Electron Beam Irradiation Applications

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International Atomic Energy Agency

IAEA

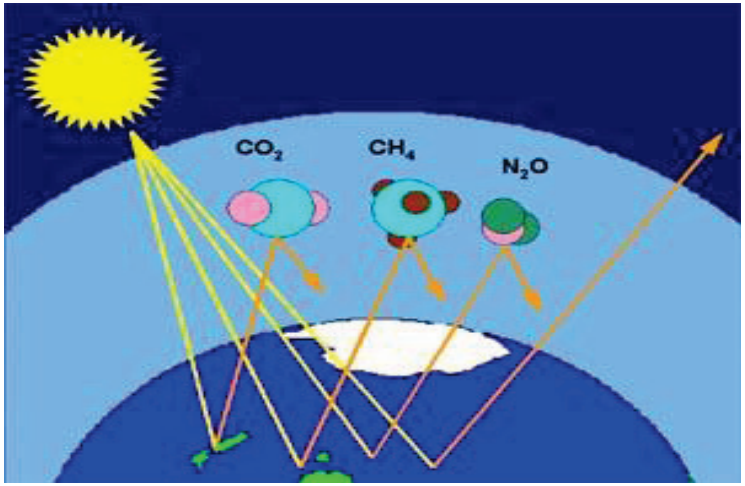
Atoms for Peace

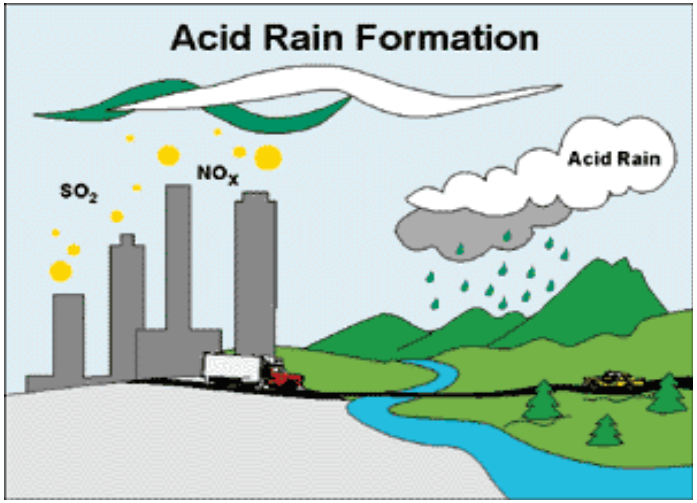
Greetings from the IAEA!

Outline of the presentation

- Fundamental aspects of radiation processing using electron beam accelerators
- Established applications of electron beam accelerators
- Emerging applications and the challenges before electron beam technologists for such applications
- Role of IAEA in enhancing applications of electron beam accelerators

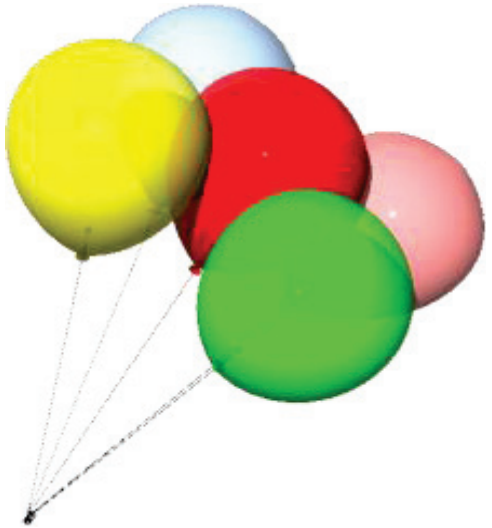
Issues related to conventional techniques





High Energy Consumption !

Toxic residues!!

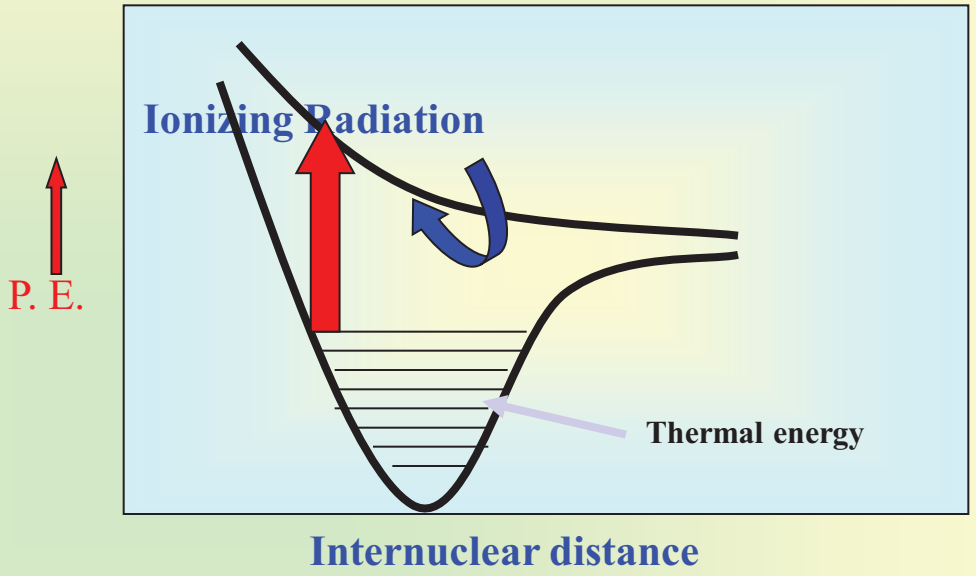


Expectations from new technologies

- **Energy Saving**
- **Must provide superior products**
- **Environment friendly**
- **Cost effective**
- **Public acceptance**

How is Radiation Different from Thermal energy ?

Thermal energy **is very strongly coupled to Translational, Rotational and Vibrational modes of the energy absorber. Ionization, bond rupture and other processes leading to chemical reactions occur only in the high energy region of the Maxwellian tail.**

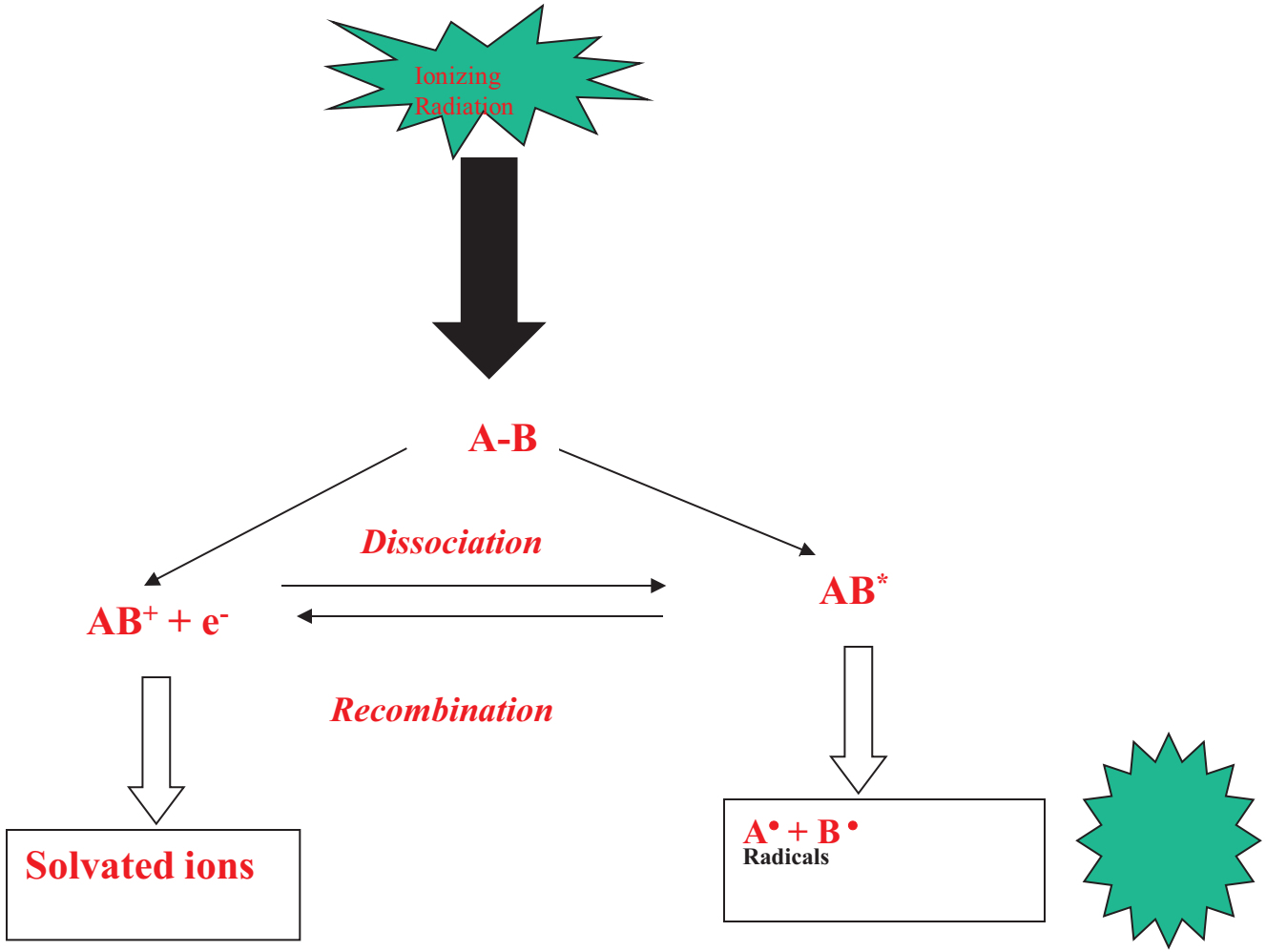


Ionizing radiation **is almost entirely absorbed by the electronic structure of absorber which increases the energy level of its orbital electrons.**

Effective, Efficient generator of reactive Species.

Energy in the form of large quanta can have more pronounced chemical effects than energy in the form of small quanta

Effects of radiation on a covalent bond



What kind of reactions are amiable with radiation (EB) processing?

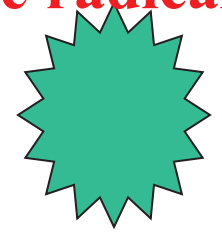
Production rate (kw-hr) = 3.74×10^{-4} G.M.f kg

where f is efficiency of radiation absorption

- **G-value (yield) of reaction should be very high**
- **M - (mol. wt. of product) should be high**
- **Small change produced should have very large effect on the properties**
- **Value addition to the product is very high**

The real dot -com

Free radical, $R^{\cdot}$



Mutli- billion dollar industry providing unique high technology products !!

Applications of Radiation Technology

- *Crosslinking of polymers*
- *Curing of polymer coatings*
- *Graft polymerization*
- *Flue gas treatment*
- *Waste water treatment*

Radiation Chemistry based applications

- *Sterilization of medical products*
- *Food irradiation*
- *Sewage Sludge Hygienization*

Radiation Biology based applications

Electron Accelerators: Tools for radiation processing

Electron Accelerator (EB):

Energy:

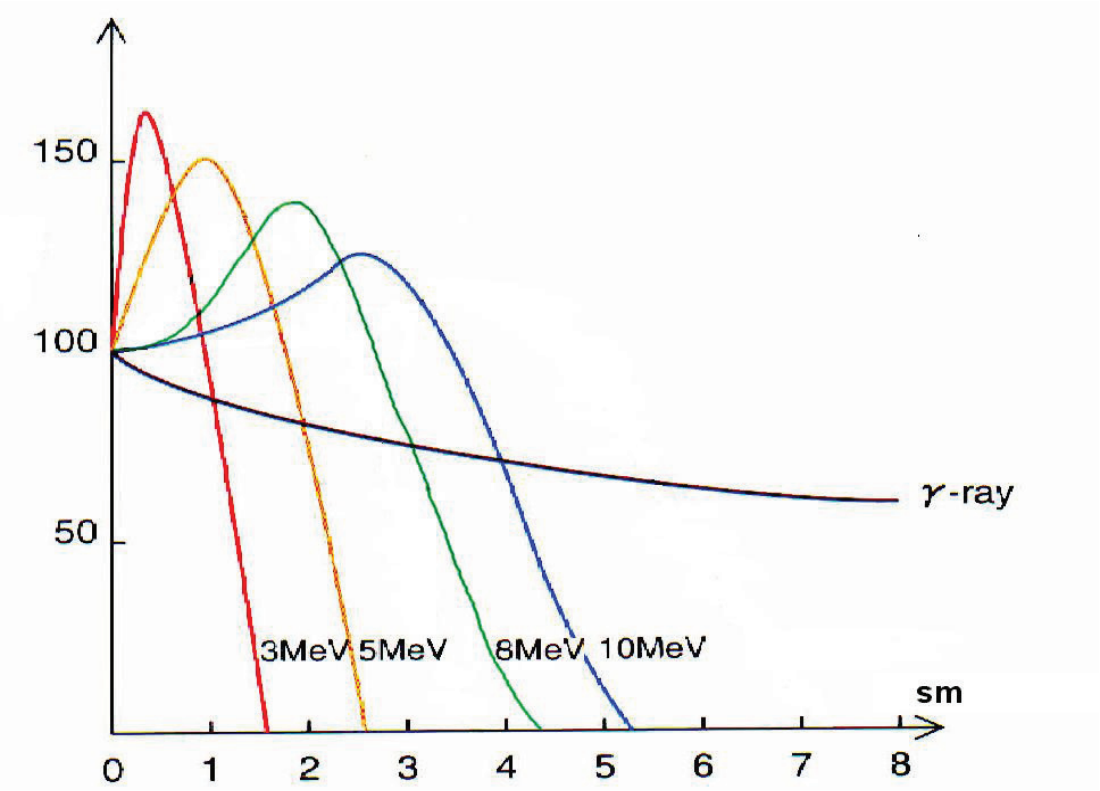
low (300-700keV),
medium (2-3MeV)
high (5-10MeV)

Power:

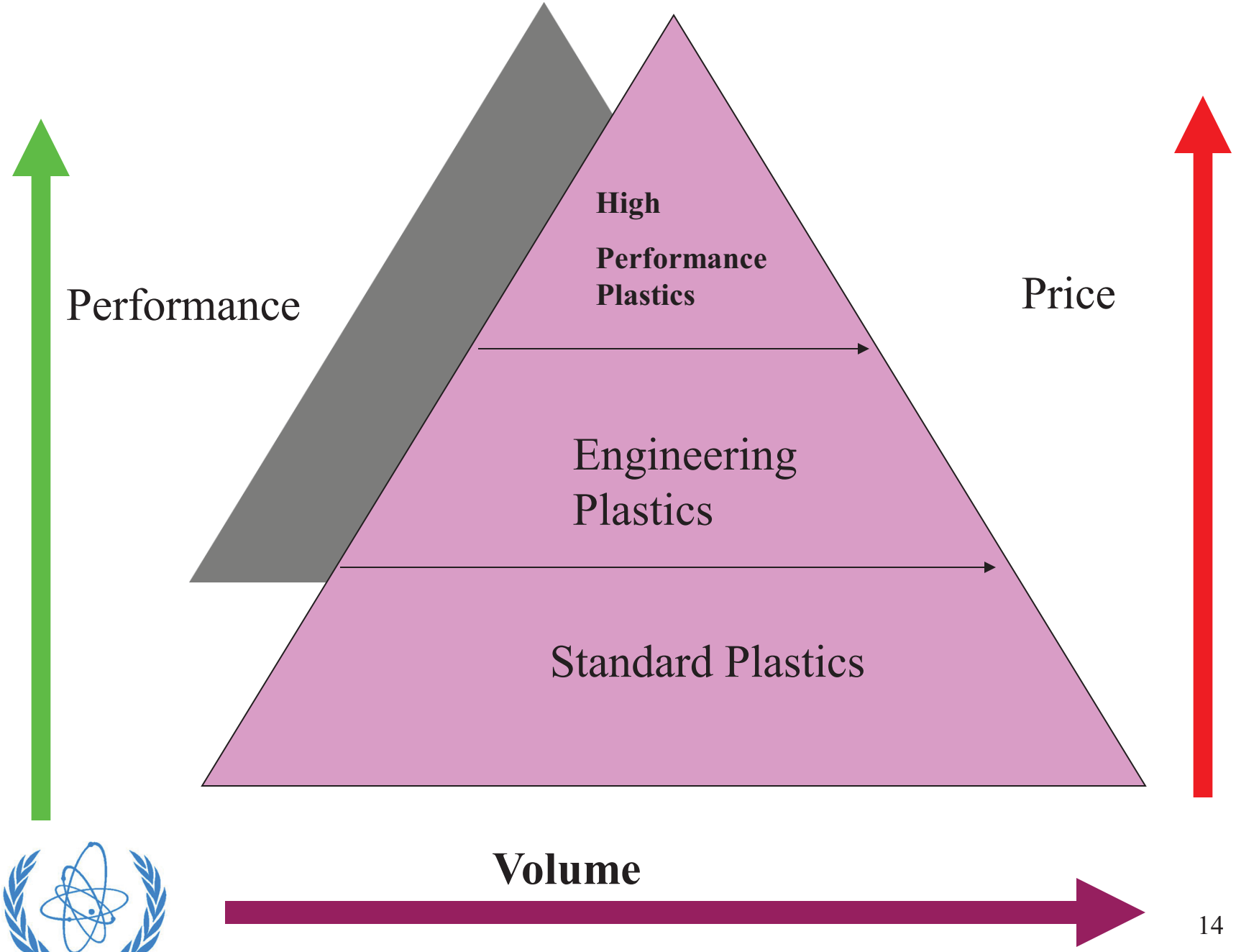
Medium (20-100kW)
High (0.5-1MW)
Electron mode
X-ray mode

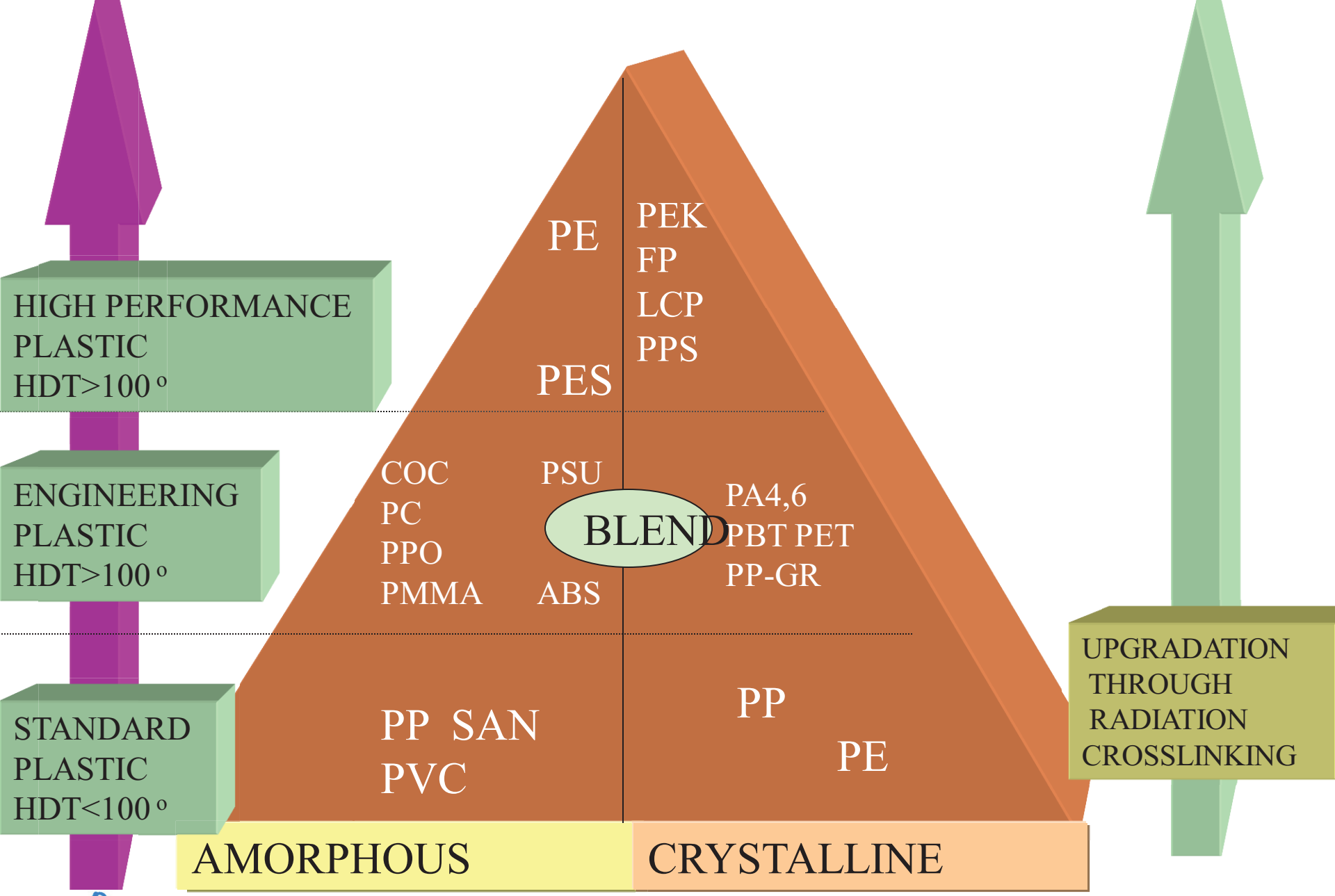
(>2000 worldwide)

Penetration Depth of γ-ray and e-beam



Applications of Medium Energy Accelerators


Performance
High
Performance
Plastics
Engineering
Plastics
Standard Plastics
Price
Volume


HIGH PERFORMANCE PLASTIC HDT>100 °
ENGINEERING PLASTIC HDT>100 °
STANDARD PLASTIC HDT<100 °
PE
PEK
FP
LCP
PPS
PES
COC
PC
PPO
PMMA
PSU
ABS
BLEND
PA4,6
PBT PET
PP-GR
PP SAN
PVC
PP
PE
AMORPHOUS
CRYSTALLINE
UPGRADATION THROUGH RADIATION CROSSLINKING

Benefits of crosslinking

- Increased tensile strength
- Increased form stability
- Resistance to deformation
- Resistance to solvents
- Shrink memory
- Viscosity or melt flow behavior change

Benefits of Electron Beam crosslinking

- Can be carried out at any temperature and in any phase
- No toxic additives are required
- Crystallinity of the material is retained as crosslinking occurs only in the amorphous phase
- Only one parameter *viz.* Radiation dose to be controlled in the process

Comparison of Energy Input of Thermal and Radiation Vulcanization of Rubbers

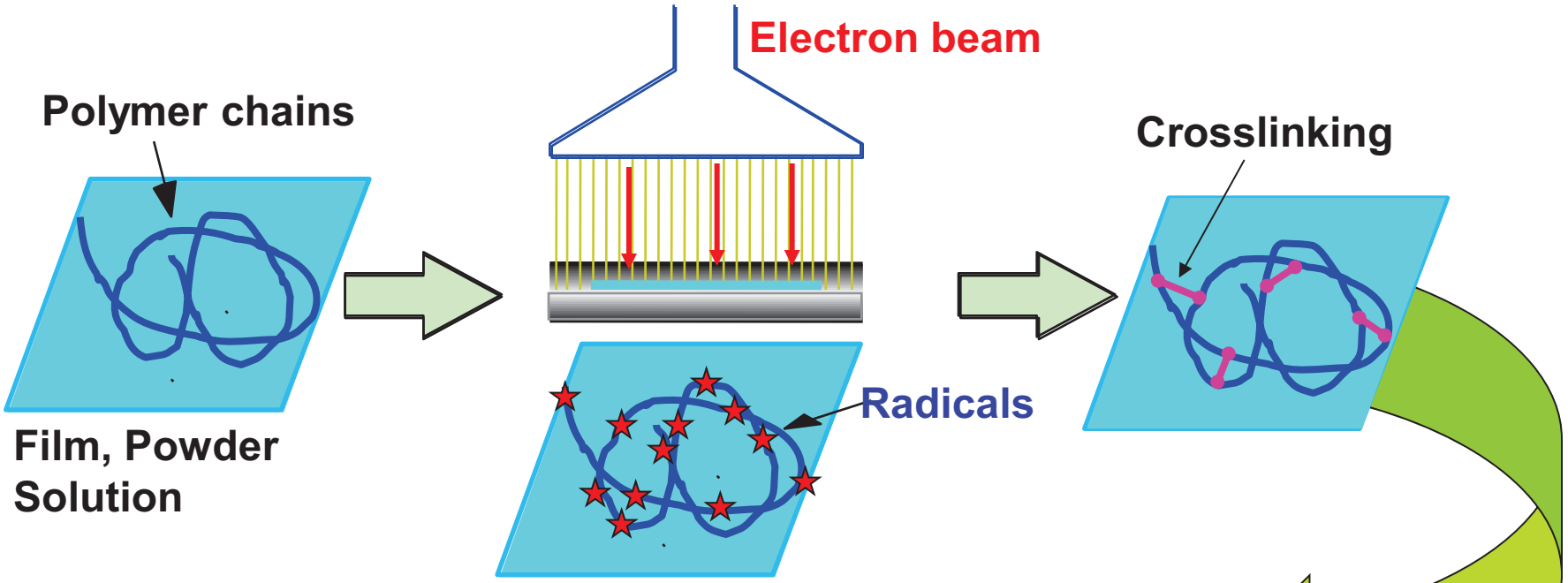
Rubber Vulcanization at 80 kGy = 80 J/g

Thermochemical vulcanization of rubber at 150 C to achieve the same crosslinking = 281 J/g

Radiation vulcanization is 3-6 times more energy efficient!

Ref: V.S.Ivanov, Radiation Chemistry of Polymers, Utrecht (1992)

Radiation Crosslinking

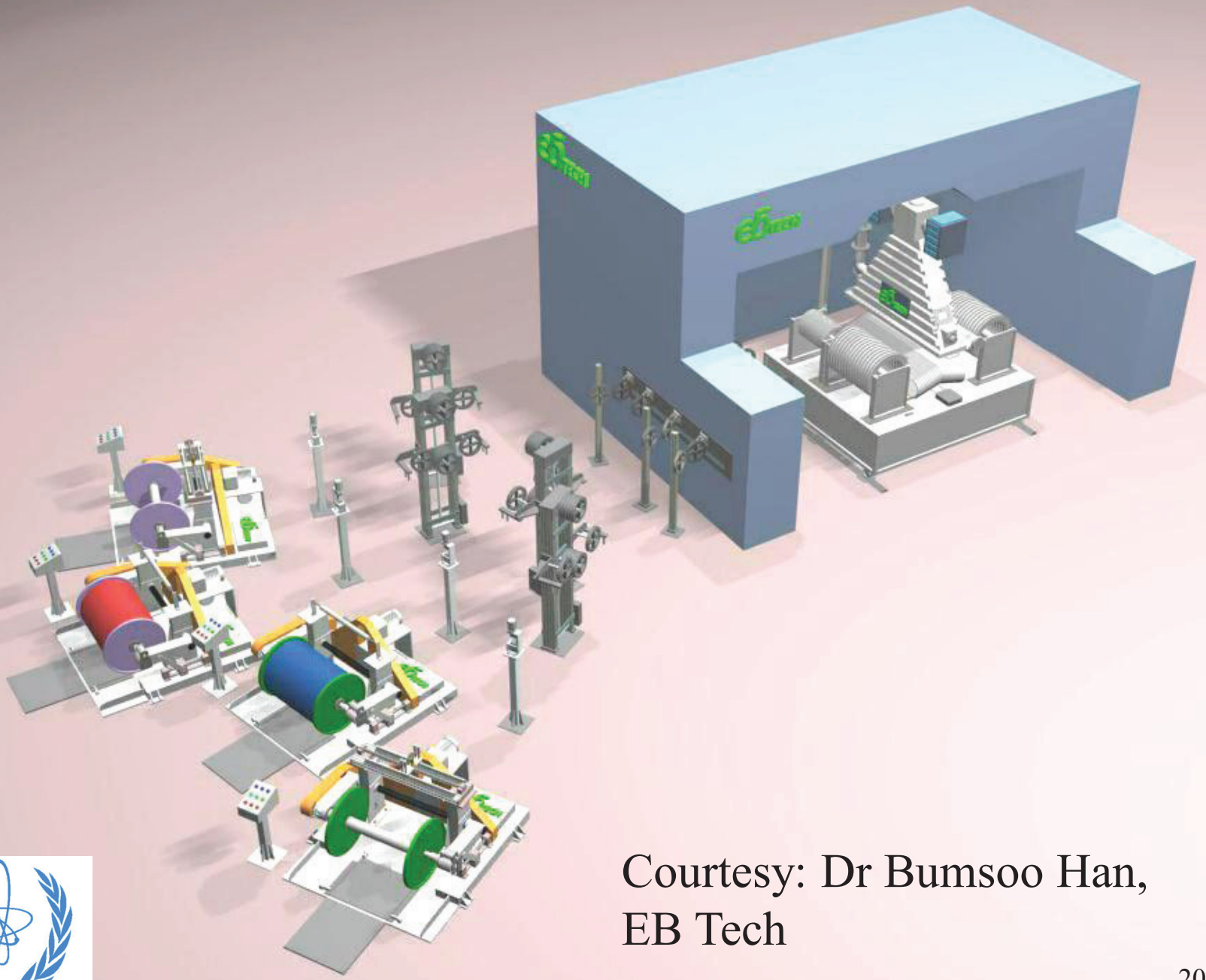


Advantages

- Clean
- Without heat
- Keep shape
- High speed

Improvement by crosslinking

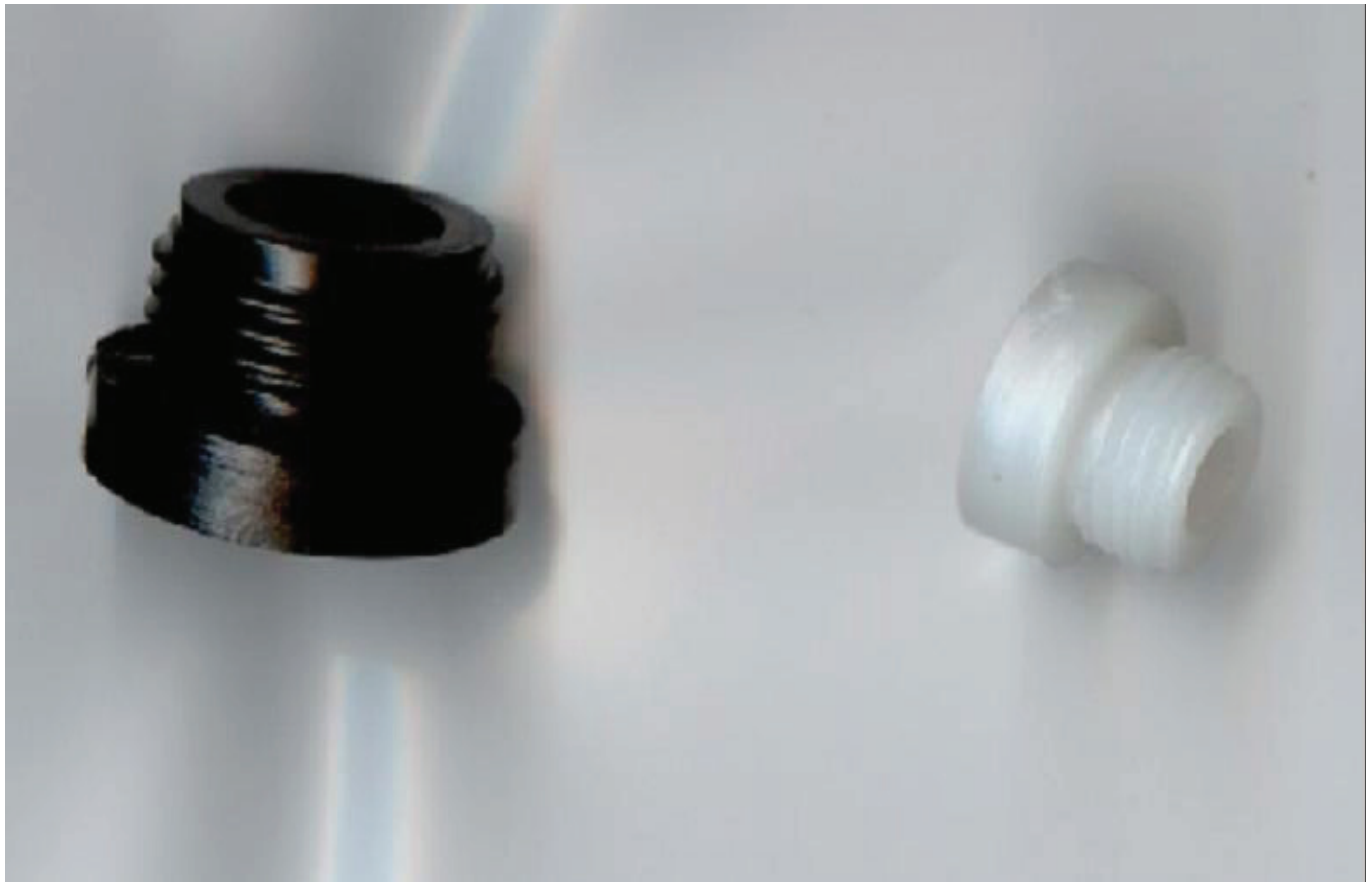
1. Heat stability
2. High strength
3. Processability
4. insoluble



Courtesy: Dr Bumsoo Han, EB Tech

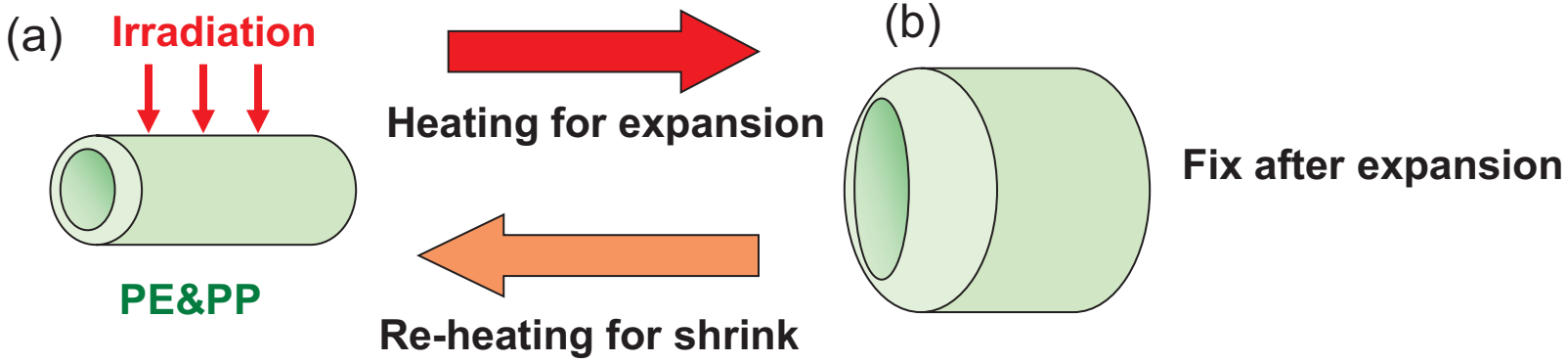
Value addition to materials using electron beams

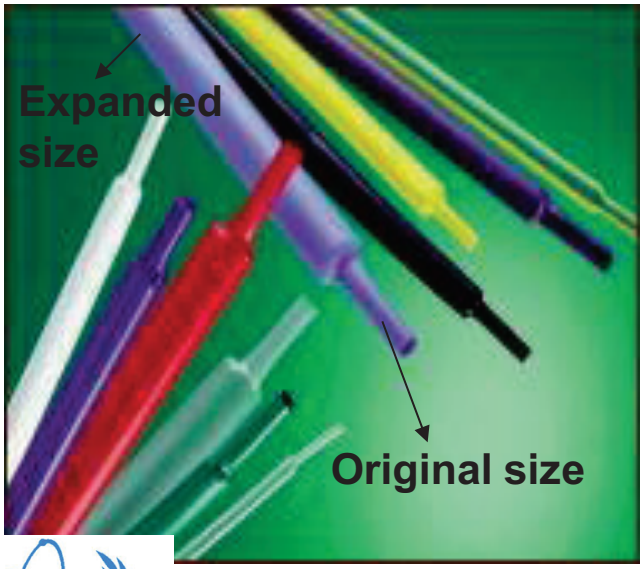
Unique advantage of electron beam (selective crosslinking)

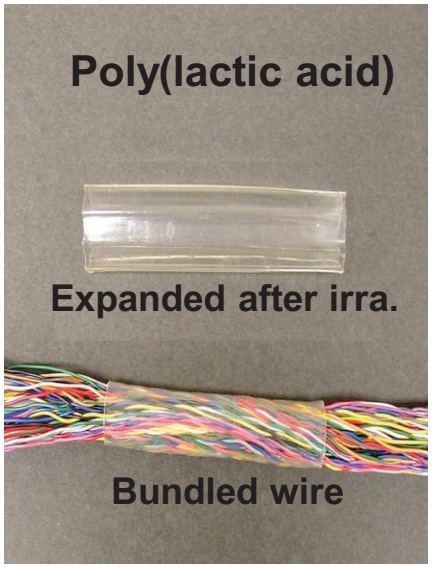


EB crosslinked HDPE

Shrinkable Tubes







Courtesy: Dr M.Tamada, JAEA

Electron Beam Crosslinked Heat-Shrink Products

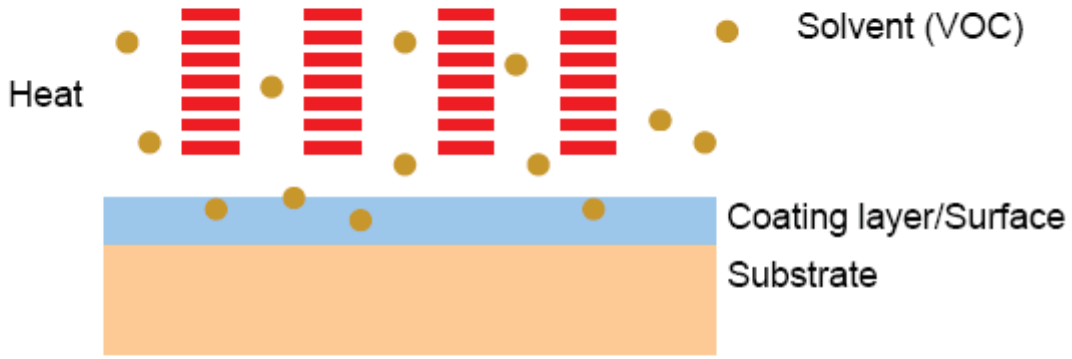
Packaging
Tubing
Sheets

Car Parts Produced by Radiation Crosslinking Technology

- Wire and Cable
- Foam
- Shrinkable Tube
- Tire
- Polyswitch

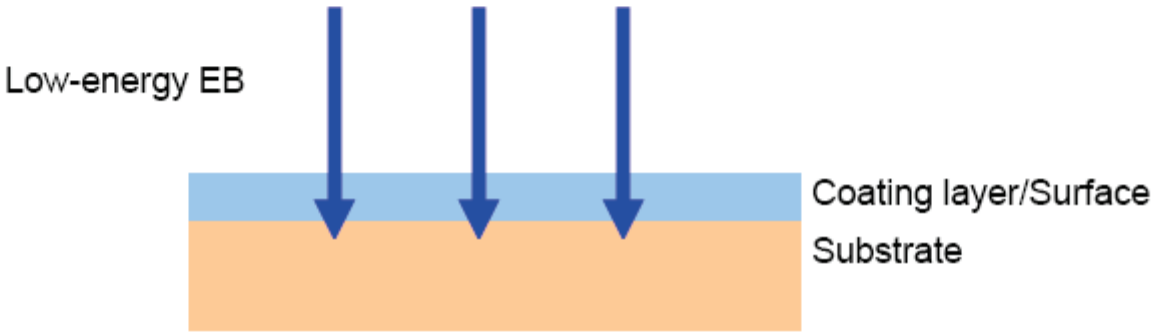
Applications of Low Energy Accelerators

Thermal drying for Curing



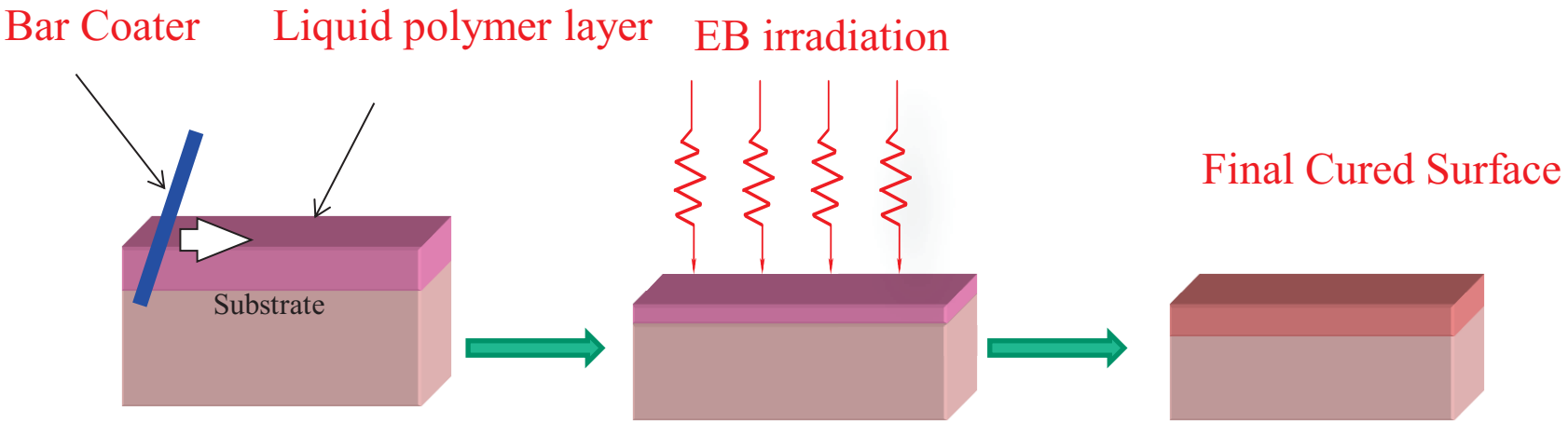
- Well-established process. Solvents required.
- VOC (Volatile Organic Compound) + CO_2
- Larger energy (heat sauce) required

Low-energy EB for Curing



- Just gives energy to surface area. No VOCs.
- Smaller size for inline, continuous process.
- High dose rate: high speed process

Electron Beam Curing for Surface Modification



Packaging
Sheets
Coating on metal, wood, glass..

(Abrasion, scratch resistance, hardness, glossy coatings)

Energy Demand to Dry/Cure Coatings

System	Solvent	Solvent	Water	EB cure
Solids	30%	40%	40%	100%
Diluent	heptane	toluene	water	none
Boiling Point,	98 ^{0}C	111 ^{0}C	100 ^{0}C	-
Vapour pressure at 20 ^{0}C	35 mm Hg	22 mm Hg	17 mm Hg	-
Heat of vapourization (cal/gm diluent)	76	88	540	-
Energy to dry 1g dried coating	740	555	3390	30 at 30 kGy

Ref: A.J.Berejka, IAEA-TECDOC-1386, 2004, 6 65-72

Applications of High Energy Accelerators

Electron Beam Sterilization of Life Saving Equipment

Enhancing food safety and security

Over half the food produced globally is lost, wasted or discarded as a result of inefficiency in the human-managed food chain.

Food Irradiation

One Process:

Multiple Uses

Sprout

Onion, Potato,
Ginger, Garlic

Quarantine

Fruits

Cereals, Pulses,
Dry Fruits

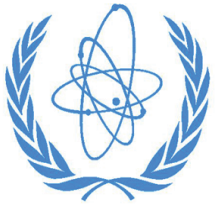
Bacteria Reduction

Chicken, Meat, Fish

Spices

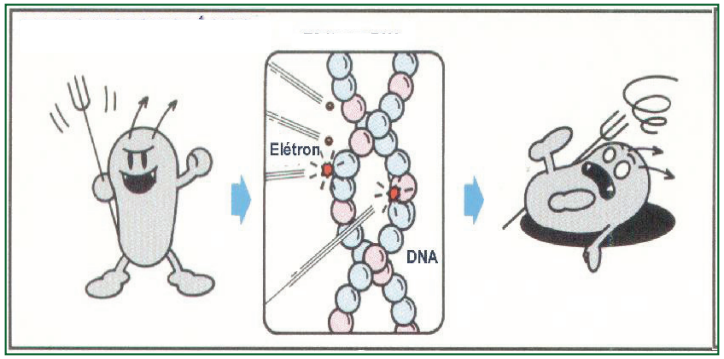
Food Irradiation in USA

- ***Approximately 8,000 MT (15-18,000,000 pounds) of ground beef irradiated annually in USA.***
- ***Approximately 14,000 MT (30,000,000 pounds) of produce irradiated annually.***
- ***Approximately 70-80,000 MT (175,000,000 pounds) of spices irradiated annually.***
- ***Approximately 18,000 to 20,000 MT (40 million pounds) of irradiated pet treats.***



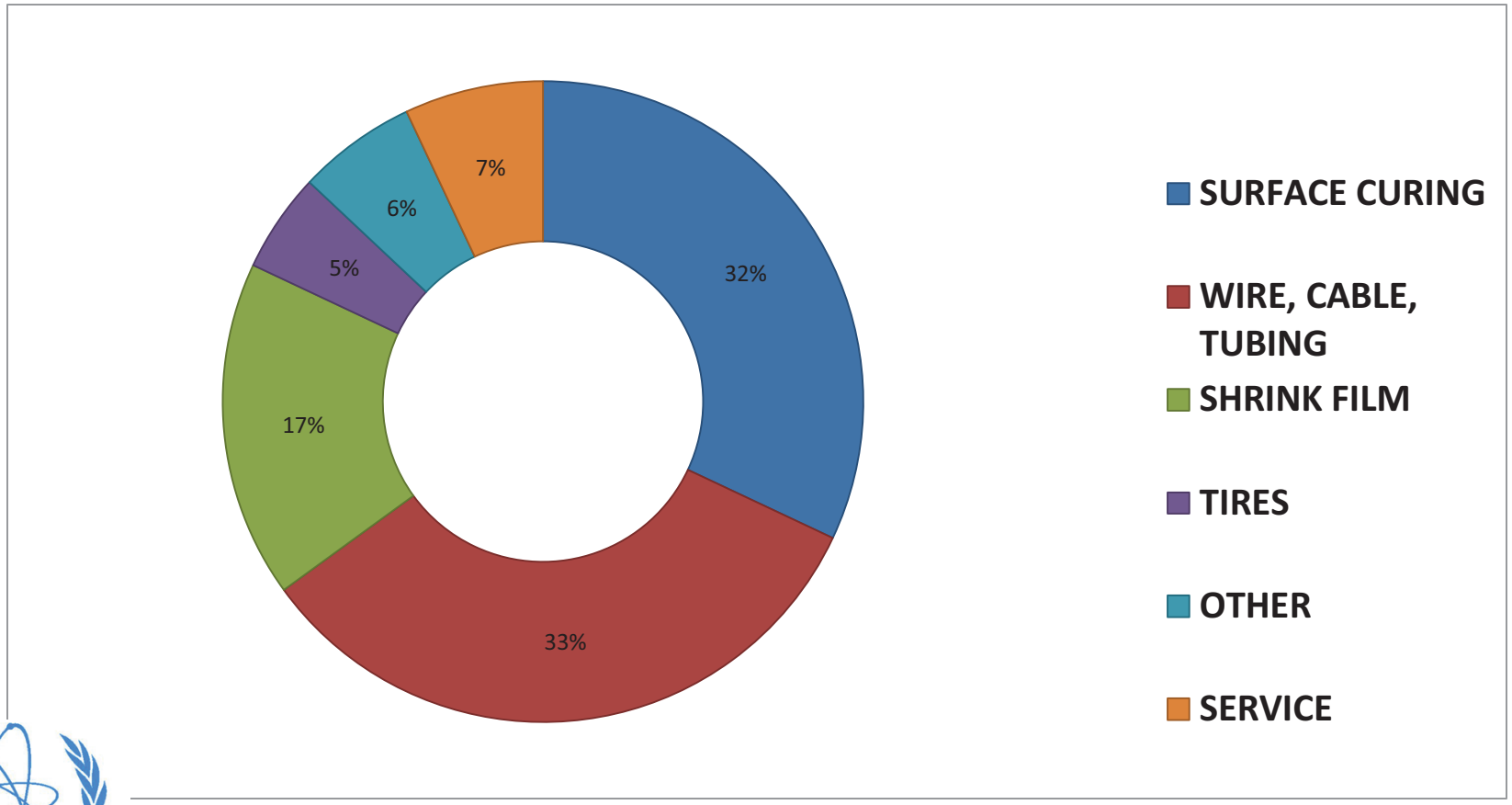
Ref: R.Eustice, NIC-2010, Mumbai

Radiation Treatment of Bio-hazards



Electron Beam accelerator for treatment of postal mail in US

Scale of utilization of radiation in various industries

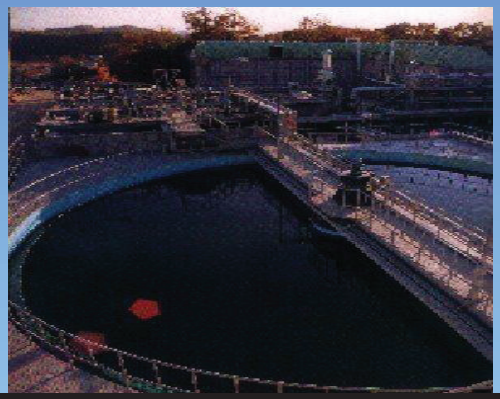


Over US$ 85 Billion industry!

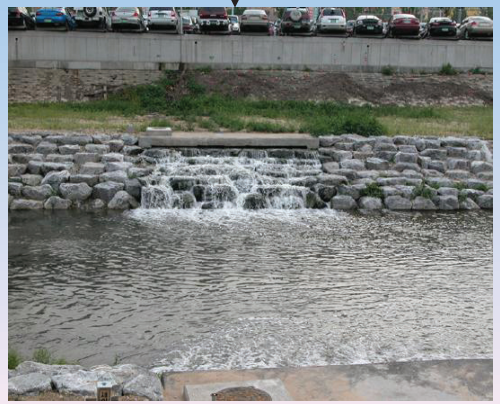
Emerging Applications And New Challenges

Electrons Beam Applications for Protection of the Environment

Flue gas Purification

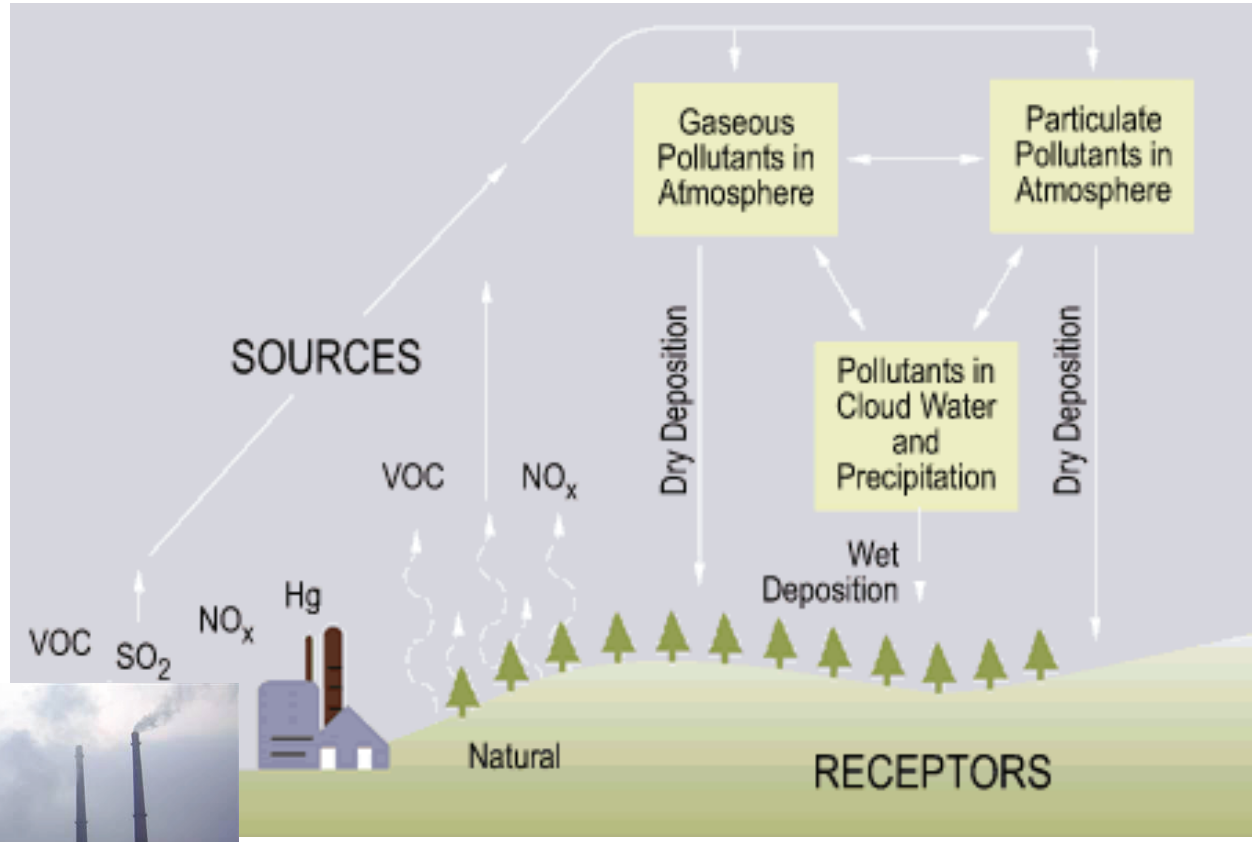


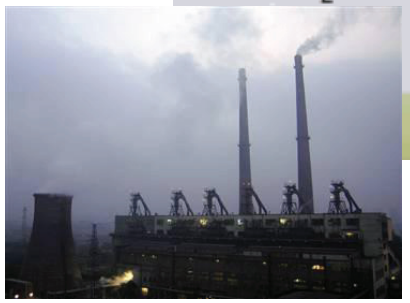
Wastewater Treatment



Sludge Hygienization

Tackling environmental challenges

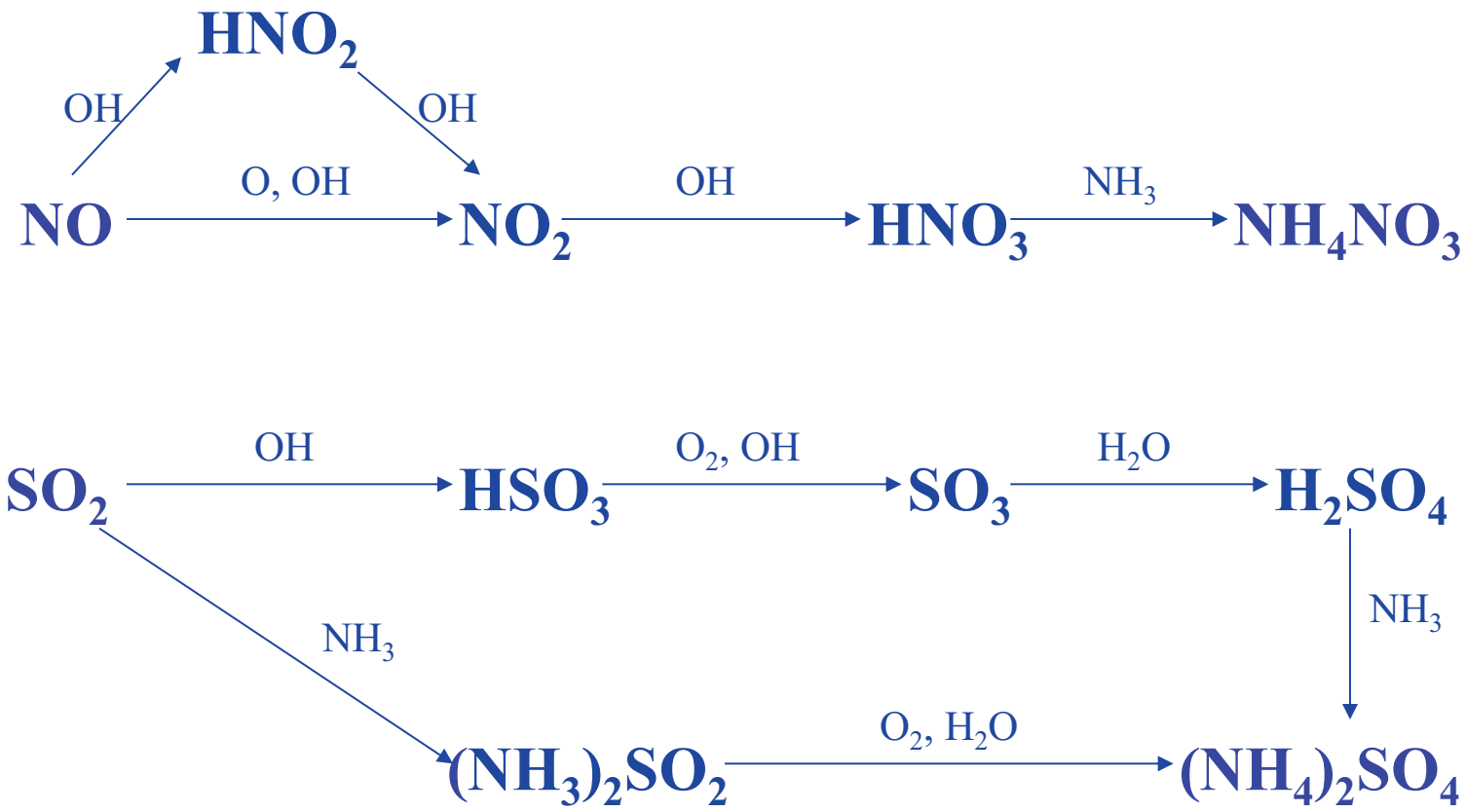




Acid rain

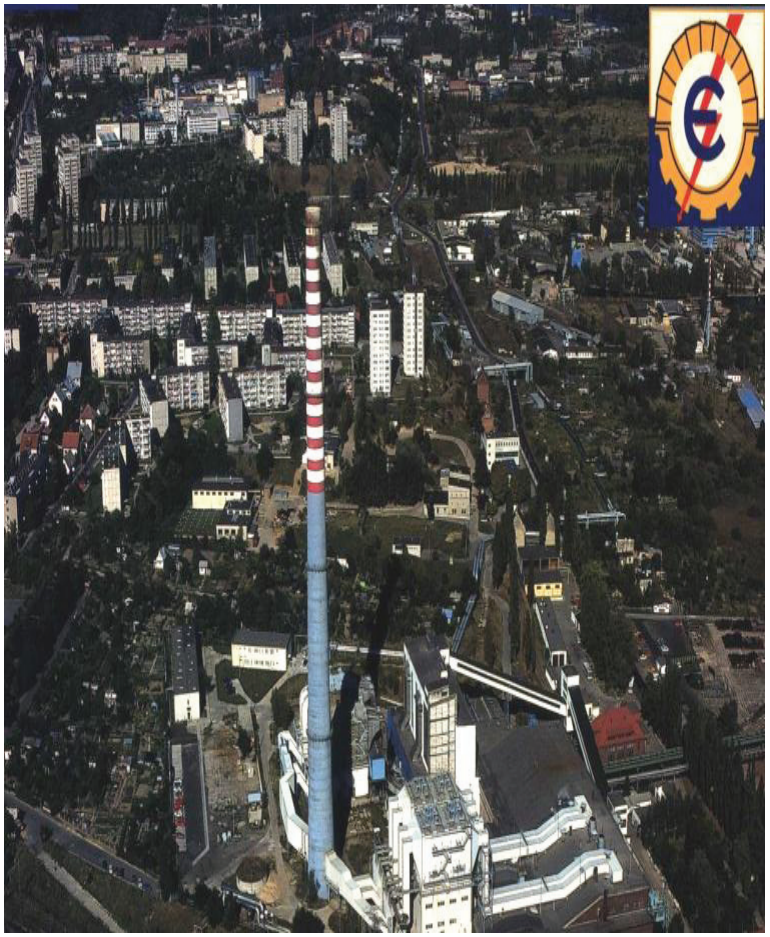
Electron Beam Flue Gas Treatment (EBFGT)

SO_2 and NO_x removal mechanism



Facility for flue gas treatment at EPS Pomorzany, Poland

- **Accelerator voltage 400-800 kV**
- Voltage stability ±2 %
- Max. Beam current 375 mA
- **Beam power 300 kW**
- EB current stability ±2 %
- Length of scan 225 cm
- Surface dose uniformity ±5 %



Courtesy: Prof A.Chmielewski

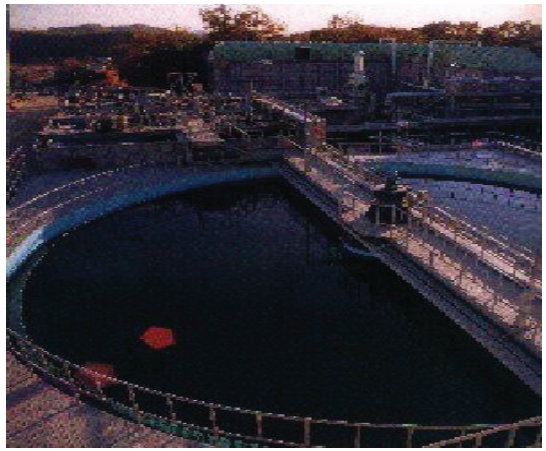
Set up in collaboration with IAEA

- Case 1 : Generalized Study for EB Process (2000)

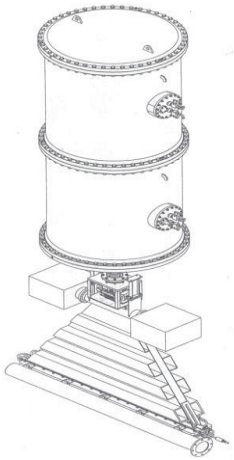
Items	Design Values
Flue gas flow	1,500,000Nm^3/h (350MW)
Inlet SO_2 / NOx concentration	5,500ppm/390ppm
SO_2 / NOx removal efficiency	85% / 60%
Dose	5~10kGy (?)
Inlet flue gas temperature	140℃
Outlet particulate concentration	≤50mg/Nm^3
By product	32.9ton/hr (100$/ton)
Electron accelerator	?
Total power consumption	10,200kW
Total capital cost	71 Million USD
capital unit cost	202$/kWe
Unit operation cost	-24$/kWe(-5.2$/t SO_2)

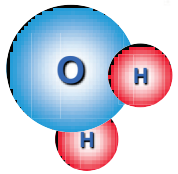
* IAEA- TECDOC-1189, Radiation processing of flue gases : Guidelines for feasibility studies, IAEA 200

Polluted industrial and municipal wastewater



Principles of Wastewater treatment with e- beam





Water Molecule

e_{aq}

OH*

H*

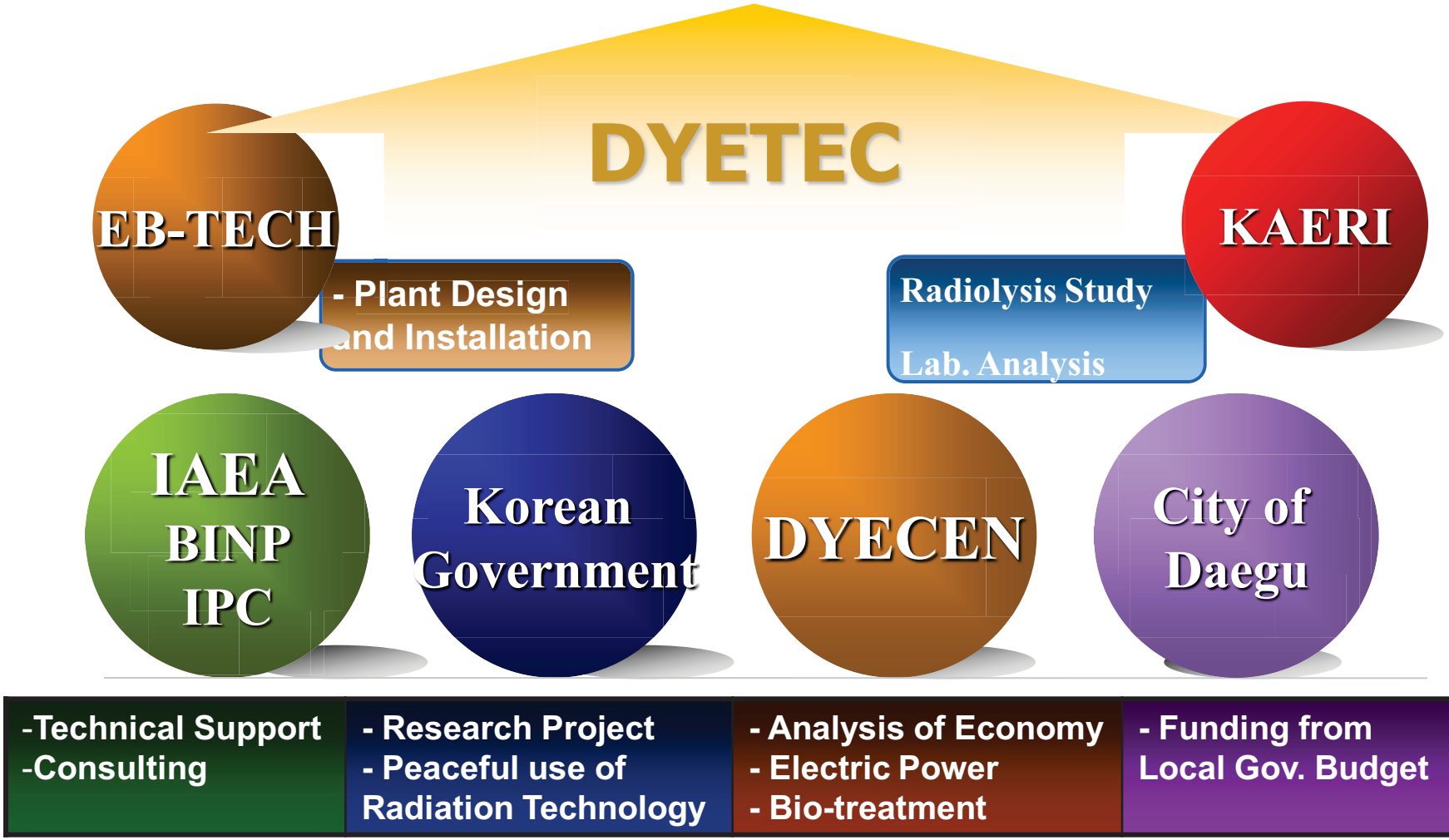
H_2O_2

Active Radicals

Harmful Organic in Waste Water like dyes, POPs, Drugs

- Complete Decomposition → H_2O, CO_2
- Partial Decomposition
- Suspended solid → Coagulation
- Monomer to Polymerization
- Removal of Toxic group → Bio-Treat
- Removal of Color, Odor

IAEA CRP on "Radiation Treatment of Waste Water for Reuse"



Established in Collaboration with IAEA

High Power Accelerator

Accelerator:
Energy : 0.6 - 1.0 MeV
Beam power: 400 kW
Beam current: 500 mA

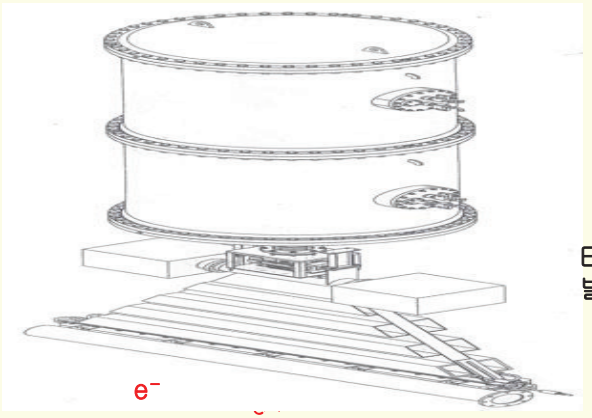
Irradiators : 3 (0~200mA)
Window width : up to 2m
Double extraction window
Discharge protection
High frequency scanning

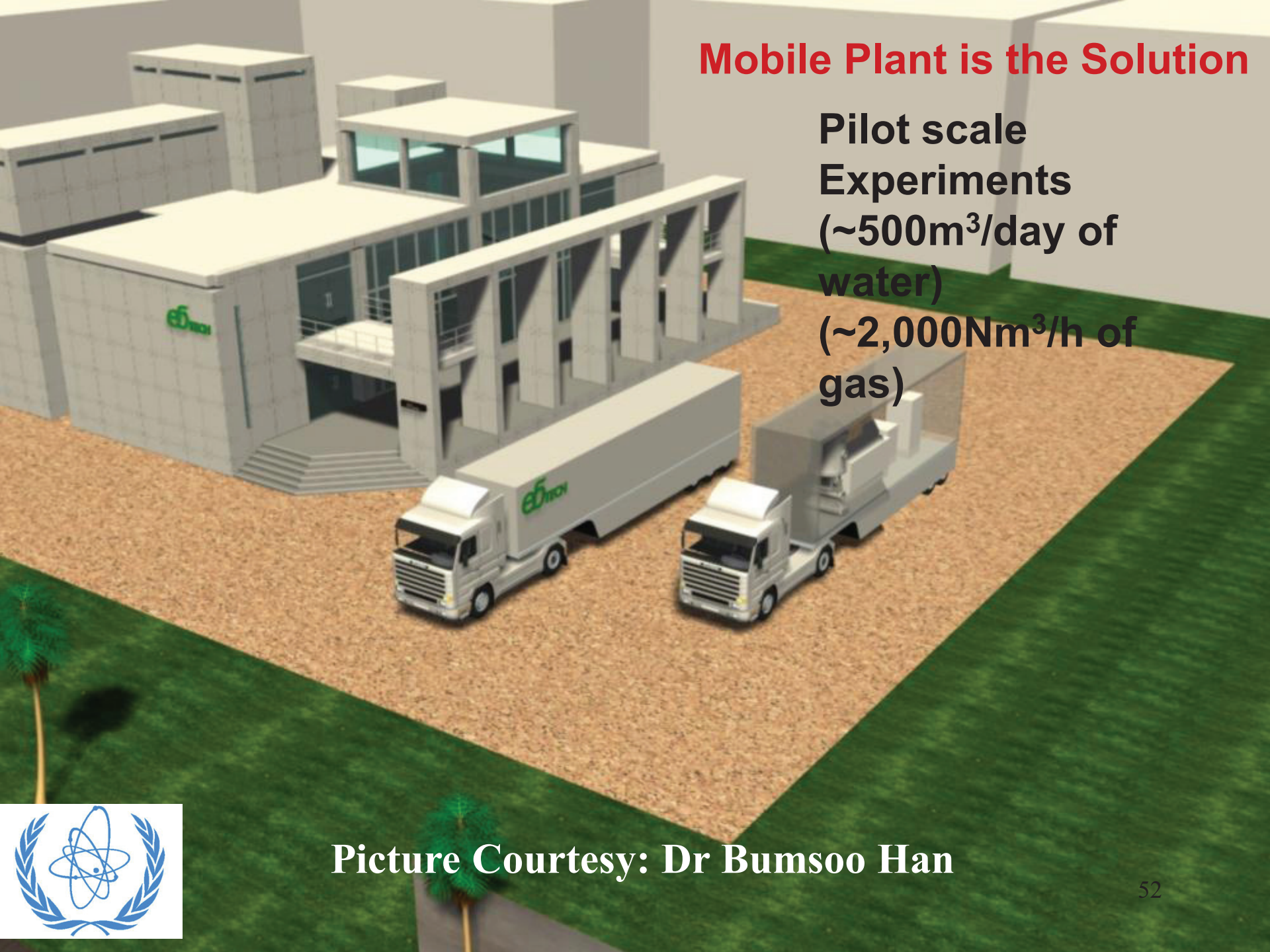
WASTEWATER TREATMENT

Daegu, Korea

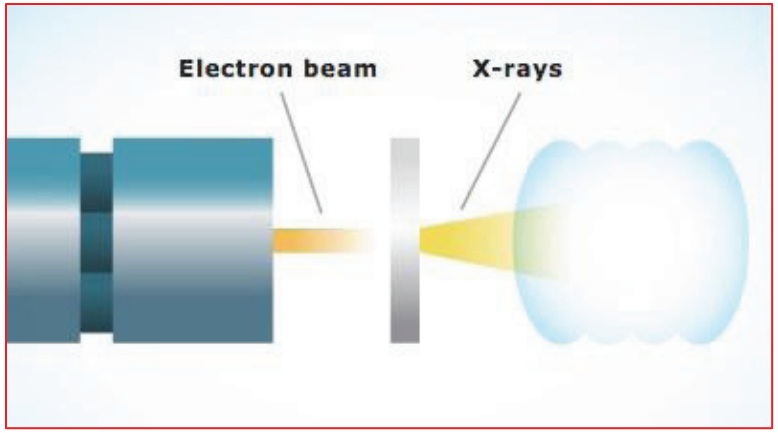
Photograph: Courtsey Dr Bumsoo Han

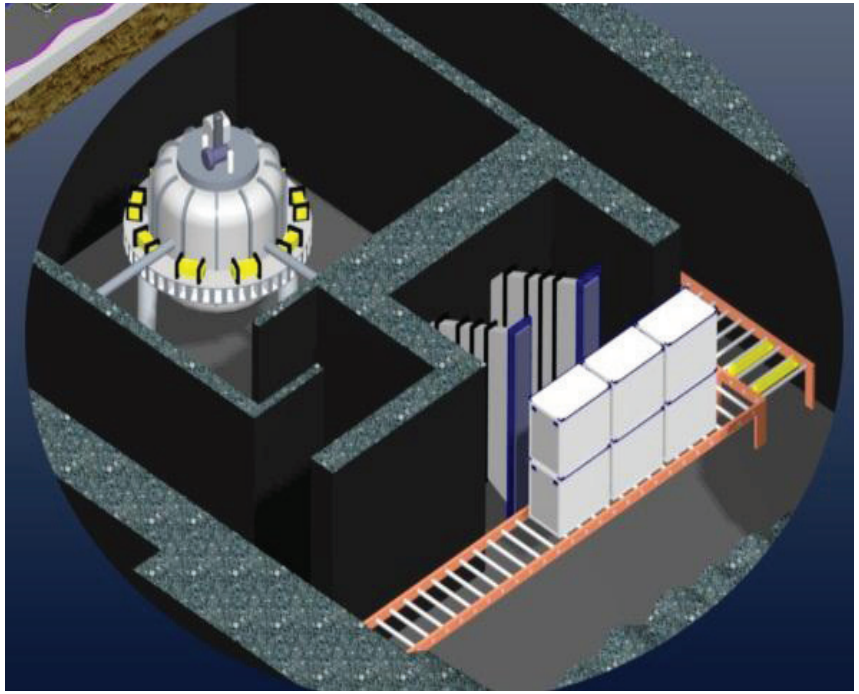
Treatment of PCBs using Electron Beam Accelerator

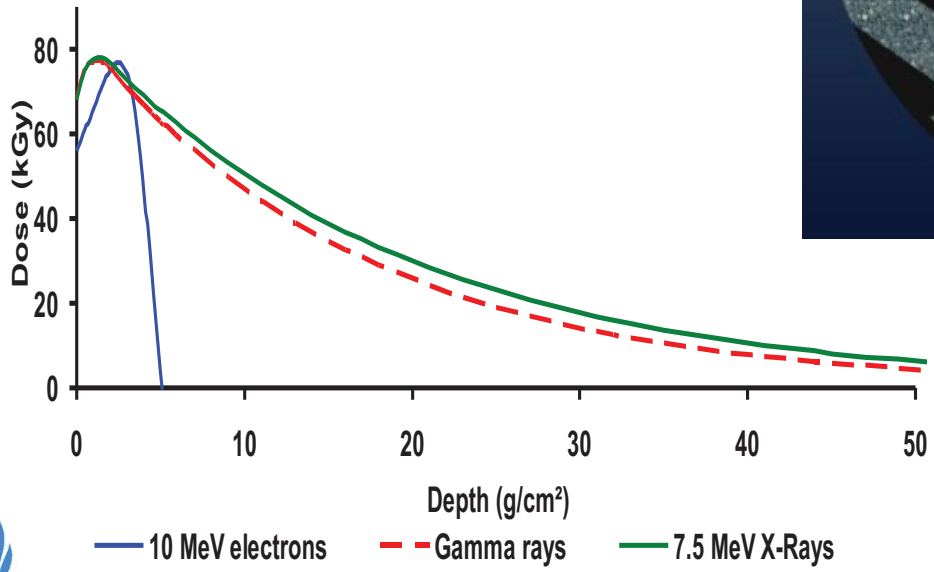



Mobile Plant is the Solution
Pilot scale Experiments (~500m3/day of water) (~2,000Nm3/h of gas)
Picture Courtesy: Dr Bumsoo Han

High Power EB Accelerators for X ray Conversion

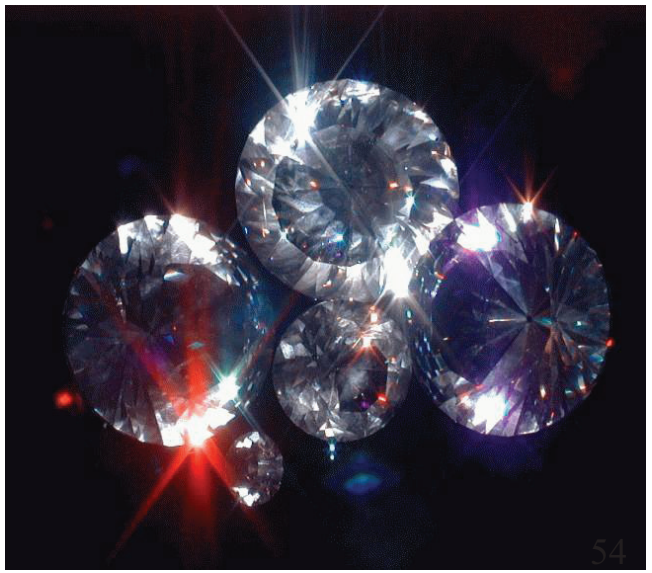






7 MeV, 700 KW
Rhodotron, IBA

Value addition to even valuable materials!!



Conclusion

- **Electron beam processing of polymeric materials for value addition and producing commercial products is a well established technology.**

- **Over 1400 industrial electron beam irradiation facilities for polymer modification, surface curing, sterilization of medical products form a US$85 billion industry producing some unique high quality products in an environment friendly manner.**

- **The emerging applications, such as food irradiation and remediation of environmental pollution offer the prospects of significant benefits to human health and welfare.**

Thank you!