



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Technology for Space Station Evolution Workshop

JSC ECLSS R&T Program Overview

599

Dallas, TX
January 16-19, 1990

P-31
A.F. Behrend
NASA - JSC

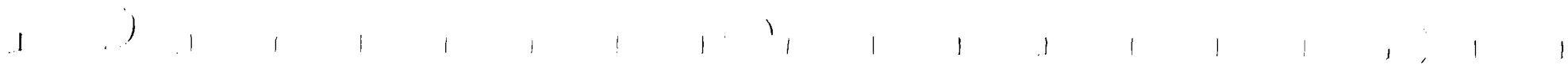
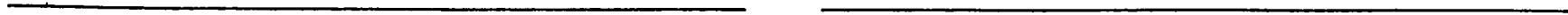
521-54
N 930737725



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Content

- **Advancements in Electrochemical CO2 Removal**
- **Supercritical Water Waste Oxidation**
- **Electrooxidation for Post-treatment of Reclaimed Water**
- **Photocatalytic Post-Treatment of Reclaimed Water**





Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Advancements in Electrochemical CO2 Removal

Objective

- Investigate and develop fundamental process enhancements in electrochemical CO2 removal

Benefit

- Improve performance and reliability
 - CO2 removal efficiency improvement (5-10% improvement achieved)
 - Cell composition improvement
 - Hydrogen feed elimination





Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Advancements in Electrochemical CO₂ Removal

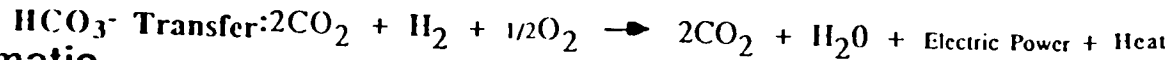
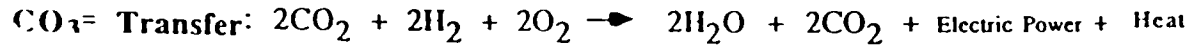
Technical Description

- Air passes through electrochemical cell where CO₂ is absorbed at cathode and evolved at anode
- Electrochemical CO₂ removal with hydrogen utilizes alkaline hydrogen/oxygen fuel cell reaction
 - O₂ from air supplied at cathode where CO₂ is absorbed
 - H₂ supplied at anode where CO₂ is evolved
 - CO₂ reacts with hydroxyl ions (OH⁻) to form carbonate and bicarbonate ions (CO₃⁼ and HCO⁻) which migrate to anode where heat energy from the fuel cell reaction releases the CO₂
 - Half-cell reactions at both electrodes are thermodynamically spontaneous
 - Process generates electricity
- Same process can be carried out without supply of hydrogen
 - Series of reactions not spontaneous
 - Power must be supplied (approximately 105W/per person)

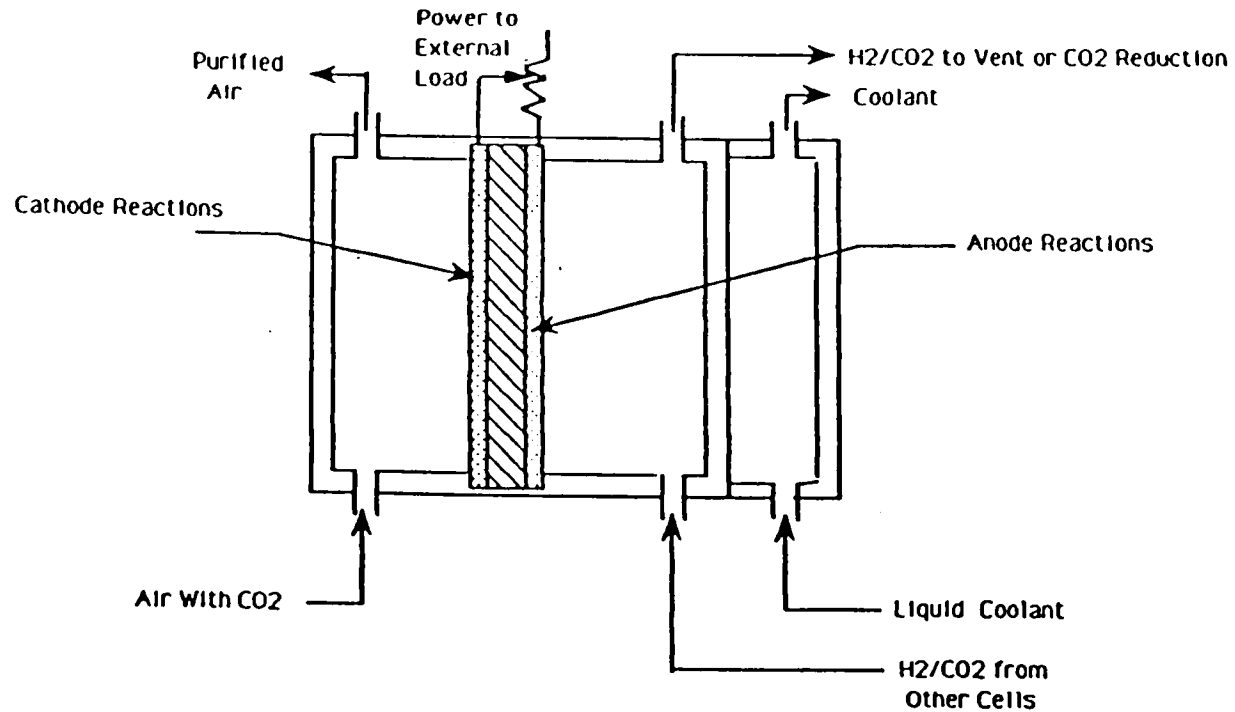


Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Advancements in Electrochemical CO₂ Removal



Schematic

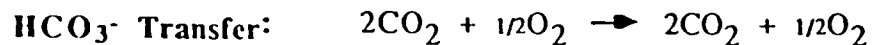
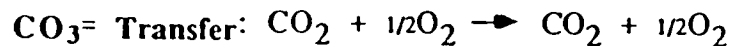


Electrochemical Carbon Dioxide Removal with Hydrogen

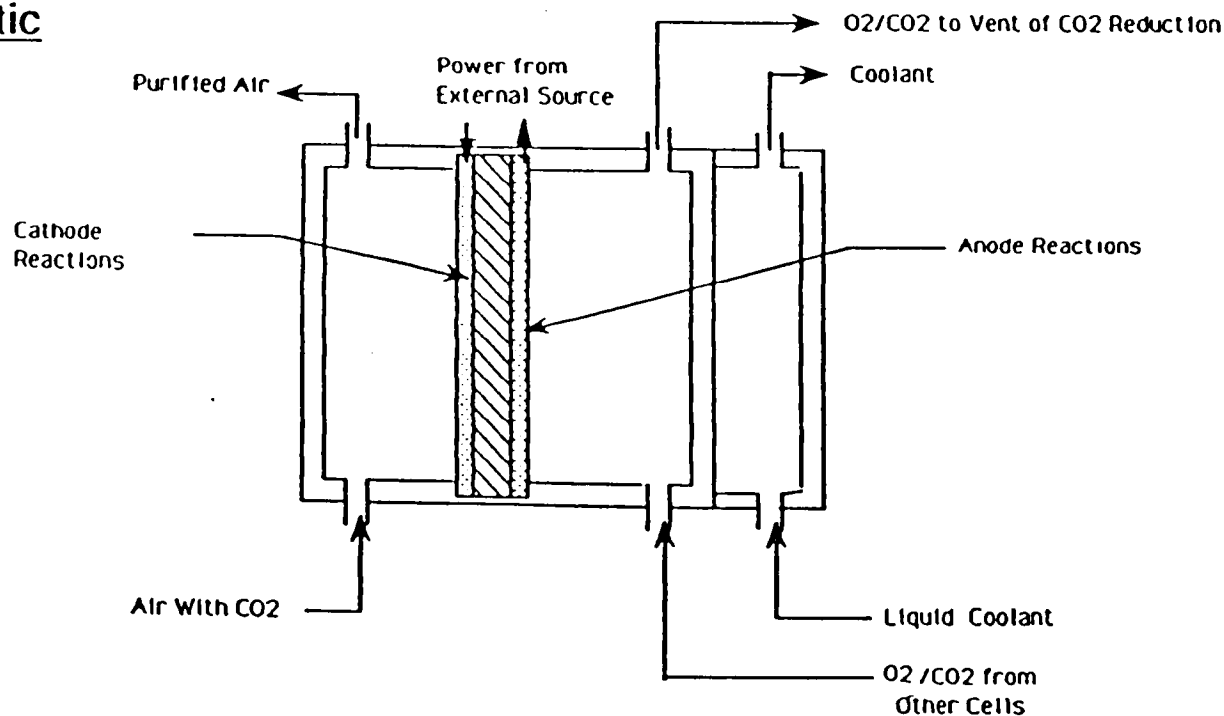


Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Advancements in Electrochemical CO2 Removal



Schematic



Electrochemical Carbon Dioxide Removal without Hydrogen



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Advancements in Electrochemical CO₂ Removal

Status

- Program with Life Systems, Inc./Texas A&M; Initiated in December 1987
- 2 year Phase I to investigate and develop fundamental process enhancements
 - Literature review to identify areas of study for improved performance and operational flexibility
 - Bench-scale laboratory testing of cell components to identify best candidates for integrated testing
 - Single cell unit design, fabrication, and testing
- Single cell testing being completed now
- 1 year Phase II for multi-cell unit design, fabrication, and test



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Advancements in Electrochemical CO2 Removal

Results

- **Determined optimum electrocatalyst loading and binding agent content for gas diffusion electrodes**
- **Developed an improved electrode fabrication method using ultrasonic device for the dispersion of gas diffusion electrode components**
- **Proved that the electrolyte matrix thickness can be reduced to half of the baseline matrix thickness for improved performance without sacrificing the differential pressure capability**
- **Identified and developed electrode materials for the anode of the "without hydrogen" electrochemical CO2 removal cell**

606

FY90 Activity

- **Documentation of Phase I Results**
 - **Initiation of Phase II Multi-cell Unit Design and Fabrication**
-



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Supercritical Water Waste Oxidation

Objective

- Expand the fundamental understanding of the SCWO waste treatment process
- Determine reaction mechanisms and effect of SCWO process variables (temperature, residence time, feed concentration, pressure) for simple compounds - methane, ammonia, etc.
- Determine mechanism of reaction residue (salt) formation - rate, temperature, etc.



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Supercritical Water Waste Oxidation

Benefit

- System and crew waste approximately 6-8 lb/person-day (approximately 0.25 ft³/person-day)
- SCWO process potentially
 - Reduces waste storage (35 ft³ reduced to approximately 0.1 ft³)
 - Produces excess water
 - o Enhanced hygiene
 - o Radiation protection supplement
 - o EVA support



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Supercritical Water Waste Oxidation

Technology Description

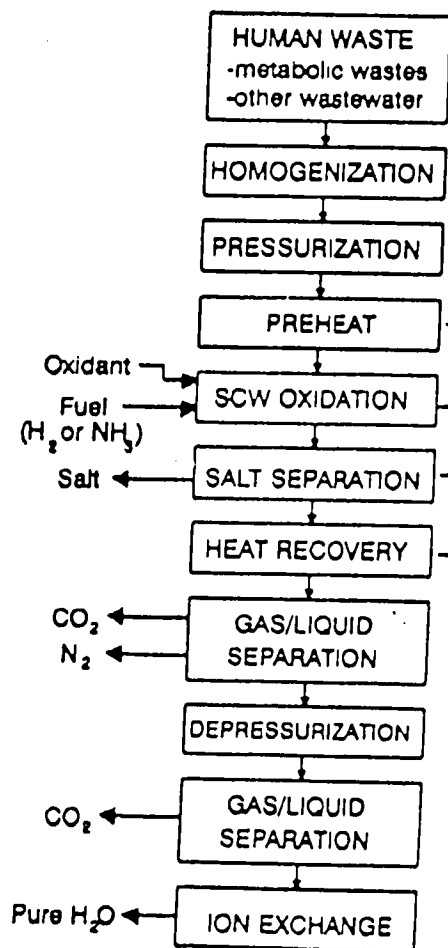
- SCWO process converts organic waste (feces, urine, trash) to carbon dioxide nitrogen, and water
- Process operation above the water critical point (3200 psia, 705 °F;
218 atm, 374 °C)
- Organic material is oxidized leaving reaction residue in the form of salts and oxides
- Process depends upon containment and removal of reaction ash

Status

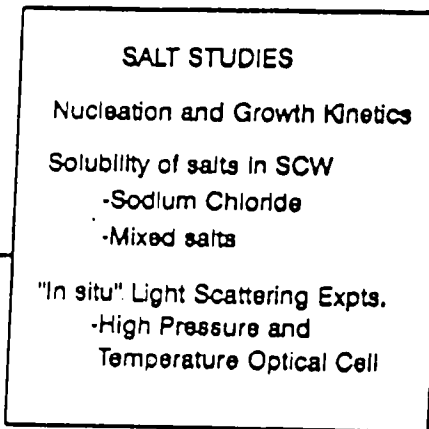
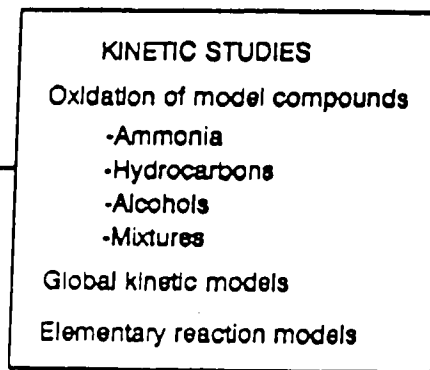
- M.I.T. grant in final phase
 - September 1987 to September 1990
 - Focus upon reaction kinetics and salt formation with analysis and experimental results
-

HUMAN WASTE TREATMENT AND RECYCLE BY OXIDATION IN SUPERCRITICAL WATER (SCW) (MODAR PROCESS)

PROCESS STEPS



MIT FUNDAMENTAL RESEARCH





Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

Supercritical Water Waste Oxidation

Results

- **Reaction kinetics**
 - Expanded experimental capability to 700 °C, 300 atm
 - Measurement of kinetics and correlation to analytical models for carbon monoxide, ethanol, methanol, methane, ammonia, ammonia/ethanol, carbon monoxide/ethanol
- **Salt formation**
 - Completed test apparatus assembly and initial checkout with water
 - Initiated preliminary sodium chloride experiments
 - Progressing with numerical modeling of salt mixing and precipitation

FY90 Activity

- **Complete salt nucleation and precipitation experiments and modeling**
 - **Expand kinetic database to examine pressure variation, alternate oxidants, dissolved salts, heat transfer rate**
-



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

ELECTROOXIDATION FOR POST-TREATMENT OF RECLAIMED WATER

OBJECTIVE

- **DEMONSTRATE FEASIBILITY OF ELECTROOXIDATION TECHNIQUE FOR POST-TREATMENT OF RECLAIMED WASTE WATERS (DISTILLATES, PERMEATES AND HUMIDITY CONDENSATES) FOR POTABLE AND HYGIENE USAGE**

612

BENEFITS

- **NEW COMPETING TECHNOLOGY FOR PURIFYING RECLAIMED WASTE WATERS**
 - **NO EXPENDABLES**
 - **REMOVES TOTAL ORGANIC IMPURITIES TO < 500 PPB**
 - **SHOWS POTENTIAL FOR PROVIDING DISINFECTION**
-



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

ELECTROOXIDATION FOR POST-TREATMENT OF RECLAIMED WATER

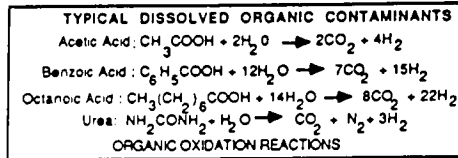
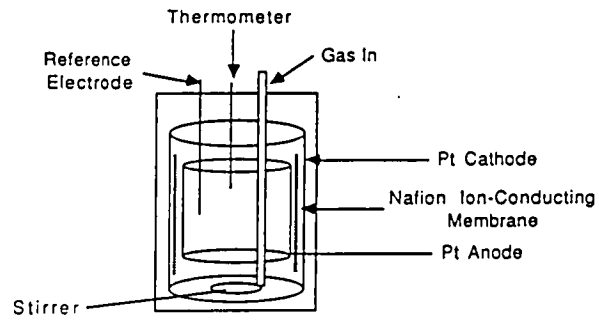
TECHNICAL DESCRIPTION

- ELECTROCHEMICAL CELL PROVIDES GENERATION OF STRONG OXIDIZING RADICALS (HO·)
- LIQUID ELECTROLYTE (0.7 M SODIUM PERCHLORATE)
- 170 W-HR REQUIRED TO OXIDIZE 50 PPM OF ORGANIC IMPURITY TO < 500 PPB IN 1 LITER OF WATER
- NO MOVING PARTS

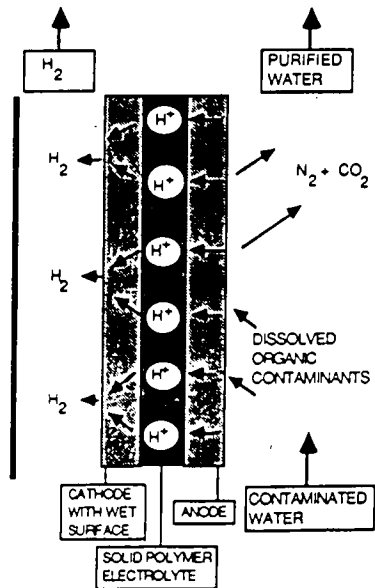
STATUS

- GRANT INITIATED WITH TAMU IN APRIL 1989
 - EVALUATING FEASIBILITY OF CONCEPT AND OBTAINING PARAMETRIC DATA FOR DESIGN AND FABRICATION OF A BREADBOARD SYSTEM
 - COMPLETION OF RESEARCH GRANT IN APRIL 1990
-

ELECTROLYSIS TEST CELL: INCORPORATING AN ION-CONDUCTING MEMBRANE



SCHEMATIC OF ELECTROCHEMICAL WATER POST-TREATMENT UNIT



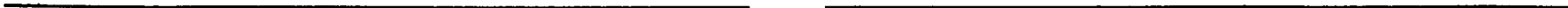


Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

ELECTROOXIDATION FOR POSTTREATMENT OF RECLAIMED WATER

FUTURE PLANS

- **DEVELOP A BREADBOARD SYSTEM USING A SOLID POLYMER
ELECTROLYTE FROM FUEL CELL TECHNOLOGY**





Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

PHOTOCATALYTIC POST-TREATMENT OF RECLAIMED WATER

OBJECTIVE

- DEVELOP A BREADBOARD PHOTOCATALYTIC SYSTEM FOR POST-TREATMENT OF RECLAIMED WASTE WATERS (DISTILLATES, PERMEATES AND HUMIDITY CONDENSATE) FOR POTABLE AND HYGIENE USAGE

616

BENEFITS

- NEW COMPETING TECHNOLOGY FOR PURIFYING RECLAIMED WASTE WATERS
- REMOVES ORGANIC IMPURITIES TO LEVELS < 500 PPB
- PROVIDES DISINFECTION
- NO EXPENDABLES



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

PHOTOCATALYTIC POST-TREATMENT OF RECLAIMED WATERS

TECHNOLOGY DESCRIPTION

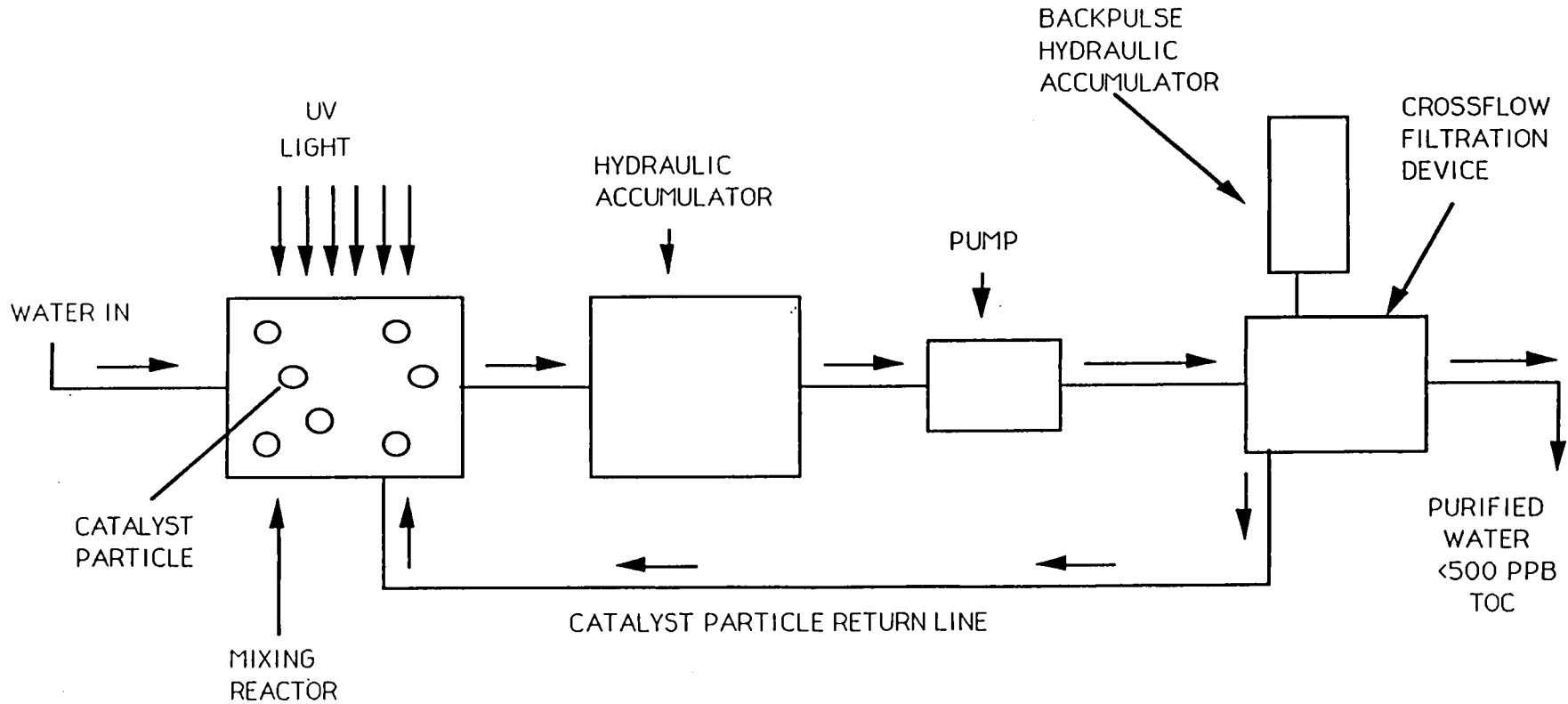
- ORGANIC IMPURITIES IN WATER ARE OXIDIZED BY POWERFUL OXIDIZING HYDROXAL RADICALS (OH•) AND HOLES (h +) PRODUCED WITH THE COMBINATION OF FINE METAL OXIDE CATALYST PARTICLES DISPERSED IN WATER WITH UV LIGHT AND DISSOLVED O₂
- BATCH SYSTEM PROCESSES 12 LITERS OF WATER EVERY 2 HOURS
- SEPARATES CATALYST PARTICLES BY CROSS-FILTRATION THROUGH MICROPOROUS MEMBRANE
- RECOVERS PARTICLES FOR REUSE BY BACKFLUSHING OF MEMBRANE
- OPERATES CLOSE TO AMBIENT TEMPERATURE (35 ° C)



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

SCHEMATIC OF PHOTOCATALYTIC BATCH REACTOR POST-TREATMENT SYSTEM

618



POST-TREATMENT SYSTEM PROCESSES
12 LITERS PURIFIED WATER PER HOUR



Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
	A.F. Behrend	1-16-90

PHOTOCATALYTIC POST-TREATMENT OF RECLAIMED WATER

STATUS

- PHASE II SBIR WITH PHOTOCATALYTICS, INC. BOULDER, CO INITIATED IN APRIL 1987
- BREADBOARD SYSTEM IN FABRICATION AND SCHEDULED FOR COMPLETION FEBRUARY

FY 90 ACTIVITY

- TEST BREADBOARD SYSTEM WITH RECLAIMED WASTE WATERS TO DEMONSTRATE PERFORMANCE FOR
 - REMOVAL OF ORGANIC IMPURITIES TO < 500 PPB
 - DISINFECTION FROM 10 EXP 7 CFU TO 0 MICROORGANISMS
- CONTRACT COMPLETION IS APRIL 1990

FUTURE PLANS

- CONTINUE TECHNOLOGY DEVELOPMENT