ELECTRON BEAM ACCELERATORS FOR WATER POLLUTION CONTROL

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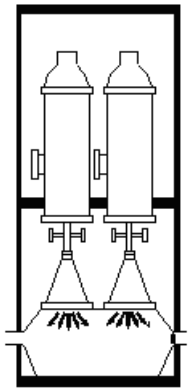
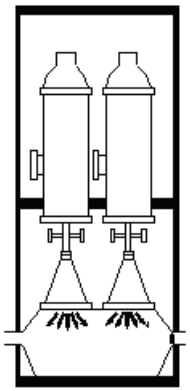




ROLE OF SHIP IN DEVELOPMENT

- **INTERNATIONAL TRADE AND COMMERCE**
- **EXPLOITING THE OCEAN RESOURCES**
- **BRIDGING INTERCONTINENTAL GAPS TO MAKE THE PLANET A FAMILY**
- **PURSUIT OF ADVENTURE LIKE THE ANTARCTICA & NORTH POLE MISSION**
- **DEFENCE**

LIFE IS UNTHINKABLE WITHOUT SHIPS.
BUT NO DEVELOPMENT IS POSSIBLE WITHOUT AFFECTING NATURE.

OUR ENDEAVOUR SHOULD BE DEVELOPMENT IN HARMONY WITH NATURE.

70% OF THE PLANET IS WATER AND IT IS THE MAJOR COMPONENT OF OUR ECOSYSTEM.

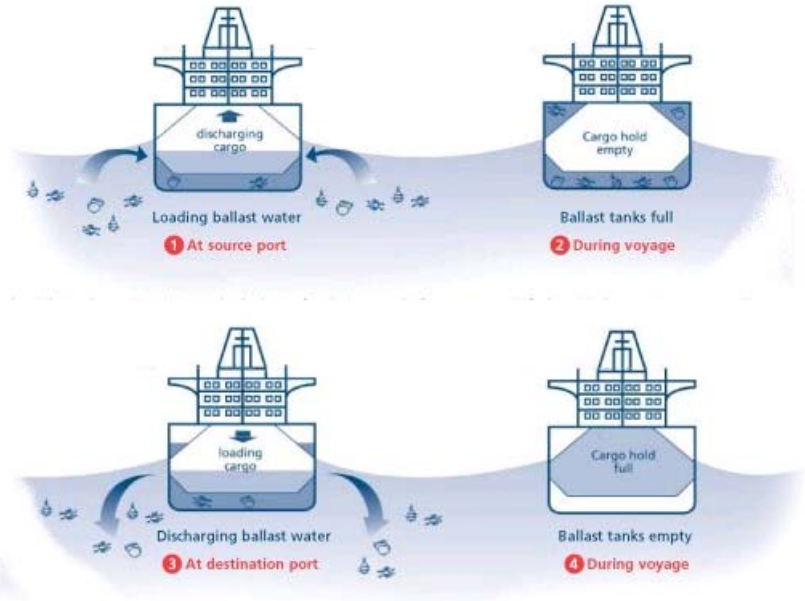
SOLUTIONS MAY LIE IN HIGH POWER ELECTRON BEAM

Ballast Water: Introduction

•Ballast Water is used to as stabilizing weight when an empty vessel travels from one port to another

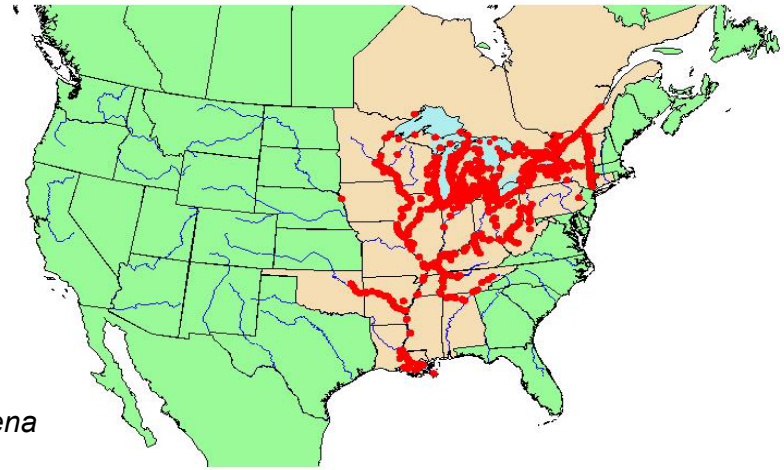
•Water is significantly easy to handle compared to other forms of ballast as sand bags, deadweights etc

•The problem arises as ships discharging ballast water can act as a vector to transport non native species from one location to another



•It is estimated that 3-5 billion tons of ballast water is exchanged every year acting as vector for over 7000 aquatic species. While most species do not survive the ballasting, transport and deballasting, those which do pose a danger to the host environment

Invasion of the species



In the USA, the European Zebra Mussel *Dreissena polymorpha* has infested over 40% of internal waterways, especially the Great Lakes area which is known for its unique species

Other examples of invasive non native species include:

- Asian kelp *Undaria pinnatifida*: an asian species invading southern Australian waters and displacing native species
- Microscopic, 'red-tide' algae (toxic dinoflagellates) which when consumed by shellfish like oysters render the shellfish unfit for human consumption
- North American jellyfish *Mnemiopsis leidyi* reaching high densities in the Black sea leading to the collapse of local fishing industry

Open Ocean Exchange

- The most prevalent method for preventing invasion of species through ballast water is based on the assumption that coastal organisms are not able to survive in deep oceans and vice versa due to differences in pH, salinity and temperature

- Methods for carrying out open sea exchange:
  - Sequential (empty/refill) exchange
  - Flow through of tanks

Shortcomings of the current methods:

- Open Ocean exchange can't always be preformed due to turbulent weather conditions
- Exchange of ballast in the ocean is detrimental to the ships hull as it induces high and uneven stresses in the hull
- Residual coastal organisms remain in the ballast tanks even after open sea exchange

BEAM PARAMETERS

- **ENERGY: FEW HUNDRED keVs TO 10 MeV**
- **CURRENT: FEW TENS OF MILLIAMPS TO FEW HUNDRED MILLIAMPERES**
- **SURFACE MODIFICATION APPLICATION: FEW HUNDRED keV IS SUFFICIENT**
- **FLUE GAS TREATMENT:**
- **LOW DENSITY MEDIUM (800 keV IS OK)**
- **HIGH BEAM POWER OF 1MW**
- **WASTEWATER TREATMENT**
- **RANGE OF 1 MeV ELECTRON IN WATER AROUND 4 mm**
- **WATER DELIVERY CAN BE FROM A JET**
- **FEW HUNDRED KILOWATTS ARE REQUIRED TO HANDLE LARGE VOLUME**

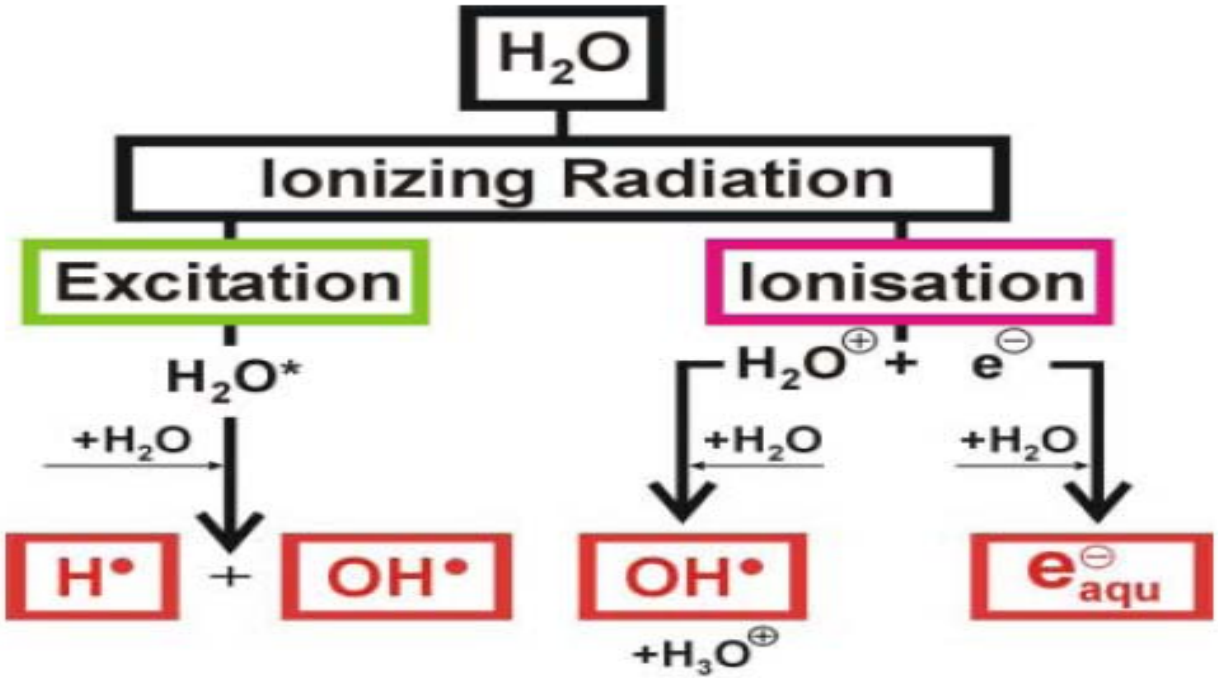
RADIATION DOSE DEPENDS ON APPLICATION

MEASURED IN GRAY, 1 Gy MEANS 1J/kg

TREATMENT OF WASTE WATER

- **CONTAMINATED/WASTEWATER SOURCES**
- **MUNICIPAL SEWAGE WASTEWATER**
- **WASTEWATER FROM TEXTILE AND PAPER MILLS**
- **GROUND WATER CONTAMINATION BY PETROLEUM**
- **OBJECTIVE**
- **REMOVAL OF TOXIC ORGANIC COMPOUND**
- **REMOVAL OF METALS LIKE Hg, Cd, Pb etc.**
- **REMOVAL OF COLOUR, ODOUR, FOAM & TURBIDITY**
- **REMOVAL OF ACIDITY**
- **REMOVAL OF HARMFUL BACTERIA**
- **PROCESS**
- **GENERATION OF OH, H & HYDRATED ELECTRON (e_{aqu}^-)**
- **OXIDATION WITH OH RADICAL**
- **REDUCTION WITH e_{aqu}^-, H**

RADIOLYSIS OF WATER



✓ **PRODUCTION OF LARGE NO. OF OH RADICALS BY INTERACTION OF EB WITH WATER**

REF: P. Gehringer, IAEA TECDOC-1487

CONVENTIONAL OXIDATION PROCESS

OH RADICAL PRODUCTION BY UV AND OZONE

- $O_3 \xrightarrow{h\nu} O + O_2$
- $H_2O + O = H_2O_2$
- $H_2O_2 \rightarrow HO_2^- + H^+$
- $O_3 + HO_2^- = OH$
- $H_2O_2 \xrightarrow{h\nu} 2\ OH$

OH RADICAL PRODUCTION DEPENDS ON CONCENTRATION OF SOLUTE (OZONE)

LESS NO. OF OH RADICAL PRODUCTION

COMBINED EFFECT OF ELECTRON BEAM AND OZONE

- $O_3 + (e_{aqu}^-, H, H_2O_2) \rightarrow OH$

e_{aqu}^- IS CONVERTED TO OH RADICALS

✓ **THIS IS IMPORTANT WHERE THE HYDRATED ELECTRONS ARE SCAVENGED BY COMPETING RADICALS**

✓ **NOW THERE ARE TWO SOURCES OF OH RADICAL 1) RADIOLYSIS OF WATER 2) DECOMPOSITION OF OZONE**

EXPERIMENTS ON DYEING WASTEWATER AT DAEGU, SOUTH KOREA

PLANT PARAMETERS

DISCHARGE OF WASTE WATER: 1000 m^3/day
PROCESS: EB TREATMENT + BIOLOGY

ACCELERATOR: 1 MeV, 40 kW (3 kGy DOSE)
MAIN IMPURITIES: TEREPTHALIC ACID & ETHYLENE GLYCOL

RESULTS

ENHANCEMENT OF BIODEGRABILITY
REDUCED CONSUMPTION OF CHEMICALS

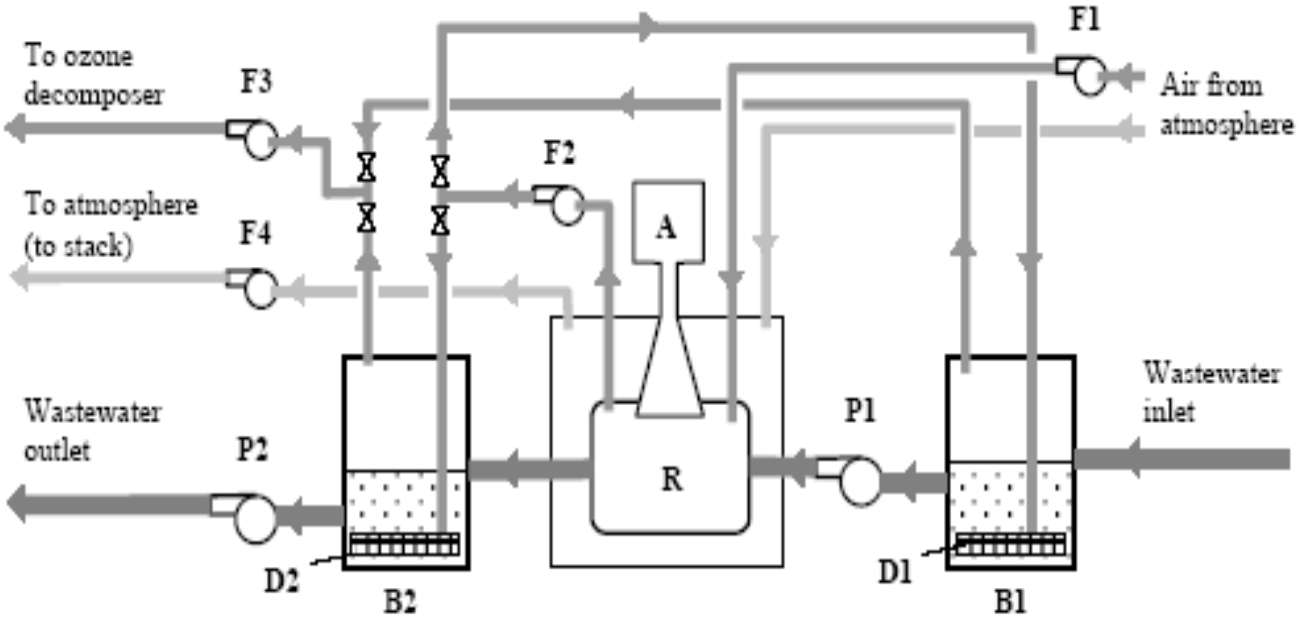
ECOFRIENDLINESS TESTED WITH SURVIVALITY OF DAFINA MAGNA

EFFICIENT COLOUR REMOVAL FOR COTTON & TERECOTTON

INDUSTRIAL PLANT CONSTRUCTION

CAPACITY: 10,000 m^3/day , CAPITAL COST: 5 MILLION US$

EB WATER TREATMENT PLANT AT DAEGUE

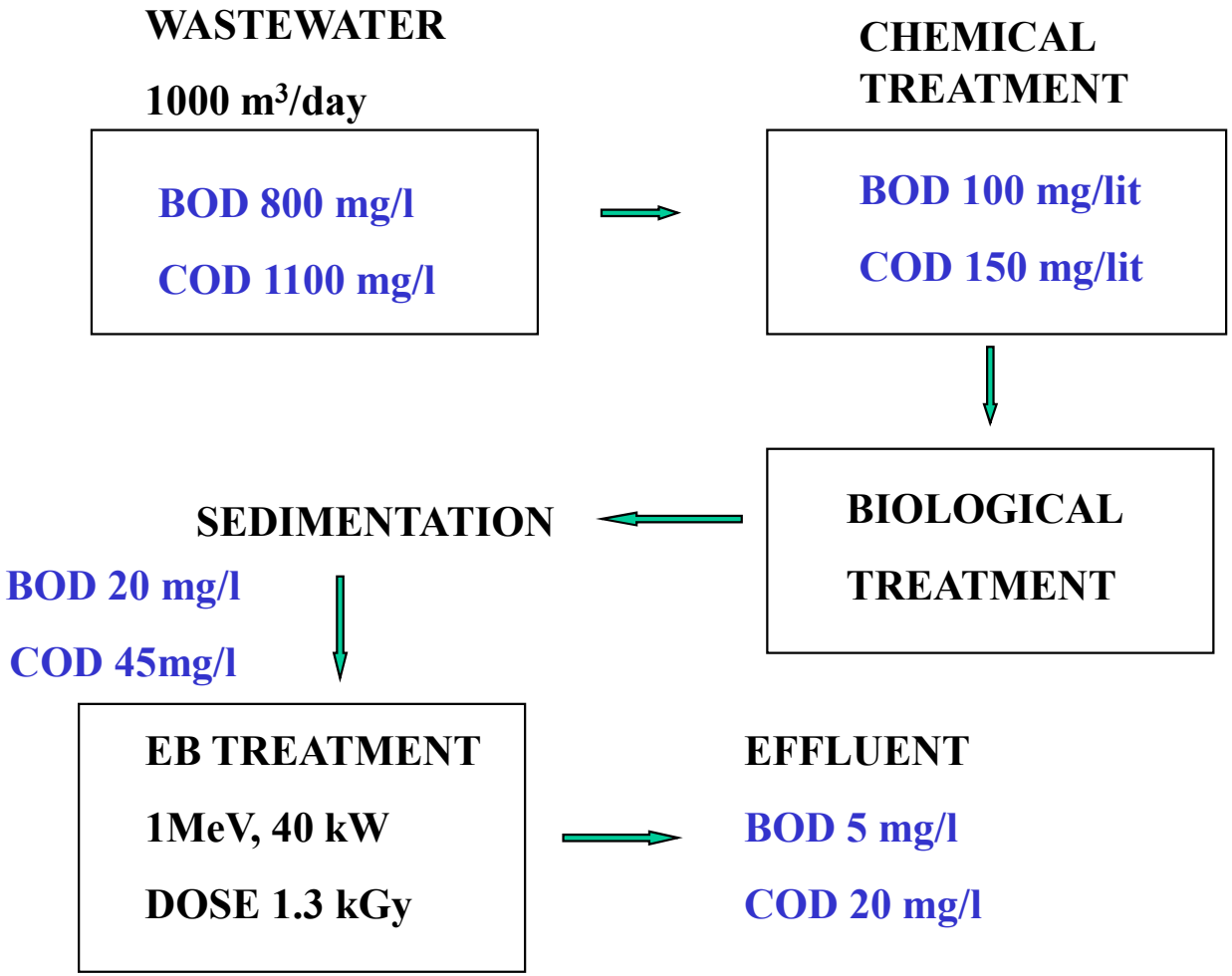


P1 & P2 PUMPS, B1 & B2, BASINS, D1& D2 DIFFUSERS, R PROCESS VESSEL , A: ACCELERATOR OF RATING 1 MeV, 400 kW

✓ **UTILIZATION OF BEAM PRODUCED OZONE**

REF: B. HAN, IAEA TECDOC-1386

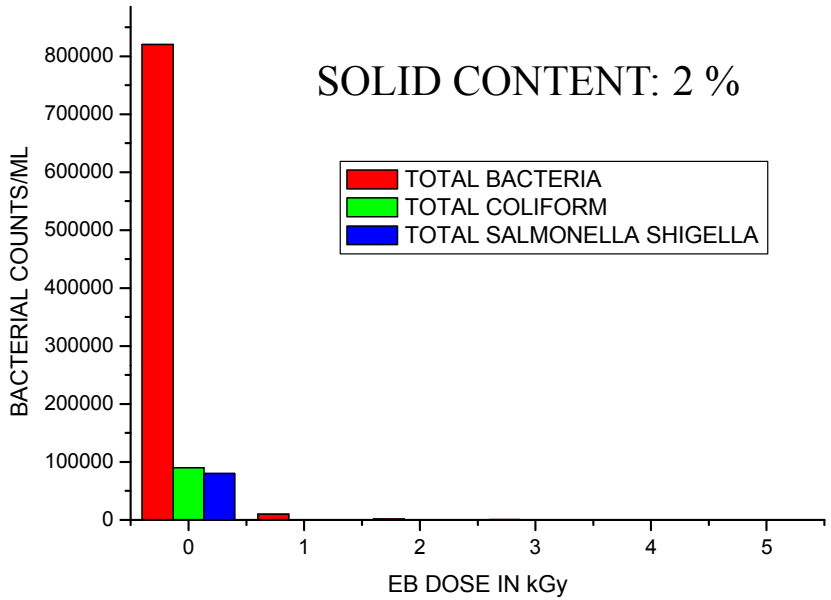
EXPERIMENTS ON WASTEWATER FROM PAPER MILLS



MECHANISM OF DISINFECTION

- **ELECTRONS CAN DIRECTLY AFFECT THE DNA**
- **OH RADICALS CAN ACT ON THE DNA CHAIN**

DISINFECTION EXPERIMENT AT BARC



EXPERIMENTS WITH 2 MeV ILU-6 ACCELERATOR AT BRIT VASHI

EXPERIMENTS WITH SAMLES OF OF 2, 14 & 27 % SOLID CONTENTS

REF: K. P. RAWAT ET AL, SEBTA, 2005

DISINFECTION EXPERIMENT IN SOUTH KOREA

EXPERIMENTAL PARAMETERS

ACCELERATOR: 1 MeV, 40 kW
DOSE: 0.2 – 1 kGy

RESULTS

100 % DEACTIVATION ECOLI & TOTAL COLIFORMS AT 0.8 kGy
INACTIVATION TO PRESCRIBED LIMIT AT 0.2 kGy
20% REMOVAL IN SUSPENDED SOLIDS AND TURBIDITY AT 1 kGy

INDUSTRIAL PLANT CONSTRUCTION

CAPACITY: 100,000 m^3/day
ACCELERATOR 1 MeV, 400 kW
TOTAL ELECTRICITY CONSUMPTION: 800 kW
CAPITAL COST: US$ 4.5 MILLION
OPERATING COST: US$ 1 MILLION/YEAR

CONVENTIONAL METHODS OF WATER TREATMENT

FILTRATION & REVERSE OSMOSIS

DECOMPOSITION OF IMPURITIES IS NOT POSSIBLE

CHLORINATION

CARCINOGENIC BYPRODUCTS, CORROSIVE IN NATURE

LIMING

INCREASES pH VALUE

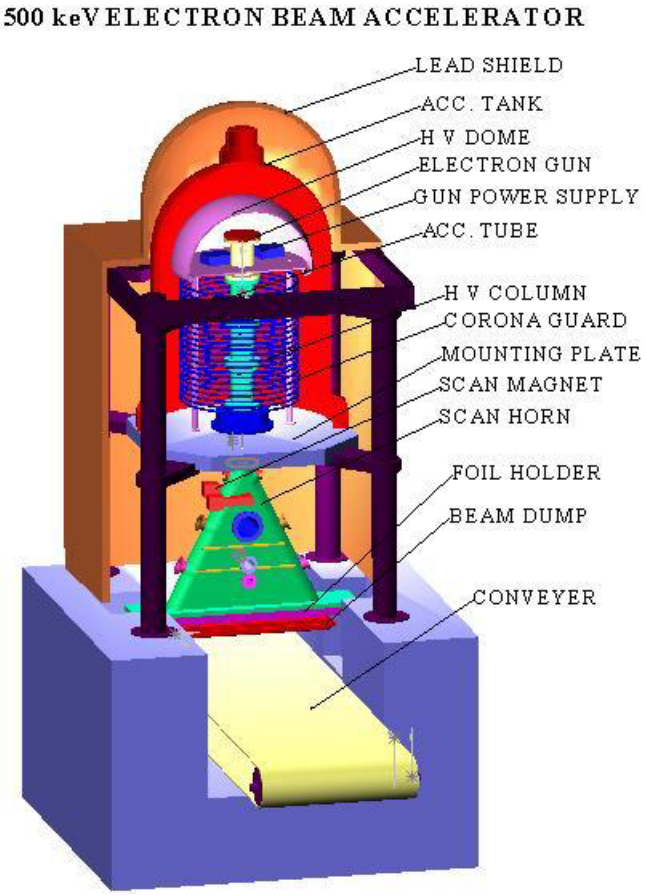
OZONIZATION

NOT SUITABLE FOR LARGE SCALE TREATMENT

SUBSYSTEMS OF AN ACCELERATOR

- ELECTRON GUN
- ACCELERATING TUBE
- VACUUM SYSTEM
- HIGH VOLTAGE COLUMN
- PRESSURE VESSEL
- SCAN HORN & SCAN MAGNET
- EXIT WINDOW
- CONVEYOR BELT
- RADIATION SHIELD
- CONTROL SYSTEM

SCHEMATIC OF AN INDUSTRIAL ACCELERATOR



HIGH POWER DC ACCELERATORS

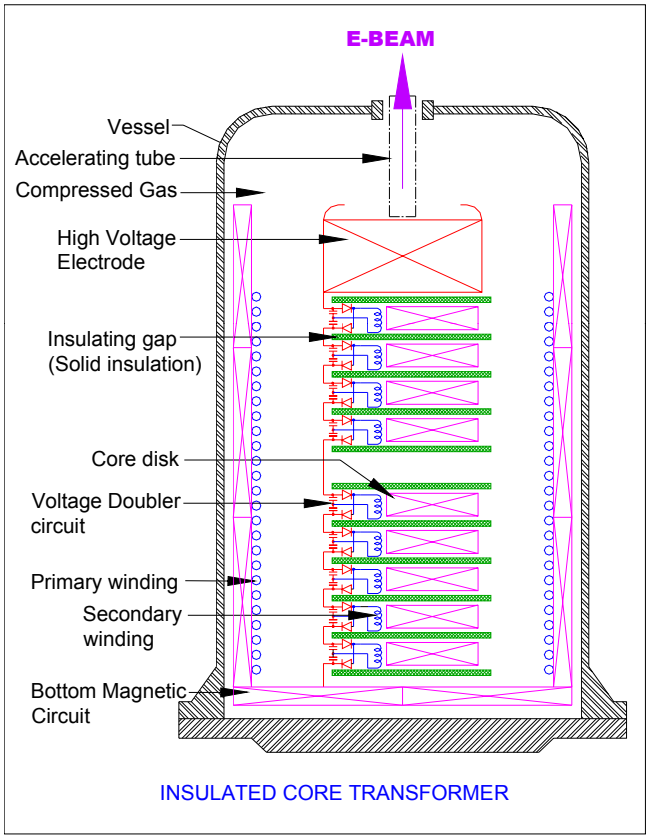
REQUIREMENT FOR INDUSTRIAL APPLICATIONS

RELIABILITY
HIGH EFFICIENCY
SAFETY
ECONOMY
COMPACTNESS

HIGH VOLTAGE GENERATION SCHEMES

HIGH VOLTAGE PRODUCES ELECTRIC FIELD FOR ACCELERATION
POWERLINE TRANSFORMER: UP TO 800 kV
INSULATED CORE TRANSFORMER: UP TO 3 MV
COCKROFTWALTON MULTIPIER: UP TO 5 MV
DYNAMITRON : UP TO 5.5 MV
ELV TYPE ACCELERATOR: UP TO 2.5 MV

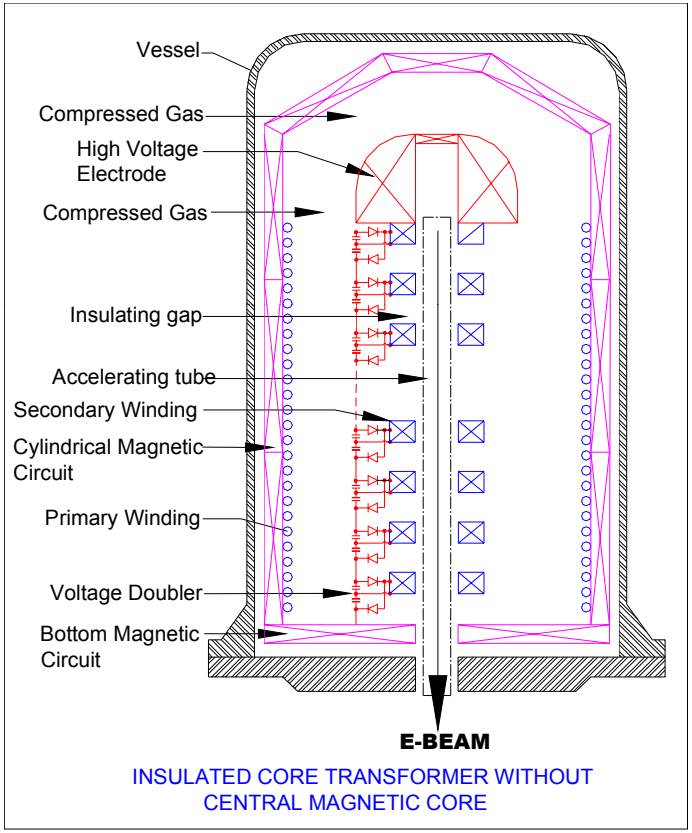
INSULATED CORE TRANSFORMER SCHEME



INSULATED CORE TRANSFORMER

- MAGNETIC CORES INSULATED FROM EACH OTHER
- LESS COUPLING THAN CLOSED CORE
- VOLTAGE: UP TO 3 MeV
- EFFICIENCY: UP TO 75-80%

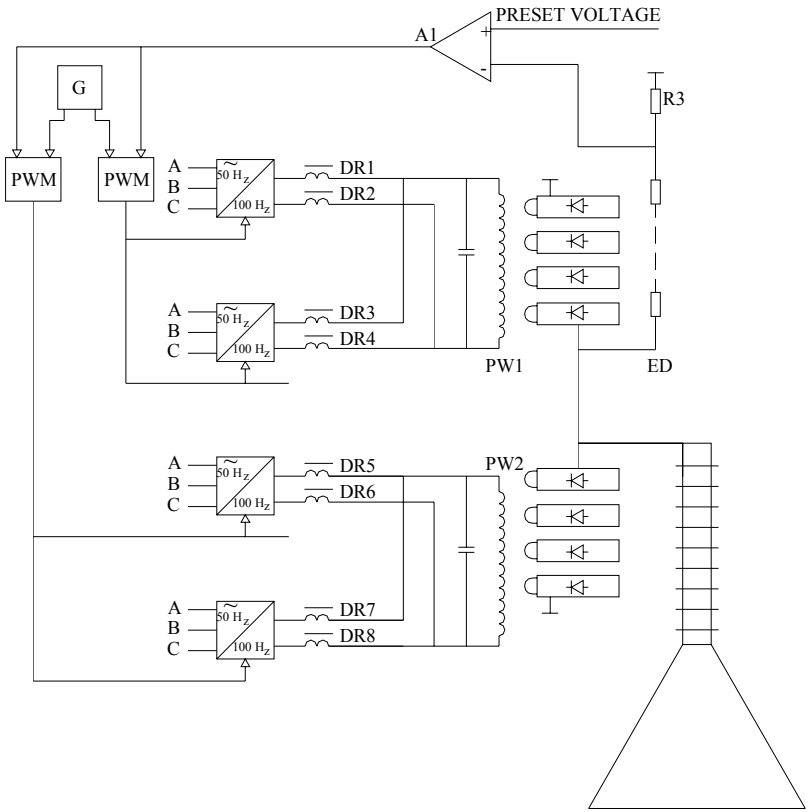
CORELESS CONFIGURATION



INSULATED CORE TRANSFORMER WITHOUT CENTRAL MAGNETIC CORE

- **NO CENTRAL CORE**
- **SPACE FOR ACCELERATING COLUMN**
- **INPUT FREQUENCY: 400 Hz-1 kHz**
- **SEVERAL SECONDARIES**
- **INDIVIDUAL RECTIFICATION AND ADDITION**

ELV-TYPE ACCELERATOR



- ❖ CORELESS TRANSFORMER TYPE
- ❖ INVERTER SCHEME
- ❖ FREQUENCY: 400Hz-1kHz
- ❖ OUTPUT CONTROL BY PWM
- ❖ TWO PRIMARIES
- ❖ THREE ACCELERATOR HEADS
- ❖ RATINGS: 1 MeV,400 kW
- ❖ EFFICIENCY: 68 %

BARC'S PROGRAMME OF INDIGENOUS DEVELOPMENT OF INDUSTRIAL ACCELERATORS

1. 500 kV, 20 mA DC ACCELERATOR

DESIGNED, DEVELOPED AND INSTALLED AT BRIT, VASHI

OPERATIONAL AT 3 kW POWER AND USED FOR POLYMERIZATION & CROSS_LINKING EXPERIMENT

2. 3 MV, 30 kW DC ACCELERATOR

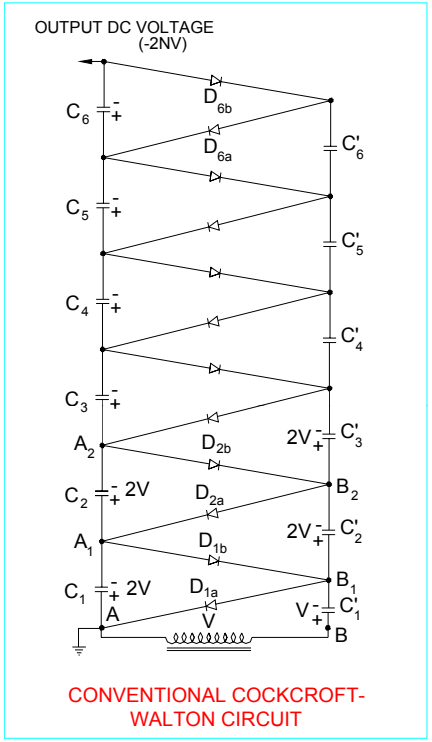
TO BE COMMISSIONED BY THE END OF 2008

BALLAST WATER TREATMENT EXPERIMENTS CAN BE PLANNED ON THIS

3. 10 MeV, 10 kW RF LINAC

ELECTRON BEAM OF FEW HUNDRED WATTS OBTAINED

COCKROFT-WALTON MULTIPLIER



CONVENTIONAL COCKCROFT-WALTON CIRCUIT

No-load output voltage = 2NV

Voltage droop, $\Delta V = \frac{I}{fC}\left[\frac{2N^3}{3} + \frac{3N^2}{4} + \frac{N}{12}\right]$

Ripple voltage, $\delta V = \frac{I}{2fC}\left[N^2 + N\right]$

PRINCIPLE OF OPERATION

IN 1st HALF CYCLE D_{1a} CONDUCTS

C_1' IS CHARGED TO V

IN 2nd HALF CYCLE C_1' AND INPUT IN SERIES

C_1 IS CHARGED TO 2V

REGULATION AND RIPPLE DEPEND ON NO. OF STAGES

INPUT FREQUENCY

1 TO TENS OF KILOHERTZ

EFFICIENCY: 60-70 %

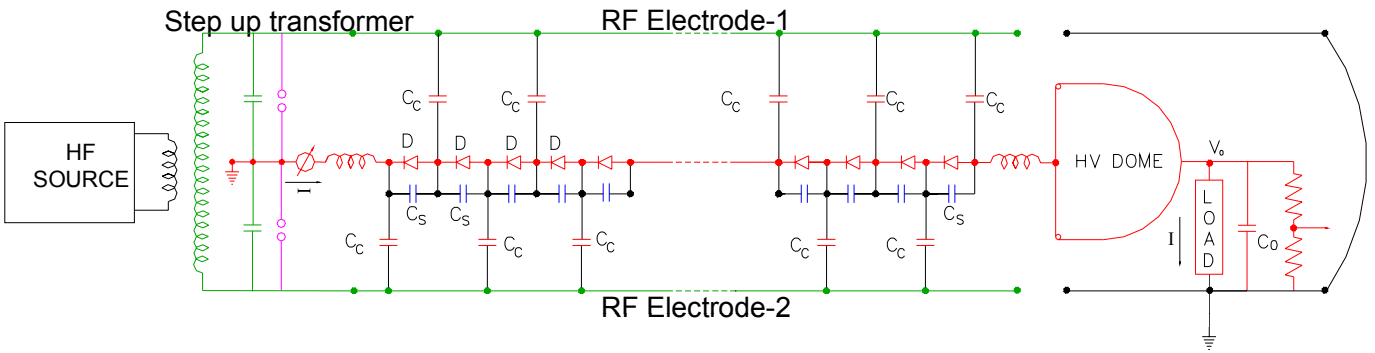
500 keV FACILITY AT BRIT, VASHI

HIGH VOLTAGE COLUMN OF 500 keV FACILITY AT BRIT

ACCELERATING COLUMN

ELECTRON BEAM CENTRE, KHARGHAR

DYNAMITRON



ELECTRICAL SCHEMATIC OF THE PARALLEL FED VOLTAGE MULTIPLIER

INPUT VOLTAGE : V **OUTPUT VOLTAGE: V_0**

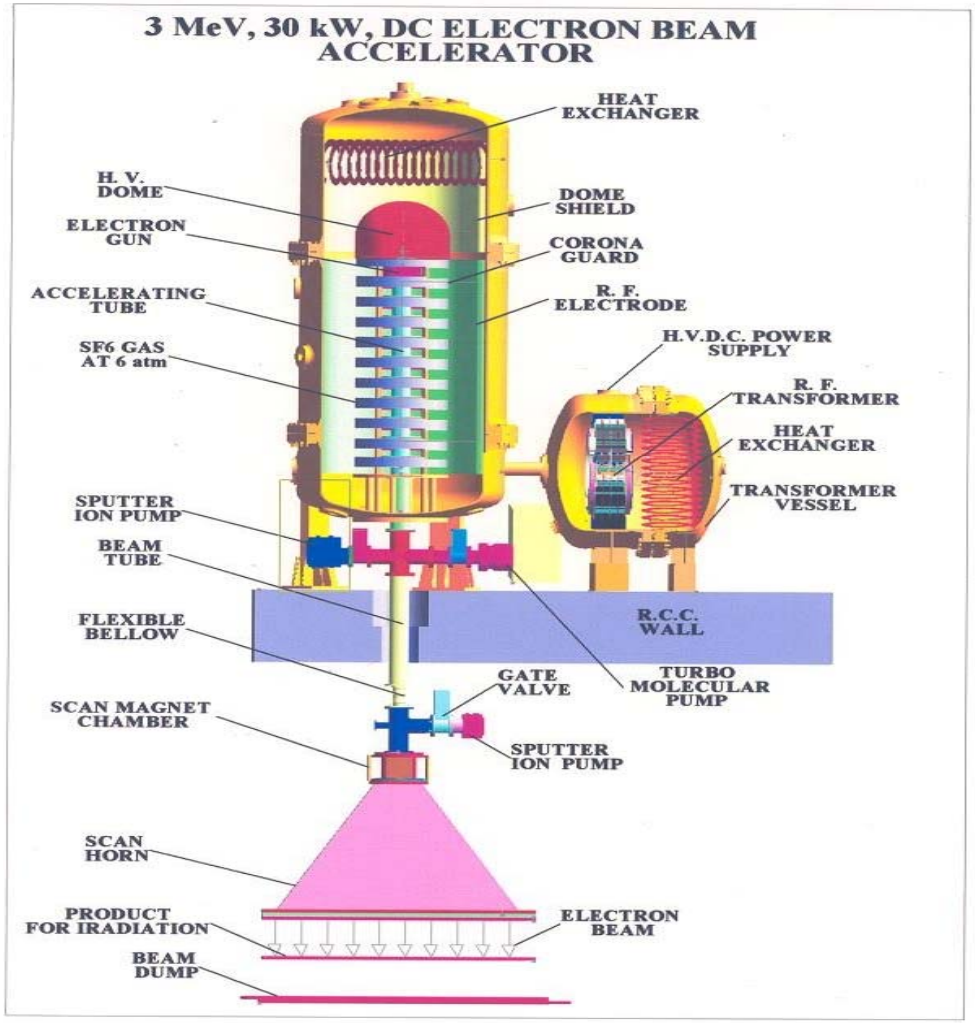
$V_0 = NV/k$ WHERE $k = 1+4C_s/C_c$, RIPPLE= $I/2fC_c$, DROOP = NI/kfC_c

C_c : CAPACITANCE BETWEEN RF ELECTRODE & CORONA GUARD

INPUT FREQUENCY: 100-150 kHz, EFFICIENCY: UP TO 60%

✓ **INTERELECTRODE CAPACITANCES ARE USED**

DYNAMITRON SCHEME AT EBC, KHARGHAR



Accelerator Tank

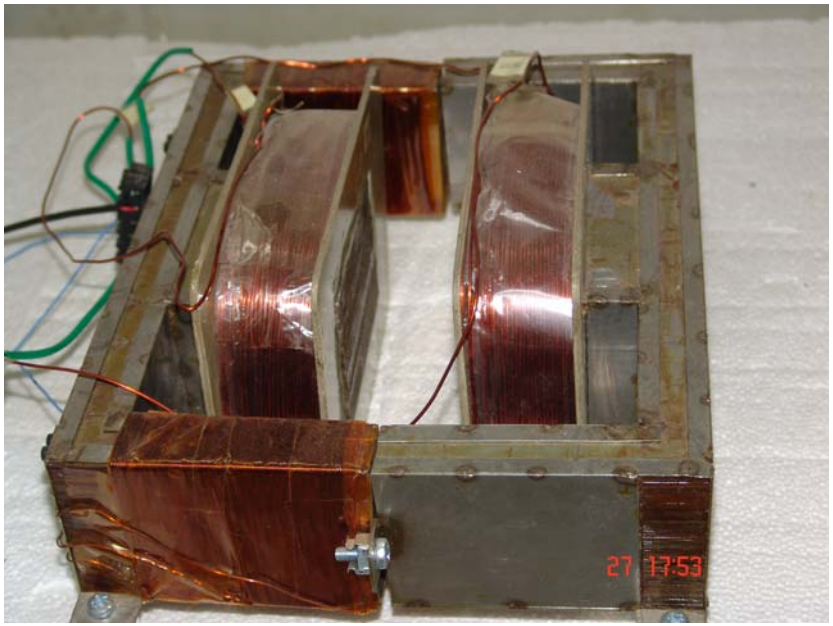
300 kV, 120kHz, 10MVA Transformer

RF Electrode Assembly

RF Electrodes Installed Inside Pressure Vessel

HV Dome

SCANNING SYSTEM



RF Linac assembly at Electron Beam Centre: First Floor View

RF Linac assembly at Electron Beam Centre: Ground Floor View

DC ACCELERATOR FACILITIES IN INDIA FOR INDUSTRIAL APPLICATIONS

PLACE	BEAM PARAMETERS	USE
BRIT, VASHI	500 kV, 3 kW COCKROFT-WALTON	R&D
RRCAT, INDORE	750 kV, few kW COCKROFT-WALTON	R&D
EBC, KHARGHAR	3 MeV, 30 kW DYNAMITRON	UNDER CONSTRUCTION FOR R&D
SBC, VIZAG	750 kV, 10 kW	SURFACE CURING

NICCO CABLES, KOLKATA	3 MeV,150 kW DYNAMITRON	CABLE IRRADIATION, DIAMOND COLOURING
RADIANT CABLES, HYDERABAD	1.5 MeV, 20 kW ICT TYPE	CABLE IRRADIATION

COMPARISON OF EB WITH GAMMA RAY SOURCES

GAMMA RAY SOURCE

- GAMMA RAY SOURCE: ^{60}Co
- ENERGY: 1.17 MeV & 1.33 MeV PHOTONS
- SOURCE STRENGTH: MEASURED IN UNITS OF CURIE
- 1 CURIE = 3.7×10^{10} DISINTEGRATIONS PER SECOND
- EMISSION IN 4π DIRECTION
- CANNOT BE SWITCHED OFF
- HALF-LIFE OF 5 .27 YEARS

ELECTRON BEAM

CAN BE SWITCHED OFF

DIRECTIONAL

VOLTAGE AND CURRENT CAN BE VARIED

1 MEGA CURIE ^{60}Co SOURCE = 14.8 kW EB (ENERGY-WISE)

MACHINE AND HUMAN SAFETY IN INDUSTRIAL ACCELERATOR

MACHINE SAFETY

INTERLOCKS PROVIDED FOR:

VACUUM,

SCANNING SYSTEM,

RADIATION MONITORS, FOIL BLOWER

CLOSURE OF RADIATION AREA

BREAK-DOWN IN HIGH VOLTAGE COLUMN CAN BE DETECTED

HUMAN SAFETY

X-RAY IS LIMITED IN THE ALLOWED ZONE TO PERMISSIBLELEVEL 0.1 mR BY LEAD OR CONCRETE SHIELDING

OZONE IN THE AMBIENCE IS LIMITED 0.1 ppm

ROUTINE HIGH VOLTAGE PRECAUTIONS

FUTURE PLANS ☞

✓ **EXPERIENCE IN INDIGENOUS DEVELOPMENT OF LOW POWER ACCELERATORS IN THE LAST DECADE**

- ☞ **INTERACTION OF R & D GROUPS WITH INDUSTRIES**
- ☞ **UTILIZATION OF AVAILABLE FACILITIES FOR EXPERIMENTS**
- ☞ **EXPERIMENTS WITH SIMULATED FLUE GAS**
- ☞ **IDENTIFICATION OF ORGANIC & INORGANIC IMPURITIES IN WASTEWATER**
- ☞ **ASSESMENT OF REQUIREMENT FOR DIFFERENT MILLS**
- ☞ **INDIGENOUS DEVELOPMENT OF HIGH POWER ACCELERATORS IN THE COUNTRY**

Typical Vessel Sizes and Ballast Capacities

			Ballast capacity		Ballast capacity
VESSEL TYPE	**DWT**	**NORMAL**	**% of DWT**	**HEAVY**	**% of DWT**
Bulk carrier	250,000	75,000	30%	113,000	45%
Bulk carrier	150,000	45,000	30%	67,000	45%
Bulk carrier	70,000	25,000	36%	40,000	57%
Bulk carrier	35,000	10,000	30%	17,000	49%
Tanker	100,000	40,000	40%	45,000	45%
Tanker	40,000	12,000	30%	15,000	38%
Container	40,000	12,000	30%	15,000	38%
Container	15,000	5,000	30%		
General cargo	17,000	6,000	35%		
General cargo	8,000	3,000	38%		
Passenger/RORO	3,000	1,000	33%		

Economics of the present system

- Calculating the fuel costs incurred by ships per ballast water exchange operation
- Assumptions made
  - number of ballast pumps used = 2
  - Ballast water pumped is 3 times the volume of the ballast tank capacity
  - capacity of each pump = 2000 MT/hr
  - power consumption of each pump = 400KW
  - specific energy of diesel oil = 40.25 Mj/Kg
  - efficiency of generator = 30%
  - price of diesel oil = $.9034/kg (U.S. prices as of 4th august 2007)

Calculations for Cost of Open Sea Exchange based on the assumptions stated above

Vessel type	**Tanker**	
DWT	100000	
Ballast condition	**Normal**	**Heavy**
Ballast water required	40000	45000
Total volume of water exchanged	120000	135000
Total time required per exchange(hrs)	30	33.75
Power consumed by the pumps(KWh)	24000	27000
Diesel required by generator(kg)	7155.28	8049.69
Total Fuel Cost($)	**6464.08**	**7272.09**

DATA OF DISINFECTION EXPERIMENT IN SOUTH KOREA SUITABLE FOR BWM

EXPERIMENTAL PARAMETERS

ACCELERATOR: 1 MeV, 40 kW
DOSE: 0.2 – 1 kGy

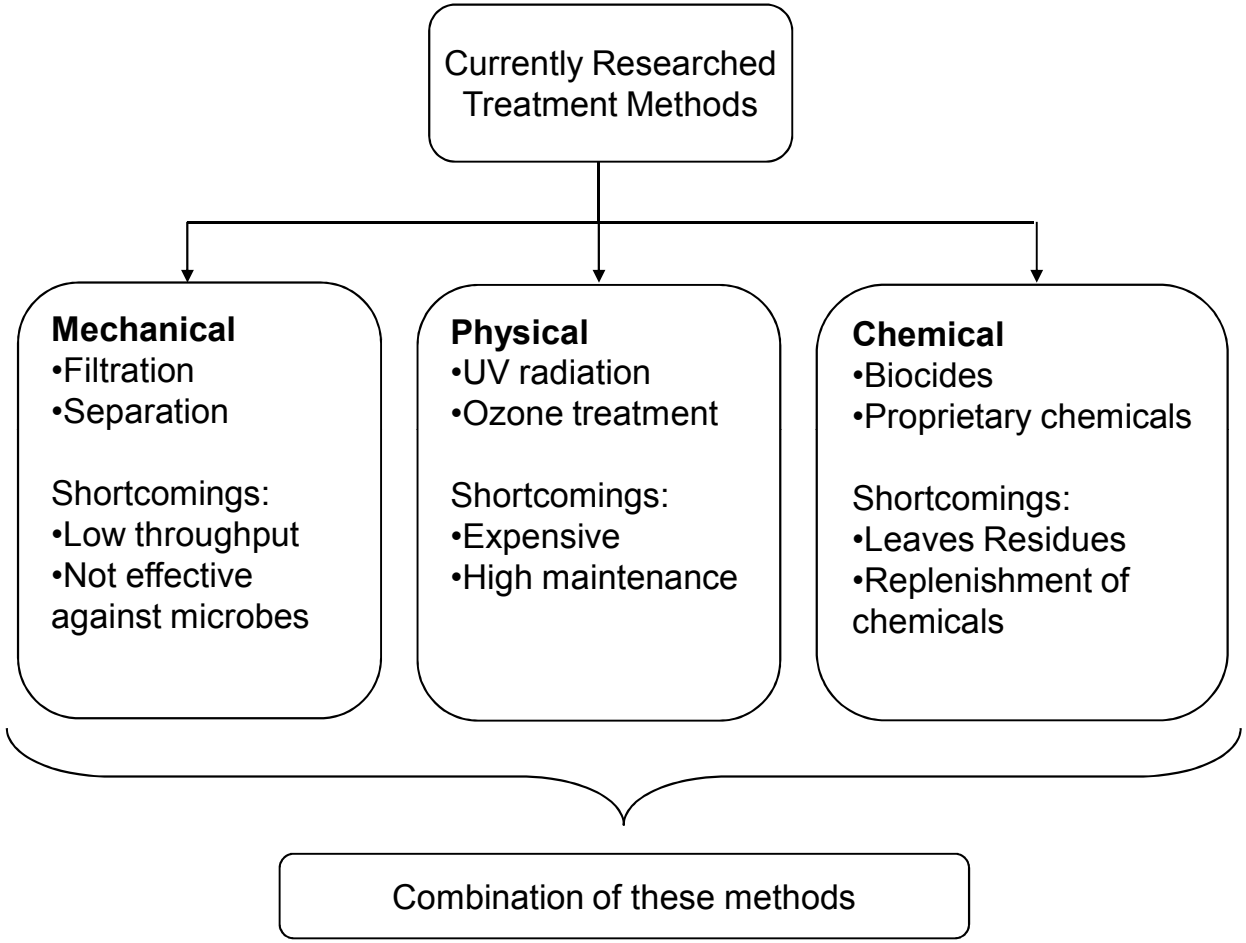
RESULTS

100 % DEACTIVATION ECOLI & TOTAL COLIFORMS AT 0.8 kGy
INACTIVATION TO PRESCRIBED LIMIT AT 0.2 kGy
20% REMOVAL IN SUSPENDED SOLIDS AND TURBIDITY AT 1 kGy

INDUSTRIAL PLANT CONSTRUCTION

CAPACITY: 100,000 m^3/day
ACCELERATOR 1 MeV, 400 kW
TOTAL ELECTRICITY CONSUMPTION: 800 kW
CAPITAL COST: US$ 4.5 MILLION
OPERATING COST: US$ 1 MILLION/YEAR

Treatment methods with ongoing research



CONCLUSION & ACTION PLAN

- **INDUSTRIAL ACCELERATORS HAVE PROVEN EXPERIENCE OF WORKING RELIABLY AT HUNDREDS OF KILOWATTS OF POWER**
- **ECONOMIC ANALYSIS OF ALTERNATIVE METHODS SHOULD BE DONE**
- **EXPERIMENTS SHOULD BEGIN IN THE COUNTRY UTILIZING THE AVAILABLE ACCELERATORS TO ESTIMATE ADEQUATE DOSE**
- **FEASIBILITY OF PORT- BASED APPROACHES SHOULD BE STUDIED**

ELECTRON ACCELERATORS CAN BE CONSIDERED FOR BWT AND INSTALLED AT THE PORT.

PRESERVATION OF FLORA AND FAUNA IS OUR DUTY,

THEY LEND THIS PLANET ITS WONDERFUL BEAUTY.

THE INDUSTRIAL ACCELERATOR AND THE CARGO SHIP ,
CAN THEY HAVE A VERY MEANINGFUL FRIENDSHIP ?

WILL THAT MAKE A SEA-CHANGE IN THE SEA ?

LET ALL OF US BEGIN EXPERIMENTS AND SEE.

ACKNOWLEDGEMENT

ALL STAFF MEMBERS OF APPD