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Informal Report
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ADVANCED BIOCHEMICAL PROCESSES FOR GEOTHERMAL BRINES

Annual Operating Plan, FY 1995

E. T. Premuzic

February 1995

Prepared for
U.S. DEPARTMENT OF ENERGY
OFFICE OF GEOTHERMAL TECHNOLOGY DIVISION
WASHINGTON, DC

DEPARTMENT OF APPLIED SCIENCE

BROOKHAVEN NATIONAL LABORATORY
UPTON, LONG ISLAND, NEW YORK 11973

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Advanced Biochemical Processes for Geothermal Brines

Annual Operating Plan, FY 1995

Prepared for
U.S. Department of Energy Headquarters
Geothermal Technology Division

by

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Under Contract No. DE-AC02-76CH00016 with the
U.S. Department of Energy

Table of Contents

EXECUTIVE SUMMARY

An R&D program to identify methods for the utilization and/or low cost of environmentally acceptable disposal of toxic geothermal residues has been established at the Brookhaven National Laboratory (BNL). Laboratory work has shown that a biochemical process developed at BNL, would meet regulatory costs and environmental requirements. In this work, microorganisms which can convert insoluble species of toxic metals, including radionuclides, into soluble species, have been identified. These organisms serve as models in the development of a biochemical process in which toxic metals present in geothermal residual sludges are converted into water soluble species. The produced solution can be reinjected or processed further to concentrate and recover commercially valuable metals. After the biochemical detoxification of geothermal residual sludges, the end-products are non-toxic and meet regulatory requirements. The overall process is a technically and environmentally acceptable cost-efficient process. It is anticipated that the new biotechnology will reduce the cost of surface disposal of sludges derived from geothermal brines by 25% or better.

I. INTRODUCTION

1. Objectives at the Category Level

As part of the overall Geothermal Energy Research which is aimed at the development of economical geothermal resources production systems, the aim of the Advanced Biochemical Processes for Geothermal Brines (ABPGB) effort is the development of economic and environmentally acceptable methods for disposal of geothermal wastes and conversion of by-products to useful forms. The interaction of the various aspects of ABPGB based technology is shown in Figure 1. This figure indicates that methods are being developed for dissolution, separation and immobilization of geothermal wastes suitable for disposal, usable in inert construction materials, suitable for reinjection into the reservoir formation, or used for recovery of valuable metals.

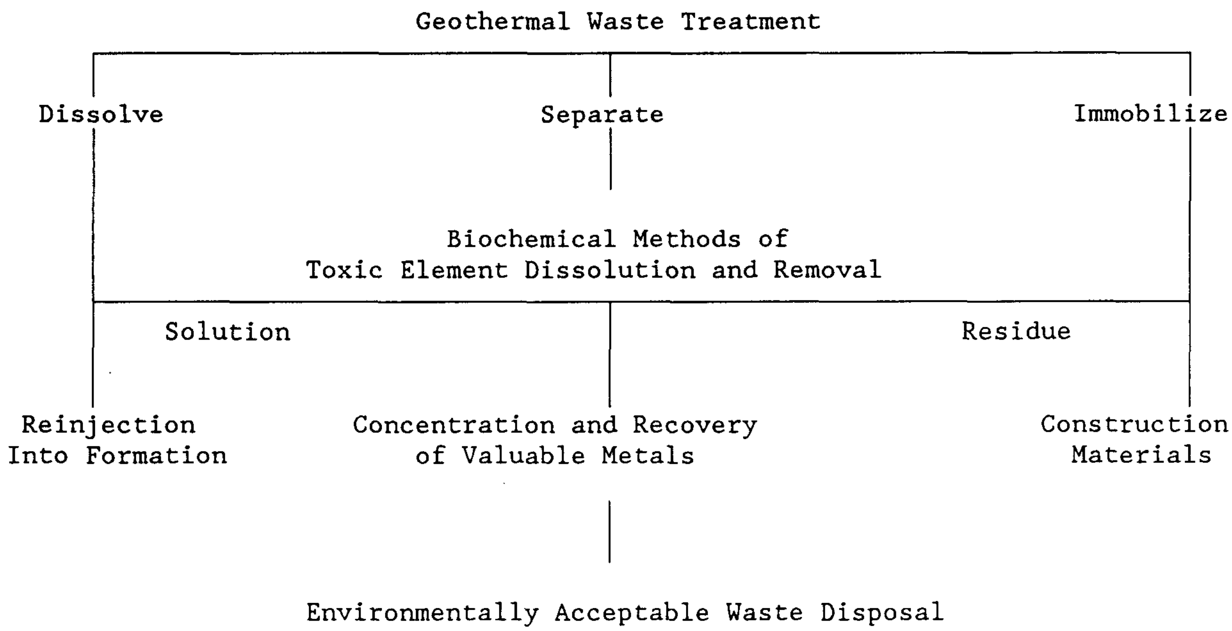

Figure 1. Objectives of "Advanced Biochemical Processes for Geothermal Brines" Activity

2. Strategy

The experimental strategy used at BNL for the development of detoxification biotechnology for geothermal waste is based on the use of biochemical methods for dissolution of toxic elements found in geothermal residues. For example, the produced solution containing toxic and valuable metals, can be reinjected or used for concentration and recovery of valuable metals. In the recovery mode, both chemical and biochemical methods are being developed.

3. Staff

E. T. Premuzic, Scientist, Chemist/Biochemist, Principal Investigator
M. S. Lin, Chemist
J. Z. Jin, Chemical Engineer
J. H. Yablon, Microbiologist
Y. Lin, Computers/Instrumentation
W. Zhou, Technician
L. Shelenkova, Microbiologist

4. Background

Disposal of toxic leachable solid waste in an environmentally and economically acceptable way may be a major impediment to large-scale geothermal development.

For example, in the Imperial Valley of Southern California, there are nine known geothermal resource areas (KGRA). Brines from the Salton Sea KGRA in the Imperial Valley may contain total dissolved solids up to 350,000 ppm. These hypersaline brines lead to the generation of geothermal solid wastes in power plants. All of the solid waste produced must be analyzed for regulated metals using the California Department of Health Services (DOHS) analytical techniques, and if found hazardous, the solid waste must be disposed of off-site in an approved waste management facility. This results in high disposal costs (> $1 million). High disposal costs and the long-term liability associated with hazardous-waste disposal provide the incentive for this study.

It is known that certain microorganisms can interact with metals specifically by several mechanisms such as surface adsorption, oxidization, reduction, and solubilization and/or precipitation. These mechanisms have served as a basis for the development of biotechnology which allows use of biochemical processes for removal and concentration of toxic metals present in the waste or makes possible solubilization of the waste.

Such biotechnology is particularly useful when large quantities of wastes are present which contain low, but nevertheless environmentally significant, concentrations of toxic metals, disposal of which is regulated. Another advantage of the biochemical processes considered in this program is due to the type of microorganisms used. These microorganisms are acidophilic and thermophilic, capable of living under very harsh conditions such as extreme acidic pH, high salt concentrations, and elevated temperatures. Such conditions are unsuitable to most other microorganisms which require mild conditions for their growth, therefore, cross-contamination by undesirable species is ruled out by processing conditions, making this technology particularly environmentally acceptable. Furthermore, biochemical processing is inexpensive and usually requires a small staff to operate.

II. PRIOR YEAR DATA (FY 1993 - FY 1994)

1. Issues

Peer reviewed studies at BNL (published papers, invited presentations, and reports) have indicated that biological/biochemical detoxification of geothermal power by-products, e.g., residual sludges, is technically and economically feasible. Based on the available data generated by the laboratory effort at BNL, several tasks were performed in FY 1993 and are continuing in FY 1994.

2. Funding/Manpower FY 1993/1994

A steady effort leading to scaling-up is man-power intensive. Further, continuing scaling-up of bioreactors, modifications, and process optimization requires capital equipment investment.

Funding Profile and FTE(s)
($000.00)

	FY 93	FY 94
Operating	480	410
Capital	50	150
Educational	50	60
FTE(s)	4.4	4.84

3. Project Description

(a) Optimize methods for the biochemical separation of toxic metals from geothermal sludge. Emphasize the area of technology using controlled variables.

(b) Expand studies dealing with the optimization of sludge concentration and decrease in the residence time, with particular emphasis on cost-efficiency.

(c) Evaluate savings in the overall cost of the new biotechnology. Particular attention has been (and is being) paid to lead, radium, and thorium salts solubilization.

(d) Continue developing methods for the biochemical separation of toxic metals from geothermal waste with concurrent recovery of valuable metals.

(e) Optimize variables for the removal of trace toxic metals such as thorium, radium and uranium were continued.

(f) Studies aimed at developing conditions for the use of mixed cultures and decreased residence times in bioreactors at elevated temperatures have already indicated that considerable savings in the overall cost of the new biotechnology can be achieved. Particular attention was and is being paid to other biosystems for solubilization of low solubility metals salts.

(g) Optimize bioreactor designs. Variations considered should significantly contribute to lowering the cost of bioprocessing. Particular attention should be paid to the automation of laboratory model processes.

(h) The R&D effort at BNL has already identified several parameters essential to the development of the new biotechnology for the biochemical treatment of residual geothermal sludges. Focus on fine-tuning of processing parameters.

4. Statement of Work

Within the programmatic needs of Advanced Brine Chemistry R&D and specifically, the Advanced Biochemical Processes for Geothermal Brines, in FY 1994, the following tasks are being addressed:

- Use laboratory plants to process and evaluate different types of sludges as supplied by industry, for example, UNOCAL, MAGMA, P.G.&E. and others.

- Conduct routinely radioactivity measurements in the analysis of residual sludges with particular attention to radium.

- Perform kinetic studies of biodetoxification processes at elevated temperatures particularly focused on short residence times and radionuclides removal.

- Evaluate the use of different bioreactors, e.g., fluidized bed or agitated tank as well as process variable trade offs. The data base generated is essential for the future scale-up and pilot-plant designs.

- Computerize best sets of data and apply to upgrading and modification of model plants.

- Develop additional collaborative programs with industry (e.g., P.G.&E., MAGMA) and other government programs, e.g., FE, EM, and other agencies (DOD, EPA).

- Conduct tests of suitable materials for coating and/or construction of corrosion resistant reactor vessels and accessory equipment.

- Evaluate several types of Geothermal Residual Sludge Biotreatment Plants (GRSBP) in conjunction with industry and initiate further economic analyses.

- Participate in peer-reviewed workshops and explore technology transfer opportunities.

- Experience with Salton Sea Drilling Project studies makes it necessary to consider sampling and chemical analysis criteria as they specifically apply to geothermal residual sludges. Therefore, continue to develop and maintain a sampling and quality control program.

- Maintain the Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) for full operational use of the instrumentation.

5. Accomplishments

(a) Scaled-up bioreactors (50 gal) have been constructed and their efficiencies in the detoxification processes have been tested under a variety of conditions.

(b) An 80% or better removal of toxic metals has been observed.

(c) Fast rates for biochemical metal removal (25 hr and less) can be achieved at temperatures of 55°C and pH 1-2.

(d) Two preliminary economic and technical analyses have consistently shown the feasibility of the bioprocesses used in these studies.

(e) Analyses of the residual sludges from the Salton Sea Scientific Drilling Project have led to recommendations for sampling and analysis of geothermal sludges. These recommendations have been submitted to DOE, HQ (see BNL Report 42274).

Note: For details, see the following reports, publications, and presentations:

Premuzic, E.T. Advanced Biochemical Processes for Geothermal Brines, Annual Report, 1993. BNL 60291.

Premuzic, E.T. Geothermal Program Review XII, April 1994 (in press).

Premuzic, E.T., M.S. Lin, J.Z. Jin, and K. Hamilton. Geothermal Waste Treatment Biotechnology. To be presented at the World Geothermal Congress, 1995. Accepted for publication in the Congress Proceedings.

Premuzic, E.T., M.S. Lin, and J.Z. Jin. Biochemical Processing of Geothermal Brines and Sludges: Applicability to Multiple Industrial Applications. To be presented at the Geothermal Resources Council, October 1994. Accepted for publication in Transactions.

A. Economics of Biochemical Waste Treatment Processes

Previous and ongoing studies have shown that there are at least ten key process variables, ranging from the reactor size to the recycling of biocatalysts, which are essential in the determination of the cost-efficiency of the bioprocesses considered. In addition to these variables, several other parameters have to be evaluated and costed into the design of the overall biochemical process. Currently, the most efficient primary process utilizes two biocatalysts whose production and the rate of delivery influence the size and the number of bioreactors needed to be operational. In Figure 2, a process for the treatment of 5294 kg/h of geothermal sludge at a 40% loading and a residence time of 5 h in the biochemical reactor, requires an input of 946.5 kg/h of each of the biocatalysts. The rate of Biocatalyst 1 production is fast and that of Biocatalyst 2 is slow. This fact influences the cost of production. Further, a 50:50 or 85:15 mix of the two biocatalysts influences significantly the economics of the process. Three additional factors have to be also taken into consideration: (1) recycling of the biocatalysts,

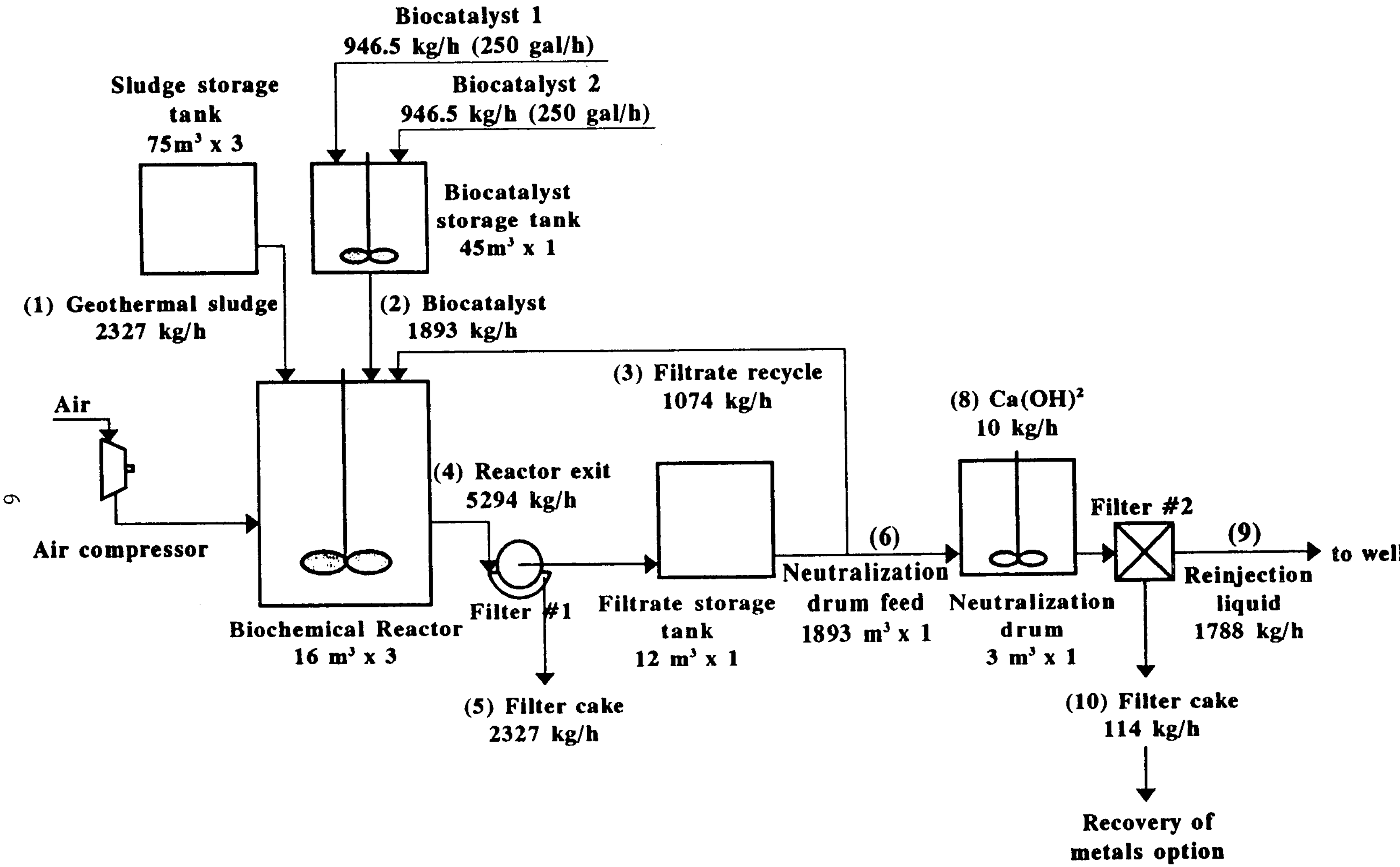

Figure 2. Total biochemical process for geothermal sludge (5130 lb/h).
Treatment: Biocatalyst 1 (50%): Biocatalyst 2 (50%).

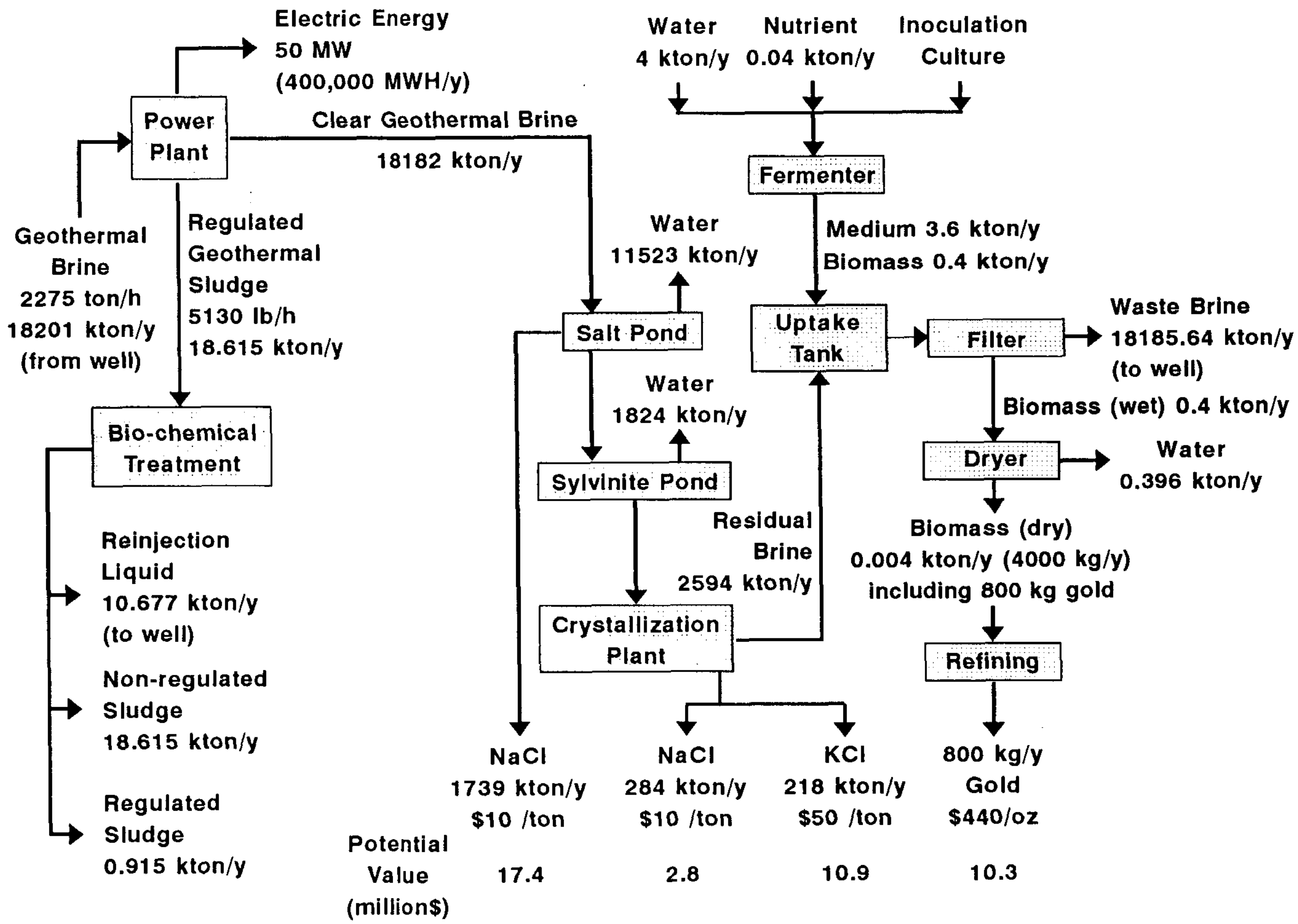

Figure 3. Biochemical processing of geothermal sludge and brine.
Scenario C: Combined processes for sludge and brine.

Table 1. Cost Comparison for Different Biocatlyst Mixes and Corresponding Total Bioprocess Costs Per Metric Ton of Sludge

	*BC1:BC2	BC1:BC2	BC1:BC2
	50:50	85:15	85:15 (3 recycles)
	250 gal/h: 250 gal/h	425 gal/h: 75 gal/h	106.25 gal/h: 18.75 gal/h
BC1			
Capital Cost (CGR)	1,838,000	2,556,000	1,196,000
Annual Treatment Fee	1,097,000	1,778,000	820,000
Unit Treatment Fee ($/metric ton) culture)	145	138	255
BC2			
Capital Cost (CGR)	7,017,000	2,573,000	1,002,000
Annual Treatment Fee	3,683,000	1,687,000	736,000
Unit Treatment Fee ($/metric ton culture)	486	743	1,298
BC1 + BC2			
Capital Cost (CGR)	8,855,000	5,129,000	2,199,000
Annual Treatment Fee	4,449,000	3,466,000	1,556,000
Unit Treatment Fee ($/metric ton culture)	316	229	411
Total Bioprocess Costs Including Biocatalyst Production			
Capital Cost (CGR)	10,195,000	6,493,000	3,415,000
Annual Treatment Fee	5,882,000	4,578,000	2,614,000
Unit Treatment Fee ($/metric ton sludge)	316	246	140

*BC = Biocatalyst

Table 2. Total Biochemical Process Cost Estimates Including Potash Plant Option for a 50 MW Power Plant

BC1:BC2	Net Gain in $Millions/year
50:50	1.83
85:15	2.74
85:15 3 recycles	5.51

(2) recovery of valuable metals, and (3) recovery of salts such as sodium chloride and potassium chloride. Options 2 and 3 generate revenues which offset the cost of initial investments as shown in Figure 3. Table 1 shows significant savings which can be achieved by different biocatalyst mixes and recycling. The combination of the biocatalyst mixes and the potash recovery option, as shown in Table 2, net monetary gain which can be accomplished by total processing.

B. Kinetic Model and Chemical Engineering Calculations

A kinetic model developed in FY 1993, has been successfully used in chemical engineering calculations. This model, together with chemical engineering calculations, will become a part of the "process" package for field applications. For chemical engineering calculations, the computer program is in basic language and has been developed for the calculation of (a) materials balances, (b) reactor volume, (c) filter area for non-regulated sludge, and (d) filter area for regulated sludge. Further refinement and integration of all processing options is in progress.

C. Construction of the First Generation Pilot Plant for Geothermal Sludge Biotreatment

Based on the current experience, fluidized bed and agitated tank type bioreactors generate comparable results. Both reactor types were tested for their usefulness and efficiency in a biochemical process for detoxification of geothermal residual sludges. Considering practical constraints of space availability, construction, and operating costs, a pilot plant has been constructed in which the agitated tank bioreactor was chosen as the operating unit. The pilot plant contains three fifty-gallon agitated tank bioreactors which serve as a bacterial culture reservoir, mixing and processing reactor, and a neutralization unit for concentration and subsequent metal and water recovery. The present system is made of polyethylene and glass components which utilize commercially available pumps, filters, controllers, and other accessories without or with minor modifications. The system has been computerized and is shown in a block diagram form in Figure 4.

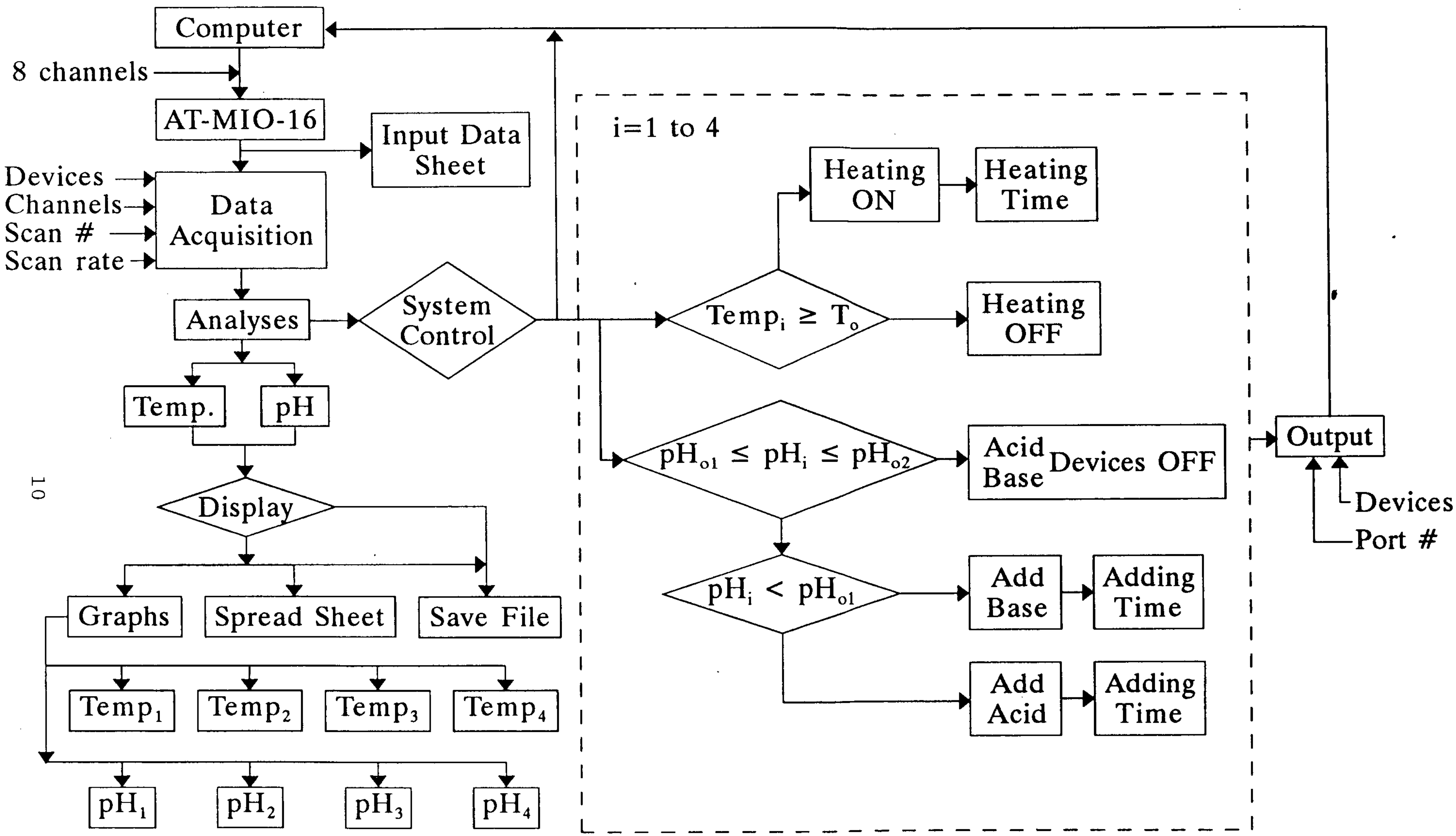

Figure 4. Block diagram of systems control and data acquisition for biochemical processing of geothermal waste streams

Table 3. Biochemical Treatment Plant Costs Vs. Costs of Treated and Untreated Waste Disposal

Quantity of geothermal sludge to be treated: 2329 Kg/h
Working hours per year: 8000 hr
Total capital cost + start up: $4,209,000

	1985	1991
Waste Disposal Cost:		
for non-regulated waste ($/ton)*	75	100
for regulated waste ($/ton)	200	500
Annual Total Expenses ($):		
untreated geothermal sludge disposed of directly	4,104,000	10,260,000
Geothermal Sludge Treated:		
by the biochemical process (non-regulated waste disposal cost)	1,539,000	2,052,000
Waste Concentrate (regulated disposal cost)	202,000	504,000
Operating Costs, etc.	1,396,000	1,396,000
Amortized Payment (fixed)	685,000	685,000

* 1 ton = 1000 kg

D. Removal of Less Soluble Salts and Radionuclides (Variance)

We have reported earlier (see refs.) that less soluble salts such as those of lead, bismuth, radium, and barium present in trace amounts are a special case to be considered. In addition, the radionuclides present are close to NORM levels which put further requirements on the bioprocess as well as sampling and method of analyses. After regular biotreatment with the BNL BC1 and BC2 system of biocatalysts described in the previous paragraphs, the geothermal material contains additional trace amounts of insoluble salts, such as those of radium and thorium. In order to meet the 5×10^{-12} Ci/g requirement, a secondary biotreatment is necessary. For description of this treatment see Refs. (page 13).

This process is being further optimized. However, the current cost estimates, based on an 80% metal removal efficiency, representing a 60% saving, are shown in Table 3. The calculations are based on current BNL costs. Thus the BNL cost in 1993 was $500 per ton.

The corresponding non-regulated waste disposal cost was $100 per ton. If the sludge contains in addition to chromium and lead, say radium, then it has to be shipped at a cost of $400 per cubic foot. On the other hand, removal of the metals leaving radium alone produces waste costing $76 per cubic foot to dispose of, or $10,800 and $2,052 per ton, respectively, representing a five-fold saving already achievable on a laboratory scale.

E. Educational Programs

In the overall effort dealing with R&D biotechnology for detoxification of geothermal brines and promotion of scientific research in general, we have established continuing projects suitable for undergraduate and graduate students, high school students, and high school teachers. All of the participants in our R&D effort are supported through the educational programs at BNL which have a broad spectrum, ranging from opportunities for university students to high school science teachers and educational funds of the DOE Geothermal Technology Division. The FY 1994 participants are listed below:

Visiting Scientist/Collaborator:
1. Dr. John Tharakan*

Summer Teachers:
1. Michael Vaccariello
2. Robert Gelling
3. Curtis Turner
4. Headley Haniford

College Students:
1. Lisa Johnson
2. Keith Chan*

High School Students:
1. Siva Vankatatachalam*
2. Debleena Sengupta*
3. Dave Verdi
4. Laura Bauer
4. Preeti Sulibavi*
5. Nicole Roost
6. Marc Silver
7. Christine Liu*

Karlene Hamilton*, a graduate student under the HBCU program, has gained a M.Sc. degree in Chemical Engineering from Howard University. Her thesis was based on her work in the design of a biochemical process of geothermal sludges derived from P.G.&E. sources and samples provided by the Los Alamos HDR program. A letter of Agreement with BNL and Howard University's Chemical Engineering Department has been signed. The object of this agreement is to expand the current graduate student programs and develop new collaborative R&D programs between the two institutions. Dr. John Tharakan is the first HU faculty member to be appointed as a BNL Scientific Collaborator.

*Minority teachers or students

F. Meetings/Reviews/Reports

Premuzic, E.T. Advanced Biochemical Processes for Geothermal Brines, Annual Report, 1993. BNL 60291.

Premuzic, E.T. Geothermal Program Review XII, April 1994 (in press).

Premuzic, E.T., M.S. Lin, J.Z. Jin, and K. Hamilton. Geothermal Waste Treatment Biotechnology. To be presented at the World Geothermal Congress, 1995. Accepted for publication in the Congress Proceedings.

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G. Funding and Manpower Requirements

Funding obtained from DOE's Geothermal Division was used to build and compare bioreactors capable of operation at 50-60°C at pH 1-2.

Experimental protocols have been developed to study the kinetics of multielement removal. These studies also included removal of metals such as uranium, thorium, and radium. In addition to measurements by ICP-MS which measures masses and, therefore, different isotopes, radioactivity measurements have also been scheduled. This is particularly important in the case of radium which is present in low concentrations (3×10^{-4} - 9×10^{-4} Ci/g) and, therefore, counting methods for its determination are preferable. All of these analytical procedures as well as scaling-up and building of new bioreactors are person-hour intensive.

A steady effort leading to scaling-up is person-year intensive. Further, continuing scaling-up of bioreactors, modifications, and process optimization requires capital equipment investment. In FY 1994, to be continued in FY 1995, a concerted effort for collaboration with industry will be intensified. This effort has already yielded a CRADA agreement between the Brookhaven National Laboratory and CET-International of California. This CRADA will be activated in FY 1995. The purpose of this joint program is to field test the BNL process. CET-International has an agreement with P.G.&E. in which the latter will allow CET to field test the BNL process. CET will engineer the BNL process and adapt it to the particular needs of the P.G.&E. operations. Further, BNL has a Confidentiality Agreement with MAGMA which allows for extended collaboration in several areas. It is anticipated that this effort will lead to additional cost shared/full cost recovery funding.

Fiscal Year Profile and FTE(s)
($000.00)
FY 1994

Operating	410
Capital	150
Educational	60
	620
FTE(s)	4.84

H. Status

o Comparison of agitated tank and fluidized bed bioreactors at room temperature and at 50-60°C	First phase of comparison studies completed.
o Optimization of sludge concentration	40% loading achieved and reproducibility of results well documented.
o Pilot plant	Pilot plant using 3 x 50 gallon-system constructed and currently tested under varying conditions.
o Computerization and process automation.	First phase completed. Second phase current.
o Processing Options	Current.
o Sensitivity studies	Fourth technical and economic study completed. This study encompasses several options such as metal recovery.
o Collaboration with educational programs	High visibility and involvement. Agreement with Howard University in place.
o Collaboration with industry	A CRADA with CET-International to process P.G.&E. wastes has been approved. Collaborative work with MAGMA has been expanded. Spin-offs from Geothermal R&P effort have generated CRADAs with Environmental Solutions Corporation and the Energy and Environment Research Company of California.

o Variances

1. Feasibility of metal recovery processes has been demonstrated.
2. Studies for the measurement and the removal of trace radionuclides: Current.

I. Summary

o Fourth comparative study of agitated tank vs. fluidized bed type bioreactor was completed. For practical purposes, i.e., space restraints, the agitated tank is being used for routine studies. The two types of bioreactors are interchangeable in the BNL process.

o Using a 40% loading and several hours residence time, a preliminary economic evaluation has also been completed. The results have been used to develop a computer program for the advanced biochemical processing of geothermal residual sludges.

o Although state-of-the-art design and/or best materials have not been taken into consideration, differences in the cost of various processes stress further the importance of loading, residence time, the type of bioreactor, biocatalysts production, process options and recycling. This study has also indicated the importance of process quality control and appropriate monitoring needs.

o First generation pilot-plant has been constructed and is being automated.

o Secondary process for the removal of radionuclides has been identified and is currently optimized.

o Currently, sludge loadings of up to 40% are practical and at temperatures of >50°C fast rates of 10 hr or less have been achieved.

o Studies at elevated temperatures have confirmed that particular attention has to be paid to construction materials, compressors, pumps and other equipment needed for an efficient detoxification process.

o The study of metal and salts recovery processes is very promising and indicates that an 80% to 90% metals recovery is possible from a small concentrate. The final aqueous phase meets drinking water standards. A complementary potassium and sodium chloride option is also very promising.

o Educational programs have proved to be successful and are continuing as part of the ongoing R&D under the auspices of BNL and DOE, Geothermal Division educational programs.

o Three CRADAs are in place. A new CRADA is to begin in FY 1995.

III. MANAGEMENT

1. Organization

o The Geothermal Technology Division at Department of Energy (DOE) Headquarters formulates overall geothermal program policy, provides program guidance and financial resources, and coordinates activities with other government agencies. Through the annual budget cycle, DOE Headquarters (HQ) establishes budgets and priorities, and assigns program responsibilities to Operations Offices and National Laboratories.

o The Idaho Operations Office (IDO) serves as the focus for coordination of the Geothermal Brine Chemistry Activity which includes Advanced Biochemical Processes for Geothermal Brines with other Operations Offices (Chicago, IL; Richland, WA), National Laboratories (Brookhaven, NY; Pacific Northwest, WA), Universities (Univ. of California at San Diego), and Contractors. With their assistance, IDO develops planning options and cost estimates; reviews and recommends program activities; and procures, administers and manages projects, consistent with Headquarters' program guidance.

o The technical and administrative management of the long term/high risk R&D phases of the task are under the direction of BNL with task policy established by the Geothermal Technology Division (GTD) Task Manager. To provide overall guidance to the task and to assure relevance, industrial and technical society advisory panels have been established.

o Fiscal control will be exercised in the form of monthly comparisons, over the task term, of actual costs incurred against corresponding line items of the budget. Technical results shall be monitored through a periodic review, by the Contractor Task Manager, of accomplishments by measuring actual performance as compared to expected progress. All work shall be conducted in conformance with generally accepted standards for R&D and other investigative or analytic procedures, as observed by universities and large independent research facilities including BNL.

o Brookhaven National Laboratory will develop recommendations for future research as requested by the Operations Office; conduct in-house geothermal waste detoxification research projects; subcontract tasks as agreed with HQ; conduct cooperative research, field tests and information exchange with the research community and geothermal industry; and participate in DOE technical reviews.

2. Interface/Contracts

Particular efforts are directed towards cooperation with MAGMA and P.G.&E. Fossil Energy has expressed interest in modifying the developing geothermal biotechnology for the use of toxic metal removal from oil wastes. EM has similarly expressed interest with possible funding for development of biotechnology for removal of toxic metals associated with DOE sites.

IV. FUNDING YEAR RESEARCH PLAN (FY 1995)

1. Goals/Objectives

The purpose of this program is to develop low-cost processes for the concentration and removal of toxic materials and recovery of valuable metals from geothermal residues. In addition, methods and materials for the utilization of environmentally acceptable storage of these waste fractions are also investigated. If the results from this high risk/high payoff R&D effort are successful, the high disposal costs and the long-term liability associated with hazardous waste disposal will be reduced significantly. This will greatly enhance the rate at which the U.S. hypersaline brine geothermal resources are developed.

2. Key Issues and Strategy

Engineering disposal technology of by-products and waste is needed to meet the objectives for the production of safe and economically attractive power from geothermal operations. The data being generated in this program provide the basis for technology which will meet the requirements. To maximize limited resources, several strategies have been activated which include, (i) utilization of summer students; (ii) joint R&D on a subcontract basis, such as support of graduate students; (iii) arranging for a visiting scientist to spend time on the project; and (iv) maximize collaboration and cost sharing with the geothermal industry.

3. Project Description

o The newly constructed plant will be used to further develop and integrate the biochemical processing of geothermal sludges.

o Process modifications will be explored which will lead to a biotechnology specifically designed to handle different types of geothermal waste.

o The area of technology using controlled variables will be maintained and further automation/computerization of the pilot plant will be emphasized.

o This effort will address the maintenance and optimization of variables including design of scaled-up processes using corrosion resistant process units.

o Optimize the variables for the removal of trace toxic metals such as thorium, radium and uranium by a secondary biochemical process.

o Interfacing of bioreactors involved in metal solubilization and metal recovery processes will be investigated.

4. Statement of Work

o Continue design and construction efforts for batch processing as shown in Figures 5, 6, and 7.

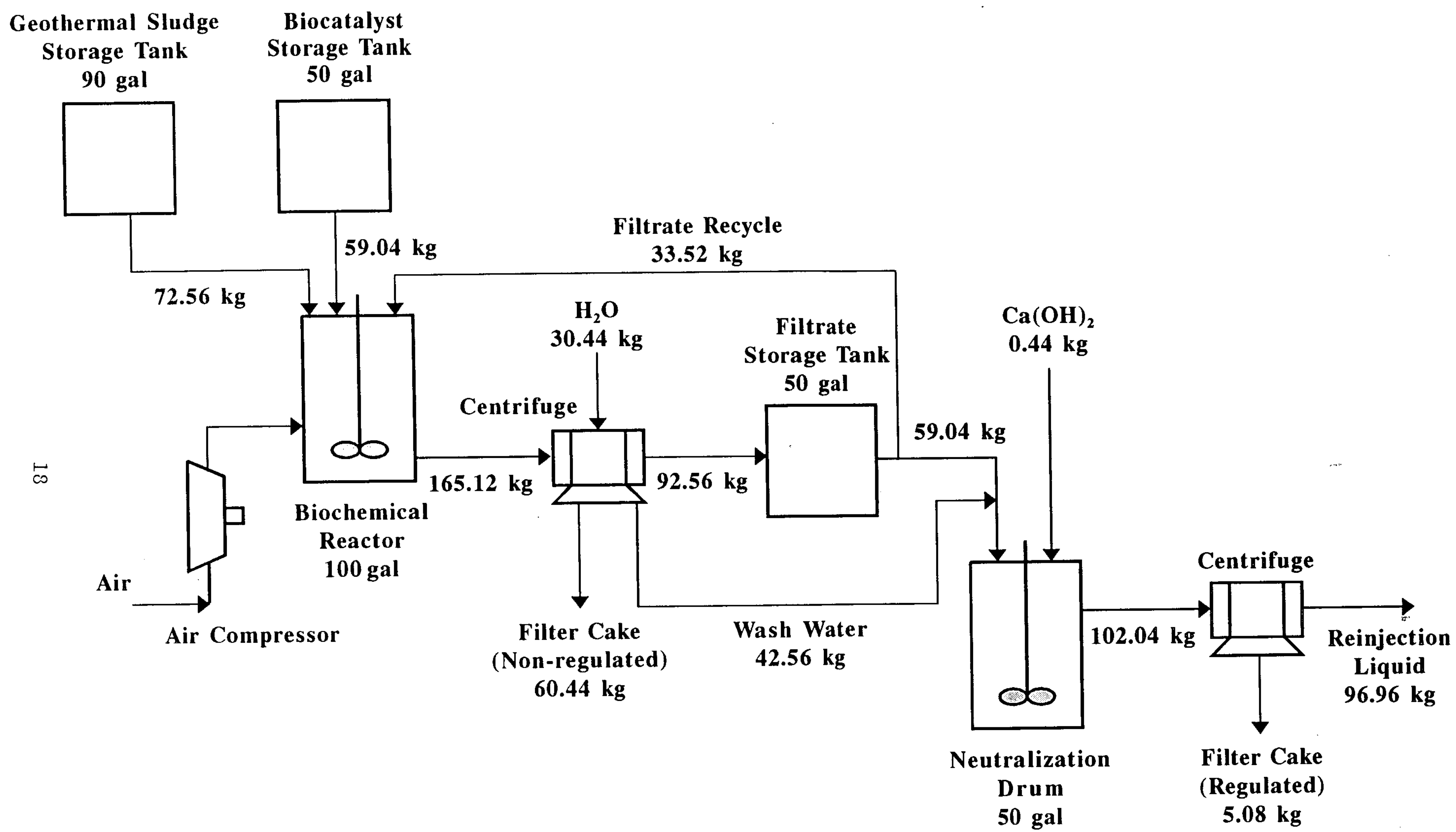

Figure 5. Biochemical process for geothermal sludge (Batch process, 1 day/batch).

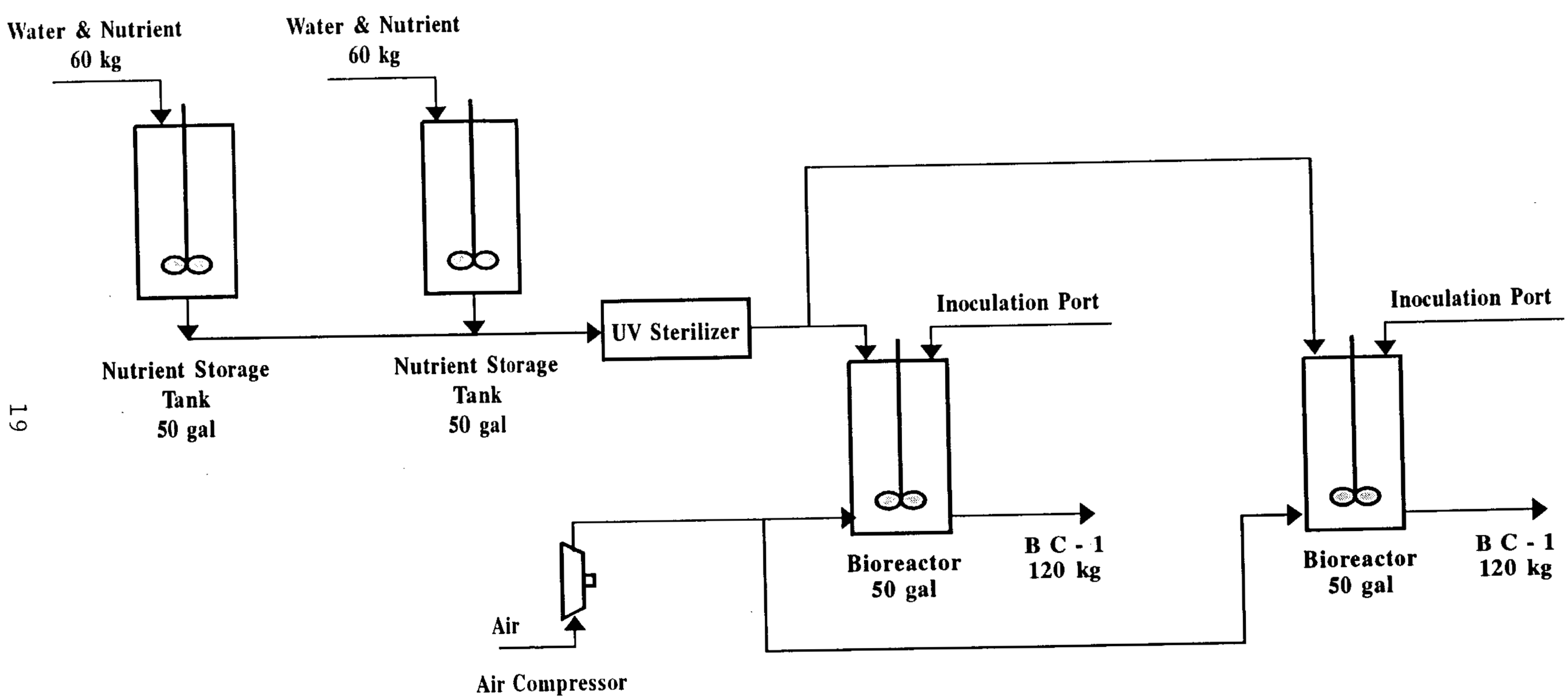

Figure 6. Production of Biocatalyst 1 (BC1) (Batch process, 2 sets, 2 days/batch).

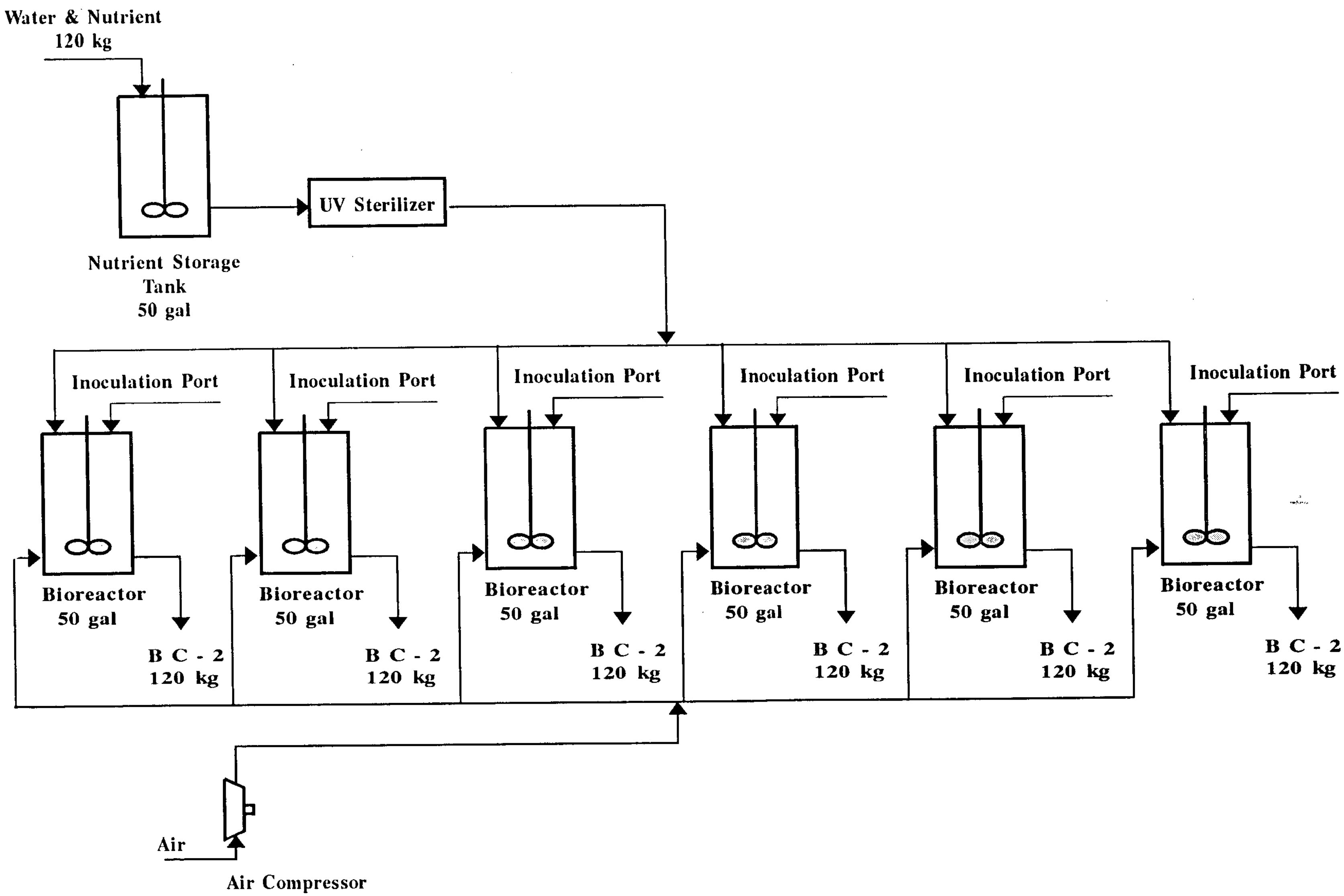

Figure 7. Production of Biocatalyst 2 (BC2) (Batch process, 6 sets, 20 days/batch).

Design for a Batch treatment plant--Operating conditions:
(1) 72 kg batch/8 h day
(2) no labor costs
(3) no utilities costs
(4) Biocatalyst mix 1:1.

o Current cost estimates for the construction of the above defined batch plant is $420,000.00, including Laboratory overhead (375 + 45).

o When completed, the batch plant will be optimized for field testing. The batch plant will also be used for engineering projections necessary for the design of continuous process(es) in which recycling, biocatalyst mix and metal/salt recovery options have been factored in.

o Use data obtained from optimization studies and conduct fifth economic analysis.

o Define additional variables.

o Consider interfacing metal solubilization with metal recovery processes.

o The metal recovery processes should distinguish between radionuclides and non-radionuclides.

o Activate the CRADA with CET-International and begin R&D for field applications at P.G.&E. site(s).

o Continue negotiations with MAGMA and emphasize metal recovery options.

o Conduct tests of suitable materials for coating and/or construction of corrosion resistant reactor vessels and accessory equipment.

o Establish an in-house data base essential for pilot/field scale designs.

o Continue "Quality Control" effort as per Salton Sea experience.

5. Funding and Manpower Requirements

A steady effort leading to scaling-up is man-year intensive. Further, continuing scaling-up of bioreactors, modifications, and process optimization requires capital equipment investment. In FY 1995, collaborative programs with geothermal industry will be established. It is anticipated that this effort will lead to additional cost shared/full cost recovery funding.

Funding Year Profile and FTE(s)
($000.00)
FY 1995

Operating	704
Capital	420
Educational	60
Total	1,184

FTE(s) 4.84

6. <u>Milestones</u>

- o Initiate preparation of a peer-reviewed papers dealing with bioprocess conditions and designs to be submitted to Geothermics and Geothermal Science and Technology. 2/95

- o Annual Operating Plan. 4/95

- o Complete analysis and recommendations based on the first generation of operating laboratory model scaled-up processes including metal recovery and biocatalyst recycling. 9/95

- o Consider options for construction of a combined process system using existing BNL facilities. 10/95

- o Annual Report. 12/95

7. <u>Expected Progress</u>

o Best results from optimization studies will be used for additional and expanded cost analysis.

o Additional process variables will be defined, particularly those needed for interfacing with recycling and metal recovery processes.

o Total available information will be reevaluated and the results will be used for process protocols suitable for field applications on a site designated by MAGMA Corporation.

V. FUTURE PLANS (FY 1996 - FY 1999)

1. <u>Key Issues and Strategy</u>

Assuming that the rate of progress and technological achievements for each R&D task are realized, it is anticipated that the work undertaken will be of significant benefit in the following respects.

o The results from high risk/high payoff materials R&D that private industry will not perform will become available. These data will result in significant long-term benefits to the economic and environmental aspects of geothermal energy production. The methodology developed in this program will also be applicable to other industrial residual wastes containing toxic and/or valuable metals.

o Close collaboration with construction and engineering expertise at MAGMA and CET will be expanded.

o Based on the information generated, integrated process will be recommended, and accepted process designs field-tested.

o The data base in hand and the emerging new information will be used for process protocols suitable for the construction of a fully operative waste treatment plants.

o All the variables will continue to be optimized. Particular attention will be paid to the cost and efficiency of candidate processes.

o "Quality control" effort as per Salton Sea experience will be continued.

2. Manpower Requirements

Scaled-up and pilot scale studies are capital and man-year intensive. A substantial capital equipment investment is necessary. Collaborative efforts and/or joint ventures with geothermal industry will be fully expanded under the technology transfer initiative.

Outyear Funding Profiles and FTE(s)
($000.00)

	FY 96	FY 97	FY 98
Operating	750	775	800
Capital	532	644	644
Educational	60	60	60
Total	1,342	1,479	1,504
FTE's	5.84	5.84	5.84

FTE's may vary depending on the staff utilized, such as Visiting Scientists and students.

3. Funding Requirements

The funding needs for manpower, materials, and supplies are estimates. Funding for capital equipment, construction of bioreactors, compliance with environmental and safety requirements, as well as analytical investigation and servicing will have to be costed in. Furthermore, more accurate projections for pilot scale construction will be possible only after additional economic studies of a number of prototype bioreactors operating under optimum conditions have been completed. Current data base indicates that the field testing and subsequent conversion to a continuous process will require a full engineering complement. A continuous process would have to be fully automated with full back-up facilities. This means multiple, parallel processing streams involving a series of bioreactors involved in sludge processing, biocatalyst recycling, and metal/salts recovery modes. Therefore, the FY 96, 97, and 98 costs will be modified according to the results generated in the previous fiscal year. Our present understanding of the "total process(es) costs" represents a conservative minimum estimate.