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PREPRINT

Capacitive Deionization with Carbon Aerogel Electrodes

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1995 R&D 100 Award Entry Form Data

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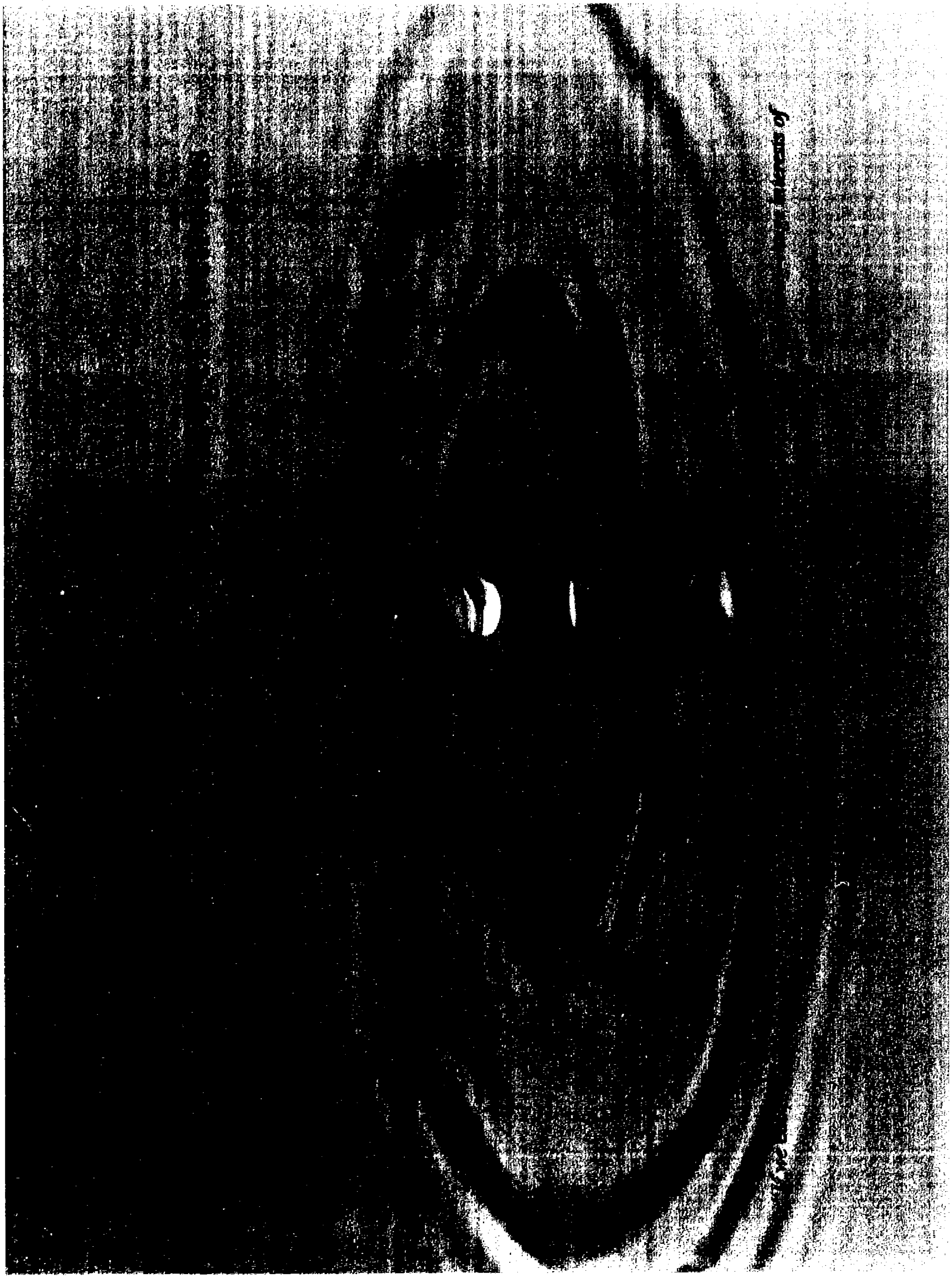
"If we could ever competitively, at a cheap rate, get fresh water from salt water, ... this would be in the long-range interests of humanity, ... (and) would dwarf any other scientific accomplishment."

President John F. Kennedy, 1961

Capacitive deionization with carbon aerogel electrodes enables the development of economical desalination plants, as well as a variety of other important water purification processes, and makes possible the safe and efficient treatment of dangerous radioactive wastes.



1995 R&D 100 AWARD ENTRY FORM
Deadline: March 1, 1995
Please type or print legibly. Entry form may be reproduced.

Please fill out all names as they should be listed in R&D Magazine

1. Submitting organization Lawrence Livermore National Laboratory (LLNL)
Address 7000 East Avenue or P.O. Box 808 Mail Stop L-369
City Livermore State CA Zip 94551 Country USA
Submitter's name Joseph C. Farmer
Phone 510-423-6574 FAX 510-422-2118

AFFIRMATION: I affirm that all information submitted as a part of, or supplemental to, this entry is a fair and accurate representation of this project.
Submitter's signature_______________

2. Joint entry with (list additional submitters on a separate sheet)
Organization None
Address_______________
City_______________State_______________Zip_______________Country_______________
Submitter's name_______________
Phone_______________FAX_______________

3. Product name Capacitive Deionization (CDI) of Water with Carbon Aerogel Electrodes

4. Briefly describe what the entry is (e.g. balance, camera, nuclear assay, etc.)
This is a new process for efficiently and economically removing salt and impurities from water. Applications include waste treatment, water purification and softening, and desalination.

5. When was this product first marketed or available for order? Month December Year 1994
(Must have been first available in 1994.)

6. Inventor or Principal Developer Joseph C. Farmer (additional developers in appendix)
(List additional developers on a separate sheet in an appendix.)
Position Principal Investigator Organization LLNL
Phone 510-423-6574 Fax 510-422-2118

7. Product price $1K to 38M If the price is proprietary, list it and check here_______________

8. Do you hold any patents on this product? Yes X No____
Do you have any patents pending? Yes X No____
Do others hold patents on this product or a similar product line? Yes X No____

9. Describe your product's primary function as clearly as possible in 1 page. What does it do? How does it do it? What theories, if any, are involved?

10A. List your product's competitors by manufacturer, brand name and model number.
10B. Supply a matrix or table showing how the key features of your product compare to existing products or technologies. Include both numerical (data) and descriptive (written) comparisons.
10C. Describe how your product improves upon competitive products or technologies.
BE SPECIFIC! Include such items as how much faster, how much less cost, etc.

11A. Describe the principal applications of this product.
11B. List all other applications for which your product can now be used.
11C. List all potential applications. Indicate why they are not now feasible.

12. **Summary**. State in layman's terms why you feel your product should receive an R&D 100 Award. Why is it important to have this product? What benefits will it provide? (The value of the award for its promotional value is understood.)

ORGANIZATION DATA

13. Chief Executive Office (corporate or university president, government research center director, etc.).

Name C. Bruce Tarter Position Director
Organization Lawrence Livermore National Laboratory
Address 7000 East Avenue or P.O. Box 808 Mail Stop L-1
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14. Contact person to handle all arrangements on exhibits, banquet, and publicity.

Name Kenneth Rhodie Position Manager, Commerical Resources
Organization Lawrence Livermore National Laboratory
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City Livermore State CA Zip 94551 Country USA
Phone 510-422-0172 Fax 510-423-0973

15. To whom should reader inquires about your product be directed?

Name Joseph C. Farmer Position Principal Investigator
Organization Lawrence Livermore National Laboratory
Address 7000 East Avenue or P.O. Box 808 Mail Stop L-1
City Livermore State CA Zip 94551 Country USA
Phone 510-423-6574 Fax 510-422-2118

ENTRY PROCEDURE

1. Any new technical product that was first available for purchase or licensing between Jan. 1, 1994 and Dec. 31, 1994 may be entered. Proof-of-concept models should not be entered until they reach a more advanced age. PHYSICAL EXISTENCE OF THE PRODUCT MUST BE SHOWN IN A PHOTOGRAPH OR ACTUAL SAMPLE.

2. Answer all questions as provided in this form. Answers should be typewritten. Retyping the form to fit additional names is allowed.

3. Supporting information, such as scientific papers, patents, or articles may be added in an appendix. Highlight important information.

4. Each entry must be signed by the submitter and accompanied by a $150 entry fee. **Make checks payable to: R&D MAGAZINE.** Mail checks and EIGHT (8) COMPLETE SETS of the entry to R&D 100, 1350 E. Touhy Ave., Des Plaines, IL 60018, USA.

5. Entries will not be returned.

6. All entries must be received by March 1, 1995. EARLY BIRD: Entries received by February 1, 1995 will be reviewed by a judging panel to see if additional information might help the judges better understand the product entry. Submitters with incomplete information will be notified by fax and allowed to submit additional information.

7. Winning products will be selected on the basis of their importance, uniqueness, and usefulness by a panel of technical experts.

8. All submitters will be notified of the judges' decision by June 30, 1995. A complete report will be published in the September 1995 issue of *R&D Magazine*. Winners will be honored at an awards banquet at Chicago's Museum of Science and Industry on September 21, 1995.

9. For more info: 708-390-2734, fax: 708-390-2618, email: *rdchi@mcimail.com* .

Appendix

9. Primary Function

- *Principle of operation.* The capacitive deionization (CDI) of water with a stack of carbon aerogel electrodes has been successfully demonstrated for the first time. A fully-automated deomonstration process based upon this concept has been developed. An aqueous solution of NaCl, $NaNO_3$, or another salt is passed between a large number of carbon aerogel anodes and cathodes, each having an exceptionally high specific surface area (600-1000 m^2/gm). After polarization, non-reducible and non-oxidizable ions are removed from the electrolyte by the imposed electric field and held in electric double layers formed at the surfaces of electrodes (Fig. 1). As desired, the effluent water from the cell is purified. The Gouy-Chapman Theory or the Stern Modification of that theory can be used to describe the effect of an imposed electric field on the surface charge density of the electric double layer [J. Newman, Electrochemical Systems, Prentice Hall, 1973]. Cell voltages ranging from 0 to 1.2 V have been investigated. The best performance (salt removal) is achieved at 1.2 V, though operation at 0.6 V is possible (Fig. 2). Successful testing has been done at solution conductivities of 7, 100, 500, 1000, and 10,000 μmho/cm. In routine single-pass experiments, more than 99% of the salt in a 100 μmho/cm (~100 ppm) feed stream is removed (Fig. 3). After the carbon aerogel electrodes become saturated with salt, breakthrough is observed. However, during operation in actual applications, the electrodes are regenerated by electrical discharge prior to breakthrough and the captured salts are released into a relatively small, concentrated purge stream. Other impurities such as dissolved heavy metals and suspended colloids can be removed by electrodeposition and electrophoresis, respectively. Unlike competing technologies, membranes, high-pressure pumps, regenerant chemicals, and excessive energy are not required.

- *Energy requirement.* The minimum theoretical work required by an isothermal process to separate sea water (~35,000 ppm NaCl) or brackish water (~1000 ppm) into saturated brine and a stream of 10 ppm drinking water can be calculated [J.D. King, Separation Processes, 1980, p. 662]. This calculation requires that the activity coefficient of NaCl be estimated with the Debye-Huckel Theory [J. Newman, Electrochemical Systems, 1973, p. 91]. The estimated minimum work requirements for desalination of sea water and brackish water are ~4 Wh/gal and 0.02 Wh/gal, respectively. The energy required by CDI is approximately $(QV/2)(1-e^{-t/\tau})$, where Q is the stored electrical charge, V is the voltage between adjacent electrodes, t is the charging time, and τ is the time constant of the CDI cell. The time constant is determined by the internal resistance and capacitance of the cell. In the case of sea water desalination at the maximum voltage (1.2V) without any energy recovery, the energy requirement is only eight times (8X) the theoretical minimum. In the case of brackish water, the energy requirement is eighteen times (18X) the theoretical minimum. If any of the stored electrical energy is reclaimed during regeneration, or electrical discharge, the energy requirement could be reduced to a level well below this. Parasitic electrochemical charge-transfer reactions, leakage currents, and ohmic losses are assumed to be minimal. Such low inherent energy requirements and the possibility of energy recovery make this process extremely attractive.

10A. Product's Competitors

	Application	Competing Technology	Energy (Wh/gal)	Regeneration	Manufacturer Source of Info.	Mfg. Address Plant Location	Capacity (gal/day)	Unit Cost ($)
1	Ion Exchange Replacement	Carbon Aerogel Capacitive Deionization	0.2-0.4	Electrical	LLNL	Livermore, CA	60 (240-7200)	(30-500K)
2	Ion Exchange Replacement	Continuous Deionization	0.5	Electrical	U.S. Filter Corporation	Roseville, MN	120	
3	Home Water Softening	Ion Exchange	Small	Salt: 120-193 lb/mo Water: 400-960 gal/mo	Culligan Water Systems	Modesto, CA	864-5760	1.5K-3K
4	Waste Treatment	Ion Exchange	Small	Acid or Base: 100 lb per lb Ion Exchange Resin	Kinetico, Incorporated	Newbury, OH	240-7200	30-500K
5	Boiler Water	Ion Exchange	Small	Acid or Base: 100 lb per lb Ion Exchange Resin	Kinetico, Incorporated	Newbury, OH	288-7200	18-500K
6	Ultra Pure Water for Manufacturing	Ion Exchange	Small	Acid or Base: 100 lb per lb Ion Exchange Resin	Western Water Equipment Co.	San Mateo, CA	50K	~150K
7	Desalination of Brackish Water	Carbon Aerogel Capacitive Deionization	0.2-0.4	Electrical	LLNL	Livermore, CA	60	
8	Desalination of Brackish Water	Electrodialysis	7.7	None	CH2M Hill	Saskatchewan, Canada	304K	
9	Desalination of Brackish Water	Reverse Osmosis	5.3-8.5	None	CH2M Hill	Saskatchewan, Canada	228K	

10A. Product's Competitors (Continued)

	Application	Competing Technology	Energy (Wh/gal)	Regeneration	Manufacturer Source of Info.	Mfg. Address Plant Location	Capacity (gal/day)	Unit Cost ($)
10	Desalination of Sea Water	Carbon Aerogel Capacitive Deionization	16-32	Electrical	LLNL	Livermore, CA	60 (7M)	(38M)
11	Desalination of Sea Water	Reverse Osmosis	18-25	None	Ionics	Santa Barbara, CA	7M	38M
12	Desalination of Sea Water	Reverse Osmosis	25-36	None	Weir-Westgarth	Bahrain	12M	
13	Desalination of Sea Water	Mechanical Vapor Recompression	25	None	Superstill Technology	Redwood City, CA	24K	135K
14	Desalination of Sea Water	Multiple Effect Distillation with Mechanical Vapor Recompression	30-41	None	Israeli Desalting Engineers	St. Croix, St. Thomas, Virgin Islands	400K	
15	Desalination of Sea Water	Electrodialysis	74	None		Kavaratti Island, India	21K	
16	Desalination of Sea Water	Multiple Effect Distillation with Thermal Vapor Recompression	215-315	None		Mirfa, Sila, Jabel Dhanna	6M	
17	Desalination of Sea Water	Multistage Flash	320	None		Abu Dhabi	12M	
18	Desalination of Sea Water	Simple Evaporation (No Energy Recovery)	2720	None				

Note: CDI with carbon aerogel has been routinely demonstrated with brackish water concentrations (1000 ppm), but has not yet been used with sea water concentrations. The greatest concentration dealt with to date is 10,000 ppm. Assumptions about the use of CDI for sea water desalination are based upon extrapolations of data at brackish water concentrations. The CDI unit capacity and cost in parenthesis are estimates. Actual product prices will be established by companys licensing the technology.

10B. Comparison of Competing Products and Technologies

	Application	Competing Technology	Disadvantage of Competing Technology	Advantage of Carbon Aerogel CDI
1	Ion Exchange Replacement	Continuous Deionization	The energy requirement is ~0.5 Wh/gal. Continuous deionization consumes electrical power, but stores none for subsequent recovery. Complicated by the simultaneous use of ion exchange resin, ion exchange membranes, and electrodes.	The energy requirement is ~0.18-0.36 Wh/gal, depending upon energy recovery. Theoretical minimum ~0.02 Wh/gal. Carbon aerogel CDI stores electrical energy for recovery. Uses only carbon aerogel electrodes. No ion exchange resin or membranes.
2	Treatment of hazardous and radioactive aqueous wastes.	Ion Exchange	Chemical regeneration is required. Approximately 100 lb of concentrated acid or base per lb of regenerated ion exchange resin. Regenerant solutions become secondary waste.	No chemical regeneration is required. Regeneration of the adsorption media, carbon aerogel, is done electrically. Elimination of 100lb of corrosive secondary waste per lb of regenerated resin.
3	Boiler Water	Ion Exchange	Chemical regeneration is required. Approximately 100 lb of concentrated acid or base per lb of regenerated ion exchange resin. Regenerant solutions become secondary waste.	Elimination of 100lb of corrosive secondary waste per lb of regenerated resin. No possible contamination of steam cycle with corrosives.
4	Home Water Softening	Ion Exchange	The salt required for regeneration is 120-193 lb/mo and the water required for regeneration is 400-960 gal/mo. Salt is introduced into drinking water and must be removed by RO system.	No chemical regeneration required. Long-term unattended operation. No salt introduced into drinking water. RO is unnecessary. No secondary waste discharged.
6	Ultra Pure Water for Manufacturing	Ion Exchange	Chemical regeneration is required. Approximately 100 kg of concentrated acid, base, or salt solution per kg of regenerated ion exchange resin. Regenerant solutions become secondary waste.	No chemical regeneration is required. Regeneration of the adsorption media, carbon aerogel, is done electrically. Elimination of 100lb of corrosive secondary waste per lb of regenerated resin.
7	Desalination of Brackish Water (1000-2000 ppm)	Electrodialysis	The energy requirement is 7.7 Wh/gal. The cost of purified water is primarily due to electricity (42%), membrane replacements (8%), and treatment chemicals (25%) [Desalination, 84, 1991, 109-121].	The energy requirement is ~0.18-0.36 Wh/gal, depending upon energy recovery. Theoretical minimum ~0.02 Wh/gal. Unlike electrodialysis, carbon aerogel CDI stores electrical energy for recovery. Expensive and troublesome ion exchange membranes eliminated. Life of carbon aerogel electrodes expected to greatly exceed that of ion exchange membranes.
8	Desalination of Brackish Water (1000-2000 ppm)	Reverse Osmosis (RO)	The energy requirement is ~5.3-8.5 Wh/gal. High pressure pumps and hardware are needed. Scale formation and fouling make chemical treatment necessary. Polymeric membranes are susceptible to chemical attack by chlorine and other chemicals. The cost of purified water is primarily due to electricity (29%), membrane replacements (32%), and treatment chemicals (21%) [Desalination, 84, 1991, 109-121].	The energy requirement is ~0.18-0.36 Wh/gal, depending upon energy recovery. Theoretical minimum ~0.02 Wh/gal. Expensive high-pressure pumps and hardware eliminated. Expensive and troublesome RO membranes eliminated. Life of carbon aerogel electrodes expected to greatly exceed that of RO membranes. Inorganic carbon aerogel electrodes are chemically resistant.

10B. Comparison of Competing Products and Technologies (Continued)

	Application	Competing Technology	Disadvantage of Competing Technology	Advantage of Carbon Aerogel CDI
9	Desalination of Sea Water (35,000 ppm)	Electric Demineralizer (U.S. Pat. No. 3,755,135, Aug. 28, 1973)	Deep beds of activated carbon powder. Drops in electric potential and hydrodynamic pressure in beds. Irreversible loss of adsorption capacity. Entrainment of carbon powder in stream. Need for porous electrode separators. Relatively low specific surface area of powder used in flow-through bed (200-300 m^2/gm). No automation or energy recovery. Such problems prevented development of commercial product.	Monolithic sheets of carbon aerogel. Insignificant potential drop. No irreversible loss of adsorption capacity. Monolithic sheets not entrained in flow. Electrode separators not needed. Channel flow with low pressure drop. Carbon aerogel electrodes have very high specific surface area (600-1000 m^2/gm). Fully automated potential-swing mode of operation with energy recovery option.
10	Desalination of Sea Water (35,000 ppm)	Reverse Osmosis (RO)	The energy requirement is ~25-36 Wh/gal [Desalination, 93, 1993, 343-363]. RO requires high-pressure pumps and hardware ($\Delta P \approx 1000$ psi). Cost of periodic membrane replacements. Chemical attack of membranes by additives. The cost of purified water is primarily due to electricity (43%) and membrane replacements (20%) [Desalination, 99, 1994, 39-55].	The energy requirement is ~16-32 Wh/gal, depending upon energy recovery. Theoretical minimum ~4 Wh/gal. Expensive high-pressure pumps and hardware eliminated. Expensive and troublesome RO membranes eliminated. Life of carbon aerogel electrodes expected to greatly exceed that of RO membranes. Carbon aerogel is more chemically resistant than membranes.
11	Desalination of Sea Water (35,000 ppm)	Mechanical Vapor Recompression	The energy requirement is ~25 Wh/gal [Superstill Technology, Incorporated]. Compressor maintenance. Scaling of heat transfer surfaces. General and localized corrosion of equipment.	The energy requirement is ~16-32 Wh/gal, depending upon energy recovery. Mimimal scaling and corrosion. No compressor.
12	Desalination of Sea Water (35,000 ppm)	Multiple Effect Distillation with Mechanical Vapor Recompression	The energy requirement is ~30-41 Wh/gal [Desalination, 93, 1993, 343-363]. Compressor maintenance. Scaling of heat transfer surfaces. General and localized corrosion of equipment.	The energy requirement is ~16-32 Wh/gal, depending upon energy recovery. Mimimal scaling and corrosion. No compressor.
13	Desalination of Sea Water (35,000 ppm)	Electrodialysis	The energy requirement is ~74 Wh/gal [Desalination, 84, 1991, 201-211]. Electrodialysis consumes electrical power, but stores none for subsequent recovery. Ion exchange membranes are more expensive than RO membranes. These membranes also require periodic replacement	The energy requirement is ~16-32 Wh/gal, depending upon energy recovery. Unlike electrodialysis, carbon aerogel CDI stores electrical energy for recovery. Expensive and troublesome ion exchange membranes eliminated. Life of carbon aerogel electrodes expected to greatly exceed that of ion exchange membranes
14	Desalination of Sea Water (35,000 ppm)	Multiple Effect Distillation with Thermal Vapor Recompression	The energy requirement is ~215-315 Wh/gal [Desalination, 93, 1993, 343-363]. Scaling of heat transfer surfaces. General and localized corrosion of equipment.	The energy requirement is ~16-32 Wh/gal, depending upon energy recovery. Mimimal scaling and corrosion.
15	Desalination of Sea Water (35,000 ppm)	Multistage Flash	The energy requirement is ~320 Wh/gal [Desalination, 93, 1993, 343-363]. Scaling of heat transfer surfaces. General and localized corrosion of equipment	The energy requirement is ~16-32 Wh/gal, depending upon energy recovery. Mimimal scaling and corrosion.

10C Improvements Over Competing Products and Technologies

- *Overview.* CDI has several potential advantages over other more conventional technologies. Unlike ion exchange, no acids, bases, or salt solutions are required for regeneration of the system. Regeneration is accomplished by electrically discharging the cells. Therefore, no secondary waste is generated. Since no membranes or high pressure pumps are required, CDI offers operational advantages over electrodialysis and reverse osmosis (RO). CDI is more energy efficient than competing technologies. The energy advantage over thermal processes is dramatic.

- *Enhanced energy efficiency for the treatment of brackish water.* Carbon aerogel capacitive deionization (CDI) can be used to treat brackish water (800 to 3200 ppm). This application is very important to communities along the coast of California, including San Diego, Los Angeles, and the San Francisco Bay Area. Competing technologies for the treatment of brackish water are electrodialysis (ED) and reverse osmosis (RO). These processes consume 7.7 and 8.5 Wh/gal, respectively. CDI is much more energy efficient, requiring only 0.2 to 0.4 Wh/gal, depending upon energy recovery, cell geometry, and operation.

- *Enhanced energy efficiency for the desalination of sea water.* Carbon aerogel capacitive deionization (CDI) can be used to desalinate sea water (35,000 ppm). This application is also important to countries around the world, especially in the Middle East. Competiting technologies for the desalination of sea water include electrodialysis (ED), reverse osmosis (RO), mechanical vapor recompression (MVR), multiple effect distillation with mechanical vapor recompression (MED-MVR), multistage flash evaporation (MFE), and multiple effect distillation with thermal vapor recompression (MED-TVR). RO consumes ~25-35 Wh/gal, MVR consumes ~25 Wh/gal; MED-MVR consumes ~30-41 Wh/gal, ED consumes ~74 Wh/gal, MED-TVR consumes ~215-315 Wh/gal, MFE consumes ~320 Wh/gal, and simple evaporation consumes ~2720 Wh/gal. In contrast, the energy consumption for carbon aerogel CDI is estimated to be ~16-32 Wh/gal, depending upon energy recovery, cell geometry, and operation. In this particular application, carbon aerogel CDI should be more energy efficient than all competing technologies. Carbon aerogel CDI has additional cost advantages over ED and RO since expensive and troblesome membranes are eliminated. Problems associated with the corrosion and scaling of heat transfer surfaces in thermal processes such as MEE, MED-MVR, MFE, and MED-TVR are avoided. Problems associated with compressor repair and maintenance in MVR and MED-MVR are also avoided.

- *Elimination of costly and troublesome membranes.* Carbon aerogel CDI has additional cost advantages over ED and RO since expensive and troublesome membranes are eliminated. For example, approximately 52% of the cost of purifying water with early RO systems was due to membrane replacements [Chemical Engineers' Handbook, Perry and Chilton, 5th Edition]. Membrane raplacements in modern systems is still relatively high, accounting for approximately 32% of the cost of purified water [Desalination, 84, 1991, 109-121]. Polymeric membranes are susceptible to chemicals used for removing deposits and treating water. Chlorine is particularly agressive. In contrast, carbon aerogel is chemically resistant.

- *Elimination of wastes from chemical regeneration.* Carbon aerogel CDI can be used for home water softening, the treatment of hazardous and radioactive wastes, the deionization of boiler water for steam and power generation, and the production of ultra pure water for manufacturing. The primary competing technology is ion exchange. This process requires chemical regeneration of the ion exchange resin. For example, the salt and water required for regeneration of a typical home water softener are 120-193 lb/mo and 400-960 gal/mo, respectively. Industrial applications of ion exchange require 100 pounds of acid for the regeneration of one pound of cation exchange resin, or 100 pounds of base for the regeneration of one pound of anion exchange resin. Carbon aerogel CDI uses electrical regeneration, thereby eliminating the need for chemical regenerants and the associated wastes.

- *Simplier and more energy efficient than Continuous Deionization.* A new electrically-regenerated process known as Continuous Deionization is now available [G.C. Ganzi, et al., Environ. Prog. 11, 1 (1992) 49-53]. This technology is a hybrid of electrodialysis and ion exchange and consumes approximately 0.5 Wh/gal. CDI is more energy efficient and requires only 0.2 to 0.4 Wh/gal, depending upon energy recovery, cell geometry, and operation. Continuous Deionization requires ion exchange resins, ion exchange membranes, and electrodes. Carbon aerogel CDI requires only carbon aerogel electrodes. The polymeric ion exchange media used in Continuous Deionization are susceptible to chemical attack during the removal of scale and fouling. Carbon aerogel is resistant to chemical attack.

- *Carbon aerogel is superior to beds of activated carbon.* Another electrochemical process known as Electric Demineralization was patented over 20 years ago [A.M. Johnson, U.S. Patent 3,755,135, August 28, 1973]. Other reports of this process appeared 30 years ago [D. D. Caudle, Oklahoma U. Res. Inst., 1966]. The principle of operation is similar to that of CDI, however, this process uses flow-through packed beds of activated carbon as electrodes. Unfortunately, problems associated with the use of such packed beds prevented the development of a commercial product. Problems include the irreversible loss of electrosorption capacity during operation, the relatively low specific surface area of the activated carbon appropriate for use in such flow-through beds, electric potential drop across beds, hydrodynamic pressure drop across beds, bed erosion due to the entrainment of carbon powder in the flowing stream, and the need for porous electrode separators. CDI with monolithic carbon aerogel electrodes offers numerous advantages over CDI with flow-through packed beds of activated carbon. Slight drops in the electrosorption capacity of carbon aerogel electrodes have been fully reversed by periodic potential reversal. System capacity can be maintained at a high level. Since the specific surface area of carbon aerogel (600-1000 m^2/gm) is significantly greater than that of activated carbon powder appropriate for use in a flow-through packed bed (230 m^2/gm or 200-300 m^2/gm), a greater quantity of salt can be electrosorbed on carbon aerogel than on a comparable mass of activated carbon powder [A.M. Johnson, J. Newman, J. Electrochem. Soc. 118, 3 (1971) 510-517]. The LLNL demonstration process has 384 pairs of carbon aerogel electrodes (768 individual electrodes) and a total activated surface area of 2.2×10^9 cm^2. Less potential drop occurs in a thin sheet of carbon aerogel than in a relatively deep bed of activated carbon. Consequently, more ions can be electrosorbed on a unit of carbon aerogel surface area than on a comparable unit of activated carbon surface area. In deep packed beds of carbon, the potential can drop to levels where the electrosorption process is not very effective. Immobilization of the carbon in the form of aerogel has made it possible to construct systems that do not require porous membrane separators. Unlike activated carbon powder, monolithic sheets of carbon aerogel are not entrained in the flowing fluid stream. Water passes through open channels between adjacent anodes and cathodes, experiencing only a modest pressure drop of only 30 psi. In contrast, flow through a packed bed of activated carbon with comparable surface area experiences a signficantly greater pressure drop (≥1000 psi).

- *Simple, modular plate-and-frame cell construction.* Electrochemical cells required for Continuous Deionization and Electric Demineralization are complicated by the need for particulate ion exchange resin and activated carbon, ion exchange membranes, electrode separators, and electrodes. CDI requires simple, double-sided planar electrodes. Double-sided electrode are made by simply gluing two sheets of a carbon aerogel composite to both sides of a titanium plate that serves as both a current collector and a structural support. Conductive silver epoxy is used for gluing. As previously mentioned, the carbon aerogel composite has an exceptionally high specific surface area of 600-1000 m^2/gm. Each sheet is 6.86 cm x 6.86 cm x 0.0125 cm and has a total active surface of approximately 2.8×10^6 cm^2. Two orifices are located along one side of the carbon aerogel electrode and admit water to the electrode gap. A pattern of holes are located around the perimeter of the titanium plate and accommodate 12 threaded rods that hold the cell stack together. Figure 4 shows a lower stainless steel header with a rubber gasket and 12 threaded rods; an array of electrodes, gaskets, and spacers; and an upper stainless steel header. The assembly of these components into a CDI cell is also very simple. The electrodes and headers are aligned by the threaded rods. An electrode separation of 0.05 cm is maintained by cylindrical nylon spacers concentric with the threaded rods and a rubber compression seal. Even electrodes serve as cathodes while odd electrodes serve as anodes. Since the orifices in each electrode alternate from one side of the stack to the other, the flow path through the stack is serpentine. A typical CDI cell configuration consists of 384 pairs of carbon aerogel electrodes with a total active cathodic (or anodic) surface area of approximately 2.2×10^9 cm^2. However, the system can be expanded to accommodate any desired concentratioin gradient across the stack, as well as any flow rate. Scale-up for capacity and concentration are straight forward.

- *Carbon aerogel is easy to make and commercially available.* Carbon aerogels were developed at Lawrence Livermore National Laboratory and are synthesized by the polycondensation of resorcinol and formaldehyde in a slightly basic medium, followed by supercritical drying and pyrolysis in an inert atmosphere. Monolithic sheets of this material are made by impregnating carbon cloth with the resorcinol-formaldehyde solution and then carbonizing. This fabrication process results in unique open-cell carbon foams that have high porosities, high specific surface areas (600-1000 m^2/g), ultrafine cell and pore sizes (≤ 50 nm), and a solid matrix composed of interconnected colloidal-like particles or fibrous chains with characteristic diameters of 10 nm. The porosity and surface area of aerogels can be controlled over a broad range, while the pore size and particle size can be tailored at the nanometer scale. This process technology has already been licensed to Aeroget of Sacramento, California for large-scale commercial production of carbon aerogel sheets. A commercial supplier of the electrode material now exists.

- *Carbon aerogel is resistant to chemical attack.* Fouling and scale formation are inevitable in process equipment used for desalination. Agressive chemical treatments are required for rejuvenation. It is desirable to construct equipment out of materials that can withstand such chemical treatments. Carbon aerogel is resistant to many of the chemicals now used for scale control, such and HCl. Unlike polymeric membranes and resins, it is also resistant to dissolution by organic solvents. Oxidants such as chlorine attack polyamide reverse osmosis membranes, but do not appear to be a significant problem in carbon aerogel systems. Similar problems are encountered with electrodialysis and Continuous Deionization. Despite this optimism, additional studies in this very important area are needed so that effective scale control strategies can be developed.

- *Fully-automated potential-swing operation.* The Electric Demineralization process was operated in batch mode with no energy recovery. For a continous flow of product water, two stacks of carbon aerogel electrodes must be operated in parallel. One stack purifies while the other is electrically regenerated. This mode of operation is called *potential swing* and also enables energy recovery. For example, energy released during the discharge of one stack of electrodes (regeneration) can be used to charge the other stack (deionization). Such synchronous operation requires user-friendly automation. This level of automation and sophisticationi has been developed for this product and is illustrated by Fig. 5. The CDI control system is implemented using a 486DX 33-megahertz computer with 16 megabytes of memory and a 340 megabyte hard disk. A 21 inch high resolution color monitor serves as the operator display. Operator input is via a mouse & keyboard. The operating system is DOS v6.22 running Windows v3.1. A single AT-MIO-16DH data acquisition board, installed in the computer, provides the interface to the Input-Output (I/O) Signal Subsystem. The I/O subsystem consist of a single 12-slot Signal Conditioning Extension Interface (SCXI) chassis. The chassis contains seven 8-channel analog-to-digital (A/D) modules to measure flow, level, pressure, temperature, pH, and conductivity; two 16-channel SPDT relay modules for controlling pumps and valves; one 6-channel digital-to-analog (D/A) module for controlling power supply voltages and pump speed. The SCXI hardware provides filtering, isolation, and amplification for the front-end signals. LabVIEW v3.1 software, running under Windows, is used for data acquisition and control. LabVIEW is a graphical based environment which provides integrated tools for acquisition, control, analysis, and presentation, as well as connectivity to serial, parallel, voltage, current loop, RTD, thermistor, and relay communication interfaces. User developed software is optimized and converted to compiled run-time code. This control system can be used for a small plant (hundreds of gallons per day) or a very large plant (millions of gallons per day).

11A. Principal Application

- *Processing radioactive materials and wastes.* This new technology was developed specifically for the removal of various ionic contaminants from aqueous streams without the generation of acid and base secondary wastes. This may be especially important in cases involving dissolved radionuclides and heavy metals. Ion exchange is now used for such applications. For example, cation exchange resings resins and solutions of HNO_3 become contaminated with PuO_2^{2+} and other radioisotopes during plutonium processing. In this case, every kilogram of cation exchange resin requires approximately 100 kilograms of 10 wt. % HNO_3 and 2 to 3 kilograms of rinse water for regeneration. Similarly, every kilogram of used anion exchange resin requires approximately 100 kilograms of 10 wt. % NaOH and 2 to 3 kilograms of rinse water for regeneration. These solutions become contaminated with ions removed from the resins and become part of a large inventory of secondary waste. Eventually, the resins also become part of the inventory of secondary waste. Similar problems are encountered with the uranium processing and the treatment of radioactive wastes. The United States Department of Energy has an inventory of approximately one billion liters of $NaNO_3$ solution contaminated with ^{137}Cs, ^{90}Sr, ^{60}Co and other radioactive materials. Given the high and increasing cost of disposal of secondary wastes in mined geological repositories, there is tremendous and still unfulfilled need for reducing, and in certain applications, eliminating the volume of secondary wastes. Due to funding sources and the immediate needs of the U.S. DOE, this application has been the primary focus of work done to date. However, due to regulatory constraints, thisproduct has not yet been operated with radioactive solutions. Thus far, only surrogates have been used. Applications listed under 11B will probably be commercialized first. The feasibilities of these applications have already been demonstrated.

11B. Other Applications

- *Domestic water softening.* This product can also be used to soften home drinking water without the introduction of sodium chloride. A typical domestic water softener uses sodium chloride to regenerate a bed of ion exchange resin. Downstream of the ion exchanger, RO is used to remove the sodium chloride introduced during regeneration. A CDI system would not require manual salt additions for regeneration and would not have to be followed by RO. CDI would also remove heavy metal and organic contaminants from the water.

- *High purity water for manufacturing.* CDI can also be used to replace ion exchange systems used for the production of high-purity water for biotechnology applications, semiconductor processing, and other demanding manufacturing processes. In addition to removing conductivity without the addition of other chemical impurities, the system probably removes small suspended solids by electrophoresis. Furthermore, organic impurities will chemisorb to the carbon.

- *Treatment of boiler water for power generation.* This technology can be used for the treatment of boiler water for nuclear and fossil-fired power plants. Such water is now treated with ion exchange to remove ionic contaminants such as Mg^{+2}, Ca^{+2}, Cu^{+2}, and Cl^{-}.

Elimination of these impurities is essential for the prevention of pitting, stress corrosion cracking, and scaling of heat transfer surfaces.

- *Treatment of waste water from electroplating.* A typical electroplating process involves immersing an object to be electroplated into an electrolyte which contains dissolved metals such as nickel, cadmium, zinc, copper, silver, or gold, as well as a variety of salts. After the electroplating process is completed, the plated object is rinsed to remove residual electroplating solution and associated contaminants. Consequently, the rinse water becomes contaminated, creating a major environmental problem for the metal finishing and printed circuit board industry. At the present time, ion exchange is used for the treatment of such rinse water. CDI could provide advantages here as well.

- *Desalination of brackish water.* The energy efficiency of CDI with carbon aerogel electrodes and the lack of troublesome membranes makes such a process a contender for desalinating brackish water in California. See the attached letters. The primary competiting technology in Calironia is reverse osmosis (RO). These processes consume 7.7 and 8.5 Wh/gal, respectively. CDI is much more energy efficient, requiring only 0.2 to 0.4 Wh/gal, depending upon energy recovery, cell geometry, and operation.

- *Desalination of sea water.* In some cases, the energy efficiency of CDI may also make it a viable competitor for sea water desalination. It offers many of the same advantages in this application as it does in the desalination of brackish water. However, this application is much more demanding since concentration gradient across the stack is much larger.

11C. Feasibility of Other Potential Applications

- *Treatment of radioactive water produced during accidents.* CDI could also be used to remove radioactive ions from the contaminated waste water of nuclear power plants before discharge. Deionizers based on columns of zeolite, silica gel, and ion exchange resins were evaluated for the removal ^{137}Cs, ^{90}Sr, and ^{125}Sb from contaminated water at the Three Mile Island Nuclear Power Station Unit No. 2. As previously discussed, ion exchange columns require chemical regeneration and thereby produce large volumes of radioactive secondary waste. Eventually, the contaminated columns also become waste. Since CDI uses electrical regeneration, it seems ideal for such applications. The feasibility of this important potential application has not yet been demonstrated. Due to the same regulatory constraints that have delayed demonstration of the principal application discussed in 11A, CDI has not yet been demonstrated with radioactive water.

12. Reasons for Receiving 1995 RD100 Award

- *Importance of Technology.* President John F. Kennedy said, "If we could ever competitively, at a cheap rate, get fresh water from salt water, ... this would be in the long-range interests of humanity, ... (and) would dwarf any other scientific accomplishment." CDI with carbon aerogel electrodes will enable the competitive, cheap production of fresh water from salt water and will provide long-range benefit to humanity.

- *Technology Transfer.* Successful commercialization of this new technology depends vitally on the involvement of industry. A patent on this process has been filed and granted. The Technology Transfer and Public Affairs Offices at LLNL have used media such as CNN and other contacts with the public to effectively market this new product. Several corporations have expressed interest in the technology and are in the process of pursuing licenses. Potential customers have also expressed interest in the technology. Customers include several large municipalities, government agencies, branches of the military, and corporations. See attached examples of letters. The RD100 Award will serve as an important marketing tool for the continued promotion of this important new technology.

- *Funding.* Continued improvements of this technology will require additional research and development. The RD100 Award will aid the developers of this important new technology to obtain additional funding to suport the product.

16. Acknowledgements

Discussions on desalination with Sherman May of Bechtel Corporation have been extremely valuable. Encouragement by John Holzrichter, Jeff Kass, Martyn Adamson, and Sam Kassatly are gratefully acknowledged. Funding for the development of the carbon aerogel CDI process was provided by the Strategic Environmental Research and Development (SERDP) Program. The development of the carbon aerogel material was sponsored by the U.S. Department of Energy (DOE) Office of Basic Energy Sciences (OBES) and the Lawrence Livermore National Laboratory (LLNL) Laboratory Directed Research and Development (LDRD) Program. This work was done under the auspices of the U.S. DOE by LLNL under Contract No. W-7405-Eng-48.

Figures

Fig. 1. Cartoon illustrating the principal of operation of carbon aerogel CDI.

Fig. 2. Data showing the effect of cell voltage on salt removal in tests with complete recycle.

Fig. 3. Data showing the removal of salt from a water during single-pass operation. Breakthrough is observed when the carbon aerogel is saturated with salt. After saturation, the system must be electrically regenerated. Salt is concentrated into a small volume of purge water.

Fig. 4. Photograph showing the components of a CDI cell.

Fig. 5. Photograph showing a computer-controlled potential-swing CDI prototype.

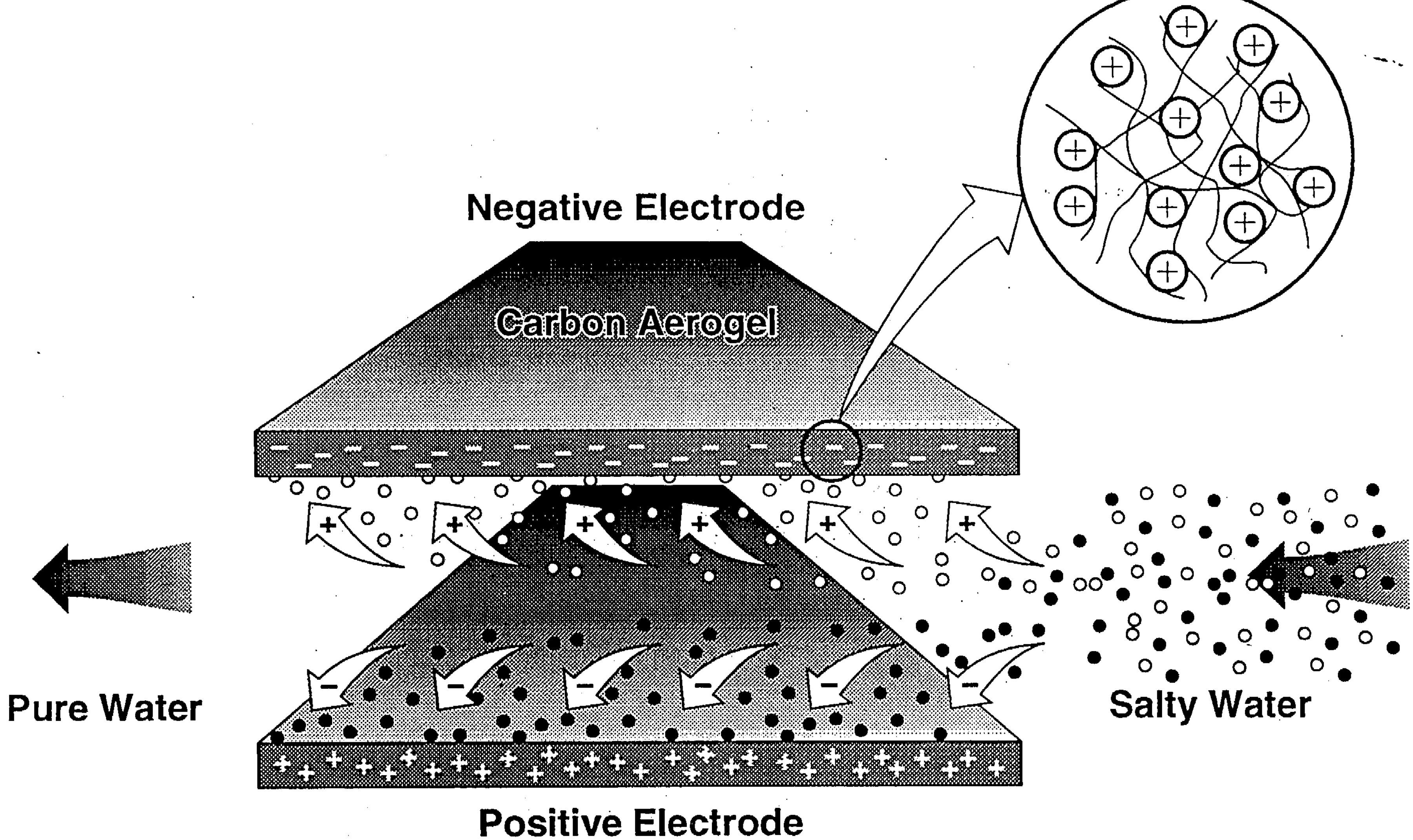

Negative Electrode
Carbon Aerogel
Pure Water
Salty Water
Positive Electrode

Fig. 1

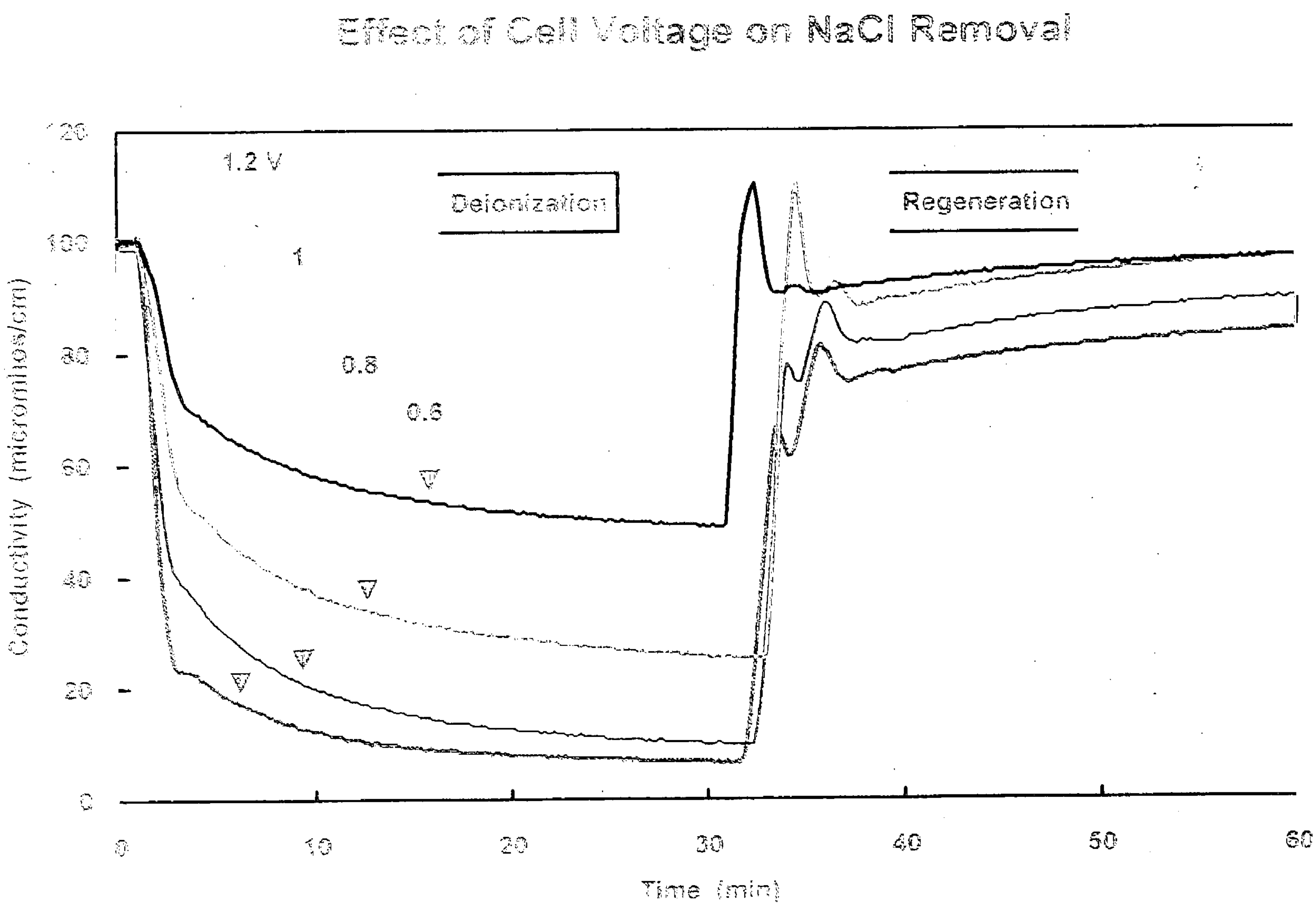

Effect of Cell Voltage on NaCl Removal
1.2 V
1
0.8
0.6
Deionization
Regeneration
Conductivity (micromhos/cm)
Time (min)
0
20
40
60
80
100
120
0
10
20
30
40
50
60

Fig. 2

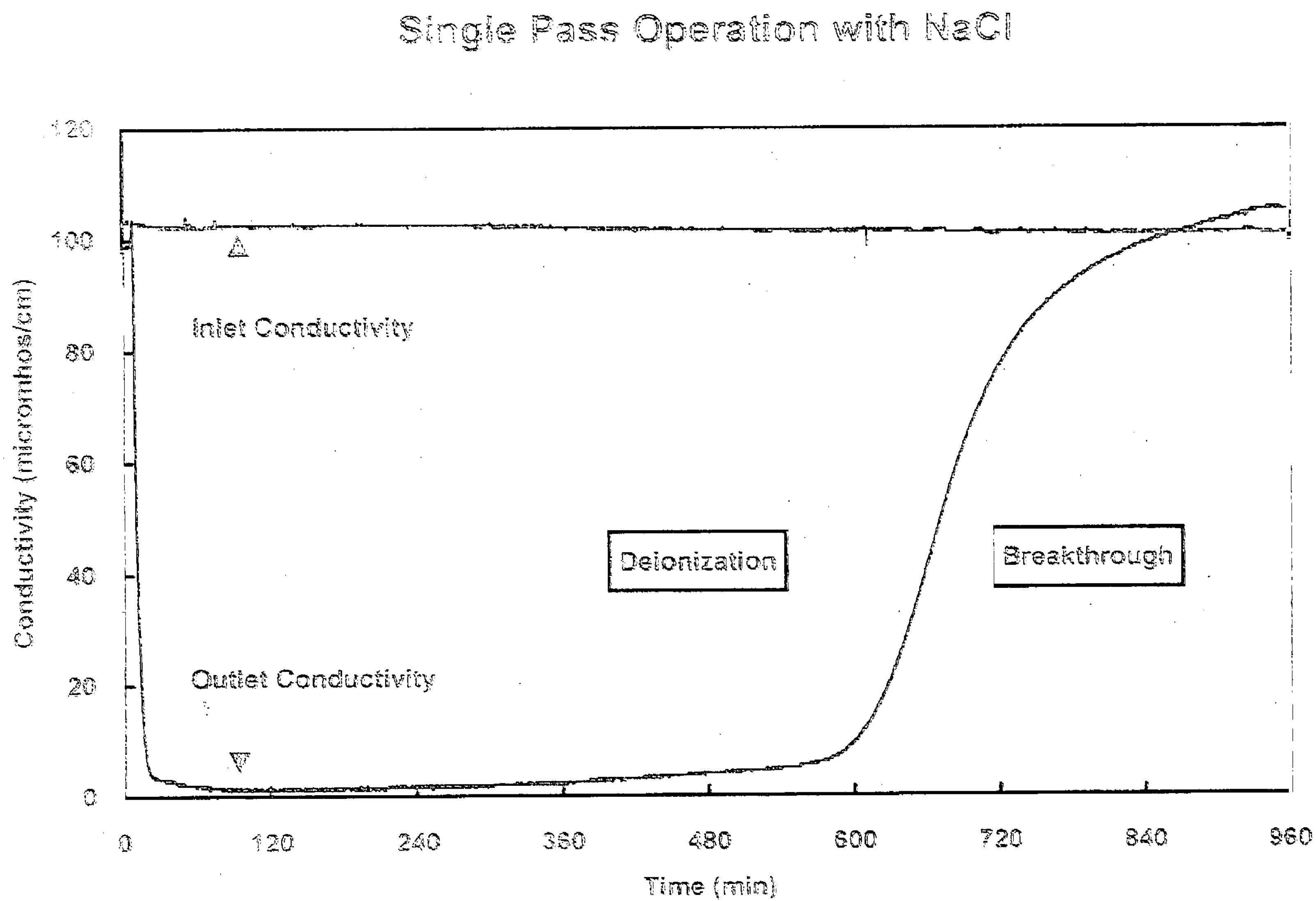
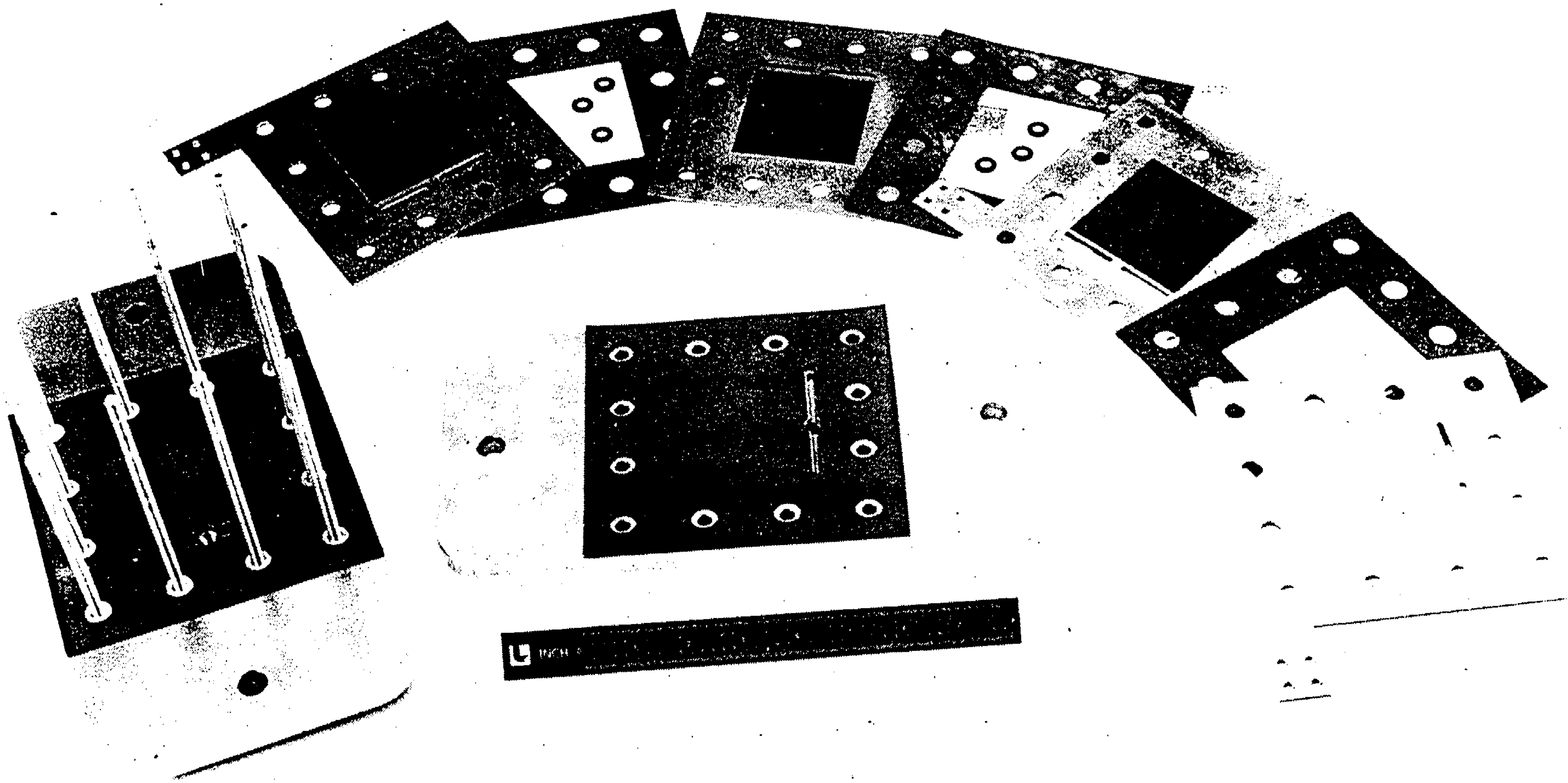
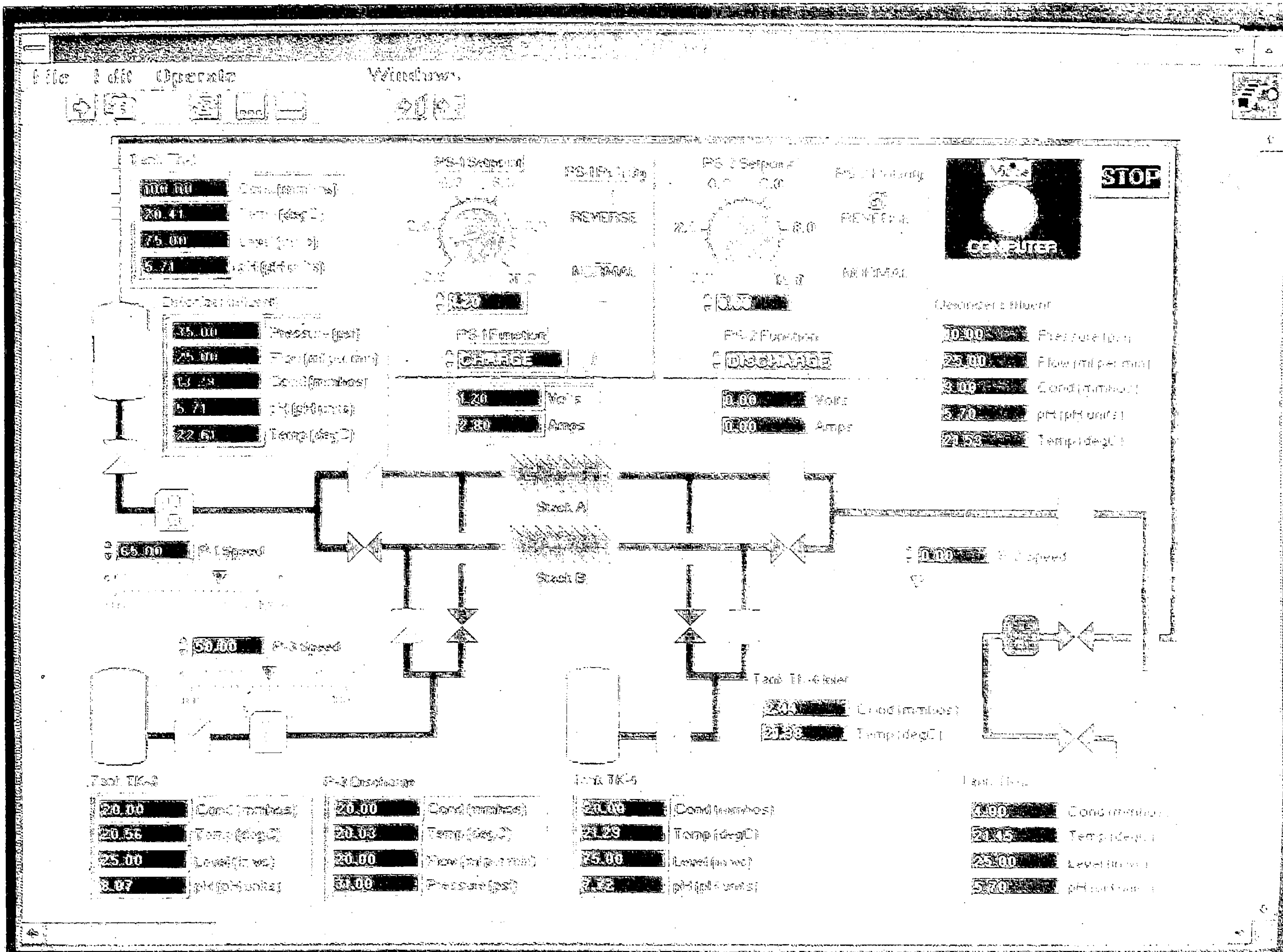
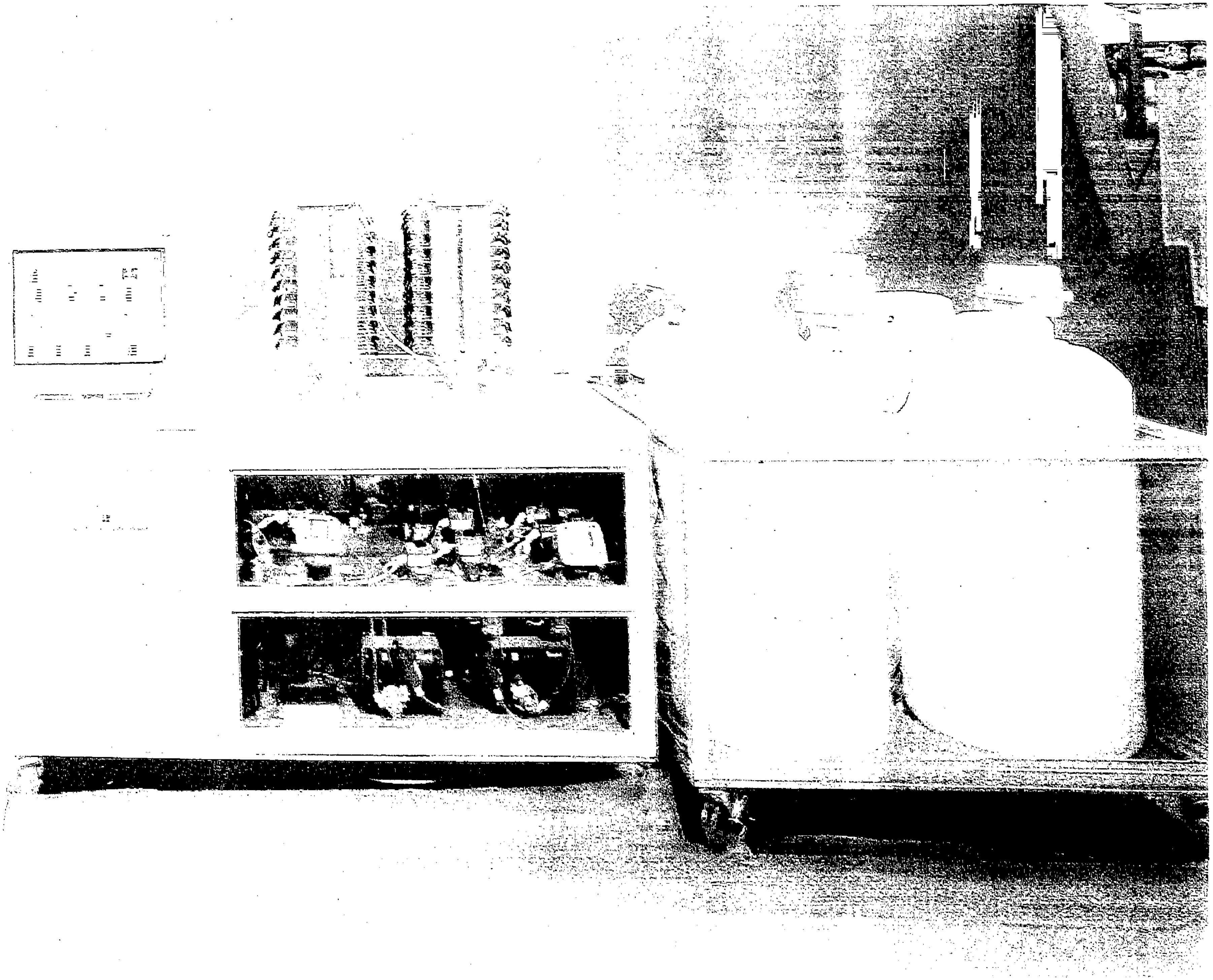

Single Pass Operation with NaCl
120
100
80
60
40
20
0
Conductivity (micromhos/cm)
Inlet Conductivity
Outlet Conductivity
Deionization
Breakthrough
0
120
240
360
480
600
720
840
960
Time (min)

Fig. 3


INCH



Windows
Tank TK-1
100.00 Cond (mmhos)
20.41 Temp (degC)
75.00
5.71
PS-1 Setpoint
REVERSE
NORMAL
35.00 Pressure (psi)
25.00 Flow (ml per min)
Cond (mmhos)
5.71 pH (pH units)
22.61 Temp (degC)
PS-1 Function
CHARGE
PS-2 Function
DISCHARGE
1.20 Volts
2.80 Amps
0.00 Volts
0.00 Amps
COMPUTER
STOP
Stack A
Stack B
65.00 P-1 Speed
50.00 P-3 Speed
Tank TK-2
20.00 Cond (mmhos)
20.56 Temp (degC)
25.00 Level (in wc)
8.07 pH (pH units)
P-3 Discharge
20.00 Cond (mmhos)
20.03 Temp (degC)
20.00 Flow (ml per min)
31.00 Pressure (psi)



Examples of Letters

1. U.S. Filter Corporation
2. Apollo Mobile Systems
3. U.S. Department of Interior
4. North Coast County Water District
5. Alameda County Water District
6. San Diego County Water Authority
7. California-American Water Company and Monterey Bay Water Works Association
8. Lou Haddad, Board of Directors, Monterey Peninsula Water Management District
9. Paul Crawford, Palm Beach Country Club

U.S. FILTER
RECOVERY SERVICES, INC.

2430 ROSE PLACE
ROSEVILLE, MN 55113
TEL: 612-633-0079
FAX: 612-633-5074

January 3, 1995

Dr. Joseph C. Farmer
Lawrence Livermore National Laboratory
Mail Stop L 369
7000 East Avenue
Livermore, CA 94551

Dear Dr. Farmer:

Enclosed is the background information on U.S. Filter Corporation that you requested. I have enclosed a variety of sources on our company to give you a broad feel for what we are all about in the water treatment industry.

I look forward towards our meeting next Wednesday January 11, 1995 at 1:00 p.m. I have sent a similar information package to Mr. Bill Grant.

I will be accompanied by our Vice President of Research and Development, Gary Ganzi, SS# 077-38-5566.

We are eager to learn more about the Carbon Aero Gel, its potential applications and the possibility of working with your research department to further its development.

Please do not hesitate to call with any questions prior to our visit.

Sincerely,

Tim Traff
Senior Vice President,
Corporate Development

TT/ll

Apollo Mobile Systems

Apollo Ultrapure Water Systems, Inc.

California Purification & Recycling

February 7, 1995

Mr. Charles Pomernacki
Lawrence Livermore National Laboratory
P.O. Box 808, L-795
Livermore, CA 94551

Dear Chuck:

Thank you for meeting with me last Thursday, February 2.

As you all know, I am very interested in the technology presented during our meeting and would like to proceed immediately. To initiate this lincensing venture, we are willing to put $100,000 into escrow.

We would also appreciate any assistance LLNL could provide to get us started in the right direction and would make ourselves available at your convenience, be it weekends, after hours, etc., to accommodate your timetables. Naturally, we would gladly recompense for any support you could extend. Perhaps Dave or Greg might be available to help us construct a prototype at our facility.

Once again, thank you for the opportunity to meet with you and to view your facility. I am very anxious to move forward with this project as soon as possible and look forward to your response.

Sincerely,

Larry Putnam
President

LP/sd

cc: Bill Grant
Joe Farmer

CORP.: 7777 Industry Avenue
Pico Rivera, California 90660

6205 Fairmount Ave.
San Diego, CA 92120
[illegible]

666 Stockton, Unit L
San Jose, CA 95126
(408) 292-1313

3802 E. Illini, Unit 1, Box 1
Phoenix, Arizona 85040
(602) 253-1216

United States Department of the Interior

BUREAU OF RECLAMATION
Yuma Area Office
P.O. Box D
Yuma, Arizona 85366

IN REPLY REFER TO:
YAO-6100
RES-3.00

JAN 1 0 1995

Mr. Joseph Farmer, L-369
Lawrence Livermore National
Laboratory
P.O. Box 94551
Livermore CA 94551

Subject: Desalting Utilizing Carbon Aerogel

Dear Mr. Farmer:

I read with interest the article in the San Diego Union Tribune on December 22, 1994, regarding utilizing carbon aerogel in water desalination projects.

I have enclosed for your information brochures describing the Federal desalting facility and our pilot plant research facilities in Yuma, Arizona. We at the Bureau of Reclamation would be interested in exploring joint research possibilities with the Lawrence Livermore National Laboratory, aimed at reducing the cost of desalting water and/or improving desalting technology.

Hopefully, we can set up a meeting to discuss these possibilities at your convenience, or perhaps meet in conjunction with the next Federal Interagency Consortium meeting on desalting technology and research to be held in April 1995.

Could you also forward a technical description of the carbon aerogel process for our information? I will be contacting you in the near future, and if you desire further information I can be reached at 602-343-8331.

Sincerely,

E Lohman

Ed Lohman
Supervisor, Desalting
Branch

Enclosure

DIRECTORS
RUSSELL F. CONROY, *PRESIDENT*
MAY GEE, *VICE PRESIDENT*
LEE L. FORSTER
BOB VETTER
TOM PICCOLOTTI

2400 Francisco Blvd.
P.O. Box 1039, Pacifica, CA 94044

North Coast County
SINCE 1944
WATER DISTRICT

STAFF
DAVID A. STEVENS
GENERAL MANAGER
ROBERTA BECHTEL
DISTRICT SECRETARY
PETER M. NELSON
SUPERINTENDENT

Phone (415) 355-3462
FAX (415) 355-0735

January 24, 1995

Mr. Chuck Polmernacki
Technology Transfer Dept., Mail Stop L-437
LAWRENCE LIVERMORE NATIONAL LABORATORIES
P.O. Box 808
Livermore, CA 94550

Dear Chuck,

It was pleasure speaking with you about Aerogel and its possible application for large scale desalination of salt water. When I briefed my General Manager, Board and our Citizens Advisory Committee on Desalination about Aerogel, they were quite enthusiastic about exploring the matter further. We have a very genuine need to establish an alternate supply of water in times of drought or emergency. However, after over two years of studying our options we concluded that current desalination technology is very expensive with no real economy of scale. Speaking only for myself, Aerogel may prove to be the exception once fully developed.

As we discussed earlier, I would like to visit your facility and talk with you and your research staff extensively about Aerogel so that I may more completely report to my superiors about its application for desalination. Myself and Mr. Paul Azevedo, a columnist for newspaper and member of advisory committee, would be the only members in our party. For security and badging purposes, I have provided the following:

Visitor Name:	Title:	Social Security No.:
Michael A. Samodurov	Assistant General Manager of NCCWD	552-96-5086
Paul Azevedo	Columnist & Advisory Committee Member	563-36-1084

Please contact my at your convenience to finalize arrangements for our visit or if you need additional information. Once again, it was a pleasure speaking with you about your work at LLNL and I look forward to hearing from you.

Sincerely,

Mike Samodurov

copy to: Judy Parker - Advisory Committee, Chairwoman
David A. Stevens - General Manager, NCCWD
Project\Desalination - File

ALAMEDA COUNTY WATER DISTRICT

P.O. BOX 5110 • 43885 SOUTH GRIMMER BOULEVARD, FREMONT, CALIFORNIA 94537
PHONE (510) 659-1970 FAX (510) 770-1793

December 21, 1994

Mr. Joe Farmer
Principal Investigator/Project Manager
Lawrence Livermore National Laboratory
PO Box 808, Mailstop L369
Livermore, CA 94550

Dear Joe:

Transmitted with this is a copy of the Desalination Feasibility Study Report that I referred to in our recent telecon. It's probably more than you want to read, but it will give you a good overview of our district and the potential for desalination of brackish groundwater which appears to be the most cost-effective alternative for us.

I am excited about the work that you're doing in advancing the science and technology of desalination and am very interested in visiting you in the near future to discuss the prospects of a joint research effort in more detail. There are potential funds available from the American Water Works Association Research Foundation and the U.S. Bureau of Reclamation for conducting potable water research. I think that we would stand a good chance of securing funding since a project like this has great potential for broad application throughout the water treatment industry, especially in coastal areas such as California and Florida.

Please give me a call at 657-6477 so that we can setup a convenient time to meet and tour your research project.

Sincerely,

James D. Beard
General Manager

Enclosure

36574

4/w

SACNET

TO: **Joe Farmer - Mail Code L-369 FAX 510-422-1370**

FROM: David Drake FAX 619-489-6583 Home 619-489-5302
3019 Hypoint Ave
Escondido, CA 92027

SUBJECT: **The recent aerogel announcement and water desalination**
DATE: December 22, 1994

COMMUNICATIONS

Dear Mr. Farmer,

Congratulations on your interesting discovery with aerogels. I'm a member of the Board of Directors of the San Diego County Water Authority and the chairman of our Desalination Committee. The SDCWA is the water wholesaling agency that buys water from the MWD in Los Angeles and sells it to 23 water agencies in San Diego County. We keep a sharp eye out for desal developments and spotted the article concerning your aerogel. Would you be kind enough to send along any appropriate reports that describe your development ? I understand that commercialization is some time away, but we typically have a 40 year planning horizon so a 5 to 10 year development cycle doesn't scare us off. Our interests in particular are:

1. Salinity reduction for Title 22 reclaimed water, dropping TDS from 1100-1200 ppm down to 600.
2. Reduction of boron and other metals in reclaimed water
3. Ocean water desal dropping 35,000 ppm to 600 ppm
4. The reversibility of the process, i.e. can we use the difference of salinity between 1100 TDS reclaimed water to the 35,000 TDS ocean water to recover energy? UCSD has been looking at this with reverse osmosis for some time. There is a potential for recovering up to 10 6 J from each cubic meter of water.
5. Does your process have the potential for removing viruses from the water or will other processes be required?
6. The SDCWA handles about 500,000 acre feet (wonderful unit = about 325 K Gallons) of water per year. We would like to desal 50,000 to 100,000 AF year in the next century.

I'm looking forward to your reply and wish you the very best for your work. Development of new, reliable water resources is particularly critical for all of California and you may be able to give us a big boost.

Sincerely,

David A. Drake

California-American Water Company

Monterey Division
50 Ragsdale Dr., Suite 100, P.O. Box 951 • Monterey, CA 93942-0951

(408) 373-3051 FAX (408) 375-4367

January 31, 1995

Mr. Joseph Farmer
Mail Stop L-369
University of California
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94551

Re: Monterey Bay Water Works Association
Speaking Engagement, February 8, 1995

Dear Mr. Farmer:

Thank you for accepting our invitation to the above-referenced meeting. Enclosed you will find a map of Laguna Seca Golf Club. Also, you will find a menu selection card. You can fax, (408) 375-4367, or mail your response. Members will be arriving for cocktails around 6:30 p.m. with dinner at 7:30 p.m. and concluding with your presentation starting at 8:20 p.m.

I am looking forward to meeting you and hearing your presentation. If you have any questions or need further information, please feel free to contact me.

Sincerely,

Mario Iglesias
Loss Control Manager

Enclosures

LOU HADDAD
CONSULTANT - LOCAL GOVERNMENT

5 Deer Stalker Path
Monterey, CA 93940
Phone: (408) 373-5222 • Fax: (408) 373-2266

Mr. Joseph Farmer, L-369,
P.O. Box 808,
Lawrence Livermore National Laboratory
Livermore, Ca., 94551

December 26, 1994

Dear Mr. Farmer:

The local daily newspaper ran a story concerning a new gel which could cut the cost of desalinating sea water to competitive levels. The article mentioned your name.

I am an elected member of the Monterey Peninsula Water Management District and the district had proposed a desalination project to augment the local water supply. The project went before the voters in June, 1993 but was rejected by a vote of 53-47 percent.

I believe that the reason some voters rejected the measure was because the information which accompanied the proposition included what was perceived as high costs of desalination.

I am speaking for myself only and not as spokesman for the board of directors, but I would be personally interested in whether the product will be available for a demonstration project locally, and whether there is now or projected in the future a government grant for such a demonstration project.

I want to compliment you and your staff for research and development of this product. As you well know, water is becoming a finite and disappearing resource, and any method by which usable water can be developed from the vast oceanic resources is certainly welcome in California, as well as the nation.

Thank you for your kind attention.

Sincerely,

Lou Haddad

Lou Haddad

Palm Beach Country Club
Palm Beach, Florida 33480
407 / 844-3501
Fax 407 / 881-8076

January 11, 1995

TO: Dr. Joe C. Farmer

FROM: Paul Crawford

It was good talking to you on the phone today. Our mailing address here is 760 North Ocean, Palm Beach, Florida 33480. My personal line is (407) 845-2395, and my fax line is (407) 863-0040. We know you are talking to some private industry people about marketing this product. When you do find a company, please refer them to us at the numbers listed above. As we would be interested in doing some testing, if not having one of their first proto type units.

Also, I will be in San Francisco the week of February 20th. And I would like to visit and spend some time discussing this with you. For security clearance, here's my social security number is 374-66-9333.

Please stay in touch.

Best Regards,

Paul

Paul Crawford

PC/bb