GammaFit Irradiator

Rhodotron

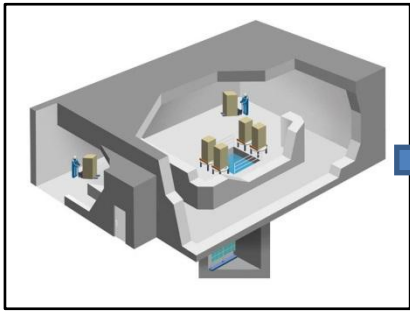
CRP/IAEA

Mobile Electron Accelerator

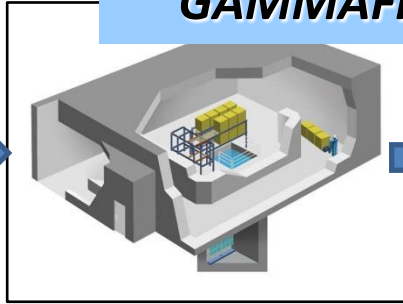
Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013

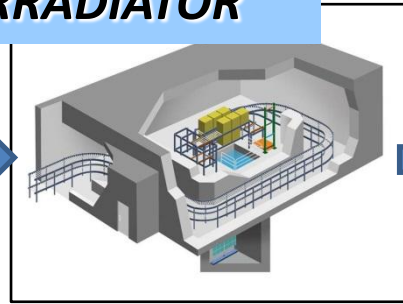
GAMMAFIT IRRADIATOR



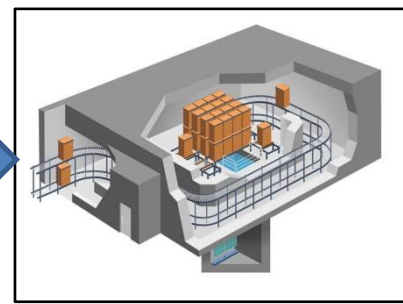
R&D Small Scale



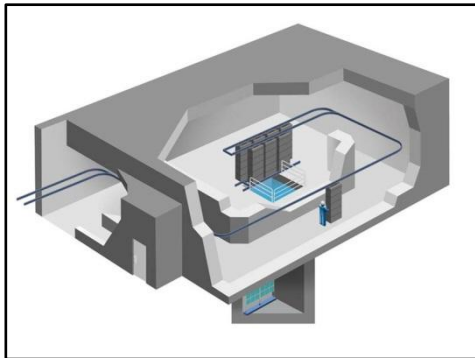
Two-Pass Batch Tote



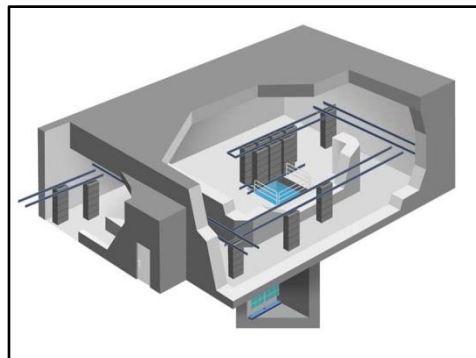
Two-Pass Automatic Tote



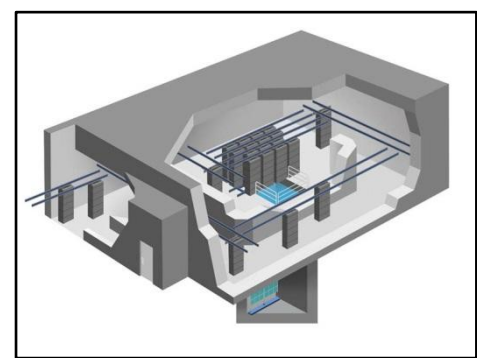
Four-Pass Automatic Tote



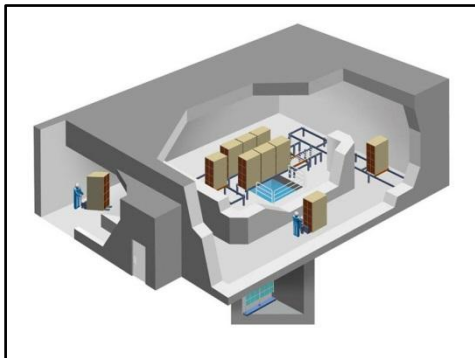
Two-Pass Batch Carrier



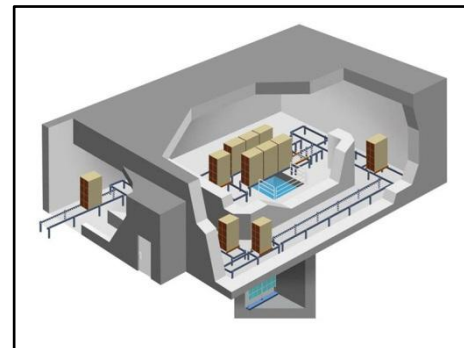
Two-Pass Automatic Carrier



Four-Pass Automatic Carrier



Batch Pallet

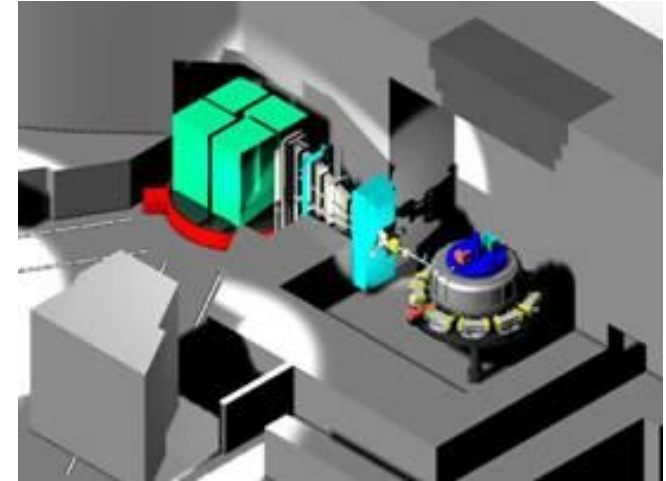
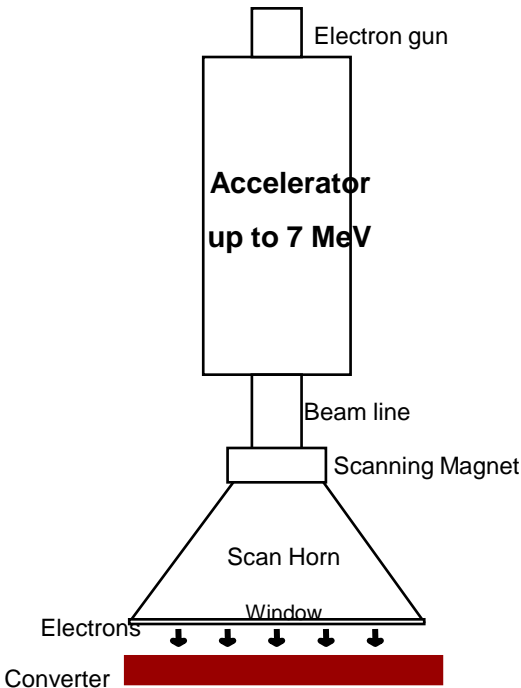


Automatic Pallet

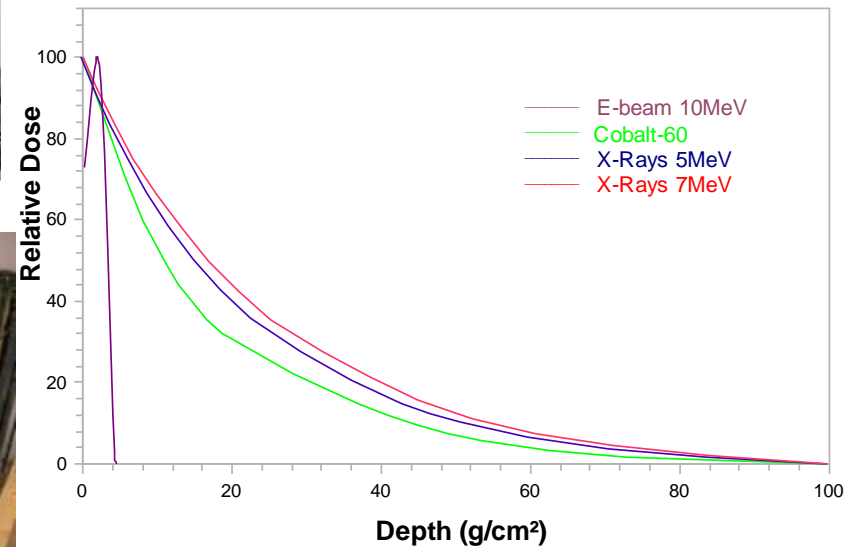
Source: NORDION

RHODOTRON TT1000 (700 kW)

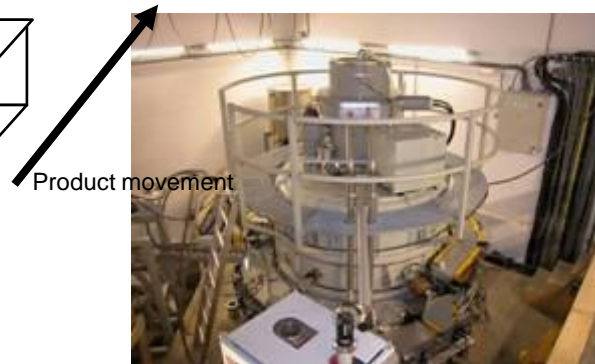
X-Ray treatment



Dose vs. Depth Profiles



Source: IBA





indc
International Nuclear Energy Research Institute

The Benefits of Nuclear
Technology for Social Inclusion

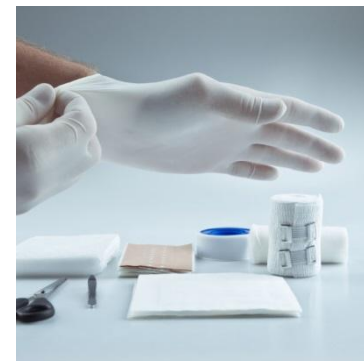
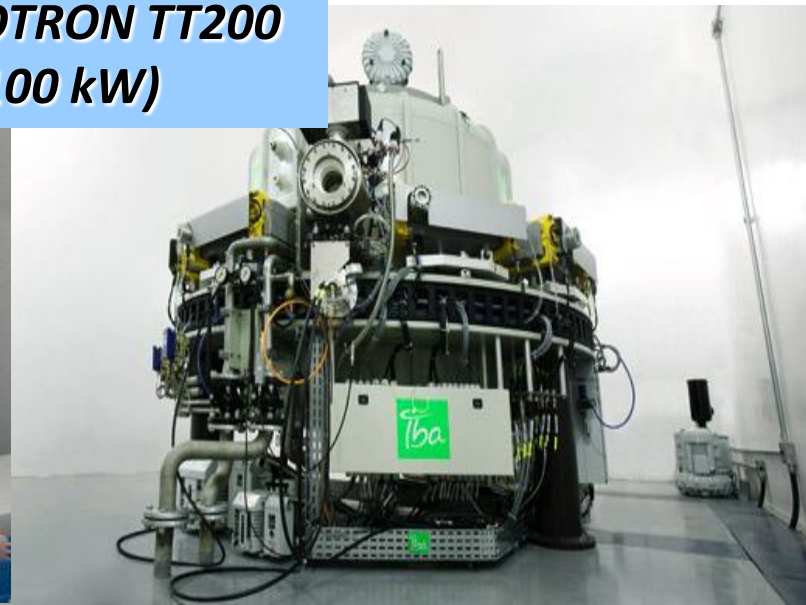
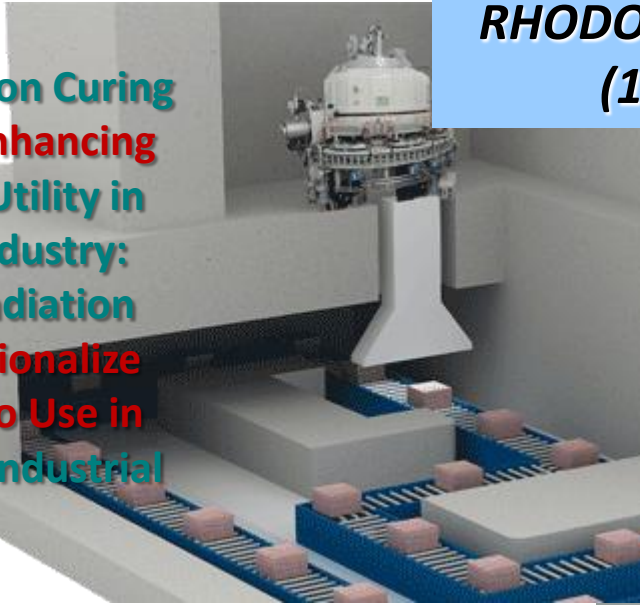
Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



⇒ **IAEA/CRP: Radiation Curing of Composites for Enhancing their Features and Utility in Health Care and Industry: Development of Radiation Processing to Functionalize Carbon Nanofiber to Use in Nanocomposite for Industrial Application**

**RHODOTRON TT200
(100 kW)**



**Sterilized
Medical
Devices:
135.000 m³/year**



Source: IAEA, IPEN-CNEN/SP and CBE

⇒ **IAEA/CRP: Application of Radiation Technology in the Development of Advanced Packaging Materials for Food Products: Development of Advanced Food Packaging Materials Based on Polymer Petroleum-Derived for Pre-Packaged Irradiated Foods and Based on Biobased and Compostable Materials for Dry Food Packaging**



Reinforced with filler from natural resources:

- vegetal fibers
- nanoparticles: bio-CaCO₃, green silica, metal, natural clay

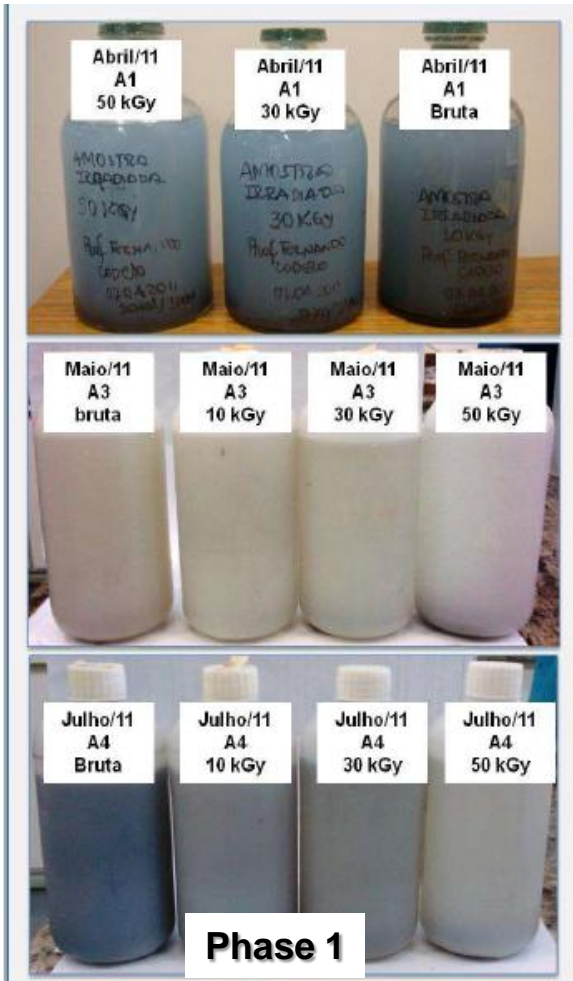
Composite materials based on:

- copolyester/starch blend
- copolyester/PLA blend

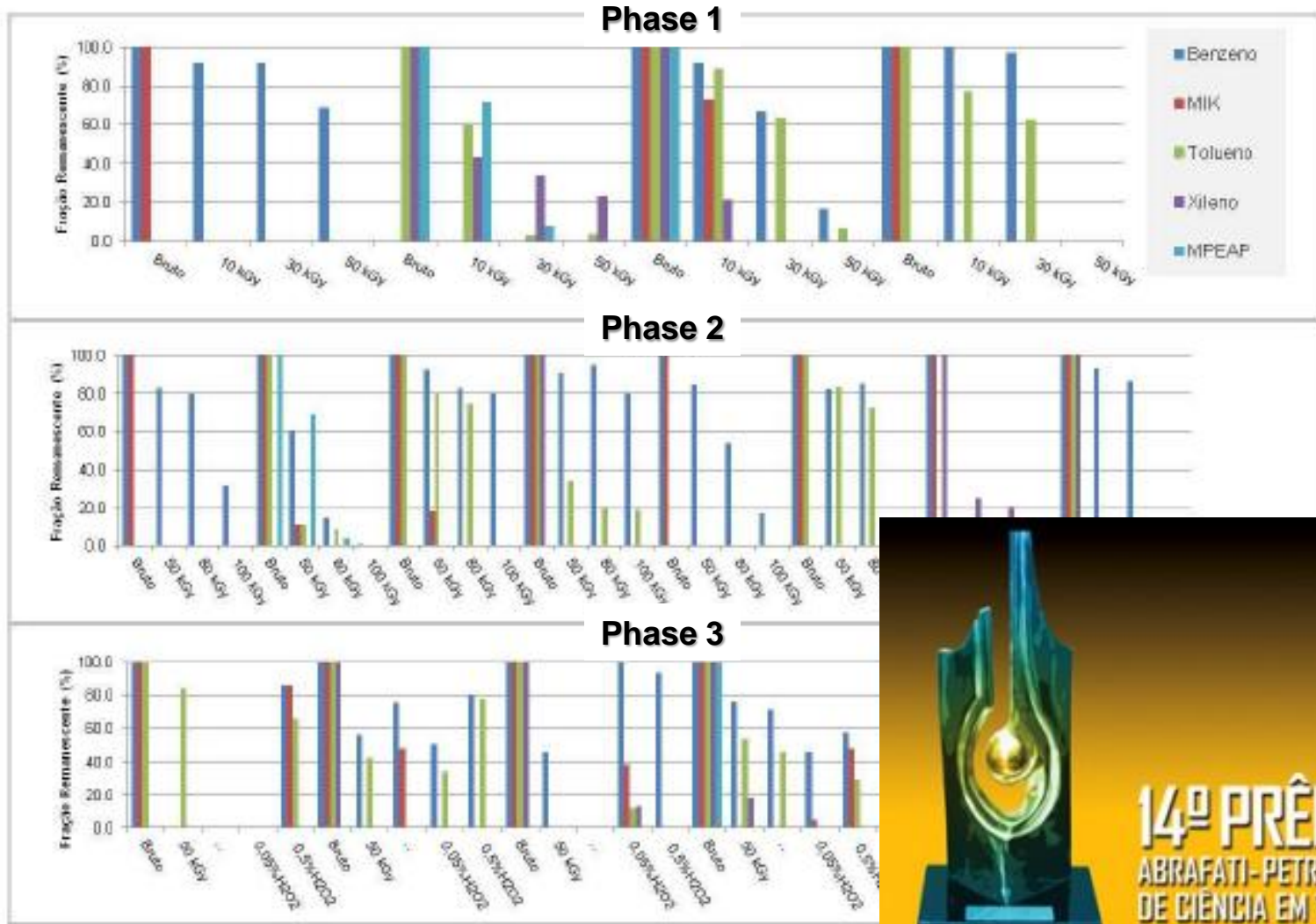




TREATMENT OF INDUSTRIAL WASTEWATER FROM PAINT INDUSTRY BY ELECTRON BEAM IRRADIATION



Efficiency of color removal by electron-beam irradiation *Source: IPEN-CNEN/SP*



Efficiency of organic compounds removal by electron-beam irradiation

Source: IPEN-CNEN/SP



2013
indc
Instituto Nacional de Energia Nuclear do Brasil

The Benefits of Nuclear
Technology for Social Inclusion

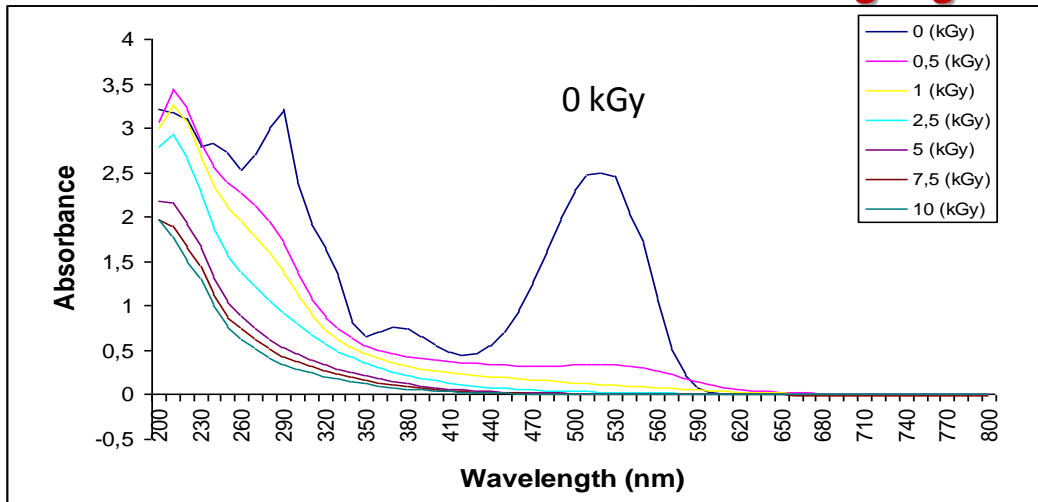
Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013

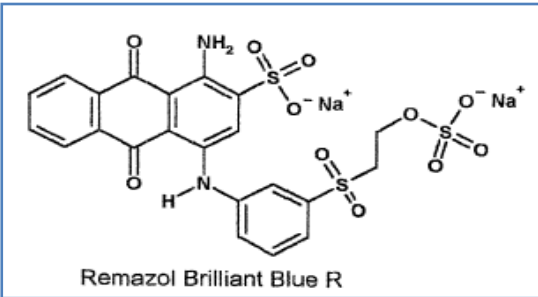


RADIATION INDUCED DEGRADATION OF REACTIVE DYES

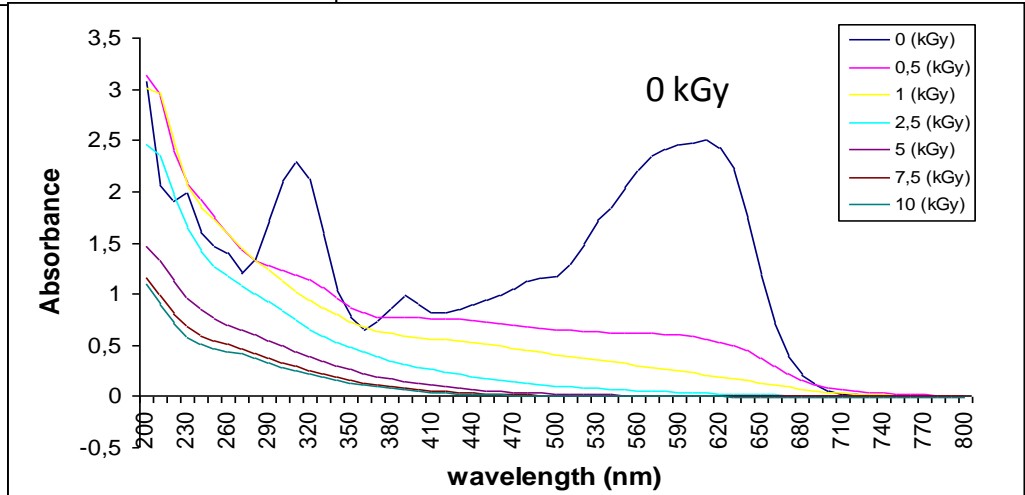
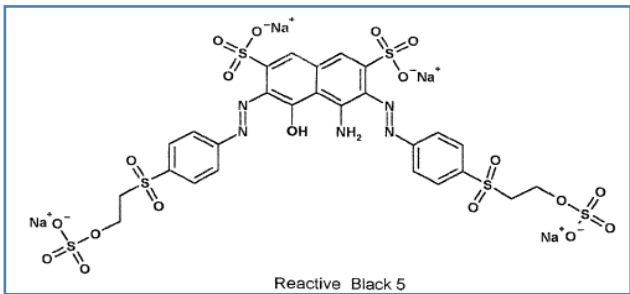
⇒ IAEA/CRP: Radiation Treatment of Wastewater for Reuse with Particular Focus on Wastewaters Containing Organic Pollutants



Red Reactive Remazol – RR 198



Reactive Black 5 – RB5



Source: IAEA and IPEN-CNEN/SP



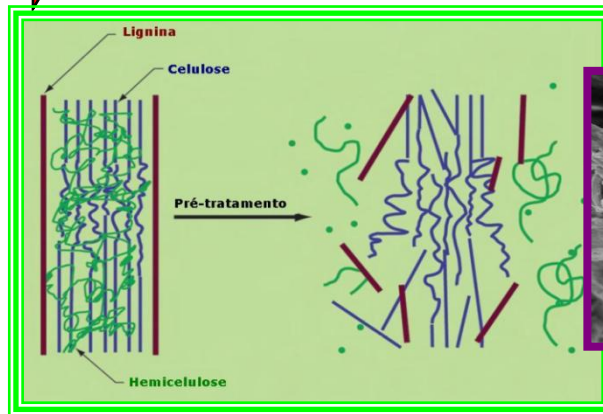
SUGARCANE BAGASSE IRRADIATION AS PRETREATMENT TO PRODUCE ETHANOL BIOFUEL

⇒ IAEA/CRP: Studies of Cellulose Hydrolysis from Sugarcane Bagasse to Production of Ethanol Bio-Fuel and New Polysaccharide Polymers Applying Ionizing Radiation

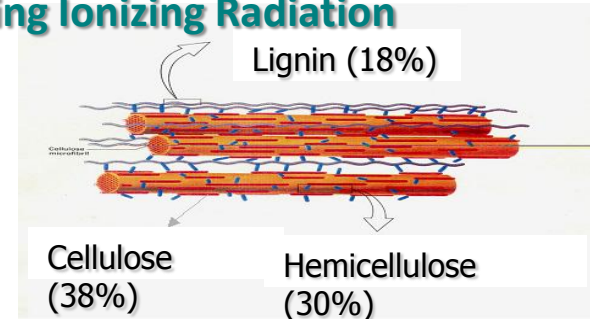


- HYDROTHERMAL
- DILUTED ACID
- STEAM EXPLOSION

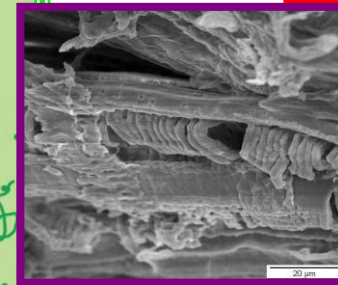
Pretreatment (delignification)



Electrons



Hydrolysis Process (depolymerization)



➤ ENZYMES, ACID

Ethanol biofuel

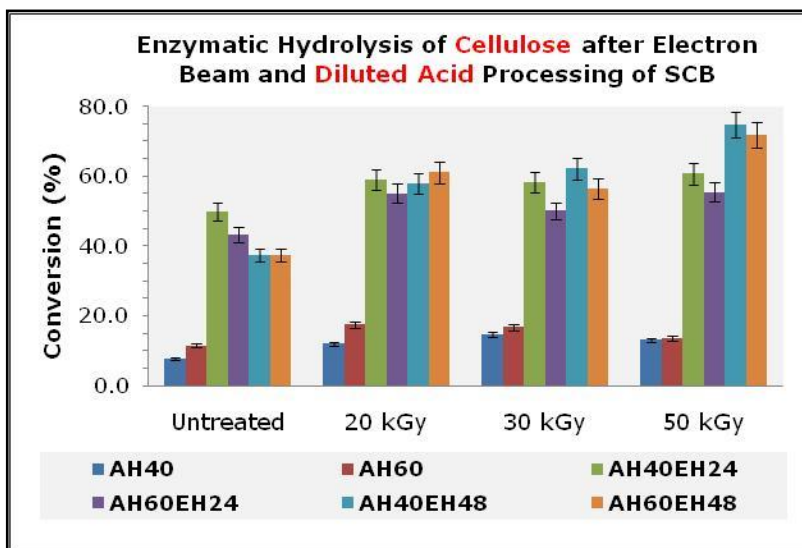
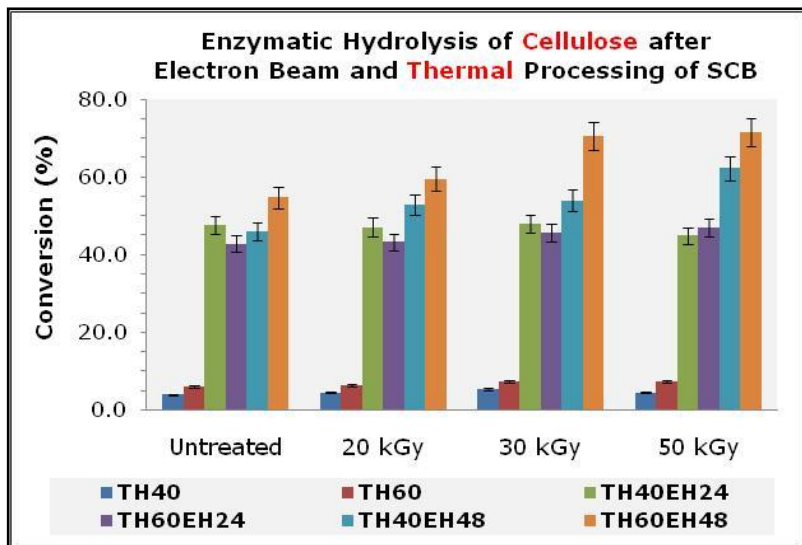
Fermentation

➤ FUNGI

➤ GLUCOSE

Free Sugars

ENZYMATIC CONVERSION OF CELLULOSE EB and Hydrothermal treatment



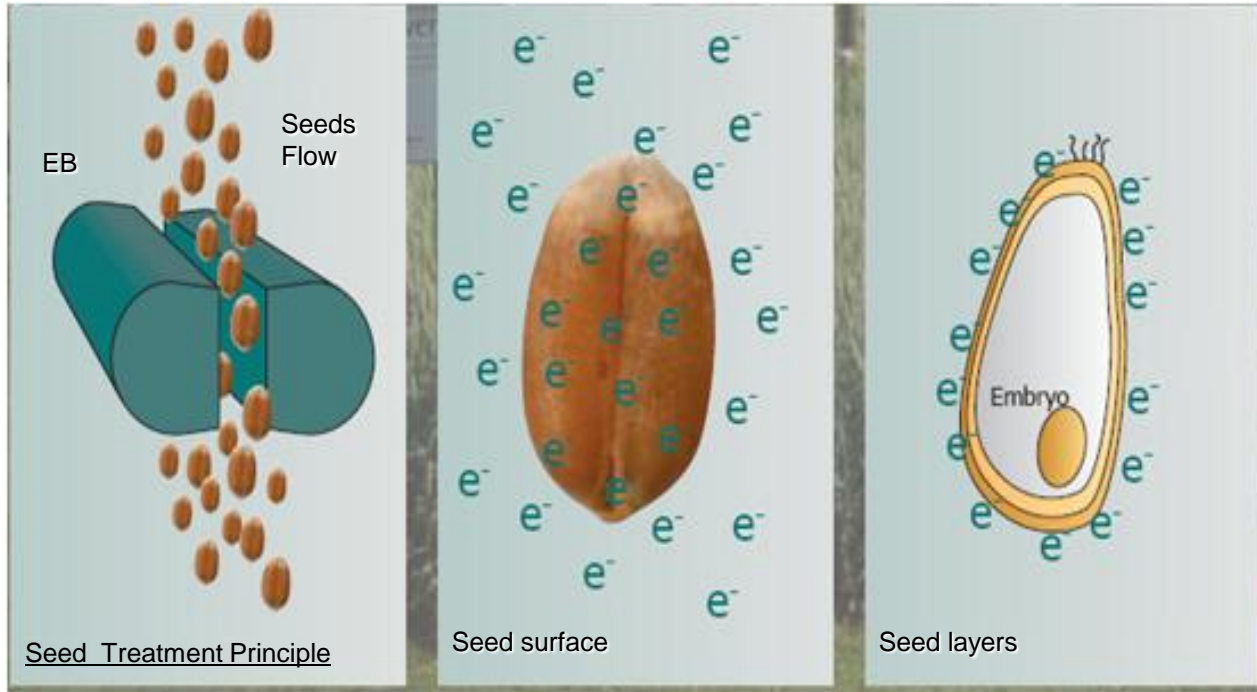
➤ Conversion of hemicelluloses reached 42% after thermal treatment by 40 minutes for sugarcane bagasse irradiated with 50 kGy. After the addition of diluted sulfuric acid (0.1% v/v), almost the totality of hemicellulose is converted in xylose and byproducts, mainly furfural.

➤ Enzymatic conversion yield of cellulose reached 72% in samples irradiated with 50 kGy and thermal treatment.

added, it was cellulose conversion was reduced was reached treatment hydrolysis



DISINFESTATION OF SEEDS

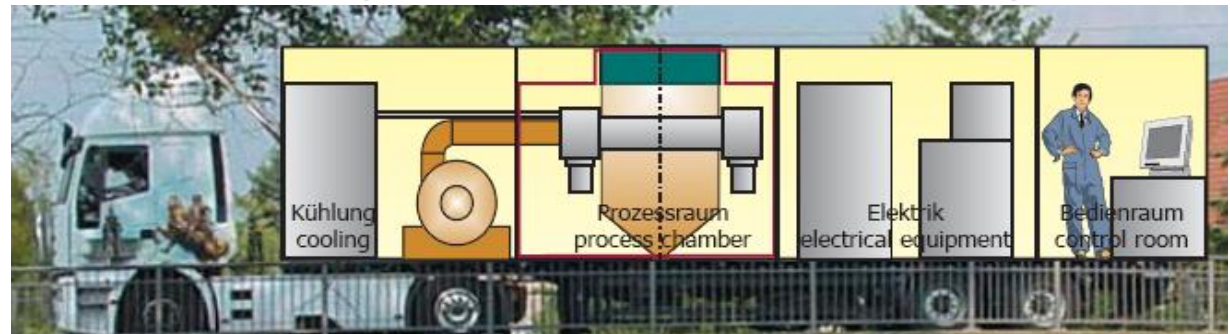


Low Energy Electron Beam (105 to 145 keV)

Disinfestation:

Chemical = 5%
EB = 11%

E-ventus (30 tons/h, € 35/ton, € 1.5 million)



**Laboratorial scale experiments
(1~50m³/day)**

MOBILE ELECTRON ACCELERATOR

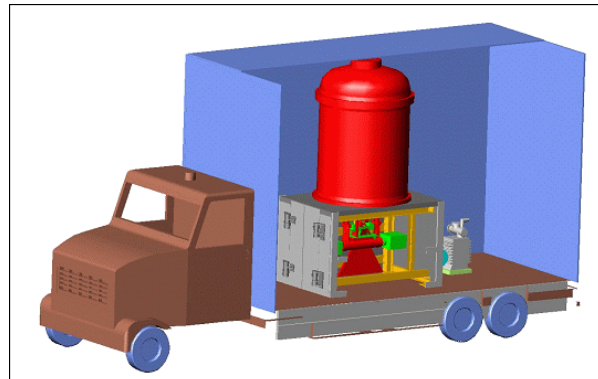
**Industrial scale wastewater plant
(10,000m³/day)**



**Pilot scale experiments
(500~1,000m³/day)**



- **Cost**
- **Space**
- **Operation & Maintenance, other**



**Laboratorial scale experiments
(1~10,000Nm³/h)**

**Industrial scale
EBFGT Plant
(~600,000Nm³/h)**



indc
International Nuclear Energy Research Institute

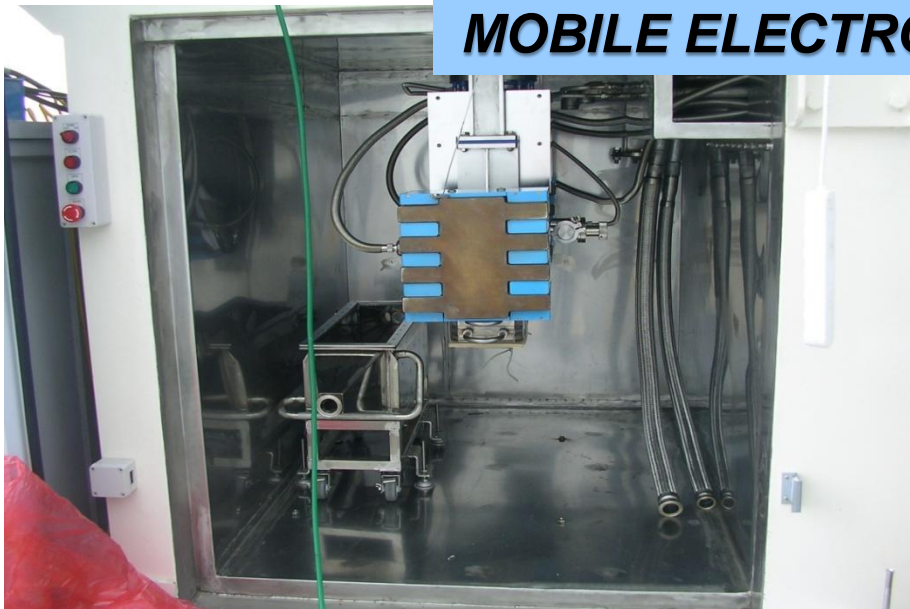
The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



MOBILE ELECTRON ACCELERATOR



- Beam Energy: 0.4 ~ 0.7 MeV
- Beam Power: 20 kW
- Total weight: 40 tons



Source: EB-Tech



indc
International Nuclear Energy Research Institute

The Benefits of Nuclear
Technology for Social Inclusion

Trends of radiation technology in industry and environmental applications

Centro de Convenções Recife, Pernambuco, Brazil - November 24-29, 2013



Mobile e-beam in flue gas purification from oil-refinery in Saudi Arabia



Source: EB-Tech

THANK YOU VERY MUCH FOR YOUR ATTENTION !

In Memoriam



Josué Dantas Martins Neto
SINC DO BRASIL