International Atomic Energy Agency

E-Beam Flue Gas Treatment Plant for "Sviloza Power Station" in Bulgaria

- Engineering Consideration & Cost Evaluation -

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Contents

1. Status of EB FGT Plant

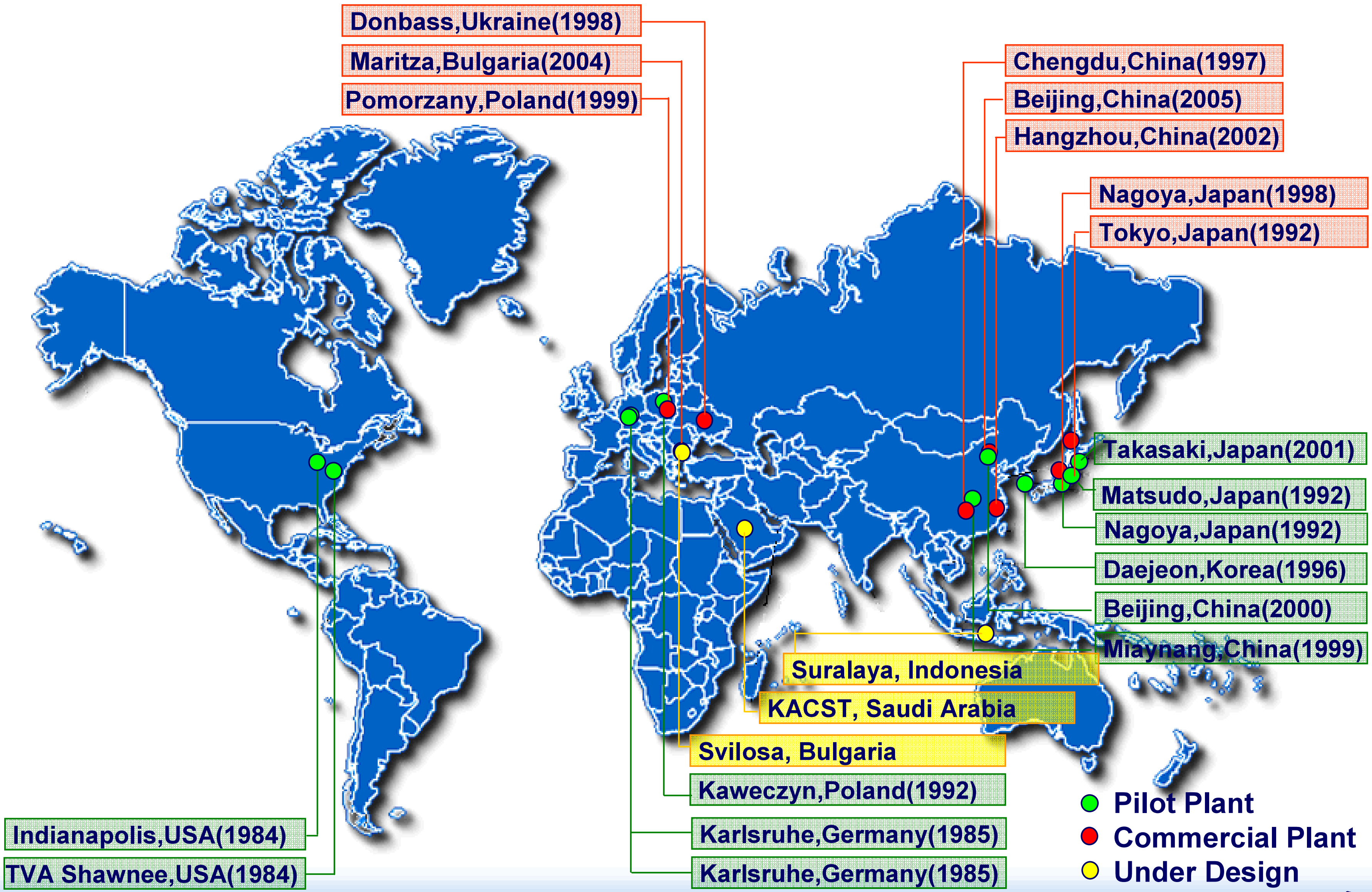
2. "Sviloza" Power Station

3. Engineering Considerations of Process

4. Cost Evaluation of EB FGT

5. Summary

1. Status of EB FGT Plant



Commercial EBFGT Plants in the World

	Chengdu (1997)*	Pomorzany(1999)**	Hangzhou(2002)*	Beijing(2005)*
Boiler Power	90MW	130MW	90MW	150MW
Flue gas flow	300,000Nm^3/h	270,000Nm3/h	305,400 Nm^3/hr	630,000 Nm^3/hr
Inlet SO_2 / NOx	1800ppm/400ppm	525ppm/292ppm	967ppm/200ppm	1470ppm/583ppm
SO_2 / NOx removal	80% / 10%	90% / 70%	85% / 55%	90% / 20%
Dose	3kGy	8-12kGy	4kGy	4kGy
Inlet flue gas temp.	132℃	130-150℃	150℃	146℃
Outlet PM conc.	≤200mg/Nm^3	≤190mg/Nm^3	≤200mg/Nm^3	≤200mg/Nm^3
By-products	2.3ton/hr (60$/ton)	300kg/h	1.7ton/hr (60$/ton)	4.9ton/hr (60$/ton)
EB Accelerator	800kV/400mA×2	800kV×375mAx4	800kV/400mA×2	1000kV/500mA×2 1000kV/300mA×1
Total power	640kW/1,900 kW	1,200kW/1,686 kW	□640kW/1,896 kW	□1300kW/2,850 kW
Total capital cost	11.4 M$	21 M$	9.1 M$	11.9M$
Process	*EBARA*	INCT	*EBARA*	IEPE

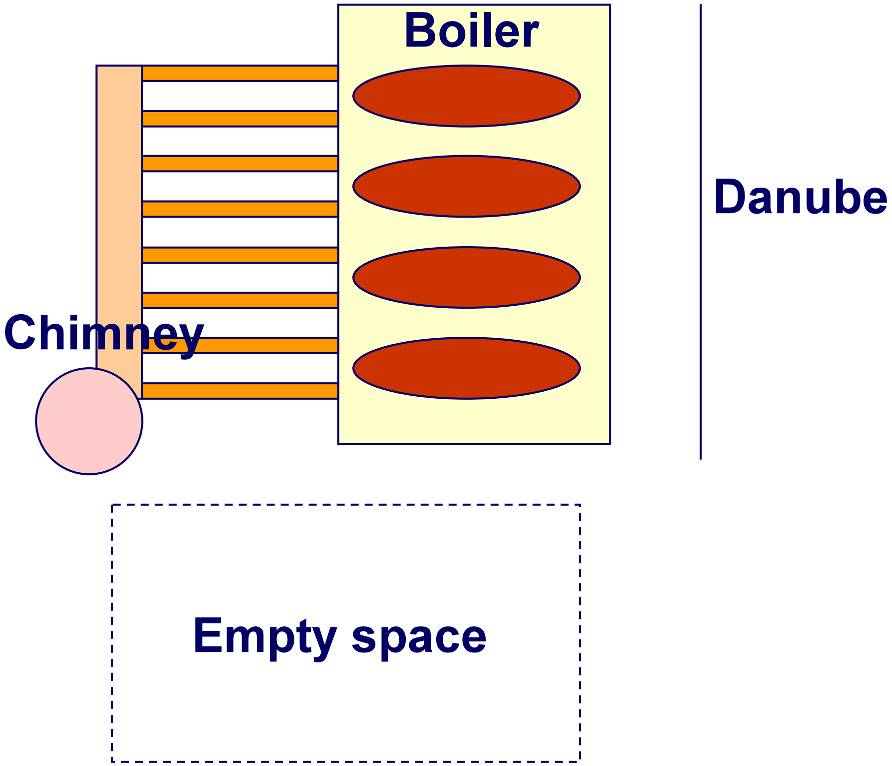
** Ben Jiang Mao, "Process Of Flue Gas Desulphuration With Electron Beam Irradiation In China", 2005*
*** Bogdan Tymiński, Andrzej Pawelec, Economical Evaluation of Electron Beam Flue Gas Treatment, IAEA Consultants Meeting on "Radiation Processing of gaseous and Liquid Effluents" 7-10 September 2004, Sofia, Bulgaria*

2. TPS(Thermal Power Station) “Sviloza”

Sviloza Power Station, photo from Danube river

- *Installation site*

- *+. All 8 stacks from 4 boilers (2 each) are connected to the chimney (150m in height)*
- *+. Planning to take by-pass lines from each stack to send the gases to EBFGT plant and connecting them to chimney after treatment.*
- *+. There is an empty space of over 50m X 60m*



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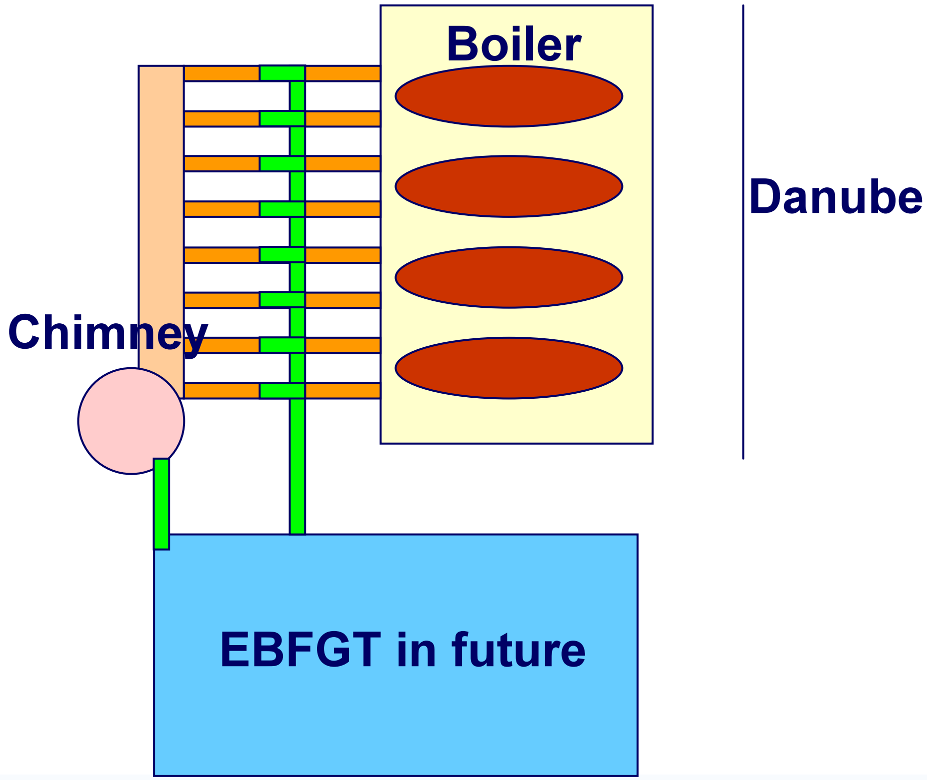

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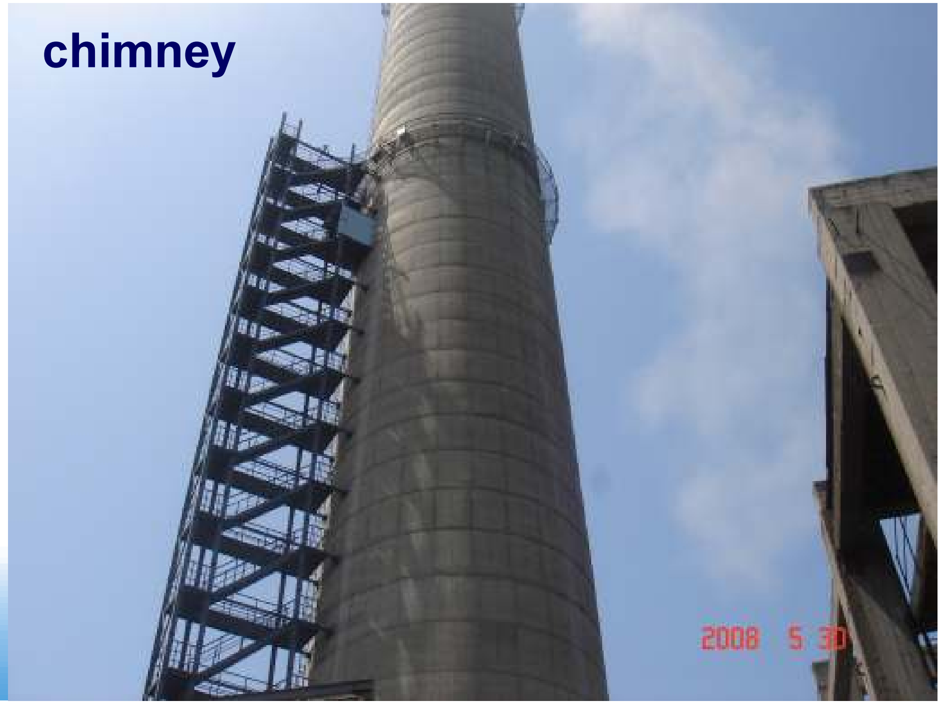
Space (from left)

Space (from right)

Connecting structure



chimney

3. Engineering Consideration of Process

1) Process Scheme

2) Electron Accelerators

- *Number of scanners*
- *Window structure*
- *H.V connection*

3) Process reactor

4) Emergency operation

1) Process Scheme

- Basic operational assumptions for TPS "Sviloza"

Flue gas flow rate (WB):	600 000 m^3/h
° Inlet flue gas temperature	160°C
° Inlet flue gas composition(O_2 6%):	
-SO_2	1680 ppm
-NO_x	780 ppm
-CO_2	10.4% vol.
-O_2	8.3% vol.
-H_2O	6.0% vol.
-N_2	to the balance
-Fly ash	< 400 mg/Nm^3
SO_2 removal efficiency	90 %
NOx removal efficiency	40 %
Maximum dose	4 kGy
Ammonia consumption	1,660 kg/h
By-product output	6,400 kg/h

- For flue gas of 600,000Nm³/hr(165MWe) with 4kGy

$$P\,(kW) = \frac{M\,(kg/s) * D\,(kJ/kg)}{3600 * F} \approx 1{,}200 \sim 1{,}400\ kW$$

Where P = required power of e-beam (kW = kJ/s)

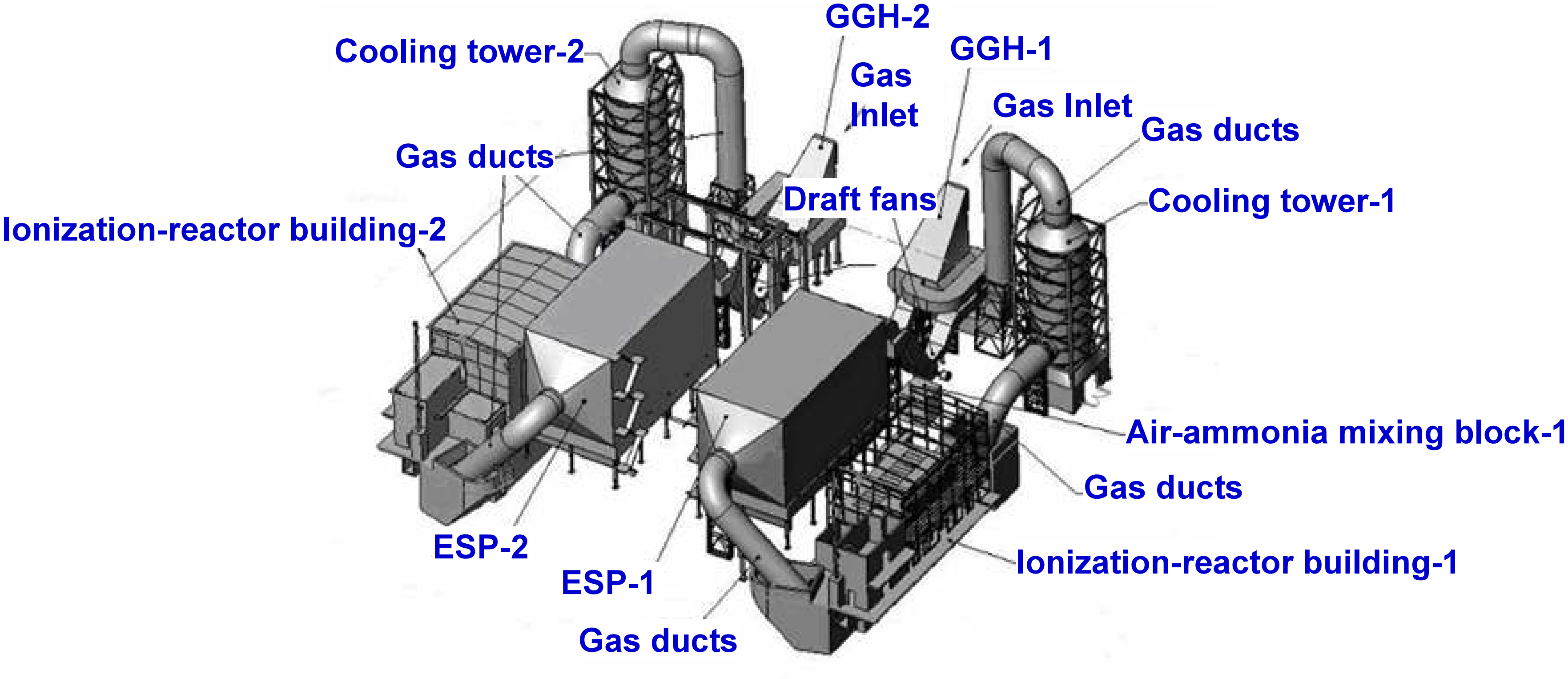
M = mass productivity (kg/hr)

flow rate (600,000Nm³/h) X 1.372 (kg/Nm³)

D = dose delivered (kGy = kJ/kg, 4kGy)

F = efficiency of beam energy transfer (0.65~0.75)

- Basic design of two-stream EBI for flue gas purification



N. Doutzkinov, K.Nikolov, "The Possibility for Implementation of E-beam Technology in TPS "Svilosa", Bulgaria, Meeting on Electron Beam Flue Gas Treatment, Warsaw, Poland 14 – 18 May 2007

2) Electron Accelerators Required for Flue Gas Treatment

- Energy range   1.0 - 2.0 MeV for wastewater

  0.7 – 1.0 MeV for gaseous waste
- 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.)

Typical Accelerators

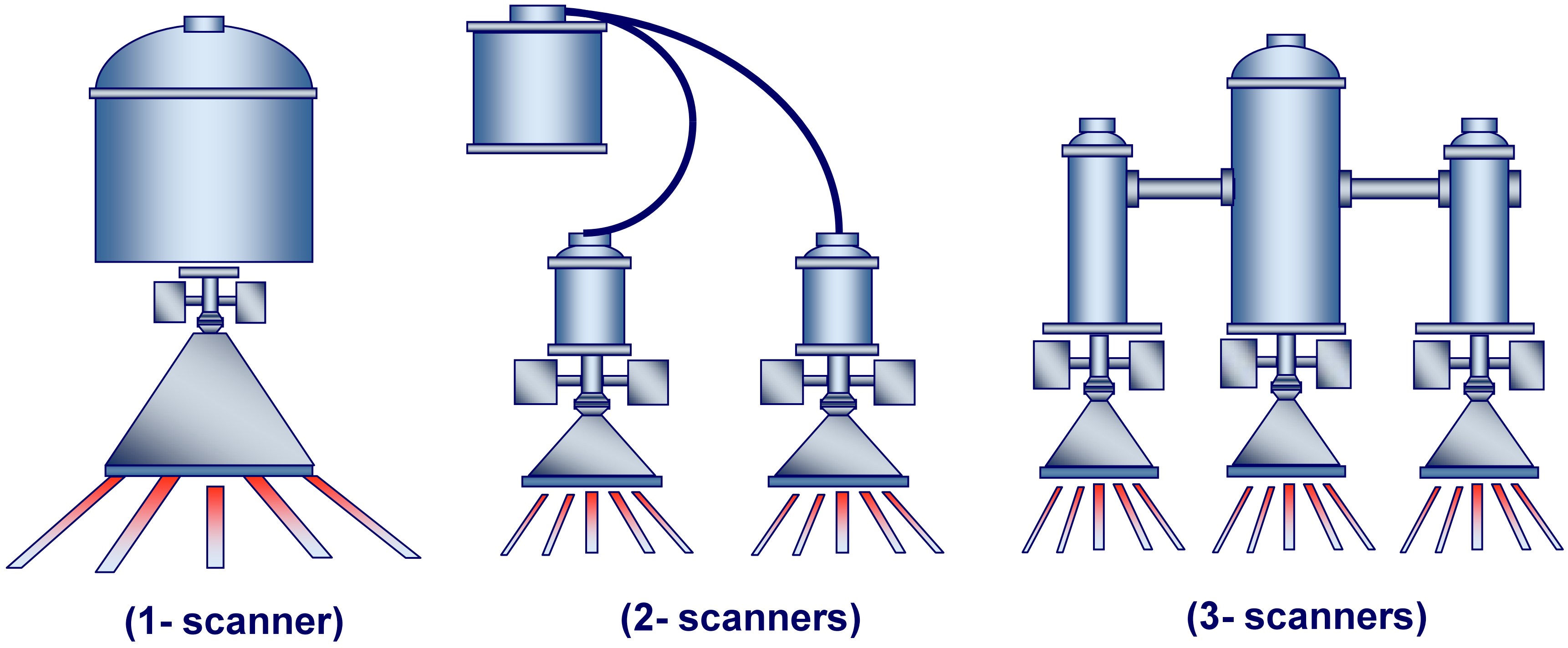
- Parameters of Typical Accelerators*

Accelerator type Parameter	EPS-800-375	Dynamitron	ELV-12
Nominal energy	800 keV	1-5MeV	0.6-1,0 MeV
Energy stability	-	± 2%	± 1%
Nominal beam current	375 mA	50mA	500 mA
Beam current stability	-	± 2%	± 2%
Beam power	300 kW*2	250 kW	400 kW
Scan width	225 cm	200 cm	200 cm
Dose uniformity	± 5 %	<± 5%	<± 5%
Mode of operation	continuous	continuous	continuous
No. of Scanner	2 heads	one head	3 heads
Total beam power	600 kW	250 kW	400 kW
Power consumption	682 kW	350 kW	500 kW
Electrical efficiency	88 %	71%	80 %
Producer:	NHV, JAPAN	RDI, U.S.A.	BINP, EB TECH

** Iller,E.,Zimek, High Power Accelerators And Processing Systems For Environmental Application, Presentation of IAEA Consultants Meeting "Radiation Processing of Gaseous and Liquid Effluents" 7 – 10 September 2004, Sofia, Bulgaria*

- ELV-12 Accelerator (BINP, EB TECH)

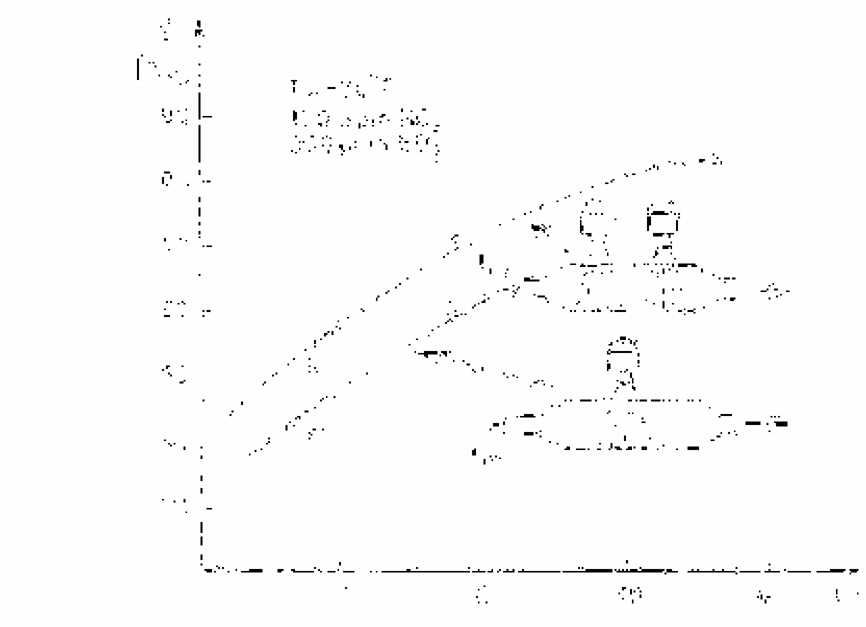
Number of scanners



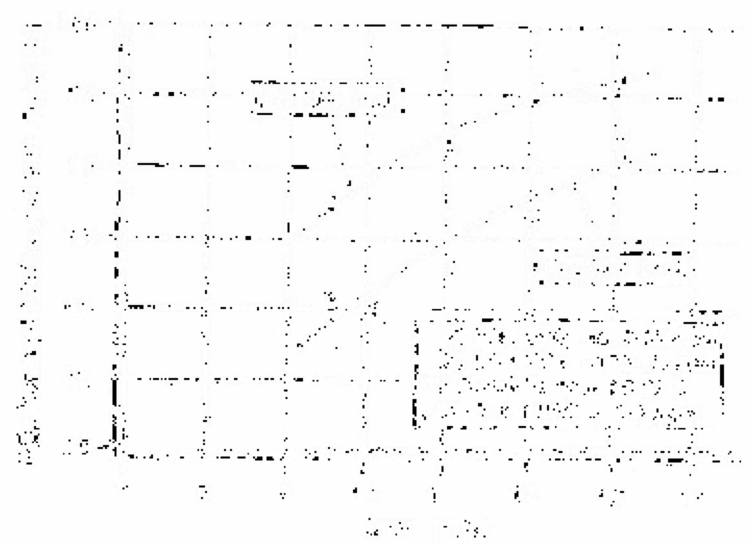
Single-irradiator system

Multi-irradiator system

Serial irradiation effect *



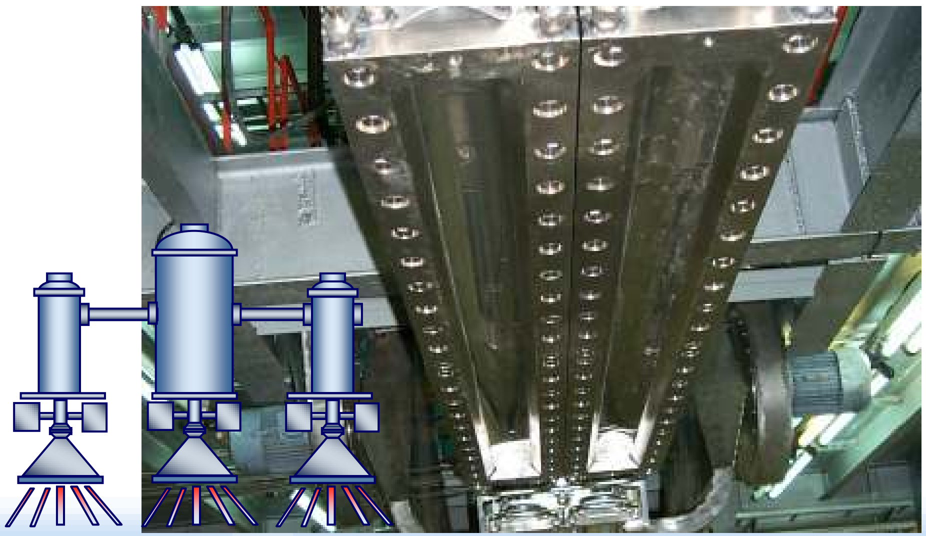
Effect of double irradiation to removal efficiency of NOx



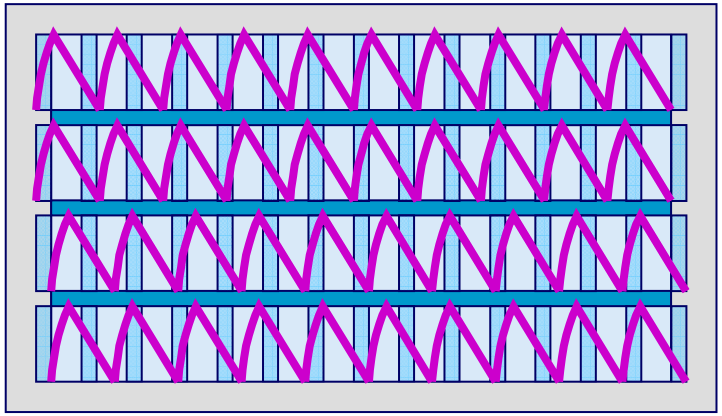
* *Chmielewski, A.G., et al., “Optimization of Energy Consumption for NOx Removal in Multistage Gas Irradiation Process”, Radiat.Phys.Chem., Vol.45, No.6, 1995.*

Window structure

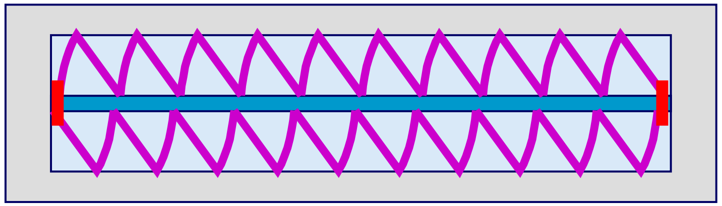
One- scanner with multiple window (inside supporters), NIIEFA



Multiple scanner with double window, BINP - EB TECH

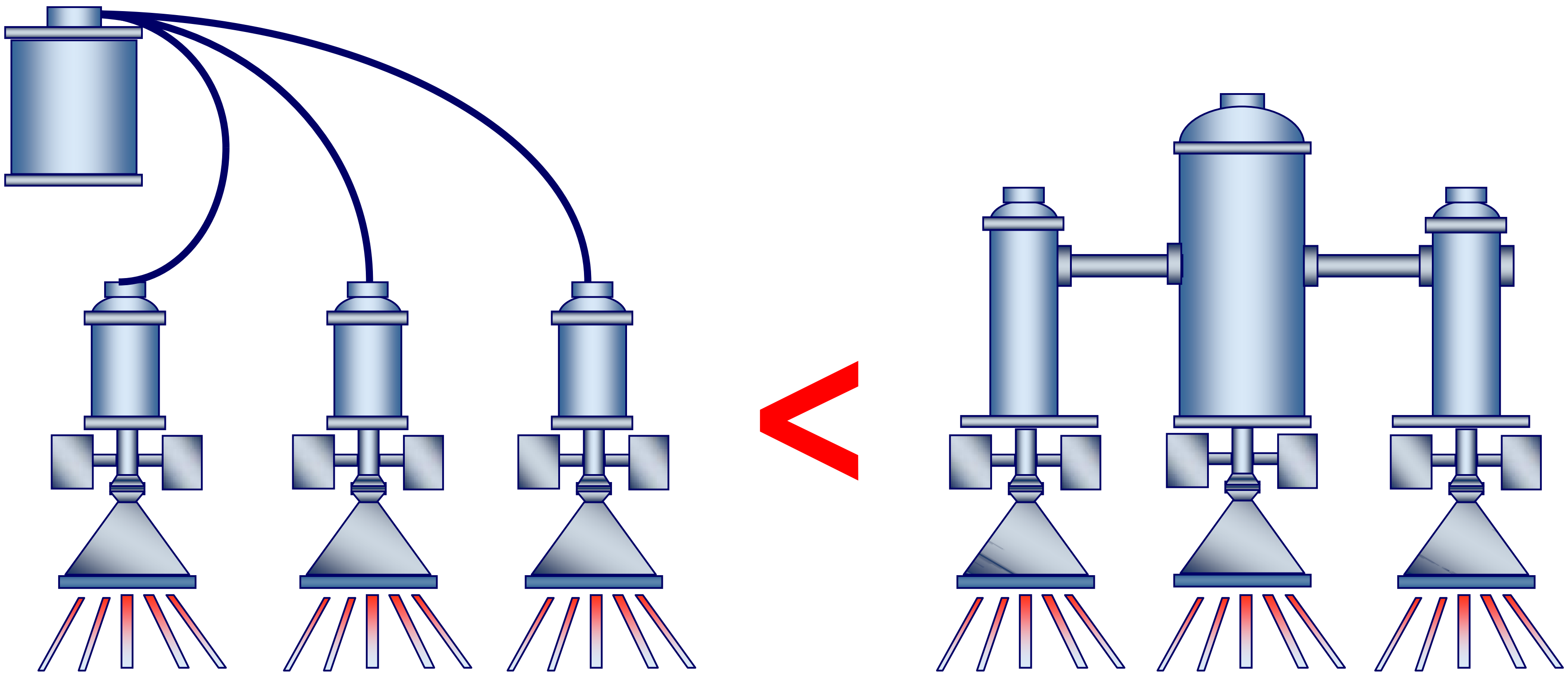


-. Power loss
  +. Theoretical 15%, 75kW for 500kW
  +. Too much power loss, requires huge cooling system



-. Power loss
  +. Less than 1%, 4~5kW for 400kW
  +. power loss concentrated on small area (jumping area)

H.V connection



H.V. Cable Connection (<700kV) < Solid Connection of H.V.

3) Process reactor

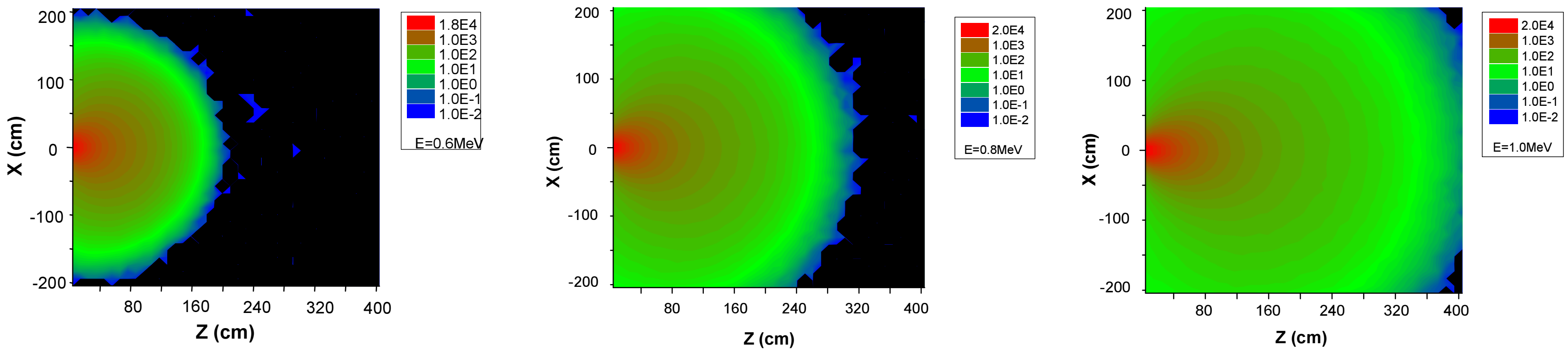
- Typical dimension of process reactor*

Name	Energy	Shape of reactor	Reactor depth
Japan, Nagoya, 12,000Nm3/h	0.8MeV	Horizontal rectangular	2400(H)x1900(W)x14000(L)
Japan, Nippon Steel 10,000Nm³/h	0.75 MeV	Vertical cylinder	φ2600
Japan, Nisi-Nagoya, 620,000Nm3/h	0.8MeV	Horizontal rectangular (Both side irradiation)	5000(H)x4600(W)x14000(L)
China, Mianyang 12,000Nm³/h	0.8 MeV	Horizontal cylinder	φ3100×11000(L)
Poland, Kaweczyn 20,000 Nm³/h	0.7 MeV	Horizontal cylinder	φ1600×7000(L)
USA, Indianapolis 24,000Nm³/h	0.8 MeV	Vertical cylinder	φ2926×12000(L)
Poland, Pomorzany 270,000Nm³/h	0.8 MeV	Horizontal cylinder	φ2600×11000(L)
China, Chengdu 300,000Nm³/h	0.8 MeV	Horizontal rectangular	2500(H)x4200(W)×13000(L)
China, Hangzhou, 300,000Nm³/h	0.8 MeV	Horizontal rectangular	2500(H)x4600(W)×13100(L)

** Mao Benjiang, "Flue Gas Desulphuration and Denitration with Electron Beam Irradiation and Ammonia Reagent", 2005*

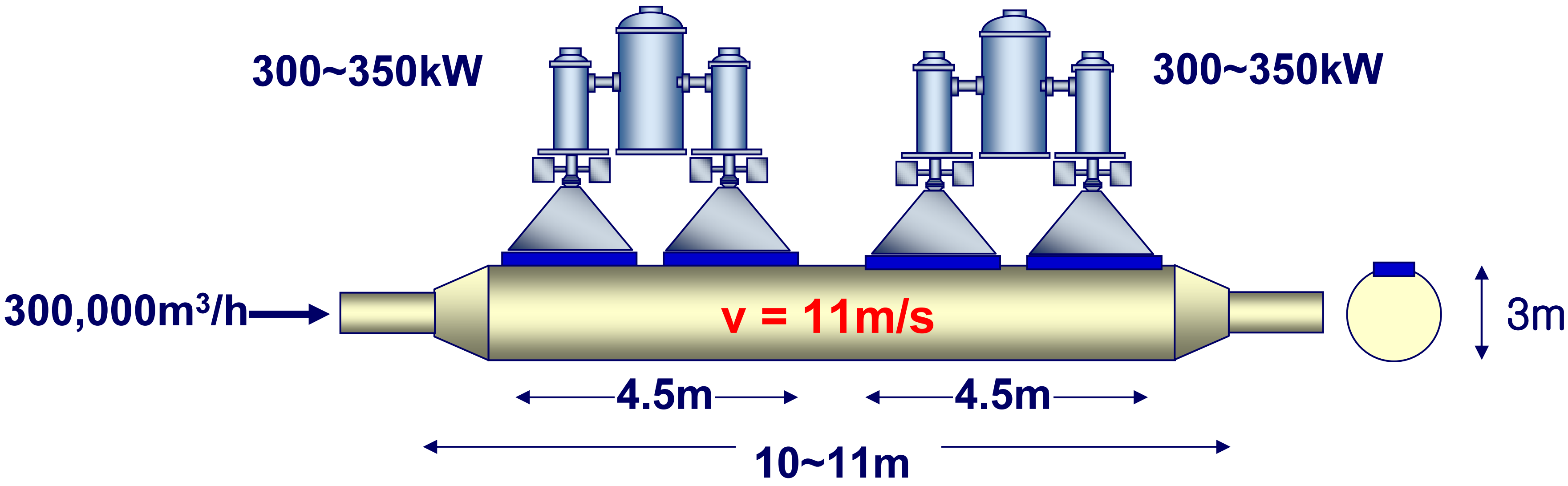
*- Determination of reactor depth**

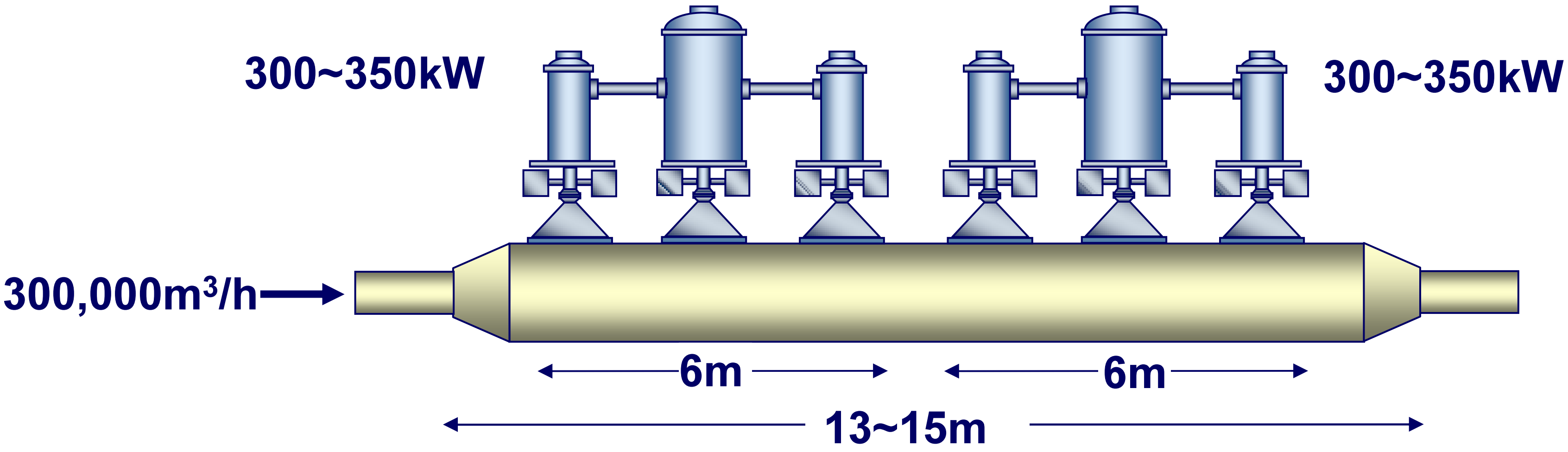
Utilization of E-beam （%）	Depth of Reactor (cm）				
	0.6*MeV*	0.7*MeV*	0.8 *MeV*	0.9*MeV*	1.0 *MeV*
85	172	230	263	287	308
90	192	253	291	315	332
95	218	280	325	345	359
96	226	290	336	353	366
97	233	295	344	360	373
98	243	305	356	365	378
99	265	325	374	384	390



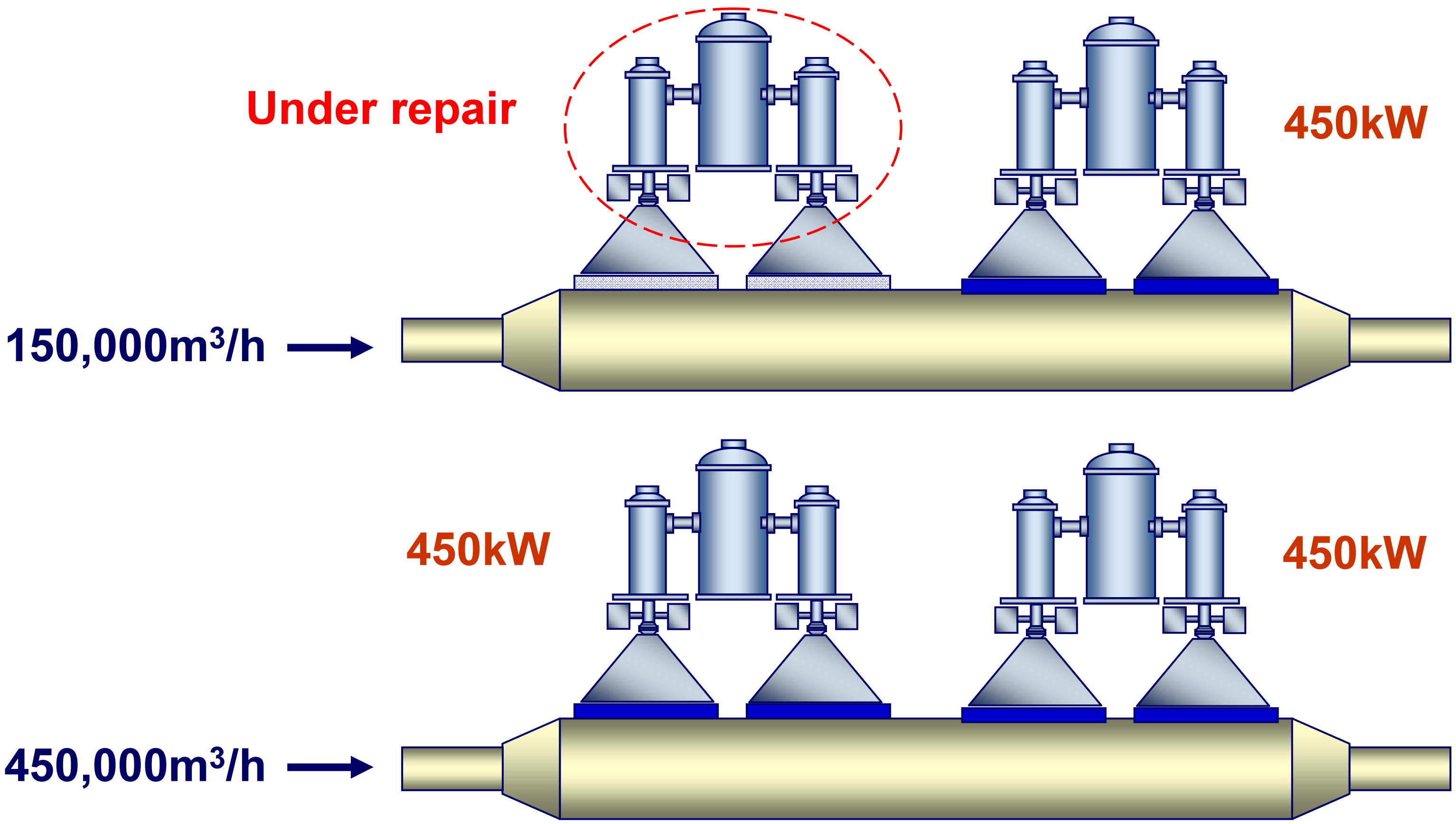
** Mao Benjiang, "Flue Gas Desulphuration and Denitration with Electron Beam Irradiation and Ammonia reagent", 2005*

Comparison on the scanner Numbers





4) Emergency Operation



Normal Operation	Emergency
0.9MeV, 300~350kW X 4 (1200~1400kW)	0.9MeV, 450kW X3 (1350kW)

4. Cost Evaluation of EBFGT

1) Comparison of Cost with 4 Case EB Plant

-. Case 1- Generalized EB Plant (2000)

-. Case 2 - Chengdu Plant (China, 1997)

-. Case 3 - EPS Pomorzany Plant (1999)

-. Case 4 - SVILOZA Plant (estimated)

- 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 2000*

- Case 2 : Chengdu (China, 1997)*

Items	Design Values
Flue gas flow (coal)	300,000Nm^3/h (90MW)
Inlet SO_2 / NOx conc.	1800ppm/400ppm
SO_2 / NOx removal eff.	80% / 10%
Dose	3kGy
Inlet flue gas temp.	132℃
Outlet particulate	≤200mg/Nm^3
By product	2.3ton/hr (60$/ton)
Electron accelerator	800kV/400mA×2
Total power consumption	≤1900kW
Total capital cost	11.4 Million USD
Unit capital cost	126.5$/kWe
Unit operation cost	16.5$/kWe(120$/ton SO_2)

** Ben Jiang Mao,"Process Of Flue Gas Desulphuration With Electron Beam Irradiation In China" (2005).*

- Case 3 : EPS Pomorzany (1999)*

Items	Design Values
Boiler Power	130MW
Flue gas flow	270,000Nm^3/h
Inlet SO_2 / NOx conc.	525ppm/292ppm
SO_2 / NOx removal eff.	90% / 70%
Dose	8-12kGy
Inlet flue gas temp.	130-150℃
Outlet PM conc.	$\leq$190mg/Nm^3
By product	300kg/h
Electron accelerator	800keV×300mAx4
Total power consump.	1,200kW
Total capital cost	21 M$
Unit capital cost	160$/kWe
Unit operation cost	7.35$/kWe (1,061$/ton SO_2)

** Bogdan Tymiński, Andrzej Pawelec, Economical Evaluation of Electron Beam Flue Gas Treatment, IAEA Consultants Meeting on "Radiation Processing of gaseous and Liquid Effluents" 7-10 September 2004, Sofia, Bulgaria*

- Cost comparison with Different method*

Emission control method	Investment cost (USD/kW_e)	Annual operational cost (USD/MW_e)
Wet flue gas desulphurisation	120	3000
Selective catalytic reduction	110	4600
Wet FGD + SCR	230	7600
Electron beam FGT (de-SOx, low NOx removal)	130	5000
Electron beam FGT (de-SOx/NOx)	160	7350

** Andrzej Pawelec et al, MEETING ON ELECTRON BEAM FLUE GAS TREATMENT "Experiences From Operation of Pomorzany EBFGT Plant and Directions of Technology Development", Warsaw, Poland 14 – 18 May 2007*

*- Case 4 : SVILOZA Plant (estimated)***

Items	Design Values
Flue gas flow rate	600,000 Nm^3/hr (165MW)
Inlet SO_2 / NOx concentration	1680ppm/780ppm
SO_2 / NOx removal efficiency	90% / 40%
Dose	4kGy
Inlet flue gas temperature	160℃ (110~150℃)
Outlet particulate concentration	≤100mg/Nm^3
By product	6.4ton/hr (50€/ton)
Electron accelerator	1MeV/400mA×4 (1400kW)
Total power consumption	≤1800kW
Total capital cost*	26 Million Euro ~ 37.4M $
Unit capital cost	227$/kWe
Unit operation cost	21.2$/kWe (157$/t SO_2)

*EB Accelerator(4set) = 8M$ included

**ENERGOPROJEKT, Feasibility Study " Installation of Electron Beam Desulfurization and Denitration Plant in TPP "Sviloza-JSC",(2006)

- Summary : Comparison with Unit Cost

	IAEA (1997)	Chengdu (1997)	Pomorzany (1999)	Sviloza (estimated)
Unit Capital Cost	202$/kWe	126.5$/kWe	160$/kWe	227$/kWe
Unit operation Cost	-24$/kWe* *(-5$/t SO2)*	16.5$/kWe *(120$/t SO2)*	7.35$/kWe *(1061$/t SO2)*	21.2$/kWe *(157$/t SO2)*

- Unit Capital Cost from Report
  - 225$/kWe (1988, Ebara, DOE)**
  - 180-250$/kWe (2005, USEPA)***

** Negative operating costs refer to profits from the by-products exceeding plant operation costs*
***Frank, N. W., et al., Final Report Ebara Electron Beam Flue Gas Treatment Process, Indianapolis, Indiana Demonstration Unit, DOE Contract AE22-830PC60259.*
****USEPA report, "Multipollutant Emission Control Technology Options for Coal-fired Power Plants", EPA-600/R-05/034, 2005.*

2) How to improve the economics ?

-. reduce operating cost

+. large scale EB Plant + high sulphur flue gas

-. reduce the cost of plant

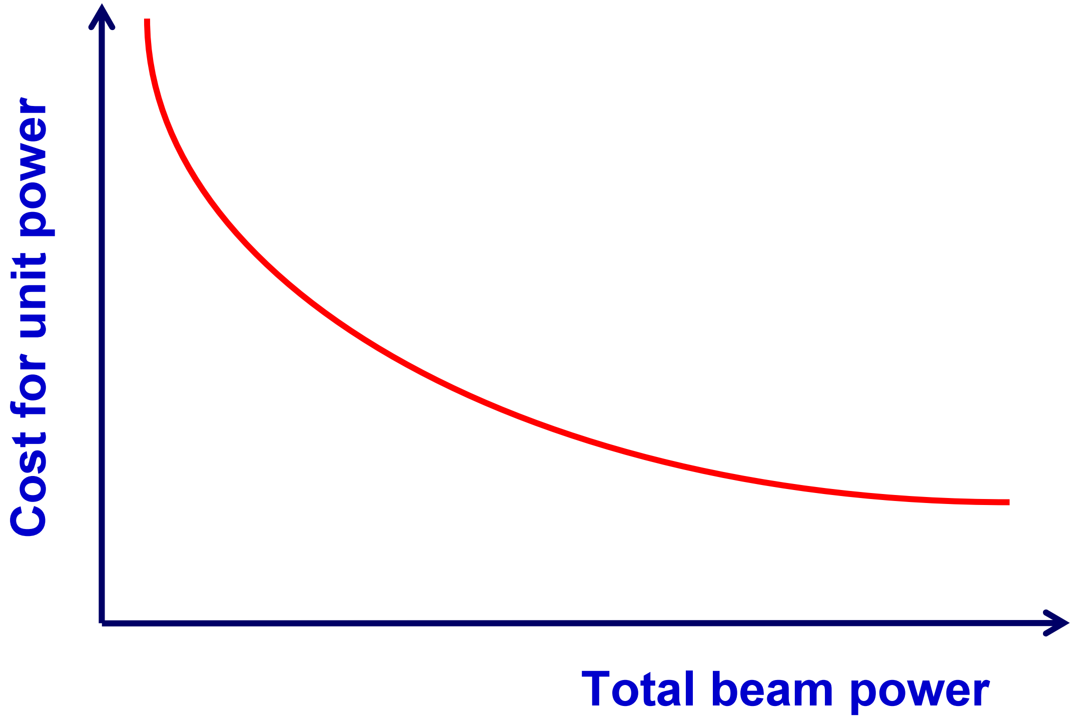
+. reduce cost ESP and Accelerator

Item	Pomorzany (Poland)	Sviloza (Bulgaria)	Remarks
Spray cooler	3%	2%	
Reaction Chamber	2%	3%	
Ammonia handling	3%	3%	
ESP	10%	32%	→15.4%(4M£)
Accelerator	25%	30%	→21.4%(8M$)
By-Products handling	20%	3%	
Civil Works & Others	37%	27%	
Total	100% (21M$)	100% (37.4M$)	

*** Bogdan Tymiński, Andrzej Pawelec, Economical Evaluation of Electron Beam Flue Gas Treatment, IAEA Consultants Meeting on "Radiation Processing of gaseous and Liquid Effluents" 7-10 September 2004, Sofia, Bulgaria*

****Feasibility Study " Installation Of Electron-beam Desulfurization And Denitration Plant In TPP "Sviloza"-jsc", 2006*

Unit cost for power of Accelerators



Beam Power	20kW	40kW	100kW	200kW	400kW	1MW*
Total Cost (M$)	0.5	0.8	1.0	1.5	2	2.2(?)
Unit Cost ($/W)	25	20	10	7.5	5	2.2(?)

** Target data in considering economics*

5. Summary

- The construction of a new "Industrial Electron Beam Flue Gas Purification plant" of "Sviloza" TPS is very important solution in Bulgaria.
- The industrial EB plants have proven the ability of the technology for efficient removal of SO_2 and NO_x from flue gases from coal combustion processes. The Sviloza EB Plant may achieve a high removal efficiency by simultaneous removal of SOx 90% and NOx 40%.
- EB technology is competitive to conventional ones from removal efficiency and economical points of views.
- Further development of EB technology can significantly reduce the costs of construction and operation of the plant, especially for accelerators and ESP with the technology development.

Thank You for your attention

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Q. Project Backgrounds ?

- Nov. 2003, Construction of EBFGT pilot plant at Maritza East 2 Power station in joint financing of IAEA, Bulgaria, and Japan.
- Feb. 2005, Thermal Power Station "Sviloza", located in the border to Romania on Danube river was chosen for construction of commercial Electron Beam Flue Gas Treatment plant.
- The project group of Bulgaria visited EBFGT facilities in Poland, China, Japan (former pilot facilities), and Korea (wastewater treatment facility).
- Mar. 2008, KEIC (Korean Export Insurance Cooperation), Bank Calyon, TPS "Sviloza" and EB TECH agreed on long term (3+7 years) loan and signed MOU on this agreement.
- May. 2008, EB TECH visited TPS "Sviloza" to discuss the documentation for KEIC and site survey for EBFGT construction. EB TECH received LOI (Letter of Intent) of purchasing accelerators from TPS "Sviloza".
- KEIC is still waiting some documents from TPS "Sviloza", Power Purchase Agreement with Bulgarian Government, and Financing information of other equipments except accelerator.
- Due to the global financial crisis, the financing is not promising now.