ACCELERATORS FOR THE ENVIRONMENT

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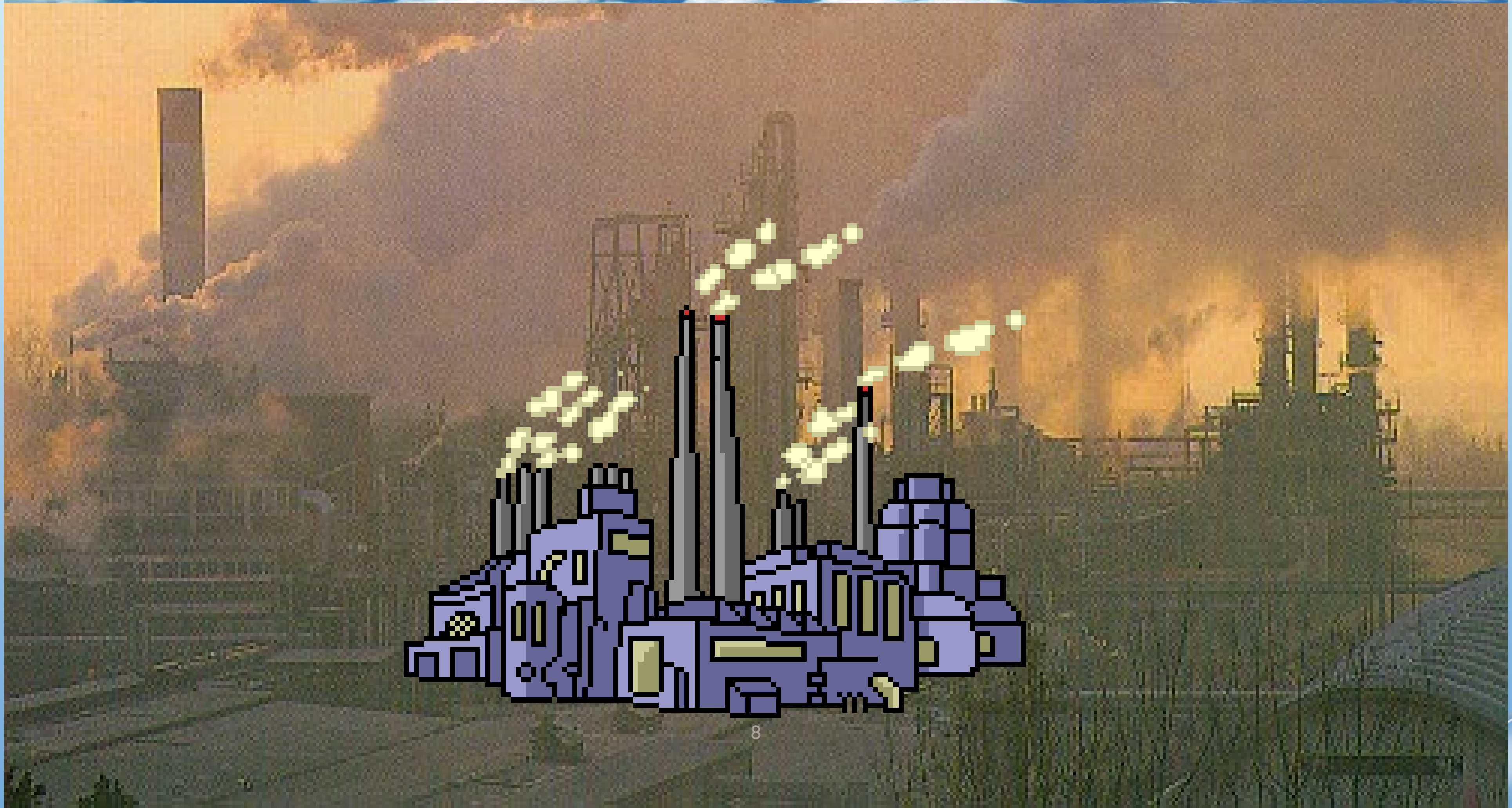
PARTICLE ACCELERATORS FOR THE ENVIRONMENT

AIR



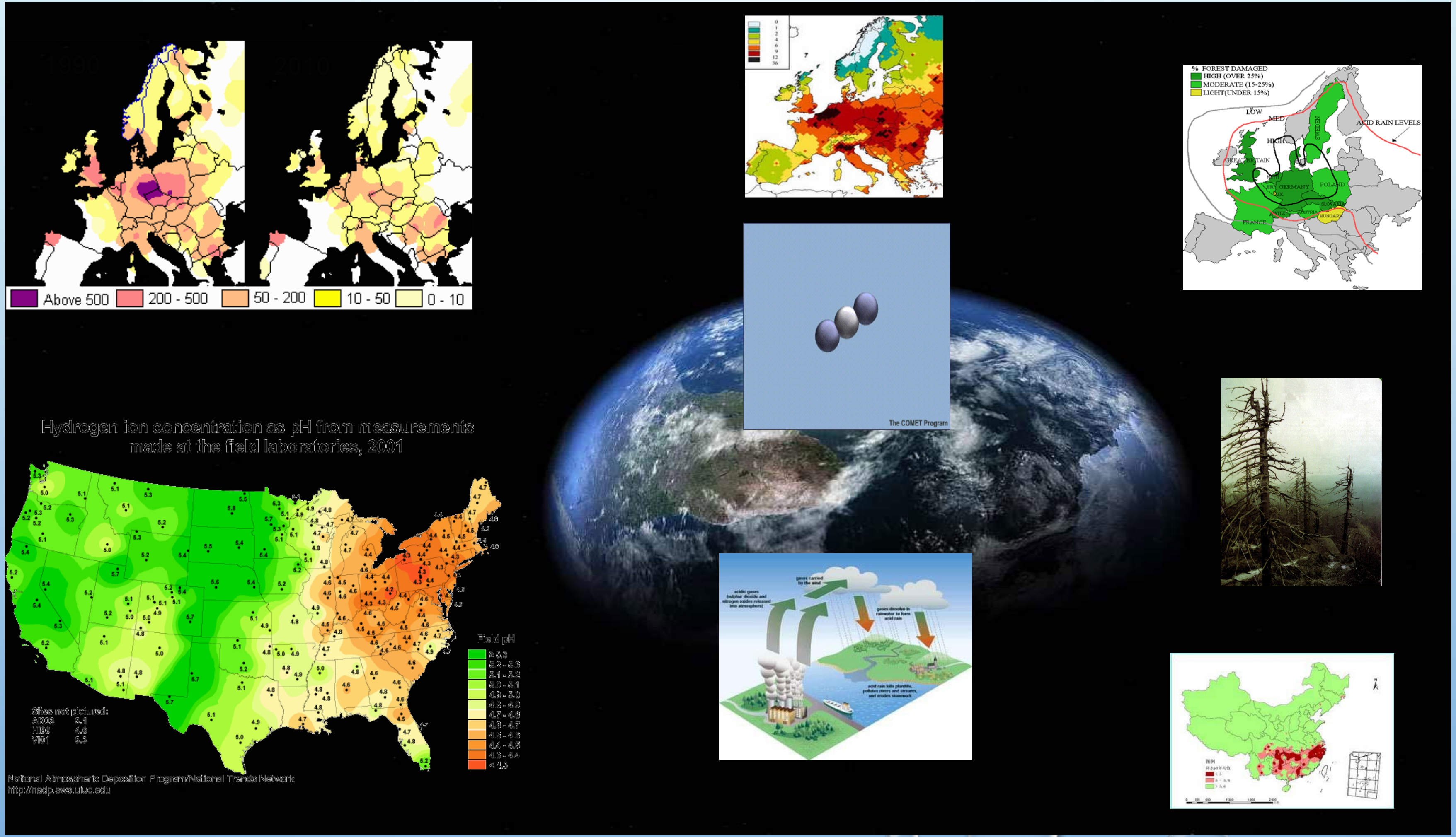
WHY THE ATMOSPHERE IS IMPORTANT ?

Mars
-53°C

Venus
450°C

Earth
13°C

ENVIRONMENTAL IMPACT OF AIR POLLUTION



GAS ELECTRON BEAM IRRADIATION

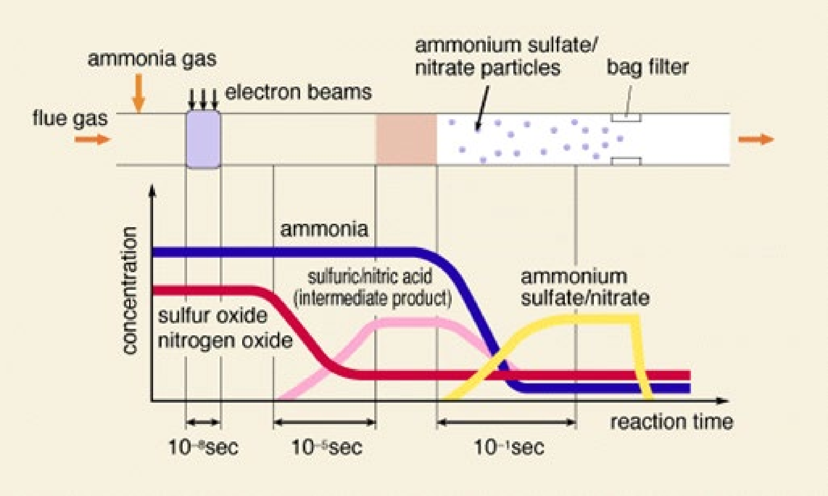
$$4.43N_2 \overset{100\ eV}{\rightsquigarrow} 0.29N_2^* + 0.885N(^2D) + 0.295N(^2P) + 1.87N(^4S) + 2.27N_2^+ + 0.69N^+ + 2.96e^- \quad (1)$$

$$5.377O_2 \overset{100\ eV}{\rightsquigarrow} 0.077O_2^* + 2.25O(^1D) + 2.8O(^3P) + 0.18\ O^* + 2.07O_2^+ + 1.23O^+ + 3.3e^- \quad (2)$$

$$7.33H_2O \overset{100\ eV}{\rightsquigarrow} 0.51H_2 + 0.46O(^3P) + 4.25OH + 4.15H + 1.99H_2O^+ + 0.01H_2^+ + 0.57OH^+ + 0.67H^+ + 0.06O^+ + 3.3e^- \quad (3)$$

$$7.54CO_2 \overset{100\ eV}{\rightsquigarrow} 4.72CO + 5.16O(^3P) + 2.24CO_2^+ + 0.51CO^+ + 0.07C^+ + 0.21O^+ + 3.03e^- \quad (4)$$

Process	Energy Dissipation (% of Input Power)
N_2 Vibrational	5.3
N_2 ($A^3\ \Sigma_u^+$)	1.1
N_2 ($B^3\Pi_g$)	1.8
N_2 Dissociation	24.0
N_2 Dissociative Ionization	13.9
N_2 Molecular Ionization	28.3
O_2 Vibrational	0.6
$O_2(a^1\Delta_g)$	0.7
O_2 Dissociation	8.3
O_2 Dissociative Ionization	2.9
O_2 Molecular Ionization	2.8
Others	10.3



REMOVAL OF NO_X

NO OXIDATION

$$NO + O(^3P) + M \rightarrow NO_2 + M$$

$$O(^3P) + O_2 + M \rightarrow O_3 + M$$

$$NO + O_3 + M \rightarrow NO_2 + O_2 + M$$

$$NO + HO_2^* + M \rightarrow NO_2 + OH^* + M$$

$$NO + OH^* + M \rightarrow HNO_2 + M$$

$$HNO_2 + OH^* \rightarrow NO_2 + H_2O$$

NO_2 REMOVAL

$$NO_2 + OH^* + M \rightarrow HNO_3 + M$$

$$HNO_3 + NH_3 \rightarrow NH_4NO_3$$

H. Namba: Materials of UNDP(IAEA)RCA Regional Training Course on Radiation Technology for Environmental Conservation TRCE-JAERI, Takasaki, September/October 1993, 99-104

REMOVAL OF SO_2

RADIOTHERMAL

$$SO_2 + OH^* + M \rightarrow HSO_3 + M$$

$$HSO_3 + O_2 \rightarrow SO_3 + HO_2^*$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$H_2SO_4 + 2NH_3 \rightarrow (NH_4)_2SO_4$$

THERMAL

$$SO_2 + 2NH_3 \xrightarrow{O_2,\,H_2O} (NH_3)_2SO_2$$

$$(NH_3)_2SO_2 \text{ --> } (NH_4)_2SO_4$$

1. H. Namba: Materials of UNDP(IAEA)RCA Regional Training Course on Radiation Technology for Environmental Conservation TRCE-JAERI, Takasaki, September/October 1993, 99-104

2. A.G. Chmielewski: Nukleonika **45(1)** (2000) 31

REMOVAL OF NO_X WITH AMMONIA

$$NO + N(^4S) \rightarrow N_2 + O$$

$$NO_2 + N(^4S) \rightarrow N_2O + O$$

$$N(^2D) + NH_3 \rightarrow NH^* + NH_2^*$$

$$NO + NH_2^* \rightarrow N_2 + H_2O$$

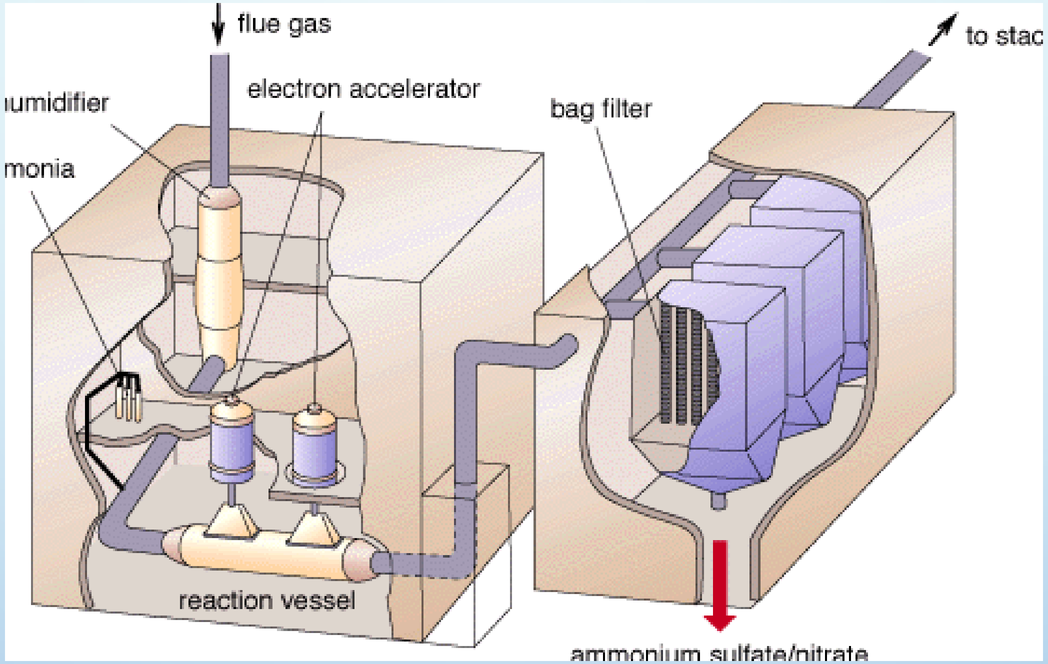
$$NO_2 + NH_2^* \rightarrow N_2O + H_2O$$

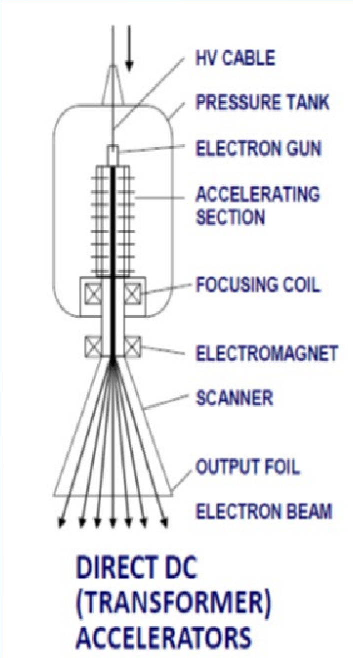
$$NO + NH^* \rightarrow N_2 + OH^*$$

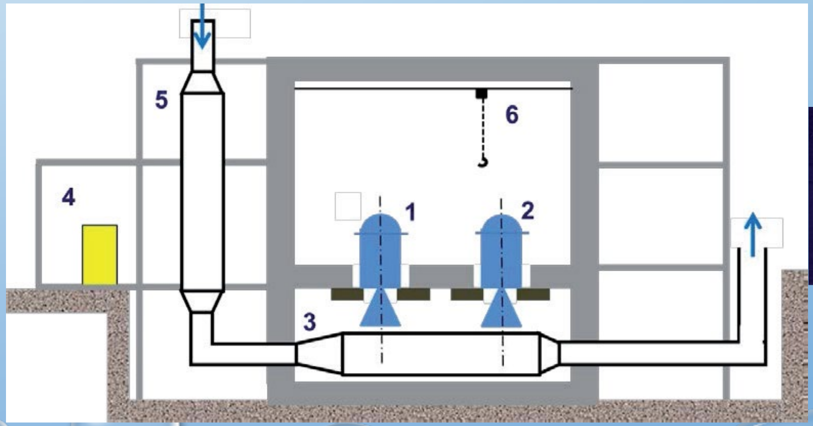
$$NO_2 + NH^* \rightarrow N_2O + OH^*$$

H. Namba: Materials of UNDP(IAEA)RCA Regional Training Course on Radiation Technology for Environmental Conservation TRCE-JAERI, Takasaki, September/October 1993, 99-104

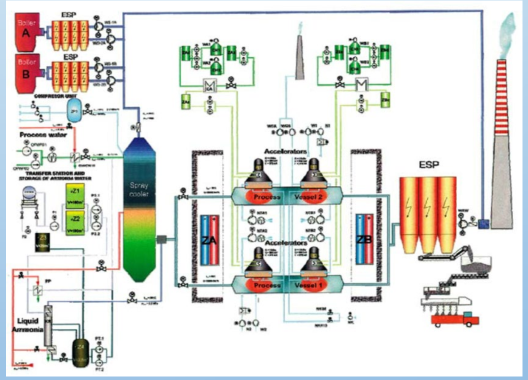
EPS KAWĘCZYN







EPS POMORZANY



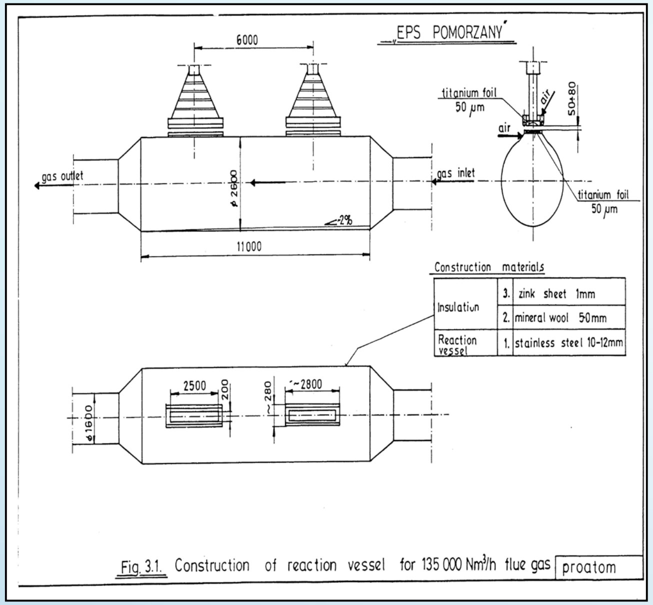
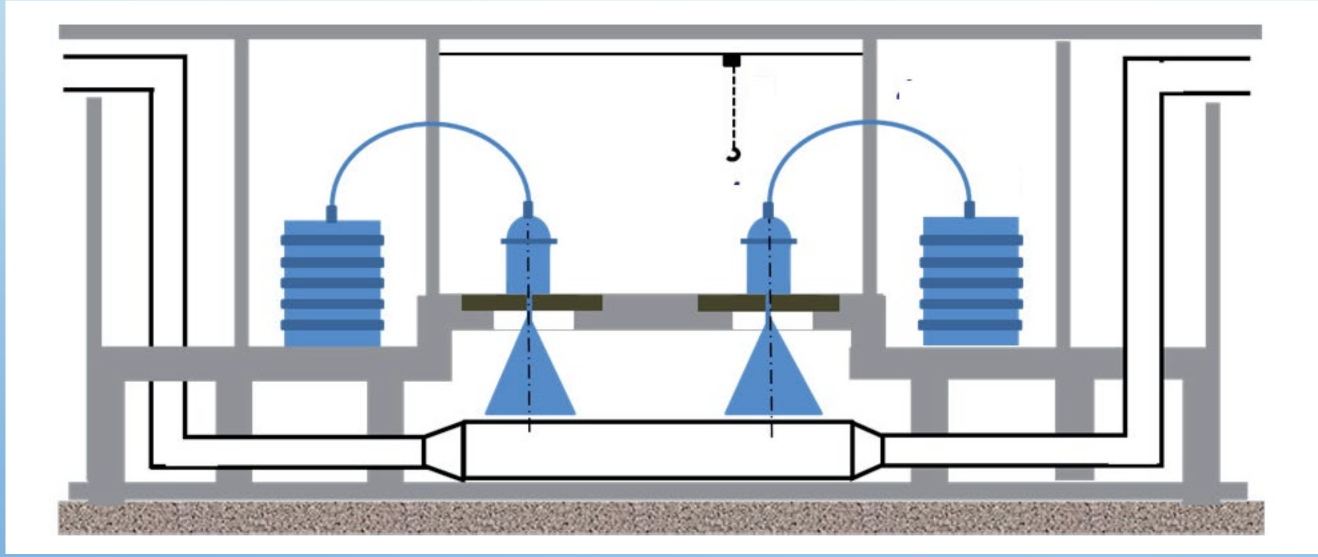
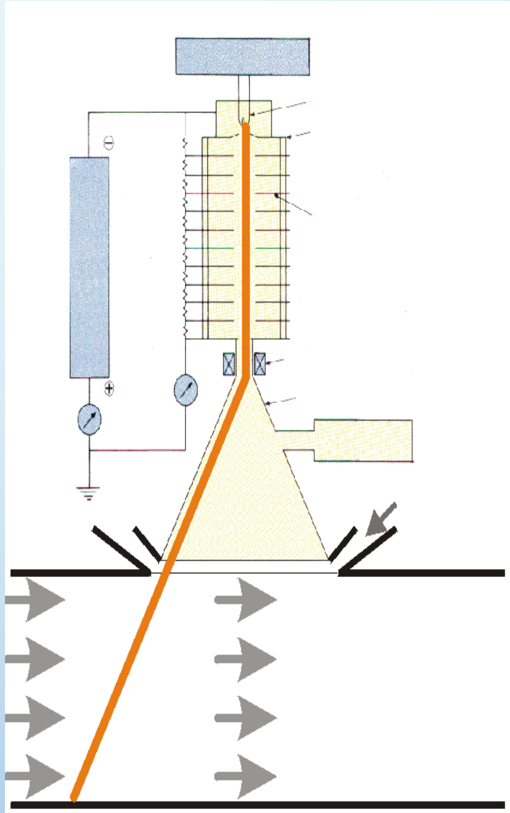


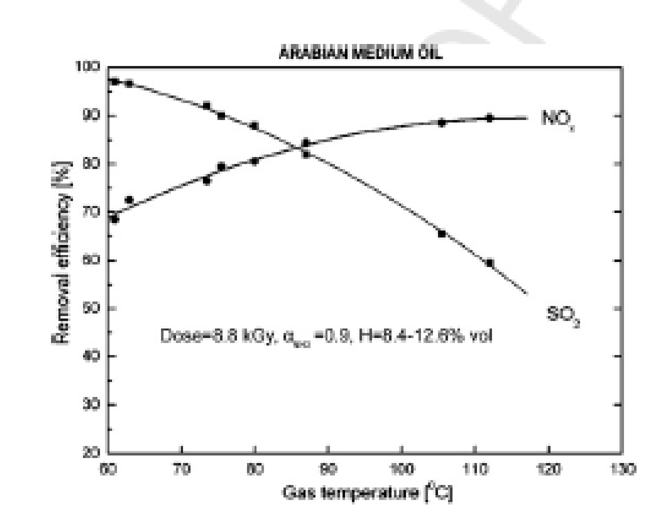
Fig. 3.1. Construction of reaction vessel for 135 000 Nm^3/h flue gas

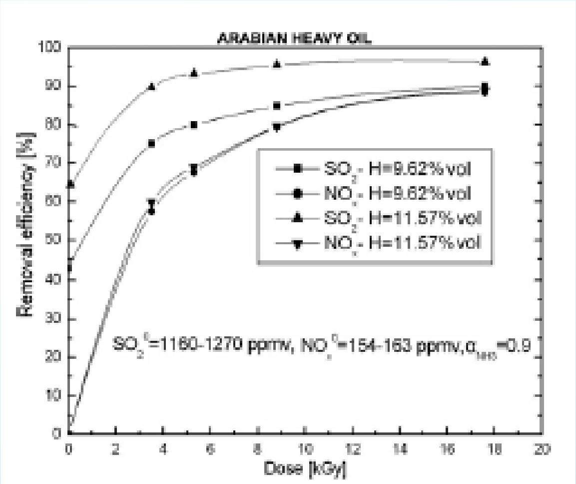


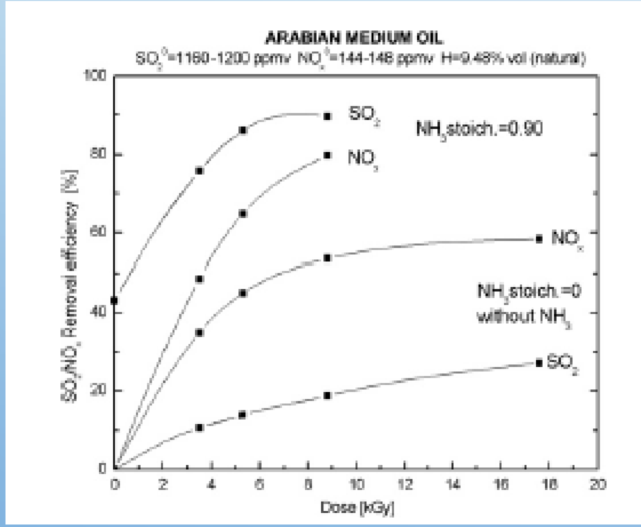


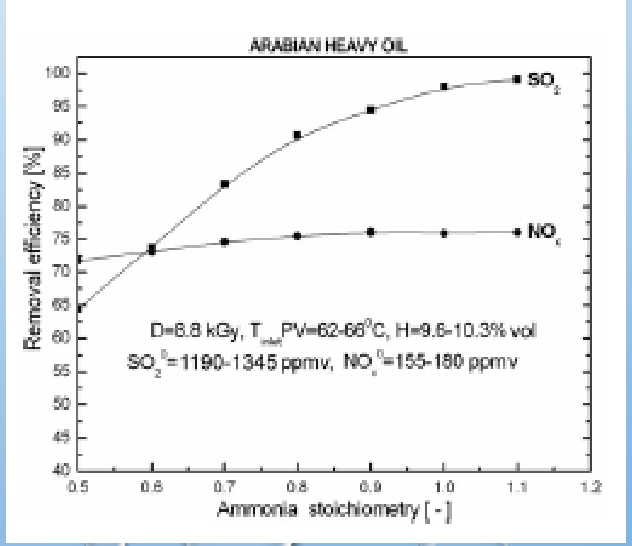
PROCESS VESSEL AND ELECTRON BEAM SCANNING

SO_x & NO_x REMOVAL









ESP BYPRODUCT COLLECTOR AND FERTILIZER

$$OH + CH_3CH_2OH = H_2O + CH_3CHOH, \quad k = 2.9 \times 10^{-12}, \tag{21}$$

$$CH_3CHOH + O_2 = CH_3CHO + HO, \quad k = 1.9 \times 10^{-11}, \tag{22}$$

$$OH + CH_3CHO = H_2O + CH_3CO, \quad k = 1.6 \times 10^{-11}, \tag{23}$$

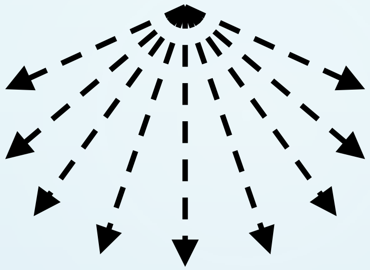
$$CH_3CO + O_2 = CH_3CO_3, \quad k = 5.0 \times 10^{-12}, \tag{24}$$

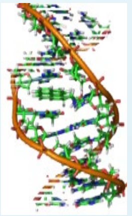
$$CH_3CO_3 + HO_2 = O_3 + CH_3COOH, \quad k = 1.0 \times 10^{-11}, \tag{25}$$

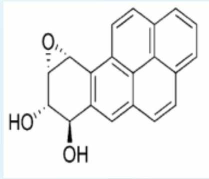
$$CH_3CO_3 + NO = CH_3 + CO_2 + NO_2, \quad k = 2.0 \times 10^{-11}, \tag{26}$$

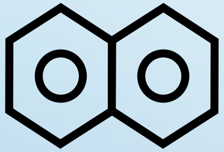
$$CH_3CO_3 + NO_2 = CH_3CO_3NO_2, \quad k = 1.2 \times 10^{-11}, \tag{27}$$

$$CH_3CHO + NO_3 = HNO_3 + CH_3CO, \quad k = 2.7 \times 10^{-15}. \tag{28}$$

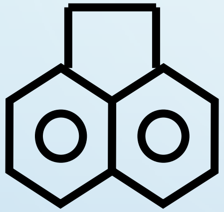




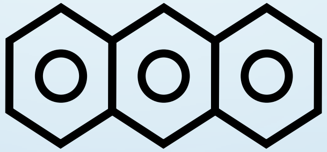




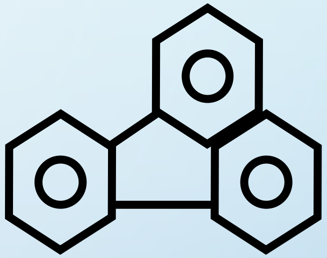
naphtalene



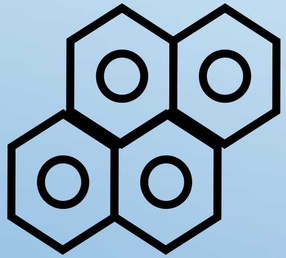
acenaphtene



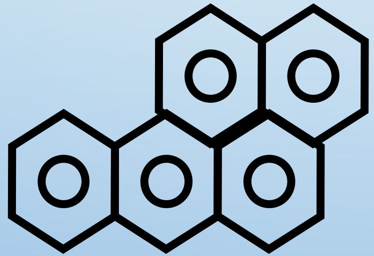
anthracene



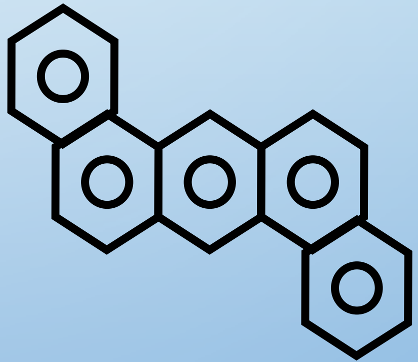
fluoranthene



pyrene



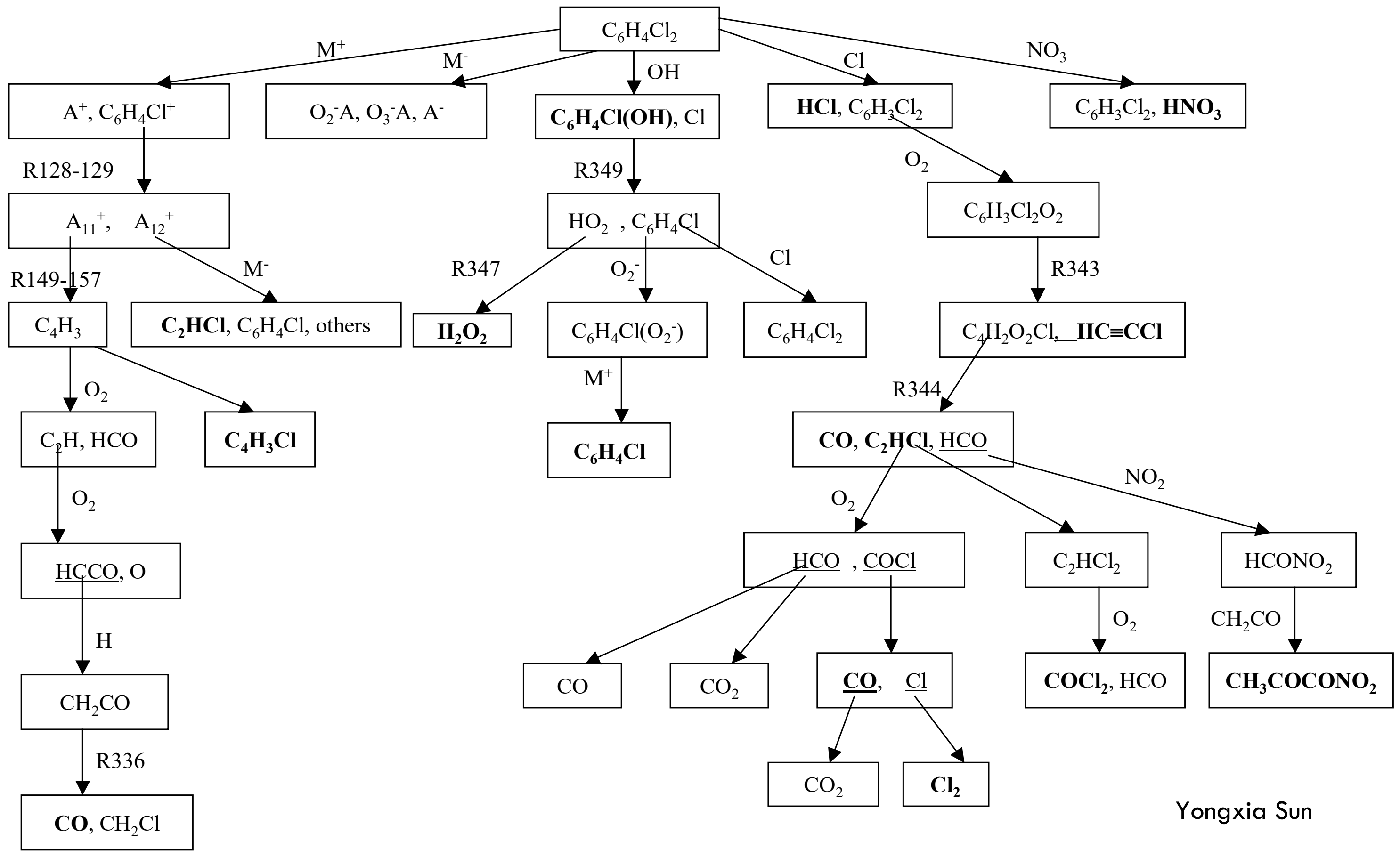
benzo(a)pyrene



dibenzo(a,h) anthracene

PAH treatment

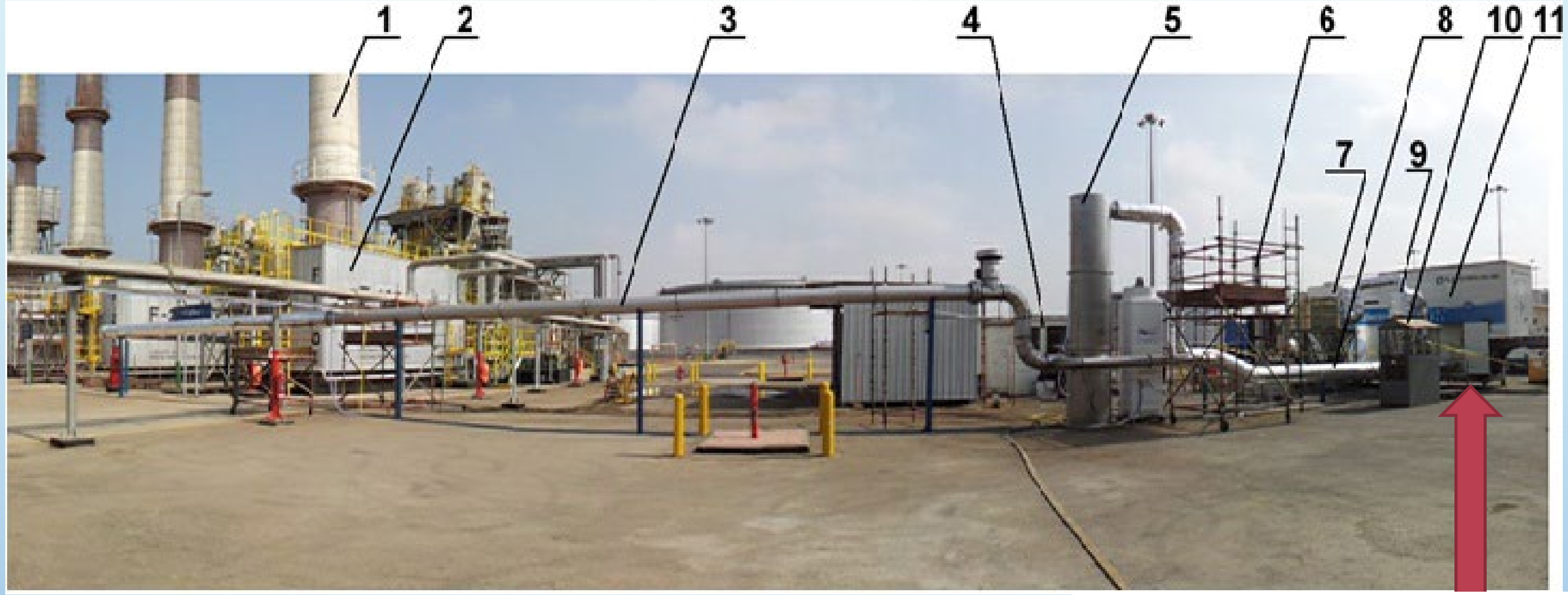
Scheme of reaction pathways of 1,4-DCB decomposition and products formation

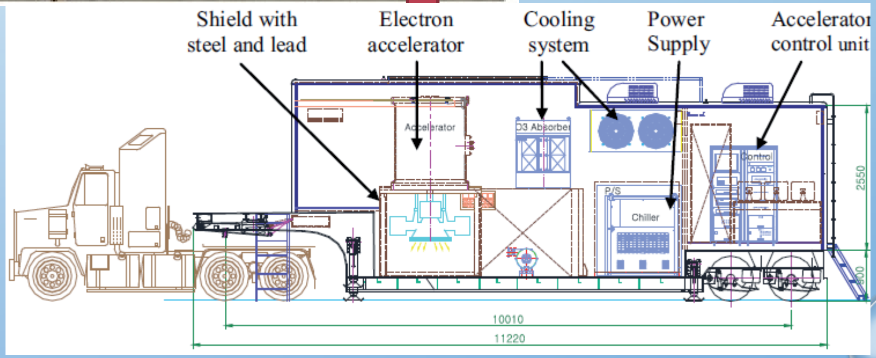


Yongxia Sun

OIL FIRED BOILER

GENERAL VIEW OF THE PILOT PLANT





1- stack of F 1001 boiler
2- boiler F1001
3-flue gas duct
4-control room
5-humidification unit
6-pilot plant stack

7 - bag filter
8 - insulated duct part
9 - cyclone
10 - ammonia storage and injection unit
11 - EB mobile unit

Andrzej G. Chmielewski, Bumsoo Han: Electron Beam Technology for Environmental Pollution Control, Top Curr Chem (Z) (2016) 374:68

EMISSIONS FROM DIESEL ENGINES MOUNTED ON SHIPS

❖Two stroke Diesel up to 81 MW

❖6 to 14 pistons (each 1820 dm^3)

❖Heavy oil

❖Consumption 250 ton fuel/day

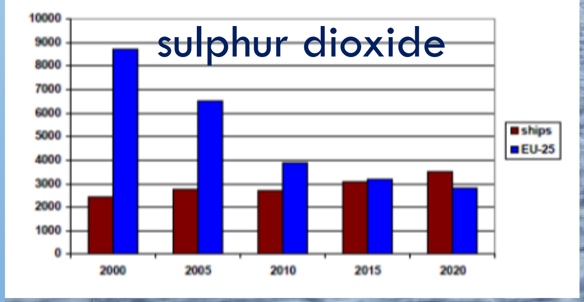
❖Typical off-gases –

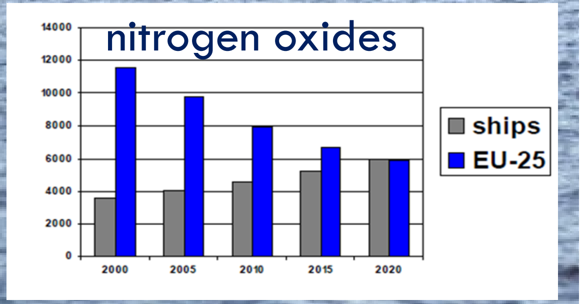
13 % O_2, 5.2% CO_2, 5.35% H_2O,

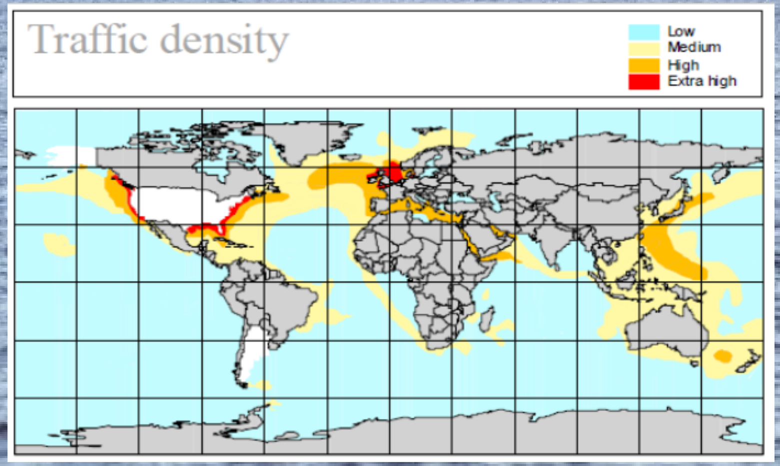
1500 ppmv NOx,

600 ppmv SOx,

60 ppmv CO,







HYBRID SOLUTION FOR NO REMOVAL IS BASED ON THE PROCESS CHEMISTRY

Back reactions !

$$NO + O = NO_2, \quad k = 3.0 \times 10^{-11},$$

$$NO_2 + O = NO_3, \quad k = 2.2 \times 10^{-11},$$

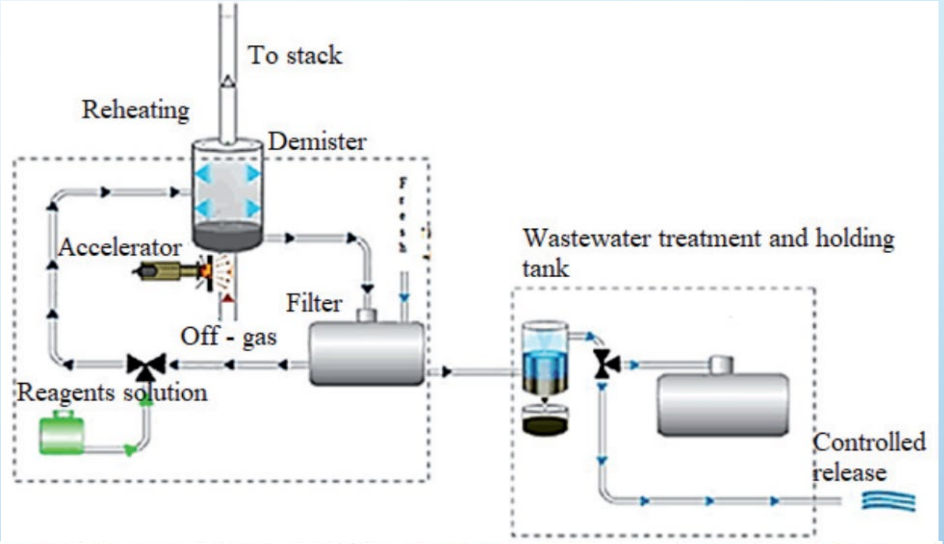
$$O + NO_2 = O_2 + NO, \quad k = 9.7 \times 10^{-12},$$

$$O + NO_3 = O_2 + NO_2, \quad k = 1.7 \times 10^{-11}.$$

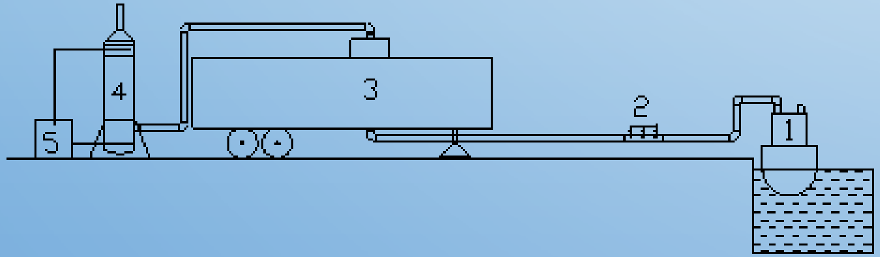
Critical reactions !

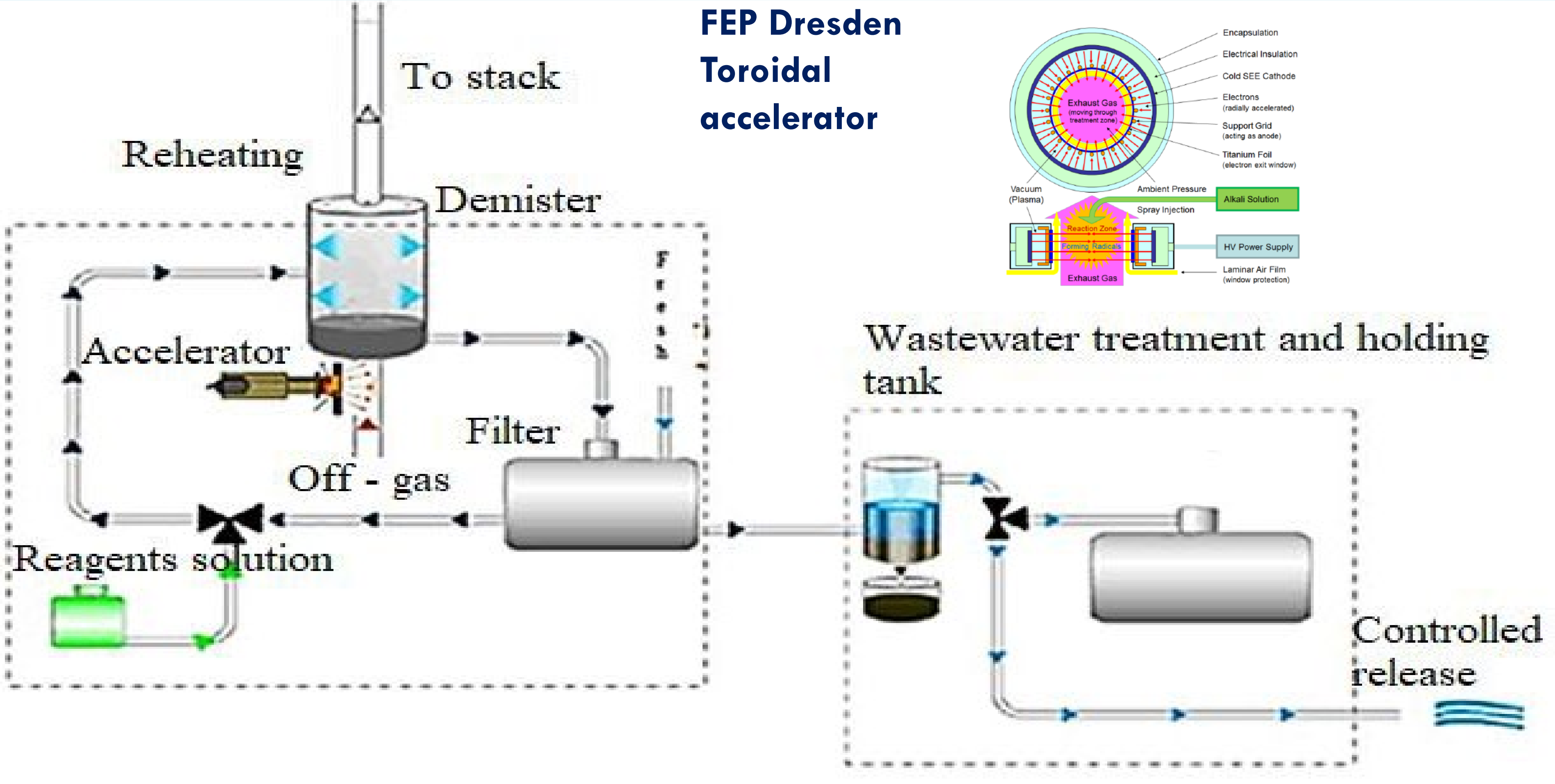
$$OH + NO = HNO_2, \quad k = 3.2 \times 10^{-11},$$

$$OH + NO_2 = HNO_3, \quad k = 6.0 \times 10^{-11},$$



FIELD TEST SHIPYARD RIGA, LATVIA

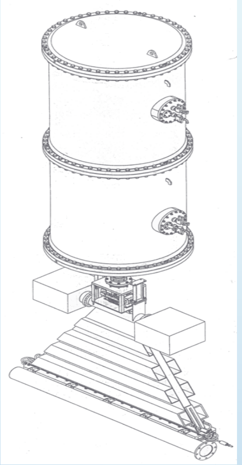


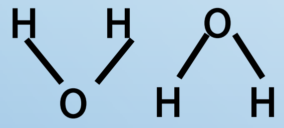


CONCEPTUAL SCHEME OF THE INSTALLATION USING EB TECHNOLOGY FOR SO_x AND NO_x REMOVAL AS APPLIED ON BOARD

WATER & SOIL

PRINCIPLES OF WASTEWATER TREATMENT WITH ELECTRON BEAM





→

e_{aq}

OH*

H*

H_2O_2

→

Harmful Organic in Waste water

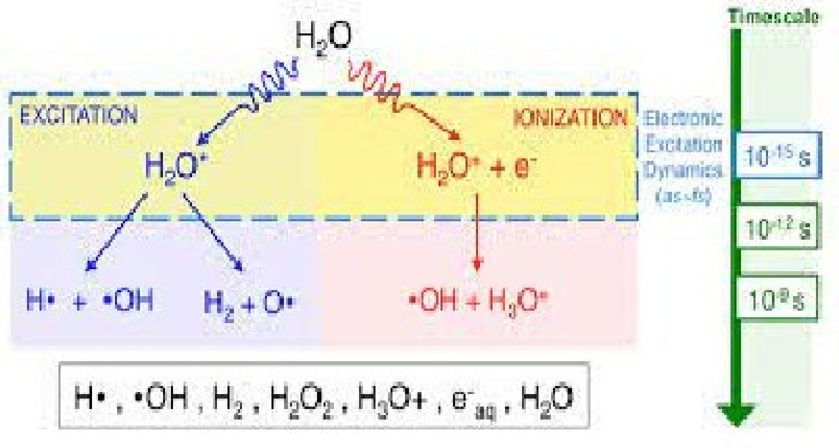
- Complete Decomposition → H_2O, CO_2
- Partial Decomposition
- Suspended solid
- Monomer to Polymerization

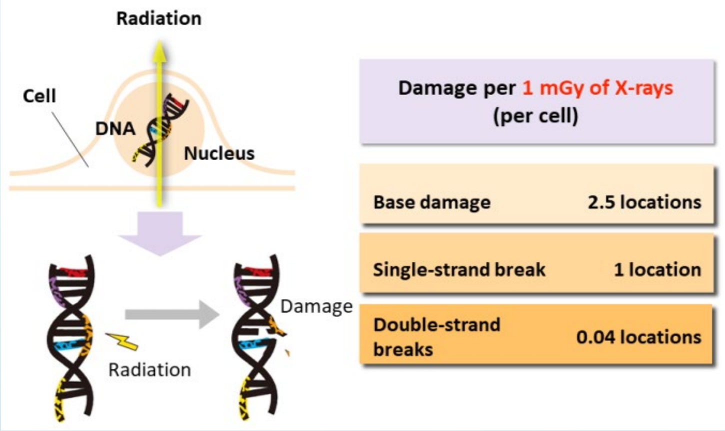
(Partial Decomposition, Suspended solid, Monomer to Polymerization) → **Coagulation**

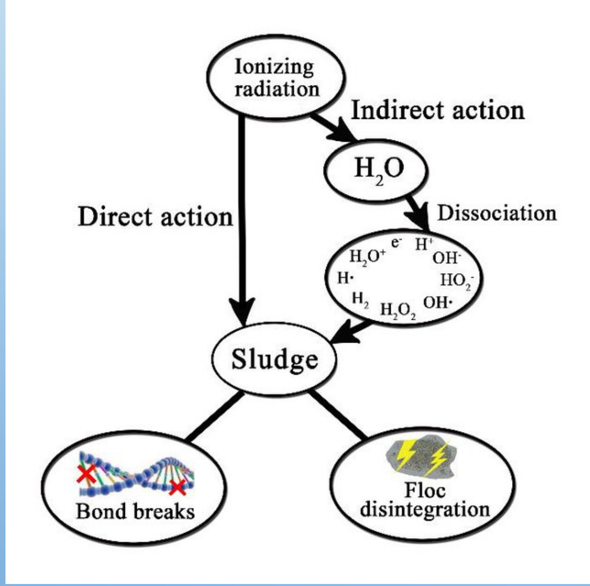
- Removal of Toxic group → **Bio-Treat**
- Removal of Color, Odor

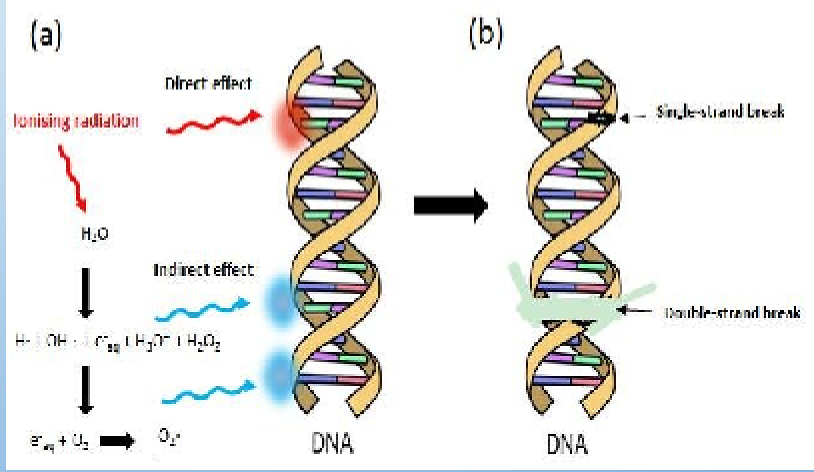
Water Molecule **Active Radicals**

PROCESS CHEMISTRY AND BIOCHEMISTRY









UV VS EB

UV-radiation of aqueous solutions	Electron beam irradiation of aqueous solutions
$O_3 \xrightarrow{h\nu} O + O_2$ $O + H_2O \longrightarrow H_2O_2$ $H_2O_2 \rightleftharpoons HO_2^{\ominus} + H^{\oplus}$ $O_3 + HO_2^{\ominus} \rightsquigarrow OH$ $H_2O_2 \xrightarrow{h\nu} 2\,OH$	$H_2O \xrightarrow{e^{\ominus}} \begin{cases} H_3O^{\oplus};\ OH^{\ominus} \\ \boxed{OH;\ e_{aq}^{\ominus};\ H} \\ H_2;\ O_2;\ H_2O_2 \end{cases}$ $O_3 + \begin{cases} e_{aq}^{\ominus} \\ H \\ H_2O_2 \end{cases} \rightsquigarrow OH$
Radiation is absorbed by solutes not water! Always just one source for OH (O_3 and H_2O_2, resp.).	Radiation is absorbed by water not by solutes! Two sources for OH (water radiolysis and O_3 decomposition).

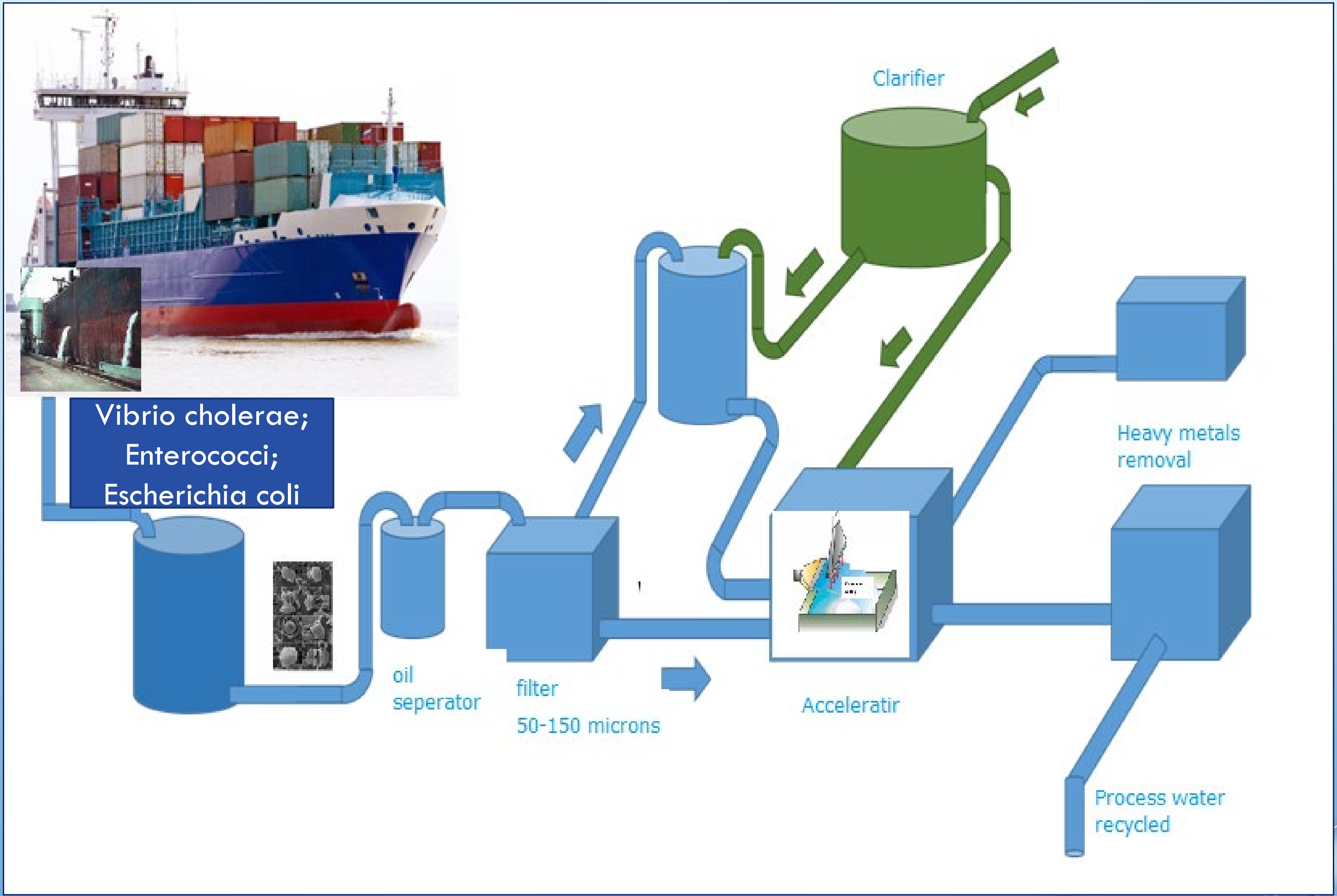
SHIPYARD REMONTOWA SA

BALAST WATER DISCHARGE

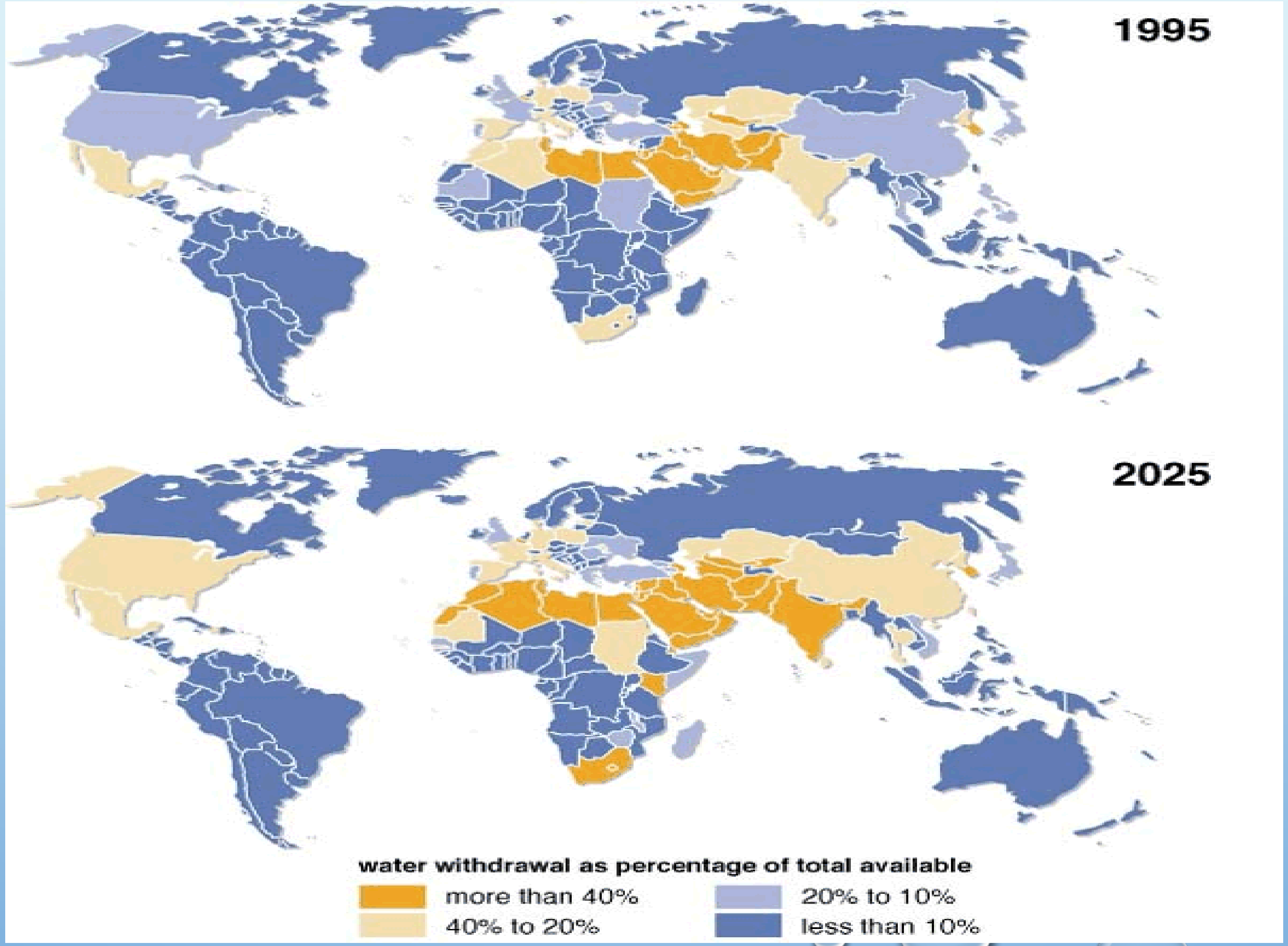
- BALLAST WATER DISCHARGE TYPICALLY CONTAINS A VARIETY OF BIOLOGICAL MATERIALS, INCLUDING PLANTS, ANIMALS, VIRUSES, AND BACTERIA. THESE MATERIALS OFTEN INCLUDE NON-NATIVE, NUISANCE, EXOTIC SPECIES THAT CAN CAUSE EXTENSIVE ECOLOGICAL AND ECONOMIC DAMAGE TO AQUATIC ECOSYSTEMS, ALONG WITH SERIOUS HUMAN HEALTH ISSUES INCLUDING DEATH.

- A) ***VIBRIO CHOLERAE*** (O1 I O139) LESS THAN 1 CFU (COLONY FORMING UNIT - CFU) PER 100 ML OR LESS THAN 1 CFU PER 1 GRAM (WET MASS) ZOOPLANKTON SAMPLE;
- B) ***ESCHERICHIA COLI*** LESS THAN 250 CFU IN 100 ML;
- C) ***ENTEROCOCCI*** LESS THAN 100 CFU IN 100 ML.

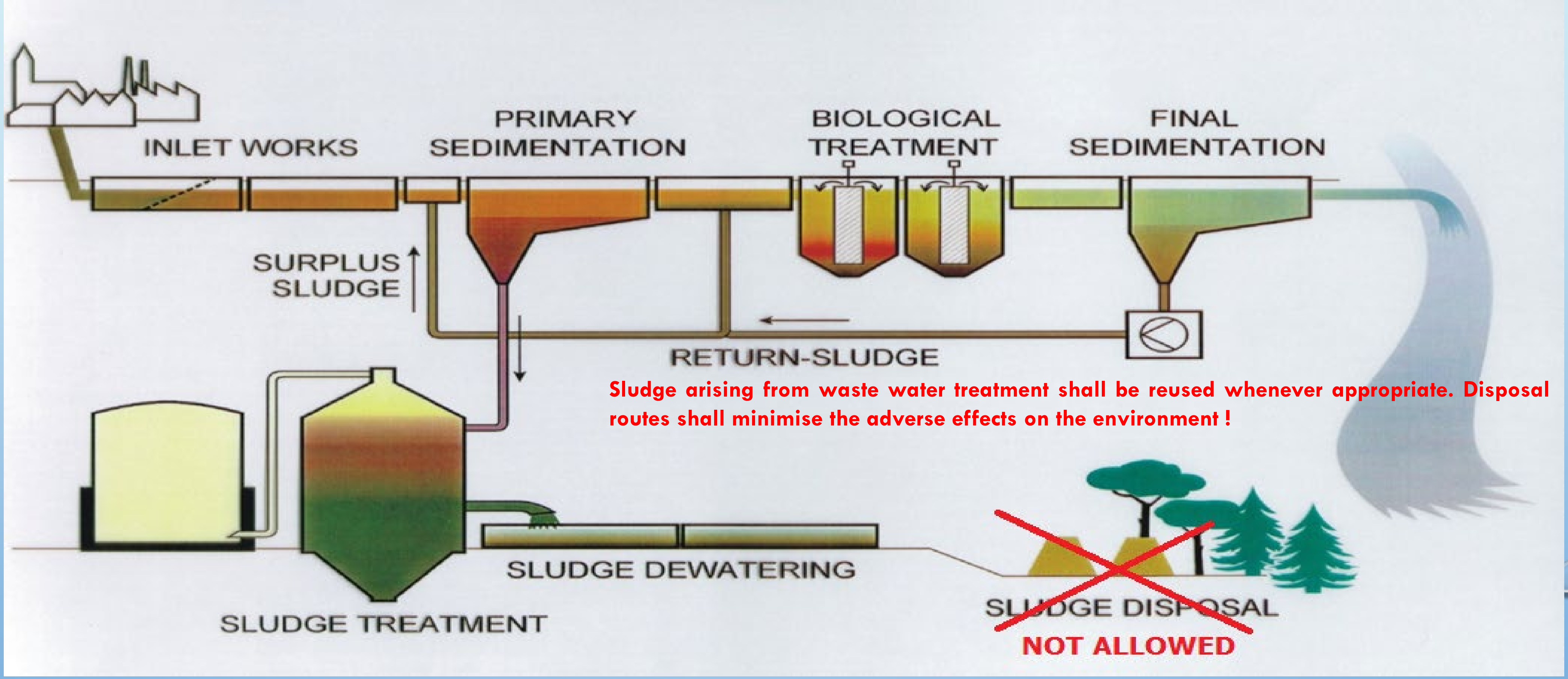
„GREEN" DOCK


Vibrio cholerae;
Enterococci;
Escherichia coli
Clarifier
Heavy metals removal
oil seperator
filter
50-150 microns
Acceleratir
Process water recycled

Severity of Water Shortage in the World



SCHEME OF A MUNICIPAL WATER TREATMENT PLANT



Sludge arising from waste water treatment shall be reused whenever appropriate. Disposal routes shall minimise the adverse effects on the environment !

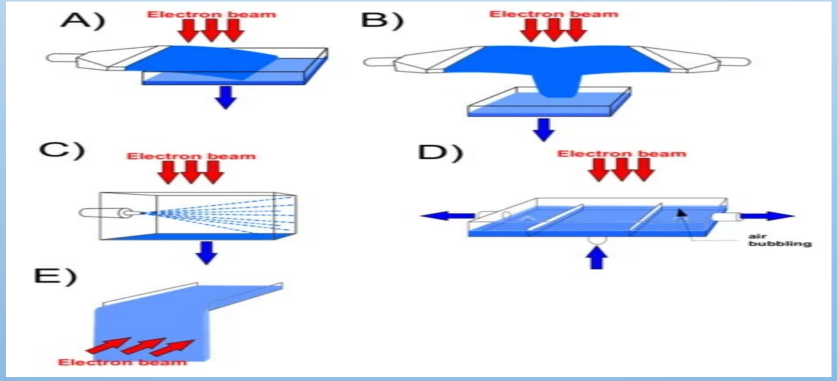
IS APPICATION OF ELECTRON ACCELERATORS FOR WASTEWATERTRETMENT IN INDUSTRIAL SCALE FEASBLE ?

PENETRATION OF ELECTRONS VS. ACCELERATING ENERGY

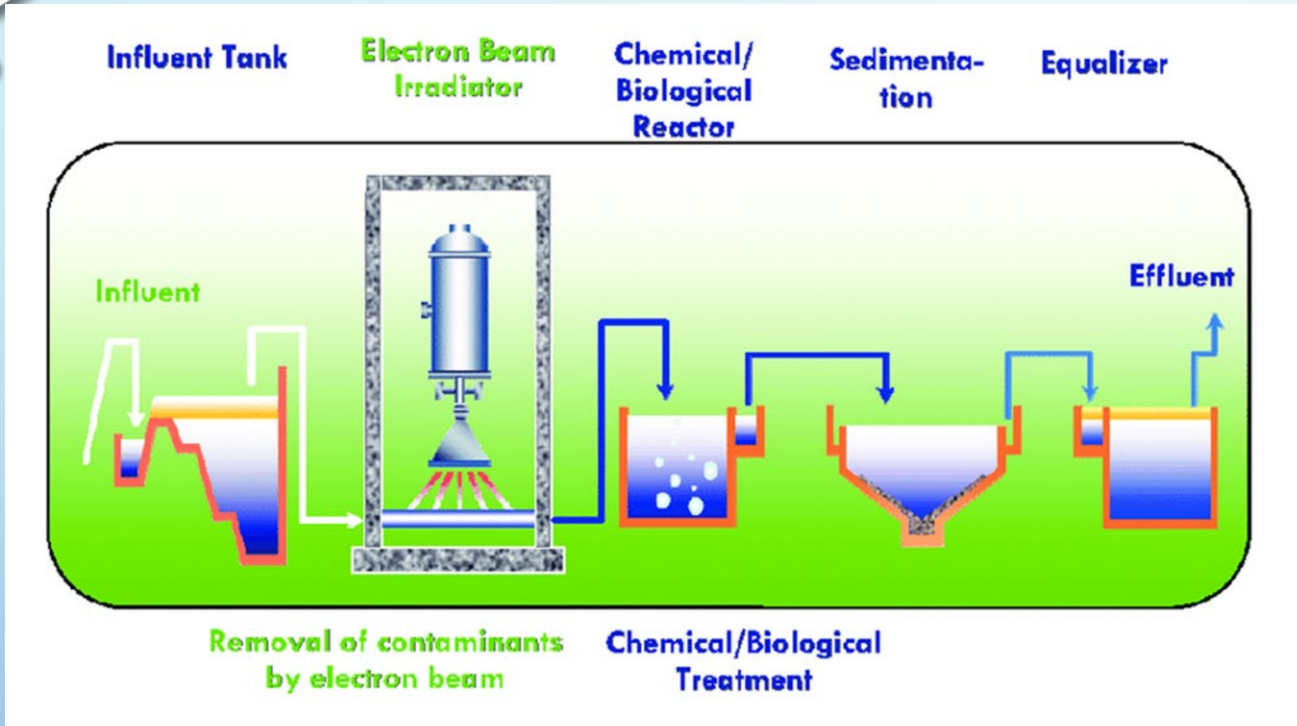
Electron Energy	Max. range in air	Maximum range in water
(MeV)	(m) (20°C, 1atm)	(mm)
10	43.1	49.8
1	4.08	4.37
0.1	0.13	0.14

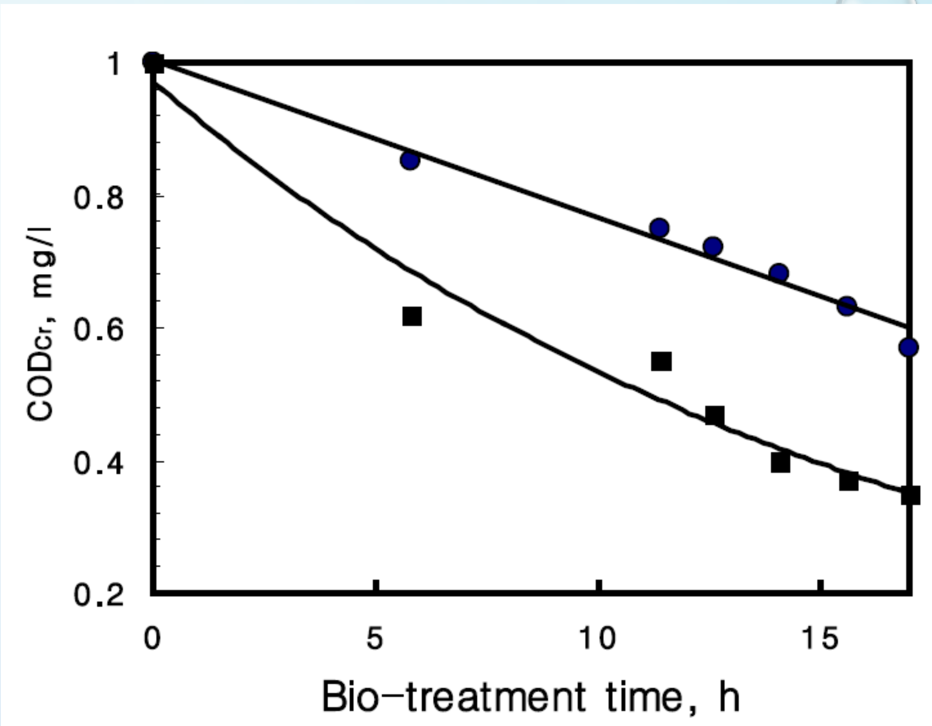
POWER OF ACCELERATORS APPLIED IN INDUSTRY

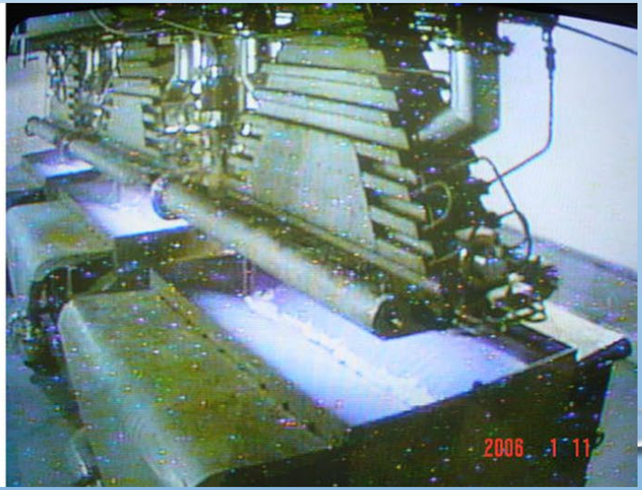
Plant	Beam energy	Power
	(keV)	kW
Flue gas, EC Kawęczyn, PL	600	2 x 50
Flue gas, EC Pomorzany,PL	600	4 x 300
Wastewater, Deagu, ROK	1000	400
Guanhua Knitting Factory, POk		7 x

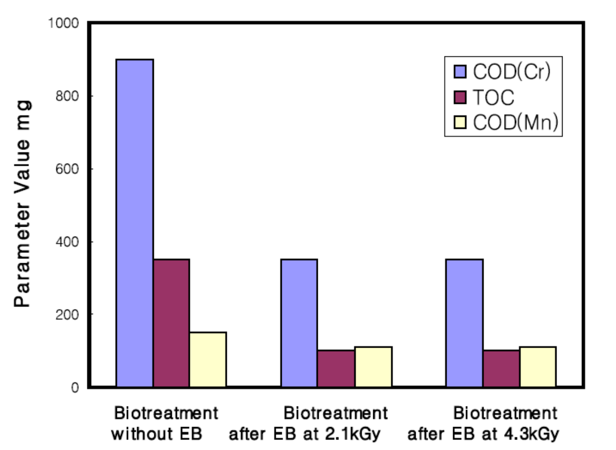


WASTEWATER EB TREATMENT PLANT ROK









WASTEWATER EB TREATMENT PLANT CHINA

30 000 m^3 / day recycling of the water in textile industry
(COD) of the wastewater dropped from 200 mg/L to less than 50 mg/L
the project will save 4.5 million tons of water annually.

PATOGENS TO BE REMOVED

PATHOGENIC BACTERIA ACCEPTABLE CONTENT

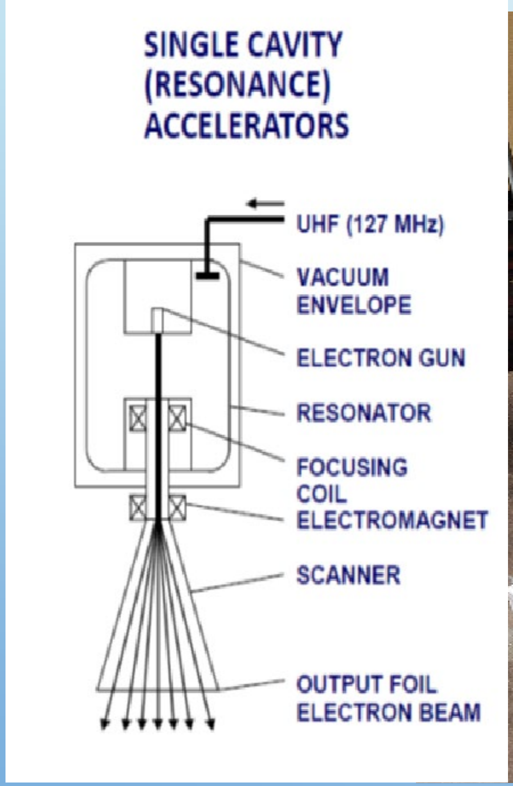
- **IN POLAND ONE PATHOGENIC BACTERIA SPECIES IS CONSIDERED: *SALMONELLA***
- **NONE LIVING CELLS OF *SALMONELLA* CAN BE DETECTED IN 100G SAMPLE OF MUNICIPAL SLUDGE**

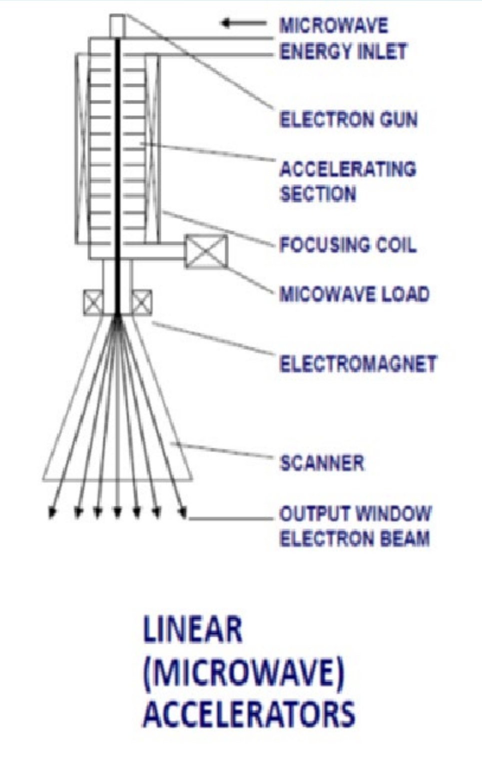
SPECIES OF PARASITES WHICH HAVE TO BE DETECTED:

- ***ASCARIS SP.* – HUMAN PARASITIC ROUNDWORM**
- ***TRICHURIS SP.* – HUMAN WHIPWORM**
- ***TOXOCARA SP.* – ANIMAL (MOSTLY CATS AND DOGS) PARASITIC WORMS**
- **PARASITES AND EGGS ACCEPTABLE CONTENT = 0**


FIS INSTALLATION USED FOR THE FLOW IRRADIATION OF SEWAGE SLUDGE CONNECTED TO AN ILU-6 ELECTRON ACCELERATOR.

SAMPLE OF SEWAGE SLUDGE SEALED IN A POLYETHYLENE BAG IRRADIATED BY AN ELEKTRONIKA 10/10 ELECTRON ACCELERATOR.



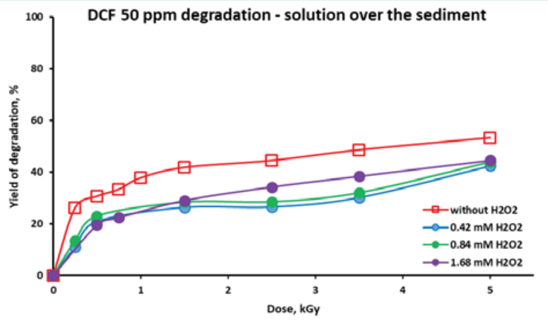


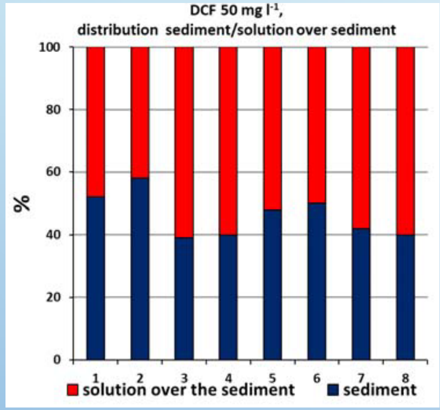
BACTERIA & LIVING EGGS OF HELMINTHS

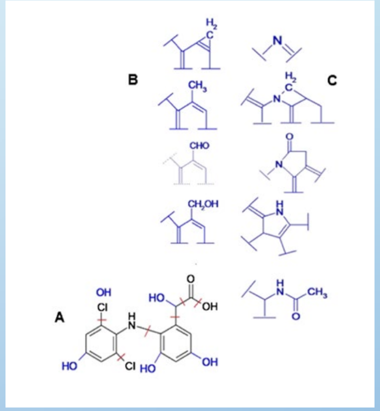
Dose (kGy)	Detected Species	Result (CFU)
0	*Escherichia coli*, *Salmonella* spp. *Clostridium perfringens*	6.2×10^4 9.2×10^2 1.1×10^2
2	*Escherichia coli*, *Salmonella* spp. *Clostridium perfringens*	9.8×10^3 1.3×10^2 0.9×10^2
3	*Escherichia coli*, *Salmonella* spp. *Clostridium perfringens*	1.4×10^2 0.4×10^2 ca.0.2×10^2
4	*Escherichia coli*, *Salmonella* spp. *Clostridium perfringens*	none detected none detected none detected
5	*Escherichia coli*, *Salmonella* spp. *Clostridium perfringens*	none detected none detected none detected

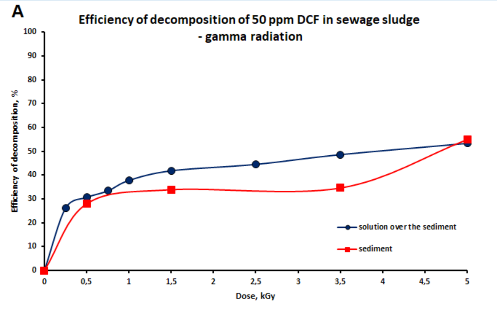
Dose (kGy)	Detected Species	Result (Number of Living Eggs)
0	*Ascaris* spp. *Trichuris* spp. *Toxocara* spp.	21 9 3
2	*Ascaris* spp. *Trichuris* spp. *Toxocara* spp.	16 4 1
3	*Ascaris* spp. *Trichuris* spp. *Toxocara* spp.	4 none detected none detected
4	*Ascaris* spp. *Trichuris* spp. *Toxocara* spp.	none detected none detected none detected
5	*Ascaris* spp. *Trichuris* spp. *Toxocara* spp.	none detected none detected none detected

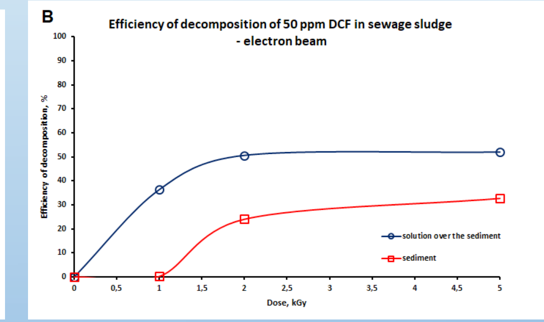
DECOMPOSITION OF DICLOFENAC IN SEWAGE FROM MUNICIPAL WASTEWATER TREATMENT PLANT USING IONIZING RADIATION











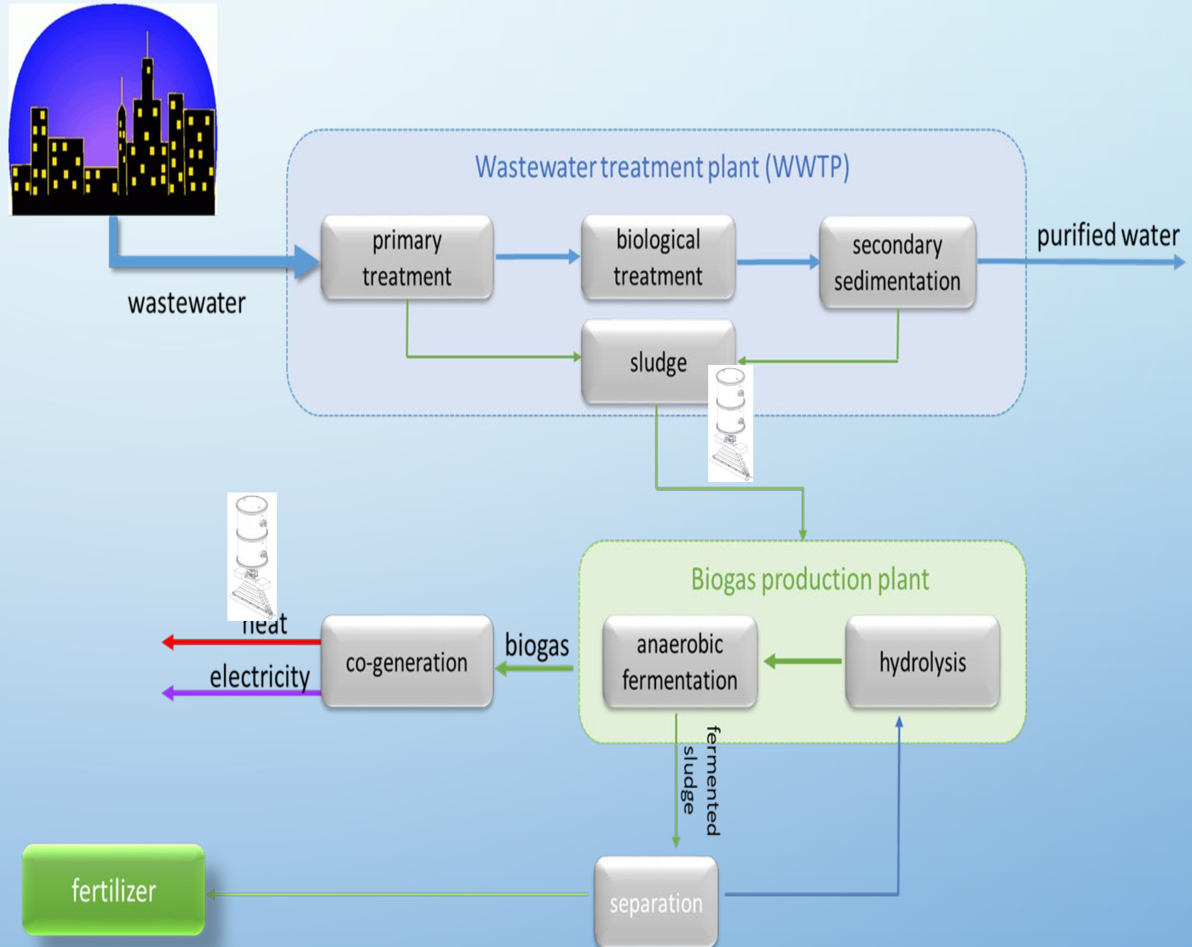
DCF is one of the most commonly used non-steroidal anti-inflammatory drugs (NSAID), and its average consumption is 0.33 ± 0.29 g/person/year

A. Bojanowska- Czajka NUKLEONIKA 2021;66(4):201-206

Hybryd biogas – EB system

Advantage of proposed solution:

- **Environmental friendly technology**
- Biogas production is **disposal of problematic wastes**
- Production of **renewable power through combined heat and power cogeneration**
- Production of microbiologically safe organic fertilizer **due to electron beam hygenization**
- Technology can be applied in any place with sufficient biomass resources while there is **no need for external electric energy supply**



Funding projects

iFAST

- I.FAST - Innovation Fostering in Accelerator Science and Technology, Grant Agreement No 101004730. & Ministry of Education and Science co-financing grant
- Tango 2 (TANGO2/341079/NCBR/2017) entitled "Plasma technology to remove NOx fromoff-gases" NCBiR/NCN
- INNOship „Eko dok" POIR.01.02.00-00-0007/18 "Design and verification on a pilot scale, environmentally friendly, integrated with the floating dock, the system of collection and treatment of ballast water and sludge from the ship and technological waters from the ship hull cleaning process, using ionizing radiation for the utilization of pollutants"NCBiR


THANK YOU FOR YOUR
ATTENTION !