



International Topical Meeting on
Nuclear Research Applications
and Utilization of Accelerators

4-8 May 2009
Vienna, Austria



Needs and Emerging Opportunities of Electron Beam Accelerators on Radiation Processing Technology for Industrial and Environmental Applications in South America

(SM/EB-02)

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Brazilian National Nuclear Energy Commission (CNEN)
Radiation Technology Center (CTR)**



Ministério da Ciência
e Tecnologia







INDUSTRIAL ELECTRON BEAM ACCELERATORS IN SOUTH AMERICA



| Country | Organization | City | Units | Products | Additional Information |
|---------------------------|--|-------------|-------|--|--|
| Brazil | Institute for Nuclear and Energy Research (IPEN-CNEN/SP) | Sao Paulo | 2 | <u>R&D</u> : wastewater treatment, polymer modification, shrink tube and film, surface curing, food irradiation | Radiation Dynamics, Inc. (RDI), JOB 188, 37.5 kW, 1.5MeV, roller bed conveyor (batch), pilot plant for wastewater treatment (30 L/min) |
| | | | | <u>Commercial</u> : wire and electric cables, semiconductors, sterilization of medical and pharmaceutical devices, PE foam | RDI, JOB 307, 97.5 kW, 1.5 MeV, continuous treatment system (300 m/min) |
| Ecuador | Escuela Politecnica Nacional | Quito | 1 | <u>R&D</u> : food irradiation, wires and electric cables | ELU-6U, 6-10 MeV |
| Mexico | Comision Nacional de Seguridad Nuclear y Salvaguardias | Tijuana | 2 | Polymer modifications (plastics and rubber) | RDI Dynamitron 300/46/1220, 3 MeV |
| | ICU Medical S.A. | Ensenada | 1 | Sterilization of medical devices, polymer modifications | Precision Scan, SB108, 10 MeV |
| | Cryovac | México City | 1 | Fresh food packaging | Nissin High Voltage, 2SP500, 500 keV |
| Costa Rica | BeamOne SRL | Alajuela | 1 | Sterilization of medical and pharmaceutical devices | Titan Corporation, 10 kW, 10 MeV |
| Dominican Republic | FENWAL International Inc. (BAXTER) | Haina | 2 | Sterilization of medical and pharmaceutical devices | Titan Corporation, TB-10/15, 10 MeV, 1.44 mA EL Surbeam/Varian, SB-1/5, 650 keV, 0.094 mA |

Sources: IAEA, IPEN-CNEN/SP



INDUSTRIAL ELECTRON BEAM ACCELERATORS IN BRAZIL



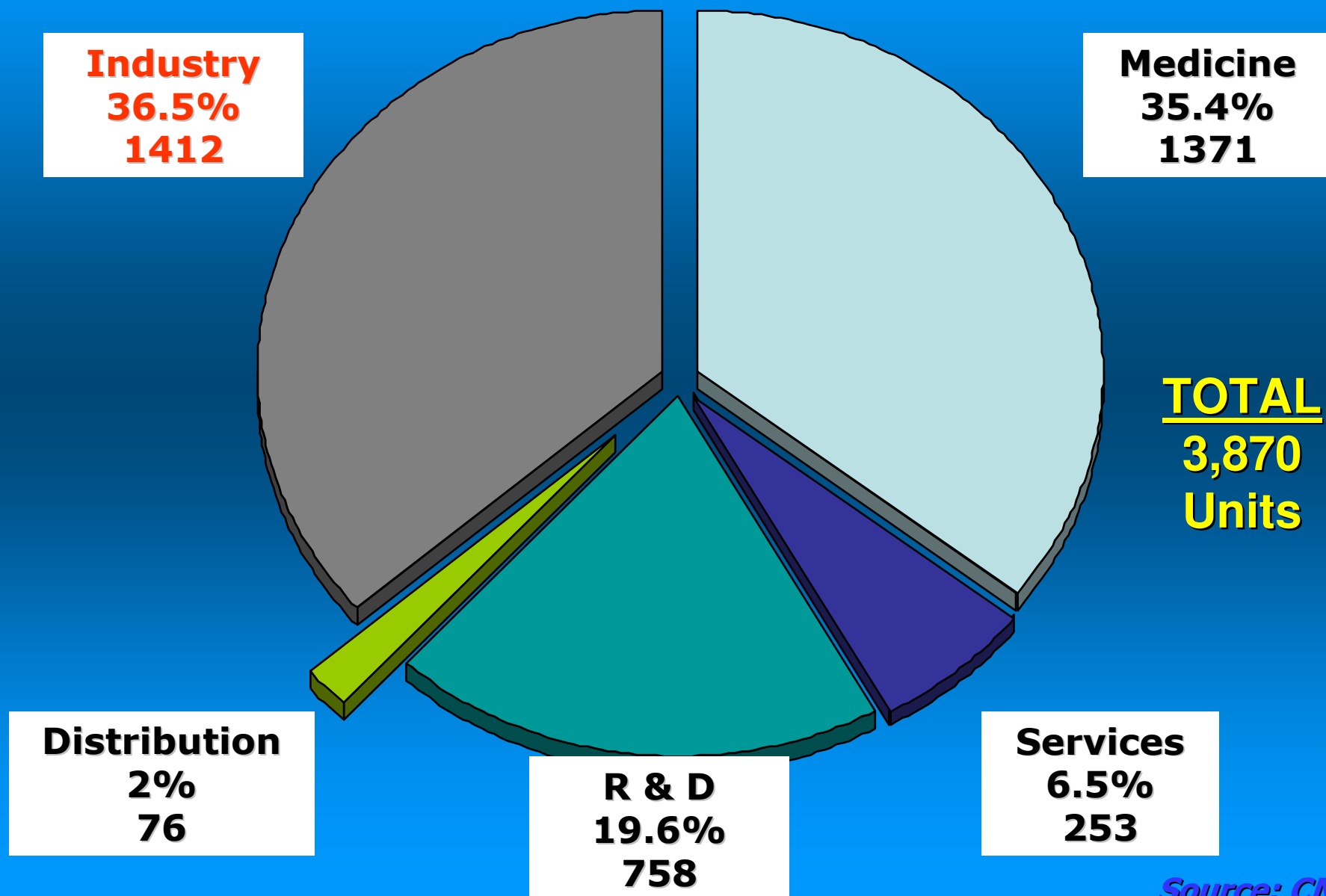
| Company | Manufacturer | Model | Energy (keV) | Current (mA) | Applications |
|---------------------------------|--------------------------------|----------------------|--------------|--------------|---|
| IPEN-CNEN/SP and Cofibam | Radiation | JOB 188 | 1,500 | 25 | R&D and crosslinking |
| | Dynamics, Inc. | JOB 307 | | 60 | |
| Bridgestone-Firestone | Energy Sciences, Inc. | EC/300 - 1 and 2 | 300 | 500 | Crosslinking |
| Cryovac Brasil | Cryovac | ECLU - 1,2,3 and 4 | 500 | 30 | Crosslinking |
| Unipac Embalagens | Energy Sciences, Inc. | CB200/060/070 | 210 | 168 | Curing |
| Curwood Itap | RPC Industries | Broad Beam - 1 and 2 | 300 | 600 | Curing |
| Acome do Brasil | Acome/Radiation Dynamics, Inc. | DPC 1000 | 550 | 66 | Crosslinking of wire and electric cables |
| Prysmian | Radiation Dynamics Inc. | JOB 307 | 1,500 | 60 | Crosslinking of wire and electric cables |
| Aceletron | Titan Corporation/EL Surebeam | LINAC - 1 and 2 | 10,000 | 1.8 | Food irradiation, gemstone enhancement, radiosterilization of medical disables, cosmetics, polymer modification |

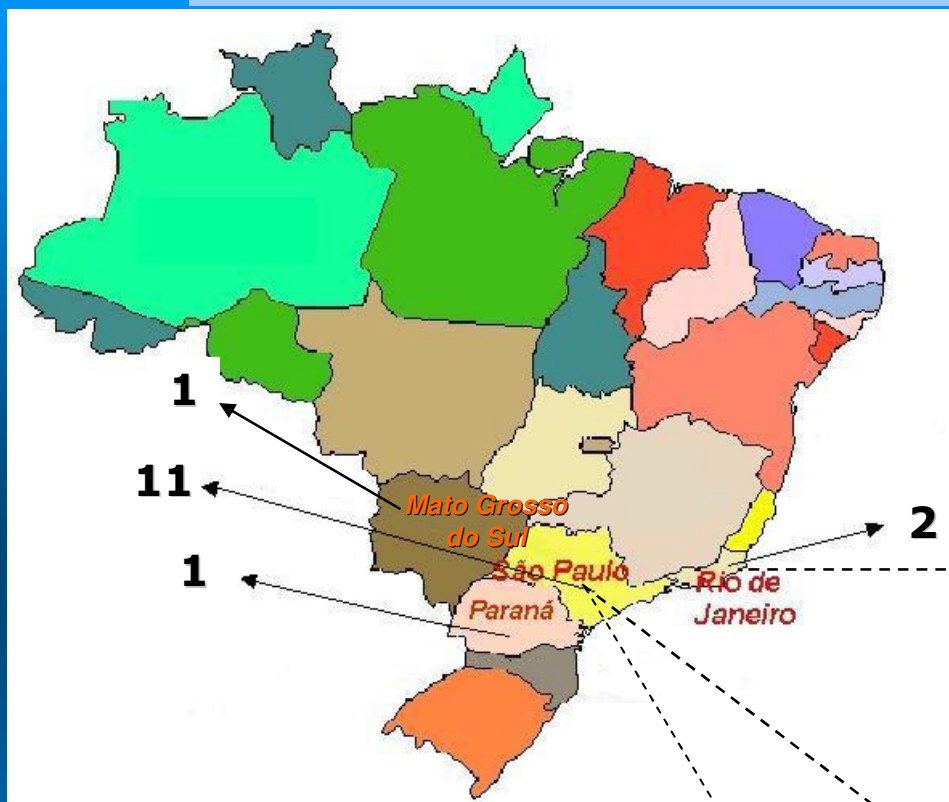
Source: IRD, IPEN-CNEN/SP

| Radioactive Facilities | South America | Brazil | Japan | USA | World |
|---|---------------|--------|-------|-------|---------|
| GAMMA IRRADIATORS (100 kCi – 10 MCi) | 14 | 7 (+1) | > 8 | > 30 | > 260 |
| ELECTRON BEAM ACCELERATORS (200 keV – 10 MeV) | 23 | 15 | > 300 | > 500 | > 1,500 |

China : > 80 Gamma Irradiators
> 140 Electron Beam Accelerators

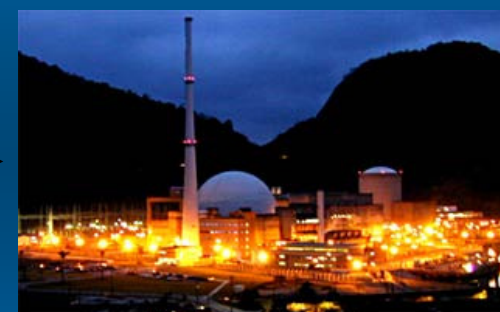
RADIOACTIVE FACILITIES PER NUCLEAR APPLICATION AREAS IN BRAZIL





Brazil:

- ✓ Area: 8,511,965 km²
- ✓ States: 26 + 1 Federal District (Brasilia)
- ✓ Inhabitants: 187 millions (81.3% urban areas)
- ✓ Gross national product: US\$ 1,100 billion
- ✓ Annual growth (2008): 4,8%
- ✓ US\$ 228.9 billion in foreign trade transactions



Nuclear Reactors (PWR):
Angra 1, 2 and 3 (ongoing)



**Brazilian Synchrotron Light
Laboratory (1,37 GeV)**



**Institute of Physics - USP
Mycrotрон (38 MeV)**

Source: IPEN-CNEN/SP

Electron Beam Accelerators

Low-energy: 150 keV – 300 keV

The Origin of RadTech South America

1993 - Foundation of **ATBCR** - *Brazilian Technical Association for Radiation Curing*

The knowledge on UV/EB technology is shared with the associated industries and partners

2006 - Agreement between **ATBCR** and **RadTech International North America**



e⁵

efficient

enabling

economical

energy savings

environmental friendly



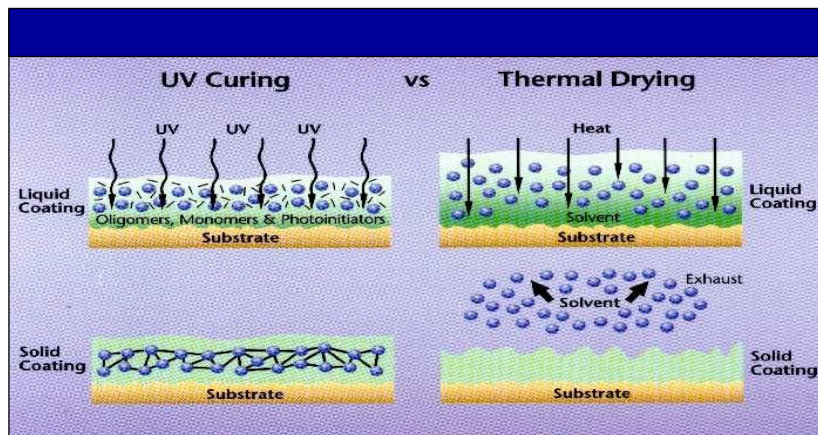
EB

versus

UV (Free Radicals)

- ✓ High energy
- ✓ High crosslinking density
- ✓ High penetration into opaque materials
- ✓ No photoinitiators
- ✓ Speed cure at hundredths of seconds

- ✓ Effectiveness on thin layers materials
- ✓ Elaborate formulation for thick layers
- ✓ Low penetration limited to clear materials
- ✓ Photoinitiators need
- ✓ Speed cure at tenths of seconds



Electron beam curing has several advantages over conventional thermal curing methods:

Improved parts; improved material handling; ability to combine various materials and functions in a single operation; ability to utilize lower cost tooling; and reduced cure times

Source: RadTech South America



Energy Scineces, Inc. (ESI) (www.ebeam.com)

Web widths: 20 to 66" (508 to 1,676 mm)

Speed capability: 335 m/min

Thickness: 0.03 mm



Web widths: 30 to 120" (762 to 3,048 mm)

Speed capability: 305 m/min

Thickness: 0.35 mm

PCT Engineered Systems, LLC

(www.teampct.com)



Voltage: 70 to 125 keV

Web widths: 36''(914mm) to 68''(1,727mm)

Voltage: 125 to 300 keV

Web widths: 130'' (3,300 mm)

ENERGY

| <u>Voltage (keV)</u> | <u>Layer thickness (μm)</u> |
|----------------------|-----------------------------|
| 150 | 100 |
| 175 | 150 |
| 200 | 250 |
| 300 | 500 |

VELOCITY PROCESSING

| <u>Dose (kGy)</u> | <u>Velocity (m/min)</u> | <u>Applications</u> |
|-------------------|-------------------------|----------------------|
| 20 | 0-600 | Silicone application |
| 30 | 0-600 | Printing |
| 60 | 0-200 | Adhesives |

ITEMS

Titanium window

Tungsten Filament

O-rings

Maintenance time *

DURABILITY

2,000 hours

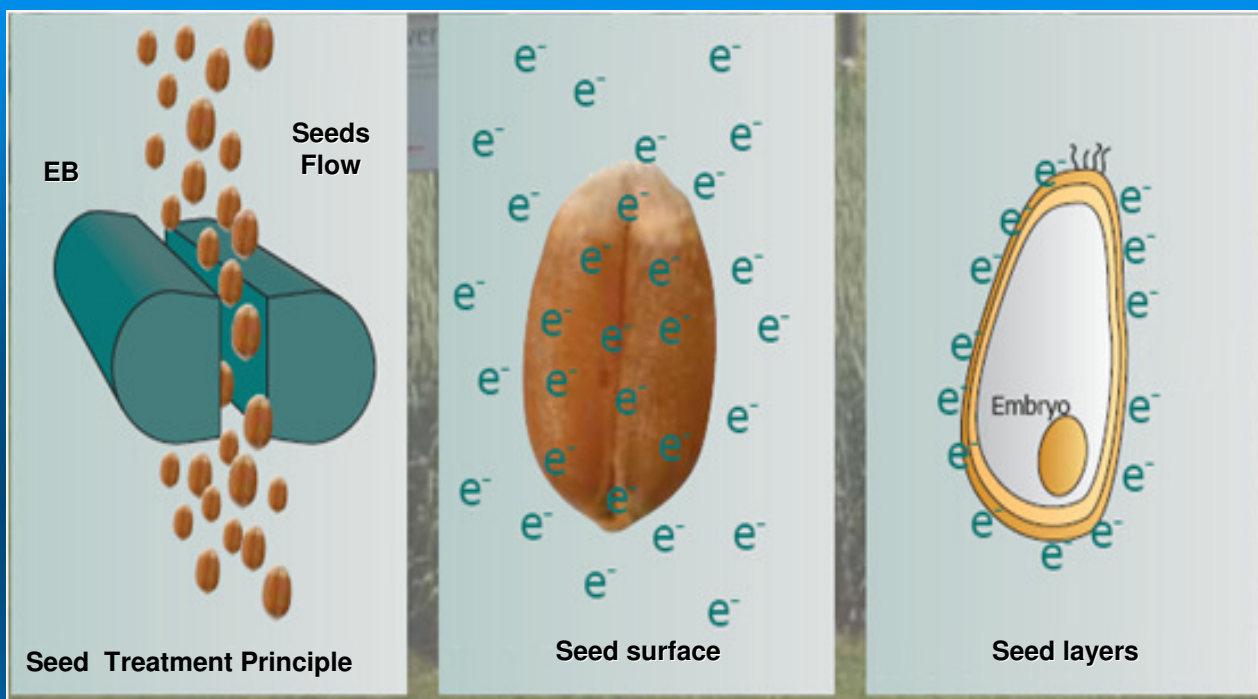
10,000 hours

2,000 - 5,000 hours

20 - 30 hours/year

* Maintenance cost per year = ~ 5% of the Electron Beam Accelerator's price

Low Energy Electron Beam (105 to 145 keV)



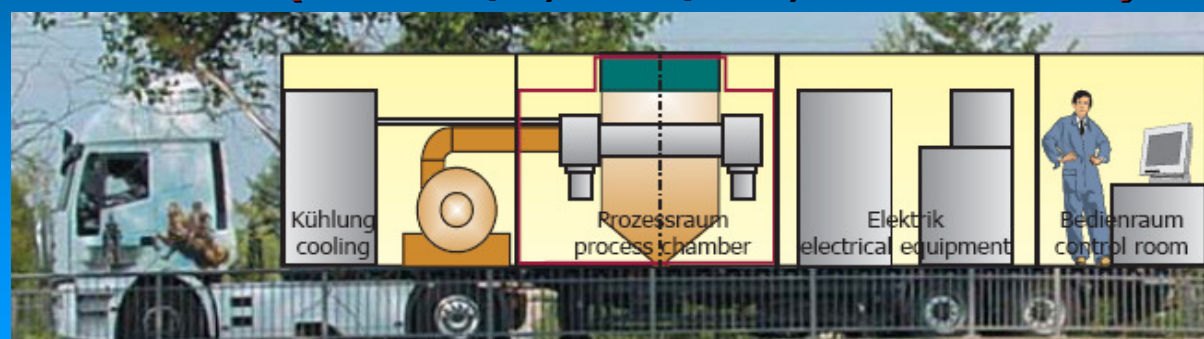
Disinfestation:

Chemical = 5%

EB = 11%



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

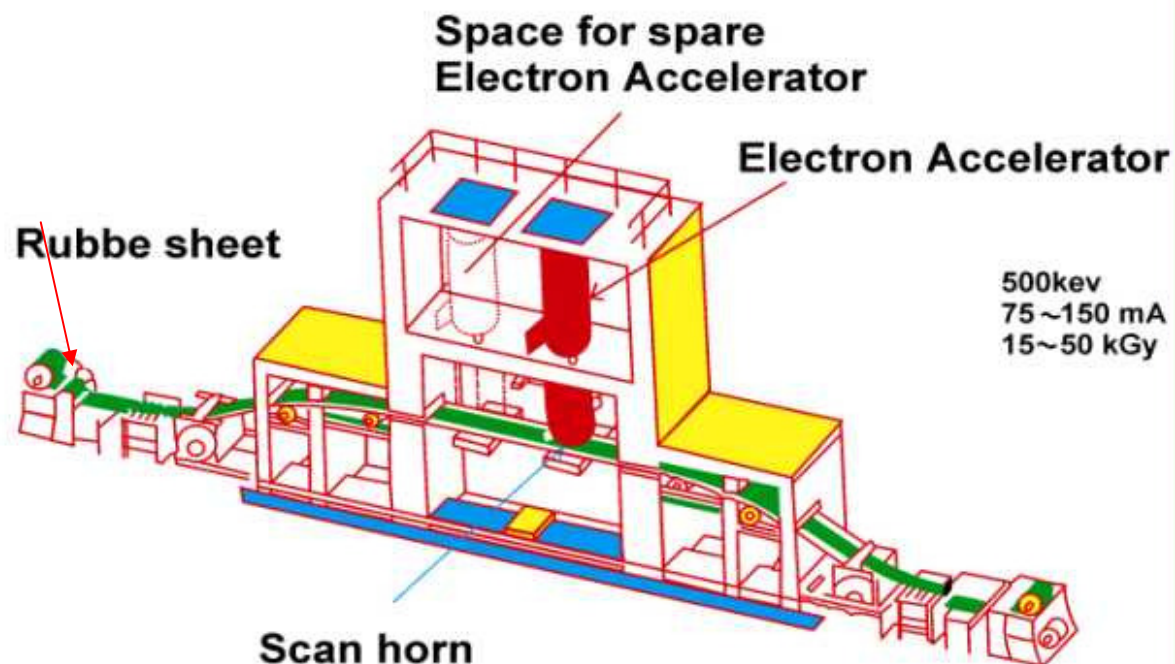
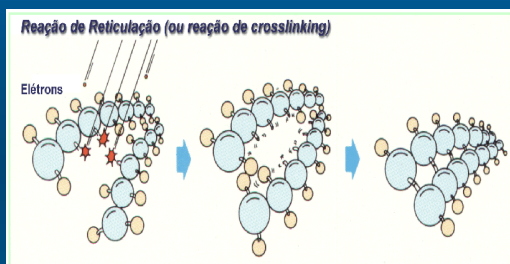


Sources: Fraunhofer Institut-FEP (DRESDEN, Schmidt Seeger AG)

Electron Beam Accelerators

Mid-Energy: 300 keV - 5 MeV

Japan: Automobiles
tires = 95%

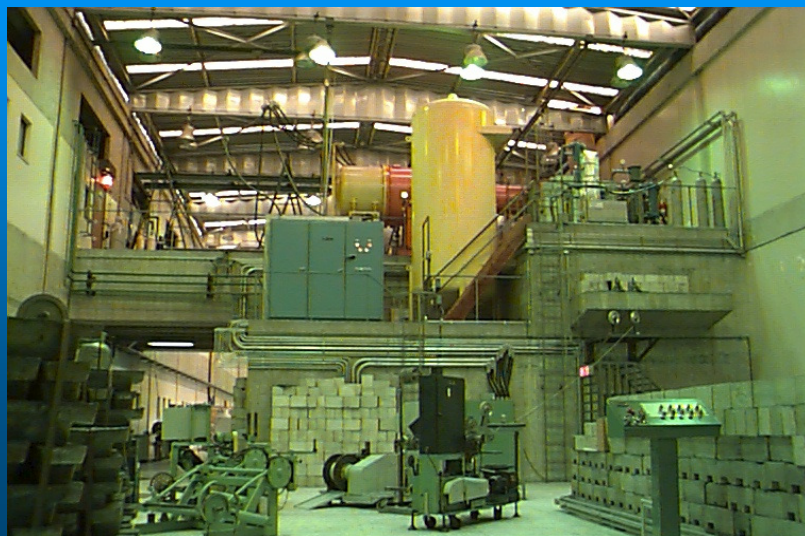


EB Processing of Rubber Sheet

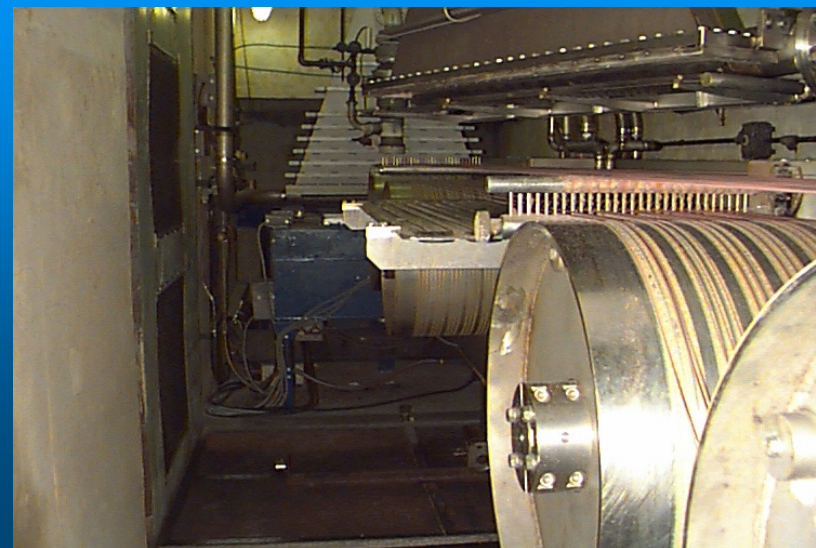


BRAZIL: Bridgestone-Firestone

Source: IPEN-CNEN/SP



97.5kW (1.5MeV and 65mA)



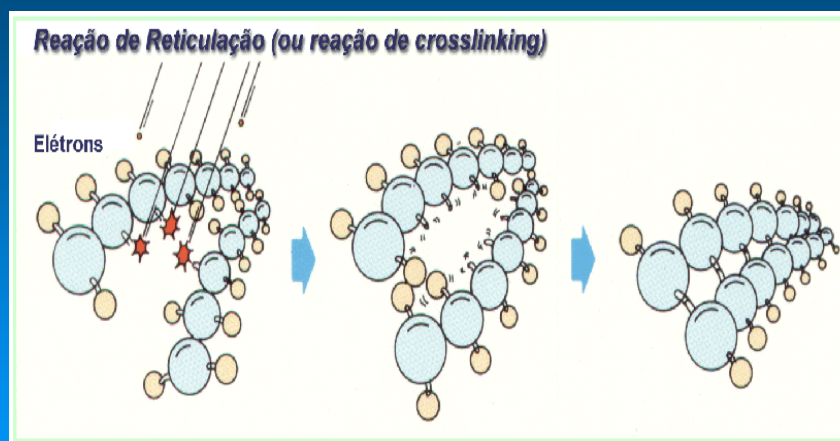
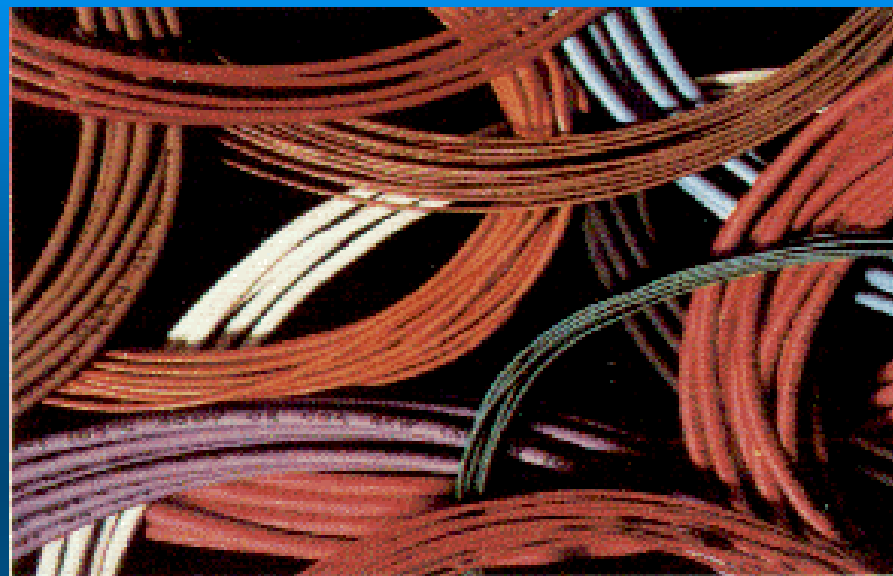
37.5kW (1.5MeV and 25mA)



Conveyer: 0.42 - 6.72 m/min

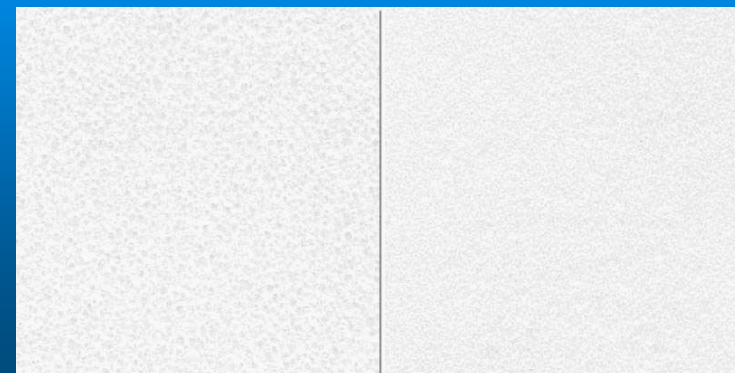
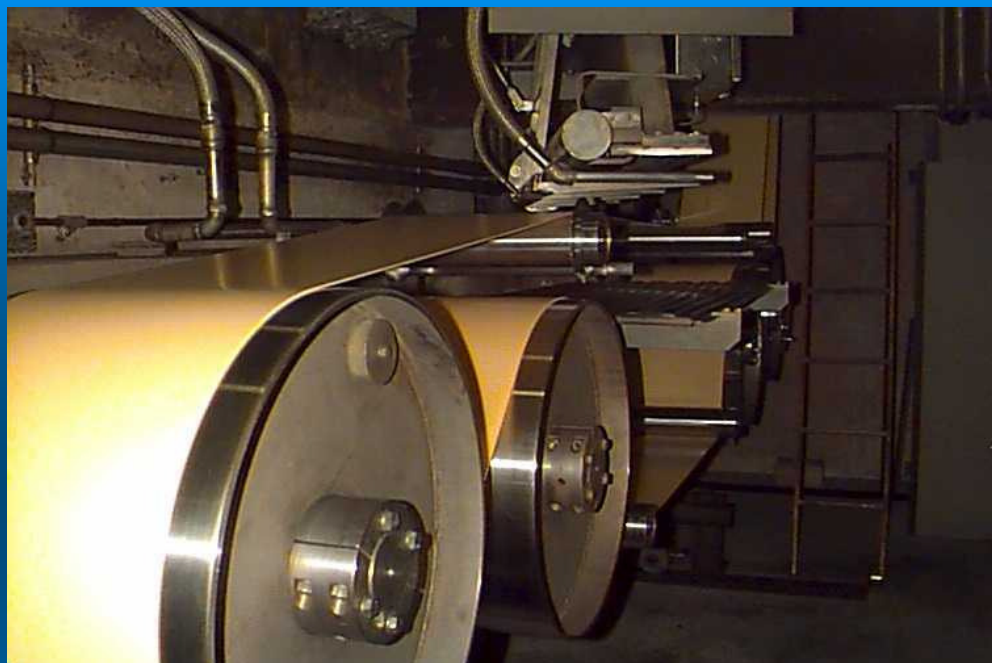
Source: IPEN-CNEN/SP

IRRADIATION OF WIRE AND ELECTRIC CABLES



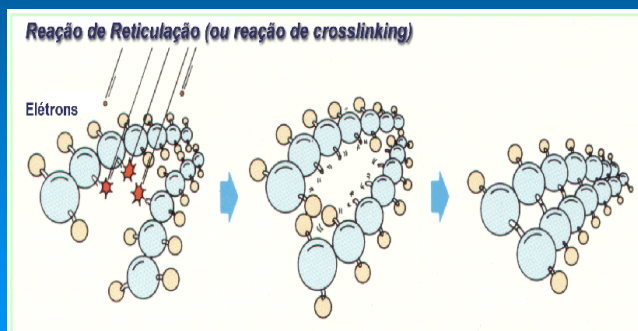
IPEN-CNEN/SP: 12,500 km (2002)

Source: IPEN-CNEN/SP



**Chemical
Crosslinking**

**Crosslinking by
irradiation**



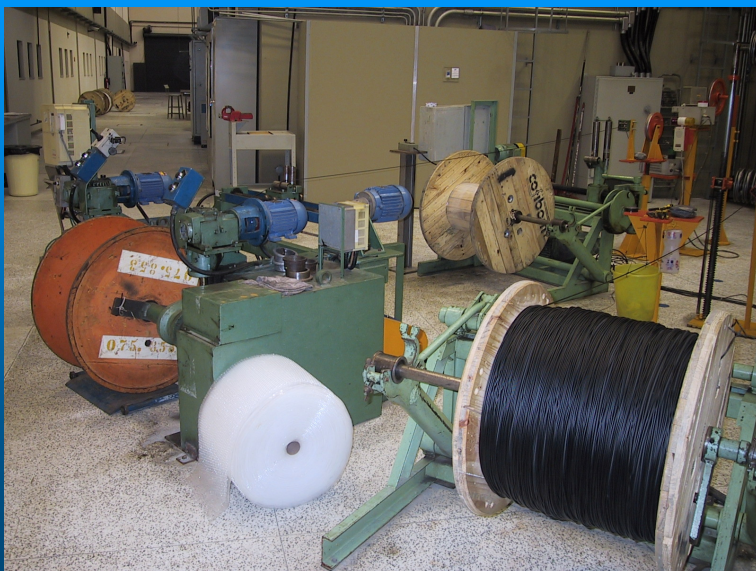
SEMICONDUCTORS IRRADIATION and POLYMER DEGRADATION



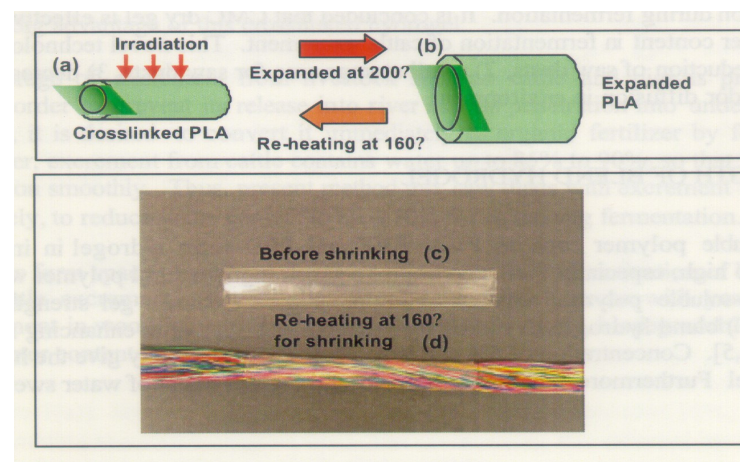
Powered Diodes Assembling



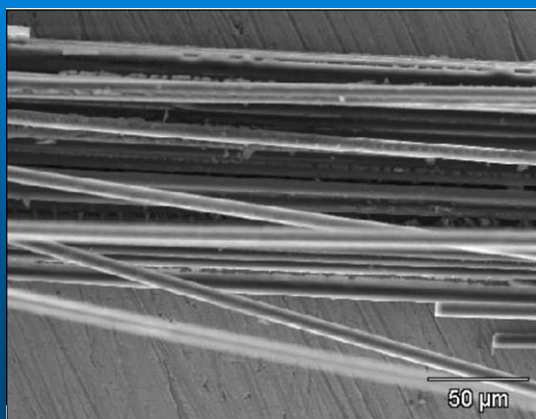
***PTFE (Teflon™)
Printing Inks and lubricants***



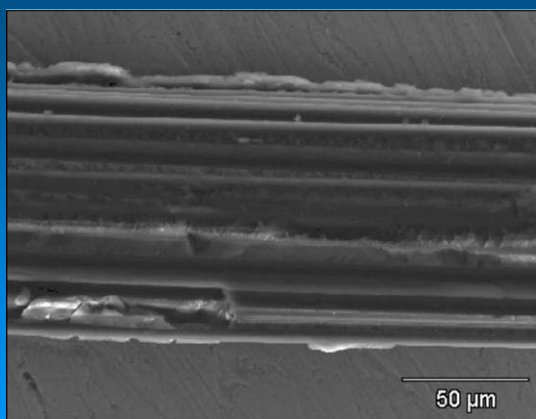
**Heat Shrinkable tubes
(80-200kGy)**



Carbon Fiber Composites (12k)

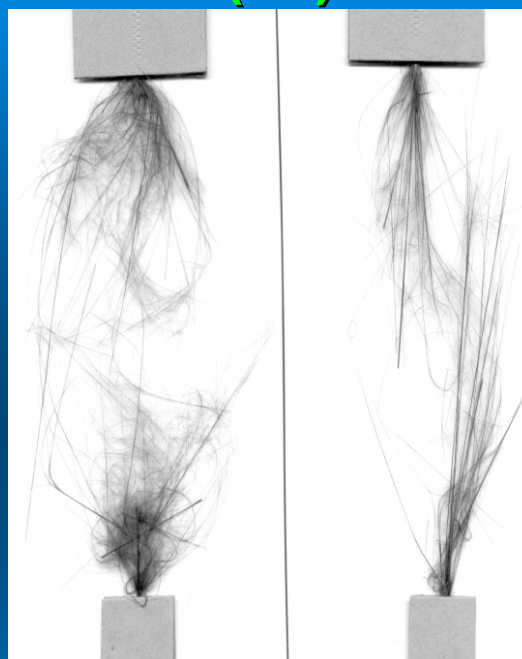


Non-Irradiated



Carbon Fibers Irradiated by EB
(50-300kGy)

Composite test specimens (6k) (12k)



a

b

c



a'

b'

c'

Composites test specimens:

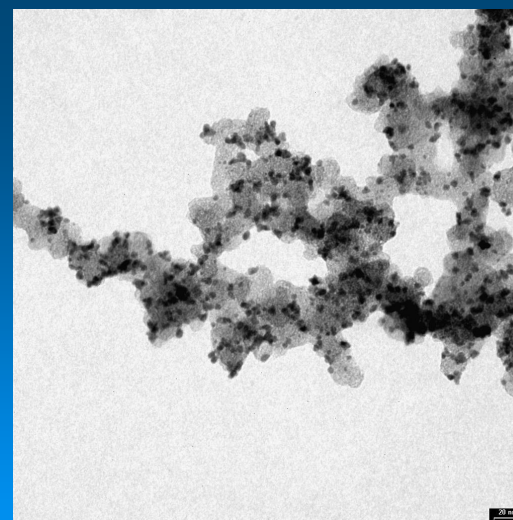
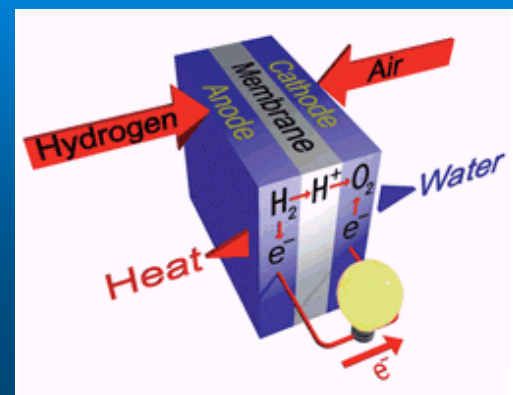
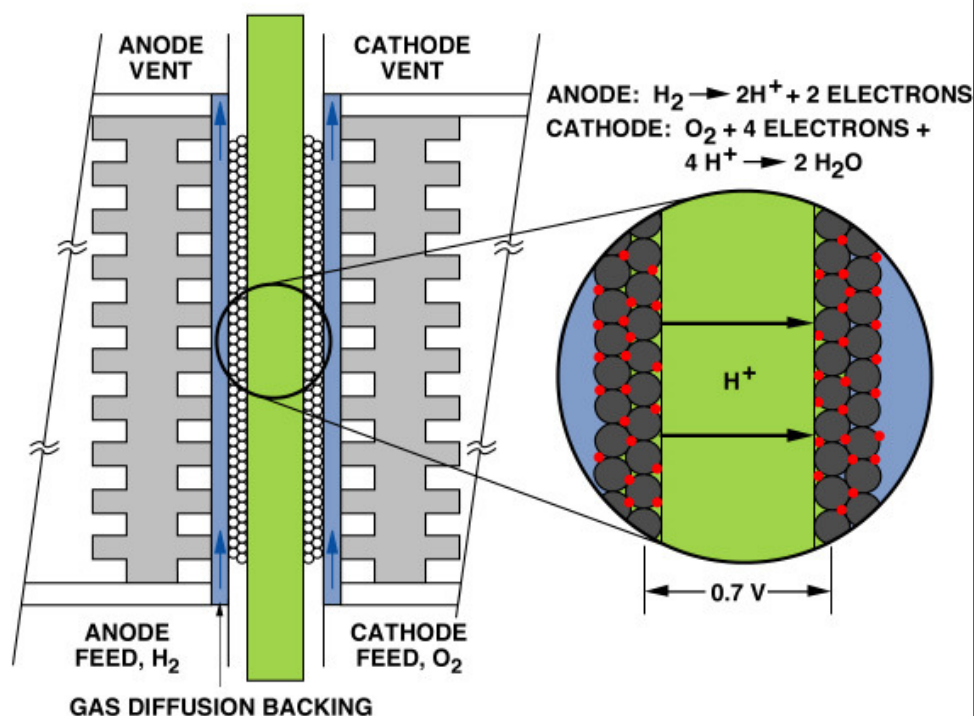
(a, a') non-irradiated, after breakage;

(b, b') before tensile test

(c, c') irradiated with 300 kGy, after breakage

Fuel Cells

CROSS SECTION OF POLYMER ELECTROLYTE FUEL CELL



Irradiation of Electrocatalyst - PtRu/C
(1-15kGy)

Source: IPEN-CNEN/SP

proton exchange membrane fuel cells - PEMFC

mechanical resistance

thermal resistance

before

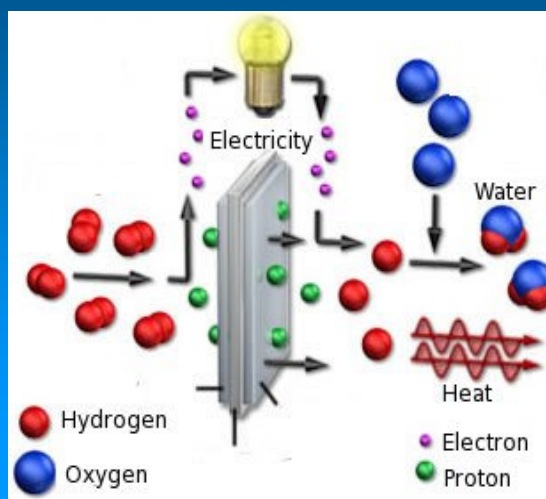
crosslinking through radiation

after

grafting through radiation

polytetrafluoroethylene (PTFE), polyvinyl difluoride (PVDF) and polypropylene (PP) films grafted by irradiation with styrene and lately sulfonated

EB



diffusion aspects
description



Films and multilayer packages



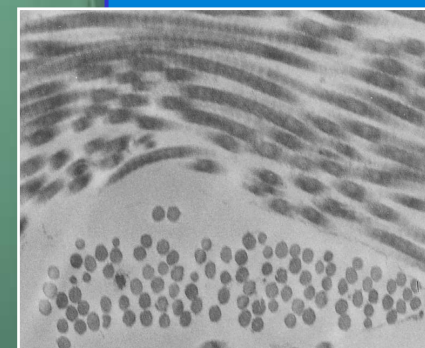
Polivinilpirolidona

PVC tubes

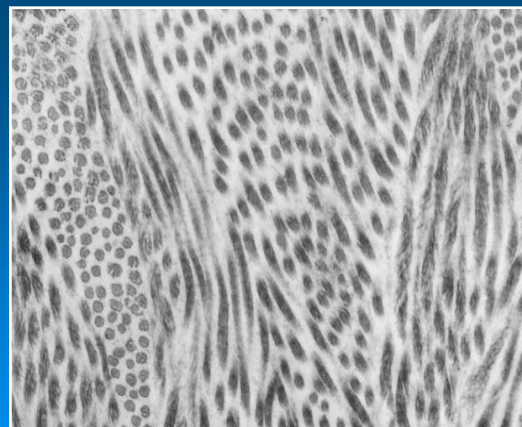


TISSUE BANKING

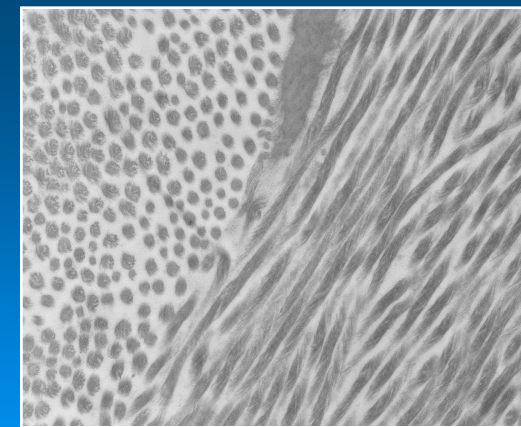
R&D Contract with "Hospital das Clínicas - HC/FMUSP"



0 kGy



25 kGy

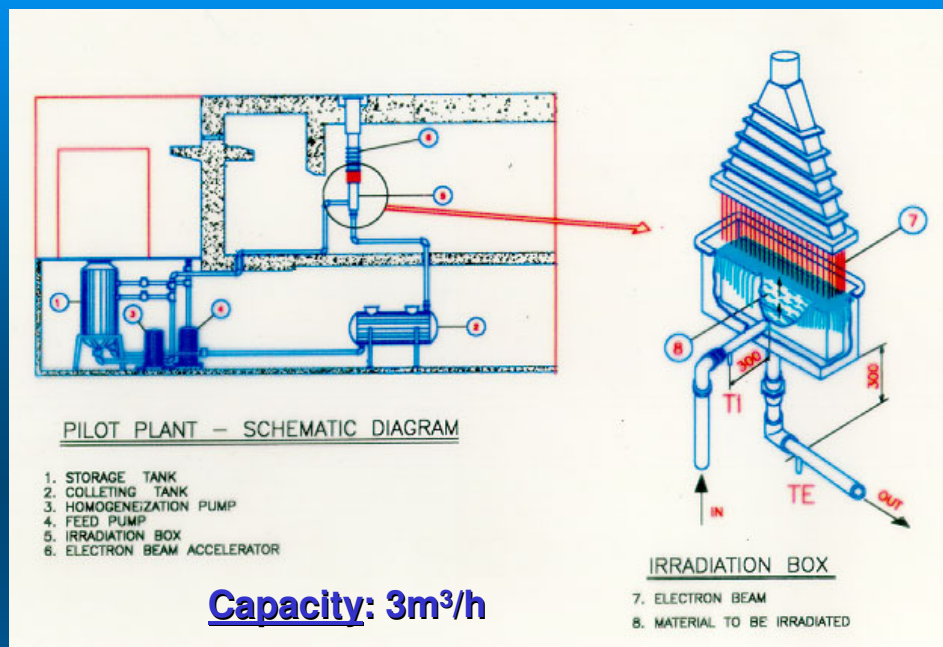


50 kGy



Source: IPEN-CNEN/SP

WASTEWATER TREATMENT BY ELECTRON BEAM ACCELERATORS



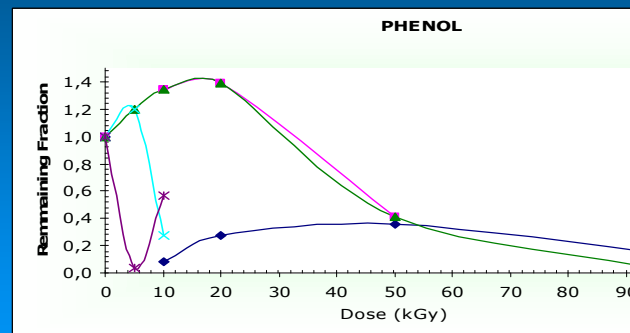
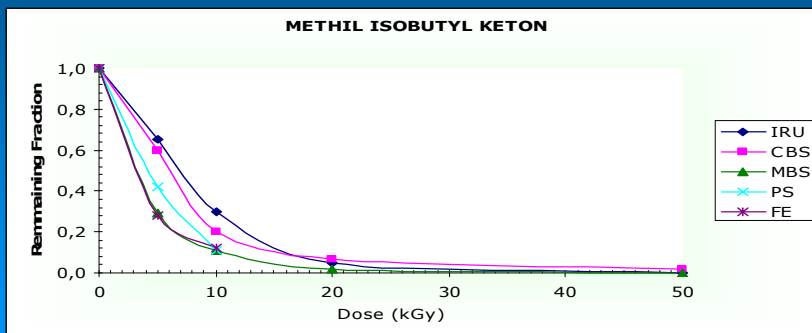
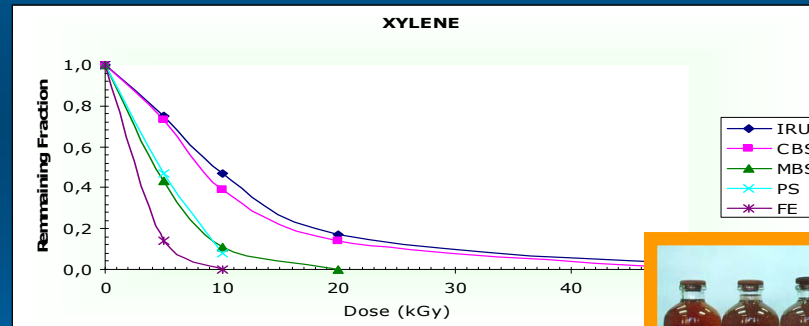
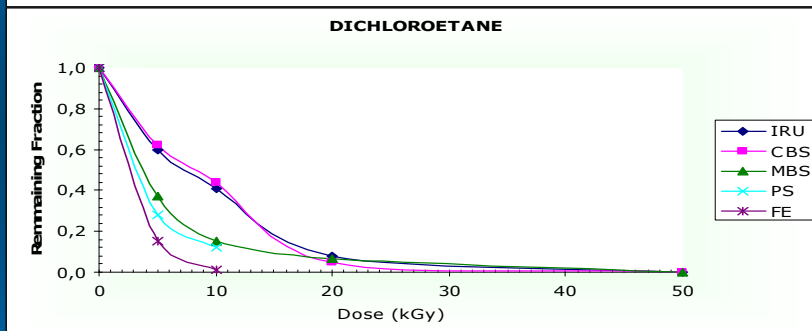
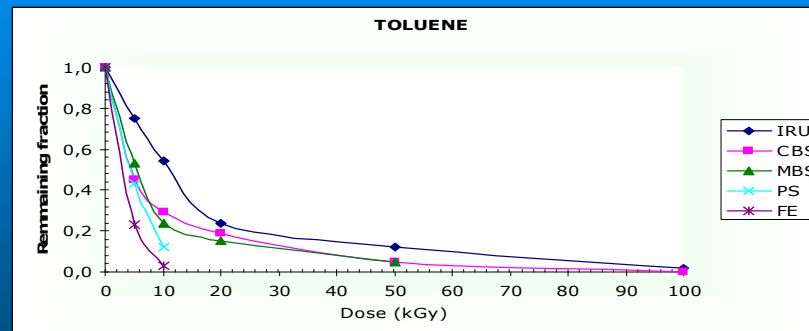
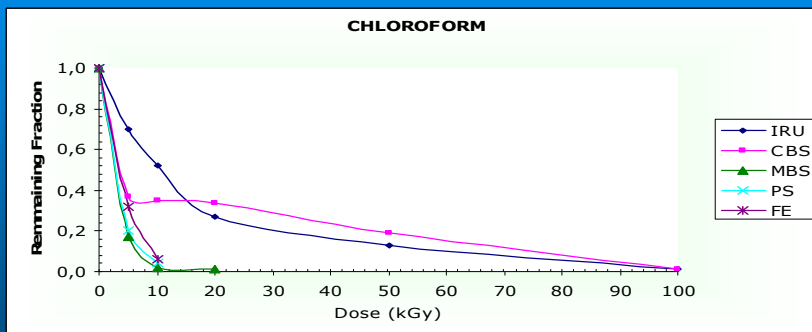
IAEA TC Project BRA/8/025
Electron Beam Treatment of
Wastewater
(1993-1997)

Model Project
(1995)



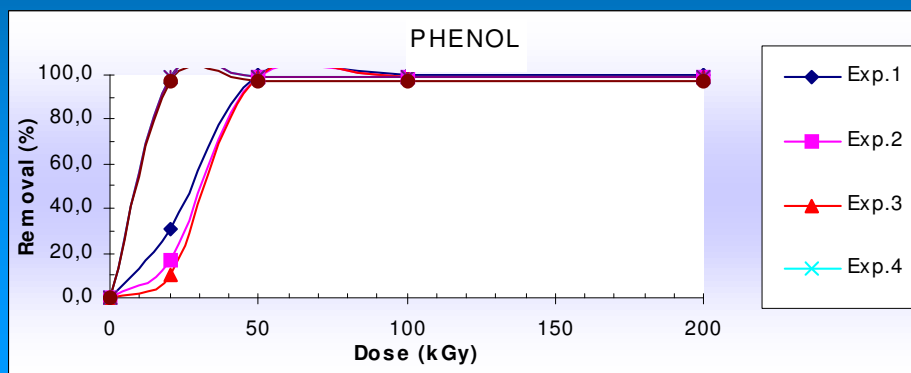
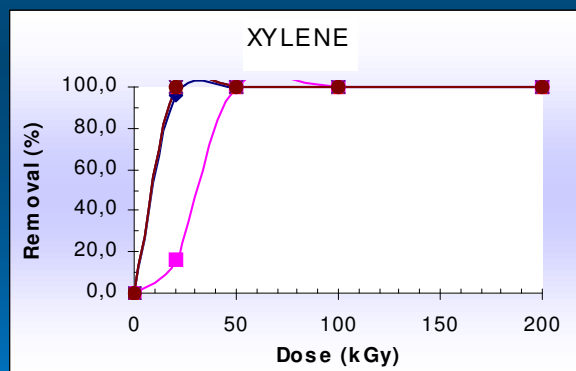
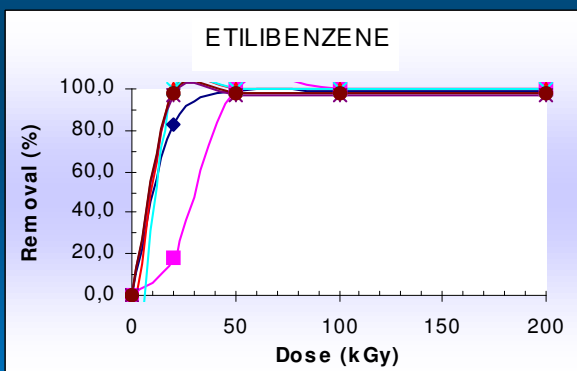
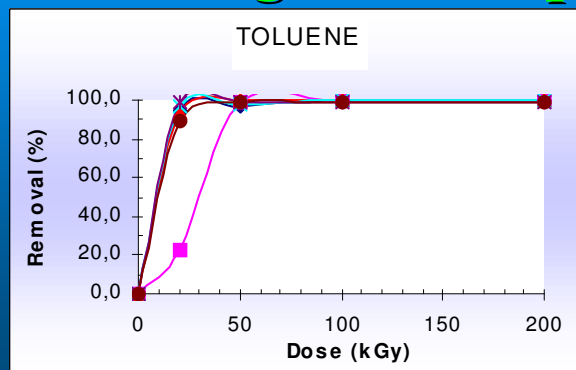
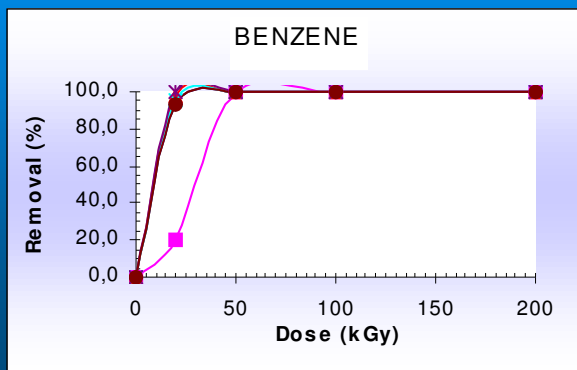
Source: IPEN-CNEN/SP

IPEN'S Studies for Organic Compounds Removal after Electron Beam Irradiation of Samples from WWTP



Source: IPEN-CNEN/SP

Removal of Organic Compounds (EB)



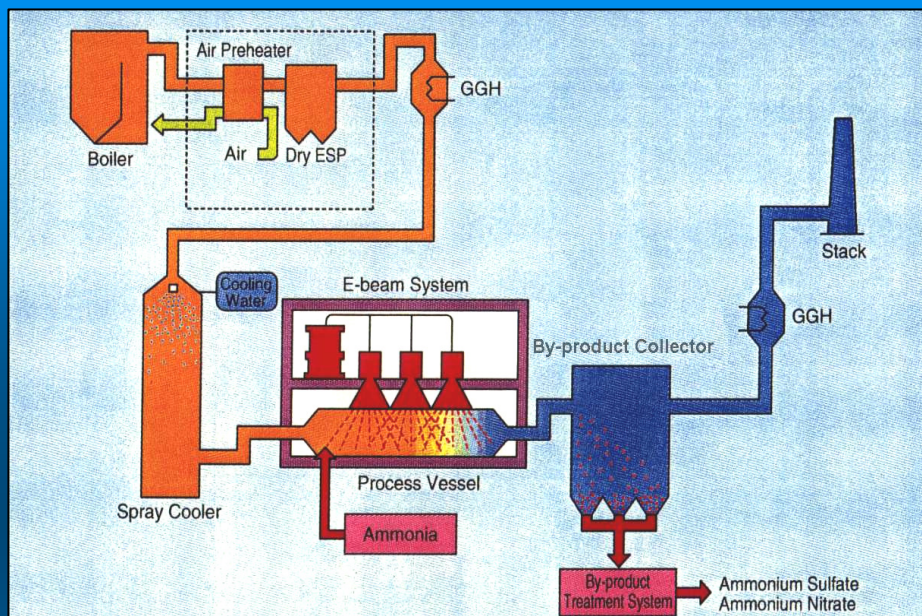
MAIN THERMAL POWER PLANTS IN BRAZIL



Wet Type
Limestone-Gypsum Process
(SO₂ removal, by-product: gypsum)

Source: IPEN-CNEN/SP

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%



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

⇒ SO₂ removal > 90%

⇒ NO_x removal > 70%

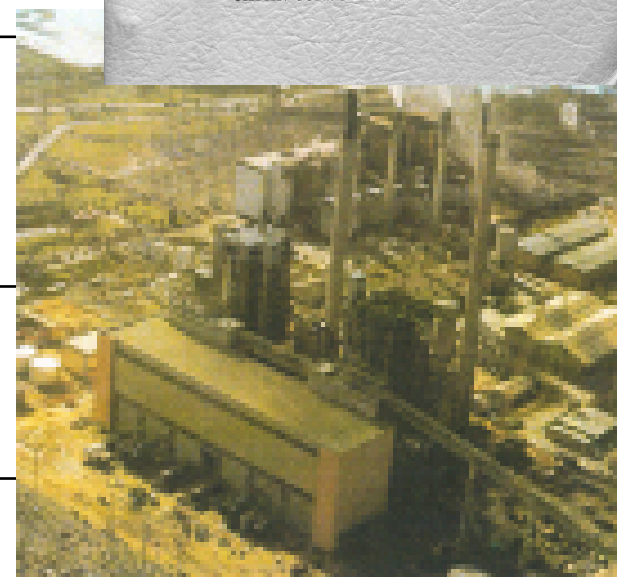
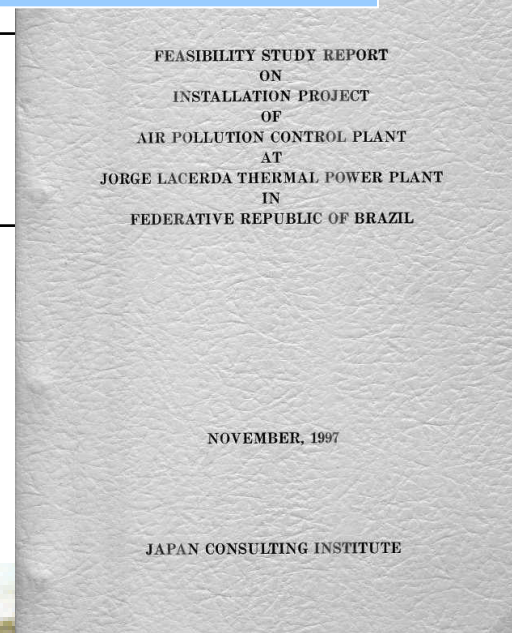
⇒ By-Product: (NH₄)₂SO₄
NH₄NO₃

Source: INCT

Expected Reduction of Air Pollutants Jorge Lacerda (857 MW) - ELETROSUL Thermal Power Plant in Santa Catarina State

| Parameters | Air Pollutants | EBA System Base (80% SO _x , 25% NO _x) |
|------------------|---|--|
| Inlet | * Gas Flow Rate SO ₂ NO _x Dust H ₂ O | 480,000 Nm ³ /h (125 MW) 1,739 ppmv 446 ppmv 1,100 mg/Nm ³ 7.3%v |
| Outlet | SO ₂ NO _x Dust | 347 ppmv 334 ppmv 50 mg/Nm ³ |
| Reduction | SO ₂ NO _x Dust | 1,769 kg/h 103 kg/h 467 kg/h |

* Wet base.

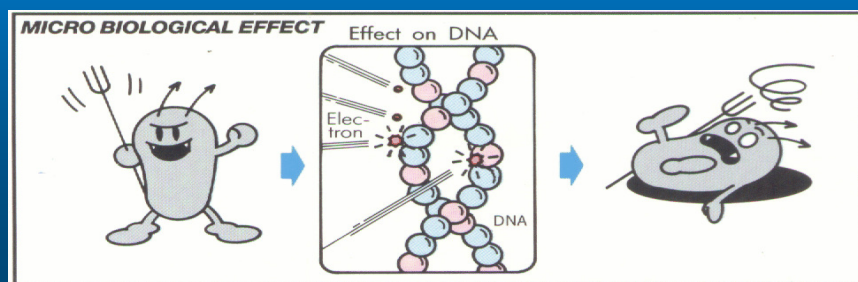


Source: IPEN-CNEN/SP

Electron Beam Accelerators

High-Energy: 5 MeV – 10 MeV

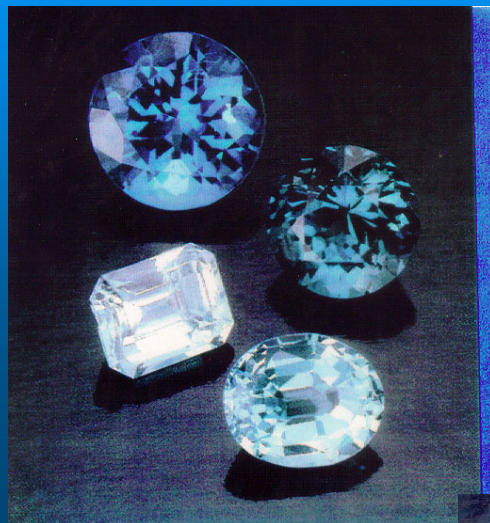
BRAZIL: ~50% (increase 10% / year)
World: ~60% (190 gamma irradiators)



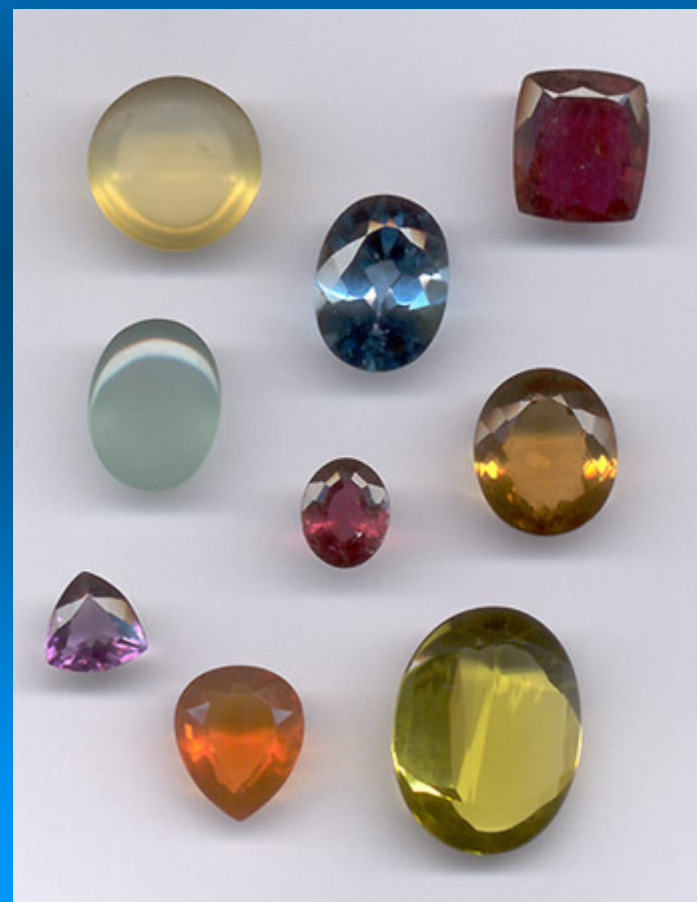
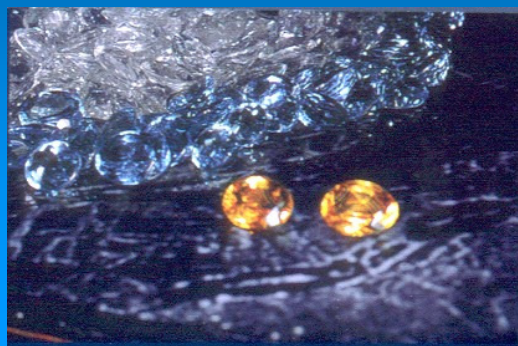
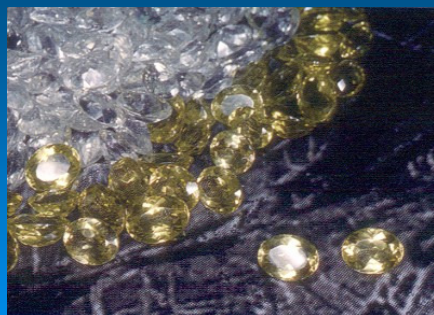
| NECESSARY CONTROLS | STERILIZATION PROCESSES | | | | |
|--------------------|-------------------------|---------|-------|------------|-----------|
| | Gases | Liquids | Vapor | Filtration | Radiation |
| Time | X | X | X | X | X |
| Temperature | X | X | X | | |
| Package | X | X | X | | |
| Pressure | X | | X | X | |
| Humidity | X | | X | | |
| Concentration | X | X | | | |
| pH | | X | | | |

GEMSTONE IRRADIATION

(EB and Gamma Rays)



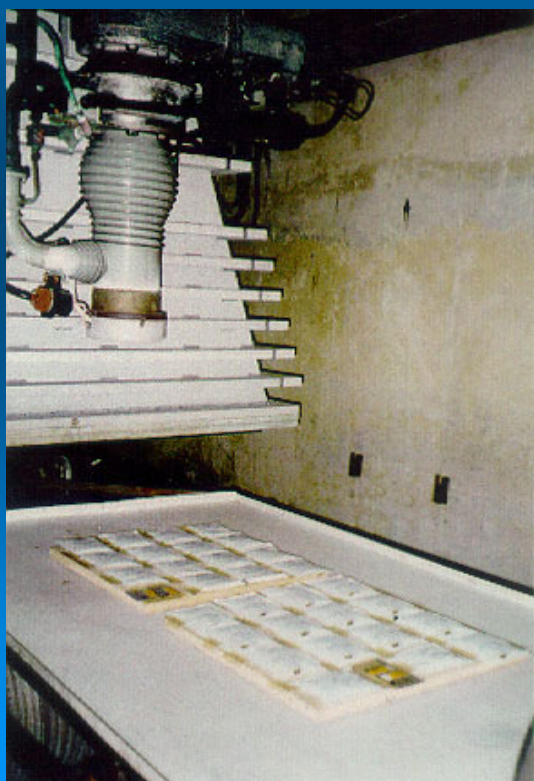
**Topaz, Rubelita, Quartz, Citrine
and Ametista**



Source: IPEN-CNEN/SP

- Military Food (10-50kGy)
- Potatoes and Onions (0.05-0.15kGy)
- Bread (2-10kGy)
- Strawberries (0.2-1.0kGy)

Brazilian Agrobusiness:
43% of the total exportation



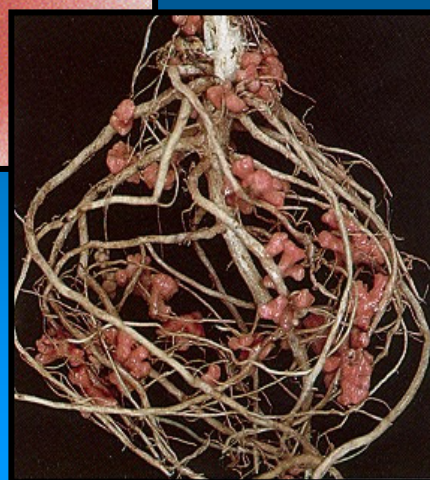
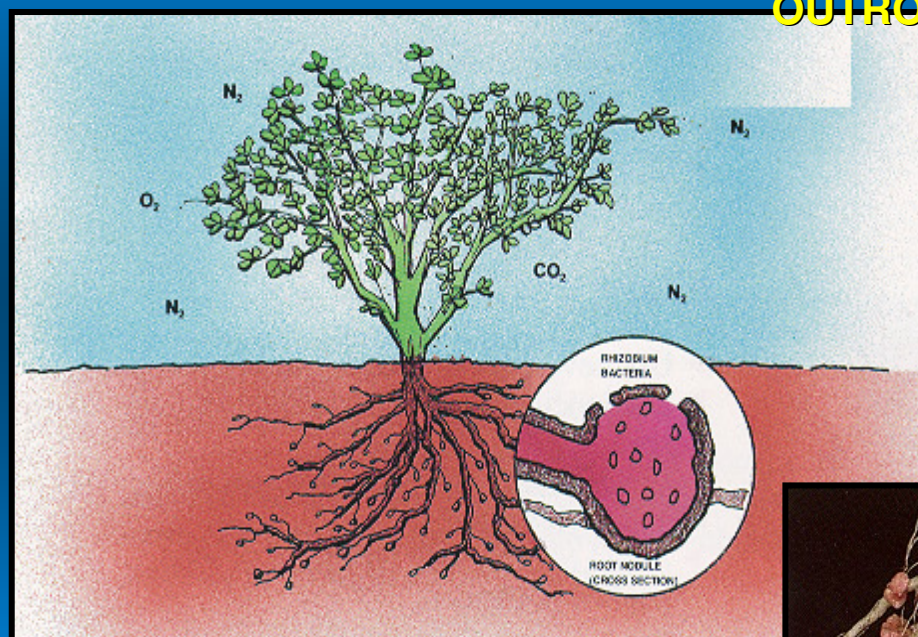
Source: IPEN-CNEN/SP

GASES ATMOSFÉRICOS:

NITROGÊNIO (N_2) = 79%

OXIGÊNIO (O_2) = 20%

OUTROS (CO_2) = 1%

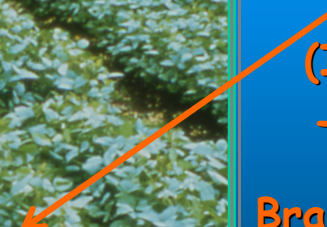


Biological
Adsorption of
Nitrogen by
Bradyrhizobium
and *Rhizobium*
(dose >50kGy)

SOY



SOY
(Irradiated
Turfa and
Bradyrhizobium)



BRAZIL: Soy plantation with irradiated turfa

- Biggest consumer and producer
- 23,7 millions of hectares (60% - 70% of total area)
- Economy of US\$ 2,5 billions of nitrogen/year
- Productivity of soy increase 8%

Source: EMBRAPA



BRAZIL:

Reduce the bioburden (*mosto*):

- **Fuel alcohol production increase 3% (1,5kGy)**
- **Reduce the consumption of antibiotic**



Sources: Usina Açucareira Guaíra and IPEN-CNEN/SP

MUNDIAL BUSINESS OF FUEL ALCOHOL

(Billions of liters)

| PRODUCTION | | | | DEMAND | | | |
|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Region | 2003 | 2005 | 2010 | Region | 2003 | 2005 | 2010 |
| Brazil | 14.40 | 15.90 | 21.20 | Brazil | 12.87 | 14.00 | 17.41 |
| EUA | 10.60 | 13.25 | 18.93 | EUA | 10.60 | 13.25 | 18.93 |
| EU | 1.89 | 3.79 | 7.19 | Canada | 0.38 | 0.76 | 1.51 |
| Other | 0.76 | 3.41 | 12.87 | EU | 1.51 | 4.92 | 12.87 |
| Total | 27.63 | 36.34 | 60.18 | Japan | 0.76 | 1.89 | 7.19 |
| | | | | Other | 1.51 | 1.51 | 2.27 |
| | | | | Total | 27.63 | 36.34 | 60.18 |

Source: New York Board of Trade

DECONTAMINATION OF PESTICIDE PACKING USING IONIZING RADIATION



STUDIED PESTICIDE:
Chlorpyrifos, o,o-Diethyl-o-
(3,5,6-trichloro-2-pyridyl)
phosphorothioate

Electrons



⇒ 288,000 tons of pesticides/year
⇒ 107,000,000 packing
⇒ 23,000 tons of solid waste

Plastic bottles



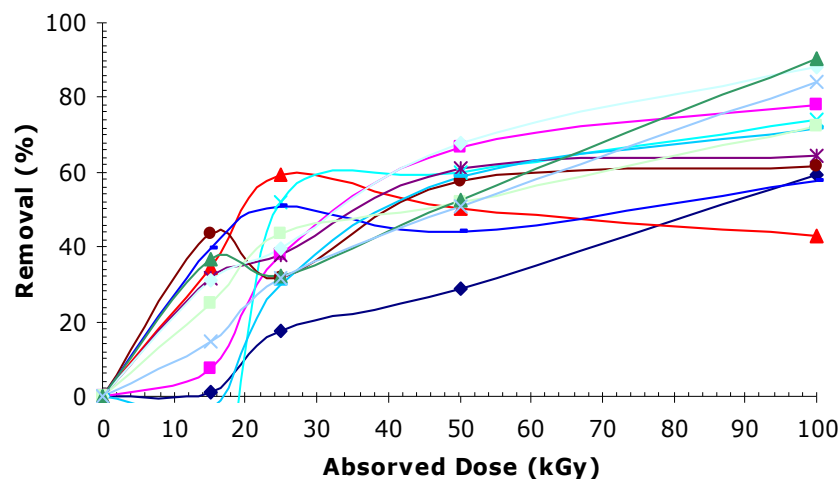
Corrugated ducts



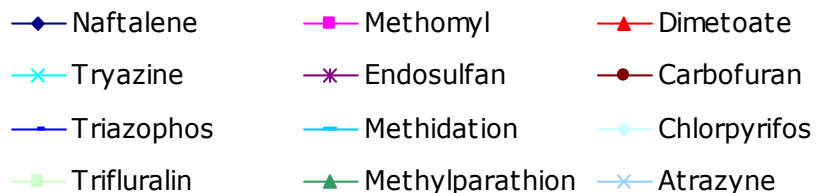
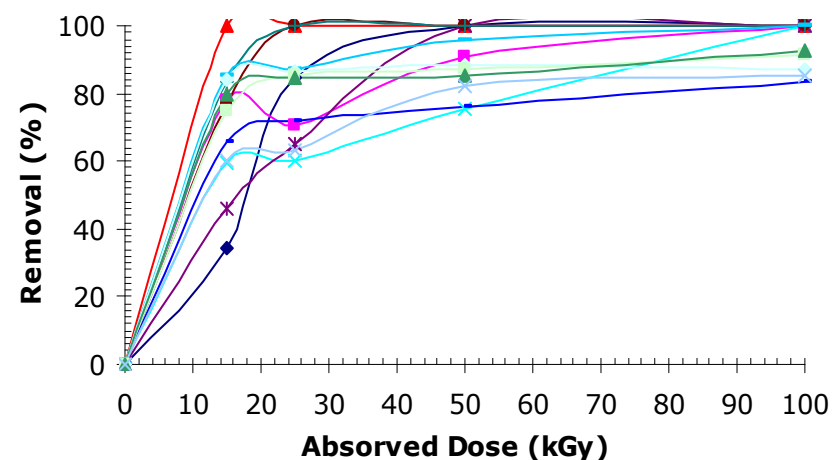
Source: IPEN-CNEN/SP

Removal of pesticides in package with and without water using electron beam accelerator

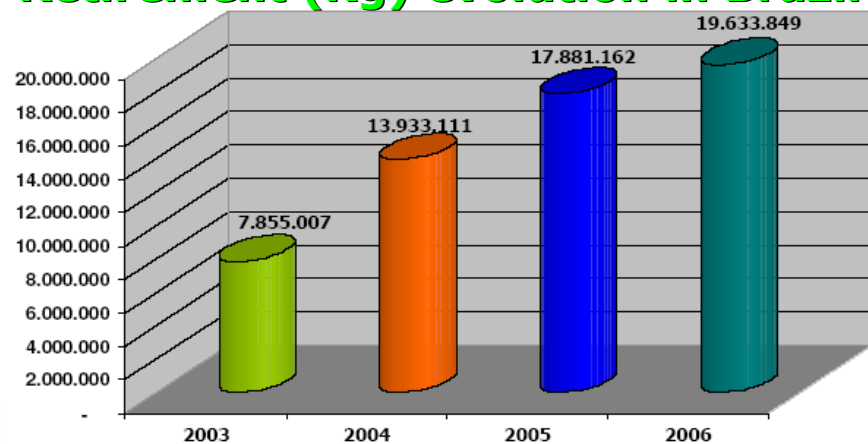
Accelerator Without Water



Accelerator With Water



Retirement (Kg) evolution in Brazil

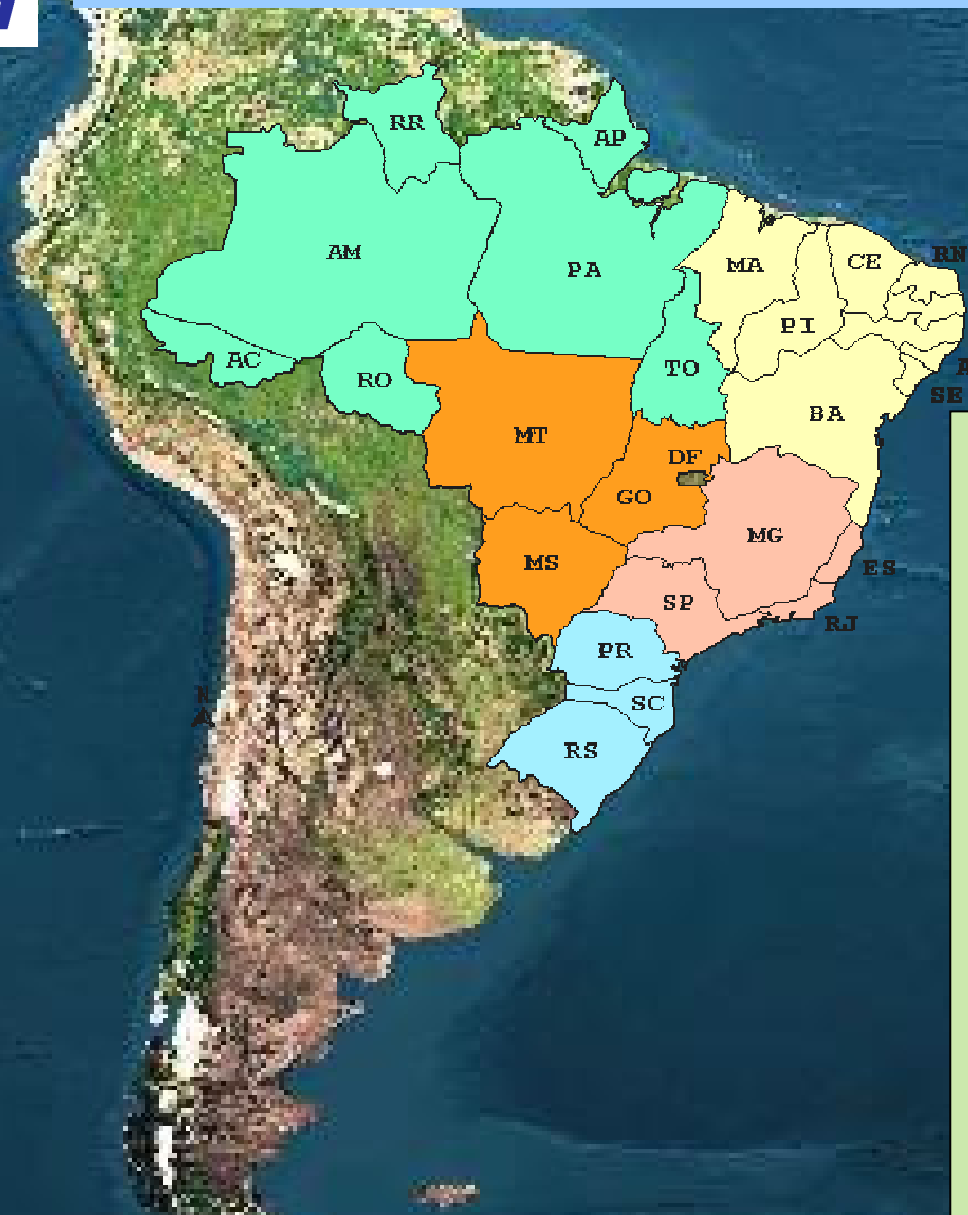


recycling (~60%) incineration (40%)

Search for new technologies to substitute the incineration



Source: IPEN-CNEN/SP



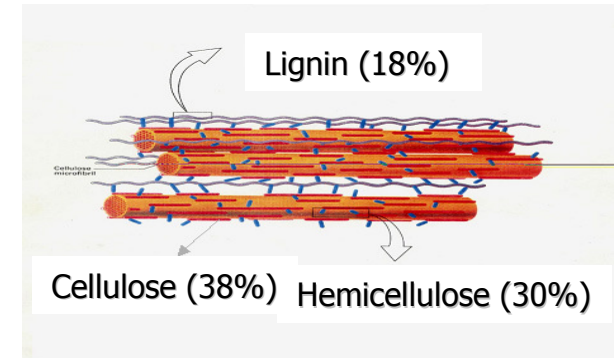
- Brazil has a long time tradition in the use of renewable energy (44.7%)
- Brazil produces and processes more than 300 million metric tons of sugarcane/year (1/4 of the 1,300 million tons grown worldwide)
- The Brazilian sugar cane sector represents around 2% of the GNP.

São Paulo State concentrate more than 60% of sugarcane production

Source: IPEN-CNEN/SP

Sugarcane Bagasse Irradiation as Pretreatment to Produce Ethanol Biofuel

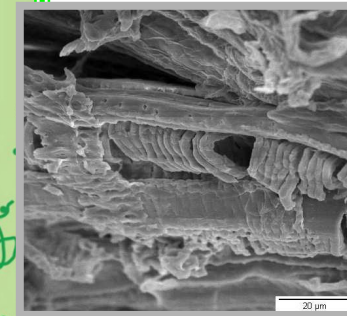
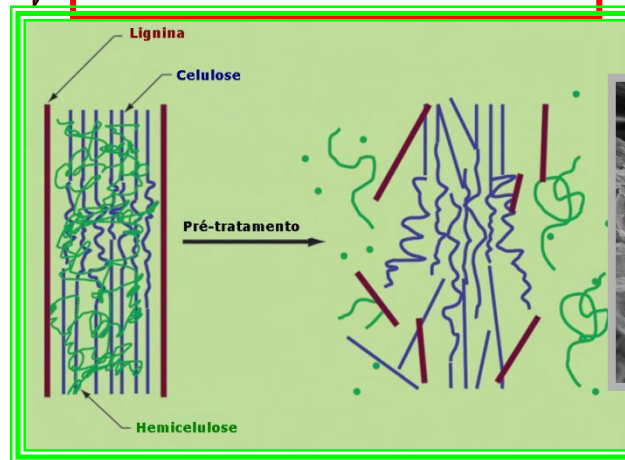
- Normally physical and chemical process
- Reduce the crystallinity
- Disrupt the hydrogen bonding of cellulose
- More accessibility to hydrolytic depolymerization reactions



Pretreatment

hydrolysis process

Electrons



Ethanol biofuel

Fermentation

Free sugars

Source: IPEN-CNEN/SP

- 1) Lower cost and low-energy EBA are commercially available
- 2) There is a growing use of low-energy EBA (eliminations of VOC's, environmental friendly, energy savings and efficiency)
- 3) There is a growing need for mobile facilities for different applications
- 4) There is an increasing diversity of products and processes that require high and mid-energy EBA
- 5) There is a need of improvements in the reliability of EBA for environmental applications, with regard to window life time, power supply and cathode
- 6) Improved efficiency, with reduction in time and required dose, and effort achieved through collaboration among INDUSTRIES, UNIVERSITIES and RESEARCH INSTITUTES could lead the products and processes to faster and more economical commercialization



International Topical Meeting on
Nuclear Research Applications
and Utilization of Accelerators

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**THANK YOU VERY
MUCH FOR
YOUR ATTENTION**

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Physics and Thermal Hydraulics

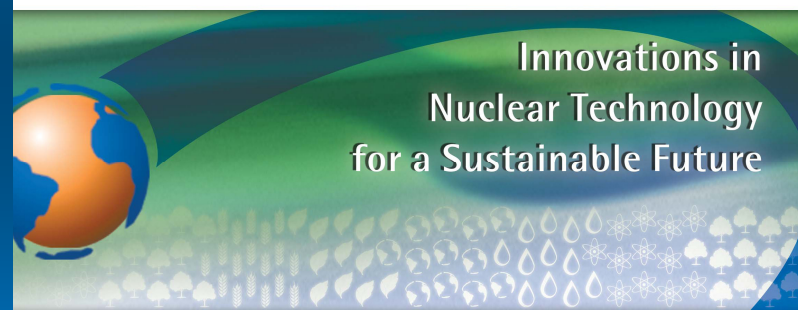


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April 20
Notification of acceptance / rejection of abstracts
June 15
Deadline for full-length paper submission

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