Operation Experiences on Industrial Scale Wastewater Treatment Plant with E-beam

-Lessons Learned from the Plant Operation

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Bumsoo Han /EB TECH Co., Ltd

Low energy electron beams for industrial and environmental applications
EuCARD-2 Workshop with Industry - 8-9 December 2016, Warsaw, Poland

Contents

1. Introduction of EB TECH and Previous Works

2. Operation Experience of Wastewater Treatment Plant

   -. Engineering Approaches and Laboratory Experiments

   -. Design and Construction of Pilot Plant

3. Accelerator for Environmental Pollution Control

   -. Service conditions of accelerator

   -. Requirements

4. Design and Construction of Industrial Plants

   -. Unexpected Problems

   -. Comparison with Conventional Processes

5. Lessons Learned from the Plant Operation

1. Introduction of EB TECH and Previous Works

EB TECH Co., Ltd.

-. Started as a Research Center of Samsung Heavy Ind. In 1991

-. Development in Industrial Accelerators from 1994

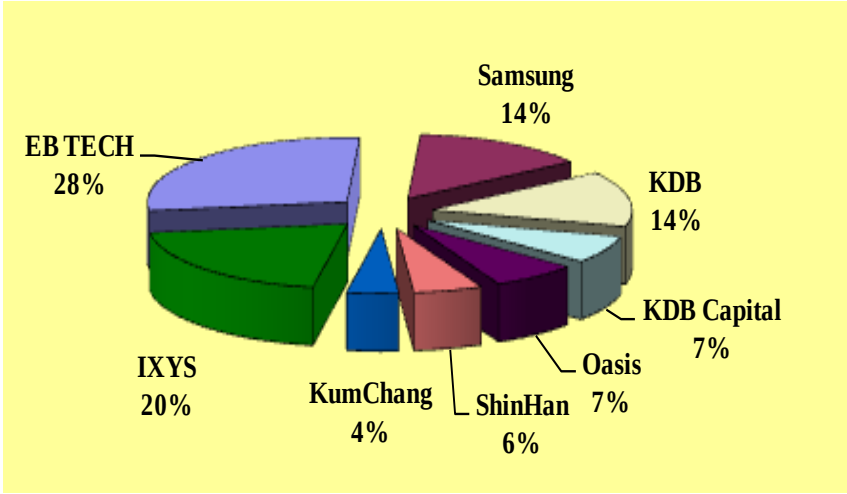
-. Researches on Water/Gas/Sludge treatment with e-beam

-. Spin-off from Samsung to establish EB TECH Co. in 2000

-. Samsung, IXYS (NASDAQ) and employees of EB TECH are major shareholders

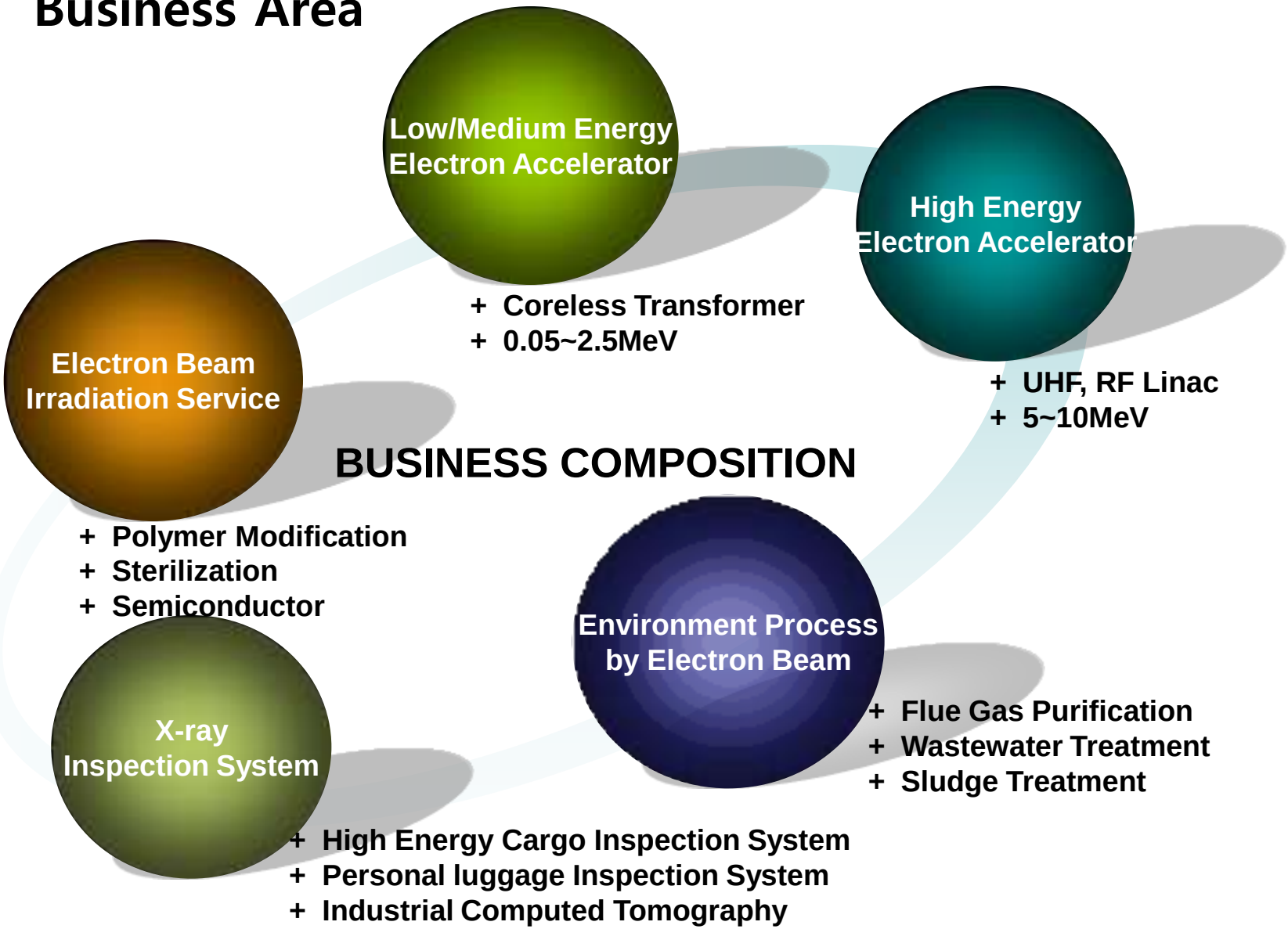
-. EB TECH is listed Korea Stock Exchange Market in June 2016

-. Headquarters :
550 Yongsan-dong Yuseong-gu, Daejeon, 305-500, Korea (rep. of)



Bring
the Scientific Result
(from Accelerator Physics and Radiation Chemistry)
into
Industrial Applications

Business Area



-. Installed over 60 electron accelerators in Korea, China, Singapore, Turkey etc.
-. Equipped 9 electron accelerators and several X-ray systems, laboratories
-. 6 accelerators in irradiation service (0.5~10MeV) for semi-con, polymer etc.

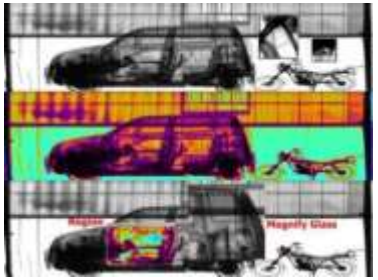




-. Mechanical Lab. and Electrical Lab. to support the design of new accelerator.
-. Chemical Analysis Laboratories to support the polymer research, wastewater/ flue gas/ sludge treatment with GC, UV, TOC and other analytical instruments.
-. NDT technique, container inspection and industrial tomography researches are also developed in X-ray Research Laboratories





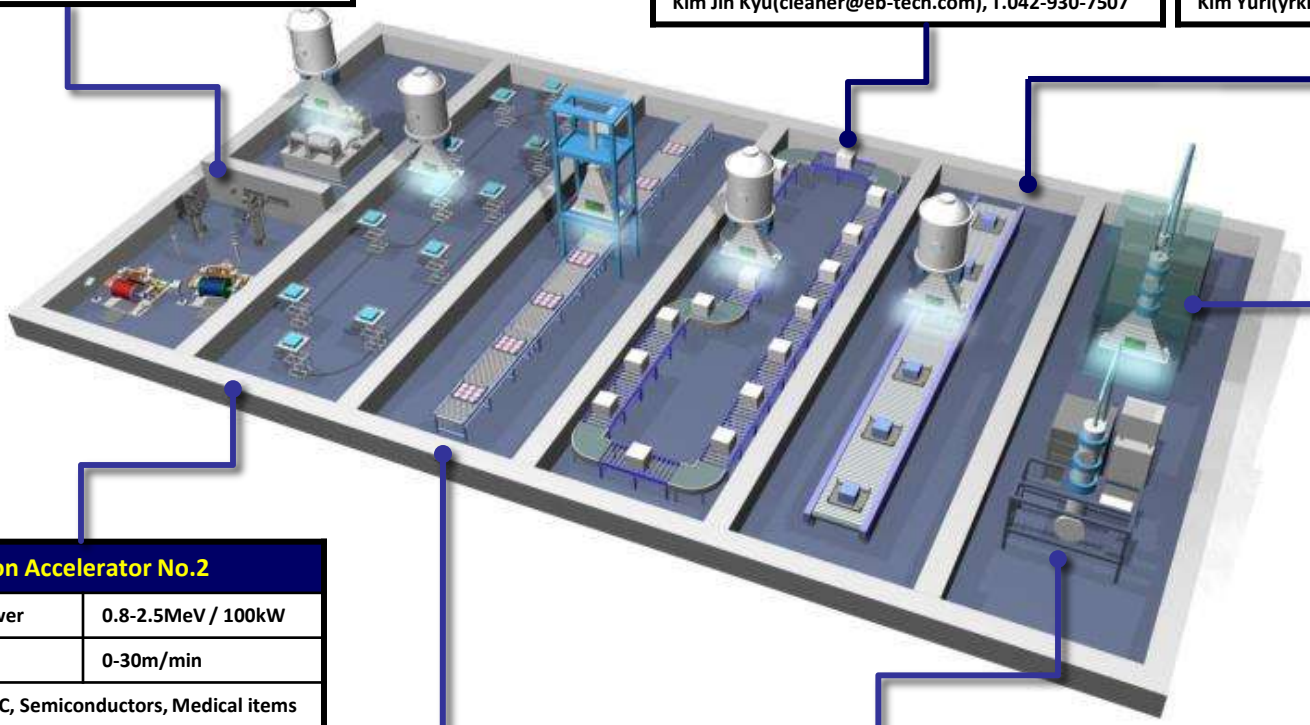


Electron Beam Processing Facilities (EBPF) of EB TECH Co.

Electron Accelerator No.1	
Beam Energy / Power	0.7-1.5MeV / 50kW
Line Speed	0-500m/min
Cable, wire and tubes	
Kim Sung Myun(smkim@eb-tech.com), T.042-930-7502	

Electron Accelerator No.4	
Beam Energy / Power	0.8-2.5MeV / 100kW
Cart Speed	0-30m/min
PTC, Semiconductors, Medical items	
Kim Jin Kyu(cleaner@eb-tech.com), T.042-930-7507	

Electron Accelerator No.5	
Beam Energy / Power	10MeV / 12kW
Line Speed	0-20m/min
Semiconductors, Medical & food items	
Kim Yuri(yrkim@eb-tech.com), T.042-930-7508	



Electron Accelerator No.2	
Beam Energy / Power	0.8-2.5MeV / 100kW
Cart Speed	0-30m/min
Cable, Polymer, PTC, Semiconductors, Medical items	
Yun Jong Ho(yunjho@eb-tech.com), T.042-930-7513	

Electron Accelerator No.3	
Beam Energy / Power	10MeV / 10kW
Line Speed	0-20m/min
Semiconductors, Medical & food items	
Lee Hyun Woo(hwlee@eb-tech.com), T.042-930-7511	

Electron Accelerator No.6	
Beam Energy / Power	65-100keV / 5kW
Line Speed	0-5MW/cm2
High temperature material testing	
Kang Won Gu(unikang@eb-tech.com), T.042-930-7506	

Electron Accelerator No.7	
Beam Energy / Power	100-200keV / 5kW
Heat load	0-50m/min
Sheet & Films, Curing	
Kim Insoo(runmac@eb-tech.com), T.042-930-7509	

Wastewater Treatment with e-beam

What was done

-. Textile Dyeing Wastewater (1993~2006)
-. Leachate from Land filling (1993~1997)
-. Wastewater from Paper Mill (1995~1998)
-. Wastewater with Heavy Metal (1995~1997)
-. Wastewater from Power plant (1997~1998)
-. Wastewater from explosives (2000~2004)
-. Algal bloom control (2002~2006)
-. Destruction of PCBs from Transformer Oil (2006~2008)

What is going on

-. Effluent from Municipal plant for re-use (with Pele and HDR, 2008~)
-. Marine Ballast water (with U. Akron, 2010~)
-. Demonstration of Mobile in U.S. (WERF LIFT program, 2017~)

Gaseous Waste Treatment with e-beam

What was done

-. Stack gases Treatment with CFB boiler (1994~1998)
-. Destruction of Dioxin from incinerator (1998~2000)
-. VOCs removal in Pilot test (2000~2002)
-. Odor removal from sludge drying (2008~2010)
-. Design of Commercial plant for Bulgaria (with INCT, 2006~2009)
-. Flue gas removal from heavy oil plant (with INCT, Saudi Aramco 2011~2012)
-. Combined treatment of wastewater and flue gas (2013~2015)

What is going on

-. Design of Demo plant in a larger scale (with INCT, Saudi Aramco 2013~)
-. VOCs removal from automobile industries (2014 ~)

Sludge Treatment

What was done

-. Improving dewatering efficiency of Sludge (1996~2000)
-. Disinfection Sludge Hygienation for re-use (2005~2009)
-. Removal of EDs for sanitary land-filling (2012 ~ 2015)

What is going on

-. Commercial plant in Israel (with Pele Inc. 2008~)
-. Mobile plant for PCBs removal in sediments (with Slovakia, 2013~)

2. Operation Experience of Wastewater Treatment Plant

-. Engineering Approaches and Laboratory Experiments

-. Design and Construction of Pilot Plant

Why Textile Dyeing Wastewater ?

(1000m^3/day)

	Number of Companies (%)	Amount of waste-water generated (%)	Amount of waste-water discharged (%)
Textile co.	1,423 (5.6)	473 (5.4)	457 (19.2)
Paperrmill	268 (1.1)	711 (8.1)	364 (15.3)
Light ind.	511 (2.0)	390 (4.5)	243 (10.2)
Processing ind.	3,376 (13.3)	439 (5.0)	200 (8.4)
Metal Fabrication	437 (1.7)	5,346 (61.1)	169 (7.1)
Others	19,284 (76.2)	1,382 (15.8)	942 (39.7)
Total	25,299 (100)	8,741 (100)	2,375 (100)

The amount of waste water generated and discharged in Korea, as of 1995


FREE MAP
Seoul
강원도
울릉도
인천
서울
경기도
충청북도
충청남도
경상북도
대구
울산
전라북도
경상남도
부산
광주
전라남도
제주도
EB TECH CO. (Central Research Institute of Samsung Heavy Ind.)
Daegu Dyeing Industrial Complex
: Existing Dyeing Complex
: Under construction
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Daegu Dyeing Industrial Complex

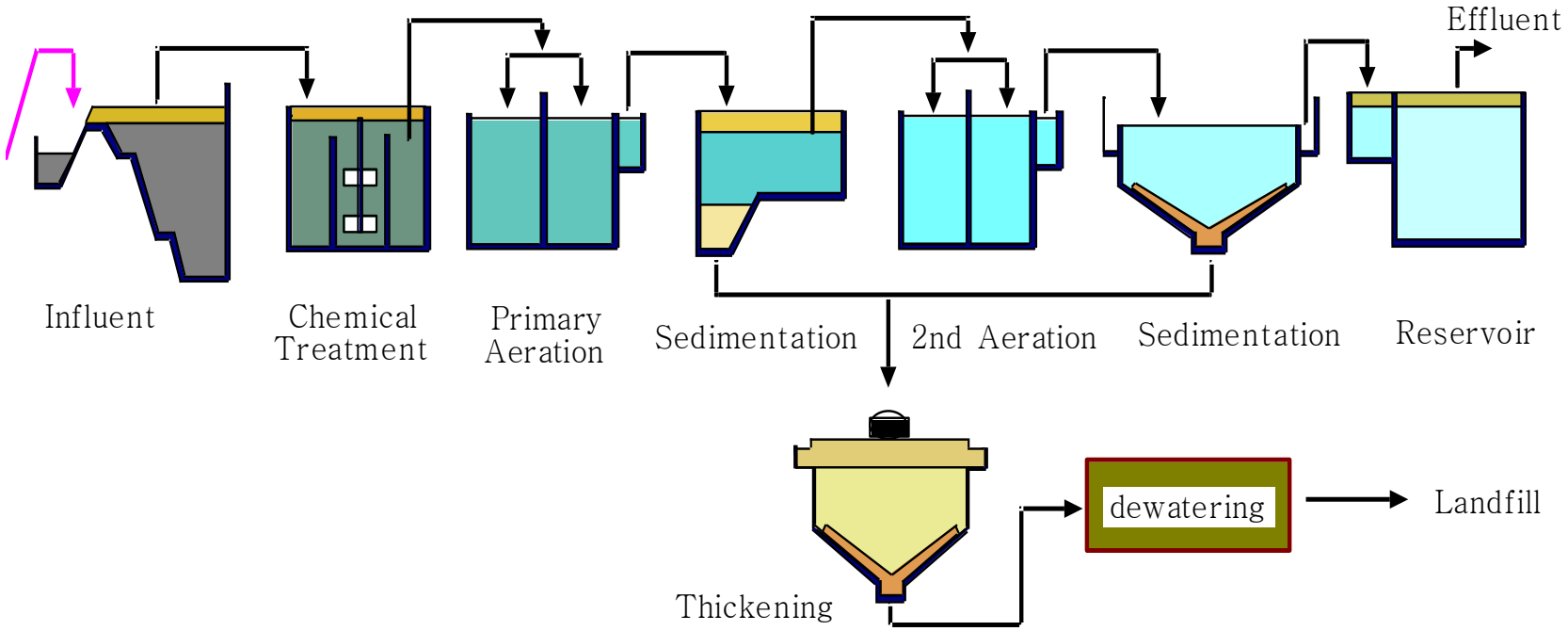
- over 120 companies of dip dyeing, printing and yarn dyeing
- high consumption of water(90,000t/day),steam(515t/day),electricity(53,100kW)

Existing Wastewater Treatment Facilities

- up to 80,000m^3/day
- coagulation with Chemical and Biological treatment
- close to limit ability

Parameter	pH	BOD_5, mg/l	COD_{Mn}, mg/l	Suspended solids, mg/l	Color, units
Raw wastewater	12	2,000	900	100	1,000
after Chemical Treatment	6.8-7.5	1,700	450	50	500
after 1st Bio-treatment	7.0-8.0	1,300	250	50	400
after 2nd Bio-treatment	7.0-8.0	30	60	50	250

Wastewater Treatment Facility in Daegu Dyeing Industrial Complex



Process Flow of Existing Wastewater Treatment Facility

What Scientists (not all of them) used to do

-. Laboratory analysis → Find useful numbers

-. Analyze the meaning of those numbers → Some publications

-. Laboratory experiments → Basic design of plant

-. Estimation of plant → Calculation of necessary equipments

-. Comparison with existing process → ?

What Engineers should do

-. Analysis of existing process → Calculate the present cost

-. Economics of radiation → Max. allowable radiation doses

-. Find useful additives or combination for lowering doses

-. Laboratory test → Confirmation of process

-. Pilot plant → Industrial scale design → Commercial plants

Engineering Approaches

-. Analysis of existing process
  → Calculate the present cost : 1.1~1.2 USD per m^3 of wastewater

-. Economics of E-beam
  → Determine the target cost : below 1 USD including bio-treat
  → Cost for radiation processing : below 0.4 USD per m^3
  → Max. allowable radiation doses : less than 2 kGy

-. Find useful additives or combination for lowering doses
  → Combined with bio-system (Activated sludge system)

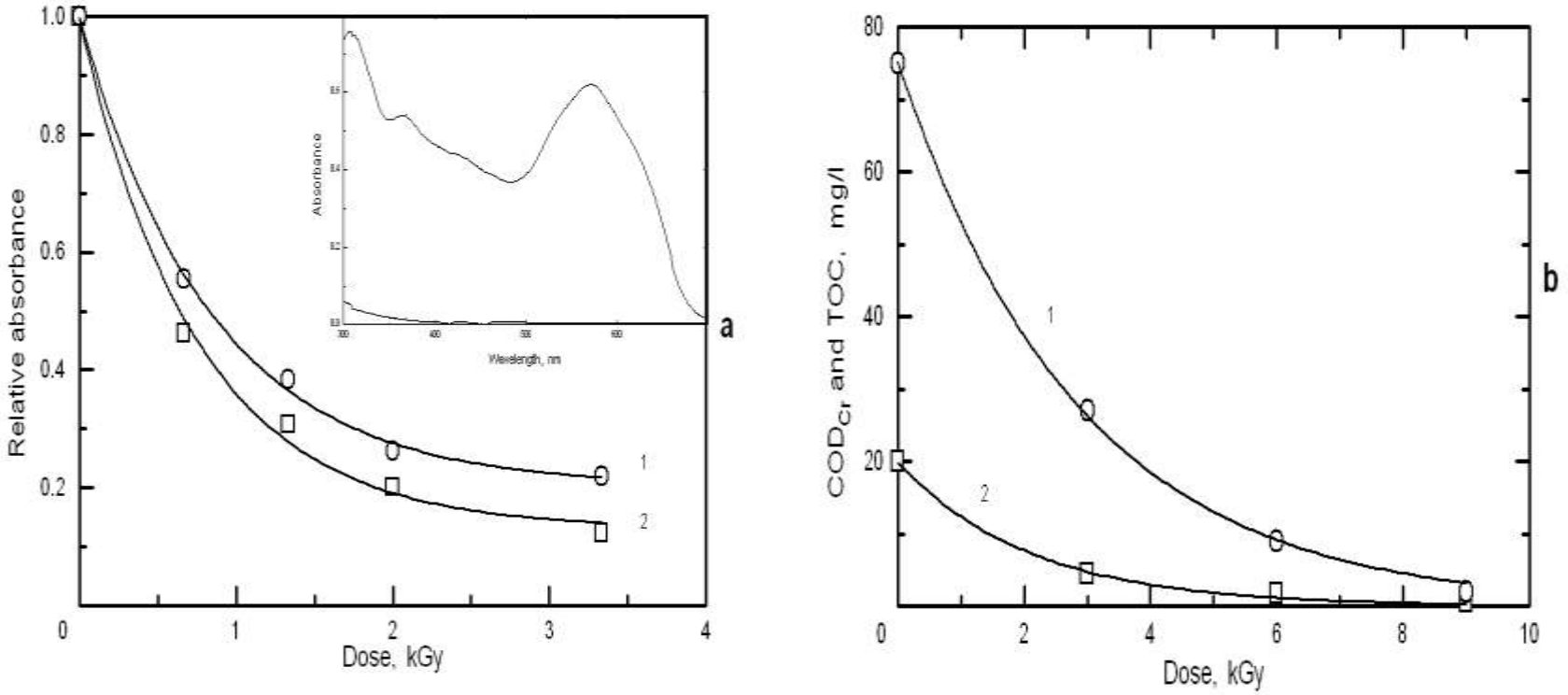
-. Laboratory test
  → Confirmation of process, engineering design (delivery etc.)

-. Pilot plant → Industrial scale design → Commercial plants

Researches on Wastewater Treatment

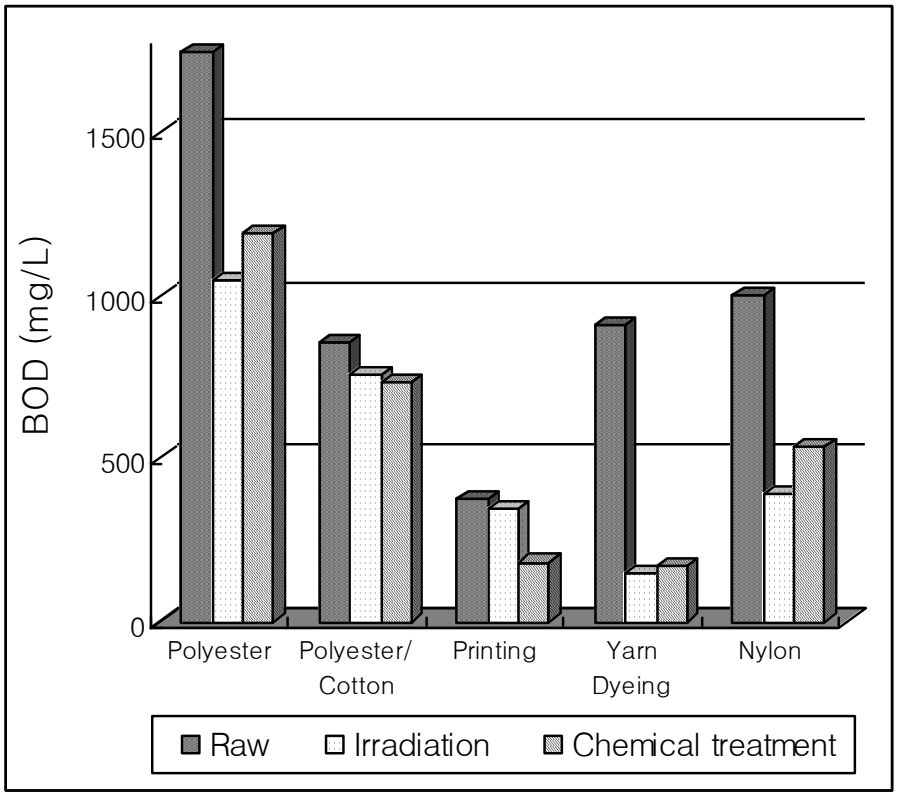
- 1994~1995 : Lab. scale feasibility Test with e-beam and Gamma ray
- 95.12~99.5 : Researches on Dyeing Wastewater Treatment with e-beam
  (Dyeing Technology Center/EB-TECH Co.)
- 96.2 ~97.2 : Treatment of Dyes and Dyeing Wastewater

Batch Type Experiment



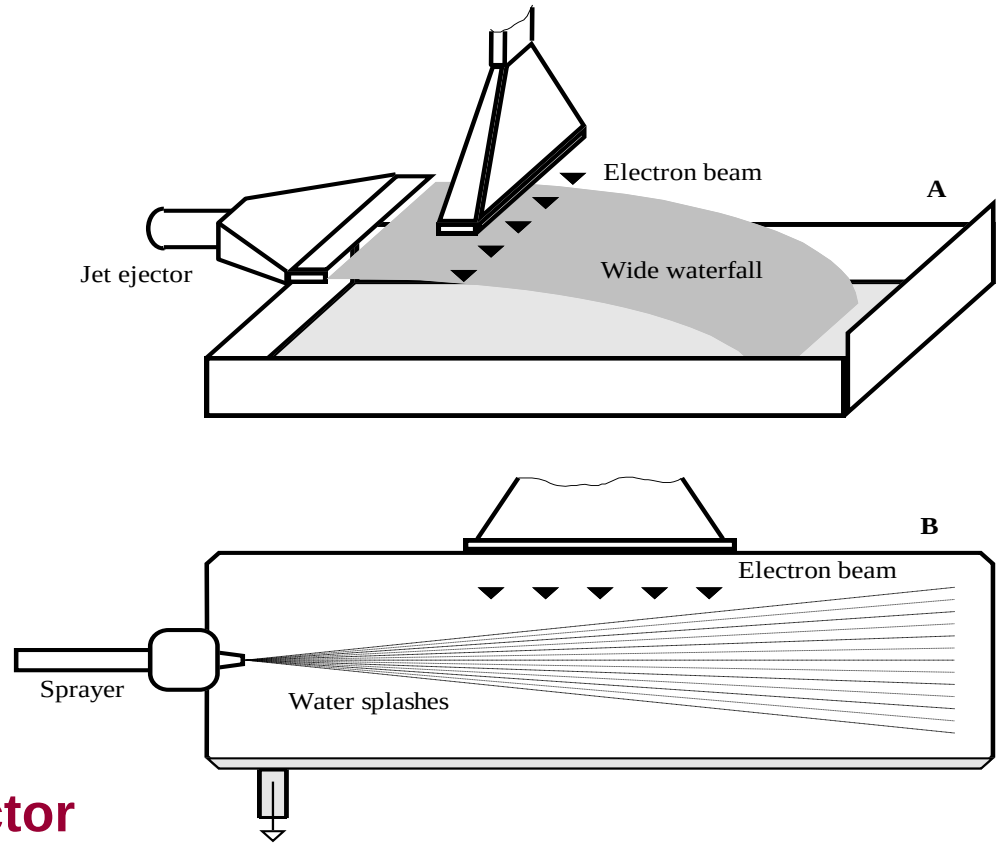
Degradation of acid red dye AB LDN in aqueous solutions (50 mg/l) upon electron-beam treatment:
a - decrease in relative absorbance at 570 nm with dose in deaerated (1) and aerated (2) solutions; b - decrease in CODCr (1) and TOC (2) with dose in aerated solutions. Insert in a - optical absorption spectra of the dye solution before and after irradiation at 9 kGy.

⦿ Removal Efficiency



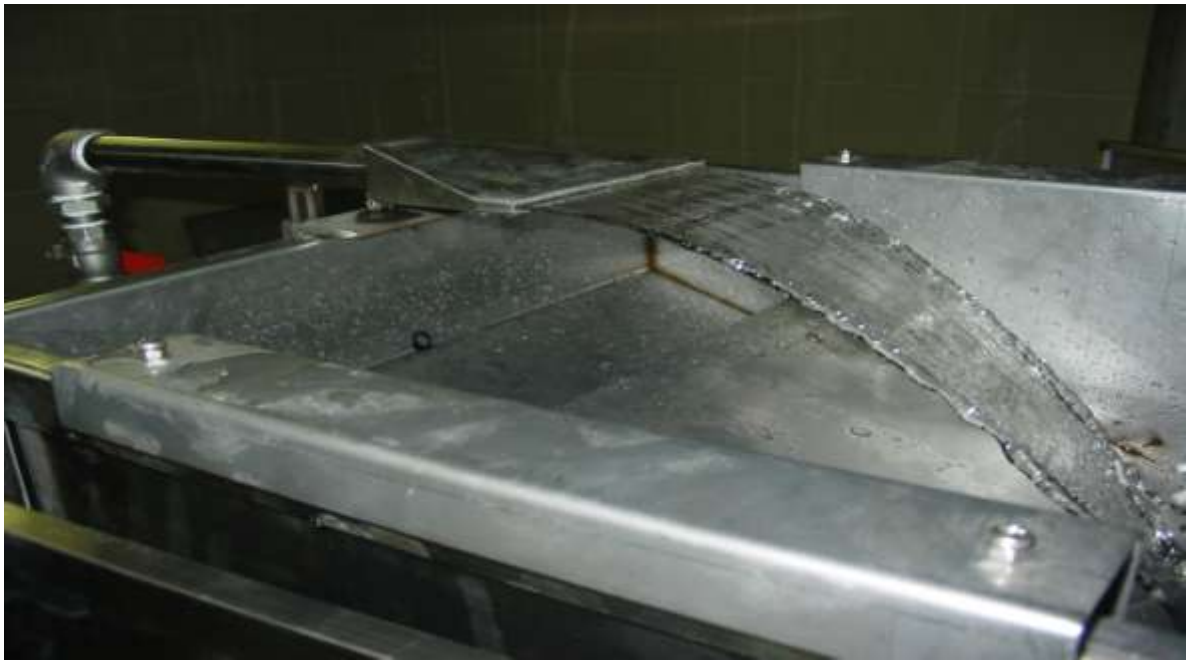
BOD_5 reduction for wastewaters from different industry

Water Delivery System



Different types of water reactor

(Spray, Injection and Flow)

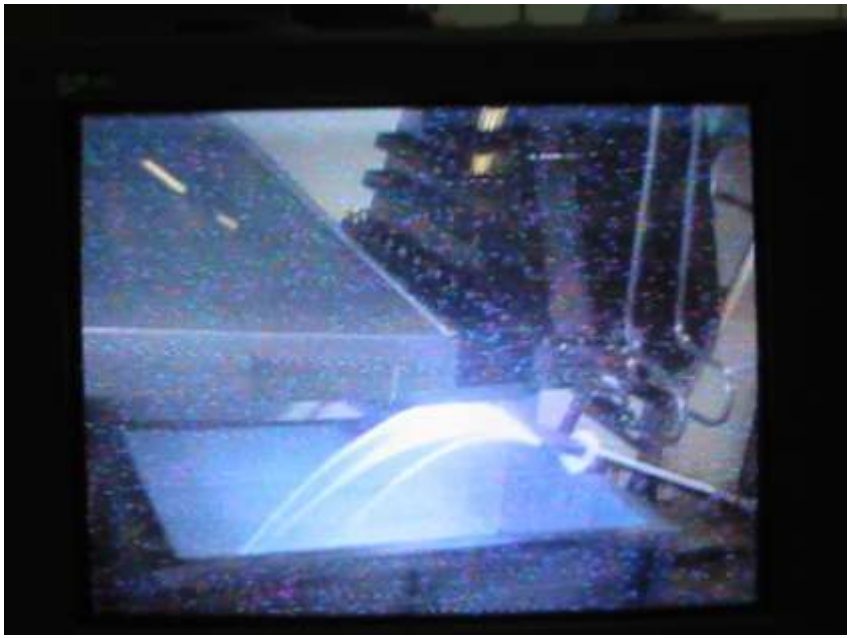


-. Uniform dose distribution

-. Less energy consumption on water delivery

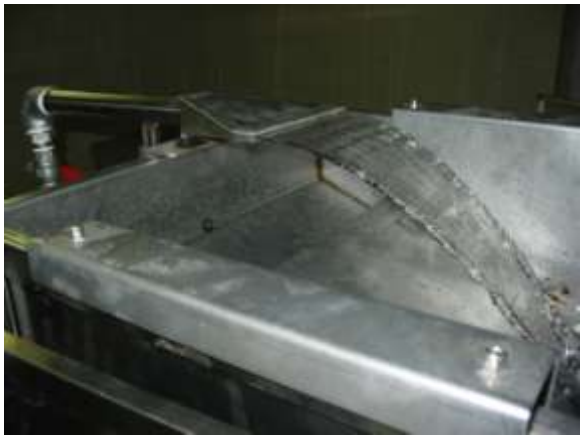
-. Mass productivity (up to 3,000m^3/d with one nozzle)

Nozzle-type Injector and Bench-scale System



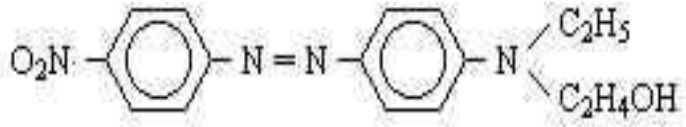
Wastewater under irradiation through Nozzle-type Injector

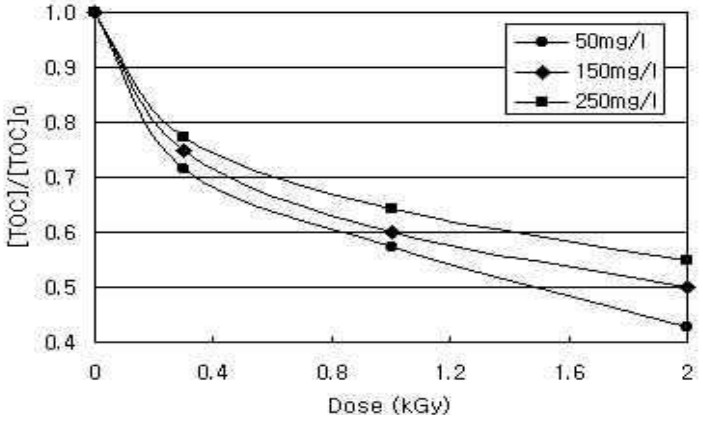
Nozzle-type Injectors used in Textile Dyeing Wastewater Treatment

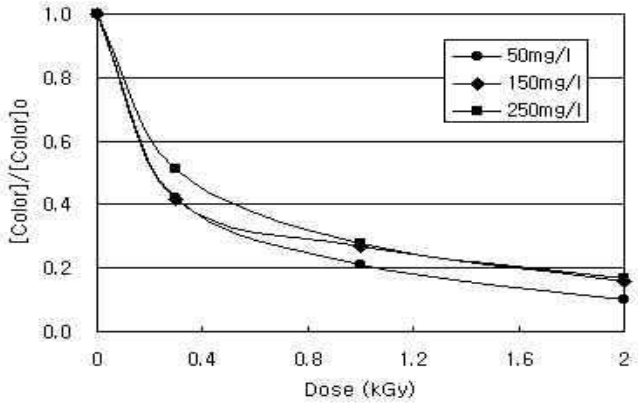


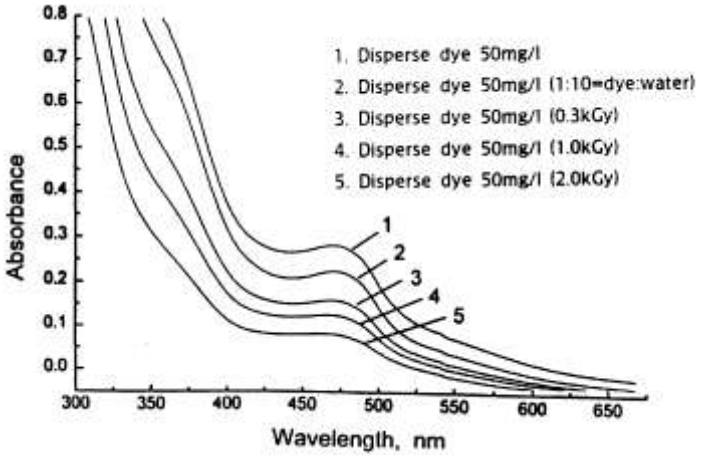
Laboratory 50m^3/day **Pilot Plant 1,000m^3/day** **Industrial Plant 10,000m^3/day**

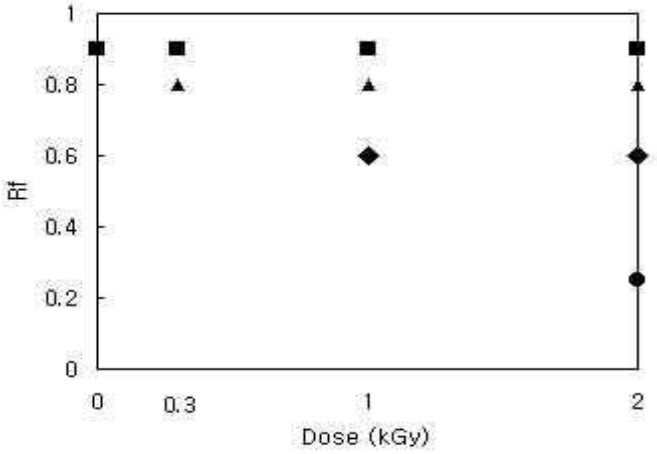
Dispersed Dyes (C.I.Disperse red 1)











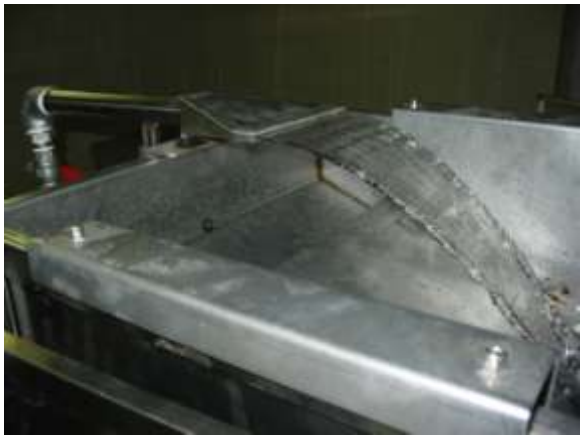
Researches on Wastewater Treatment

- 1994~1995 : Lab. scale feasibility Test with e-beam and Gamma ray
- 95.12~99.5 : Researches on Dyeing Wastewater Treatment with e-beam
  (Dyeing Technology Center/EB-TECH Co.)
- 96.2 ~97.2 : Treatment of Dyes and Dyeing Wastewater
- 97.2~98.10 : Construction of e-beam Pilot Plant (1000m^3/day)

Electron Energy (MeV)	Max. range in air (m) (20℃,1atm)	Maximum range in water (mm)	Maximum range in Al (mm)	Maximum range in lead (mm)
30	109	132	53.8	10.2
10	43.1	49.8	21.7	5.42
1	4.08	4.37	2.05	0.69
0.1	0.13	0.14	0.069	0.027
0.01	0.0024	0.025	0.0013	0.00073

Maximum range of accelerated electrons

Nozzle-type Injectors used in Textile Dyeing Wastewater Treatment

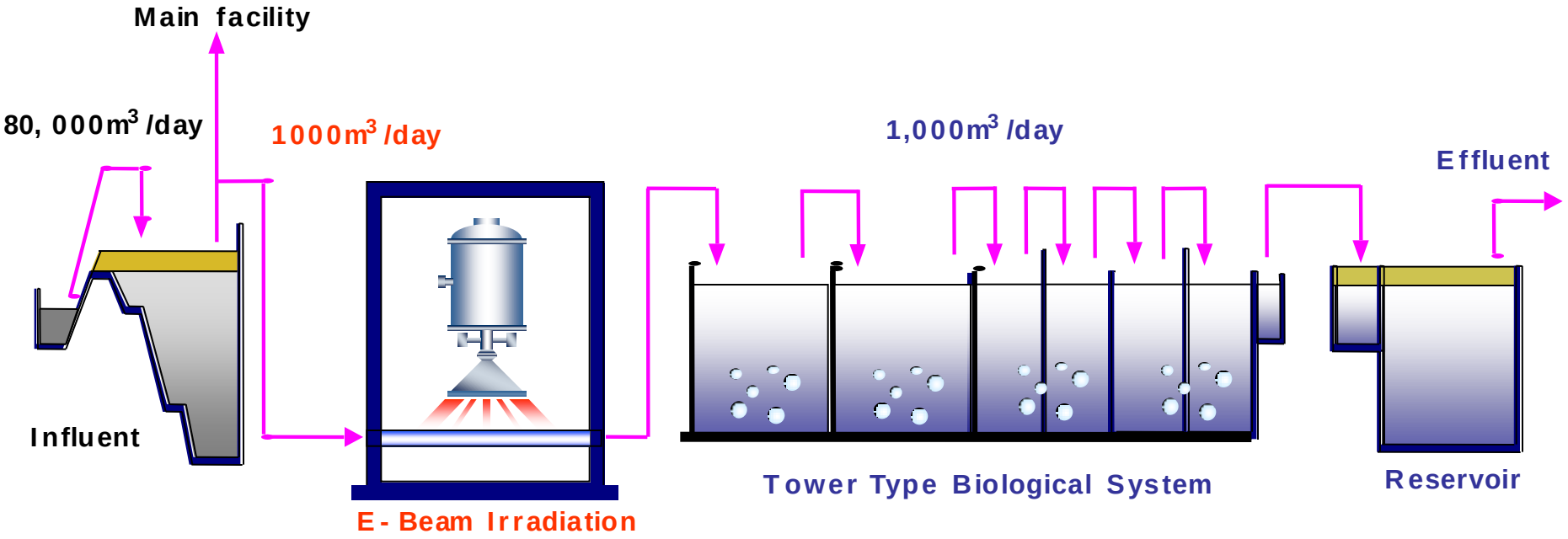


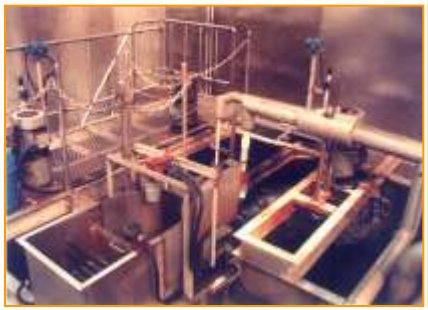
Laboratory 50m^3/day **Pilot Plant 1,000m^3/day** **Industrial Plant 10,000m^3/day**

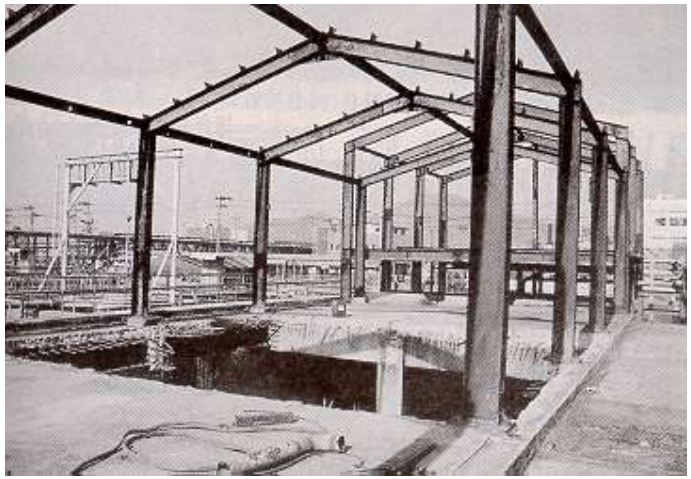
Wastewater Treatment Facility in

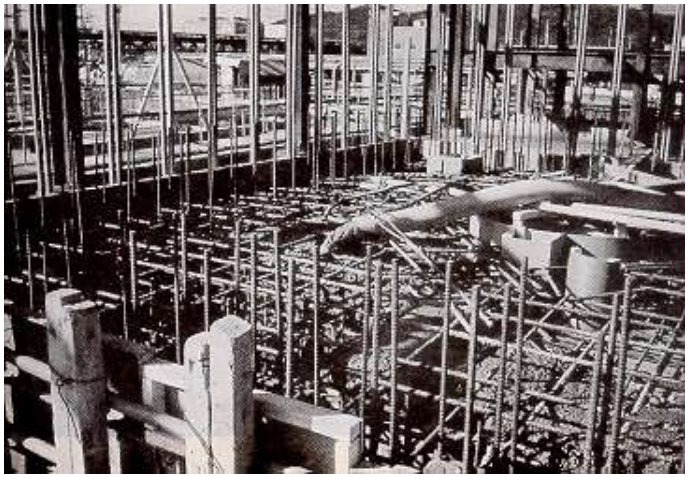
Daegu Dyeing Industrial Complex

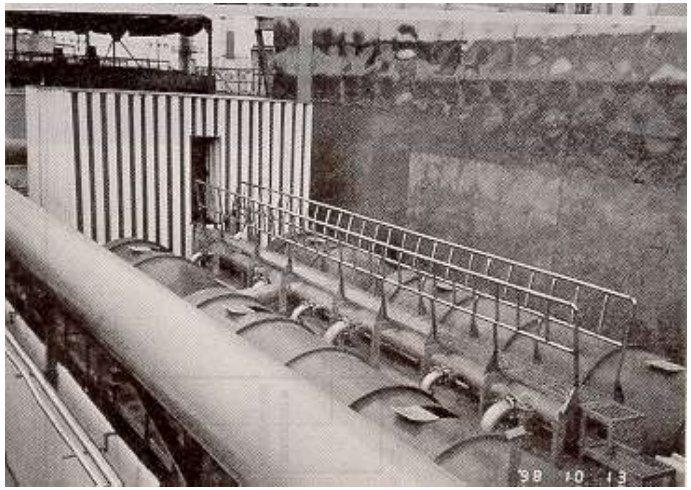
Schematic Diagram of Pilot Plant



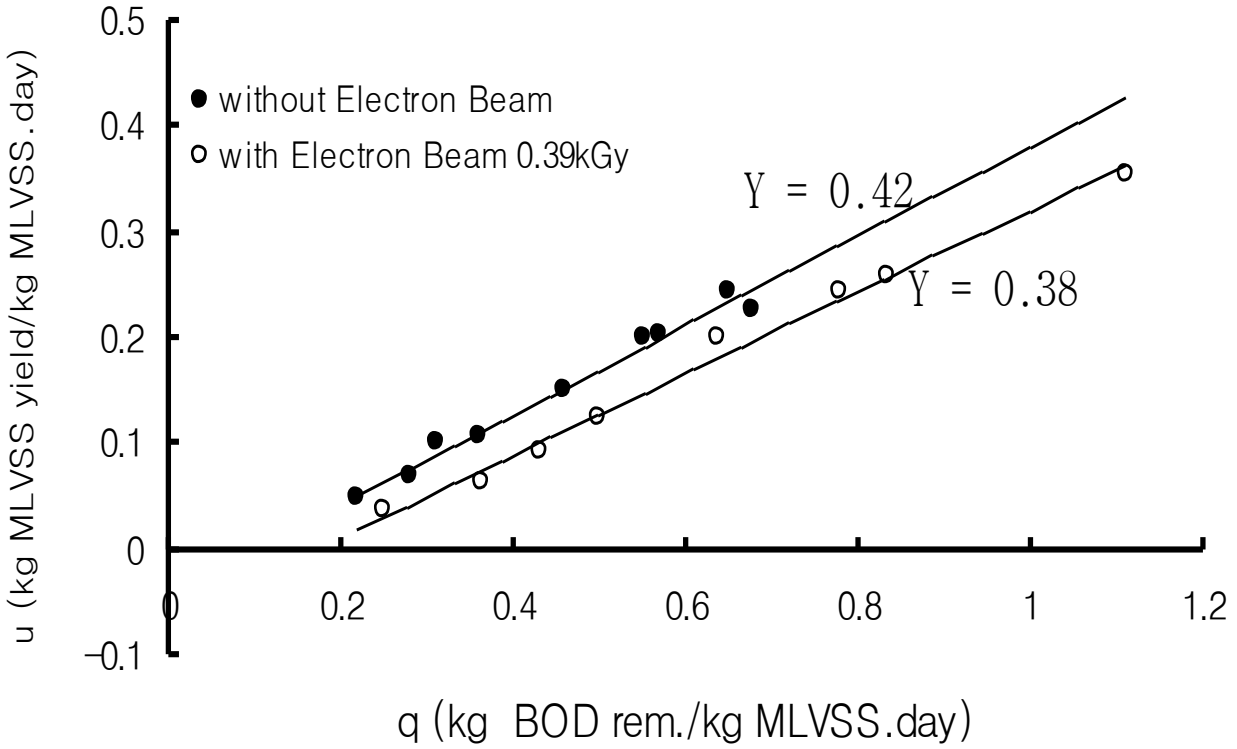






Sludge Conversion Rate from the organic Compounds

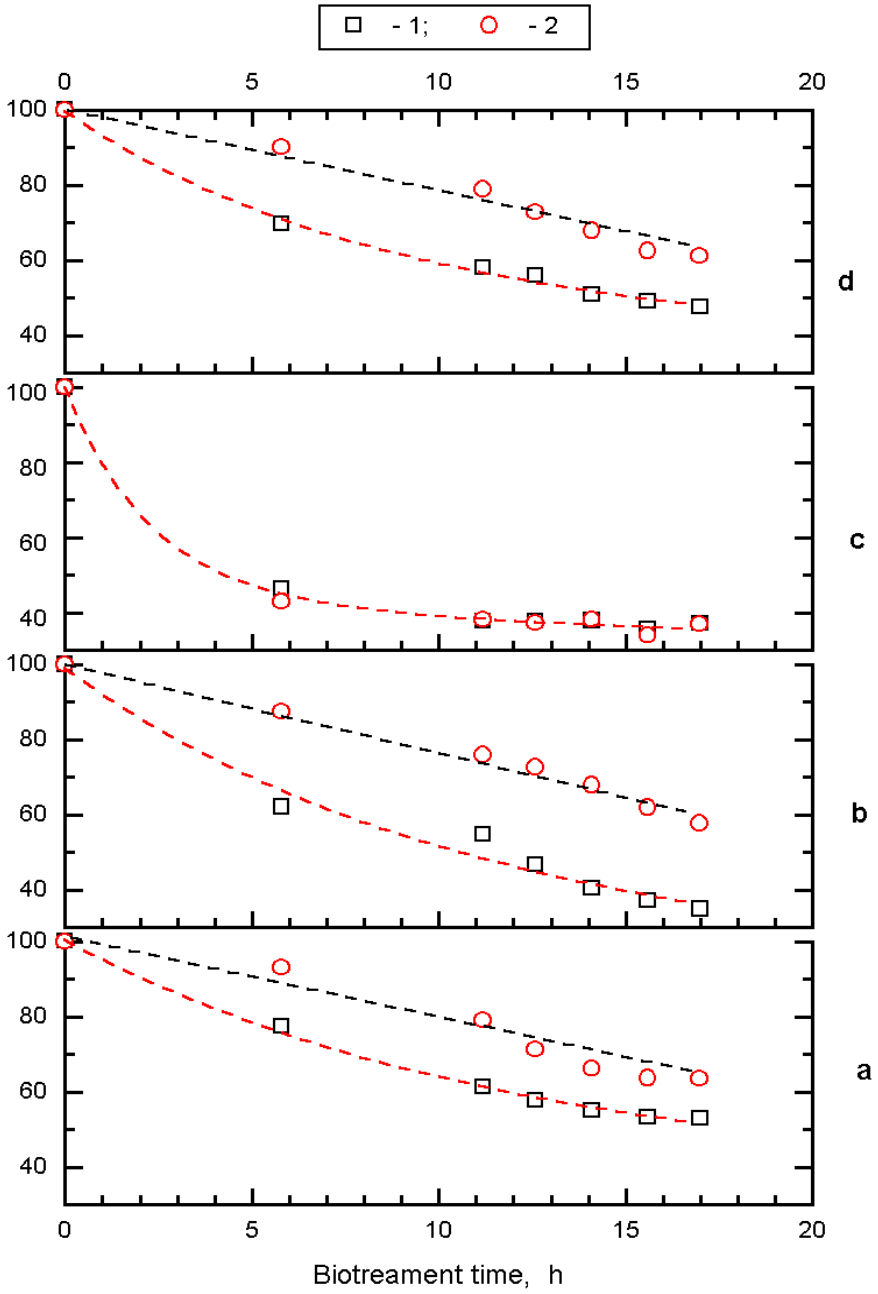


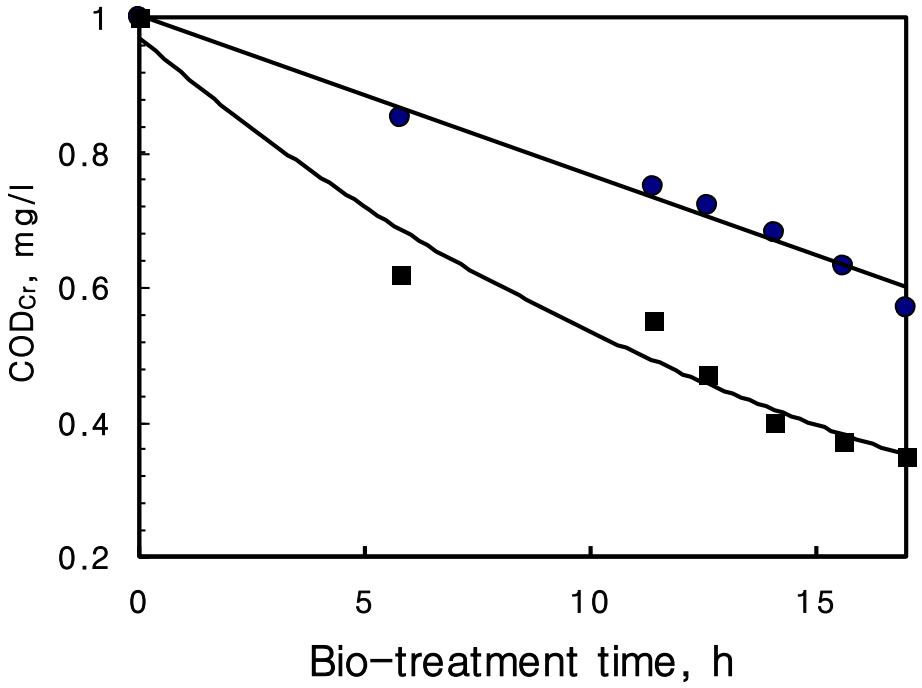
Effect of irradiation and biological treatment on wastewater parameters:

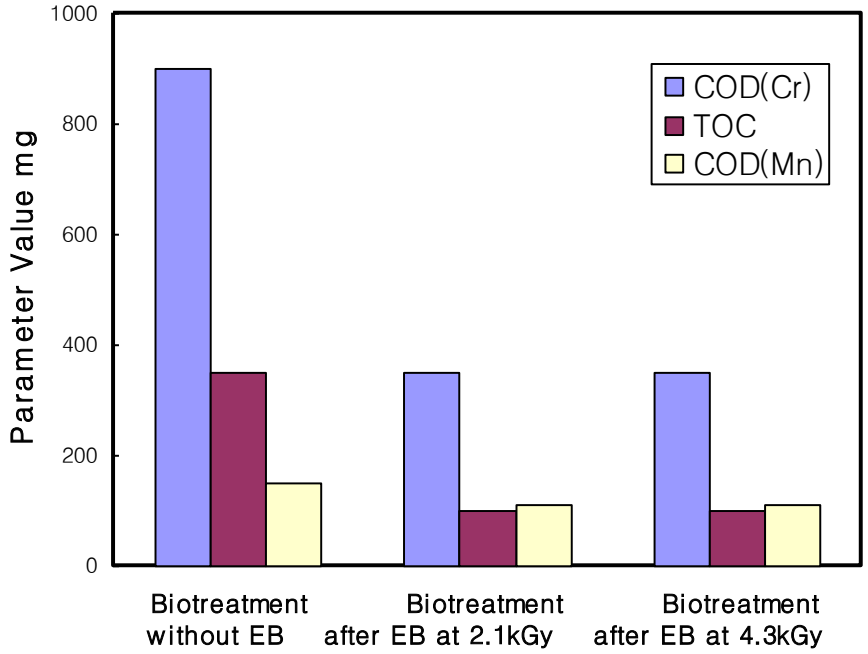
a-TOC; b-COD_{Cr}; c-COD_{Mn}; d-BOD.

1- after EB treatment

2- without EB treatment







Effect of electron-beam treatment on biological treatment of dyeing wastewater:
a - kinetics of biotreatment of irradiated (*1*) and unirradiated (*2*) wastewater;
b - absorbed dose effect on combined electron-beam/biological treatment.

Researches on Wastewater Treatment

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- 95.12~99.5 : Researches on Dyeing Wastewater Treatment with e-beam (Dyeing Technology Center/EB-TECH Co.)
- 96.2 ~97.2 : Treatment of Dyes and Dyeing Wastewater
- 97.2~98.10 : Construction of e-beam Pilot Plant (1000m^3/day)
- 98.10~ : Continuous operation of treatment facility
- 1998.9.16 : KT (Korea New Technology) Award
- 2000.7.19 : IR52 Industrial Research Award

Construction of Demonstration Facility

Industrial Plant for Treating Wastewater from Dyeing Process

- Decrease the Amount of Chemical Reagent up to 50%
- Improve the Efficiency of Biological Treatment by 30%
- Decrease the Retention time in Biological Treatment Facility

Characteristics of Industrial Plant

- Maximum flow rate of 10,000m^3/day with one 1MeV, 400kW accelerator
- Combined with existing Biological Treatment Facility

Construction Schedule

-The actual construction started on Summer of 2004, and finished by the end of 2005. (Actual construction was 17 months)

3. Accelerator for Environmental Pollution Control

- -. Service conditions of accelerator
- -. Requirements

Service Conditions of Accelerator for Environmental Uses

Flue gas/VOC Purification

Ti foil between accelerator and reactor

Wastewater treatment

Window is open to wastewater

Sludge treatment

Sufficient gap to Sludge

Electron Accelerators Required for Environmental Uses

- **Energy range 1.0 - 2.0 MeV for wastewater**

  0.6 – 1.0 MeV for gaseous waste

Electron Energy (MeV)	Max. range in air (m) (20℃,1atm)	Maximum range in water (mm)	Maximum range in Al (mm)	Maximum range in lead (mm)
30	109	132	53.8	10.2
10	43.1	49.8	21.7	5.42
1	4.08	4.37	2.05	0.69
0.1	0.13	0.14	0.069	0.027
0.01	0.0024	0.025	0.0013	0.00073

Maximum range of accelerated electrons

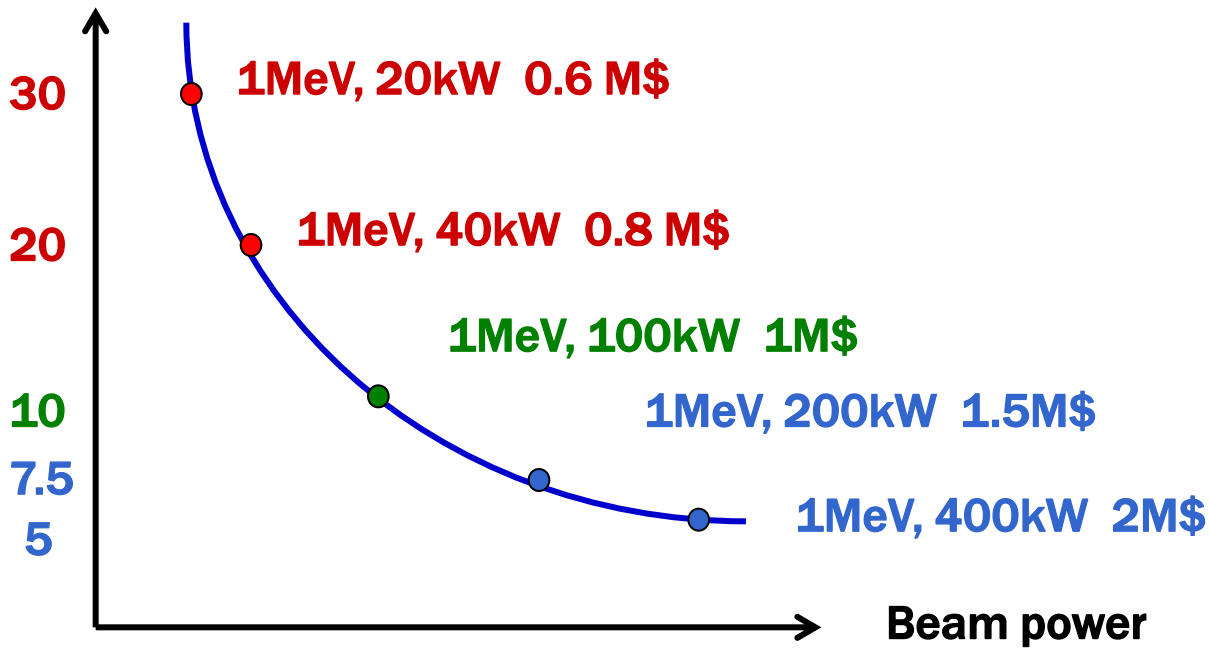
Electron Accelerators Required for Environmental Uses

- Energy range 1.0 - 2.0 MeV for wastewater

  0.6 – 1.0 MeV for gaseous waste

- Power of electron beam up to some MW

Cost for unit power ($/W)



Beam Power	20kW	40kW	100kW	200kW	400kW	1MW
Total Cost (M$)	0.6	0.8	1.0	1.5	2	2.2*
Unit Cost ($/W)	30	20	10	7.5	5	2.2

Parameters of Typical Transformer Accelerators

Accelerator type Parameter	EPS-800-375	EPS-4	Dynamitron
Nominal energy	800 keV	1-5 MeV	1-5MeV
Energy stability		± 2%	± 2%
Nominal beam current	375 mA	30 mA	50mA
Beam current stability		± 2%	± 2%
Beam power	300 kW	150 kW	250 kW
Scan width	225 cm	140 cm	200 cm
Dose uniformity	± 5 %	<± 5%	<± 5%
Mode of operation:	continuous	continuous	continuous
No of accelerating head	2 sets x 2	one head	one head
Total beam power	1200 kW	-	250 kW
Power consumption	1364 kW)	220 kW	350 kW
Electrical efficiency	88 %	68 %	71%
Producer:	NHV, JAPAN	NHV	RDI, U.S.A.

ACCELERATOR
EPS-800-375

Ratings:

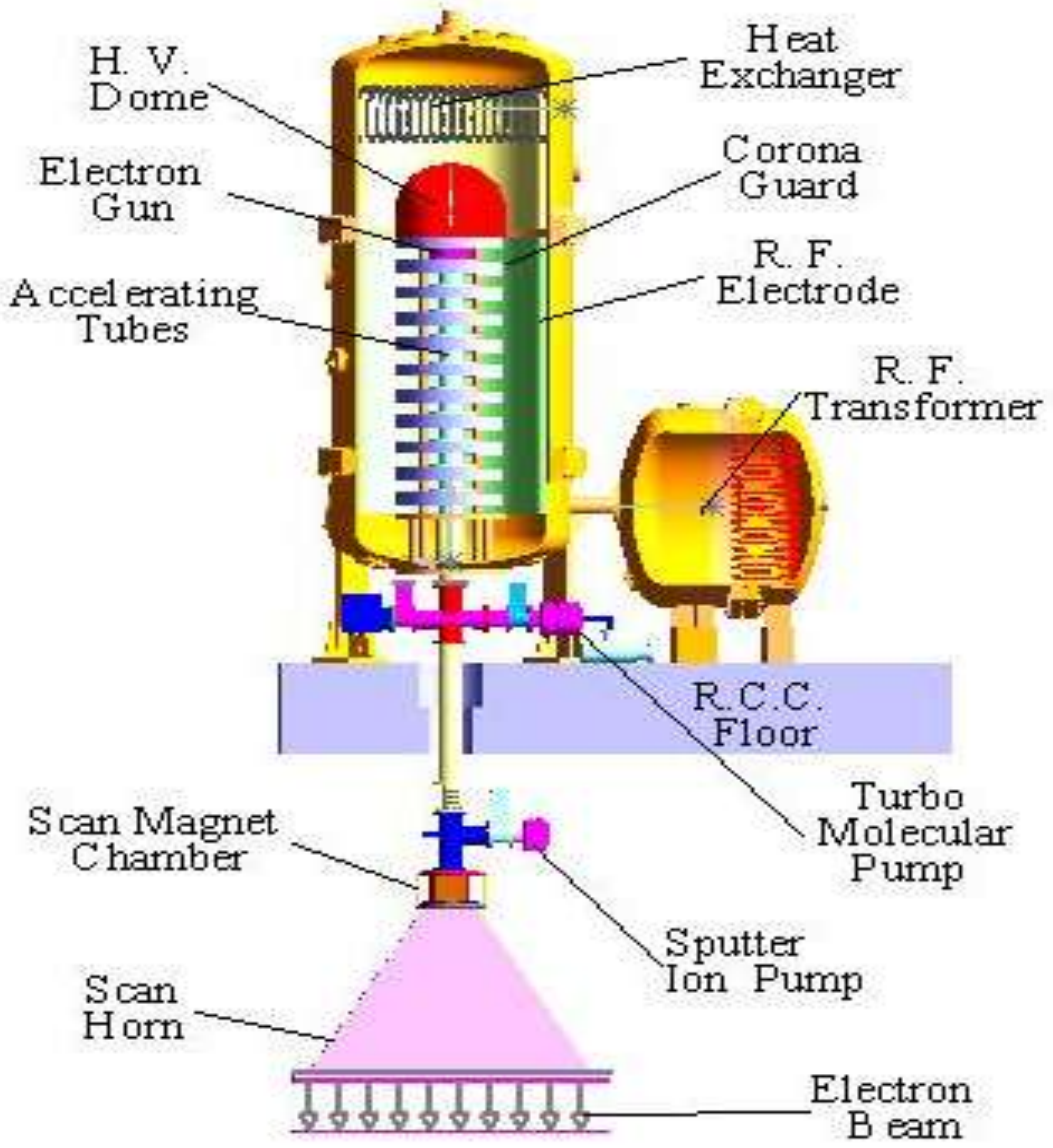
Nominal energy	**700 keV**
Nominal beam current	**375 mA**
Beam power	**262.5 kW**
Scan width	**225 cm**
Dose uniformity	**± 5 %**
Mode of operation:	**continuous**
Nº of accelerating heads	**4**
Total beam power	**1050 kW**
Producer:	**Nissin HV**

CASCADE ACCELERATOR EPS-4 type NISSIN HV, Japan

PARAMETERS:

ENERGY	**1-5 MeV**
STABILITY	**± 2%**
BEAM CURRENT	**30 mA**
STABILITY	**± 2%**
BEAM POWER	**150 kW**
SCANNER	**1400 mm**
HOMOGENAITY	**<± 5%**

A VIEW OF 3MeV DC ACCELERATOR
Dynamitron RDI, U.S.



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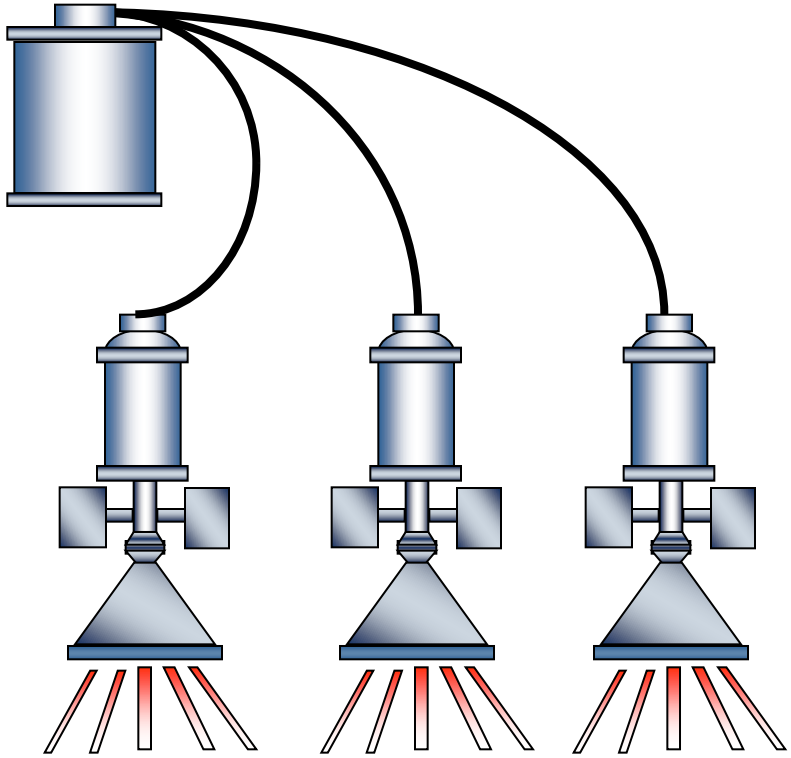
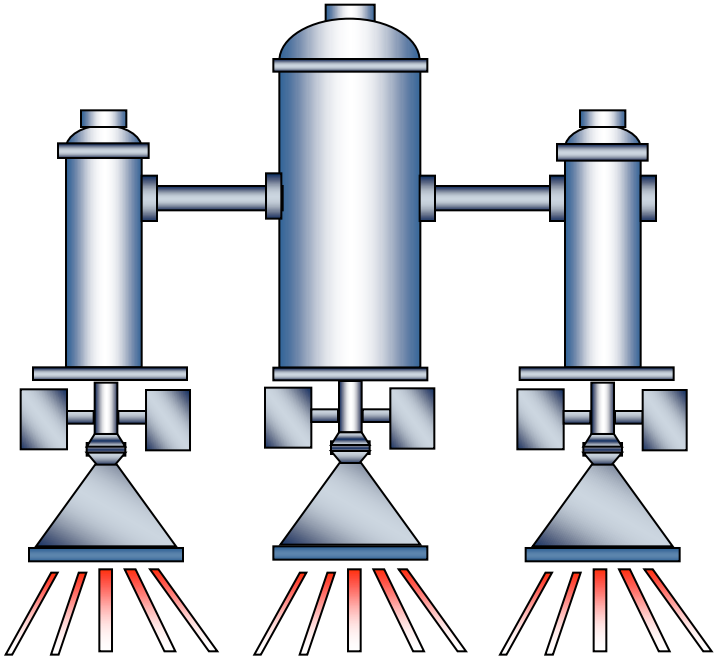
Electron Accelerators Required for Environmental Uses

- Energy range 1.0 - 2.0 MeV for wastewater

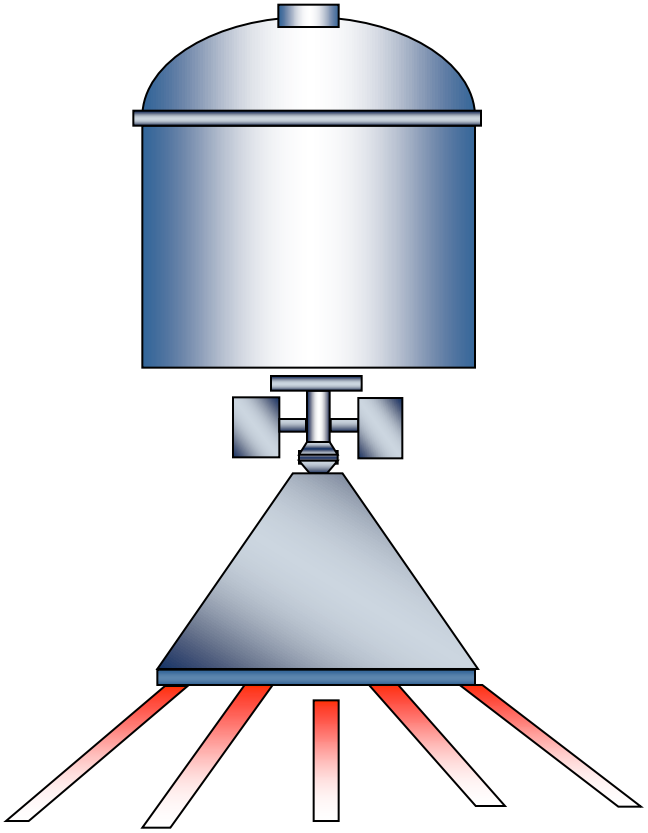
  0.6 – 1.0 MeV for gaseous waste
- Power of electron beam up to some MW
- Consist of several hundred kW units



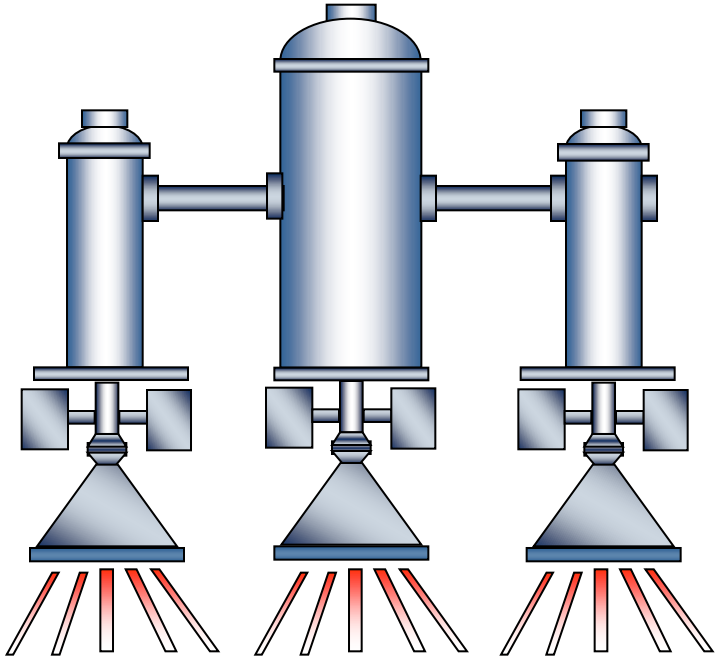
H.V. Cable Connection (<700kV)



Solid Connection of H.V.

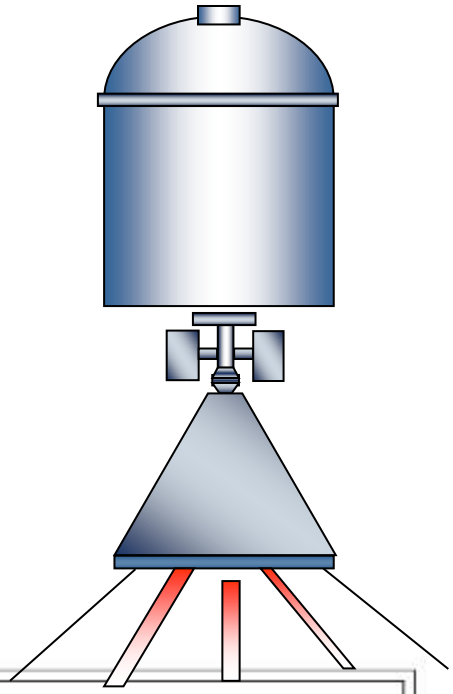


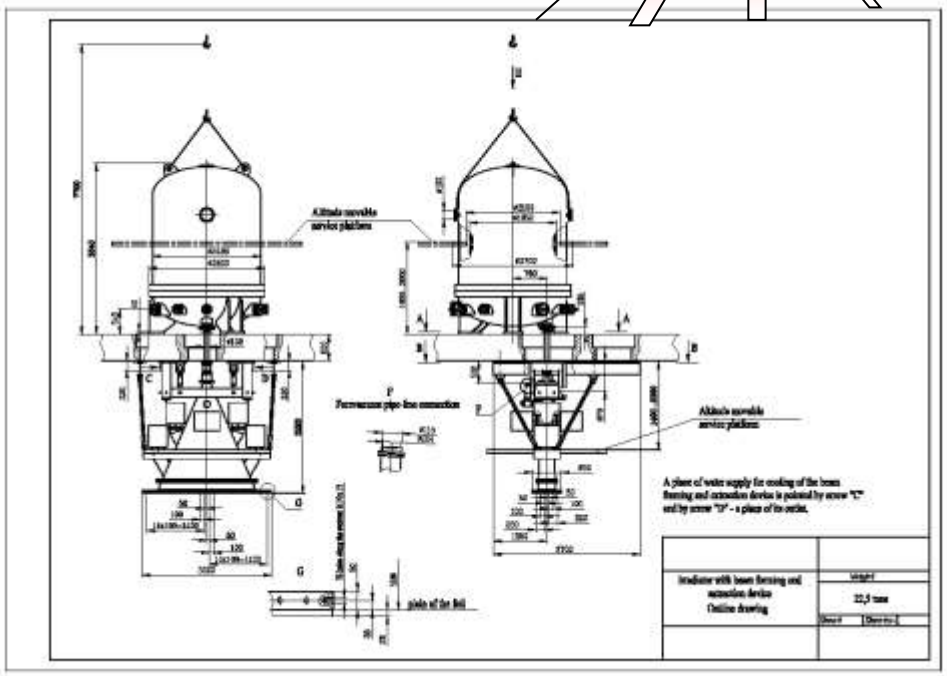
One- window system



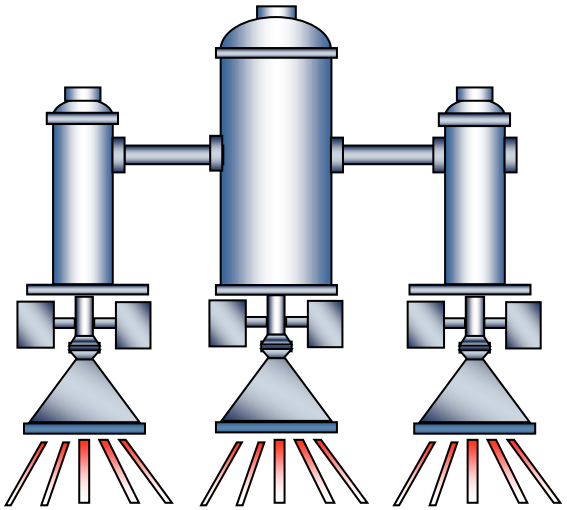
Multi-irradiator system

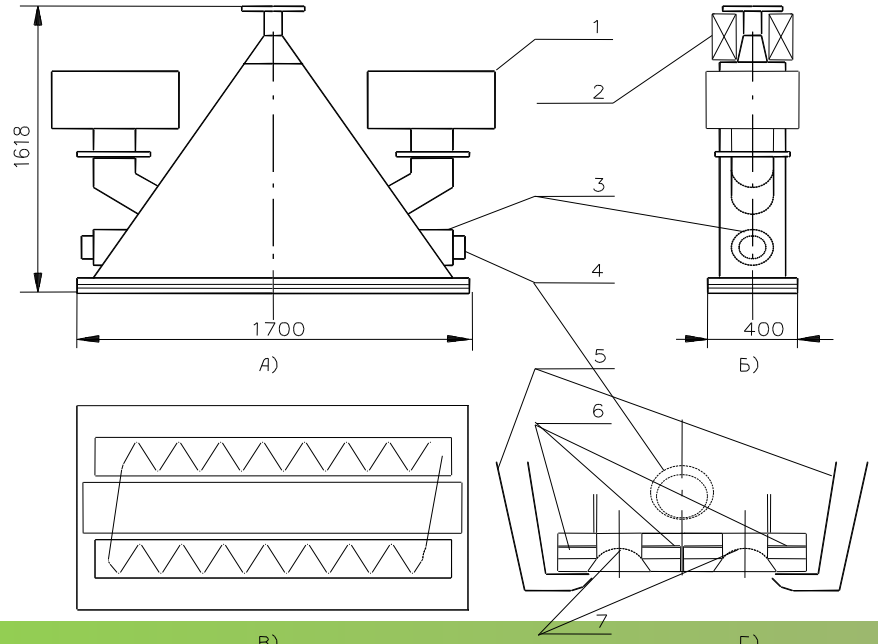
One- extraction horn with multiple window (inside supporters)





Multiple irradiators





Electron Accelerators Required for Environmental Uses

- Energy range 1.0 - 2.0 MeV for wastewater

  0.6 – 1.0 MeV for gaseous waste
- Power of electron beam up to some MW
- Consist of several hundred kW units
- **Efficiency : 85 – 95%**

ELV-12 Accelerator:

Energy : 0.6 - 1.0 MeV

Beam power: 400 kW

Beam current: 500 mA

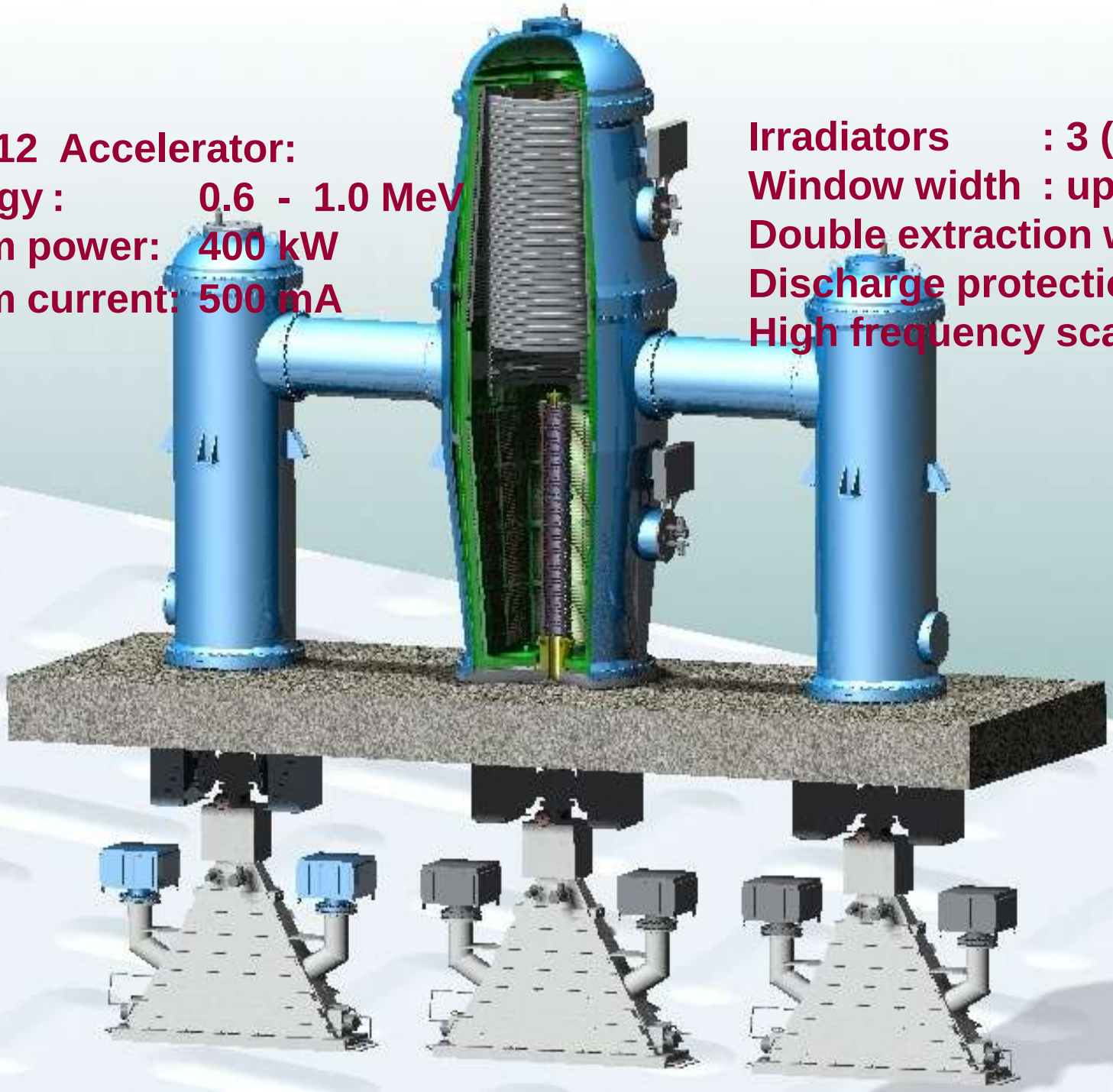
Irradiators : 3 (0~200mA)

Window width : up to 2m

Double extraction window

Discharge protection

High frequency scanning



Parameters of Typical Transformer Accelerators

Accelerator type Parameter	EPS-800-375	EPS-4	Dynamitron	ELV 12
Nominal energy	800 keV	1-5 MeV	1-5MeV	0.6-1,0 MeV
Energy stability		± 2%	± 2%	± 1%
Nominal beam current	375 mA	30 mA	50mA	500 mA
Beam current stability		± 2%	± 2%	± 2%
Beam power	300 kW	150 kW	250 kW	400 kW
Scan width	225 cm	140 cm	200 cm	200 cm
Dose uniformity	± 5 %	<± 5%	<± 5%	<± 5%
Mode of operation:	continuous	continuous	continuous	continuous
No of accelerating head	2 sets x 2	one head	one head	3 heads (*1)
Total beam power	1200 kW	-	250 kW	400 kW
Power consumption	1364 kW)	220 kW	350 kW	500 kW
Electrical efficiency	88 %	68 %	71%	80 %
Producer:	NHV, JAPAN	NHV	RDI, U.S.A.	BINP, EB TECH

Electron Accelerators Required for Environmental Uses

- Energy range 1.0 - 2.0 MeV for wastewater

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- Power of electron beam up to some MW
- Consist of several hundred kW units
- Efficiency : 85 – 95%
- Continuous operation (over 8,000hrs/yr)
- Computer control & Automatic system
- High reliability in operation (discharge protection etc.)

4. Design and Construction of Industrial Plants

-. Unexpected Problems

-. Comparison with Conventional Processes

Construction of Demonstration Facility

Industrial Plant for Treating Wastewater from Dyeing Process

- Decrease the Amount of Chemical Reagent up to 50%
- Improve the Efficiency of Biological Treatment by 30%
- Decrease the Retention time in Biological Treatment Facility

Characteristics of Industrial Plant

- Maximum flow rate of 10,000m^3/day with one 1MeV, 400kW accelerator
- Combined with existing Biological Treatment Facility

Construction Schedule

-The actual construction started on Summer of 2004, and finished by the end of 2005. (Actual construction was 17 months)

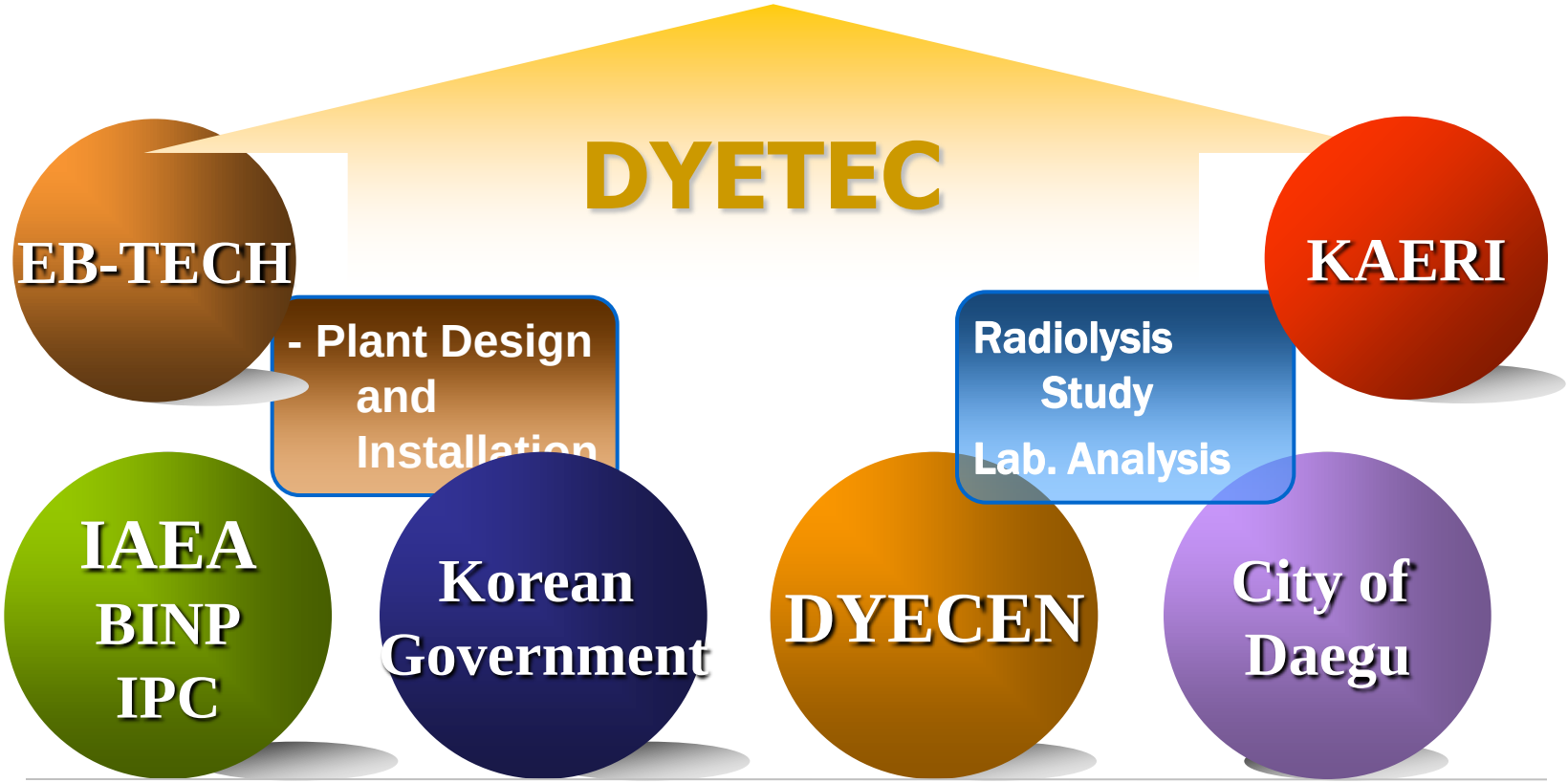
Researches on Wastewater Treatment

- 1994~1995 : Lab. scale feasibility Test with e-beam and Gamma ray
- 95.12~99.5 : Researches on Dyeing Wastewater Treatment with e-beam (Dyeing Technology Center/EB-TECH Co.)
- 96.2 ~97.2 : Treatment of Dyes and Dyeing Wastewater
- 97.2~98.10 : Construction of e-beam Pilot Plant (1000m^3/day)
- 98.10~ : Continuous operation of treatment facility
- 1998.9.16 : KT (Korea New Technology) Award
- 2000.7.19 : IR52 Industrial Research Award
- 2001~2006 : IAEA TC Project (Demo Plant Construction)
- 2001~2003 : Preparation for Plant Construction
- 2004 : Start up of Demo Plant Construction
- 2005.12 : Operation of Industrial scale plant (10,000m^3/day)

Location of Pilot Plant

Industrial plant

Wastewater Treatment Facility in Daegu Dyeing Industrial Complex



-Technical Support -Consulting	- Research Project - Peaceful use of Radiation Technology	- Analysis of Economy - Electric Power - Bio-treatment	- Funding from Local Gov. Budget

Double-window extraction device

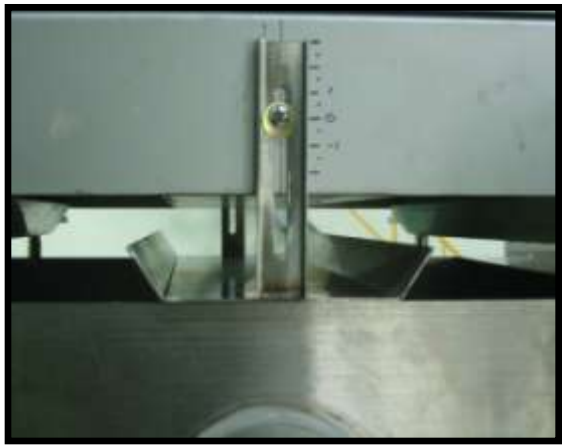
Extraction Window

Cooling Air

Cooling Air

Ti foil

Ti foil

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High Power Accelerator (EB TECH & BINP)

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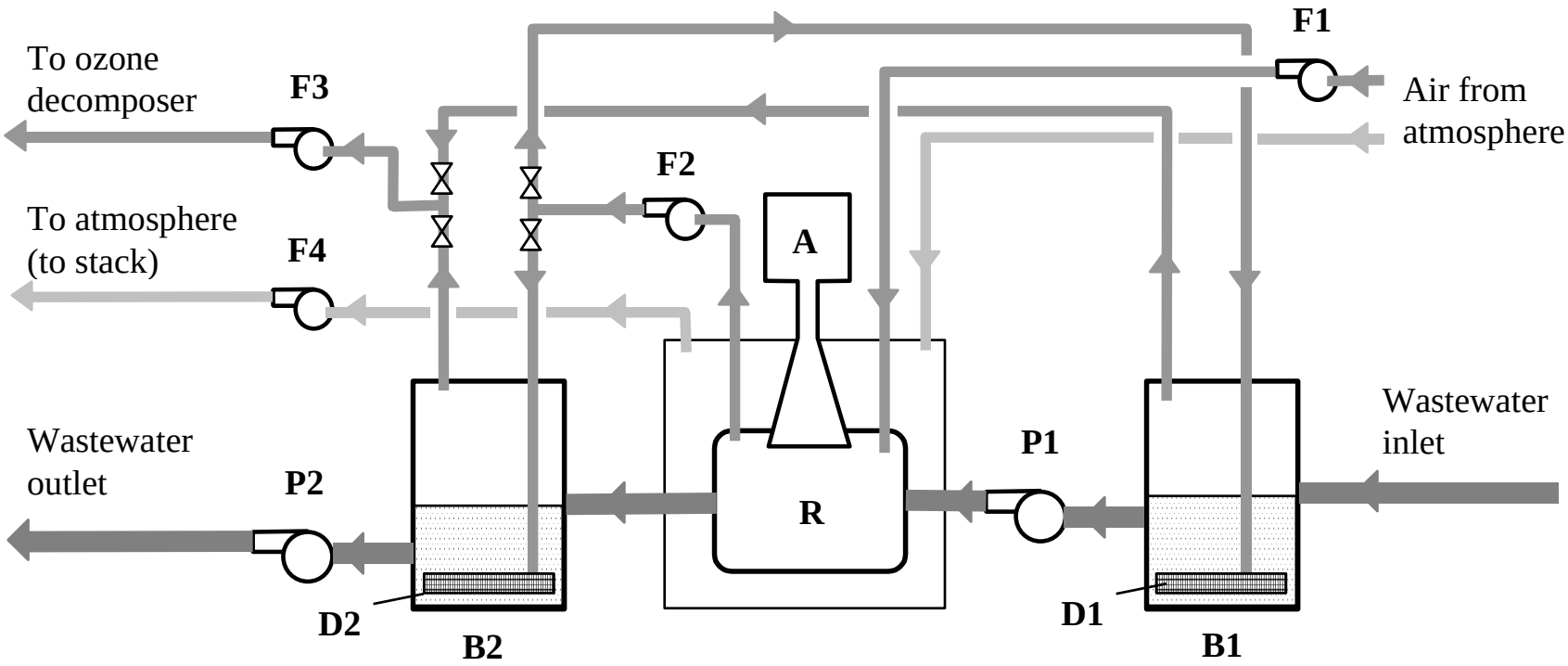
Beam power: 400 kW
Beam current: 500 mA

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

Location of Pilot Plant and Commercial Plant

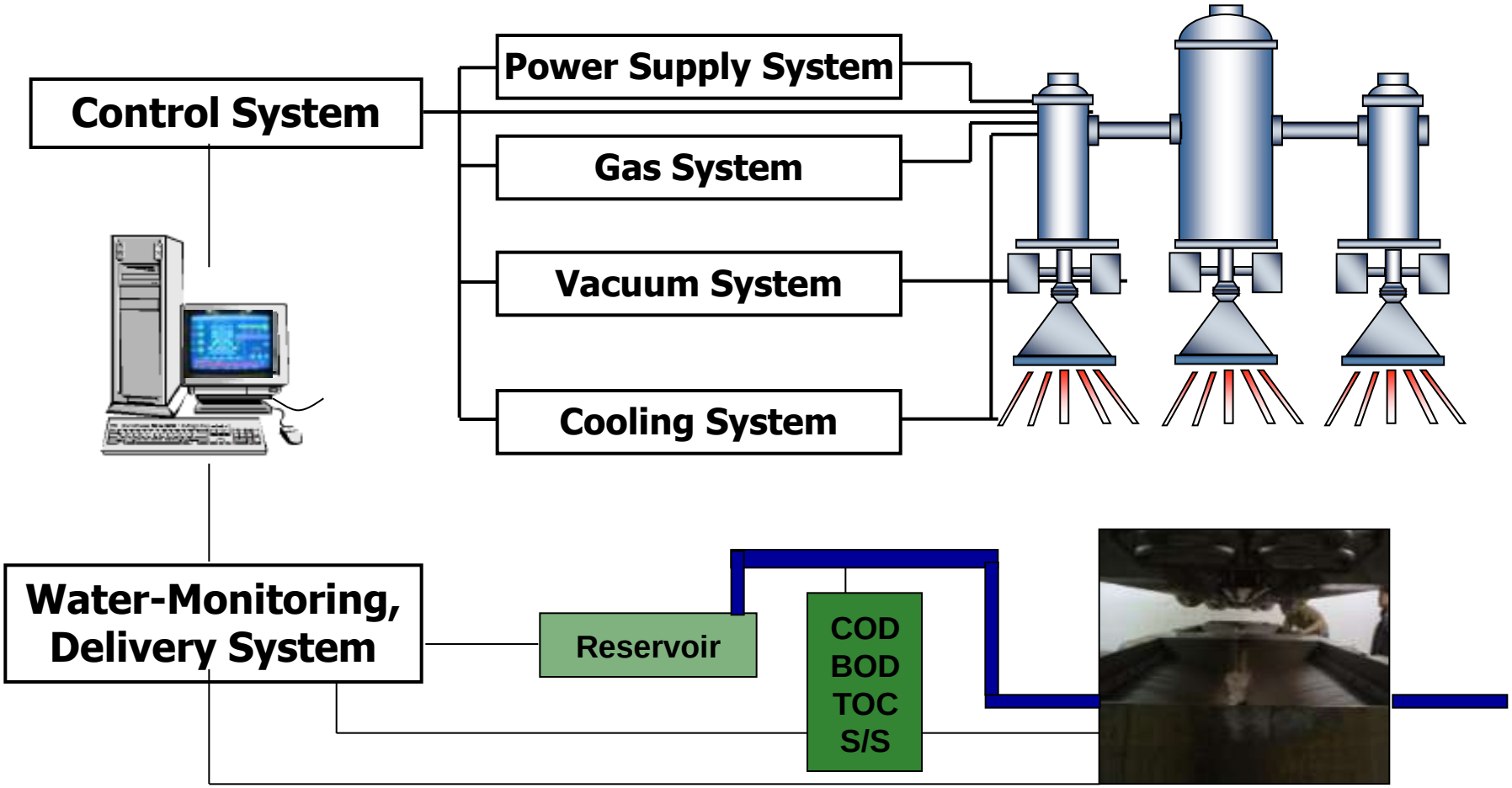
Wastewater Treatment Facility in Daegu Dyeing Industrial Complex

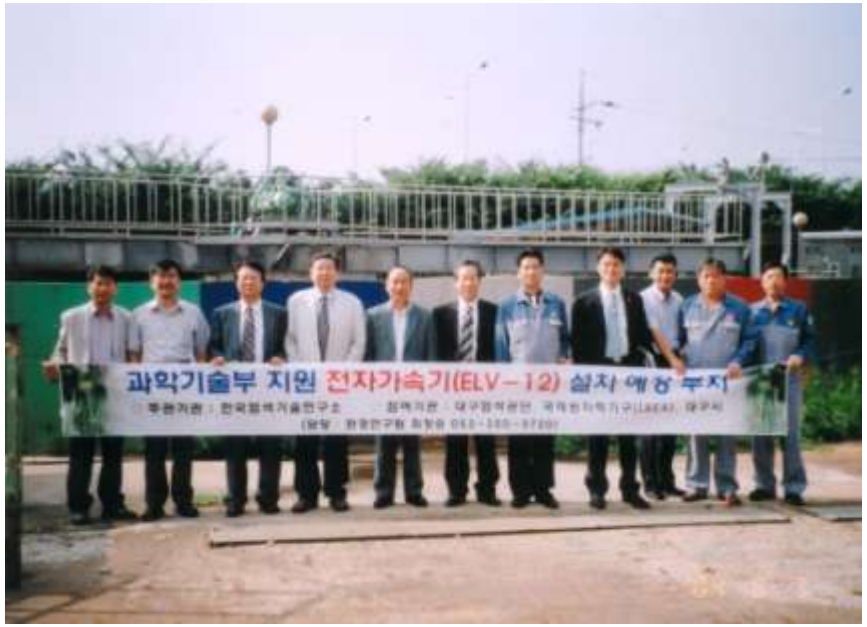
Technological Scheme of Commercial E-Beam Plant



Simplified technological scheme of the plant. F1-F4 – Air fans, P1-P2 – Water pumps, D1 and D2 – Diffusers, A – Accelerator, R – Reactor, B1 and B2 – Primary and secondary basins

Configuration of E-Beam Wastewater Treatment





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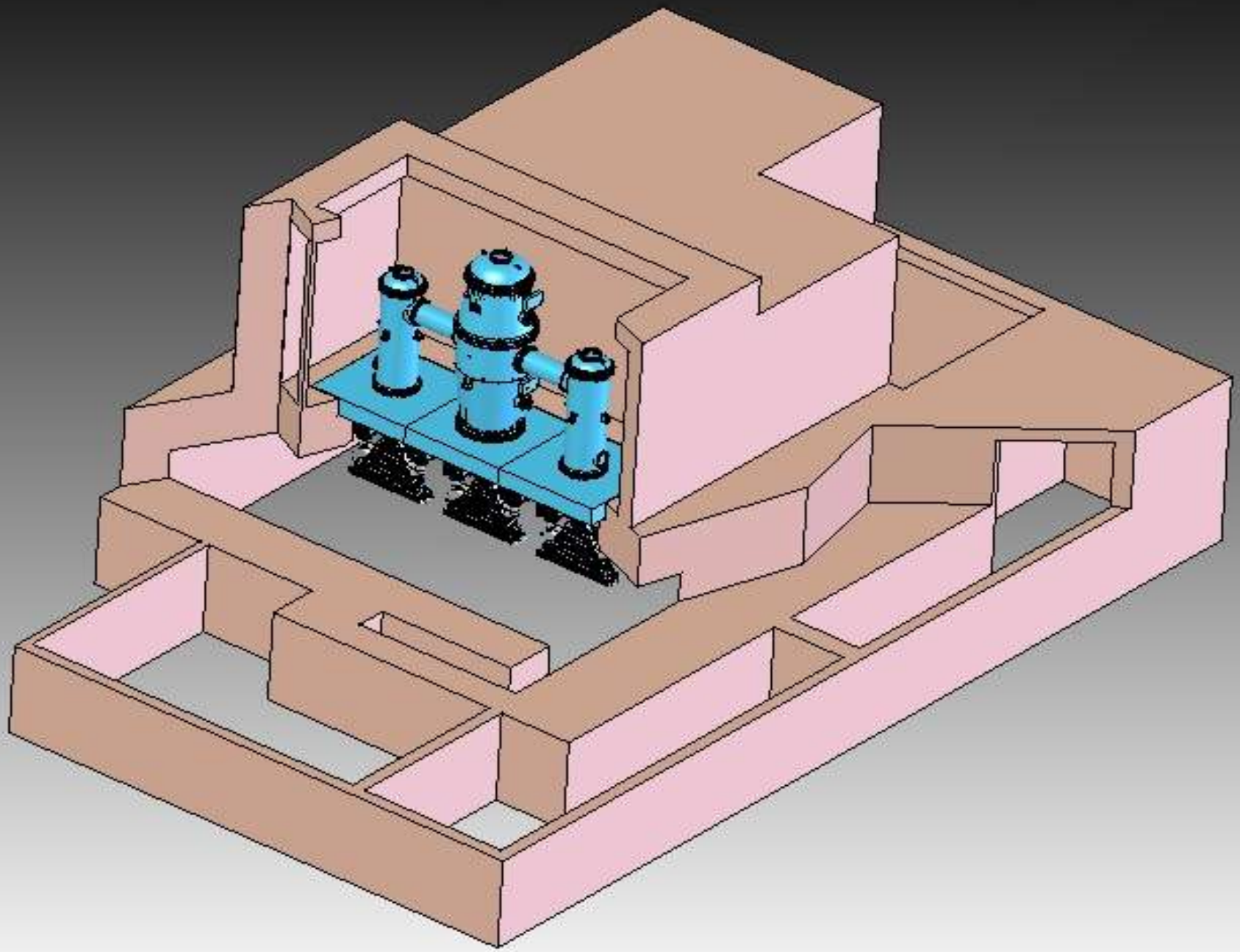


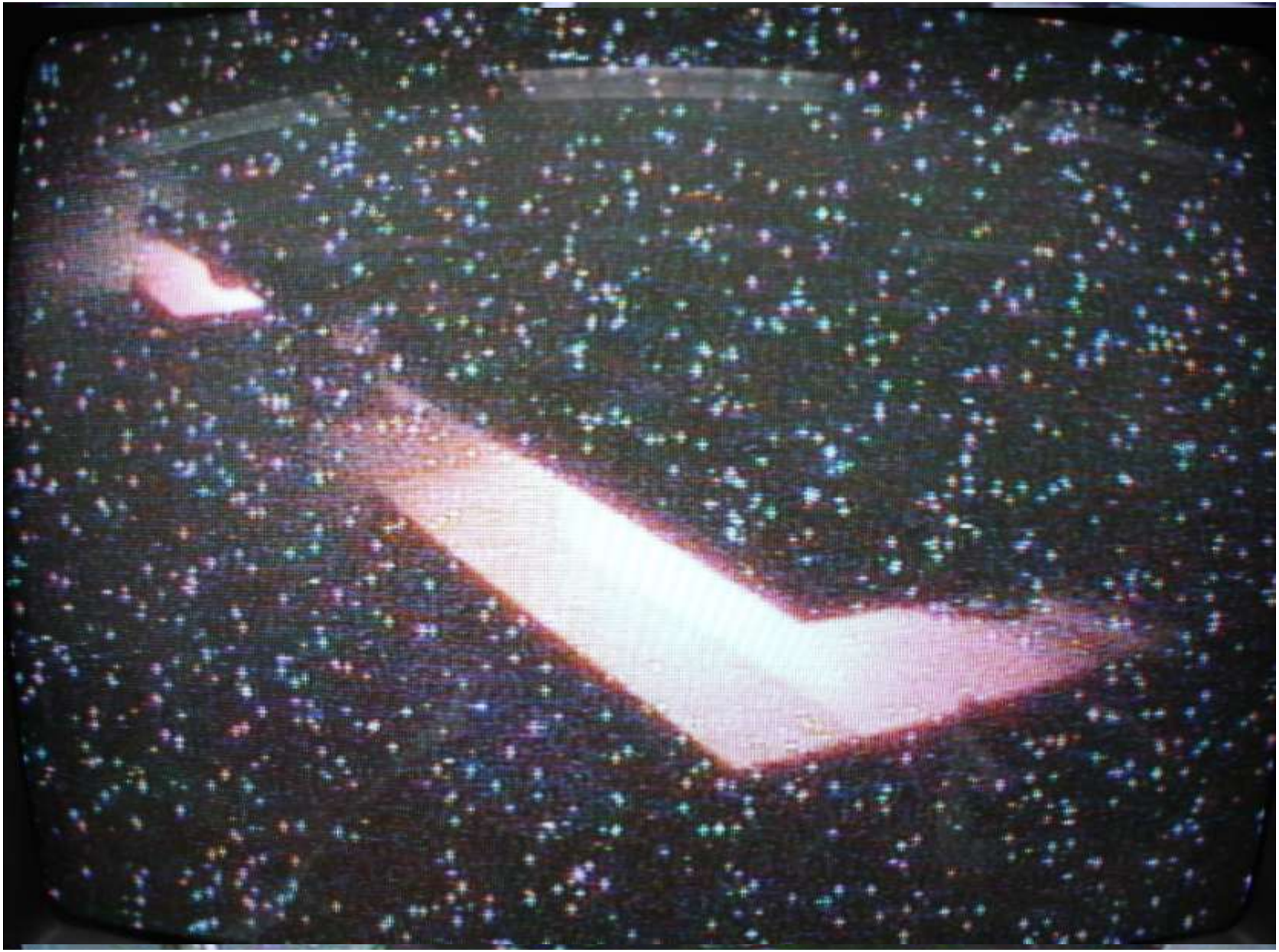

2005 6 8

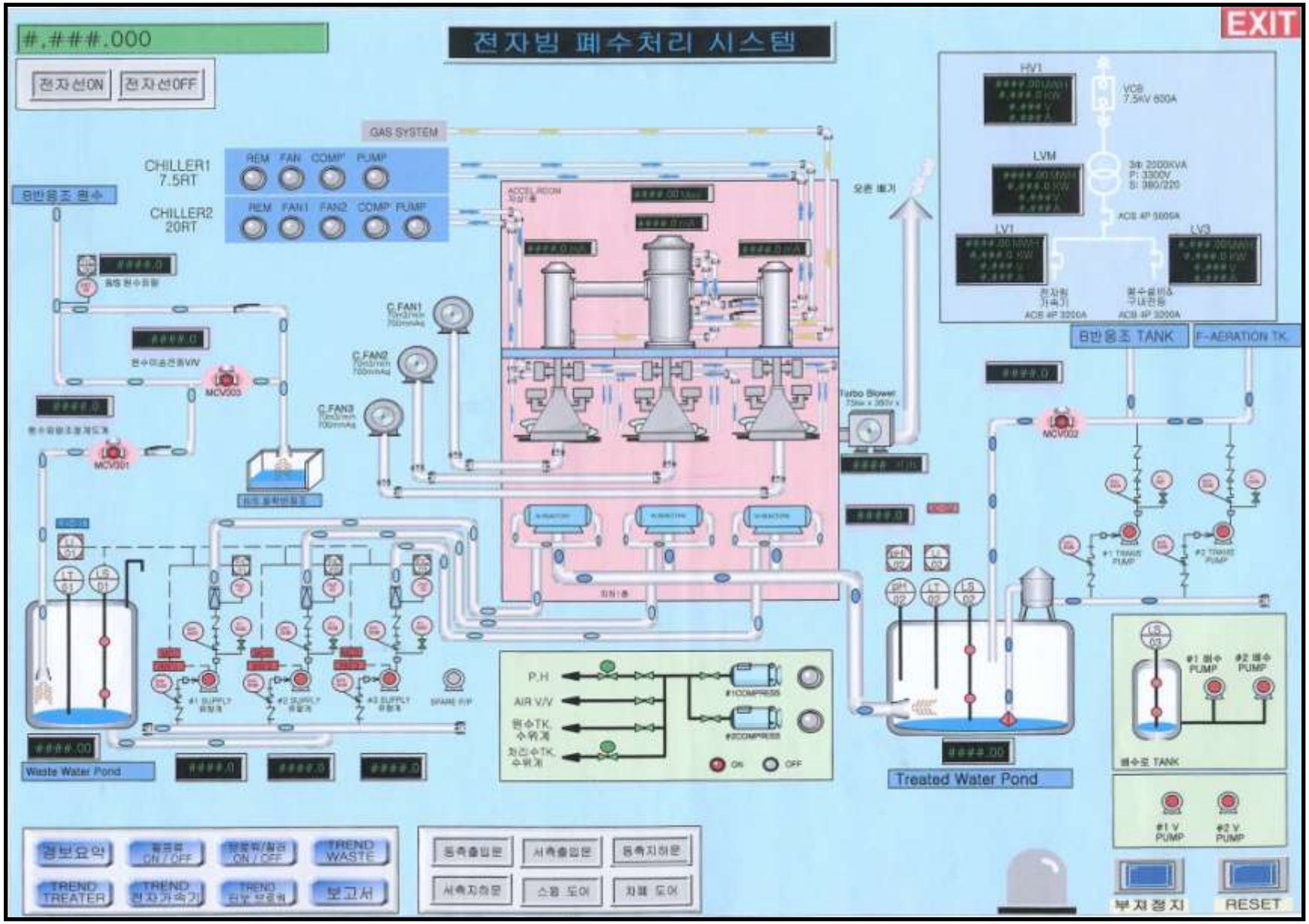

2005 8 3


2006 1 12


2006 1 12


2006 1 12





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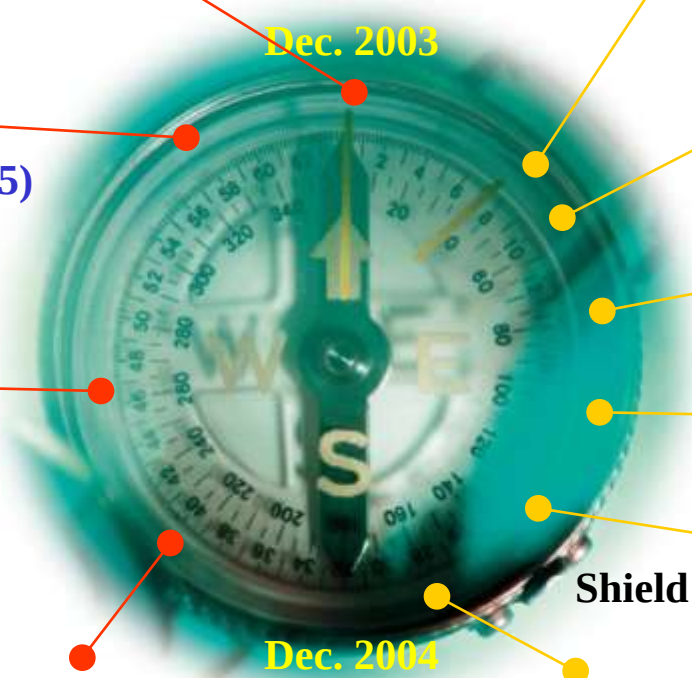
Construction of Commercial Plant

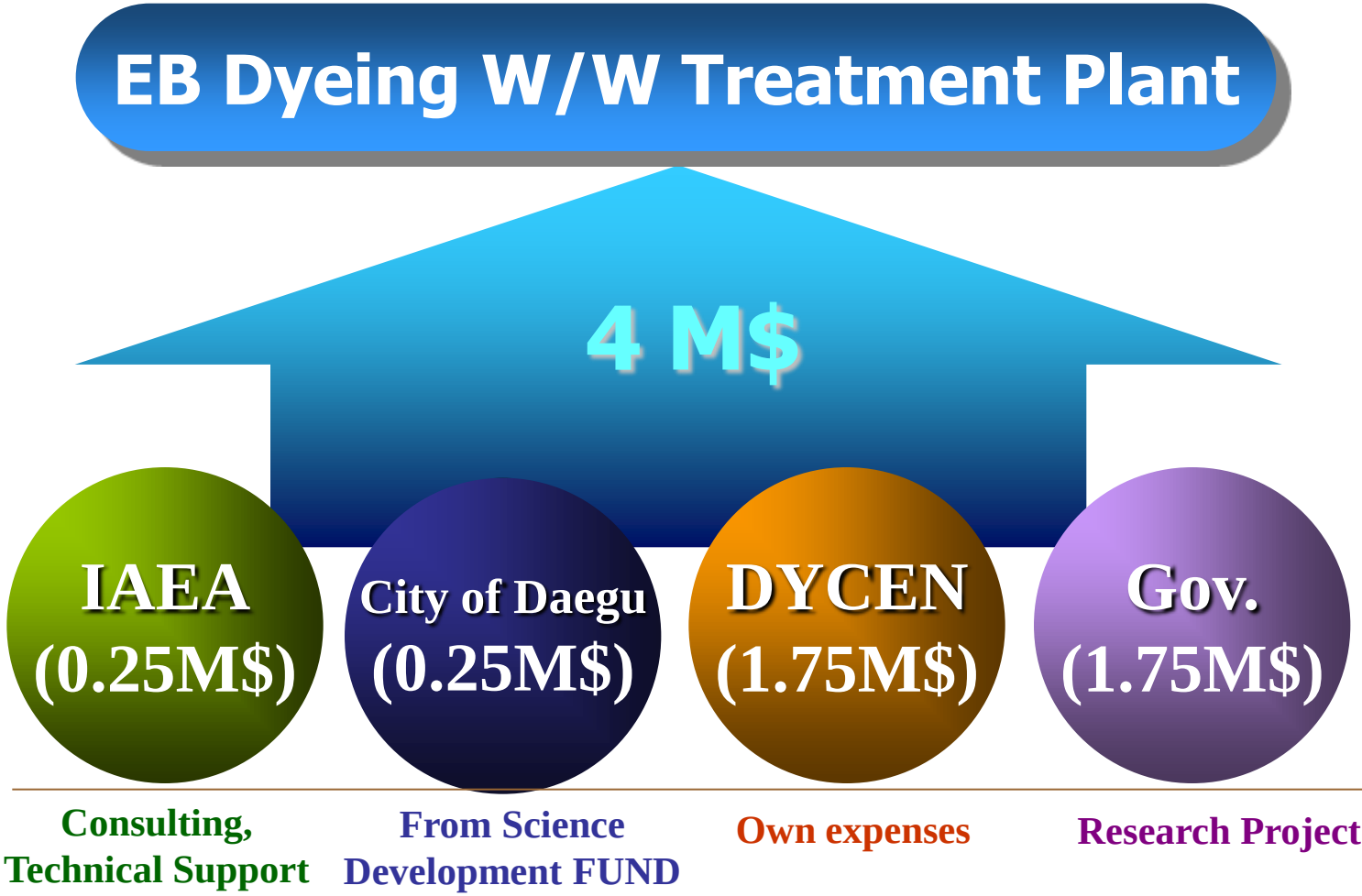
Master Schedule



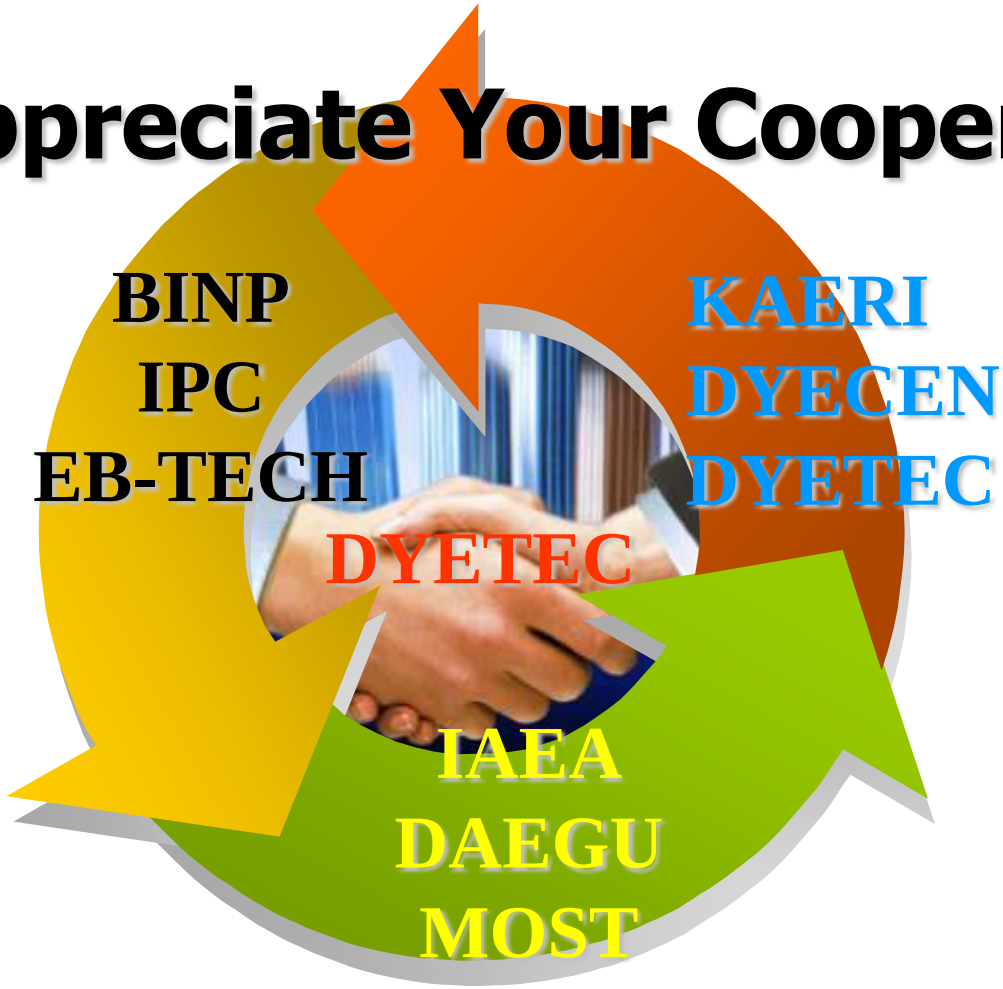
- Project reporting (Dec. 2005)
- Long-term Operation (Nov. 2005)
- Operation of Plant (July 2005)
- Installation of Accelerator (May. 2005)
- Decision of Process (Mar. 2004)
- Basic Design (Mar. 2004)
- Detail Design (May 2004)
- Purchase Orders (Jul. 2004)
- Shield Room Construction (Oct. 2004)
- Piping & Equipment (Nov. 2004)

Exhibition at 50th General Meeting of IAEA, Vienna 2006

EB Dyeing W/W Treatment Plant



We Appreciate Your Cooperation



5. Lessons Learned from the Plant Operation

1. Requirements of accelerator for pollution control

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1. Requirements of accelerator for pollution control

2. No universal solutions for Wastewater Treatment

1. Requirements of accelerator for pollution control

2. No universal solutions for Wastewater Treatment

3. Strong competition with conventional technology

Management Lesson

"A crow sat on a tree doing nothing..,
When a Rabbit thought to do
the same & sat on the ground..,
A fox came & ate him..,

1. Requirements of accelerator for pollution control

2. No universal solutions for Wastewater Treatment

3. Strong competition with conventional technology

4. EB treatment is better for larger volume of water

		Amount of wastewater (m^3/day)		
		1,000 or less	*1,000~10,000*	*over 10,000*
A/S	Invest	H	M	L
	Operation	M	L	L
Ozone	Invest	M	MH	H
	Operation	M	MH	H
Membrane	Invest	M	H	H
	Operation	M	H	H
E-beam	Invest	H	M	L
	Operation	LM	L	L

Relative cost for treating lowly-polluted industrial wastewater


"NO!
Try not!
DO or DO NOT,
There is no try."

Thank You