1-1-2004

ALS-NSCORT 2003 Annual Report

Table of Contents

1.0 Message from the Center Director

Dear Colleagues:

A NASA Specialized Center of Research and Training (NSCORT) in Advanced Life Support (ALS) was awarded during 2002 to a tripartite academic consortium consisting of Alabama A & M University (AAMU), Howard University (HU), and Purdue University (PU), with Purdue serving as lead university for the consortium. The following pages document the parameters of the ALS NSCORT and first-year progress in developing a workable administrative infrastructure, an effective outreach and education program, meaningful collaborations within the Center as well as between the Center and the ALS community, and preliminary results from individual research projects.

The mission of the ALS NSCORT is to create and test proof of concept for a range of novel and innovative candidate life-support technologies to lower the Equivalent System Mass (ESM) penalties for developing independent life-support systems in space. Because life-support accommodations (environment, available energy, *in situ* resources) will vary considerably from one planetary habitation site to another and with specific configurations of exploration missions, candidate technologies showing promise for one life-support scenario may not be feasible for another. Many combinations of sub-system technologies remain to be modeled and tested for different mission profiles. The major focus areas covered by the ALS NSCORT include developing efficient treatment and resource-recovery options for solid, liquid, and gaseous human, crop, and food-process wastes, effective food-processing and food-safety-testing procedures, low-energy crop-production technologies, and global systems-analysis procedures. The NSCORT emphasizes technologies that leverage the energy-saving advantages of enzymatic, especially microbiological, biomass transformations. Research challenges include optimizing conditions for biomass conversions to occur rapidly enough so that biological processes can be competitive with physico-chemical approaches.

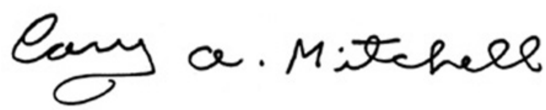
The ideal advanced life-support system for a planetary habitat would be 100% closed with respect to mass, doesn't leak gases, and would have adequate external energy available to power the particular suite of life-support technologies deployed for a given mission. However, *in situ* resources, where and when available, likely will be important to leverage for certain missions in terms of modeling and eventually testing different combinations of life-support technology. All such considerations are being factored by the NSCORT into the selection of candidate technologies to evaluate at the project level. Individual laboratories specializing in sub-system technologies are working closely with the systems-analysis team to determine the inputs and outputs of candidate technologies for each sub-system and how those inputs and outputs will affect the stability and robustness of the overall life-support system. A major contribution of the NSCORT will be new information on the costs and efficiencies of different technologies for efficiently creating biomass from carbon dioxide, for efficiently transforming edible biomass to food, for extending harvest index by transforming non-edible biomass to edible biomass, and for efficiently cycling non-edible biomass back to renewable resources, including carbon dioxide. The costs of new and different ways for reclaiming dirty air and water and returning them to purities acceptable for human consumption within a closed system also are investigated by the Center.

A second important mission of the ALS NSCORT is to train a cadre of multi-disciplinary technologists and thinkers who will become part of the new age of ALS researchers to develop the first independent, closed, life-support systems for testing on Earth, and later for deployment on the moon and Mars. The value of graduate students and post docs collaborating outside their specific disciplines of training to synergistically create new technologies not possible within their separate disciplines will have immeasurable value in realizing the goals of ALS, and will create a generation of researchers who never again will feel constrained to think exclusively within the box of their disciplinary training! Their future careers as civil servants or government contractors working directly for NASA to implement the first space-deployed ALS, or as university PIs funded by NASA to research the next generation of ALS technologies, will ensure a continuum of ALS brainpower and leadership for the future! The Center is developing a multi-disciplinary distance-education ALS course to be offered by the Partners during year 2 of operations to foster development of that new breed of researcher. Course-development plans will be included in the following pages.

There are people in the world today who see every aspect of the space program as a colossal waste of public resources. A few such detractors are politically vocal and some even attempt to embarrass NASA. They ignore the many Earth benefits and spinoffs of NASA programs that already have improved the quality of life on Earth, not to mention the promise of things to come. In more than 27 years of working in NASA space life science programs, I have noticed a major grassroots appeal of the CELSS and ALS concepts to the general public. Anything that has implications for cleaning up Earth's environment, for recovering resources from waste materials, for the production of healthful, safe food without pesticides, for hydroponics and productive controlled environment agriculture, and especially for the combination of all these things under a single roof pushes a magic button that captivates public imagination and attention in a very positive way! ALS in particular encompasses multiple concepts that project hope for the future that the public is quick to embrace, and its story may be the very best emissary of NASA to the tax-paying, voting public! Children and adults alike thrill to the concept of a system that is materially closed but energetically open sustaining human life independent of resupply on some foreboding planetary destination millions of miles from home. ALS is a microcosm of Earth's recycling environment, although a much smaller version that does not have the benefit of oceanic or atmospheric "buffers" or the time luxury of self-regulating ecosystems. In order to achieve system sustainability and stability, rapid, dynamic regulation and control of component processes is required, and to the extent that they grasp this concept, the public is enthralled by possibilities for "intelligent control" of the human living environment. The NSCORT Outreach and Education Program finds the ALS concept to be an "easy-selling", appealing topic for K-12 and adult audiences alike. Teachers find the normally problematic attention span of fourth and fifth graders to rivet on ALS topics for unprecedented periods of time. Great potential exists for developing entire educational curricula around ALStheme-based approaches to learning fundamentals in virtually all fields and especially those crossing disciplinary boundaries. The E & O program finds adult audiences to be more receptive to NASA in general following exposure to ALS presentations by NSCORT personnel. A listing of first-year outreach activities is summarized in the document that follows.

The ALS story will play a pivotal role in sustaining NASA's constituent support base for future Congressional appropriations for the nation's space program. The ALS NSCORT is thrilled to be part of this important program and looks forward to contributing to this exciting team effort in collaboration with the entire ALS community.

Best wishes,



Cary A. Mitchell, Director
ALS NSCORT

2.0 ALS NSCORT
Composition, Infrastructure and Personnel

5 - year grant with NASA

- **1 Dec. 2002 -30 Nov. 2007**
- **$1.6 Million in funding for Year 1**
- **$0.2 Million cost share supported by Purdue University for Year 1**
- **17 Projects at 3 universities**

Partnering Universities

- **Alabama A&M University (2 projects)**
- **Howard University (3 projects)**
- **Purdue University (11 projects & Outreach)**

Resource breakdown:

- **50% to waste management/recovery**
- **20% to systems analysis**
- **10% to food safety & technology**
- **10% to crop production**
- **10% to education and outreach**

Annual Deliverables:

- **Host ALS NSCORT Symposium**
  Involving all PIs, EAC, NASA Observers
- **ALS NSCORT Report to NASA**
- **Support ALS PI Meeting**
  Habitation Conferences

External and Internal Advisory Committees

External Advisory Committee

Gary Coulter	Colorado State University
Marc Deshusses	University of California – Riverside
Alan Drysdale	Boeing/NASA Kennedy Space Center
Les Grady	Clemson University
Fred Pohland	University of Pittsburgh
Hua Wang	The Ohio State University
Ray Wheeler	NASA Kennedy Space Center
Ex officio NASA:	
Dan Barta	NASA Johnson Space Center
Mark Kliss	NASA Ames Research Center
NASA Observers:	
Charles Barnes	Lead – NASA Adv. Human Support Tech Program
Jitendra Joshi	NASA Adv. Human Support Tech Program

Executive Committee

Primary Member	Alternate Member	Area Represented
Charles Rutledge	Pete Dunn	Vice-Provost for Research Office
Joe Pekny	Ned Howell	Discovery Park
Randy Woodson	Dale Whittaker	Agriculture
Jay Gore	Klod Kokini	Engineering
Caula Beyl	McArthur Floyd	Alabama A&M University
	Govind Sharma	Alabama A&M University
Kimberly Jones	James Johnson	Howard University
Bruce Applegate	Lisa Mauer	Focus Area Lead, Food Science
James Alleman		Associate Director
Kathy Banks		Associate Director
Cary Mitchell		Director

ALS NSCORT Personnel by Focus Area

Focus Area	Name	Function	Telephone	e-mail Address
Outreach & Education	Julia Hains-Allen	**Manager**	765.496.6694 765.496.6545	hains@purdue.edu
Systems	Joseph F. Pekny	**Lead**	765.494.7901	pekny@ecn.purdue.edu
Systems	Yuehwern Yih		765.494.8026	yih@purdue.edu
Systems	George T-C Chiu		765.494.2688	gchiu@ecn.purdue.edu
Systems	Bin Yao		765.494.7746	byao@ecn.purdue.edu
Systems	John Trimble		202.806.4822	trimble@scs.howard.edu
Systems	Gary Blau		765.494.9472	blau@purdue.edu
Systems	Seza Orcun		765.494.2181	sorcun@purdue.edu
Systems	George Applequist		765.494.4821	applequi@ecn.purdue.edu
Solids	James E Alleman	**Lead**	765.494.7705	alleman@ecn.purdue.edu
Solids	Charles C. Glass		202.806.6571	cglass@howard.edu
Solids	Jeffrey J. Volenec		765.494.8071	jvolenec@purdue.edu
Solids	Paul B. Brown		765.494.4968	pb@fnr.purdue.edu
Solids	Brad C. Joern		765.494.9767	bjoern@purdue.edu
Air & Water	M. Katherine Banks	**Lead**	765.496.3424	kbanks@ecn.purdue.edu
Air & Water	Kimberly L. Jones		202.806.4807	kjones@scs.howard.edu
Air & Water	Ernest R. Blatchley		765.494.0316	blatch@ecn.purdue.edu
Air & Water	Albert J. Heber		765.494.1214	heber@ecn.purdue.edu
Food Science	Bruce M. Applegate	**Lead**	765.496.7920	applegate@foodsci.purdue.edu
Food Science	Lisa J. Mauer		765.494.9111	mauer@foodsci.purdue.edu
Food Science	Leonard L. Williams		256.372.4165	lwilliams4@aamu.edu
Food Science	Michael R. Ladisch		765.494.7022	ladisch@ecn.purdue.edu
Crops	Cary A. Mitchell	**Lead**	765.494.1347	mitchell@hort.purdue.edu
Crops	Caula A. Beyl		256.372.4193	cbeyl@aamu.edu
Crops	R.P. Pacumbaba			aamrpp01@aamu.edu
Crops	Govind C. Sharma		256.372.4178	gsharma@aamu.edu
Crops	Gioia Massa		765.496.2124	gmassa@purdue.edu
Center	Dave Kotterman	**Ops Mgr**	765.494.0536	dkotter@purdue.edu

3.1 Education and Outreach Program
Executive Summary

Participants: Julia Hains-Allen and Kathy Banks

The NSCORT Education and Outreach Program is designed to engage audiences through concepts and technologies highlighted in the NSCORT research program. The outreach program is composed of three thrust areas. These areas are technical outreach (technology transfer, presentations to industry, etc.), educational outreach (graduate, undergraduate, K-12), and public outreach (museums, state fairs, etc.) We have been active in all three areas during the first nine months of NSCORT operation.

The initial challenge for NSCORT's new outreach program was to communicate and cooperate with NASA and another groups involved in ALS outreach efforts. After devoting the first three months to establishing links with key organizations and programs, the outreach leaders completed an impressive list of activities. Presentations were given to a variety of industrial, governmental, educational, and general public groups. Several other highlights of our outreach efforts were:

> ***Summer Fellowship Program*. During the summer of 2003, nine undergraduate students from Purdue, Howard, and Alabama A&M participated in the first NSCORT Summer Fellowship Program. After working diligently with mentor faculty and graduate students for eight weeks, the program ended with a Student Symposium held at Purdue University. The Symposium included presentations from the undergraduate fellows and selected NSCORT graduate students from all three partner universities.**
>
> ***Key Learning Community Project*. The NSCORT has formed a partnership with a Key Learning Community in Indianapolis, Indiana. The collaboration will focus on developing successful 9^{th}-12^{th} grade outreach strategies for NSCORT. The overall goal of the project is motivate students to pursue careers in science, technology, and engineering.**
>
> ***After-School Program*. This pilot program will organize and nationally disseminate curriculum for a standards/inquiry based after-school program focusing on the science and engineering that is the basis of the ALS NSCORT research program.**
>
> *Hometown, Mars*. The concept behind Hometown, Mars is a multi-dimensional project highlighting NSCORT ALS research. There are three components of the project; a traveling museum display for small museums, five traveling growth chambers for museums or learning centers, and a 3-D movie showcasing the NSCORT life support system in a Mars habitat. The project is a partnership between the Challenger Learning Centers, NSCORT, and Purdue. We are seeking additional funding for the project from NSF and/or industrial partners.
>
> Kathy Banks, Group Leader
> Education and Outreach

3.2 Education and Outreach

Co-Investigators: Julia Hains-Allen and M. Katherine Banks
Graduate Students: Neepa Shah, Sybil Sharvelle

Significance of Project in ALS
Education and Outreach provides an avenue to engage and educate higher education students, K-12 educators/students and the general public in the ALS/NSCORT center's investigations of the synergistic concepts and principles required for regenerative life-support in extended-duration space exploration.

Project Goals

1. Increase the number of minority students who pursue graduate degrees and research careers in science, engineering and technology.
2. Increase the scientific literacy of K-12 educators, students and general public, fostering public awareness and the earth benefits of NASA research.
3. Increase student interests in science, engineering and technology careers.

Project Progress
Education and Outreach project development focuses on three major areas:

1. Technical/Higher Education

Major Projects

- <u>Summer Fellowship Research Program</u>:
  A highlight of the ALS/NSCORT Center, this program offers undergraduate students from Alabama A&M, Howard and Purdue universities eight weeks of research experience under the direction of an ALS/NSCORT researcher. A two-day scientific symposium, culminating the summer research experience, was held July 30-31, 2003 at Purdue University, allowing each student fellow to present their work to their peers. Graduate students from the three participating universities presented their research, as well. Abstracts from the summer symposium are included in the Appendix
- <u>ALS/NSCORT Distance Learning Course</u>
  This course will provide a multi-state, multi-disciplinary, and multi-speaker opportunity for ALS/NSCORT faculty members to mutually build upon and reinforce their expertise in the area of advanced life support, while transferring this knowledge on a credit (3-hr) earning basis to students either directly working with, or academically curious about, our research mission.
  Furthermore, this course provides an avenue for ALS/NSCORT researchers to participate in, and contribute to, a team-building process that should help to catalyze the center's success. Dr. James Alleman, Purdue University, is responsible for the design and implementation of the course. A course outline is included in the Appendix 9.1.2.

- ALS/NSCORT Seminar Series
  The ALS NSCORT is in the process of developing a speaker list inviting individuals to the Purdue campus. The focus-area experts would share their knowledge through lectures or seminars about developments in the ALS community. The objective is to broadcast these presentations over the web using Sametime software so all interested parties in the NSCORT or NASA could actively participate at minimal costs. The goal is to have a speaker every two months, if not more frequent, beginning in the fall of 2003.

2. K-12 Education

Major Projects

- Key Learning Community Collaborative Project
  In the fall of 2003, the ALS/NSCORT Center at Purdue University and Key Learning Community in Indianapolis formed a coalition to enhance the learning of students in Indianapolis. The coalition has designed a rigorous course of action to address the problem that many underrepresented students in Indianapolis are not pursuing careers in science, technology and engineering.
  The collaboration will provide exposure, mentoring and research opportunities for 9-12th grade students at Key Learning Community via classroom visits, university trips and guidance provided by teachers at the public school and professors/ graduate students at Purdue University and NASA. Consistent with the overall goals of the partners, the project will: 1) inspire and motivate students to pursue careers in science, technology, and engineering; 2) engage students in shaping and sharing the experience of exploration and discovery and; 3) enhance student's learning of core concepts through applications of science, technology, and engineering in everyday life.
  This collaborative project provides Key Leaning Community students with an arsenal of experiences which make learning science, technology, and engineering exciting without sacrificing rigor.

- Lafayette Community School Corporation After-School Program
  ALS/NSCORT Education and Outreach will develop and nationally disseminate curriculum for a standards/inquiry-based after-school program stressing the interdisciplinary fundamentals of science, technology and engineering that underlies Advanced Life Support research.
  A pilot program, beginning in October 2003, will be used to test the curriculum in the informal education setting of a children's science museum. This pilot program, Mission to Mars, targets 4thand 5th grade students in the Lafayette School Corporation. ALS/NSCORT is leveraging funds provided by Lafayette School Corporation to test the pilot program for four elementary schools in the LSC district. The school corporation will provide funds, supervision and transportation for 100 students to participate in this pilot program.
  Following the pilot period, curriculum will be nationally disseminated via NASA resources, national and local conferences and professional development workshops. Materials developed will include existing NASA activities, adapted for after school environments along with new activities developed by ALS/NSCORT. The complete curriculum will consist of student guides, teacher guides and resources, timelines, materials lists and assessment. A topic list is included in the Appendix 9.1.3.

Minor Projects

- <u>Tippecanoe School Corporation</u>
  ALS/NSCORT is supporting a Lilly Foundation funded project at Tippecanoe School Corporation to provide resources for two activities for middle school students. Educator Linda Clark (TSC) is leading a team of middle school educators to design and implement investigations of tilapia and hydroponic plant growth. ALS/NSCORT outreach manager and graduate students are providing resources for the investigations.

3. Public Education

Major Projects

- <u>Hometown, Mars Collaborative Project</u>
  Hometown, Mars is a multi-dimensional project showcasing the research of NASA Specialized Center of Research and Training in Advanced Life Support (ALS/NSCORT). The project will develop and disseminate three interrelated yet independent components: 1) a traveling museum exhibit targeting small museums, 2) five traveling plant growth chambers for museum/learning centers and 3) a traveling 3-D "movie" showcasing the entire life support system within the Mars habitat. This project is a collaborative effort between ALS/NSCORT, Purdue University Envision Center, Science Central, Brownsburg Challenger Learning Center and Imagination Station.
  The *Hometown, Mars* Project envelopes a commensurately focused plan to increase the scientific literacy of our project participants. This project will use high resolution, interactive experiences to engage participants in NASA-based scientific inquiry and hands-on activities. Through 3-D, spatial/stereo sound and haptic interfaces, the *Hometown, Mars* project will target small science museums/science centers across the country to educate and engage the participants in cutting-edge science, technology, mathematics and engineering. This project will bring the excitement of NASA research into the informal education arena, preparing students and the general public for the world that is and will be. A $2.4 M Informal Education National Science Foundation proposal has been submitted to support this project.

Minor Projects

- <u>Discover Purdue</u>
  ALS/NSCORT provided an interactive booth and display showcasing the NASA research on-going in the Center at "Discover Purdue" held at the Chicago Field
- <u>Discover Purdue (Continued)</u>
  Museum on June 14^{th}. Highlights include a growth-chamber from the ALS Crop Production research group, a take-home instructional packet including dwarf wheat seeds provided by Bruce Bugbee at Utah State, an ALS/NSCORT adaptation of "Farming in Space" for the assembly of a growth chamber similar to the center's laboratory chamber, along with at-home experiments for parents and children adapted from various NASA activities. More than 47,000 invitations to the event were sent out to Purdue alumni and supporters in Chicago and surrounding areas.
- <u>Indiana State Fair</u>
  ALS/NSCORT participated with members of Indiana Space Grant Consortium to provide an interactive booth and display at the Indiana State Fair in August. This booth, "History of Flight", featured hands-on activities for K-12 students along with providing numerous

take-home activities. ALS/NSCORT specifically provided "space seeds" for on-site planting in recyclable containers and instructions for at-home growth chambers.

- Indiana Science and Engineering News
  Science Education Foundation of Indiana sponsors an electronic newsletter three times a year for teachers, students, parents and the general public in Indiana. This newsletter's focus is to raise awareness and promote interest in cutting edge science and engineering topics. The first in a series of articles produced by ALS/NSCORT was published in the Spring 2003 issue.

Trainees Involved

ALS/NSCORT Graduate Students

Sybil Sharvelle	Purdue University
Kelly Pennell	Purdue University
Chit-Hui Ang	Purdue University
John Gonzales	Purdue University
Selen Aydogan	Purdue University
Charita Brent	Howard University
Ilan Weiss	Purdue University
Ressa Chee Wah	Howard University
Joffrey Levy	Howard University

ALS/NSCORT Summer Fellows

Deidra Carr	Howard University
Rachael Jennings	Howard University
Christine Tibbs	Purdue University
Kavita Manohar	Howard University
Joi Dunham	Purdue University
Wendall Khunjar	Howard University

Marc Aim Students

Christian Ghauttas	MARC/AIM Program

SURF Fellows

Katherine Graham	Purdue University
Erin Maloney	Purdue University

Research abstracts are included in the appendix 9.1.1.

Presentations/Programs

ALS/NSCORT principal investigators and graduate students were responsible for presentations. Those presentations are discussed in the individual report sections. The following presentations are focused on Education and Technical Outreach specifically.

Technical Outreach

- **Purdue Day in Chicago** [June 2002 and June 2003]
  - To engage alumni and general audiences
- **Indiana State Fair and Indiana2016** [August 2002, 2003]
  - To promote Indiana2016 initiative of First Lady Mrs. Judy O'Bannon
- **Homecoming Event** [September 2002 and October 2003]
  - To engage alumni
- **Science Discovery Day/Indiana Einsteins Day** [April 2003]
  - To promote science discovery among 6-8 graders and support IN2016 initiative
- **External Engineering Visiting Committee** [April 2003]
  - To engage alumni for schools of engineering
- **Greater Lafayette Chamber of Commerce Exposition** [April 2003]
  - To engage local businesses
- **International Council on Systems Engineering Workshop** [May 2003]
  - To support system of systems superproject
- **Business Plan Competitions** [March/April 2003]
  - To engage corporate sponsors and promote entrepreneurships
- **Washington Advisory Group** [December 2002]
  - To share vision and mission and seek recommendations on Discovery Park/University Research Infrastructure
- **Central Indiana Corporate Partnership** [October 2002]
  - Sponsor for Life Sciences Business Plan Competition
- **Office of Critical Infrastructure, U.S. Department of State** [December 2002]
  - To engage federal government for infrastructure needs
- **Marshfield Clinic** [January 2003]
  - To seek partnership and joint research projects in food safety, facilitate communication with Purdue based start up BioVitesse.

Higher Education

- **e-Enterprise Center at Discovery Park Research Colloquium [January 2003]**
  - Poster Presentation: *The NASA ALS/NSCORT Center*
- **Lilly Endowment Committee [March 2003]**
  - Presentation: *The Implementation of NASA Sponsored Advanced Life Support Research for Economic Development on Earth*
- **Indiana Space Grant Symposium Conference [April 2003]**
  - Presentation: *Sustaining an Independent, Regenerative Life Support System in Space*
- **Energizing the Enterprise Symposium: Technology Connecting Science, Business, Manufacturing, and Service [May 2003]**

- Poster Presentation: *The NASA ALS/NSCORT Center*

K-12 Students/Educators

- **Key Learning Community Indianapolis Public School Faculty [March 2003]**
  - Presentation: *Preparing for a Mission to Mars*
- **Project 2016 – Indiana Einsteins [April 2003]**
  - Presentation and Program: *Preparing for a Mission to Mars*
- **Delphi Parks Program [June 2003]**
  - Program: *Guppy Ecosystem*

General Public

- **Westminster Retirement Village [January 2003]**
  - Presentation: *Independent Living in Space*
- **Purdue Alumni Association [April 2003]**
  - Presentation: *Preparing for a Mission to Mars*
- **Kiwanis [March 2003]**
  - Presentation: *Sustaining a Safe, Healthful, and Independent Living Environment in Space*
- **Indiana Health Industry Forum [March 2003]**
  - Presentation: *Sustaining A Safe, Healthful, and Independent Living Environment in Space*.

Collaborations/Partners

- Indiana Space Grant Consortium
- NSF funded LSAMP Program
- Marc Aim Program
- SURF Program
- Challenger Learning Centers
- Envision Center, Purdue University
- Science Central
- Imagination Station
- Lafayette School Corporation
- Tippecanoe County School Corporation
- Indianapolis Public Schools
- Space Ag in the Classroom
- Astro-Venture
- Utah State University
- Science Education Foundation of Indiana

4.1 Integrated Systems Group
Executive Summary

The unique role of the Integrated Systems Group is to foster productive interactions among all researchers across different ALS disciplines in furtherance of several goals.

One goal is to guide NSCORT research toward the overall design of a life support system of acceptable cost and reliability. Equally important, the ISG aims to promote collaboration among researchers at all three institutions. In addition, the group is collecting and disseminating considerable knowledge from past and ongoing worldwide ALS research to help the current NSCORT build upon previous accomplishments rather than reinvent them.

Significant investments in human resources and technology have allowed the ISG to achieve several steps toward its objectives. The principal investigators, postdoctoral staff, graduate students, and technical staff have engaged in several projects and events. The systems modeling work leading to two ICES-2003 papers were important ISG products. These presentations showed the initial steps in the long-term systems strategy which makes innovative use of optimization. Special events organized by the ISG included seminars by distinguished visitors and a workshop to introduce the systems group and other researchers to each other. Members have visited colleagues at Kennedy Space Center and in Europe and upon return presented their findings. Regular group meetings have generated ongoing discussion to identify the key research questions worthy of focus for the duration of the NSCORT, and the pursuit of adequate data which remains one of the main modeling challenges.

The group is gaining much leverage from donated collaboration software, such as the web-based QuickPlace for exchange of documents and reference information, and is assisting in Outreach by creating the NSCORT website for the general public.

The close one-to-one cooperation of ISG members with subsystem specialists is accelerating the refinement of our modeling efforts and is anticipated to provide new developments for presentation in 2004.

Joseph F. Pekny, Group Leader
Integrated Systems Focus Area

4.2 Integrated Systems Group Activity Summary 2003

Principal Investigator: Joseph F. Pekny

The first year effort of the Advanced Life Support (ALS) NSCORT Integrated Systems Group (ISG) has been directed towards the following areas.

(1) Begin a web based compilation of reference material and develop an electronic means for ALS/NSCORT wide collaboration. Training material and people oriented processes are being developed to promote use of these tools. This activity will continue throughout the project duration.

(2) Become familiar with past ALS work, identify key ongoing activities, and develop a network with potential national and international collaborators. This activity will continue throughout the project duration.

(3) Develop a list of questions associated with ALS that could be addressed by ISG effort. This list of questions will be refined throughout the project duration.

(4) Recruit students and begin technical work towards the development of ALS systems models that provide insight into integrated behavior of an ALS, can address important questions associated with ALS, and allow subsystem researchers to assess the potential impact of their efforts. These models will become more sophisticated over the project duration as planned in the project proposal.

(5) Develop close connections between the ISG faculty and students and the other ALS/NSCORT researchers. In this way the ISG will provide an informal and people oriented integration service to the ALS/NSCORT. This activity will continue throughout the project duration.

Note that the ISG includes all systems analysis effort at Purdue University (Chiu, Pekny, Yih) and Howard University (Trimble). Also note that the ISG benefits from full time participation of Dr. George Applequist who is a researcher within Purdue University's Discovery Park, 25% effort of Dr. Seza Orcun who is a researcher within the School of Chemical Engineering at Purdue University, and extensive participation of Professor Gary Blau of the School of Chemical Engineering at Purdue University. Professor Blau is a visiting professor with over 30 years of experience at Dow Agrosciences. His specialty is statistical modeling with particular interests in the modeling of plants. These three individuals have been critical to beginning ISG efforts. Activity in each of the above areas will be summarized in the sections below.

Web Site and Electronic Based Collaboration

In collaboration with Professor Jim Alleman (ALS/NSCORT Knowledge Management Director), Dave Kotterman (NSCORT Operations Manager), Julia Hains (ALS/NSCORT Outreach Manager), and the e-Enterprise Center at Discovery Park development team (led by John Burr), the ISG has established a web site

http://www.purdue.edu/DiscoveryPark/als/nscort/

which is visible to the public. On the left hand side of this web page please notice the login box for the ALS/NSCORT Quick Place (an IBM Product). This area is a restricted access collaboration area with the welcome page shown below in Figure 1 after an authorized ALS/NSCORT user logs into the Quick Place.

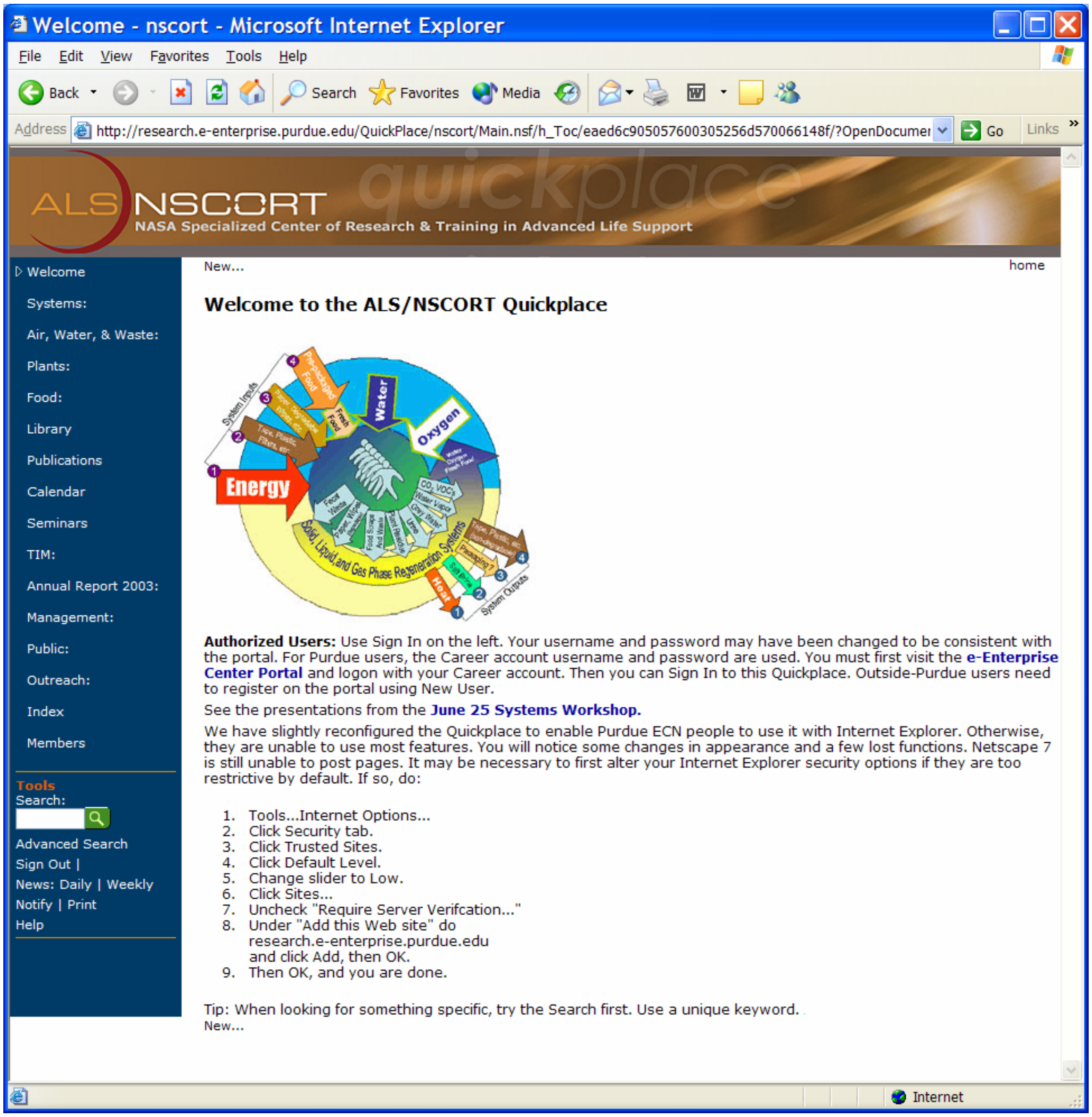


Figure 1 – ALS/NSCORT Restricted Area Quick Place Home Page

The left hand side of this screen shot indicates the classification of material to date in the Quick Place. The Quick Place provides for web based exchange of files, revision control of documents, discussion threads, calendaring, and a search facility (visible in the above diagram on the left) that allow all Quick Place entries to be searched for text strings. The search facility is able to search the bodies of archived documents in many standard formats (e.g. Word, pdf, etc.). To support the web site for ALS/NSCORT activities the Purdue University Discovery Park staff provides training and support of the web site. Figure 2 shows the beginning Quick Place screen for the ISG area.

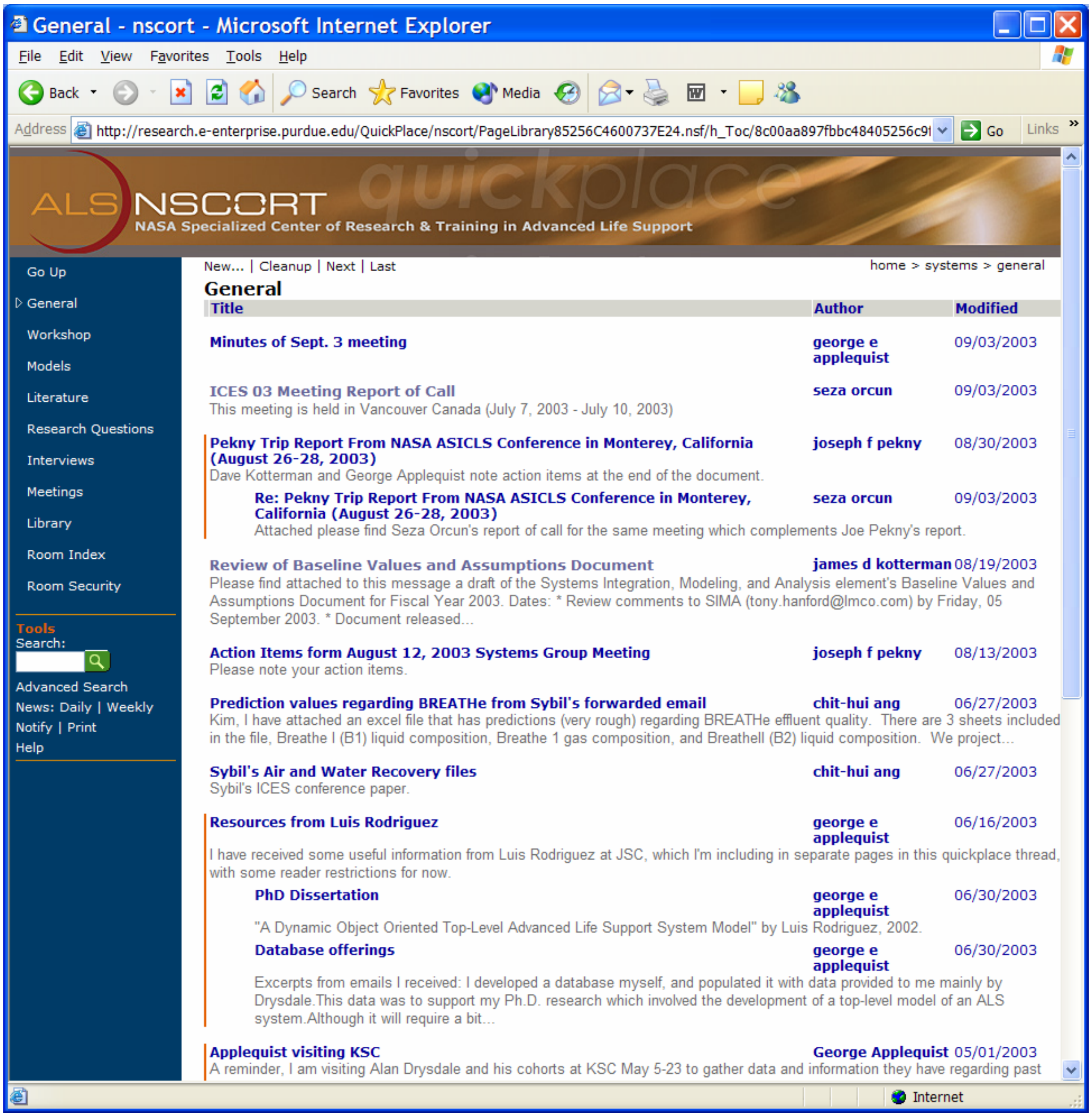


Figure 2 – Home Area of the ISG Quick Place.

The ISG maintains comprehensive documentation of activities in its Quick Place area. Clicking on any of these entries brings up a formatted web page created by the author that can contain text, graphics, and attachments.

For example the web page shown in Figure 3 was created in the ISG Literature section of the Quick Place. The ISG has posted over one hundred key documents or references to the Literature review area.

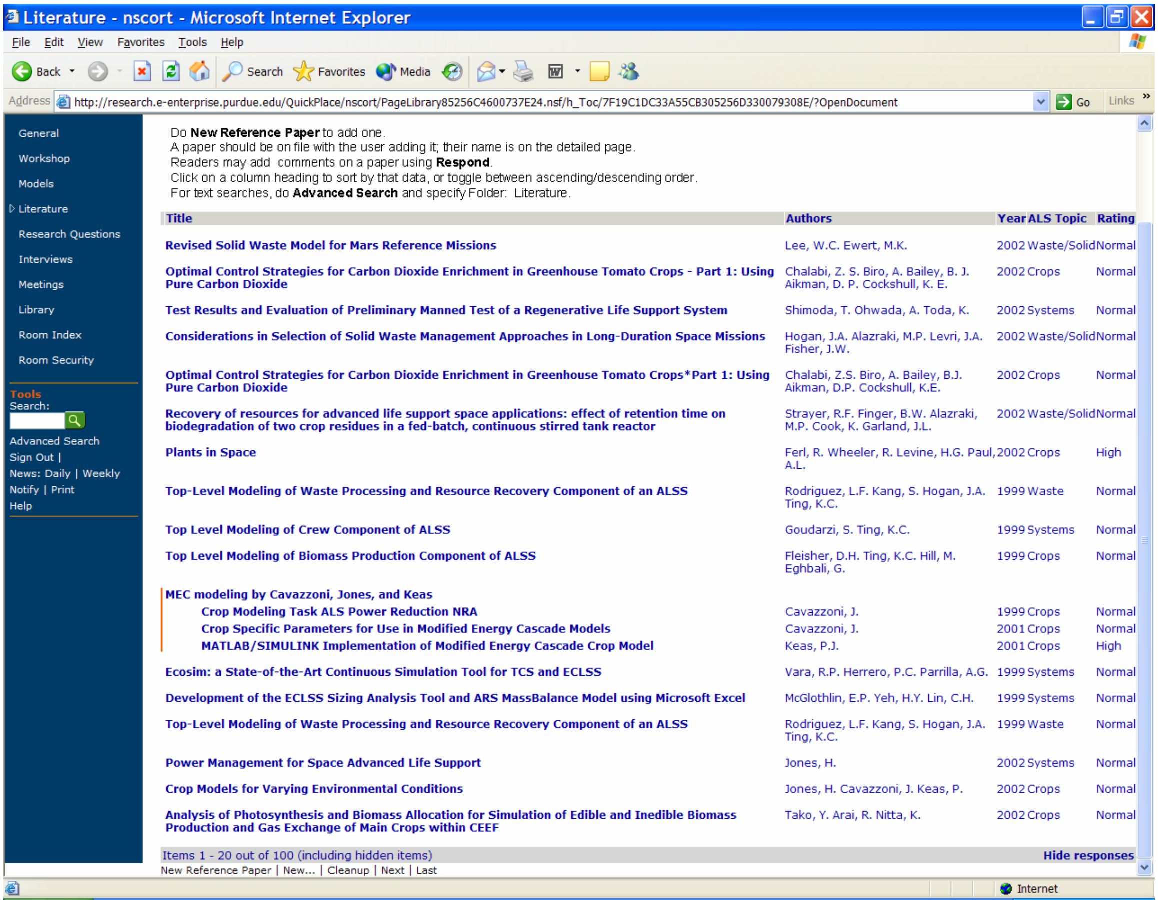


Figure 3 – Home Page of ISG Literature area of the Quick Place

Background Research and Networking

As Figure 3 indicates the ISG has developed an extensive compilation of over hundred key ALS reference documents. We expect to continue adding material to our collection by monitoring NASA and MELiSSA efforts; by attending ICES, Habitation, and specialty (e.g. ASICLS) conferences; and monitoring key literature.

The ISG has undertaken several activities to better learn the ALS research network.

- We have invited Alan Drysdale (affiliated with NASA/KSC) and Dr. Julie Levri (affiliated with NASA/Ames) to give seminars. This fall we hope to invite Tony Hanford and others to give seminars.
- In addition to the seminar visits by outside ALS researchers, Dr. George Applequist visited NASA/KSC for three weeks to learn about ALS-oriented KSC activities, obtain background material, and develop contacts. The rest of the ISG benefited from Dr. Applequist's visit through his trip report and the extensive reference material that he obtained, available to researchers on the QuickPlace. This fall we hope to place Dr. Applequist at another NASA site for some period of time.
- Along with other researchers from the ALS/NSCORT, Professor Gary Blau visited with MELiSSA researchers in Clermont, France during the period May 22-23, 2003. He reviewed ALS/NSCORT plans and received an extensive briefing on MELiSSA efforts. Participants in this special meeting included the European Space Agency (ESA), MELiSSA Team including University of Guelph, MELiSSA sponsors Crestech (Center

for Research in Earth and Space Technology) and the Canadian Space Agency (CSA), MELiSSA Technology Transfer Firm (JRA Technologies), Blaise Pascal Chemical Engineering Department Professors, the Russian Space Agency, and NASA.

- On July 7-10, 2003, Professor George Chiu, Professor Yuehwern Yih, Dr. Seza Orcun, and Selen Aydogan attended ICES 2003 in Vancouver. The paper "An Advanced Scheduling Model for Crop Production in Bio-Regenerative Advanced Life-support (ALS) Systems,"[2] was presented by Seza Orcun, and "Aggregate System Level Material Analysis for Advanced Life Support Systems."[1] was presented by Selen Aydogan.
- In August 2003, Dr. Seza Orcun and Professor Joe Pekny attended the NASA ASICLS conference in Monterey, CA, along with Professor Cary Mitchell.

One issue that is clear early in the ALS/NSCORT, that bears close monitoring, and proactive pursuit is obtaining experimental based data to support modeling activities. Existing NASA documentation and available literature have been invaluable to current ISG activities, but more sophisticated models may be limited by available data. The ISG will keep close account of data needs.

Development of ALS/NSCORT Key Question List

ISG activities over the life of the project will be driven by key questions associated with ALS. Over forty questions have been compiled by the ISG based on various discussions (see the previous section) within and outside the ALS/NSCORT. A comprehensive list of questions and comments on these questions is maintained in the ISG Quick Place area.

Student Recruitment and Technical Work

In order to help guide future efforts the ISG has developed an initial material balance based model of an ALS. This work was presented at ICES 2003 ("Aggregate System Level Material Analysis for Advanced Life Support Systems"[1]). This model involves major components in an ALS system and their transformations through the main subsystems: the human crew, crop growth, food processing, and waste processing/resource recovery. Variables were assigned to the mass rates of material entering and exiting each subsystem, operating at steady-state (i.e. no accumulation in any subsystem) for a single crewmember in a one-day interval. In addition, crop area for a predefined mixture of crops was a decision variable. Major components were water, oxygen, carbon dioxide, and biomass; key subcomponents were carbon in food and wastes, and edible/inedible biomass. Material balances involved the flows of mass to satisfy steady state conditions and other constraints, such as daily human inputs and crop growth requirements. The BVAD provided almost all necessary data, and resource recovery efficiencies were assumed for simplification. An innovation in this work was the solution of the overall ALS model with linear programming, manipulating the variables systematically to obtain an optimal (minimal) solution for a given cost function. It was shown how various mission scenarios would imply different relative costs of materials or supplied food, and the effects on the optimal crop area, material supply requirements, and all other system variables.

In addition a scheduling model was developed and presented at ICES 2003 to coordinate crop consumption, planting, and harvesting ("An Advanced Scheduling Model for Crop Production in Bio-Regenerative Advanced Life Support (ALS) Systems"[2]). This fall an energy balance will be added to the material balance model to provide very rough estimates of energy usage in an ALS. Also this fall the ISG will begin the development of a more detailed model in which subsystem models will be developed and integrated for the specific ALS/NSCORT technology being proposed. The purpose of this model is to guide subsystem development and test the integrated effectiveness of the proposed effort. This model will be used to answer key questions concerning an ALS in various proposed mission scenarios.

To augment future efforts five graduate students have been recently recruited by the ISG (Elif Aksoy, Chit Hui Ang, Selen Aydogan, Charita Brent, Yan Fu Kuo). These students are being assigned to interact with the various other subsystem researchers. We plan to have the ISG graduate student serve internships with the other subsystem groups in order to develop relationships among the ALS/NSCORT graduate students and to develop deep knowledge of subsystem design intent and underlying phenomena. For example Professor Trimble's student, Charita Brent, spent one month at Purdue University (July, 2003) leading knowledge elicitation activities for ISG graduate students.

ALS/NSCORT Networking Activities

In order to build cohesion among the ALS/NSCORT team the ISG has conducted several activities. In particular the ISG hosted an all day intra-ALS/NSCORT workshop on June 25. All subsystem team leaders presented overviews, plans for their subsystems, and summarized modeling issues from their perspectives. Professor John Trimble gave a presentation on knowledge elicitation and subsequent to the workshop, Professor Trimble's student, Charita Brent, spent one month leading knowledge elicitation activities for ISG graduate students among the subsystem researchers. By having the ISG graduate students intern with subsystem group members we hope to establish informal collaborations. In addition to graduate student interactions, the ISG has assigned faculty and full time researchers to liaison with the subsystem groups. Together with the graduate student contacts this will provide for several modes of interaction.

Presentations

1. S. Aydogan, S. Orcun, G. Blau, J. F. Pekny, G. Applequist, Y. Yih, G. Chiu, B. Yao. (2003) *Aggregate System Level Material Analysis for Advanced Life Support Systems*. ICES 2003-01-2362.

2. S. Orcun, G. Blau, J. F. Pekny, C. A. Mitchell. (2003) *An Advanced Scheduling Model for Crop Production in Bio-Regenerative Advanced Life Support (ALS) Systems.* ICES 2003-01-2358.

Integrated Systems Status Report for the Howard University Systems Effort
PI Dr. John Trimble, lead graduate student Charita Brent
August 22, 2003

The Systems group recognizes that the knowledge acquisition process is central to developing and implementing knowledge management systems. Knowledge elicitation is the primary approach to knowledge acquisition required in this situation. During our first year emphasis has been placed on developing and implementing a knowledge elicitation protocol used to solicit knowledge from the various NSCORT principal investigators, project faculty and project graduate students. We were able to initiate this protocol during the Spring at Howard University and during the summer at Purdue University. We are now starting a phase of assessing and revising this protocol.

To restate from our initial proposal "the 1st objective of this project is to identify and apply critical developments in knowledge management to the knowledge engineering and knowledge management tasks of the overall NSCORT effort". Advances have been made in the development of software tools to aid knowledge management. An examination of various tools concluded that the IBM - Lotus Notes suite of tools installed, tested, and utilized at Discovery Park, Purdue University was the best choice at this time.

The 2nd objective of Howard University system's component of the NSCORT project is to apply the system dynamics methodology and associated modeling and simulation tools to the overall ALS system as well as the subsystems. The initial effort to apply the system dynamics methodology involved the water subsystem. Interviews of Dr. Kim Jones were the source of the knowledge used to develop the first set of system dynamic models of the water system. Several scenarios using these models were presented at the first seminar given by Dr. Trimble at Purdue. Feedback from faculty and student researchers has provided the basis for revising this model. Plans to extend this approach to other subsystems will be initiated this academic year.

A limited amount of our effort has been devoted to preparing faculty and students for work on the semantic web. This has been done with the believe that the semantic web will be our best long term approach to knowledge management and initial knowledge constructs should be developed with this foresight.

Timeline of Activities

1. September 2002 – Interviews of Dr. Kim Jones and meetings to discuss the water cycle in ALS and the role of membrane technology. This resulted in the development of the 1st cut at a simplified system dynamics model of the water cycle. Also Dr. Trimble worked with one of his graduate students, Shirley Boampeng, to investigate several knowledge management tools including Placeware and QuickPlace.

2. October 21-22, 2002 – Dr. Trimble made a visit to Purdue to give a lecture on "Knowledge acquisition and system dynamics". After a visit to Purdue University's Discovery Park Dr. Trimble agreed that the IBM – Lotus Notes suite of tools that include

QuickPlace was the most appropriate choice for the initial work of knowledge management.

3. January – February 2003 – Dr. Trimble included lectures on simulation of the ALS system in his graduate Modeling and Simulation course.

4. February 10th – April 7th 2003- Howard University, Washington D.C. Toured Dr. Kim Jones Water Filtration Laboratory. Graduate students Charita Brent and Tolulope Folarin met frequently with Dr. Jones and graduate students to gather parameter and system dynamics data for the Membrane Subsystem. Data was gathered and used in membrane filtration simulation constructed in Stella version 7.0, by High Performance Systems Incorporated.

5. April 8th 2003 – Howard University Annual Graduate School Research Symposium, Washington, D.C. Graduate students Tolulope Folarin and Charita Brent presented paper "Simulation of Membrane Filtration Water Recycling System." Paper discusses the simulation of a 100% closed water recycling system through the software Stella version 7.0, by High Performance Systems Incorporated.

6. June – July 2003, Two undergraduate students and one graduate student, Moses Elias, worked with Drs. Trimble and Keeling investigating the potential utilization of the semantic web for knowledge management. This effort involved multiple projects and was only partially funded through the NASA grant. The main concern is the training of students in web development, web services and the semantic web tools in preparation for future utilization by the ALS project.

7. June 1, 2003 – ADMI 2003 Conference, Washington D.C. Graduate student, Charita Brent presented the revised paper "Simulation of Membrane Filtration Water Recycling System." Revision included a control system framework which would allow the user of the system to manipulate control variables during simulation. Framework was constructed using the software Stella version 7.0, by High Performance Systems Incorporated.

8. June 12th 2003, Dr. Trimble participated in the Systems group meeting via telephone conference call and QuickPlace files.

9. June 25th, 2003 – ALS NSCORT Systems Workshop, Purdue University, West Lafayette, IN. Graduate Students and Project Investigators attended the Systems workshop to learn about the dynamics of the entire NSCORT project. PI Dr. Trimble gave a lecture on knowledge acquisition. Assignments for various projects for the summer were distributed. Charita Brent was assigned to work under George Applequist to assist with the implementation of nitrogen to the Systems Aggregated Model. Charita Brent was also assigned to conduct interviews with PIs and graduate students at Purdue University in addition to gathering information from PIs and graduate students at Howard University.

10. June 26th 2003 – Dr. Trimble conducted a workshop on "knowledge elicitation" at Purdue for the graduate students assigned to the ALS project for the summer. A knowledge acquisition protocol was presented for use by the students over the summer. An initial group interview was conducted with a focus on the air and water subsystem. Dr. Trimble

led the effort but several other system group tea members were involved and made valuable contributions.

11. June 26th – July 31st 2003 – ALS NSCORT Internship, Purdue University, West Lafayette, IN. Graduate student Charita Brent conducted interviews with Air and Water Subsystem PIs and graduate students at Purdue University.

12. August 1st, 2003 – ALS NSCORT Graduate Research Symposium, Purdue University, West Lafayette, IN. Graduate student Charita Brent presented work completed at Purdue University. Presentation "Knowledge Acquisition Framework for ALS NSCORT Program" included knowledge elicitation techniques such as a structured parameter form, flowcharts and graphs applied during and after interviewing NSCORT subsystem members. Ms. Brent's presentation also included progress from implementing nitrogen to the Aggregated Systems Model.

13. August 4th – present – Howard University, Washington D.C. Ms. Brent interviewed PI Dr. Paul Brown and his graduate student at Purdue University. Dr. Brown is involved in Tilapia fish growth of the ALS project. Graduate student Charita Brent is also posting project information for various subsystem groups on QuickPlace by Lotus Notes, NSCORT data repository.

14. August 18th – A taxonomy of the research questions was developed and placed on QuickPlace as an aid to knowledge management. Also an approach to selecting priority questions and the results were posted on QuickPlace.

15. September 11-13 Charita Brent is scheduled to present a talk on 'Knowledge elicitation protocol in ALS System Analysis' at the National Technical Association's (NTA) National conference in Orlando Florida.

16. September 2003 – PI Dr. Trimble and graduate students are conducting work on extending the system dynamics model of the water cycle.

5.1 Solids Executive Summary

Team Integration, Collaboration, and Startup

Our NSCORT 'solid waste group' has maintained a high-level of collaborative interaction during its first eight months of research startup. For the three Purdue projects, we've held several (approximately monthly) faculty-student meetings both to lay out our upcoming laboratory activities and to debate alternative strategies for selecting and processing waste materials. As for our interaction with Charles Glass at Howard, I've been fortunate in having two meetings with him in Washington DC during the Spring 2003 semester due to travels on other projects, and we've also spoken on the phone a number of times to fine-tune his project's focus. Of course, as might be expected due to the fledgling nature of our efforts, tangible research results are only now starting to come in. In each case, our projects involved sizable expenditures of time on reactor design and construction, and in all cases our faculty and students have spent considerable time developing their own levels of understanding in regard to the technical issues at hand as well as trying to resolve 'who' has already done 'what' and 'where' in regard to prior, and also current, ALS solid waste research. All of us would likely agree that the latter aspect of a project startup period, relative to helping students appreciate the overall context of the project, was particularly time consuming due to the fact the NASA's ALS requirements represent such a highly complex challenge. As part of this 'learning curve' we've also tried to participate on a regular basis with both the general TIM calls and also the specific 'solid waste' calls now managed by John Fisher at AMES.

Project Student Recruiting

All four of our group projects are now fully staffed in terms of graduate student 'trainees.' Rather notably, and in spite of his initial funding constraints (see later note), Charles Glass was able to assign a student to this effort by way of creatively leveraging internal funding. In each case, these students all represent outstanding additions to our program as a whole…and in the particular case of our four Purdue 'solid waste' students they have all provided a catalytic influence on student collaboration within our center as a whole, as is clearly manifested by their formative creation of their own student 'team meetings.'

Significant Project Issues

1) STAR Solid Waste Processing (Jim Alleman @ Purdue): Reactor mixing and aeration concerns are still being worked out, with an inherent degree of optimism that upcoming optimization strategies will be forthcoming.

2) STAR Off-Gas Processing (Charles Glass @ Howard): Although faced with serious funding constraints, this project has done extremely well in terms of early lab outcomes.

3) STAR Residuals Processing via Tilapia (Paul Brown @ Purdue): Given our belated identification of an ammonia carryover problem with the STAR residuals, a new solids dewatering scheme is now being sought to obviate this difficulty.

4) STAR Residuals Water Recovery and Post-Processing via Reed Beds (Jeff Volenec and Brad Joern @ Purdue): This project has proceeded smoothly, using surrogate STAR-type residuals (e.g., thermophilically processed sludges).

James E. Alleman, Group Leader
Solids Focus Area

5.2 Project Title

Solid-Phase Thermophilic Aerobic Reactor (STAR) Processing of Fecal, Food, and Plant Residues

Principal Investigator
James E. Alleman, Purdue University

Co-Investigators
None

Project Significance for ALS

The key significance of this project would be that of demonstrating the conceptual applicability, and practical utility, of a thermophilic digestion process for biodegradable waste solids generated within a space or planetary habitat. The projected benefits, compared to previously researched waste processing technologies (1), of the innovative 'Solids Thermophilic Aerobic Reactor' (STAR) strategy would include: reduced reactor volume, reduced retention time, pasteurization of applied solids, and reduced manpower requirements.

Project Goals and Objectives

The primary goal of this project is to develop an original high-temperature solids digestion system for processing waste organics within a sustainable closed-loop ecosystem, whereby a pathogen-free residuals stream generated by this process would then be amenable to direct water and nutrient recovery. The design is loosely modeled after the successful, commercial Autothermal Thermophilic Aerobic Digestion (ATAD) wastewater sludge treatment process. (2) In turn, the associated objectives would be as follows:

1- To create a thermophilic STAR reactor system mechanically able to suitably mix and aerate high input solids levels at the expected range of 6 to 10% solids, (3)
2- To maximize this STAR reactor's positive, ESM-enhancing attributes in terms of gas transfer rates, solids shear, solids and organic destruction performance, and pathogen pasteurization, (4,5)
3- To minimize this STAR reactor's negative, ESM-degrading attributes, in regard to noise generation, vibration, energy consumption, heat shedding, and foaming,
4- To evaluate this STAR system's performance when supplied with a long term mission waste stream including real fecal and plant materials, (6)
5- To evaluate the complementary use and operational performance of a vacuum waste collection system, particularly in regard to high-solids waste pickup with reduced levels of water spray and dilution, and
6- To provide collaborative support for three subsequent post-processing NSCORT research project's, including those of Charles Glass (off-gas air processing), Paul Brown (residuals uptake via fish), and Jeff Volenec and Brad Joern (residuals water separation via plants).

Research Progress

Our initial efforts with this project have ranged from background literature reviews to hands-on reactor development and experimentation. At present we are working with a 3rd generation reactor configuration, and are planning to begin studies with real fecal waste materials within the coming month. Plans for subsequent experiments exploring reactor performance with a more complex waste stream, including inedible biomass, are being developed.

One of the clear motivations behind our initial review of the literature on waste solids processing in the context of ALS operations has simply been that of upgrading our own knowledge base and inherent appreciation for the diverse alternatives presently available with waste solids management. In turn, we sequentially prepared two summary databases, including an initial Excel-format spreadsheet and an improved Access-format version (see attached sample pages from each), with which we could fundamentally grasp not only the overall breadth of these options but also their particular technical features and affiliated champions (i.e., who was overseeing each such project, and where). (1, 7) Given the overarching ESM-driven challenge faced by all of these projects, we also tried to weave in this specific issue with our improved Access database, at least in a quasi-quantitative fashion. However, in all honesty we came to the conclusion that the quality of available detail was not going to be sufficient for this task, at which point we opted for a moreso qualitative assessment.

As for reactor development and testing efforts with our so-called STAR system, we have successively constructed a series of units whose design and operating regimes have progressively been refined in order to secure improvements with mixing and gas transfer. Our 1st generation reactor (shown in the accompanying photograph) represented an initial attempt to meld the key elements of our reactor design, whereby an in-line pump was in combination with a series of air-bladder valves whose open and closed configurations would allow for side-stream flow movement either through aeration or deaeration zones. What we quickly learned with this first system, though, was that the complexity of manipulating the attached six (6) air-bladder valves was simply too overwhelming, and that this aspect of the reactor's eventual operation would have to be temporarily side-tracked in lieu of simple manual valving.

In turn, our 2nd generation STAR system (see accompanying photograph), included a totally redesigned approach to flow control, as well as being upgraded with two gas-transfer columns by which we would be adding oxygen to the system while at the same time stripping off carbon dioxide and other off-gas residuals. As had been done with the previous unit, a cross-over pumping action was again built into this 2nd generation reactor such that aeration and/or gas stripping could be selectively maintained on separate left- and right-side flow streams. The conceptual operation of this dual-column design mode, with its associated cross-over pumping regime, is schematically depicted in an accompanying diagram. However, three significant findings were made during a subsequent series of oxygen transfer rate measurements. First, the observed oxygen transfer rate was unexpectedly less than expected, at 156 mg/L-hr, which would then be marginally able to meet our expected STAR reactor average oxygen utilization rate. Second, we were surprised to find that the pump's left and right side displacement volumes were not the same, or at least were sufficiently different to progressively shift the reactor contents away from a uniform left-versus-right balance. In fact, the degree of this unbalanced flow eventually became so severe that the entire right-side column nearly went empty, at which time the pump intake on that side started to aspirate gas as well as liquid directly from the aeration column. Secondly, we learned that our expected operating temperatures were going to be sufficiently close to the permissible temperature limit with standard PVC materials that softening and deflection of these materials would likely be experienced.

As a result, we have now shifted our efforts to yet another, 3rd generation reactor (see accompanying figure) where the cross-over pumping configuration was dropped while at the same time the dual gas transfer columns were dropped in lieu of a simple one-sided gas transfer arrangement. This current version was again built with standard PVC such that suitability of this basic flow scheme could be quickly confirmed, and so that we could derive a quick calibration of likely oxygen transfer capacity, prior to rebuilding the unit with CPVC materials able to withstand our higher temperatures. Extending beyond the resultant improvement in column throughput obtained with this new design, it's oxygen transfer rate nearly doubled, to a value of just over 290 mg/L-hr.

Lastly, we have been working on the installation, and research integration, of an experimental vacuum toilet system (see accompanying photograph) by which we are planning to procure real-world fecal waste materials to be processed within our STAR reactor. This device was temporarily loaned to us by NASA-JSC, and upon arrival we were surprised to find that the involved modular components had not been sold to NASA with any hands-on instructions or guidelines with which installation efforts could be streamlined. Several difficulties were then encountered with respect to setting up the operative electrical, water, and vacuum lines, including that of having to fashion four separate wiring harnesses (i.e., which had to be hand-built with complex, aircraft-quality hardware) to connect the toilet, storage tank, and logic control box.

Furthermore, several unexpected complications came up while actually mounting with this toilet within our lab, including fire safety issues (triggered by a wood base built to support our toilet which the campus 'fire marshall' objected to), physical plant complications (i.e., with water and electrical provisions), health code concerns, and even 'human subjects' research concerns which required us to secure formal approvals from our university's 'human subjects research committee.'

Future Research Directions

1- Waste generation, storage, and transfer via the vacuum toilet will be fine-tuned during the coming Fall 2003 quarter,
2- Reconstruction of the current 3rd generation STAR reactor using high-temperature CPVC will be shortly completed, at which time gas-transfer-rate will be reassessed (required due to inherent plumbing changes)
3- Following completion and gas transfer testing of the reconstructed 3rd generation STAR real-world waste loading will be started with the fecal-solids stream,
4- Optimization work with fine-tuning STAR reactor performance relative to mixing rates, aeration intensities, operating temperatures, REDOX levels, pH levels, etc. will be continued during the Fall 2003 and Winter 2003-2004 quarters,
5- Product dewatering studies with STAR effluent will be launched during the Fall 2003 quarter, and
6- STAR off-gas analyses will be initiated during the Fall 2003 quarter, including on-line oxygen and carbon dioxide measurements plus intermittent measurements of ammonia, hydrogen sulfide, and mercaptans.

Trainees

Post-Doctorates-	None
PhD Candidates-	Dawn Whitaker, Purdue University (0.5 Research Assistant)
MS Candidates-	Becky Riaño, Purdue University (0.5 Research Assistant)
	Kanish Jindal, Purdue University (unfunded)
	Neepa Shah, Purdue University (unfunded)

Research Collaboration

This project has several collaborative aspects. First, assistance has been provided to system group, and in particular to the efforts of George Chiu, relative to their ongoing efforts to develop an initial zero-order system model for this STAR reactor. Second, assistance and residuals samples have been provided for both of the 'downstream' processing projects, including Paul Brown's fish growth study and the joint effort by Jeff Volenec and Brad Joern to examine STAR residuals dewatering.

Publications and Presentations To-Date

No publications have yet been generated on this project other than internal NSCORT documents and Powerpoint materials. As for presentations, four internal university lectures have been presented on our NSCORT activities here at Purdue, including three within our School of Civil Engineering (i.e., two-each regular class lectures at CE394: Case Studies, History, Ethics, and Global Issues, and one invited lecture for the 'CE Student Advisory Committee') and one other invited lecture with our campus's 'Sustainable Ecosystems' club. Lastly, an abstract covering the STAR project was submitted for presentation at the upcoming Habitation 2004 conference in Orlando, Florida in January 2004.

Pending Research Milestones and Benchmarks

There are two upcoming, interrelated milestones at-hand, whereby our newly installed vacuum toilet waste generation and collection system will be successfully mated to the thermophilic STAR system's solids input lines. Once this point is reached, the system will effectively emulate a real-world, and near-full-scale, solids processing unit suitable for space and planetary habitat environments….albeit working within a gravity-rich context.

Supporting Graphs, Charts, Illustrations, Photos

Five (5) pages of supplemental information and images are attached, including:

1) Schematic View of Excel-Format Database of ALS Solid Waste Processing Options
2) Schematic View of Access-Format Database of ALS Solid Waste Processing Options
3) Conceptual STAR Design and Processing Issues
4) 1st and 2nd Generation STAR Flow Schemes Using Air Diaphragm Pumping
5) Projected Next_Generation STAR Reactor System with Push-Pull or Bellows-Type Flow Scheme

References

1- Verostko, C., Joshi, J., Alazraki, M., Fisher, J., "Solid Waste Processing and Resource Recovery Workshop Report Appendix - Volume II", NASA, CTSD-ADV-474, (2002)
2- Gould, M.S., Drnevich, R.F. "Autothermal Thermophilic Aerobic Digestion" *Journal of the Environmental Engineering Division* (1978): 259-270
3- Golub, M.A., Wydeven, T. "Waste Streams in a Crewed Space Habitat" NASA Technical Memorandum 102799. (1990)
4- Levri, J. *et. al.* "Advanced Life Support Equivalent System Mass Guidelines Working Draft" (Feb 2003)

5- Appleton, A.R. Jr., Leong, C.J., Venosa, A.D. "Pathogen and Indicator Organism Destruction by the Dual Digestion System" *Water Pollut. Control Fed., 58* (1986): 992-999.
6- Hanford, A.J. "Advanced Life Support Baseline Values and Assumptions Document", NASA, CTSD-ADV-484. (2002)
7- Office of Biological and Physical Research Task Book, NASA

ALS Solids (fecal, food residue, and plant residue) Research Paths

	Bio_Composting				Bio_Immobilized		Bio_Suspended/Fluidized			SCP	Bio_??
Technology	Composting Aerobic	Composting Anaerobic	SEBAC	Composting Off-Gas	IMWPS	Immobilized Biofilm	CFSTR	SSF	FFB	SCP Single_cell Production	???
Where	NASA_KSC Dynamac	Florida	Florida	Rutgers	NASA_JSC	Stevens Institute	NASA_KSC Dynamac	NASA_KSC Dynamac	NASA_KSC Dynamac	Purdue_CELSS	Tuskegee
Who	Dick Strayer Jim Wright	David Chenowyeth Art Texiera	David Chenowyeth Art Texiera	Dave Cowan ?? Hartman	Karen Pickering	Christos Christodoulatos	Dick Strayer	Dick Strayer	Dick Strayer	Mike Ladisch George Tsao	Audrey Trotman
Technical Issues and Related Details			Sequencing batch anaerobic composting	focus on system off-gas properties, including VOC's	Immobilized water processing system		standard suspended growth system	??? What is this???	fixed film bioreactor system...w/ unknown media		
ESM Mars Planetary Mission	1197 (21 day) 505 (7 day)									14,090	

Figure 1
Schematic View of Excel-Format Database of ALS Solid Waste Processing Options

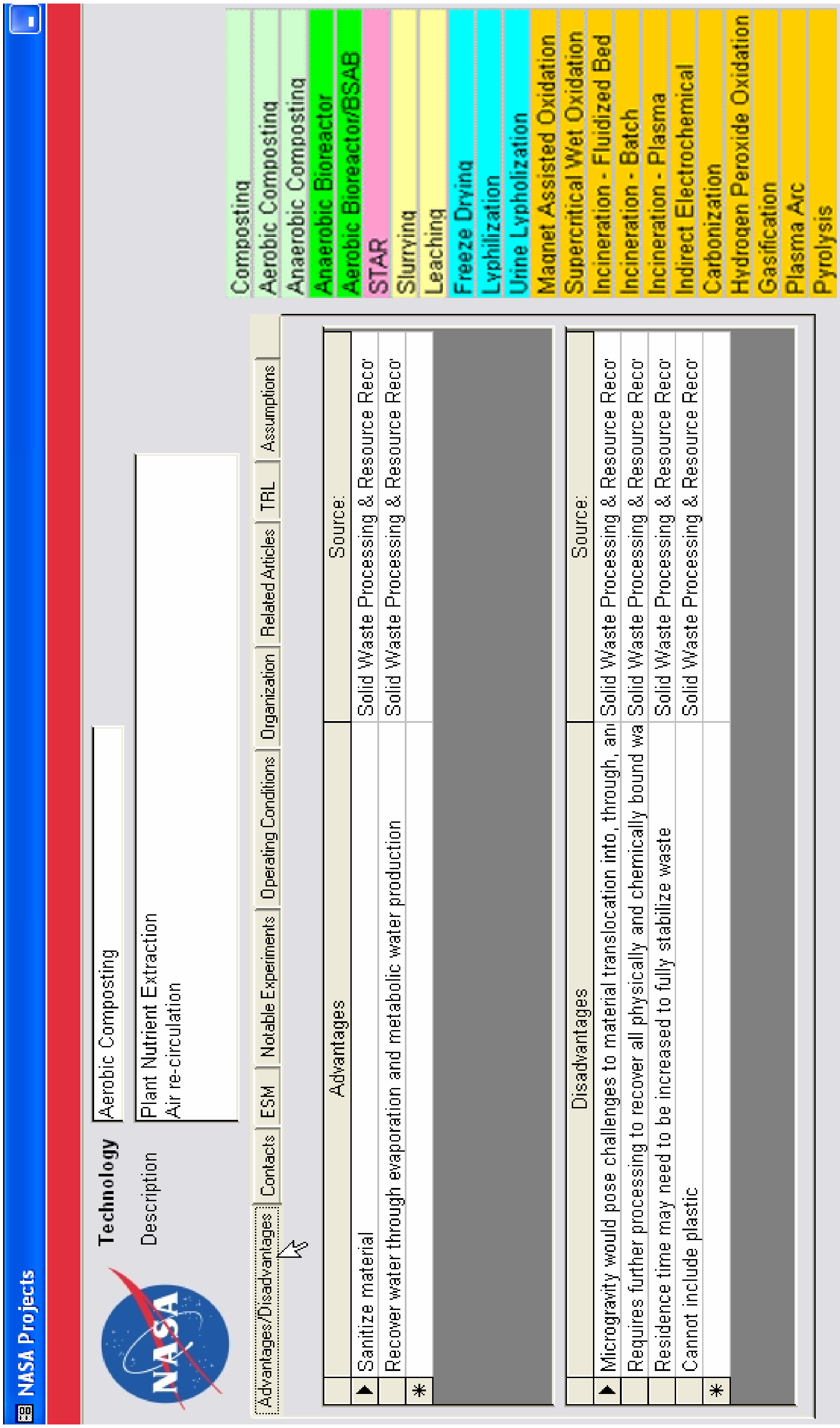


Figure 2
Schematic View of Access-Format Database of ALS Solid Waste Processing Options

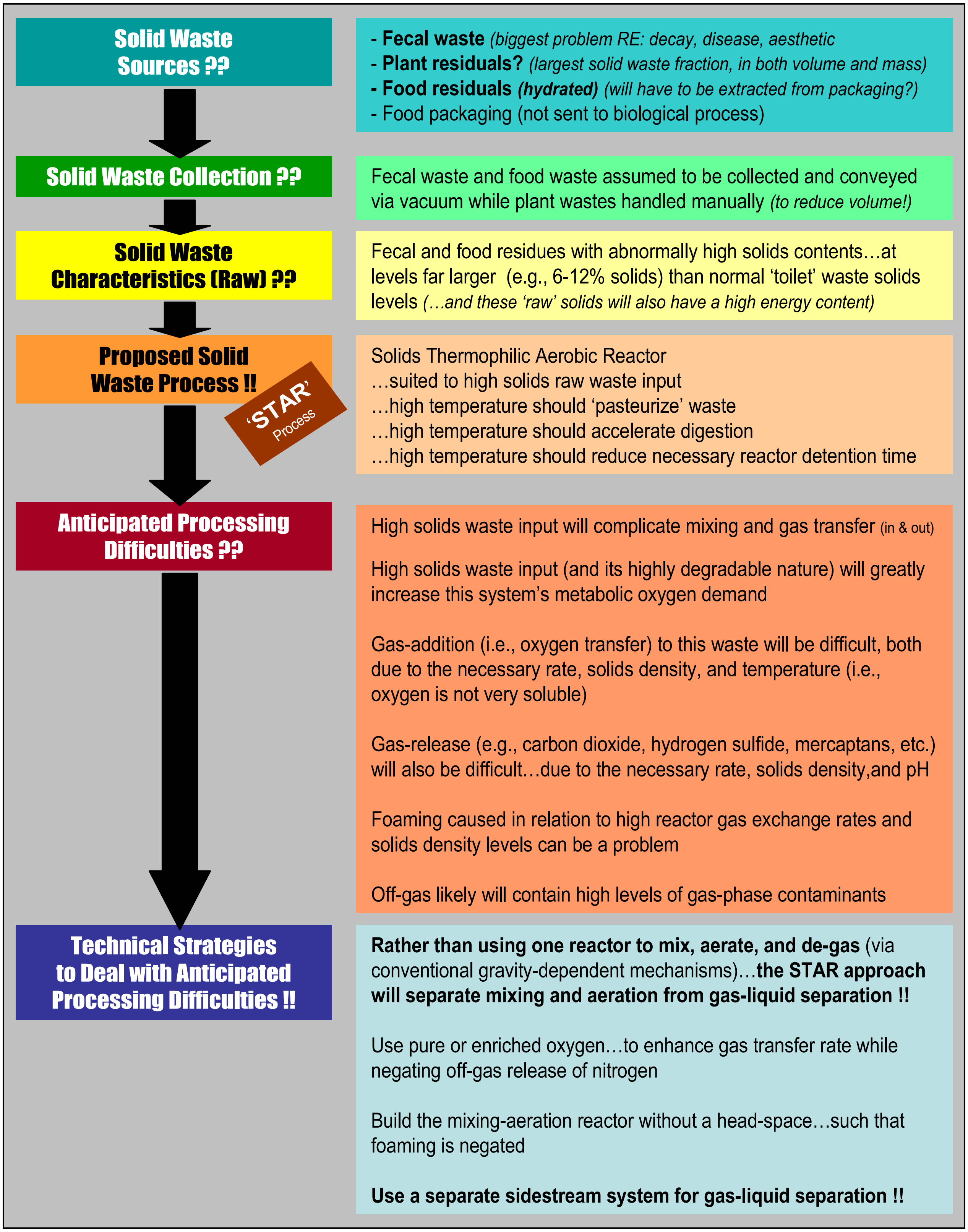


Figure 3
Conceptual STAR Design and Processing Issues

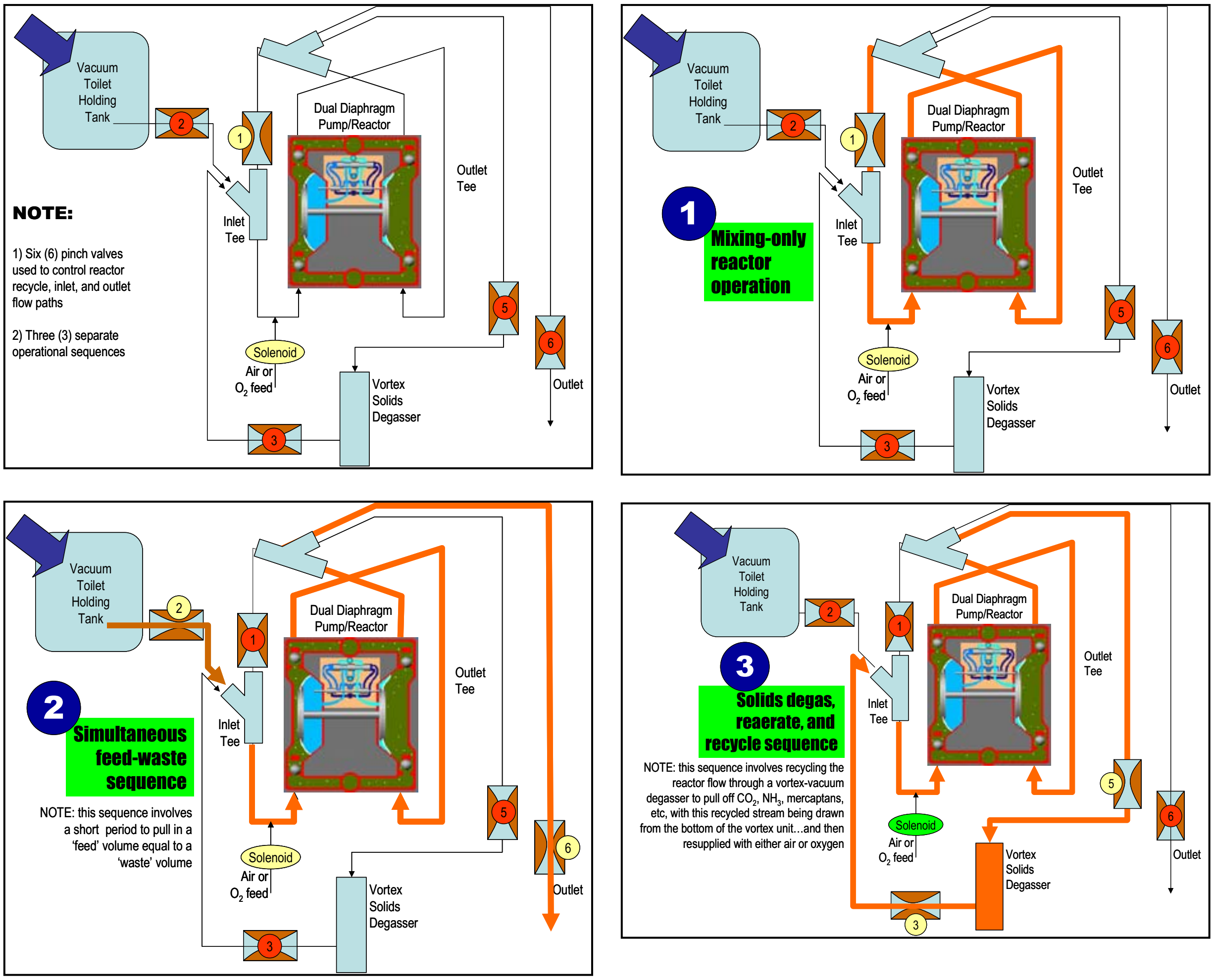


Figure 4
1st and 2nd Generation STAR Flow Schemes Using Air Diaphragm Pumping

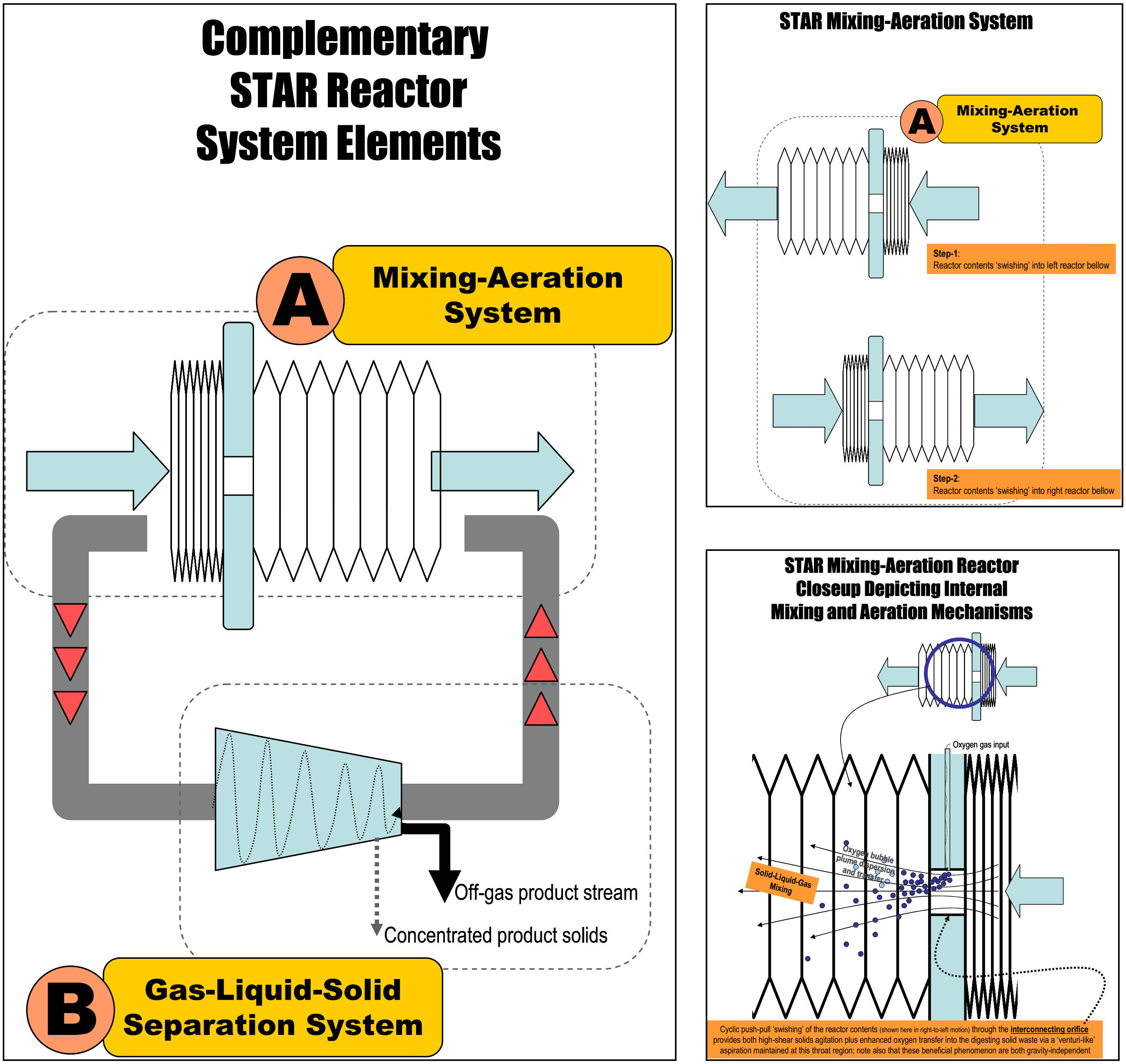


Figure 5

Projected Next_Generation STAR Reactor System with Push-Pull or Bellows-Type Flow Scheme

5.3 Project Title: Nitrogen Cycling in ALS

Principal Investigator Involved on this Project: Dr. Charles C. Glass

Significance of Project to ALS

Forms of nitrogen will be critical to the growth of all plants in the system that will be used to produce oxygen, treat water, and produce food for the astronauts. Nitrogen gas on the earth represents approximately 70% of the atmosphere. In addition to N_2 gas, nitrogen oxide species are passed between the atmosphere, the soil, water, and microorganisms in the soil. In the ALS microbiological uptake and the fluxes of various forms of nitrogen will have to be balanced continuously and passively. The purpose of this project is to return a significant portion of the nitrogen from waste products back to the plant system in ALS in a useful form.

Project Goals and Objectives

The primary objective of this research project will be to effectively treat ammonia rich wastewaters from various process streams and convert it to a form that is amenable to uptake by plants in order to complete the nitrogen cycle throughout the ALS. The sources of ammonia will include the off-gas from the STAR operation (on the order of 1,000 ppm of ammonium as nitrogen) and the urine freeze-thaw treatment system, which will also have an ammonium-rich brine discharge. This ammonia, that has been scrubbed from the off-gas from grey water treatment and STAR, will have to be converted to a form that can be used in other processes, both downstream water treatment processes like Breathe and to a source that can be utilized by different plant systems in the ALS.

The objective of effectively treating an ammonia rich wastewater will be met by constructing a dual zeolite-nitrification system. At this point we believe that the use of a zeolite to remove the concentrated ammonia to lower the toxicity of the waste enough for a consortium of nitrifiers to convert the ammonia to nitrate is the most advantageous technology available given the constraints of the system.

NASA currently employs physiochemical-processing means to purify water for "short" space journeys. Wastewater must be converted into potable water. Ammonia sources include the off-gas from the Sequential Thermophilic Aerobic Reactor (STAR) operation. In the Phase III Lunar-Mars Support (91 day) Test ammonium ions were removed using clinoptilolite. This research will provide a design to convert an ammonia-rich brine fluid into nitrate by oxidizing the ammonia in a bioregenerative process using zeolite.

Research Progress

During this first year the primary goals were to:

1) Identify sources of zeolite and begin to determine the optimum zeolite for this process, in particular to confirm that clinoptilolite is the optimum zeolite for ammonia uptake.
2) To acclimate a nitrification culture to a synthetic ammonia rich wastewater and to begin to evaluate limitations of ammonia toxicity.

During this first year there were two students on this project, with each student being assigned to focus on one of the two objectives. For the zeolite evaluation the following factors are being varied during the experiment to acquire a better understanding of the capabilities of zeolite as a potential ammonia absorbent.

1. Type of Zeolite: Four compositions (two Clinoptilolites and two Chabazites)
2. Temperature: 20, 30, 40, 50°C
3. pH: 3, 4, 5, 6, 7, 8, 9
4. Particle Size: 0.30 – 0.85 mm
5. Regeneration treatments: KCl (basic) KCl (acidic)

Dry zeolite weighing 1 g will be placed along with varying concentrations of NH_4^+ and observed at differing conditions (pH, temperature) in a 250 mL flask. The flasks will be mixed vigorously in a Mixer. The samples will be centrifuged to separate the zeolite and the concentration of ammonia (NH_4^+) will then be analyzed using an ion chromatograph.

A zeolite is a micro-porous crystalline solid with a framework of silicon, aluminum and oxygen with cations, water and/or other molecules within their pores. Zeolites occur naturally as minerals, which can be mined, and are also synthetically made commercially for specific uses by research scientists. The porosity of zeolites allows them to act as catalysts in petroleum cracking and as excellent ion exchangers. They have a cage-like organization of the aluminum and silicon atoms that allow for ions (Na^+, K^+, Ca^{2+}) and molecules (H_2O, NH_4^+) absorption and even volatile organics adsorption.

Clinoptilolite is preferential for ammonium ion absorption (Semmens Ćurković et al. 1997). The chemical structure of clinoptilolite shows that it exchanges Na^+ for $NH4^+$. It is structurally stable at 500ºC. Within these pores cations are highly mobile and allow for free exchangeability:

In clinoptilolite the mobile cation is Na^+, while in chabazite the mobile cation is: Ca^{2+}, K^+, and/or Na^+. The following list of reactions are the

$Z\text{-}Na + NH_4^+ \rightarrow Z\text{-}NH_4 + Na^+$ (Adsorption of Ammonia)

$Z\text{-}NH_4 + Na^+ \rightarrow Z\text{-}Na + NH_4^+$ (Chemical Regeneration)

$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$ (Biological Conversion of Ammonia to Nitrate)

$Z\text{-}NH_4 + Na^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$

So far 3 clinoptilolites and 1 chabazite have been tested for their absorbent capabilities. The zeolites have been obtained from GSA Resources, Inc. a company that produces zeolites in Cortaro, Arizona. The company names for the zeolites are; Clinoptilolites ZS403H, ZS403TM, SK406H and Chabazite; ZS500RW/H

The Freundlich isotherm model is used to compare the adsorption capabilities of the zeolites that have been obtained.

Freundlich Isotherm Model $q_e = k_F C^{1/n}$

The results for the four analyzed clinoptilolites are:

ZS403H: $qe = 9.506C^{0.284}$ ($R^2 = 0.988$)

ZS403TM: $qe = 2.262e\text{-}10C^{4.684}$ ($R^2 = 1$)

ZS500RW/H: $qe = 2.2.14e^{-06}C^{3.7726}$ ($R^2 = 0.938$)

ZK406H: $qe = 2.33e^{-2}C^{0.967}$ ($R^2 = 0.9639$)

The zeolite ZK403 exhibits absorption properties up to 100 ppm, however ZS403H has a greater absorption is capacity than ZS403TM. ZK406H removes 93% of ammonium ions at initial concentration 100 ppm. Figures 8 and 9 show preliminary data on the adsorption capabilities of ZK406H, ZS03H and ZS403TM. Other experiments will be completed by the early spring of 2004.

The microbiological phase of this experiment has begun with the acclimation of bacteria to greater and greater concentrations of ammonia. The success of biofilm systems in removing large quantities of pollutants is attributed to their resistance to high levels of toxicity due to their ability to function as protected environments (Xu et al., 1998; Chen and Stewart, 1996; Hoyle et al., 1992). The mechanism for this protection is the mass transport resistant through the layers of biofilm. This mechanism also enables the biofilm to behave as a heterogeneous environment supporting different cultures of bacteria with different needs for growth (Gonzalez-Martinez and Wilderer, 1991; Iwai and Kitao, 1994).

Reactors were constructed from existing 36 in long glass columns. The arrangement for serial operation of column pairs is shown in Figure 1. Two units will be used per setup, i.e., one unit per column.

The system will be composed of two stages:

Stage 1: The stage 1 reactor will be operated under completely mixed, fully aerated and submerged conditions. In this stage, excess biochemical oxygen demand (BOD) will be removed. The oxygenated unit will be operated as a completely mixed system.

Stage 2: The stage 2 reactor will be operated under anoxic conditions to allow for optimum denitrification conditions. During this stage, both organic and inorganic nitrogen will be removed. The reactor itself will be operated as a plug flow employed with a de-oxygenation unit.

The $NH_4^+ - N$ concentration in the influent was increased to 80 mg/L $NH_4^+ - N$. From Figure 2, it can be seen that the effluent from the nitrification column reflected 37.5% removal of $NH_4^+ - N$. Subsequently, 75% nitrification occurred in stage 2 of the reactor. Nitrification is occurring within the configured biofilm reactor. 90% nitrification was achieved at the mass loading rate of 0.05 g $NH_4^+ - N/$ day. Subsequent doubling of the feed concentration to 40mg/L $NH_4^+ - N$ reduced efficiency to 25 % at the mass loading rate of 0.1 g $NH_4^+ - N/$ day. Further increase in the concentration of the influent to 80 mg/L $NH_4^+ - N$ resulted in a dramatic decline in the pH within the nitrification column. This accelerated the inhibition of nitrifiers resulting in 37.5% nitrification occurring at a mass loading rate of 0.2 g $NH_4^+ - N/$ day. Addition of $NaHCO_3$ to the influent is currently being undertaken such that 12 g of $NaHCO_3$ is consumed per every 1g of $NH_4^+ \rightarrow NO_3^-$. Efficiency of the reactor may also be improved by facilitating controlled heterogenous growth within the nitrifying column to aid in the attachment of additional nitrifiers. This control growth can be achieved through the addition of glucose or yeast extract as a source of organic carbon (Cecen et al. 1995).

Future Directions of the Research

Currently both of the first phases of this research, to evaluate the optimum zeolite and to continue to increase the ammonia concentration in a biofilm system to test the toxic limits, are continuing as planned.

Trainees Involved in the Study

Graduate Student: Ressa Chee Wah, is the lead graduate student on the project. Ms. Chee Wah is a second year Masters Candidate and has been focusing on the selection and characterization of a zeolite to use as the support material for the system.

Undergraduate Student: Wendell Khunjar is a senior Civil Engineering student. Mr. Khunjar has been working on nitrification and denitrification in a biofilm system for the past year, even prior to the initiation of the NSCORT project. Mr. Khunjar also participated in the NSCORT Summer Fellowship program over the 2003 summer.

Publications and Oral/Poster Presentations

An abstract titled, "Nitrogen Recovery during Solid Waste Treatment in Advanced Life Support Systems", has been accepted for Habitation 2004, an international conference on space habitation research and technology development. At this point I have not been told whether this abstract will be presented as a poster or an oral presentation. Upon the completion of the investigation of the optimum zeolite for ammonia removal there are plans to publish this work, with a submission of some time in the spring.

Presentation Milestones/Benchmarks

Year One:	Determine relative effectiveness of removal of ammonia by clinoptilolite
Year Two:	Determine reproducibility and regeneraton of clinoptilolite
Year Three:	Identify maximal specific ammonia remove with a zeolite/nitrifier system
Year Four:	Optimize reactor system with systems upstream and downstream
Year Five:	Develop a computational mass-balance assessment

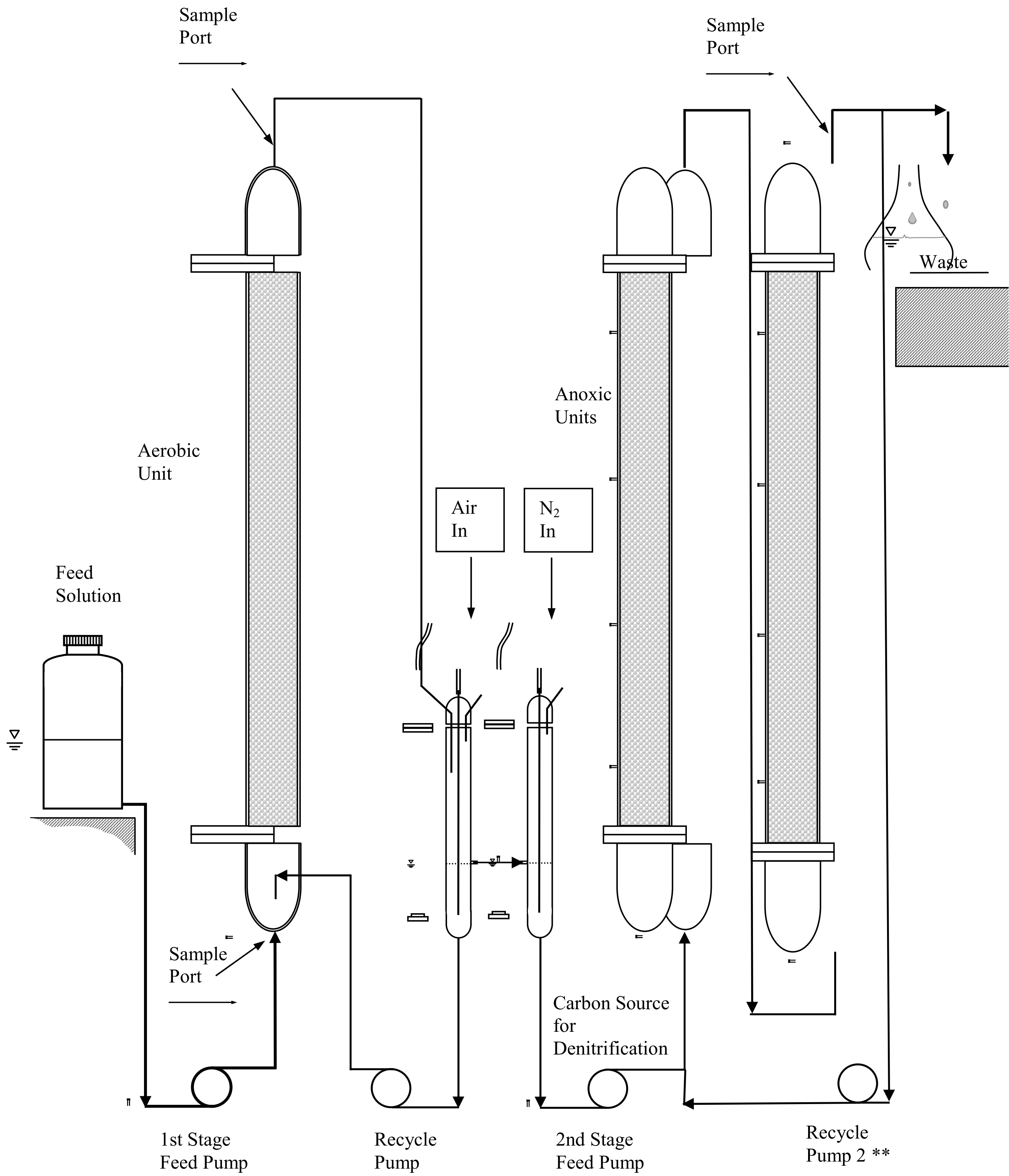


Figure 1 Reactor Setup Schematic

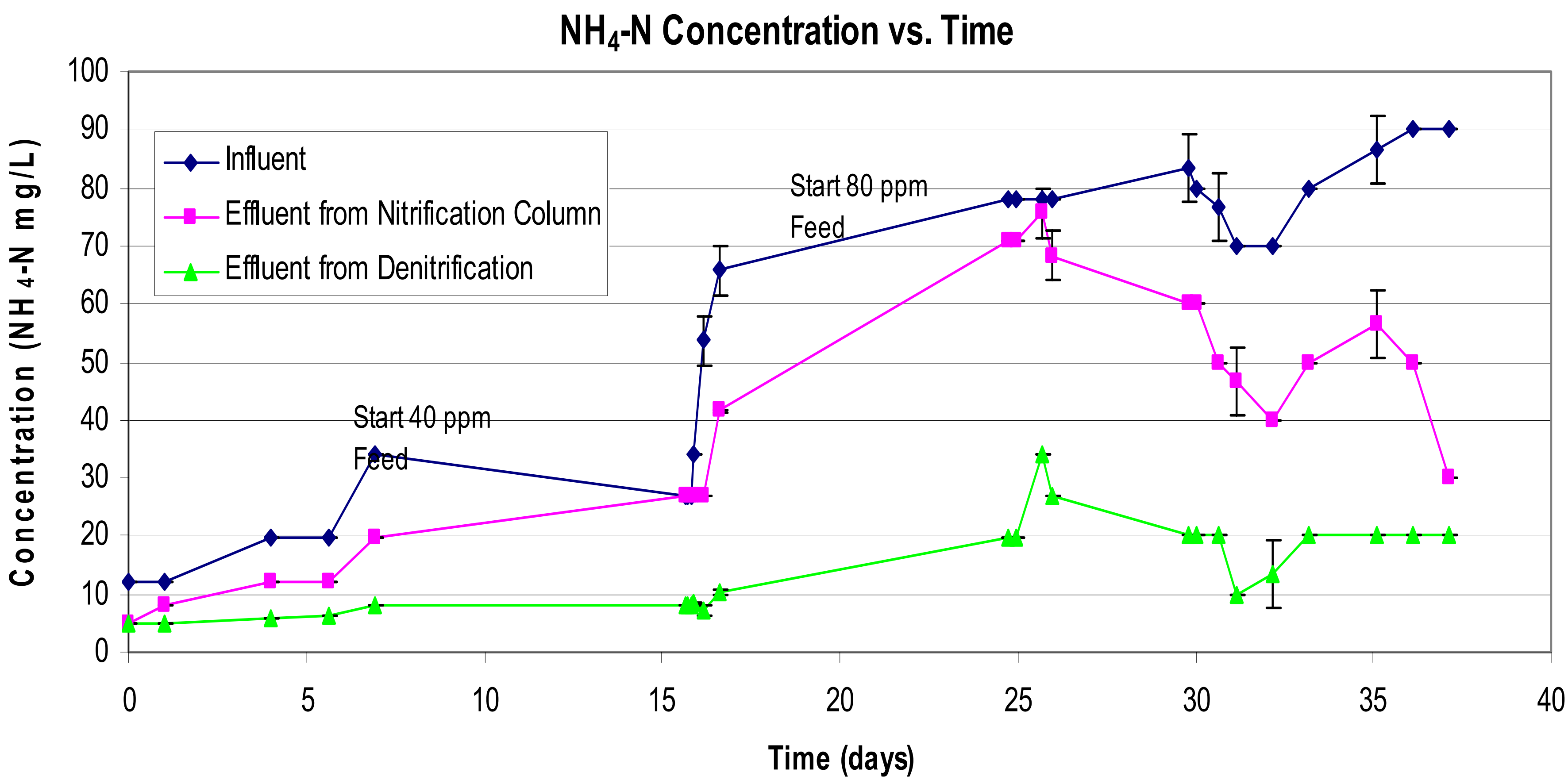


Figure 2: $NH_4^{\pm}$-N Concentration

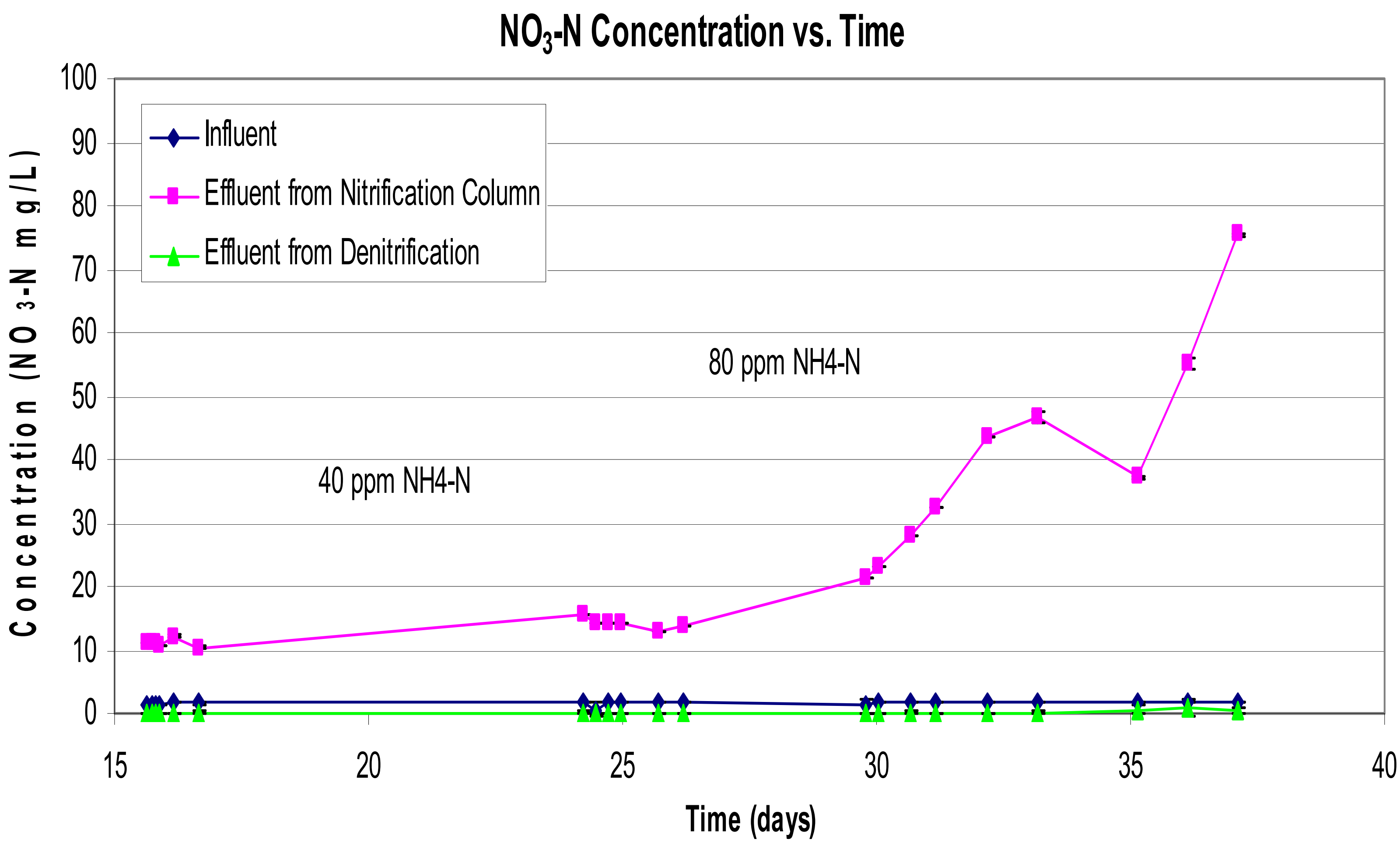


Figure 3 : NO_3^--N Concentration

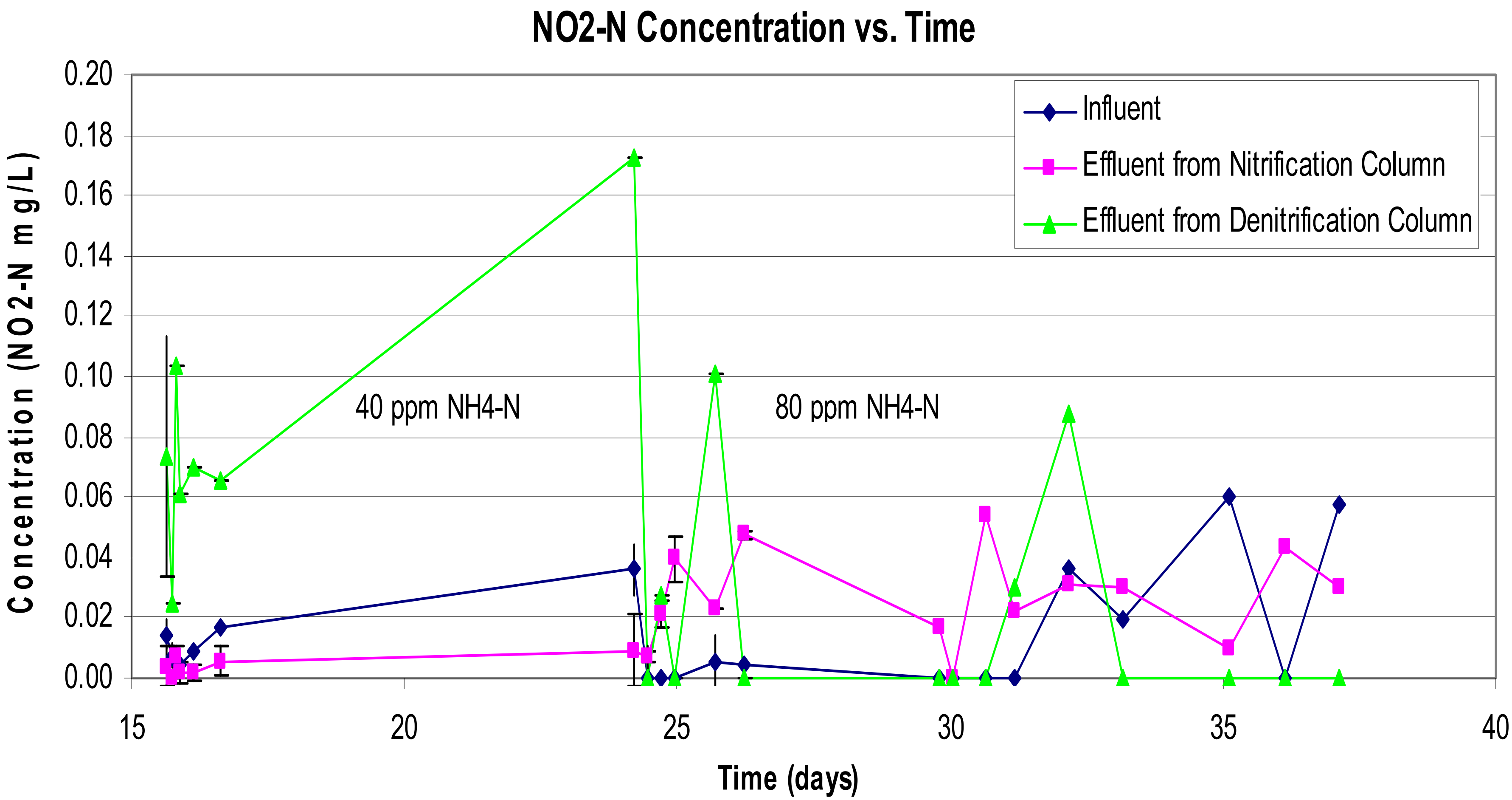


Figure 4: NO_2^--N Concentration

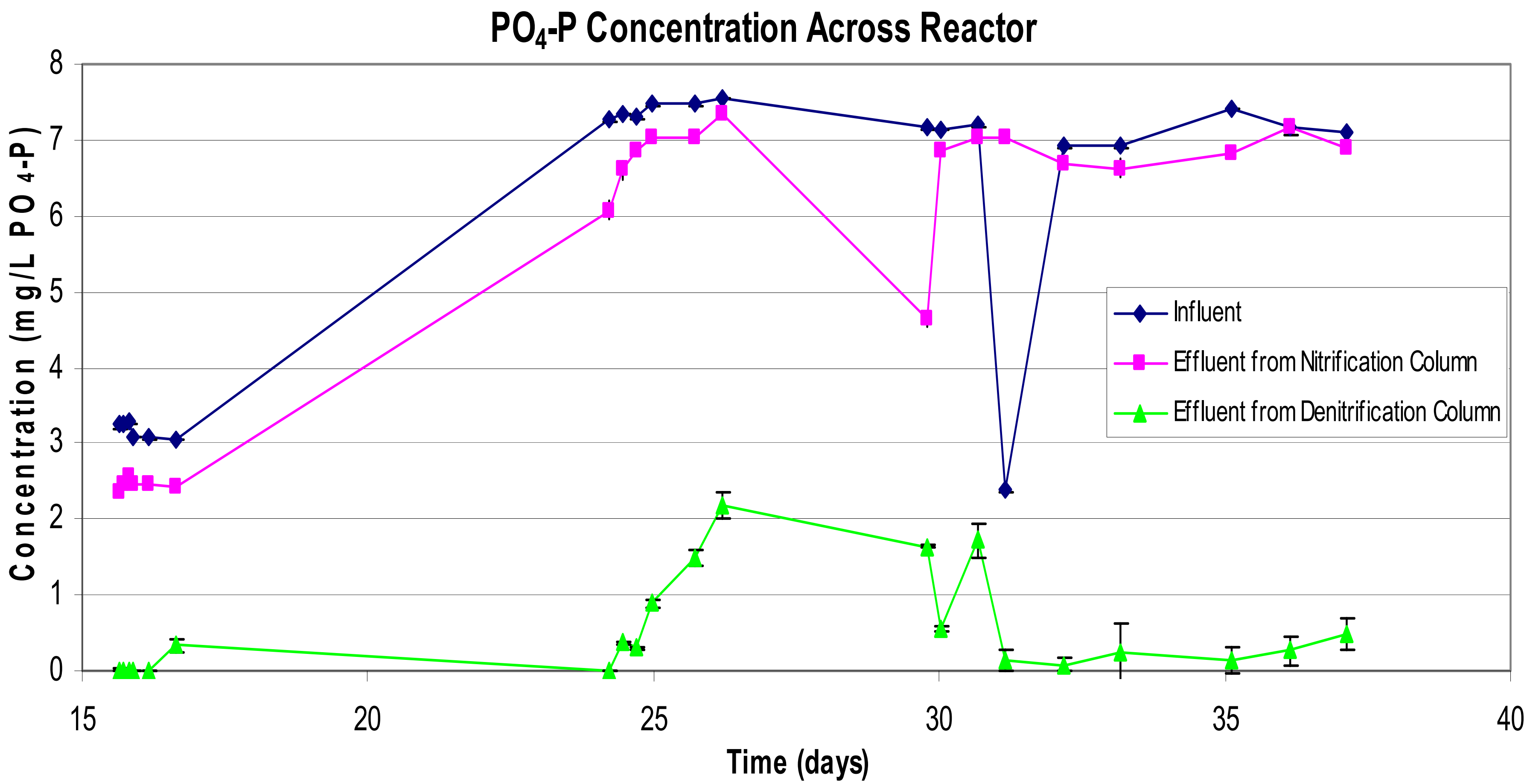
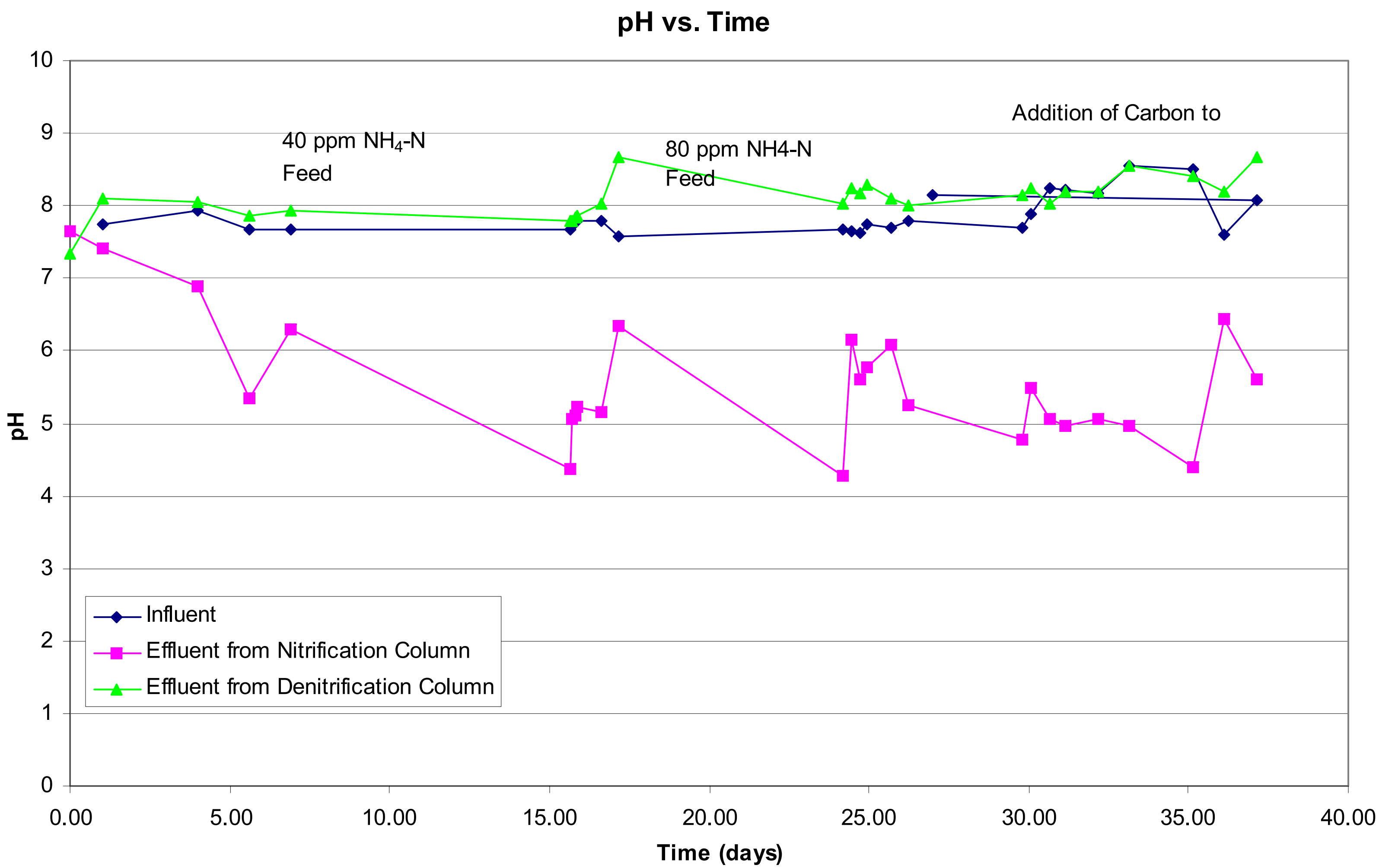


Figure 5:PO_4^{3-}-P Concentration



pH vs. Time
40 ppm NH4-N
Feed
80 ppm NH4-N
Feed
Addition of Carbon to
pH
Time (days)
10
9
8
7
6
5
4
3
2
1
0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
Influent
Effluent from Nitrification Column
Effluent from Denitrification Column

Figure 6 : pH

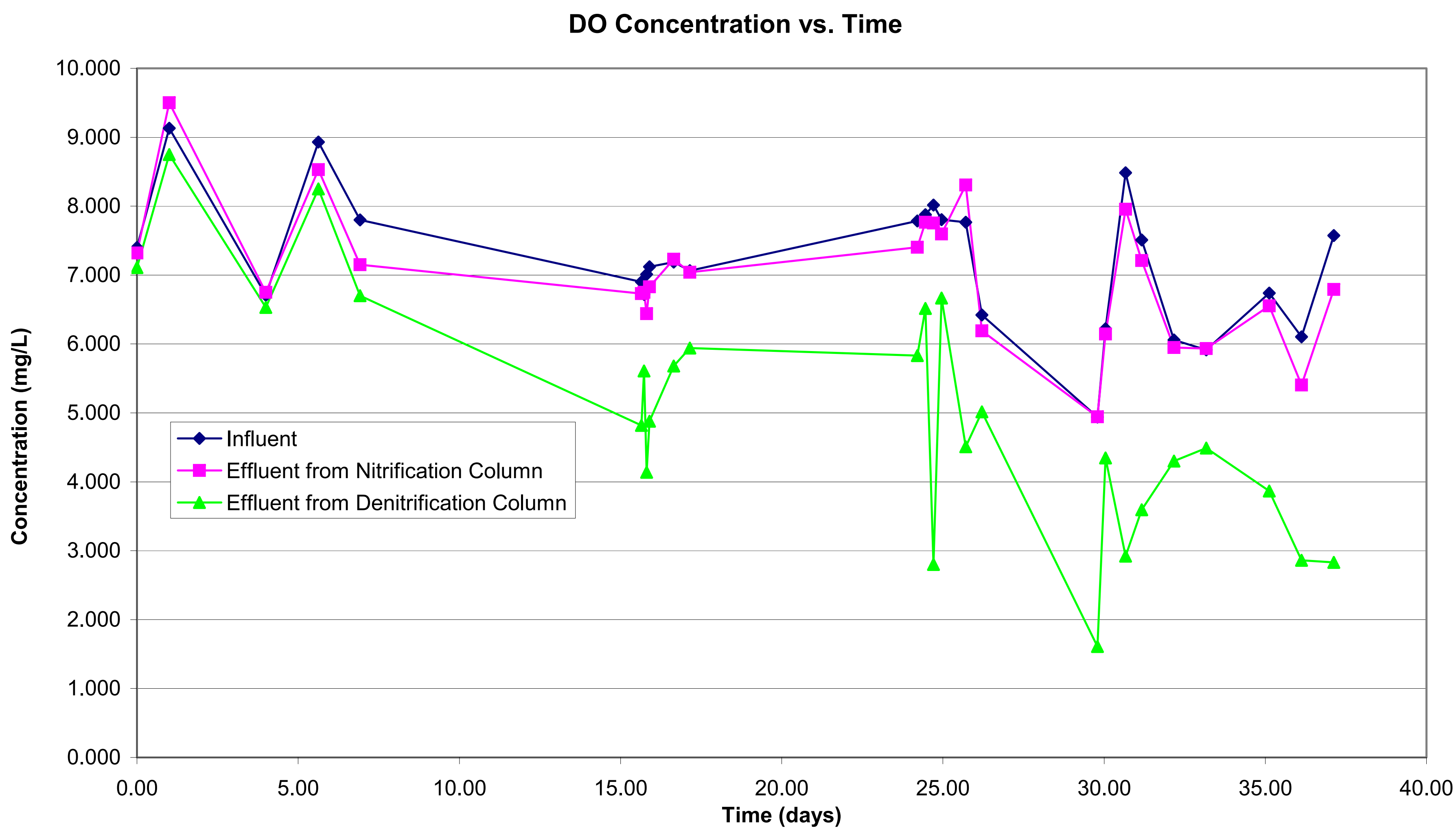


Figure 7: DO Concentration

Figure 8: Ammonia removal as a function of grams of zeolite

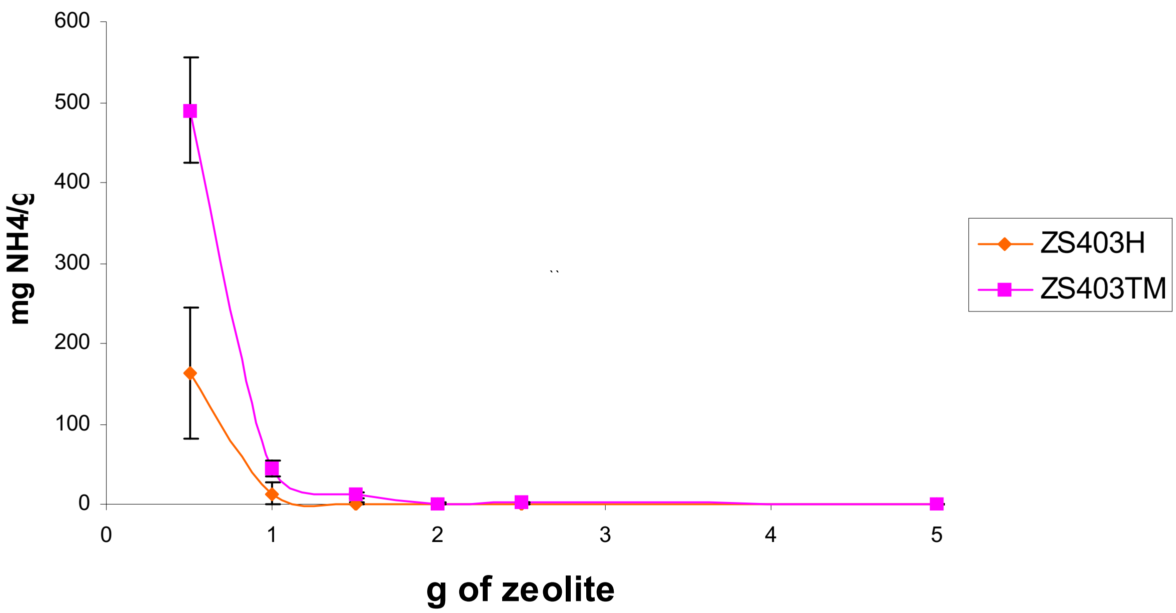
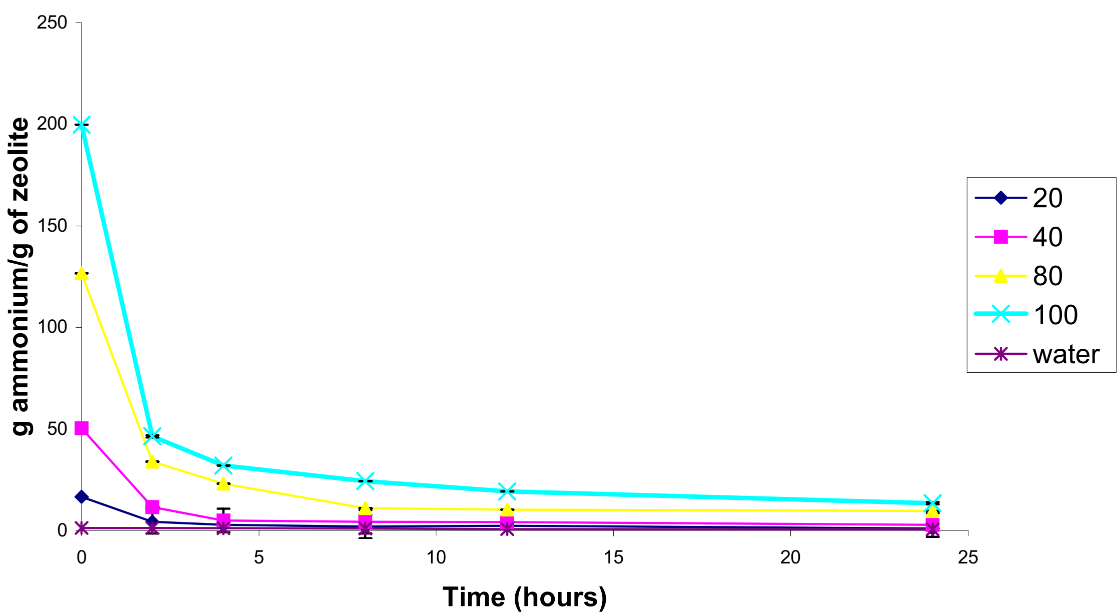


Figure 9: ZK406H ammonia removal as a function of time



References

Cecen, Ferhan, Orak, Elvan (1996). "Nitrification Studies of Fertilizer wastewaters in a biofilm reactor." *J. Chem. Tech. Biotechnol*., 229 -238.

Cecen, Ferhan, Orak, Elvan, Gokcin, Pinar (1995). "Nitrification Studies on Fertilizer wastewaters in activate sludge and biofilm reactors." *Water Sci. Tech.* Vol 32 No. 12 141-148.

Chen, X. and Stewart, P.S (1996). "Chlorine penetration into artificial bio-film is limited by a reaction-diffusion interaction." *Environmental Science and Technology*, 30(6): 2078-2083.

Gonzalez-Martinez, S. and Widerer, A. (1991). "Phosphorus removal in biofilm reactor." *Water Science and Technology*, 23(7/9), 1405-1415.

Hoyle, B.D, Alcantora,J. and Costerton, J.W. (1992). "Psuedomonas aeruginosa biofilm as a diffusion barrier to piperacillin." *Antimicrobial Agents and Chemotherapy*, 36 (9): 2054 - 2056.

Iwai, S. and Kitao, T. (1994). Wastewater Treatment with Microbial Films, Technomic Publishing Co. Inc, Lancaster, PA.

Nichols, W.W. (1989). "Susceptibility of biofilms to toxic compounds." 321-331 in W. G Characklis and P.A Wilderer (eds.),

Xu, K.D., Stewart, P.S., Xia, F., Huang, C.T and McFeters, G. (1998). "Spatial physiological heterogeneity in Psuedomonas aeruginosa biofilm is determined by oxygen availability." *Applied and Environmental Microbiology*, 64 (10): 4035 – 4039.

5.4 Solids Research Group

Faculty Participants: Jeff Volenec, Brad Joern

Solids Separation Water Removal from STAR Biosolids Effluent Using Plants

Hypothesis and Objective for 2003. Our hypothesis is that species will differ in their effectiveness as biomass species for dewatering biosolids created by the STAR waste treatment plant. In addition, the composition of the biomass produced in the dewatering process will dictate its subsequent use as food, feed, fiber, and fertilizer. Our objective for this initial study was to identify the biomass specie best suited for dewatering and capturing nutrients in STAR waste effluent.

Research Progress. Candidate species for dewatering of biosolids include the following grasses, legumes, and food crops from the NASA ALS program:

Grasses	Legumes	Food Crops
Palaton Reed canarygrass	Endura Kura Clover	Super Dwarf Rice
Dakotah Switchgrass	Kopu II White Clover	USU Apogee Wheat
Eastern Gamagrass	Jumbo Ladino Clover	Micro-Tina Tomato
Bronson Tall Fescue	Big Trefoil	Triton Pepper
Millennium Tall Fescue		USU Perigee Wheat
Shawnee Switchgrass		

Plants of each species were established in 1 L pots containing coarse sand. Plants were provided complete nutrient solution twice weekly during the two months of establishment in the greenhouse. Legumes will be inoculated with the appropriate strain of *Rhizobium* to facilitate symbiotic fixation of atmospheric dinitrogen gas into plant-available forms. Pots were placed in a greenhouse set to control temperature (25ºC±5ºC) and photoperiod is extended to 15 h with artificial lighting. On August 29, 2003 after two months growth, pots were grouped into three replicates each containing four pots of each species. The following four STAR effluent treatments were randomly assigned to pots of each species within each replicate: control (no effluent); 1/2 acre-inch of effluent (86 mL per 1 L pot); 1 acre-inch of effluent (172 mL per 1 L pot); and 2 acre-inches of effluent (344 mL per 1 L pot). Cups were placed under pots to catch liquid that drained from the bottom of the pots following effluent application. Pots remained in the greenhouse and watered with reverse-osmosis water as needed. Photos of plants were taken one week after effluent application. Plans are in place to destructively samples plants two weeks after effluent application to obtain dry weights of roots and shoots, and tissues for mineral analysis. These data cannot be included in this report because of the impending deadline for this report, but we plan to have the dry weight data available by Oct. 1, 2003. Poor establishment prevented inclusion of three replicates of Eastern Gamagrass. Both wheat cultivars developed very rapidly, and were setting seed after two months so they were not included in this study, but will be evaluated in a subsequent study.

Temperatures after effluent application were excellent for plant growth (20ºC±5ºC), but cloudy weather resulted in three consecutive days of low light intensity. During the week following effluent application there was no visible injury to any species caused by the ½ acre-inch effluent application (see attached photographs). Species exhibiting the least injury included kura clover and switchgrass, while tall fescue and reed canarygrass exhibited mild and moderate injury, respectively, to at the 2 acre-inch effluent rate. Leaf tips of rice were necrotic on plants provided 1 and 2 acre-inch effluent rates, but otherwise these plants were relatively uninjured. Several species receiving 2 acre-inches of effluent were severely injured including big trefoil, Ladino clover, and pepper. Tomato appeared to be most sensitive to effluent application with severe injury exhibited by plants provided 1 and 2 acre-inch effluent treatments.

Dry weight data agree with observations (Tables 1 to 13). These data can be summarized as follows:

Eastern Gamagrass (Table 1): No negative effects of STAR effluent on root, shoot, or total plant biomass even at the 2 acre-inch rate.

Reed canarygrass (Table 2): A significant reduction in root biomass occurred with STAR effluent rates of 1 acre-inch or more. Shoot biomass was unaffected by STAR effluent. Trends in total biomass followed those of roots, with significant reductions in mass occurring at the 1 and 2 acre-inch rates.

Dakotah switchgrass (Table 3): Root mass stimulated slightly by the 0.5 and 1 acre-inch rates of STAR effluent. Shoot mass and total mass were unaffected by effluent application rate.

Shawnee switchgrass (Table 4): Root mass was stimulated by the 1 acre-inch effluent rate. Like Dakotah switchgrass, there was no impact of effluent on shoot and total dry mass of this plant.

Bronson tall fescue (Table 5): Root mass increased with the 0.5 and 1 acre-inch effluent rates. Shoot mass was unaffected by effluent application rate. Total plant mass was greatest when 0.5 acre-inch of STAR effluent was applied.

Millenium tall fescue (Table 6): Root mass tended to increase with effluent application rate, but the high standard errors of these means indicates that they are similar to the control treatment. Shoot mass was not reduced by 1 or 2 acre-inch rates of effluent. Total mass was greatest when 2 acre-inch of effluent was applied, but the high standard error indicates high variation in this response.

Endura Kura clover (Table 7): Root mass was unaffected by effluent application. Shoot dry mass was reduced at the 1 and 2 acre-inch effluent application rates. Trends in total mass followed those of shoot mass, with reductions occurring at the 1 and 2 acre-inch effluent rates.

Kopu II white clover (Table 8): Root mass was not influenced by effluent application. Shoot mass was reduced incrementally with increasing effluent application rates. Total dry mass mirrored the shoot mass response, with reduced dry mass at the 1 and 2 acre-inch effluent rates.

Jumbo Ladino clover (Table 9): Root, shoot, and total masses were reduced at the 1 and 2 acre-inch effluent rates.

Big trefoil (Table 10): Root, shoot, and total dry masses were all reduced at the highest rate of effluent application.

Triton Pepper (Table 11): Root mass was not affected by effluent application rate. Shoot and total mass were reduced at the 2 acre-inch effluent rate.

Super dwarf rice (Table 12): Root growth was sensitive to effluent, being one of the few species with reduce root mass at the 0.5 acre-inch effluent rate. Shoot mass gradually declined with increasing effluent rate. Total mass of plants provided effluent was reduced irrespective of rate.

Micro-Tina tomato (Table 13): Root, shoot and total mass of tomato was reduced with 1, and especially 2 acre-inch effluent rates.

<u>Future Research Direction.</u> Our near-term plans are to obtain the mineral analysis data for the experiment described above. Analysis of variance will be used to determine species, effluent rate effects, and to learn if there is a species by effluent rate interaction for these characteristics. We will repeat this initial study using effluent resulting from human sewage fed into the STAR bio-reactor (instead of this effluent that was obtained from the reactor fed plant residues). Based on this study we will modify rates of effluent application in order to test the upper limits of plant tolerance to effluent. We hope to identify the species(s) that are most tolerant to STAR effluent by early 2004. Detailed compositional analysis of tissues from these select species (including food crops) will follow so that we can understand how to best utilize the biomass produced during dewatering. Water mass balance studies aimed at determining dewatering efficiency of these species also will be initiated once the list of candidate species is narrowed to those most tolerant to effluent.

Trainees Involved in the Study. Mr. Shane Howard is taking a leadership role in the day-to-day activities of this research. He plans to begin his MSc. degree spring semester 2004. Mr. W. Kess Berg, a Ph.D. candidate in Dr. Volenec's research program also assisted with the study described above even though his salary support is provided from other sources. Ms. Suzanne Cunningham assisted in her role as Dr. Volenec's research assistant.

Supporting Materials. Photos are attached as a separate PowerPoint file (Appendix 9.2). Tables 1 to 13 below contain the data for each of the species evaluated in this experiment.

Table 1. Effect of STAR effluent on root, shoot, and total biomass of Eastern Gamagrass. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -		$g\ pot^{-1}$	
0.0	0.63 (0.25)[§]	1.33 (0.40)	1.96 (0.65)
0.5	0.71 (0.54)	1.91 (1.78)	2.62 (2.32)
1.0	0.67 (0.02)	1.08 (0.12)	1.75 (0.13)
2.0	0.88 (0.63)	1.48 (1.26)	2.36 (1.89)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

Table 2. Effect of STAR effluent on root, shoot, and total biomass of Reed Canarygrass. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -		$g\ pot^{-1}$	
0.0	11.40 (2.80)[§]	13.43 (1.05)	24.83 (1.95)
0.5	10.52 (2.06)	15.37 (0.92)	25.89 (2.26)
1.0	7.44 (1.62)	13.66 (1.61)	21.11 (3.22)
2.0	5.68 (1.62)	13.70 (1.83)	19.39 (3.41)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

Table 3. Effect of STAR effluent on root, shoot, and total biomass of Dakotah Switchgrass. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -		$g\ pot^{-1}$	
0.0	4.92 (1.50)[§]	13.07 (0.52)	17.99 (2.00)
0.5	7.87 (3.45)	13.13 (4.80)	21.00 (8.25)
1.0	7.87 (3.66)	13.29 (2.10)	21.16 (5.54)
2.0	6.07 (1.61)	12.18 (0.65)	18.25 (1.82)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

Table 4. Effect of STAR effluent on root, shoot, and total biomass of Shawnee Switchgrass are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate†	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	g pot^{-1}		
0.0	2.64 (0.85)§	8.49 (1.01)	11.13 (1.81)
0.5	3.13 (0.75)	7.29 (1.64)	10.42 (2.39)
1.0	4.10 (2.40)	8.29 (3.02)	12.39 (5.38)
2.0	2.12 (0.86)	7.91 (2.02)	10.03 (2.56)

† Soybean-based plant by-products digested in the STAR reactor.
§ Standard error of the mean.

Table 5. Effect of STAR effluent on root, shoot, and total biomass of Bronson Tall Fescue. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate†	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	g pot^{-1}		
0.0	8.38 (1.35)§	13.54 (0.23)	21.93 (1.17)
0.5	15.20 (4.28)	13.82 (0.99)	29.02 (3.93)
1.0	10.49 (0.45)	13.18 (1.15)	23.67 (0.71)
2.0	8.84 (1.88)	13.80 (0.58)	22.64 (2.41)

† Soybean-based plant by-products digested in the STAR reactor.
§ Standard error of the mean.

Table 6. Effect of STAR effluent on root, shoot, and total biomass of Millenium Tall Fescue. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate†	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	g pot^{-1}		
0.0	7.57 (1.00)§	12.47 (0.84)	20.04 (0.81)
0.5	10.63 (5.36)	8.33 (2.28)	18.96 (3.09)
1.0	10.18 (5.56)	10.96 (1.47)	21.14 (7.00)
2.0	11.91 (4.09)	13.35 (1.84)	25.25 (5.12)

† Soybean-based plant by-products digested in the STAR reactor.
§ Standard error of the mean.

Table 7. Effect of STAR effluent on root, shoot, and total biomass of Endura Kura Clover. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate†	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	g pot^{-1}		
0.0	2.61 (0.55)§	5.77 (0.39)	8.38 (0.50)
0.5	3.39 (0.45)	5.43 (0.18)	8.82 (0.52)
1.0	2.11 (0.52)	3.86 (0.36)	5.96 (0.87)
2.0	2.09 (0.32)	3.22 (0.17)	5.31 (0.42)

† Soybean-based plant by-products digested in the STAR reactor.
§ Standard error of the mean.

Table 8. Effect of STAR effluent on root, shoot, and total biomass of Kopu II Clover. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	g pot^{-1}		
0.0	1.94 (1.96)[§]	10.31 (0.64)	12.25 (2.56)
0.5	2.35 (0.73)	9.08 (2.64)	11.43 (3.37)
1.0	2.17 (0.64)	7.73 (1.26)	9.89 (1.78)
2.0	1.53 (0.74)	6.01 (2.56)	7.54 (3.25)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

Table 9. Effect of STAR effluent on root, shoot, and total biomass of Jumbo Ladino Clover. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	g pot^{-1}		
0.0	4.02 (1.30)[§]	10.23 (1.17)	14.25 (2.44)
0.5	4.16 (0.46)	9.91 (1.01)	14.06 (1.36)
1.0	2.04 (0.49)	7.46 (1.05)	9.50 (1.42)
2.0	2.34 (0.58)	8.81 (0.81)	11.15 (1.16)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

Table 10. Effect of STAR effluent on root, shoot, and total biomass of Big Trefoil. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	g pot^{-1}		
0.0	1.65 (0.31)[§]	6.95 (0.51)	8.60 (0.68)
0.5	1.39 (0.24)	6.36 (0.62)	7.74 (0.60)
1.0	1.27 (0.62)	5.22 (0.88)	6.49 (1.42)
2.0	0.54 (0.23)	3.57 (0.39)	4.11 (0.60)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

Table 11. Effect of STAR effluent on root, shoot, and total biomass of Triton Pepper. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	g pot^{-1}		
0.0	2.30 (0.49)[§]	11.22 (1.13)	13.52 (1.37)
0.5	1.71 (0.20)	8.37 (0.14)	10.08 (0.35)
1.0	2.19 (0.71)	12.37 (1.99)	14.56 (2.70)
2.0	1.89 (0.39)	6.76 (1.60)	8.65 (1.72)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

Table 12. Effect of STAR effluent on root, shoot, and total biomass of Super Dwarf Rice. Data are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	----------------	g pot^{-1}	----------------
0.0	2.49 (0.42)[§]	2.90 (0.21)	5.39 (0.52)
0.5	0.88 (0.10)	2.38 (0.50)	3.26 (0.56)
1.0	1.39 (0.32)	2.27 (0.25)	3.66 (0.18)
2.0	1.03 (0.20)	2.07 (0.24)	3.11 (0.43)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

Table 13. Effect of STAR effluent on root, shoot, and total biomass of Micro-Tina Tomato are means of three replicates, and were obtained two weeks after effluent application.

STAR Effluent Rate[†]	Root Dry Weight	Shoot Dry Weight	Total Dry Weight
- acre-inch -	----------------	g pot^{-1}	----------------
0.0	1.23 (0.36)[§]	29.92 (1.74)	31.15 (2.09)
0.5	0.96 (0.18)	28.83 (0.96)	29.79 (0.78)
1.0	0.27 (0.90)	21.74 (4.16)	22.01 (5.04)
2.0	0.60 (0.15)	8.69 (3.90)	9.29 (3.98)

[†] Soybean-based plant by-products digested in the STAR reactor.
[§] Standard error of the mean.

5.5 Project Title: Evaluation of tilapia in an integrated food production/waste management system

Principle Investigator:
Paul Brown, Department of Forestry & Natural Resources, Purdue University

Significance of Project:

The integration of fish and plant production via hydroponics is a logical linkage that offers a multitude of advantages over traditional food production systems. Fish excrete carbon dioxide and ammonia that must be removed from their rearing water, while plants uptake nitrogenous products and carbon dioxide, producing edible plant tissue and oxygen. Further, fish are considered one of the best quality foods for human consumption and are among the most efficient digesters of food products among the vertebrates. The low concentrations of connective tissue in relation to muscle tissue make fish an easier and healthier source of animal protein. Thus, there is potential for fish to use waste products from several components of the overall system, produce high-quality food for the crew and critical nutrients for plant production. The other important potential component of fish is alleviation of the psychological pressures of long stays in cramped quarters with few colleagues.

Projects Goals and Objectives:

The overall goal of this component of the project is evaluation of fish as a component in the system. Specific objectives are to:

1. Evaluate the ability of fish to digest and utilize waste nutrients from STAR, plant processing, and uneaten food;
2. Evaluate the quality of fish fillet produced using these inputs into the fish;
3. Evaluate the ability of fish to reproduce when fed these feedstuffs;
4. Quantify the outputs of waste products from fish for use by plants; and,
5. Evaluate the psychological benefit of having fish in the system.

Research Progress:

Following four months of searching, pure Nile tilapia (Oreochromis niloticus) were acquired from a private producer in Bonds Head, Canada, transported to the Purdue University Aquaculture Research Laboratory. These fish were sexed, separated and are currently housed in a $4m^3$ recirculating system for holding broodstock. These fish will serve as a means to produce tilapia continuously for research purposes.

A 3 m^3 recirculating spawning system has been built to allow for 1/3 of the total broodstock population to spawn during any spawning cycle of eight days. Spawning has been initiated and has led to the development of a spawning protocol. Modifications of such protocol will change as needed. Plans are underway to build a larval rearing system and experimental research station designed to meet the needs of this project

Waste products, to include wheat bran/wheat germ, crude pressed soybean meal, and bread waste, have been collected. Further waste collection will continue throughout the year.

Research Collaboration:

Collaborations with Drs. Caula Beyl (Alabama A&M University), Jeff Volenec (Purdue University), Jim Alleman (Purdue University) and Cary Mitchell (Purdue University) have been discussed and coordinated. Dr. Beyl will be providing composted waste products originating from Dr. Volenec's research. Combined with raw waste produced from Dr. Volenec, it will be possible to determine the most effective means to treat wastes originating from grasses, legumes and other vegetable matter by comparing the rates of consumption of raw and composted waste matter by Nile tilapia. Ongoing collaborations with Dr. Alleman consist of determining a means to properly evaluate thremophilic bacteria as a food source for Nile tilapia. Waste leaving the STAR will have an ammonia concentration of 400 mg/L, approximately, and will prove fatal to fish. Therefore, ongoing talks with a private producer to design and create a mesh filter capable of tolerating the extreme temperatures of STAR effluent while efficiently collecting solid matter has led to the development of a woven fabric membrane with a pore size of 0.2 micron to implement in this project (picture 1). Until proper protocol has been established for proper use of this filter, bacterial cells will be filtered out of the STAR effluent via the use of a centrifuge.

Waste products will be analyzed for their nutritional content, then fed to tilapia in a controlled series of comparative slaughter studies using nutrient retention as the primary indicator of waste degradation. Nutrient analysis will be performed using an induced coupled plasma spectrophotometer for mineral excretion, high performance liquid chromatography for amino acid analysis, AOAC methods for proximate analysis of waste products. Collaboration with a private analytical company for determining vitamins and percent relative fatty acids is underway.

Figure 1. Picture of the housing unit for the woven fabric membrane meant to filter out bacterial cells and other organics

Future Directions of the Research:

There are many potential paths we could explore within this overall goal. Initially, young tilapia will be evaluated for their role in minimizing equivalent system mass. Continuing from those evaluations, affects of waste products on sexual performance and successive generations will be evaluated. In the event that Nile tilapia are found to be an unsatisfactory component, other species will be evaluated. Ultimately, the most appropriate research path will be chosen once we have preliminary data from our initial studies.

Trainees:

Mr. John Gonzales, M.Sc. student, Department of Forestry and Natural Resources
Mr. Aaron van Y, B.S. student, Department of Forestry and Natural Resources

Publications: None yet

Presentations: None yet

6.1 Water and Air Research Group

Group Leader: K. Banks

Faculty Participants: J. Alleman, K. Banks, E. Blatchley, A. Heber, K. Jones

Summary

The NSCORT Air and Water Research Group consists of five projects with five faculty principal investigators. The research investigators have successfully completed a number of project objectives in the nine months of Center operation. Highlights of our research accomplishments are:

Water Disinfection with UV irradiation and Iodine. *A computational model has been developed which couples simulated fluid flow field information and UV radiation field data, and will be used to determine UV radiation dose. In addition, mathematical models have been developed to predict iodine speciation. Over the next year, experiments will be conducted to determine the optimal disinfection process design.*

Membrane System for ALS Wastewater Recycle. *A cross-flow bench-scale nanofiltration and low-pressure reverse osmosis membrane system has been constructed and initially evaluated. In the next few months, evaluation of optimal membranes for BREATHe effluent and system modeling will be conducted.*

Liquid Freeze-Thaw Urine and RO Brine Processing. A first-generation prototype reactor was been constructed and evaluated. This prototype was found to be relatively inefficient. Therefore, in collaboration with Nanomaterials Company, a second generation prototype is currently in design phase.

Development of BREATHe for Water Recycling. Waste and flow characteristics were identified for the two BREATHe reactors. Two prototype reactors were designed and the first was evaluated experimentally for surfactant removal. To assist with reactor predictive modeling, microbial degradation kinetics were evaluated via batch studies for two commercially available surfactants. The next phase of the experimentation will involve reactor performance assessment with a representative gas and liquid influent.

Gas Phase Revitalization Using BREATHe. The optimal design and operating parameters of the BREATHe system have been investigated through process modeling. The gas phase contamination process has been chosen and will be conducted using permeation tubes. The reactor set-up has been designed, with up to 40 reactors evaluated simultaneously using real-time assessment of contaminant removal through a new FTIR gas spectrometer.

Student involvement with our research projects has been extensive and has resulted in the training of nine graduate and four undergraduate students to date. Integration of the projects is continuous. The principal investigators and graduate students interact often in this early stage of the projects by providing characteristics of influent and effluent waste streams for each treatment process. This type of interaction is essential since the projects are significantly interrelated. Also, significant research collaborations between NASA field center scientists and NSCORT water/air PIs have been established and are expected to continue. In conclusion, our group has successfully completed the start-up phase of the research projects and has made significant progress toward NSCORT research objectives.

Kathy Banks, Group Leader
Water and Air Focus Area

6.2 Project Title: Liquid Freeze-Thaw (LiFT) Urine & RO Brine Processing for Advanced Water Recovery and Salt Separation

Principal Investigator: James E. Alleman, Purdue University
Trainees: Jeff Schmidt, Graduate MS Candidate, Purdue University (0.5 RA)

Background

This project was initially originally conceived while preparing for the 2002 NSCORT competition. At that time, and based on our review of various NASA, ICES, etc. publications and contacts (e.g., journal articles, conference papers, Task Book abstracts, NJ-SCORT web reports and abstracts, JSC site visit and discussions, KSC site visit and discussions, etc.), we felt that a 'research window of opportunity' existed with respect to improving water recovery from urine and other salt-laden waste water streams based on the following four sequential hypotheses:

Hypothesis_1: That urine and other high-salt waste water streams (e.g., as might be generated via membrane reject, ion exchange backwash streams, etc.) would be discretely collected and processed for water recovery rather than being blended with fecal and plant solid-waste residues.

Rationale: Although mixing urine and fecal wastes is standard practice for municipal sewer operations, discrete collection of these streams at their source in a space environment would be beneficial on two accounts. First, co-blending and diluting of waste streams with divergent properties (e.g., high liquid content *versus* high total solids content) creates subsequent processing difficulties. Second, processing urine on a discrete basis will negate, or at least minimize, problems with sodium-related stress impacts on plants exposed to product residuals from the solid-waste processing procedures.

Hypothesis_2: That water separation from these salt-rich streams would not be readily suited to reverse osmosis or other direct separation process.

Rationale: Reverse osmosis or other 'membrane' type processing would be difficult to efficiently secure due to the initial high dissolved solids content of these discrete urine and brine streams.

Hypothesis_3: That water separation from these salt-rich streams using sequential heating and condensation phase-change steps (e.g., as practiced with the 'vapor compression distillisation' [VCD] procedure) also has its own inherent difficulties which detract from its apparent long-term utility.

Rationale: High temperature processing of salt- and mineral-laden wastes leads to scaling on heat-exchange surfaces which must be currently obviated with the recurring, and commensurately problematic, use of oxalic and sulfuric acids.

Hypothesis_4: That water separation from these salt-rich streams using sequential freezing and thawing phase-change steps could be energetically more favorable…and unaffected by the aforementioned scaling tendencies.

Rationale: The relative 'heat values' for freezing *versus* vaporization strongly suggest that 'cold' as opposed to 'hot' phase-change separation of water would be more efficient, while at the same time scaling of undesired minerals would be effectively negated.

Research Project and Goals Evolution

As we began this project, our key research premise was that a high-quality, low-solids content water could be selectively recovered from urine by way of a sequential freeze-thaw separation process, hence the 'LiFT' acronym (i.e., for 'Liquid Freeze-Thaw). Numerous precedents were found in the literature while developing this line of research, including not only an extensive range of related patents tied to direct freeze-thaw desalinization technologies (see Reference #1), but also NASA's own research initiative conducted at Marshall Space Flight Center on the specific topic of direct water crystallization and recovery from urine (NOTE: see Reference #2; this latter project was funded for a one-year period in 1999, but no further efforts to secure details regarding this project beyond the Task Book abstract have been unsuccessful).

The basic strategy of this process consisted of controlled cooling and freezing urine at ambient pressure to a point where water molecules would then crystallize via a so-called zone refining nucleation process. In turn, ice particles formed in this fashion would, at least in theory, progressively exclude soluble contaminants (e.g., salt, urea, etc.) with a resultant high purity ice product which could then be physically sifted from the remaining urine solution. However, during the course of preliminary testing with this concept, several obstacles were uncovered with respect to the long-term feasibility of treating urine in this fashion, with separation of pure *versus* partially-contaminated water being the main concern. The end result of this preliminary assessment, therefore, was a conclusion that it would be difficult, if not altogether impossible, to prevent the unwanted carryover of contaminants (either by way of surface sorption or bound as an interstitial matrix) into the product water using this technology, at which point further processing would still be required.

Having concluded that direct freeze-and-thaw separation at ambient pressure would not likely yield a product with adequate quality, our focus then shifted shortly after this project was formally initiated towards alternative freeze-drying procedures whose phase-change lyophilization mechanism under vacuum conditions appeared to offer two potential processing advantages: 1) that an improved product water quality could be secured which would be adequate for subsequent reuse with only nominal post-processing (e.g., disinfection), and 2) that the cold temperature and vacuum of space or remote planetary environments could potentially be tapped as a means of energetically improving the efficiency of this technology.

Moving into this alternative line of research, therefore, we initiated an investigation and assessment of ongoing freeze-drying research tied to waste processing which revealed that there have been four such current lines of NASA-oriented research focused on the treatment of waste water and solids, as given in the following table:

Table 1: Current NASA-Related Waste Processing Research Involved With Freeze-Drying Technology

Reference	Investigator	Focus of Freeze-Drying Technology Research
3	Eric Litwiller and Martin Reinhard Stanford University Michael Flynn and John Fisher NASA Ames	Treatment of wastes include feces, concentrated brines, and other wastewaters; thermoelectric heat pumps used in place of traditional fluid cycle heat pumps
4	Michael Flynn and John Fisher NASA Ames	Vapor compression ammonia recovery
5	Nicholas Coppa Nanomaterials Company	'Sublimation' treatment of combined water system brine and feces
6	Peter Holland, Donald Bird and Carolyn Miller Air Force Academy	Urine freeze-drying via standard lyophilization

There are clear variations between these projects relative to their involved hardware (e.g., a unique Peltier-based thermoelectric [TEC] heat pump device is being used in the first such study), operational conditions (e.g., varied vacuum ranges, temperatures, etc.), and desired waste processing goals (e.g., fecal plus urine *versus* brine-only treatment) but in each case, and as aptly pointed out by Nicholas Coppa (with Nanomaterials Company in Malvern, PA), it is the 'sublimation' context of these freeze-drying processes which will produce the desired high-quality water product. Indeed, whereas freeze-drying is almost universally used to secure optimal drying or lyophilization of an initially wet substrate (e.g., coffee, pharmaceuticals, etc.), NASA's interests for waste processing and water recovery lie at the opposite end of the standard freeze-drying spectrum.

Conventional lyophilization focuses on securing an optimally dried product with little or no concern about the sublimed water other than a hardware maintenance issue associated with the unwanted passage of water vapor beyond an 'evaporator' zone and consequent collection within, and degrading impact on, lubricating oils used inside the downstream vacuum equipment. When applied to waste processing, though, NASA's consequent emphasis on sublimation considers 'sublimed' water recovery as its primary goal. One of the associated keys to this effect will clearly be that of maximizing water trapping inside the so-called 'evaporator' (i.e., where water vapor previously released from frozen waste refreezes back to ice).

As applied to NASA's specific challenge of water recovery from urine or other salt-laden waste streams, sublimation processing would then transform these frozen residues into water vapor, which then condensed at the evaporator-end of a refrigeration cycle from which it would be collected and stored for potable use. As mentioned previously, it would appear that the vacuum and cold of a space environment might also be beneficially tapped as a means of optimizing this process by way of a suitably adapted refrigeration cycle.

At least theoretically, the sublimation process consequently appears to represent a viable option for potable water recovery from water-bearing wastes…and there is a resultant common thread with NASA's three current research efforts dealing with urine, brine, and feces treatment. Yet another recurring link appears to be that of their overlapping focus on strategies to optimize heat input to, and water vapor release from, the initially frozen wastes, particularly when applied to high-solids waste matrixes whose physical distortion and insulating effect during sublimation creates specific heat-transfer difficulties.

What is also evident, though, is that sublimation technology is quite new and that there are several approaches that can be taken to obtain a desired product, such that additional research is needed on several aspects of its use in order to secure optimal process efficiency. On the whole, lyophilization systems used in industrial settings are actually quite poorly suited to condensing a high percentage of their water vapor throughput, such that a significant research aspect of sublimation processing has not, as yet, been resolved. Before sublimation technology can be considered a highly viable option waste water recovery within an advanced life support system, water recovery efficiencies at near-100% levels from processed wastes must be achievable...and therein lies the conceptual focus of our newly 'evolved' NSCORT research effort, with urine as our primary waste target.

'Evolved Project' Progress

After switching paths from our initial 'direct freeze-thaw' research strategy to the current concept of 'urine sublimation processing,' we have channeled our efforts over the past ~seven months into three lines of effort, as follows:

First, we enlisted the support of Purdue's Physical Plant technical staff responsible for on-campus maintenance and repair of freeze-drying equipment, with the immediate goal of expediting our learning curve with the general 'art and science' of this technology while at the same time reinforcing this knowledge base with suitably directed text and journal readings. This interaction paid rapid dividends, as we were able to procure a *gratis* donation of a working (albeit slightly 'used') freeze-dryer and new vacuum pump, as well as having them reconfigure this system with an on-board digital vacuum sensor display. At the same time, this catalytic interaction has led to a number of technical suggestions on their part regarding prototype developments and refinements which were ultimately melded into our first experimental unit which featured a stand-alone urine sample chamber (see accompanying photograph). The main purpose of this first prototype was to develop a general hands-on concept of sublimation technology and to secure a general appreciation for water recovery efficiency with a standard 'evaporator' system. Only simple tests were performed, and once it became evident that water vapor capture efficiency would be quite low this system was mothballed

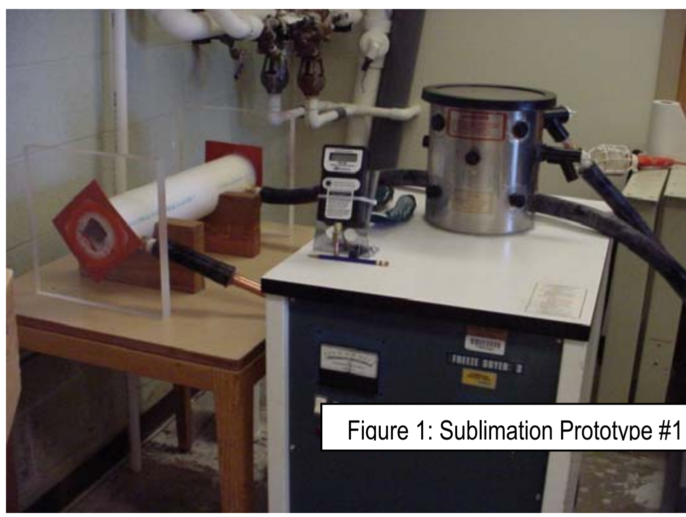


Figure 1: Sublimation Prototype #1

Second, and pursuant to our review of Nicholas Coppa's (i.e., Nanomaterials Company, Malvern, PA) documentation distributed in conjunction with his TIM call presentation in May 2003, we established a collaborative interaction with this individual (initiated via direct phone-call and continued at the ICES program in Vancouver) which has afforded yet another significant enhancement to our understanding of 'sublimination' technology. As noted earlier, this individual is currently pursuing a NASA-SBIR funded project on sublimation technology for the treatment of combined feces and brine solutions…and his leadership in this field and gracious willingness to share insights has been extremely beneficial to our efforts. By means of this interaction, therefore, we have fortuitously secured several valuable suggestions on basic design strategies for sublimation system. One such notable example was his recommendation of building a glove box around any experimental sublimation system due to the fact that the dried solid residue could create an unpleasant, and even potentially hazardous, lab environment.

Third, and most recently, we have started to lay out our design for an improved second-generation urine sublimation system which will provide a platform for evaluating the critical design and operational parameters tied to optimization of water vapor capture efficiency, energy efficiency, processing time, and final water quality. One of the anticipated innovations with this new system will be a distinctly different type of 'plate evaporator' whose enhanced surface area, controlled water vapor flow path, and reconfigured heat transfer strategy should afford beneficial improvements in the efficiency of both water vapor collection and release, as compared to conventional technology.

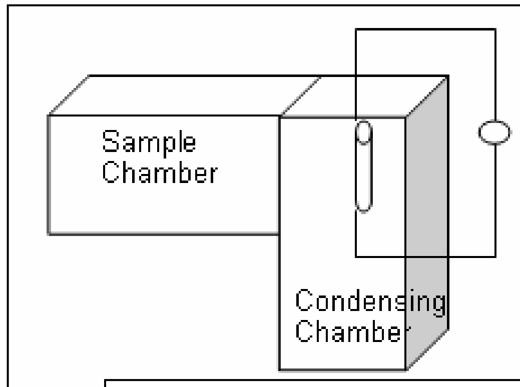


Figure 2: Sublimation Prototype #2

The basic design of our second prototype is shown in the accompanying schematic. This device will feature two acrylic vessels married together, with one vessel holding the frozen urine sample and the other vessel holding the condensation unit. Temperature data from the frozen urine sample and from the evaporator/condensor will be monitored using a computer-interfaced data acquisition device.

Overall, the main goal with testing this new prototype, and subsequent revisions thereof, will be to evaluate design and operational strategies and tradeoffs relative to desired water recovery efficacy. There are, to be sure, a considerable number of factors to be considered before this technology can be considered serviceable, as our covered in the following upcoming goals. One aspect which this testing will likely not address, though, is that of microgravity concerns. However, when these goals are met the information gathered would be used to develop another prototype that can further optimize the system.

Upcoming Research Goals

7- To optimize the evaporator configuration, water vapor channeling across the evaporator, and heat transfer control in order to secure maximal qualitative and quantitative water recovery
8- To identify and evaluate optimal operating regimes for maximal sublimation water recovery, relative to vessel vacuum levels, urine 'ice-block' heating strategies, chamber volume allocation for sample versus void/vapor space, etc.
9- To identify and evaluate automation strategies for batchwise evaporator freeze-thaw cycling
10- To identify and evaluate optimization strategies for securing maximal batchwise water extraction from an intermittently warmed evaporator
11- To identify and evaluate automation strategies for batchwise urine freezing, urine 'ice-block' introduction, and dry urine salt residue removal

Research Collaboration: We are working with the Systems Group, primarily via George Chiu and Yanfu Chan, in collaboration on their development of an initial zero-order LiFT system model.

Publications and Presentations To-Date: None

References

8- Ranney, M.W. (1971). *Desalinization by freeze concentration*, Noyes Data Corporation, Park Ridge, NJ.

9- Alexandre, K.L. (1996). Water Purification in Microgravity by Freeze Separation, NASA Task Book

10- Litwiller, E., Reinhard, M., Flynn, M., Fisher, J. (undated). "Lyophilization for Water Recovery," Personal Powerpoint presentation document.

11- Litwiller, E., Reinhard, M., Flynn, M., Fisher, J. (2001). "Lyophilization for Water Recovery from Solid Waste," International Conference for Environmental Systems Paper #2001-01-2348.

12- Flynn, M. (undated). Vapor Phase Catalytic Ammonia Reduction System. Personal Powerpoint presentation document.

13- Coppa, N.V., Schaeffer, R.W. (2003). "Sublimation Water Recovery and Applications to Space Flight," International Conference for Environmental Systems. ICES Paper #2003-01-2373.

14- Holland, P.J., Bird, D.M., Miller, C.L. (1986). "Extraction of Potable Water from Urine for Space Applications," Proc 3rd Int Conf Eng Constr Oper Space III., Publ by ASCE, New York, NY, USA. pgs. 1680-1689.

6.3 Membrane System for ALS Wastewater Recycle

Principal Investigator: Kimberly L. Jones, Ph.D.
Graduate Student: Joffrey Leevy

Significance of Project to ALS

Wastewaters (grey water, urine) processed via the BREATHe and LiFT systems will require final polishing to meet stringent potable/reuse drinking water standards. A typical water-reclamation unit for ALS would consist of a series of processes (biological treatment, membranes, ion exchange, etc). However, since membranes are available in a large range of pore-sizes, configurations and materials, they are well suited to treat water efficiently enough to meet drinking water standards with few additional processes. Given that membranes are also robust enough to be regenerated and reused many times, they are then robust enough for long-term usage with minimal disposal needs.

Recently, researchers have evaluated reverse osmosis (RO) membranes for use in the treatment of wastewater in space missions [1 – 3]. However, reverse osmosis membranes suffer from fouling, low flux, and high pressure requirements, especially during use for wastewater recycling. Fouling due to concentration polarization or solute adsorption reduces the permeate flux and recovery, which consequently limits the applicability and efficiency of RO membranes in wastewater recycling applications. Methods to reduce concentration polarization or fouling usually focus on changing the hydrodynamics of the system to increase removal of material from the surface of the membrane. Methods such as increasing crossflow velocity, increasing turbulence in the feed channels, pulsing flow, and using rotating cylinders have been evaluated for effectiveness in reducing concentration and maintaining a desirable flux [4 – 6]. These methods can be effective, but they increase the operational complexity of the system.

Nanofiltration (NF) is very effective at removing particulates, small molecular weight organics, and other contaminants from a waste stream. Nanofiltration membranes can typically remove divalent ions and molecules with mass up to ~500 g/mol. In addition, NF membranes operate at much higher fluxes and lower operating pressures as RO membranes [7], and should be less susceptible to fouling by organics (eg. surfactants) than RO membrane. NF membranes, which separate by size and electrostatic interactions, exhibit low rejection of monovalent ions. However a low pressure RO (LPRO) membrane or NF membrane should be able to be used successfully in applications where higher flux is required, such as the recycling of wastewater for space missions.

This project will test the following three hypotheses: 1) Wastewater can be recycled and treated to meet EPA guidelines for drinking water with an integrated combination of biological treatment, membrane operations and disinfection. 2) A low pressure reverse osmosis (RO) or nanofiltration (NF) membrane system can be designed to remove particulate and dissolved wastes from a recycled wastewater feed stream with minimal operational complexity and energy requirements, and 3) Membrane fouling can be minimized to allow maximum product recovery (flux) with minimal volume of concentrate for disposal by optimizing operational parameters (crossflow velocity, backwash frequency) and choosing the best configuration (spiral wound, tubular) and membrane material (cellulose acetate, polyamide, thin film composite).

Project Goals and Objectives

The overall goal of the research is to design and model a LPRO and NF membrane system for treating wastewater. Operation of both systems will be evaluated experimentally and modeled to predict long-term operational variables. Specific tasks to meet these objectives are:

- To construct two bench scale membrane systems: one LPRO unit, and one NF unit, and evaluate each unit for flux of permeate and rejection of ions, total dissolved solids (TDS) and total organic carbon (TOC) from RO and NF membrane.
- To operate systems in matrix of 5 scenarios to determine operational parameters required to maximize product, minimize fouling and reduce volume of concentrate
- To model operation of system with solution-diffusion model to allow prediction of long-term operation of the membrane system.

Research Progress

Funding on the subcontract for this grant was received in April, 2003. Since that time, the crossflow NF and LPRO membrane system has been set up in the laboratory. A picture and schematic of the system is shown in Figure 1. This system utilizes a Sepa CF II unit, in which the hydrodynamics are similar to that of a spiral wound unit commonly used in full scale applications (Figure 2). The effective membrane area is 267 cm^2. The system operates at a pressure of 250 psi (1.72 MPa).

Initially, we will evaluate five different membranes (all Sepa CF membranes from GE Osmonics):

Membrane Type	Material	Rejection	Flux @pressure $\frac{L}{m^2 \bullet day}$ @MPa	Flux@pressure $\frac{gal}{ft^2 \bullet day}$ @psi
RO	Cellulose acetate	97% NaCl	957@2.89	23.5@420
RO	Polyamide	99.5% NaCl	1058@1.55	26@225
RO	Thin film composite	98.2% NaCl	896@1.55	22@225
NF	Cellulose acetate	92% Na_2SO_4	1140@1.52	28@220
NF	Thin film composite	98% $MgSO_4$	1588@0.689	39@100

Each membrane will be evaluated for flux and contaminant rejection. Each crewmember will consume 45.03 kg/day of water for potable and hygienic use [8]. Therefore, for the lowest flux RO membrane evaluated (RO TFC membrane), each crewmember will need 0.05 m^2 of surface area at the manufacturer's stated flux/pressure. The highest flux membrane, the NF TFC will require 0.028 m^2 of surface area. The manufacturer rating for these membranes assumes a clean membrane and single salt rejection. In order to decrease required surface area, it will be important to minimize concentration polarization and maintain high flux.

Characteristics of the feedwater and reduction required for the membrane unit are listed in Table 2. The major contaminants of concern for the membrane system are ammonium carbonate (from transformation of urea to ammonia in BREATHe units), surfactants, and trace organics. The feed to the membrane is increased by 10% to take into account uncertainty in modeling of expected influent.

Table 2. Contaminant table for LPRO or NF membrane system

Constituent	BREATHe Effluent (mg/L)	Membrane Feed (mg/L)	NASA/EPA Standard (mg/L)	% Reduction Required
Urea	0	NA	1.5	0
Creatinine	Not given	NA	No data	0
Ammonium Carbonate	136	150	Ammonium = 0.5 NH_3-N = 0.5	99
Surfactant	560.9	617	0.5	99
NaCl	5.7	6.3	Na not regulated Cl = 200	0
Trace Organics	14.7	16.2	TOC = 0.5	97

Research Collaboration

We have made contact with Rich Lueptow at Northwestern University. Dr. Lueptow has investigated the use of RO for removing contaminants in space mission wastewater, and the use of a rotating RO unit for reduced concentration polarization. Our system will use a crossflow system, but the influent feedwater has a lower contaminant load, which should reduce fouling and should make the use of a rotating RO unit unnecessary, however, we plan to consult Dr. Lueptow on the solution diffusion modeling work that begins in December 2003.

Future Directions of the Research

Following initial evaluation of the optimal membrane for contaminant rejection and flux characteristics, another graduate student will join the project to begin work on the solution diffusion model. System modeling will begin relatively early in the project to evaluate long-term operation of the system under different conditions.

Trainees Involved in the Study

Grad Students – Joffrey Leevy

Publications and Oral/Poster Presentations

This project began in April 2003, and results have not been published. Oral presentations are listed below:

Jones, K. and Leevy, J., *Membrane Processes in ALS*, May 2003, Oral Presentation, NSCORT Strategic Planning Meeting, West Lafayette, IN.

Leevy, J. and K. Jones, *Design of a High Flux, Low Fouling Membrane System*, July 2003, Oral Presentation, NSCORT Summer Fellowship Symposium.

Presentation Milestones/Benchmarks

Results from the experimental flux/rejection experiments will be submitted for presentation at the 2004 International Conference of Environmental Systems and 2004 AWWA conference (University forum). Modeling work will begin in December; those results will be obtained over the next year and may be presented in late 2004.

Supporting Graphs, Charts, Illustrations, Photos

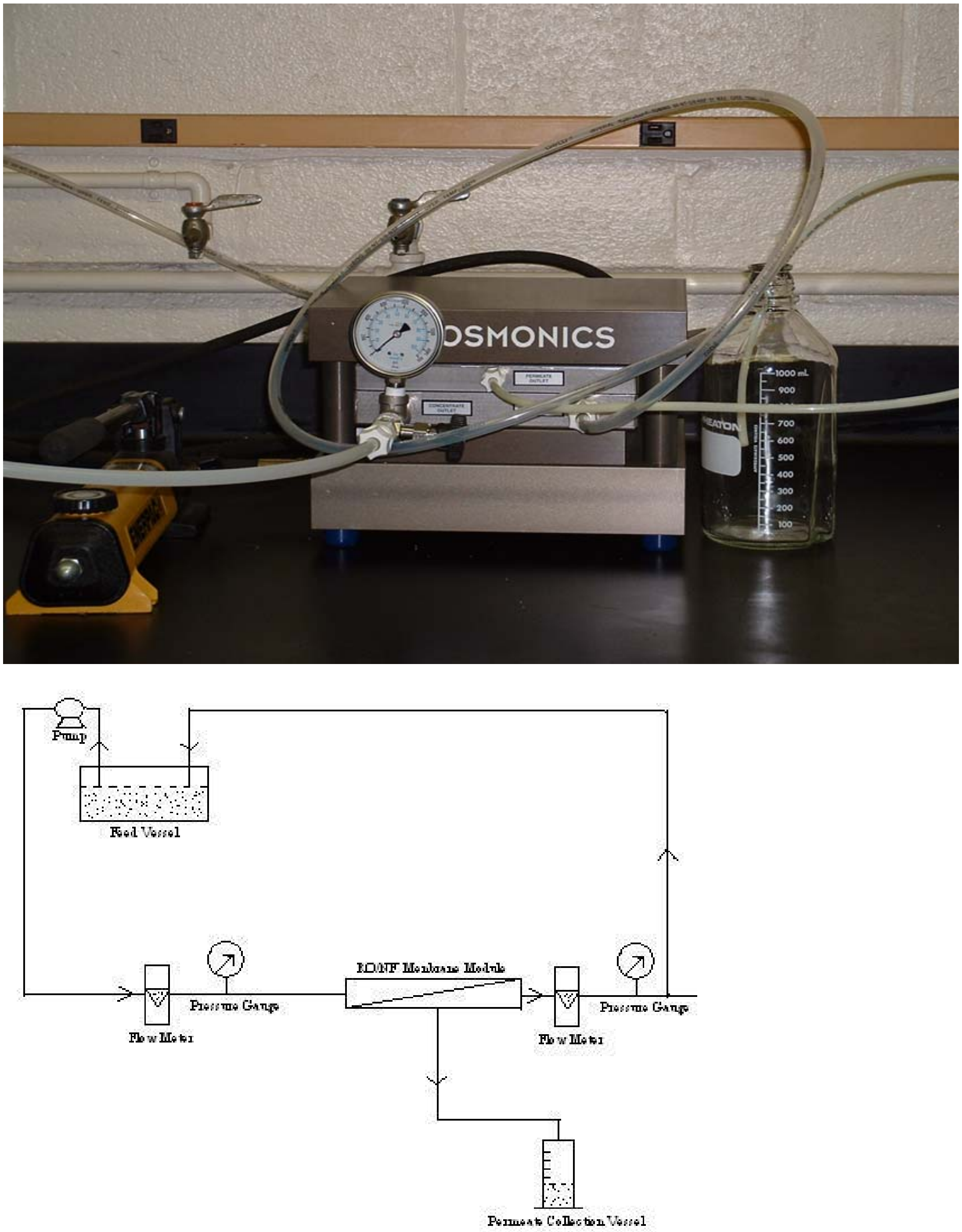


Figure 1. a. Picture of membrane system, and b. Schematic of process

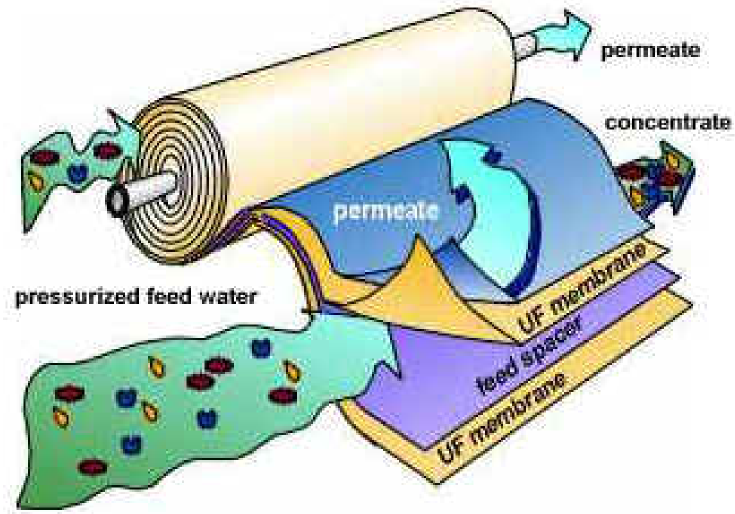


Figure 2. Spiral wound membrane unit.

References

1. Lee, S. and Lueptow, R.M., Reverse osmosis filtration for space mission wastewater: membrane properties and operating conditions, *J. Membr.Sci.* 182 (2001) 77 – 90.
2. Lee, S. and Lueptow, R.M., Toward a reverse osmosis membrane system for recycling space mission wastewater, *Life Support & Biosp. Sci*. 9 (2000) 251 – 261.
3. Pickering, K.D, Wines, K.R., Pariani, G.M., Franks, L.A., Yeh, J., Campbell, Finger, B.W., Verostko, C.E., Carrier, C., Gandhi, H., and Veta, L., Early results of an integrated water recovery system test, NASA report 2001 – 01-2210.
4. Lee, S. and Lueptow, R.M., Rotating reverse osmosis: a dynamic model for flux and rejection, *J. Membr.Sci.* 192 (2001) 129 - 143.
5. Kennedy, T.J., Merson, R.L., McCoy, B.J., Improving permeation flux by pulsed reverse osmosis, *Chem, Eng. Sci*. 29 (1974) 1927 – 1931.
6. Engler, J., Wiesner, M.R., Particle fouling of a rotating membrane disk, *Water Res*. 34 (2) (2000) 557 – 565.
7. Ko and Sirkar, *Membrane Handbook* (1992).
8. NASA Exploration Team Human Subsystem Working Group, *Guidelines and Capabilities for Designing Human Missions*, (2002).

DEVELOPMENT OF THE BREATHe (Bio-Regenerative Exhaust Air Treatment for Health) FOR WATER AND AIR RECYCLING

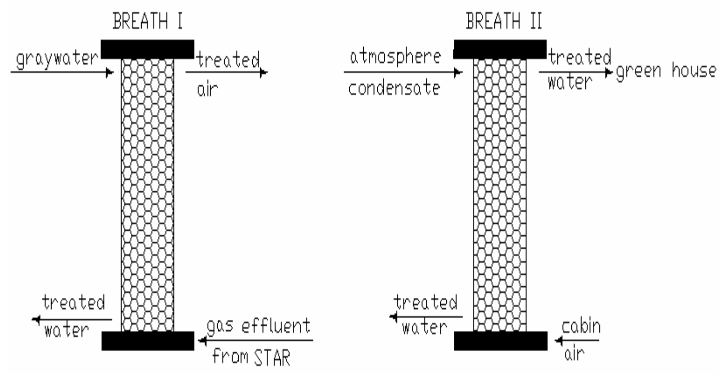
Principal Investigator: M. Katherine Banks, PhD, PE
Graduate Students: Sybil Sharvelle, Yong Sang Kim, and Jinliu Xia
Undergraduate Students: Katherine Graham, Erin Malony, Chris Ghattas, Joi Dunham

BACKGROUND

An integral part of a NASA life support system is the ability to recycle air and water. The Bio-Regenerative Environmental Air Treatment for Health (BREATHe) process is an important component of an integrated system that will recycle air and water at nearly 100% efficiency during a long duration (more than 365 days) mission to Mars. The BREATHe system will consist of two packed bed biofilter reactors that will simultaneously treat contaminated air and water. The first reactor, BREATHe I, will primarily treat graywater and gas effluent from the Solid Phase Thermophilic Aerobic Reactor (STAR), another component of the integrated ALS system. The primary waste streams that will be processed in the BREATHe II system include habitat air and atmospheric condensate. Trace organics present in both the air and atmospheric condensate will be removed by aerobic biological degradation in the BREATHe II reactor. It should be noted that urine will not be processed in the BREATHe reactors and will removed from water by means of a physico-chemical process, also included in the NASA NSCORT ALS system. Shown in Figure 1 is a conceptual design of the BREATHe reactors. The exact configuration of the reactors is currently under investigation though assessment of several prototypes. The BREATHe system will enable efficient treatment of water and air while minimizing mass, volume, power, and crew time maintenance requirements.

The design and optimization of the BREATHe reactors will involve an in-depth developmental phase where bench scale reactors will be used to simulate full-scale systems. During the developmental phase of the project, design parameters such as size, recirculation rates, and flow rates will be optimized. It will be essential to use simulated waste streams for this study because it is not possible to obtain realistic waste streams on a regular basis Therefore, it is necessary to characterize the expected chemical composition of each waste stream. Numerous studies have been conducted to characterize wastewater generation, graywater composition, atmospheric condensate composition, and air contamination in a representative space habitat and data sets addressing these topics exist in the literature. However, as of yet, this data has not been compiled into one comprehensible format that is relevant to the wastestreams that would be expected on a long-term human mission to Mars. Anticipated chemical concentrations will be predicted for graywater, cabin air, atmospheric condensate, and effluent gas from the solid waste treatment system. In addition, because each reactor will treat both gas and liquid phases, it will also be important to assess liquid/gas equilibrium for each chemical constituent in a complex waste matrix.

Figure 1. Conceptual Design of BREATHe Reactors



RESEARCH OBJECTIVES

- Prepare a conceptual design of a dual treatment process (liquid and gaseous effluents) in a trickling biofilter reactor.
- Construct and operate a representative pilot-scale biofilter treatment system.
- Develop and experimentally verify a mathematical model for the BREATHe system.
- Identify and optimize system design parameters, such as gas/liquid flow rate, to maximize treatment efficiency.

RESEARCH PROGRESS

Experimental Design. A major challenge that was encountered during experimental planning for the BREATHe systems was the determination of expected inputs for each of the two reactors. BREATHe I will receive a liquid waste stream consisting of gray water (hygiene, dishwash, and laundry wastewater) and the waste gas stream will be STAR effluent with high concentrations of ammonia and hydrogen sulfide. An extensive literature review was performed to determine expected contaminant concentrations for each waste stream and results are presented in the referenced ICES paper written by Sharvelle et al., 2003. The primary functions of BREATHe I will be conversion of carbon in surfactants to carbon dioxide, conversion of hydrogen sulfide to sulfate, and conversion of some percentage of ammonia to nitrate. BREATHe II will treat atmospheric condensate and cabin air. These waste streams primarily consist of trace organics. However, a significant amount of ammonia is expected to be present in both streams. Because it is very difficult to determine exact contaminant concentrations that would be expected during a long term space mission, the predicted values will be used as a starting point and contaminant concentrations will be varied throughout experiments to determine effects on reactor performance.

Over the last nine months in the laboratory, we have focused on analytical protocol, reactor prototype selection, and two experimental thrust areas. In the analytical protocol area, we have purchased an LC/MS. Sybil Sharvelle traveled to KSC and worked with Jay Garland's research group to learn LC/MS analytical protocols for assessment of target surfactants. We are now able to assess surfactant concentrations and metabolic by-products in grey water.

Over the summer of 2003, we constructed two prototypes for the BREATHe system. After operation of the first prototype, channeling of liquid was noted and a significant amount of water was entrained in the gas phase. The second prototype eliminated the channeling problems, and demisters were strategically placed to reduce water droplets in the gas stream.

Figure 2. BREATHe Prototype I

Figure 3. BREATHe Prototype II

For the first experimental focus, we assessed the effectiveness of BREATHe Prototype I for removal of Pert Plus from the water phase using a mixed microbial culture. Pert Plus was chosen as the target contaminant after discussions with KSC and JSC scientists. Of note is that the gas phase was ambient air without gaseous contaminants. The data are shown in Figure 4, indicating good removal efficiency of the contaminant over a 30 period.

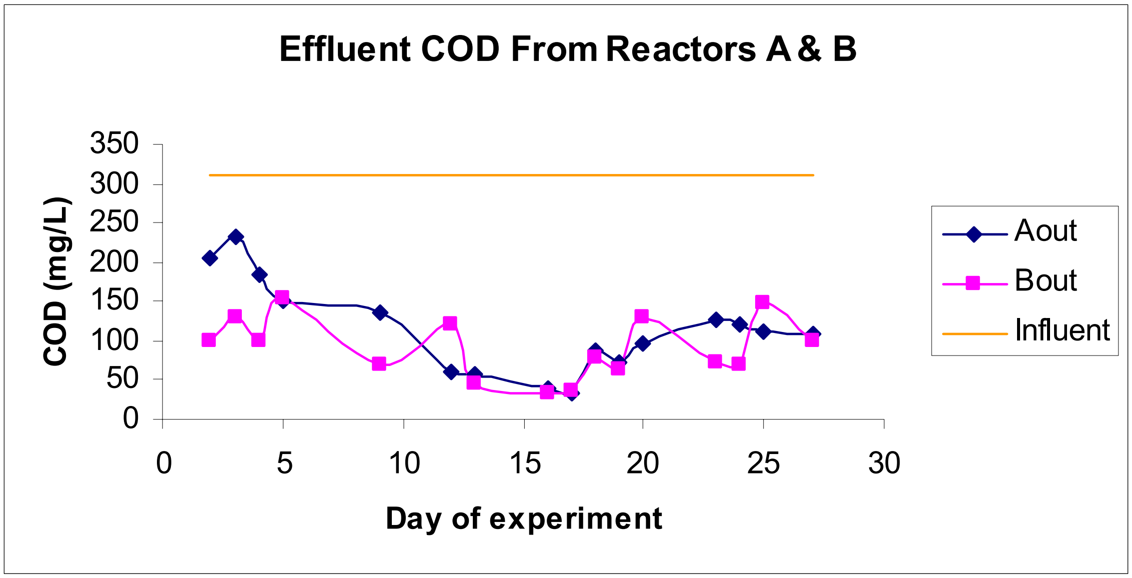


Figure 4. Removal of target surfactant (Pert Plus measured as COD) in the BREATHe reactor.

For the second experimental focus, we determined the growth rate kinetics associated with two commercially available cleaning products. This will assist us with our modeling efforts. For Tide, the concentration (C) variable was 928 mg/L (powder detergent) (Figure 5). For Cheer, we used a concentration of 1.2 mL/L (liquid detergent) for the variable C (or concentration) (Figure 6).

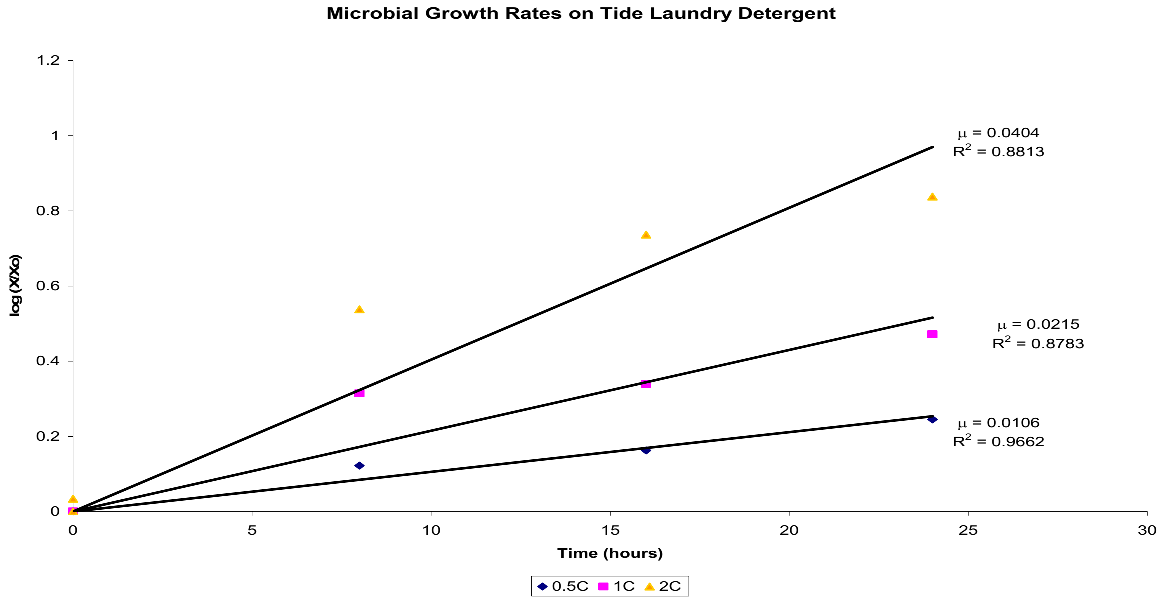


Figure 5. Microbial Growth Rates on Tide Laundry Detergent

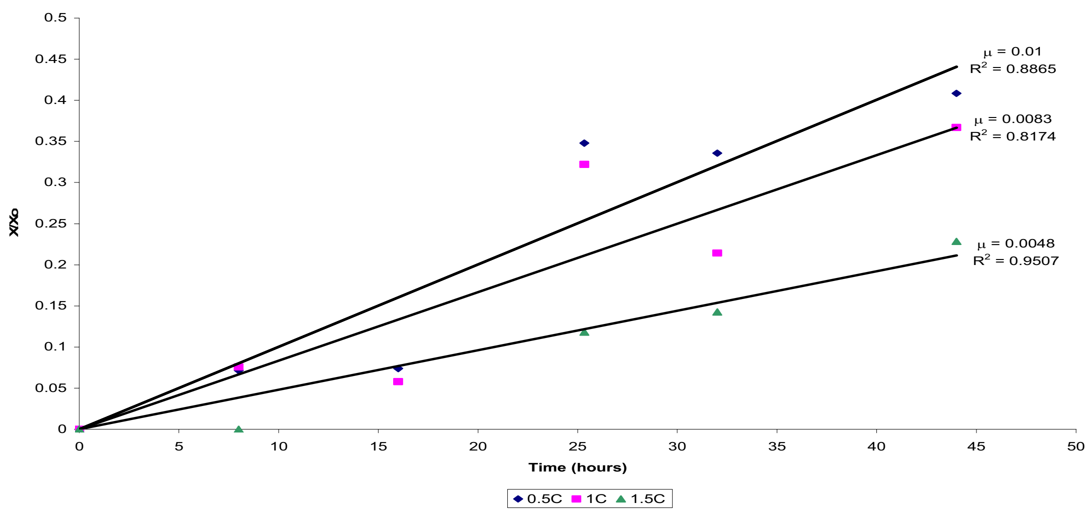


Figure 6. Microbial Growth Rates on Cheer Laundry Detergent

Our upcoming short-term experimental projects are: 1) to operate both the BREATHe I and BREATHe II reactors with contaminated air and water and analyze effluents accurately, 2) to continue assessment of growth rate kinetics for surfactant degradation, and 3) to assess gas/liquid partitioning coefficients for target contaminants in the complex gray water matrix.

RESEARCH COLLABORATION

We have collaborated directly with Jay Garland, Kennedy Space Center, and Karen Pickering, Johnson Space Center. There have been several conference calls involving the members of this group. Sybil Sharvelle traveled to Kennedy Space Center and worked for four weeks with Dr. Garland's research group in June of 2003. Dr. Garland has agreed to serve as a PhD committee member for Sybil. In addition, Dr. Garland and I will be co-chairing an ICES session in 2004 focusing on Biological Waste Treatment and Microbial Processes. To promote cooperation between NASA Centers, we have invited Professors David Mazdak (water treatment area) and Jean Andino (air treatment area) from the NASA Commercialization Center to present seminars for NSCORT participants in the fall of 2003.

PUBLICATIONS AND PRESENTATIONS

Sharvelle, Sybil, Banks, M. K., A. J. Heber, "Wastestream Characterization for a Packed Bed Biofilter Intended for Simultaneous Treatment of Graywater and Air," ICES 2003, Paper 03ICES-182, 2003.

Sharvelle, S., M. K. Banks, and A. Heber, "BREATHe Treatment for Air and Water," Presented at the International Conference on Environmental Systems, Vancouver, Canada, 2003.

6.5 Progress Report
September 11, 2003
Project 7: Gas-Phase Revitalization Using BREATHe Biofilters in ALS
Principal Investigator: Albert Heber, PE, PhD
Graduate Students: Huang Hong, Sang-hun Lee

Introduction

Bioregenerative life support systems will play a crucial role in future long-term space missions. Continuous removal of gas and liquid-phase pollutants using biological treatment methods are possible for long term missions, and it is relatively inexpensive compared with other physico-chemical techniques.

The Bio-Regenerative Environmental Treatment for Health (BREATHe) will decontaminate the pollutants in both air and water using a packed bed biofilter. BREATHe I will primarily treat gray water and gas effluent from the Solid Phase Thermophilic Aerobic Reactor (STAR). BREATHe II will clarify habitat air and atmospheric condensate.

The optimal design and operational parameters of the BREATHe II system have been investigated, first by studying the expected characteristics of influent air waste streams, evaluating the design of the reactor, and developing the process modeling strategy for BREATHe II.

Immediate Objectives

1. Determination of BREATHEe II reactor volume

Pertinent data from the literature upon which the design of the experimental BREATHe II reactors (airflow rate, contaminant mass flow rates, etc.) will be based is being studied. Specifically, we are determining the airflow and contaminant mass flow rates. Realistic assumptions of pollutant generation rates and spacecraft maximum allowable concentrations (SMAC) of each compound are available in the BVAD and other documents. For initial design of experimental BREATHe II reactors, we will use recommended air velocities and empty bed retention times (EBRT) found in the literature.

2. Modeling of BREATHe II reactor

In addition to air flow and contaminant loading rates, other parameters must be considered, such as maintenance of proper moisture content for optimal biofilm performance. To predict and monitor all the important parameters in BREATHe II, proper selection and construction of the model is necessary.

Unlike conventional biological treatment systems, few models are available for simulating the biofilter reaction. For biofiltration, the reaction generated at the gas and water (or biofilm) interface must be added to the model for conventional biological treatment.

One of the most widely known models for simulating the dynamic reaction of the biofilter was been developed by Dr. Marc Deshusses and his colleagues. Their models were the first to describe the dynamic and transient behaviors of the biofilter reaction. However, the Deshusses' models do not describe the temporal variation of biofilm growth during the reactions, so our group is also considering the biofiltration models that include biofilm variation terms, such as the model proposed by C. Alonso and his colleagues.

3. Experimental set up of the BREATHe II system

Our group will use our extensive analytical infrastructure to conduct scaled-down laboratory tests of BREATHe reactors that are approximately 5% of the estimated size needed for the spacecraft for the Mars mission. The test will feature multiple reactors (up to 40), a multipoint gas sampling system, and a calibrated mixture of standard pollutants that represents the contaminants expected in the Mars spacecraft.

Progress

1. Determination of pollutant loading rates and the BREATHe II reactor volume

The contaminants of most concern are listed are listed in Table 1. Among them, ammonia has the highest generation rate, coupled with a relatively low allowable concentration value (SMAC). Consequently, upon the simplifying assumption that treatment is only dependent on the mass loading and concentration, the air flow for a complete ammonia removal is the highest among all the contaminants. As a result of the calculation, we obtained an air flow rate of 140 L/min based on the SMAC for ammonia divided by the generation rate of ammonia.

Also, recent studies recommended that air velocity in the packed bed be below 0.2 m/s and an EBRT of at least 100 seconds provides stable removal of some kinds of VOC. With an assumption of 60 s for EBRT, the reactor volume of 140 L for the spacecraft was calculated.

2. Modeling of the BREATHe II reactor

The efficiency of BREATHe II depends on the maximum biofilm growth rate, Henry's constants, and the specific surface area of the biofilm. The microbial characteristics are the most important parameter in most cases. We therefore propose to monitor and analyze the microbial degradation properties during laboratory tests.

The contaminant concentration along the depth profile shows exponential and linear decreases both in contaminant concentration and biofilm thickness. The Deshusses' and Alonso's models are similar in description of diffusion and convection phenomena in the gas and biofilm (or water) phases. However, in Deshusses' model, the major driving force to attract contaminant into the biofilm phase is sorption phenomena, specifically, direct adsorption between the contaminant and the biofilter media, together with concentration gradients and microbial kinetics. However, Alonso, et al. assumed biofilm growth and decay phenomena resulting in gradient changes during biofilm growth that may influence contaminant mass transfer into the biofilm. We intend to incorporate this feature into our model.

3. Experimental Testing of the BREATHe II System

We are designing the experimental setup for testing the biofilters. Whereas the size of the BREATHe II is preliminarily 1/20 of the full size of 140 L, the experimental reactor will be 7 L and the airflow will be 7 L/min.

Permeation tubes will be used to generate known amounts of contaminants into each reactor in a mixture of the 12 most important contaminants (Table 1). The details of the 12-gas permeation system are still being developed. Conceptually, clean compressed air will flow under pressure through the permeation system and into a manifold that distributes air into each reactor at 7 L/min. Up to 40 reactors will be tested in a temperature-controlled walk-in chamber and inlet and outlet gas concentrations measured sequentially and automatically.

The ventilation system of the walk-in chamber was repaired. The compressor system was repaired. The data acquisition system was upgraded to a 1.0 GHz PC and Labview v. 6.1. Analog input and temperature modules (Field Point, National Instruments) were purchased, installed and tested with the data acquisition system. The gas sampling system has been set up for 12 sampling locations and leak-tested. It was upgraded with a new manifold pressure sensor. The ammonia, hydrogen sulfide and carbon dioxide analyzers were set up and calibrated using standard gases.

A Thermo Nicolet Nexus 670 FTIR gas spectrometer with a Gemini 8-L gas cell was purchased and set up in the laboratory. A 2-d training session from Thermo-Nicolet personnel is scheduled for October 22-23, 2003. A purge gas generator needed to continuously purge the spectrometer was delivered in early September. A more sensitive detector for the Nexus 670 was ordered but has not yet arrived.

Peristaltic pumps are being selected to provide the liquid flow through the biofilters. The number of biofilters that can be tested in the fall of 2003 will depend on the cost of the experimental set up.

A special topics course entitled "Air Biofiltration" is being developed and taught in Fall of 2003.

Immediate Future Plans

We will conduct bench scale tests of BREATHe II as well as BREATHe I.

Simultaneously with the experiments, the dynamic modeling efforts for simulating the biofiltration reaction will be continued. Some modifications or development of mathematical terms will be explored to describe the chemical and microbiological effects and heterogeneous characteristics of complex interactions in the micro scale of the biofiltration.

For example, the influent air velocity of the indoor biofilter is conventionally very high, so they can create a shear dominant condition of attached biofilm in the biofilter reactor. Also, in the indoor biofiltration, there might exist substrate and/or nutrient limitation condition. The constitutive modeling efforts will provide the scientific analysis of the process.

A paper describing the methodology of tests of BREATHe will be presented at the Habitation Conference in January, 2004.

Table 1. Biofilter airflows required to treat spacecraft contaminants assuming 100% removal efficiency and SMAC levels inside the cabin.

Substance	Loading	SMAC	Biofilter Airflow		
	mg/day	mg/m^3	m^3/day	L/h	L/min
Ammonia	1412	7.0	202	8404	140
Ethyl cellosolve (2-ethoxyethanol)	49.8	0.3	166	6917	115
Indole	32.8	0.3	131	5468	91
Formaldehyde	1.8	0.1	35.2	1467	24
Benzene	10.5	0.3	32.8	1366	23
Carbon monoxide	222	10	22.2	926	15
Methyl ethyl ketone	497	30	16.6	690	12
Methylene chloride (dichloromethane)	162	10	16.2	673	11
Methanol	99.0	9.0	11.0	458	7.6
Acrolein (2-propanel)	0.3	0.0	8.7	361	6.0
Ethanol	606	94	6.4	269	4.5
Ethylene dichloride (1,2-dichloroethane)	5.8	1.0	5.8	242	4.0

6.6 Water Disinfection: UV Irradiation and Iodine

Principal Investigator: Ernest R. Blatchley III, PE, PhD
Graduate Students: Zorana Naunovic and Kelly Pennell, PE

Introduction

NASA has been using iodine as the disinfectant of choice for drinking water supplies on space missions for decades. While past use has demonstrated that iodine is effective against many microorganisms, iodine resistant bacteria, such as *Burkholderia cepacia*, have been identified, thereby suggesting the need for further development of water disinfection systems for long-term space missions. Additionally, since inactivation of recalcitrant pathogenic microorganisms (*e.g.*, enteric viruses, *Cryptosporidium parvum*) has been identified as a potentially important limitation of halogen-based disinfection systems, a more comprehensive disinfection approach is warranted.

The disinfection approach that is the focus of this research includes complementary disinfection processes: ultraviolet (UV) radiation to act as the primary (physical) disinfectant, and iodine to serve as the secondary (chemical) disinfectant. Since UV and iodine inactivate microorganisms according to different mechanisms, using this complementary approach is anticipated to allow a broader range of microorganisms to be inactivated.

The selection of these two disinfectants, UV and iodine, was made for several reasons. First, UV does not require the addition of chemicals, and has been demonstrated to generate only small quantities of disinfection by-products. Since UV will be relied on for the majority of microbial inactivation, it is anticipated that astronaut health and safety will be promoted by consumption water that had been UV irradiated, as opposed to disinfection by iodination. In addition, UV has been demonstrated to be effective at inactivating a broad spectrum of bacteria, viruses, and protozoa. However, once UV treats water, new microorganism communities may grow if a residual (chemical) disinfectant is not maintained. Typically, the concentration of the residual disinfectant is less for water that is pre-treated with UV, than if the residual disinfectant was used to perform the disinfection by itself.

Iodine was selected as the residual disinfectant for several reasons, including low reactivity (*i.e.*, stability) *and* proven success as a disinfectant. However, of equal or perhaps greater importance is the ability of an iodine-based system to function as a monitor for the UV disinfection process, on-line and in real time. In order to verify the UV system is accomplishing disinfection, dose monitoring is required. One means of monitoring UV dose is the iodide/iodate actinometer. Conceptually, the actinometer solution could be continuously recycled and physically/chemically converted for use as a chemical disinfectant.

While iodine offers benefits over other conventional disinfectants, adverse health affects related to thyroid function have been identified due to prolonged exposure to iodine. For this reason, the iodine concentration in potable water must be reduced prior to consumption. Currently, it is unknown what concentration of iodine will be required in the proposed complementary disinfection approach; however, it is assumed that iodine will be completely removed prior to consumption. The constraint of total iodine removal prior to consumption of water actually will serve a beneficial role in this application, as the recovered iodine could then be re-used continuously in the actinometer, and as a disinfectant.

Research Objectives

As discussed previously, the proposed research incorporates a complementary disinfection process with UV as the primary disinfectant and iodine as the residual disinfectant. Accordingly, the research objectives have been divided into two categories: UV and iodine.

UV

The UV portion of the research will focus on developing a computational method (*i.e.*, numerical model) for prediction of reactor efficiency. The model will incorporate fluid flow simulations using a commercially available computational fluid dynamics (CFD) code, FLUENT. A numerical method known as line-source integration (LSI) will be used to simulate the radiation intensity field within the reactor system. The output of the CFD and LSI simulations will be integrated to yield a numerical estimate of the dose distribution delivered by the system. In turn, these predictions will be combined with known or measured UV dose-response behavior for target microorganisms. This method has previously been shown to provide accurate predictions of reactor performance; however, the method has only been applied to a narrow range of reactor geometries and operating conditions.

Work in this portion of the project will be directed towards development of a generalized numerical simulation method, following the scheme described above. Following this, the generalized method will be used as a tool for development of a UV reactor system that will satisfy the constraints of an extended space travel mission.

Iodine

1. Develop means for dual-use of iodine as an actinometer and disinfectant

Research will be performed to determine an efficient manner in which the iodide/iodate actinometer can be used not only to measure UV dose, but to also yield an iodine-based product that can be easily converted and used as a residual disinfectant. The method being developed to convert the actinometer product will build on previous work related to the Microbial Check Valve (MCV). The MCV is the current method by which iodine is added to water for disinfection purposes aboard Shuttle. It is also expected that the method being developed to recover the iodine from the potable water prior to consumption will build on previous work performed in conjunction with the Galley Iodine Removal Assembly (GIRA), which is the method used to remove iodine from water on Shuttle.

2. Determine disinfectant dose

In addition to developing a method to convert and recover iodine, research will also be performed to determine the amount of iodine needed as a residual after UV treatment. This research will be performed in conjunction with tests to determine the UV dose required for inactivation of *Burkholderia cepacia*, which is iodine resistant and is commonly detected in water aboard US Spacecraft.

3. Investigate disinfection byproducts

Over the past ten years, research has begun to examine the production of disinfection byproducts (DBPs) that form from residual iodine concentrations and organic compounds, or precursors, which are present in the water stream. Iodinated DBPs cause taste and odor problems as well as potential health risks. Fortunately, because iodine is generally less reactive than chlorine and bromine, the formation of DBPs tends to be less prevalent in waters treated with iodine compared to chlorine. However, additional research is needed to better characterize DBP formation. This research will include defining kinetics for known precursor compounds.

Research Progress

UV

A computational method for prediction of UV reactor efficiency has been developed based on a computer program which couples simulated fluid flow field information and UV radiation field data, then calculates the UV radiation dose delivered to the microorganisms. This program was written in FORTRAN 90/95 and successfully calculates the UV dose distribution delivered to microorganisms in the system. An example of dose distribution for a model UV reactor is presented in Figure 1 for 1000 simulated particle trajectories.

The UV spatially dependent intensity field is simulated using the LSI model in MathCAD and the output file gives values for UV radiation intensity at one millimeter increments at a cross-section of the reactor. Figure 2 displays the spatially variant UV radiation intensity field at a cross section of a model UV reactor, and the velocity contours of the flow field at that same cross-section of the reactor. Three-dimensional fluid flow field simulations were performed using FLUENT and microbial particle trajectories through the UV reactor were simulated as a discrete second phase in a Lagrangian frame of reference. FLUENT provides graphical and alphanumeric reports for the discrete phase, including reports of the particle position, velocity, temperature and diameter in designated time intervals (time intervals chosen for performed simulation is on the order of 10^{-5} seconds). A graphical display of the microbial particle trajectories is presented in Figure 3. It is visible that as microorganisms traverse the reactor they follow different paths, and are exposed to different intensities. For presentation purposes only 25 particle trajectories are shown, while simulations have been accomplished with 1000 particles. The alphanumeric report format allows monitoring of particle position and velocity as the trajectory proceeds. The FOTRAN program links the position of the particle in every time instant with the radiation field at that position in the reactor and calculates the UV dose as the product of its exposure time to UV radiation and the intensity of that radiation at that instantaneous position. The total UV dose delivered to a microorganism in the reactor is then defined as the sum of all instantaneous doses delivered to the microorganism for the time that it spends traversing the reactor.

Simulations were performed with different reactor geometries and inlet fluid velocities. Thus various UV dose distributions were obtained, and the next step is to couple these calculations with UV-dose response behavior for target microorganisms and analyze UV reactor performance under various operating conditions.

Iodine

To satisfy the objectives discussed previously, an understanding of past research attempts in the area of actinometry, disinfection byproduct formation and aqueous iodine chemistry is necessary. For this reason, significant effort has been focused on conducting a comprehensive literature search. The information gathered during the literature search will be used as a foundation when designing future experiments.

In addition to completing the literature search, two mathematical models have been developed to predict iodine speciation. When iodine is added to water, (at least) ten different iodine species can simultaneously exist. To date, two models have been published on iodine speciation as a function of pH in aqueous solution (Atwater 1996 and Gottardi 1999). To elaborate and improve upon these models, two additional models were developed as part of the subject research. These iodine speciation models were developed using eight equilibrium reactions, a redox balance equation and a mass balance equation.

Figure 4 shows a model developed in MS Excel that allows the user to define the iodine species added to solution. Previous models have not allowed +1-valent iodine to be added to the solution. Figure 5 shows a three-dimensional model, also developed in MS Excel, which predicts iodine speciation as function of pH and $p\varepsilon$. Previous published models did not include $p\varepsilon$ as a variable.

Research Collaboration

In order to build on research and knowledge of the NASA community, we plan to work with personnel from the Microbiology Laboratory at Johnson Space Center (JSC) to perform UV dose experiments on *Burkholderia cepacia*, an iodine resistant bacterium. In addition, we have initiated contact with James Atwater of Umpqua Research Center to obtain MCV resins. URC developed the MCV, which is NASA's current method of iodine delivery for water disinfection.

Future Research Plans

As the next academic year begins, experiments will be conducted to achieve the objectives for the UV and iodine portions of the research. Experiments will be performed to determine the disinfectant dose necessary to achieve disinfection. In addition, communication with Umpqua will continue to acquire ion exchange resins. Once the resins are acquired, experiments will be performed to determine an efficient means to convert the various iodine species. Lastly, it is expected that collaboration between JSC and Purdue to determine the dose-response relationship between *Burkholderia cepacia* and UV radiation will be completed this academic year.

Oral Presentations

To date, several oral presentations have been given relating to UV and iodine disinfection. Below is a list of presentations that have been given. Given the early stage of this project, no results have been published.

Water Disinfection for the Mission to Mars, April 2003, Poster Presentation, 4th Annual Environmental Science Symposium, Lafayette, Indiana, Presenters: Zorana Naunovic and Kelly Pennell

Water Disinfection System: Complementary Use of Ultraviolet (UV) Irradiation and Iodine, May 2003, Oral Presentation, NSCORT/NASA Strategic Planning Meeting, West Lafayette, Indiana, Presenter: Kelly Pennell

Optimization of Physical and Chemical Disinfection Processes Subject to Extended Space Travel Constraints, June 2003, Oral Presentation, Johnson Space Center-Houston, Texas, Presenter: Kelly Pennell

Water Disinfection for Long Term Space Missions, July 2003, Oral Presentation, NSCORT Summer Fellowship Symposium, Presenter: Kelly Pennell

Presentation Milestones/Benchmarks

It is anticipated that results of experiments performed over the next academic year will be submitted for acceptance at the International Conference of Environmental Systems (ICES), July 2004. It is expected that both Kelly Pennell and Zorana Naunovic will present their findings at this conference.

References

Atwater, James and Richard Sauer. Numerical Simulation of Iodine Speciation in Relation to Water Disinfection Aboard Manned Spacecraft I.Equilibria. *Journal of Environmental Science and Health.* pp 1965 to 1979. 2003.

Gottardi, Waldemar. Iodine and Disinfection: Theoretical Study on Mode of Action, Efficiency, Stability, and Analytical Aspects in the Aqueous System. Arch. Pharm. Med. Chem. Pp 151-157. 1999.

Figure 1. Dose distribution for a model UV reactor for 1000 microbial particles.

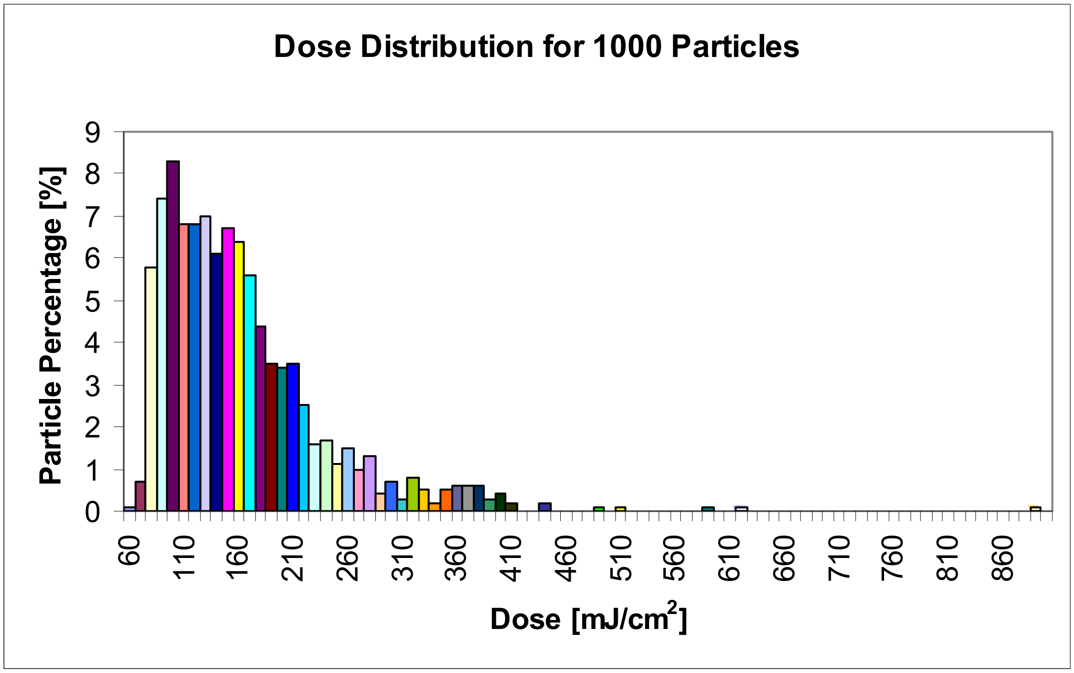
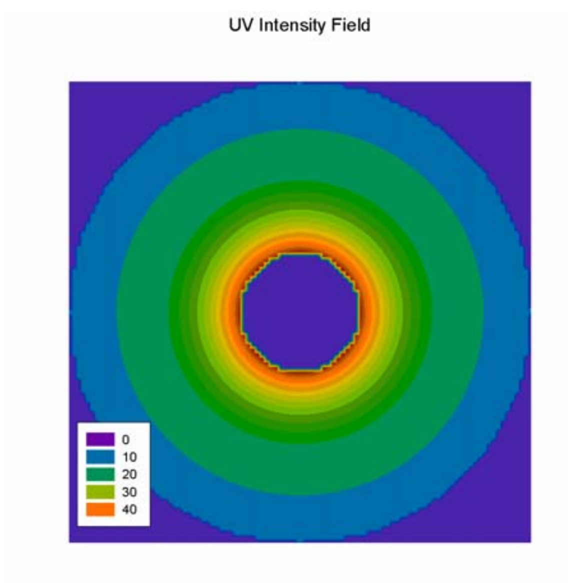


Figure 2. UV radiation intensity field at a cross section of a model UV reactor (units are mW/cm^2) and the velocity contours of the flow field at that same cross-section of the reactor.



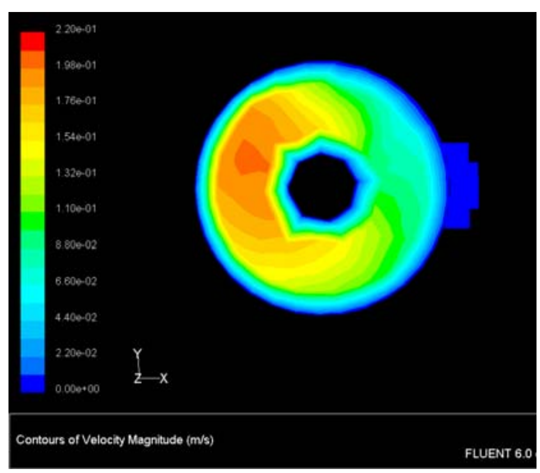


Figure 3. Microbial particle trajectories through a model UV reactor (simulations performed in FLUENT).

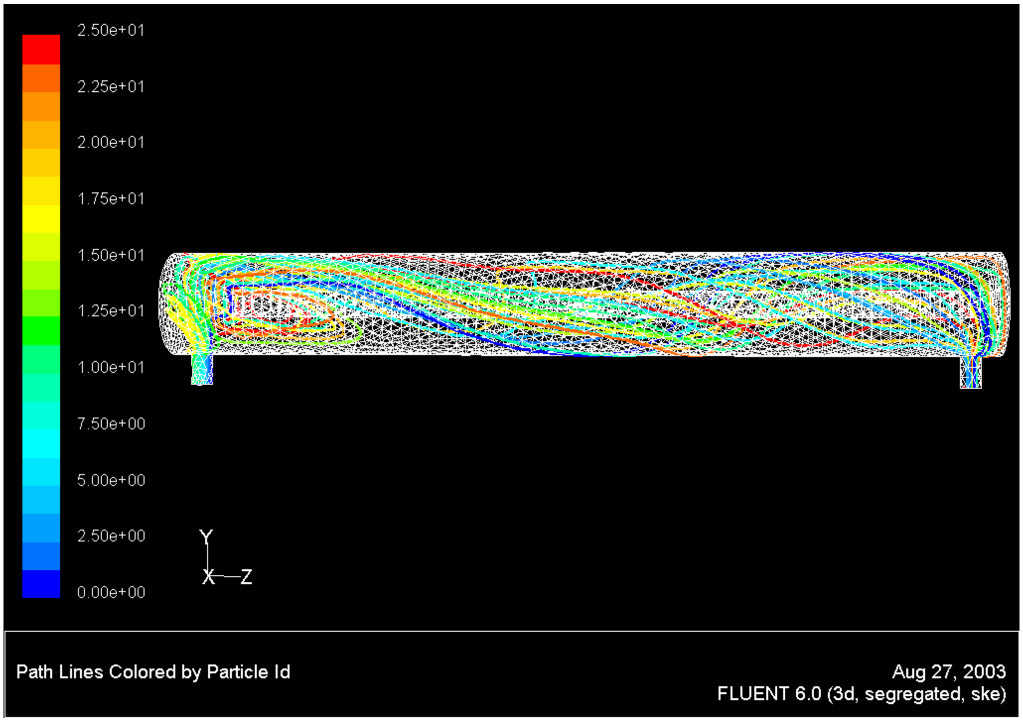


Figure 4. Iodine Speciation Model as a Function of pH

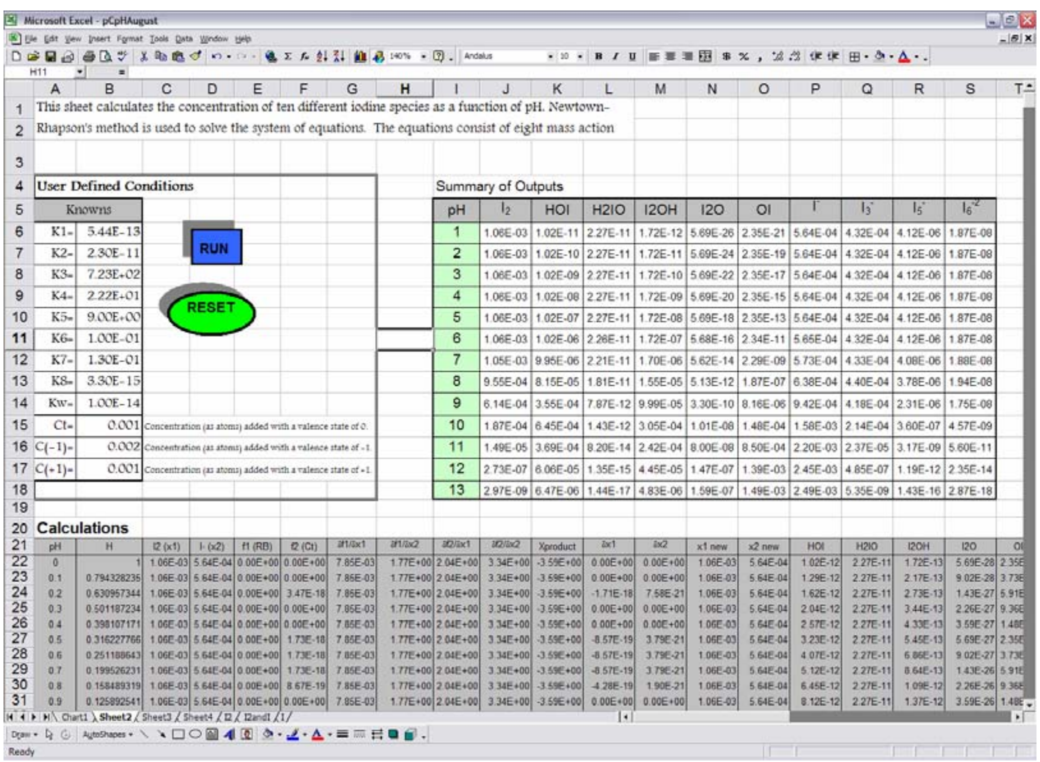
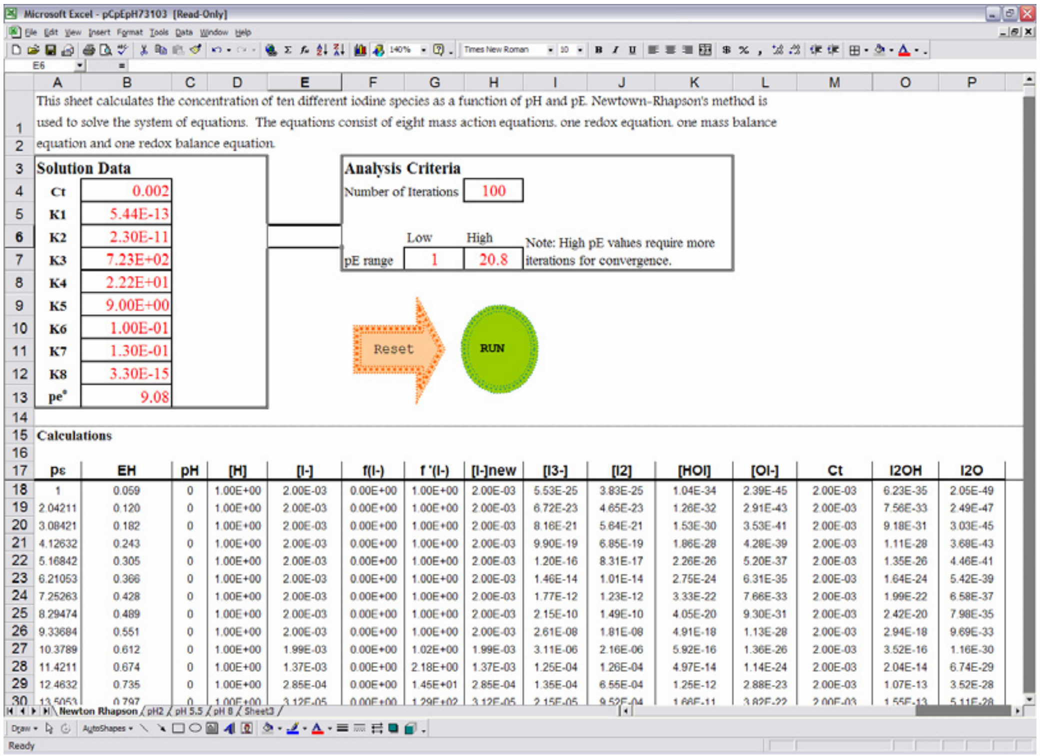


Figure 5. Iodine Speciation Model as a Function of pH and pε



pε	EH	pH	[H]	[I-]	f(I-)	f '(I-)	[I-]new	[I3-]	[I2]	[HOI]	[OI-]	Ct	I2OH	I2O
1	0.059	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	5.53E-25	3.83E-25	1.04E-34	2.39E-45	2.00E-03	6.23E-35	2.05E-49
2.04211	0.120	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	6.72E-23	4.65E-23	1.26E-32	2.91E-43	2.00E-03	7.56E-33	2.49E-47
3.08421	0.182	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	8.16E-21	5.64E-21	1.53E-30	3.53E-41	2.00E-03	9.18E-31	3.03E-45
4.12632	0.243	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	9.90E-19	6.85E-19	1.86E-28	4.28E-39	2.00E-03	1.11E-28	3.68E-43
5.16842	0.305	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	1.20E-16	8.31E-17	2.26E-26	5.20E-37	2.00E-03	1.35E-26	4.46E-41
6.21053	0.366	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	1.46E-14	1.01E-14	2.75E-24	6.31E-35	2.00E-03	1.64E-24	5.42E-39
7.25263	0.428	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	1.77E-12	1.23E-12	3.33E-22	7.66E-33	2.00E-03	1.99E-22	6.58E-37
8.29474	0.489	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	2.15E-10	1.49E-10	4.05E-20	9.30E-31	2.00E-03	2.42E-20	7.98E-35
9.33684	0.551	0	1.00E+00	2.00E-03	0.00E+00	1.00E+00	2.00E-03	2.61E-08	1.81E-08	4.91E-18	1.13E-28	2.00E-03	2.94E-18	9.69E-33
10.3789	0.612	0	1.00E+00	1.99E-03	0.00E+00	1.02E+00	1.99E-03	3.11E-06	2.16E-06	5.92E-16	1.36E-26	2.00E-03	3.52E-16	1.16E-30
11.4211	0.674	0	1.00E+00	1.37E-03	0.00E+00	2.18E+00	1.37E-03	1.25E-04	1.26E-04	4.97E-14	1.14E-24	2.00E-03	2.04E-14	6.74E-29
12.4632	0.735	0	1.00E+00	2.85E-04	0.00E+00	1.45E+01	2.85E-04	1.35E-04	6.55E-04	1.25E-12	2.88E-23	2.00E-03	1.07E-13	3.52E-28
13.5053	0.797	0	1.00E+00	3.12E-05	0.00E+00	1.29E+02	3.12E-05	2.15E-05	9.52E-04	1.66E-11	3.82E-22	2.00E-03	1.55E-13	5.11E-28

7.1 Food Safety and Processing Focus Area Executive Summary

In an ALS, the food subsystem must integrate with other subsystems. Researchers at Purdue and Alabama A&M Universities are addressing the energetics, safety, and other requirements for an ALS food subsystem for a NASA mission to Mars. Three major research areas are ongoing to meet these needs. The first area focuses on development of a phage display assay for the multiplexed detection of pathogens in potable water and food. The goal of this research is to harness the power of bacterial phage display to develop a biological amplifier for the detection of small numbers of pathogenic organisms in potable water and foods. The second research area focuses on optimizing food safety through development of an integrated HACCP (hazard analysis and critical control points) system for both food safety and non-food safety personnel. Sampling plans at each point in processing and packaging will be developed. Monitoring, critical limits, and corrective actions for problematic microorganisms will be defined. The third research area focuses on defining and minimizing ESM (equivalent system mass) requirements of the food system while maintaining safety, quality, and nutrition in the food supply.

Bruce Applegate, Group Leader
Food Safety and Processing Focus Area

7.2 *Project Title:* ***Bioamplification using phage display for the multiplexed detection of pathogens in potable water and food.***

Investigators: Bruce Applegate (PI), Department of Food Science, Purdue University; Michael R. Ladisch (Co-PI), Department of Agricultural & Biological Engineering , Purdue University

Significance of Project to ALS:

This technology platform can be integrated with antibody-based assays coupled with impedance based spectroscopy, biochips, fluorescence microscopy, and enzyme-linked immuno-assays (ELISA's) which address the diverse earthbound needs of detection methods for food and waterborne pathogens. However these technologies can require significant equipment expense and mass. Therefore collaborating with Lisa Mauer we propose to develop a test strip format which will provide low mass and multiplexed detection of a variety of pathogens to be utilized for direct testing of potable water and food for both coliforms and pathogens. The test strip will be utilized as a stand-alone kit to test potable water or in an integrated food packaging format, which will allow the testing of foods prior to their removal from the package. This technology will also be coordinated into HACCP plans developed by Leonard Williams at Alabama A&M. The integration of the phage bioamplification step with ELISA's will provide a sensitive and low mass approach to both water and food safety.

Project Goals and Objectives:

The goal of this research is to harness the power of bacterial phage display to develop a biological amplifier for the detection of small numbers of pathogenic organisms in potable water and foods. The research will generate and purify phages that are designed to selectively detect water and foodborne pathogens. Using specially designed markers that are inserted into the DNA of the phage, the expression of the phage can be tuned to reflect the presence (or absence) of the target cell as well as give a measure of concentration and type of cells in a given sample. Proteins displayed on the outside of the phages can be used as "handles" to distinguish one type of phage from another, much like a license plate will identify one car from another, even if the cars are alike in every way except for the owner. Since the protein is displayed on the outer surface of the phage and since it reflects a special characteristic of the DNA contained inside the phage particle, this is referred to as phage display. The proposed project combines the knowledge and experiences of fundamental molecular biology of phages and applies this knowledge to existing technologies in both the molecular construction and detection of the modified bacteriophages. The fundamental hypothesis of this research is: Bacteriophage can be genetically modified using recombinant DNA technology to produce an antigenic peptide which is only expressed in progeny phage after infection of a specific viable pathogenic organism.

The hypothesis will be tested by addressing the following objectives:

1. Genetically modify and propagate modified bacteriophages for the detection of viable pathogens.
2. Recover and purify modified bacteriophages using affinity chromatography.
3. Develop an assay using the modified bacteriophages to detect pathogenic organisms in potable water and food using an ELISA format.
4. Integrate the developed bacteriophage assay into novel food packaging materials.

Research Progress:

Research has begun on objective one in the above section, the genetic modification of the relevant bacteriophage. Modified bacteriophages for the detection of *E. coli* O157:H7 and *Salmonella spp.* are currently being constructed for the detection platform. Details of the progress are described below:

Salmonella spp bacteriophage: To facilitate the construction of a modified P22 bacteriophage for *Salmonella spp.* it was necessary to construct a recombination vector for insertion of a modified tail spike protein. The vector was modified from a previously constructed vector pTP369 (Casjens et al). Plasmid pTP369 contains a 2558 bp region of the P22 genome corresponding to the region containing gene 23 (antitermination protein), gene 13 (lysis protein), gene 19 (lysozyme) gene 15 (lysis control), orf 201 (unknown protein) and orf 80 (unknown protein). The recombination vector was constructed by removing approximately 1 kb of the P22 genome in the region of orf 201 and orf 80 to allow the insertion of DNA for recombination. A multicloning site and a TA cloning site were inserted to facilitate rapid insertion of modified DNA to construct the appropriate epitope.

E. coli O157:H7 bacteriophage*:* Phage based detection of *E. coli* O157:H7 will be accomplished using phage ϕV10. *Bacteriophage* ϕV10 was originally isolated by R. Khakhria and has been shown to specically infect many strains of *E.coli* O157:H7. It has a genome of approximately 42 kb and classified as a temperate phage (can form lysogens). The phage was obtained from Dr. Rafiq Ahmed at the National Laboratory for Enteric Pathogens in Winnipeg Canada. Total DNA has been isolated from the phage and currently we are generating a genomic library for sequencing the entire phage genome. The sequence data will allow a more deliberate construction of the recombinant phage avoiding the use of transposon mutagenesis.

To further evaluate the specificity of ϕV10 a previously characterized library from pathogenic *E. coli* outbreaks responsible for disease was screened for ϕV10 susceptability. Environmental isolates were also screened to provide evaluation of false positives. The assay consists of a simple plaque assay using a previously prepared phage solution with a titer of approximately 2×10^{-3} plaque forming units per mL. Approximately .5ml portions of top agar in capped test tubes were prepared and kept in an isotemp water bath at 50º C. Approximately 100µL of the phage was added to the tube immediately followed by the addition of 200 µL of bacterial test suspension, mixed then the contents of the tube were poured on LB agar plates. Plates were incubated overnight at 37ºC and examined for plaque formation. Results of the assay are shown in Table 1.

Research Collaboration:

Dr. Applegate in collaboration with Dr. Rafiq Ahmed at the National Laboratory for Enteric Pathogens (Winnipeg, CA) are currently sequencing the genome of the *E. coli* O157:H7 bacteriophage *phiV10*. Project should be completed by the end of 2003. Dr. Applegate is also collaborating with Dr. Len Peruski at the Indiana Medical School in Gary Indiana on development of a *Bacillus anthracis* bacteriophage using this detection format.

Table 1. Results of *E. coli* bacteriophage ϕV10 plaque assay.

***E. coli* Isolates (serotypes)**	**plaque forming**	**non-plaque forming**	**total number of isolates tested**
O157:H7	288	79*	367
O157:NM	0	2	2
O157:H16	0	1	1
O111:H11	0	1	1
O111:H8	0	3	3
O5:NM	0	1	1
O46:H38	0	1	1
O91:H21	0	1	1
O118:H38	0	1	1
OR:H7	0	1	1
ATCC 11775	0	1	1
O26:H11	1	3	4
O113:H21	0	1	1
O22:H8	0	1	1
O29:NM	0	1	1
O103:H2	0	1	1
O5:NM	0	1	1
non-O157 type E. coli	0	47	47
Hafnia alvei	0	4	4
Total	**289**	**151**	**440**

*** Includes no growth and contaminants. All 79 are being reevaluated.**

Future Directions of the Research:
In 2004 the laboratory will begin work the development of a modified *Listeria monocytogenes* bacteriophage detection platform.

Trainees Involved in the Study:

Graduate Students: Udit Minocha (Ph.D. Student)
Undergraduate Student: Amanda Lewis
NSCORT Summer Fellowship Undergraduate Student: Rachael Jennings (Howard University)

Publications and Oral/Poster Presentations (in addition to presentations at local NSCORT meetings) :

1. L.J. Mauer and B.M. Applegate. 2002. Space needs, Earth applications. Industrial Associates Semi-Annual Meeting. Purdue University, West Lafayette, IN. May 8-9.
2. L.J. Mauer and B.M. Applegate. 2002. Space Needs, Earth Applications. Indiana Section Institute of Food Technologists Meeting. Lafayette, IN. October 16.

7.3 Project Title: Novel Food Processing and Packaging Operations

Investigators: Lisa Mauer, ***Assistant Professor of Food Science***
Department of Food Science, Purdue University

Significance of Project to ALS:

In addition to a pre-packaged food supply, the ALS NSCORT proposes to utilize crops to provide food and oxygen for astronauts during long-term space missions beyond low earth orbit. Research is required to better understand the ability to convert edible biomass into safe, nutritious, and acceptable food products in a closed system with many restrictions (mass, volume, power, crew time, etc.).

Project Goals and Objectives:

As presented in the original NSCORT proposal, the objectives for this project are to:

1. Utilize biomass produced by Purdue and AAMU researchers to produce food products and ingredients and generate solid and liquid wastes from food processing and packaging operations. All mass, energy, and ESM data will be provided to the systems analysts.
2. Define, model, then minimize ESM for unit operations used in food production
3. Measure food acceptability, proximate or key nutrient composition, and select functional properties of products and ingredients produced in objectives 1 and 2.
4. Define, model, then minimize ESM and residual waste for packaging systems used for foods.
5. Develop an integrated package-safety indicator system for extended shelf-life foods incorporating biosensor technology with Dr. Applegate in years 3-5.

Research Progress:

In the first year of the NASA-NSCORT program, we have begun research projects that address parts of objectives 1-3 presented in the original proposal. A summary of each research project follows:

1. *Equivalent system mass (ESM), shelf-life, and acceptability of wheat products to meet NASA requirements for extended space travel*.
   The significance of this project is based on the knowledge that wheat products provide the majority of carbohydrates in the western diet. During space travel, the body and mind undergo extreme stress. These conditions are exacerbated during extended space travel. Thus it is important to provide foods that are familiar, "comforting," and nutritious, while maintaining safety and sensory characteristics. Previous research has indicated that the chemical composition of hydroponically grown crops is different from soil grown crops. Anti-nutritional compounds such as nitrites from the hydroponic solution have been shown to accumulate in these crops. This is of great importance because NASA has proposed growing crops utilizing this type of technology. Effect of different growth mediums on functional characteristics of wheat has not been examined and will allow NASA to better determine possible wheat supply scenarios. The objectives for this project are to:
   a. Calculate and compare the ESM parameters for yeast and flat bread systems. This work was presented at the 2003 ICES and IFT meetings. Work will be completed in September 2003.
   b. Compare chemical composition and processing functionality of hydroponic and soil grown wheat. Dr. Bruce Bugbee from Utah State University has agreed to supply both Apogee and Perigee wheats grown in the field and hydroponically. Initial

analyses will begin in October 2003, and work will be completed in May 2004. We hope to present this study at the 2004 ICES meeting.

c. Investigate ESM for other wheat products (beginning with pasta) as time permits. An undergraduate student has begun working with pasta.

d. Initiate a 4 or 5-year shelf life storage study of wheat. An undergraduate student has begun planning for this study.

2. *Oil production scenarios for long term space missions.*

The significance of this project is related to the limited shelf-life of oils (especially when exposed to radiation) and how the chemical composition and physical properties of edible oils are influenced by growing conditions and production processes. Of the candidate ALS crops, only two provide quantities of oil high enough to consider for separation: the legumes peanuts and soybeans. In space, these two legumes will likely be mechanically pressed to extract the oil. Further steps for refinement may be restricted due to the limitations of an ALS system. This develops concerns regarding the characteristics of the obtained products. Shelf-life as well as use-life are critical parameters for all food products including oils. Properties such as oxidative stability, heat sensitivity, viscosity, color, and flavor affect the acceptability of the extracted oils. Commercially produced oils undergo several refinement steps to ensure quality and stability of the oil. In space missions, where the power, volume and mass are restricted, refinement steps will be limited. Such practices will likely affect the quality of the obtained oil. This project will investigate the various properties of oils extracted from peanuts and soybeans using simple machinery with low ESM values. Elementary refinement practices will be applied. Further comparison with refined peanut oils as well as soybean oils will be done to assess the quality and stability. Soybeans (Hoyt) and peanuts (Red Georgia) were planted during the first week of August 2003. The first harvest is expected to be during the last weeks of October 2003. Other varieties of the legumes have been located and will be included in the investigation.

3. *Food processing equipment and equivalent system mass (ESM).*

An ALS system that will enable long duration missions must include a food processing subsystem able to produce edible ingredients and products from re-supply ingredients and crops grown on shuttle or on planetary surfaces. However, designing, building, developing, and maintaining such a subsystem is bound to many constraints and restrictions. Limited power supply, storage locations, working space, restricted crops, and crew time influence the processing equipment and techniques. Furthermore, reduced gravity will affect the behavior of fluids and heat transfer involved in food processing. In order to direct NASA's research and technology efforts in the area of advanced food, the technologies available on Earth for food processing, preserving, and packaging must be identified and the viability of these technologies must be assessed. Minimizing mass, volume, and energy consumption are important factors to be considered when locating Earth food technologies and equipment to be used in an ALS. In addition, the feasibility to modify and develop multi-functional equipment must be evaluated. The food subsystem must allow minimal astronaut involvement. Reducing waste and biomass resulting from processing is desirable. Ensuring food safety and controlling the growth of bacteria and pathogens are as well critical aspects of the food subsystem. The objective of the study is to locate available food processing technologies and equipment, and calculate their respective Equivalent System Mass (ESM) based on mass, volume, power, and cooling. The data will be compiled into a spreadsheet. ESM values are also affected by the number of applications the equipment can perform, as well as the crew time required to operate it. For the purpose of simplification, each piece of equipment will be assumed to perform a single task in the initial analysis, the power required for cooling set equivalent to the power needed to operate the technology, and the crew time will not be considered for preliminary assessment. As of September, 2003, data for 236 technologies used for food processing were collected. These include: hand mixers, stand mixers, food processors, blenders, bread machines, convection ovens, griddles, grills, and juice extractors. ESM values for different missions were calculated based on manufacturer's specifications: shipping mass (weight), shipping volume, and input power consumption. We hope to present this study at the 2004 ICES meeting.

Research Collaboration:

In addition to Drs. Applegate, Mitchell, and Williams in the NASA-NSCORT project, we have initiated collaborations with Dr. Michele Perchonok at Johnson Space Center related to the food system modeling and development and Dr. Bruce Bugbee at Utah State University related to wheat varieties he has developed for NASA (Apogee and Perigee).

Future Directions of the Research:

Work will continue through 2004 on the 3 projects identified. Additionally, an undergraduate student has begun compiling data related to the current food packaging system used and other possible packaging systems available and will continue this work through 2004.

Trainees Involved in the Study:

Graduate Students: Ilan Weiss, M.S. student

Undergraduate Students: Jake Gandolph (Aug. 2003 – present)
Patrick Getts (Aug. 2003 – present)
Dina Romano (Jan. 2003 – present)
Sri Budiarty (Aug. 2003 – present)

NSCORT Summer Fellowship Undergraduate Student: Deidra Carr (Howard University)

Publications and Oral/Poster Presentations (in addition to presentations at local NSCORT meetings) :

3. Weiss, I. B.F. Ozen, M. Perchonok, K.D. Hayes, and L.J. Mauer. 2003. Comparison of Equivalent System Mass (ESM) of Yeast and Flat Bread Systems. Proceedings of the SAE International Meeting, Vancouver, BC, Canada July 7-10.
4. I. Weiss, K.D. Hayes, M. Perchonok, and L.J. Mauer. 2003. Comparison of equivalent system mass (ESM) and food metric value (FMV) of yeast and flat bread systems. Institute of Food Technologists' Annual Meeting and Food Expo. July 12-16, Chicago, IL.
5. L.J. Mauer and B.M. Applegate. 2002. Space needs, Earth applications. Industrial Associates Semi-Annual Meeting. Purdue University, West Lafayette, IN. May 8-9.
6. L.J. Mauer and B.M. Applegate. 2002. Space Needs, Earth Applications. Indiana Section Institute of Food Technologists Meeting. Lafayette, IN. October 16.
7. L.J. Mauer. 2003. "Mars, Food, and Agriculture". Council for Agricultural Science and Technology VIP Day, Purdue University, West Lafayette, IN, January 17.

7.4 Title: Efficacy of Sodium Hypochlorite and Hydrogen Peroxide for Inactivating *Listeria monocytogenes* on Carrot Seeds.

Principal Investigator: Leonard L. Williams, Ph.D.

Organization: Alabama A&M University

Significance

Outbreaks of food borne illnesses associated with the consumption of fresh fruit and vegetables have occurred more frequently in recent years in the United States (Park and Beuchat, 1999). Salad crops (lettuce, tomatoes, carrots, potatoes, etc.) are considered to highly susceptible to microbial contamination because of microbial cross-contamination through shredders and slicers (Garg et al., 1990) and through the exposure of inner tissues to microbial attachment and growth after post-harvest preparation.

Currently, the National Aeronautic Space Administration (NASA) has identified specific salad crops to serve as baselines for guiding the Advance Life Support Program. Each salad crop that is identified for space and planetary food system must be free of harmful bacteria. Therefore, fundamental and feasible studies are needed to examine the efficacy of disinfectant on the reduction of pathogenic and spoilage bacteria in these salad crops.

Chemical agents such as chlorine dioxide (Zhang and Farber, 1996), organic acids (Adam et al., 1989), trisodium phosphate (Zhang and Farber, 1996) and several other agents have all been studied as potential disinfectants of fresh-cut vegetables. Sodium hypochlorite with a maximum concentration of 2000 ppm is only chemical agent currently allowed by federal regulations for washing fruit and vegetables (FDA, 1996). Currently, chlorinated water is widely used for reducing bacterial contamination on whole fruits, vegetables and fresh-cut produces on the commercial processing (Beuchat et al., 1988). A problem with use of chlorine treatment is that a buildup of organic acid materials in wash water inactivates chlorine rapidly; therefore, more reliable agents such as hydrogen peroxide are being investigated.

Because there are many steps in which microbial contamination can occur, it's vital to understand and determine the efficacy of disinfectants on reduction of pathogenic and spoilage microorganisms in salad crops. In addition, hazards analysis critical control point plans are needed to address potential hazards that may exist pre-harvest.

Project Goals and Objectives:

The overall goal of this project is to conduct a hazard analysis and identify critical control points (CCPs) at which *L. monocytogenes* can be eliminated on carrot seeds at (pre-harvest). To accomplish this goal, several objectives were established to determine the efficacy of sodium hypochlorite, hydrogen peroxide and heat treatment in the reduction of *Listeria monocytogenes* inoculated onto carrot seeds. Secondly, determine the viability and behavior of *L. monocytogenes* on dry seeds as affected by storage temperatures.

Research Progress

No *Listeria monocytogenes* was detected in uninoculated carrot seeds. Population of *L. monocytogenes* in the two suspensions used to dip seeds were 322 and 275 cfu/ml at 0 and 7 days of incubation. The *L. monocytogenes* population gradually decreased as the holding time at refrigeration and room temperature increased from 0 to 21 days. Compared with dipping seeds in water at 21° C (control), dipping seeds in water at 54 and 60° C for 5 min did not substantially reduce the percentage of seeds sprouting after 3 days at 30° C. However, treatments at 54 and 60° C for 10 min did reduce sprouting percentage from 50% (control) to 40 and 30% respectively. Treatment of seeds at 66 and 70° C for 5 min reduced sprouting to 30 and 40% respectively, while treatments at the same temperatures for 10 mins reduced sprouting to 30 and 20% respectively. With scanning electron microscopy, bacterial biofilm, an adhesive threadlike substance surrounding the bacterial cells, was observed on the inoculated carrot seeds after 7 and 21 day storage at 8 and 21°C. No biofilm was observed on the uninoculated carrot seeds (control). This study showed that treatment of carrot seeds contaminated with *Listeria monocytogenes* using chlorine and hydrogen peroxide up to 300 μg/mL and 0.5% may be effective in inactivation of *L. monocytogenes*. Treatment in hot water is lethal to *L. monocytogenes*, but may reduce the sprouting of seeds, thus would not be practical in commercial setting. Treatment of carrot seeds with 300 μg/mL to 2000 ug/mL of chlorine and 0.5% or higher of hydrogen peroxide substantially reduced the population of *L. monocytogenes*. Therefore, we suggested a 300 μg/mL of chlorine and 0.5% hydrogen peroxide soak for 5 min and 2 min, respectively, be used as a method to significantly reduce populations of *L. monocytogenes*, and possibly other pathogenic organisms, while not affecting sprouting.

Research Collaboration

Collaboration on this project was conducted with Drs. Caula Beyl and Alan Zipf in the plant pathology laboratory at Alabama A&M University. All seeds were geminated and sprouted using growth chambers provided by their labs.

Future Directions

Research will continue in the area(s) of conducting hazard analysis and critical control points at both pre and post harvest of salad crops. Several commercial disinfectants, including filtrates from Shitake mushrooms will be used to examine the reduction of pathogenic and spoilage bacteria on salad crops at different stages of development (i.e., germination, sprouting, etc.). In addition, we plan to examine the microbial biota of gray water supplied by the crop and water group. Finally, determining the hazard analysis of salad crops grown in gray water and recycled gray water, is another future prospect in our lab.

Trainees Involved in Study

Currently, one graduate student has been selected to conduct his M.S. Thesis on this ALS project. Also, two undergraduates are currently assisting and conducting studies as well. Therefore, a total of 3 students are currently being impacted by the NASA-ALS funded NSCORT project.

Publications and Presentations

One summer apprentice student from Purdue University presented her preliminary findings at the Annual NASA/NSCORT Summer Research Symposium on July 27-29, 2003.

References

Adam, M.R., Hartey A.D., Cox L.J. 1989. Factors affecting the efficacy of washing procedures used in the production of prepared salads. Food Microbiol. 6:69-97.

Beuchat L.R., Nail B.V., Adler B.B., Clavero M.R.S. 1988. Efficacy of spray application of chlorinated water in killing pathogenic bacteria on raw apples, tomatoes, and lettuce. J. Food Prot. 61:1305-11.

FDA. 1996. United States Code of Federal Regulations. Title 21, chapter 21, part 173, secondary direct food additives permitted in food for human consumption: section 173.315. U.S. Food and Drug Administration, Dept. of Health and Human Services, Washington, D.C.

Garg, N. Churey J.J., Splittstoesser D.R. 1990. Effect of processing conditions on the microflora of fresh-cut vegetables. J. Food Prot. 53:701.

Park, C.M. and Beuchat L.R. 1999. Evaluation of sanitizers for killing *E. coli* O157:H7, Salmonella, and naturally occurring microorganisms on cantaloupes, honeydew melons, and asparagus. Dairy Food Environ. Sanit. 19:842-7.

Zhang S. and Farber J.M. 1996. The effect of various disinfectants against *Listeria monocytogenes* on fresh-cut vegetables. Food Microbiol. 13:311-21.

8.1 Edible-Biomass/Crop-Production Focus Area
Executive Summary

Early crewed missions back to the moon and on to Mars will be like “camping trips” in which processed food will be transported in forms that can be stored without refrigeration for periods of time exceeding nominal mission length. Some salad greens and vegetables may be grown on site during early missions for dietary augmentation and to satisfy crew psychological needs. As mission duration and crew size increase, and as available power and energy issues are resolved, reliance upon photosynthetic organisms will have to increase for both dietary and air-revitalization purposes. The ALS NSCORT captures the spirit of both early and later advanced life-support scenarios in its suite of research projects involving edible biomass production.

One such project emphasizes production of wood-rotting fungi whose fruiting bodies are exotic, edible mushrooms. Mushrooms contribute vitamins, minerals, and interest to the human diet. Can the hydrolytic enzymes of fungal mycelia reduce the oxygen requirement external to the crew for breaking down biomass that is not digestible or safe for direct human consumption by converting it first to alternative food sources? In addressing that question, the fungal/mushroom research project bridges solid-waste treatment and edible-biomass production focus areas.

Fungal pretreatment also may enhance the digestibility of ligno-cellulosic biomass by certain fresh-water fish that already have some capability to do this by enzymatic and acid hydrolysis within their own digestive tract. If such fish can be grown to a functional harvest size while being fed mainly fungal-pretreated crop residues that humans cannot digest directly, crew diets could be supplemented with protein and essential fatty acids from an animal source. Both bridging projects of the NSCORT have potential to demonstrate production of edible biomass while degrading recalcitrant crop waste.

As ALS crew habitats progressively achieve higher degrees of mass closure, photosynthetic sources of edible biomass for on-site food processing gradually will replace food prepared on Earth. However, ALS has temporarily suspended funding of new plant projects pending resolution of power and energy issues surrounding crop production as the main source of food and oxygen for human consumption. The ALS NSCORT crop-production project directly addresses the specific issue that prevents early life-support scenarios from involving substantial mass closure and production of crops for a mainly vegetarian diet. Planetary surface dangers and environmental limitations preclude reliance upon solar energy to consistently energize life support on both Luna and Mars, which further exacerbates the operational energy dilemma. Energetic penalties of crop quantum inefficiency as well as for heat rejection related to traditional controlled environment crop growth and for condensation of transpired water vapor account for the majority of energy costs in closed systems. The NSCORT crop-production project aims to significantly reduce these cropping penalties by taking a non-traditional approach to light distribution requiring significantly lower electrical power input than do traditional lighting systems.

Cary A. Mitchell, Group Leader
Crop Focus Area

8.2 Project Title: Minimizing Equivalent System Mass for Crop Production in an Advanced Life-Support System

Principal Investigator: Cary A. Mitchell

Principal Collaborator: George T-C. Chiu

Significance of project to ALS. The NSCORT crop-production project directly addresses the most important issue that NASA has with use of higher plants for regenerative human life support at distant planetary destinations. The issue relates to energy and power costs of providing adequate lighting for densely planted food crops. For a variety of reasons, it appears that the sun will not be a consistently reliable source of energy for life support on Luna or Mars, (McKay, 2002), so artificial plant-growth lighting, probably generated underground, likely will be energized by portable nuclear-power generators. Even then, power availability for crop growth will not be unlimited. What's worse, conventional lamps are very inefficient converters of electrical energy to photon energy; furthermore, dense crop stands quickly close with respect to overhead light penetration, blocking access of lower leaves to photons incident at the top of the canopy; worse yet, the quantum efficiency of absorbing and converting the energy of incident photons is extremely low; and lastly, waste heat generated by high-intensity discharge lamps and ballasts must be actively rejected from the system.

Because of inefficient energy transduction at several levels, calculated energy expenditure for crop lighting using traditional lamps and methods of light distribution is enormous and accounts for most of the projected energy needs for a space-deployed ALS (Mitchell et al., 1996). This is why NASA presently views early-generation, crewed exploration missions to Mars more as "camping trips" using stored, processed food rather than as self-sufficient, independent bases where fresh food will be grown. NASA awaits the development of crop-production technologies that will make on-site food generation competitive with storage and/or re-supply scenarios in trade-off analyses.

Project Goals and Objectives. The objective of the ALS NSCORT crop-production project is to develop and test a new paradigm of crop lighting with promise for significantly improving lighting efficiency. If successful, this project should bring higher plants back into focus as sources of fresh food and oxygen for long duration space exploration missions.

Background. Overhead-lighted stands of cowpea become very limited in productivity and yield once the foliar canopy "closes" with respect to light penetration (Ohler and Mitchell, 1995). Lower leaves senesce and abscise prematurely; flowers and juvenile pods abort; and photosynthesis in lower leaves ceases. However, allowing cowpea stands to grow around fixed arrays of low-power fluorescent lamps sustained the productivity of inner-canopy leaves (Frantz et al., 1998; 2000; 2001). Such "intracanopy-lighted" crop stands have been measured to be half as productive as those lit overhead with bright light, using only one-tenth as much electrical energy (Frantz et al., 1998). The bulk of suspended fluorescent lamps within the headspace of test compartments precluded the possibility of further increasing interior light without displacing crop volume. However, these cowpea studies established proof of concept that intracanopy lighting is considerably more efficient than overhead lighting for sustaining the photosynthetic productivity of planophile crops (plants that present leaves perpendicular to the plane of incident light). What is needed is a light-emission source that not only occupies minimal volume within crop stands to allow maximal plant occupation, but also has light emitters cool enough to prevent scorching of contacted plant tissues.

A variety of crops have successfully been grown under narrow-spectrum light-emitting diodes (LEDs) using overhead irradiation and maximizing photon flux from planar banks (Brown et al., 1995; Bula et al., 1991; Goins et al., 1997; 1998; Hoenecke et al., 1992; Ono et al., 1998; Tennessen et al., 1994). LEDs are attractive for artificial lighting of plants grown in space for several reasons: emitters are extremely long-lived at ~100,000 hours, they are light-weight, shock-resistant, and emit at specified wavelengths. Combining the intracanopy light-distribution approach with LED technology would appear to provide a powerful approach to crop lighting that combines the best of both while eliminating many shortcomings of traditional crop lighting in controlled environments.

Research Progress. The NSCORT crop-production group is developing a new lighting technology optimized for low electrical power utilization that will distribute light uniformly to all leaves within a crop stand, will emit only photons near peak wavelength absorption of the major photosynthetic pigments, will minimize waste-heat burden on the system, and will avoid emitting photons in spaces not populated by photosynthetic tissue.

Two analogous types of LED lighting-system arrays will be developed: Intracanopy (IC), vertical strips, or "lightsicles", and Close-Canopy (CC), "bulls-eye" horizontal plates. Both lighting systems will utilize novel LED-switching approaches to keep pace with changes in crop height (IC) or crop spread (CC).

LED Strip Concept. The LED strip concept was inspired by the "Pathlight" technology of LEDTronics Corp. (Torrance, CA), in which discrete LEDs are crimp soldered to one side of a flexible plastic strip. For intracanopy lighting, many short strips populated densely with LEDs would be hanged vertically from the top of a growth chamber, and as a crop stand grows in height, the strips would switch on from the bottom up. Test strips custom-manufactured for the PI by LEDTronics emitted 275-350 $\mu mol/m^2/s$ of photosynthetically active radiation (400 to 700 nm) from red, white, and blue LEDs at the emitter, but PPF dropped precipitously with linear distance away from the emitter. Because LEDs were spaced 1-inch apart on the strips and the emitter capsules had a 17-degree emission angle, a 4-inch spatial separation was required to achieve overlap of emissions from adjacent LEDs, at which distance PPF had decayed to an insignificant level. Both from the perspective of spectral blending as well as intensity, the density of LED's needs to be increased.

To avoid such shortcomings, we recently shifted preference away from large, discrete LEDs to tiny LEDs arrayed densely in multiple, closely spaced, parallel rows along a rigid strip. The Norlux Corporation (Carol Stream, IL) has clustered printed-circuit patterns of conductive traces on thin, composite wafers, from which it arrays the wafers in different patterns. The Orbital Technologies (Orbitec) Corporation (Madison, WI) has adapted Norlux's "Chip-on-Board" technology into wafers with LEDs in closely spaced, parallel rows. Rectangular panels of LEDs consisting of a composite of these wafers have been developed by Orbitec for plant lighting in NASA's Space Station Plant Research Unit (PRU). Individual 1 in^2 wafers contain 132 LEDs arrayed in nine parallel rows of different-colored LEDs. The NSCORT crop-production group and Orbitec feel that the PRU wafer design can be reconfigured into linear strips. Accordingly, the NSCORT and Orbitec are moving toward a research collaborative agreement in which Norlux will manufacture wafers modified from Orbitec's design, substituting different LED colors within certain rows according to NSCORT specifications.

Computer controls are being developed to uniformly switch on LED wafers one-by-one from the bottom up along each LED strip hanging within a growth compartment. Controls will be developed to synchronize signals to each channel on drivers downstream from each power supply to accommodate the variable numbers of LED light strips to be tested within each of the four growth compartments. Automatic switching on of wafers along vertical strips to keep pace with increasing crop stand height will involve photoelectric cells mounted along the median edges of each wafer, which will send signals involving switching decisions to a control computer located outside the growth chamber. Intensity and hue of blended colors coming off the strips will be controlled by separately varying current through red and blue LEDs in parallel rows. Planophile crops to be tested for growth, productivity, and yield responses to IC LED lighting include cowpea, soybean, peanut, basil, and sweetpotato. Intensity will be used to vary photosynthesis and regulate senescence, while hue will be used to control height, stomatal aperture, tropisms, and onset of reproductive development. Fig. 1 shows a schematic of an IC LED array.

The first generation of LED arrays received from Norlux for testing were hexagonal wafers containing 30 each red, blue, and green LEDs clustered separately from other colors on the wafer. Effects of variable current on PPF at incremental distances from the color cluster, as well as LED and heat-sink temperatures (data not shown), were measured for each color LED cluster on the hexagonal wafers (Fig. 2 and 3). PPF at the emitter surface was well above the light-compensation point of photosynthesis at all current levels tested, but decayed exponentially with linear distance away from each LED cluster, which performed like a point source of light. PPF decayed to levels below light compensation within 5 cm from the source, for all currents tested. Thermocouple measurements of the LED surfaces, as well as of heat sinks mounted behind the wafers, indicated that temperature did not increase more than 2 to 3° C above ambient air temperature. Spectroradiometeric scans validated the spectral purity of each colored LED cluster (Table 1). These tests indicate that LED strips could be operated at low electrical power, but plant tissues would have to be close to the strips. Although strip density is an anticipated variable for future growth tests with ALS candidate crop species, previous experience lighting the interior of cowpea stands indicates that plants will grow toward the brightest source of light perceived, so they may naturally compromise in our quest to find a balance between adequate light distribution and avoidance of excess heat.

Cultural Optimization. In addition to pursuing a critical-path need of the ALS Program Element, the NSCORT Crop-Production Group is growing a variety of ALS-relevant crop species on a larger scale under the semi-controlled-environment conditions of a greenhouse (Fig. 4). This allows sufficient production of edible and non-edible crop biomass to pass along to other focus-area researchers in the Center who need sources of ALS crop biomass for their experiments. As controlled-environment, hydroponic crop-production experiments with LEDs ramp up, smaller-scale samples will be generated for analysis by the air/water-quality group. While producing useful biomass and by-products for other groups, the Crop-Production Group is engaged in cultural experiments with those crops as well, to improve the quality and quantity of edible harvest while minimizing non-edible biomass production. Among the projects progressing include evaluation of an ever-bearing peanut cropping protocol; comparing vegetative vs. reproductive vs. mixed harvest of the versatile cowpea as a salad vegetable, snap bean, and/or dry-bean crop; and determining optimum root-zone volume and root/shoot ratio for sweetpotato yield without producing copious non-edible biomass.

Technology & Facilities Development. A partnership is being developed between NSCORT and Orbitec. Orbitec has agreed to let NSCORT reconfigure their die design into linear rather than planar arrays for intracanopy strip lighting. Individual wafers of the first-generation linear arrays will have fewer rows densely populated with LEDs than for the Orbitec design, and will include only red and blue emitters. Computer controls will be developed for sequential switching of all LEDs on a wafer so that inner-canopy volume among plants in a stand is lighted while empty headspace is not.

Four 32 x 25 x 40 inch test compartments have been constructed on a metal table within a 100 ft^2 walk-in growth chamber. Compartment walls are lined with a white, light-diffusing plastic film to reflect back light that escapes the edges of the canopy. A recirculating, deep-batch hydroponics unit has been constructed within each compartment, consisting of a reservoir and pump below the table and a multi-plant container on the table (Fig. 5). Each compartment will constitute an experimental unit, permitting four different lighting treatments to be tested for performance simultaneously. The growth chambers themselves are Environmental Growth Chamber (EGC) model M11-75 walk-in growth rooms that have been renovated for touch-screen, Window's-based, computer controls. The growth chamber not only will house four crop-growth test compartments, but will provide temperature, humidity, and CO_2 controls for all test compartments. As well, exhaust fans and access ports have been added to the renovated growth chambers to prevent ethylene accumulation and allow access of wiring into the chamber, respectively.

Research Collaborations. The primary collaboration is between the PI's lab and Dr. George Chiu in the Department of Mechanical Engineering at Purdue University. Dr. Chiu also is a member of the NSCORT Systems Analysis group. Dr. Chiu's laboratory is emphasizing computer controls for the IC and CC LED lighting systems, as well as outfitting the growth-chamber system for automation of lighting and hydroponic culture controls and monitoring.

The Orbitec Company will collaborate with the NSCORT crop-production group in developing first-generation LED lighting systems utilizing their die designs and control software modified in configuration from their PRU project.

The Norlux Corporation will subcontract manufacture of the LED wafers and design the dies for future IC and CC LED arrays as the project evolves based on results of crop testing and performance.

The Tuskeege University NASA Center is providing germplasm for ALS-relevant selections of sweetpotato. The NSCORT will assist Tuskeege in extending the range of cultural optimization protocols for both sweetpotato and peanut.

The NSCORT crop-production group is providing edible and non-edible crop biomass to other groups within the NSCORT for analysis or testing. Those groups include food technology, solid waste management, exotic mushroom production, and Tilapia production. In addition, hydroponic nutrient solutions and air samples from crop-growth chambers will be made available to the water and air-quality laboratories.

Future Directions of the Research. As soon as the first-generation strip arrays are received from Norlux through Orbitec, ALS-relevant, planophile crops will be grown in the test compartments as a function of 3 dimensional light distribution, intensity, and hue. During production, leaf temperature will be measured, as will the light profile throughout the canopy. Leaf and stem tropisms in response to lateral lighting will be captured by digital photography. Immediately following crop harvest, total biomass will be collected and divided into edible and non-edible portions. Partitioning of fresh and dry weight between edible and non-edible biomass, harvest index, yield rate, and total electrical energy consumed by IC-LED strips during crop production will be determined.

While LED intracanopy lighting is being tested with planophile ALS crop species, LED Close-Canopy technology also will be developed for ALS erectophile crop species. Close-Canopy lighting will involve planar arrays maintained close above crop stands, operated at low power, and programmed to switch on in concentric rings centered on individual, regularly spaced plants, keeping pace with the lateral spread of their growth. For both IC and CC lighting technologies, photodiodes will be mounted on arrays to automatically switch on the next step of arrays as plant tissues occupy new vertical distance or horizontal area.

A second EGC walk-in growth room identical to the first has been similarly renovated for the LED-IC and CC project. Four whole canopy cuvettes identical in dimensions to the previous growth compartments will be constructed from plexiglass and outfitted for temperature control, air mixing, and dynamic gas-exchange analysis for CO_2 and H_2O_v. IC strips or a CC plate will be installed within each cuvette and real-time photosynthetic rates will be measured for small crop stands as a function of the same experimental treatments as previously tested. Gas exchange will be monitored continuously throughout crop production, with automatic switching of the flow-through atmospheres to gas analyzers at regular, short intervals. The dynamic gas-exchange data will shadow the growth curve of crop stands that can't be disturbed for periodic harvests of biomass during development.

The capability of IC and CC lighting with narrow-spectrum LEDs as sole sources of radiation for plant growth also will be evaluated for effects on internode elongation, leaf expansion, stomatal aperture and transpiration rate, as well as on leaf and stem tropisms. Capability to grow crops successfully and productively at much-reduced power and energy cost will be the most important measure of success for this technology development and radiation optimization project.

Trainees Involved in the Study:

- **Post-Doctoral Research Associates**
  Dr. Gioia D. Massa-PhD Penn State University: July 2003 to present
- **Graduate Students**
  Search in progress
- **Undergraduate Students**
  Richard Kennedy – September, 2003
  Jason Mayes-January through May, 2003 (graduated)
  Jill A. Montgomery-May through July, 2003 (graduated)
- **Others**
  Adam Santone-March through May (graduated)

Publications & Oral/Poster Presentations

Mitchell, C. 2002. Satellite uplink interview with Maria Guday of Tech TV, San Francisco about the ALS NSCORT, March 25.

Mitchell, C. 2002. Radio interview with Jason Manning of KQDS, Duluth, MN about the ALS NSCORT, March 27.

Mitchell, C. 2002. TV interview about the ALS NSCORT on "Sound Medicine: IU School of Medicine", Indianapolis, June 11.

Mitchell, C. 2002. Presentation on ALS NSCORT to EGADS, West Lafayette, June 25.

Mitchell, C. 2002. Classroom presentations entitled "Mars Morsels" to three sections of the Ag 101 course in introductory agriculture, Purdue University, October 16.

Mitchell, C. Boardroom presentation entitled "Lunar and Mars Morsels" to the Food Science Industrial Associates, Purdue University, October 23.

Mitchell, C. 2002. Guest lecture on "Use of Plants for Water Purification in Space" in AGRY 598/CIVL 697 Phytoremediation course, Purdue University, December 4.

Mitchell, C. 2002. Presentation on the ALS NSCORT to the Discovery Park Directors, Purdue University, December 11.

Mitchell, C. 2003. Presentation entitled "Independent Living in Space", Westminster Men's Club, West Lafayette, January 25.

Mitchell, C. 2003. Presentation to the Burton D. Morgan Center for Entrepreneurship entitled "Commercial Applications of Products and Technologies spinning off from NASA-sponsored research", Discovery Park, Purdue University, January 31.

Mitchell, C. 2003. NASA Technical Interchange Meeting (TIM) telecon presentation on "An overview of the ASL NSCORT", from Purdue University, February 22.

Mitchell, C. 2003. Presentation on "The History of ALS" to the ALS NSCORT Graduate Student seminar group. Purdue University, February 28.

Mitchell, C. 2003. Presentation to the Lily Endowment Fund officers at the President's Forum on "The Implications of NASA-sponsored ALS Research for Economic Development on Earth", Purdue University, March 4.

Mitchell, C. 2003. Morning presentation to the Indiana Health Forum on the ALS NSCORT, Indiana University-Purdue University, Indianapolis (IUPUI), March 6.

Mitchell, C. 2003. Noon presentation on the ALS NSCORT to the Kiwanis Club, West Lafayette, March 6.

Mitchell, C. 2003. Presentation on the ALS NSCORT to the Indiana Space Grant Consortium, Purdue University, West Lafayette, April 11.

Mitchell, C. 2003. Presentation on the ALS NSCORT to the MELISSA Partners of the European Space Agency, Clermont-Ferrand, France, May 22.

Massa, G. 2003. Poster presentation on LED intracanopy and close-canopy lighting systems for ALS, to the Plant Biology Program, Purdue University, August 20.

Massa, G., Montgomery, J.A., Badger, J.M., Chiu, G.T., Mitchell, C.A. 2003. Poster presentation "Optimizing LED Lighting Strategies For ALS-Related Crops.", American Society for Gravitational and Space Biology, Huntsville, AL, November 15.

Mitchell, C. 2003. Oral presentation overview of the ALS NSCORT to the American Society for Gravitational and Space Biology conference, Huntsville, AL, November 15.

Massa, G. 2004. Poster presentation on development of LED intracanopy and close-canopy lighting systems for ALS crop production at the ALS Habitation PI conference, Orlando, FL, January 4-7.

Supporting Graphs, Charts, Illustrations, Photos

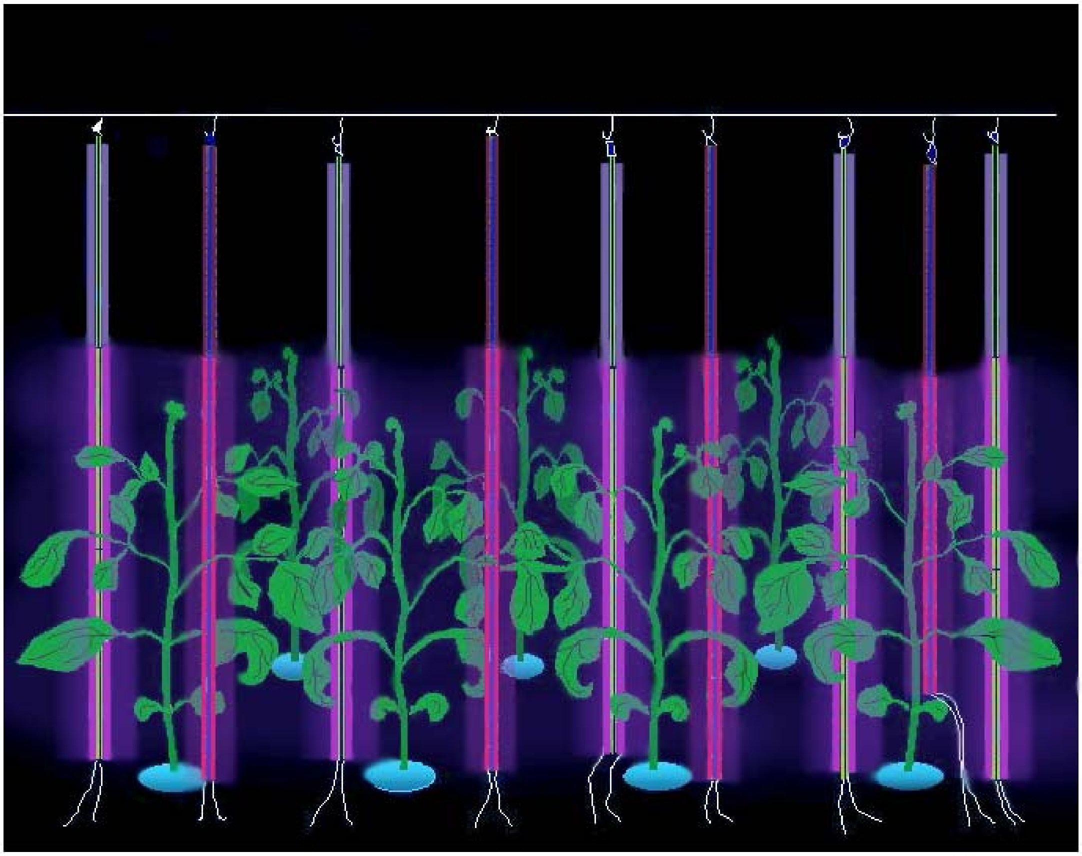


Fig. 1 An intracanopy (IC) LED array based on strips of chip-based densely packed LEDs.

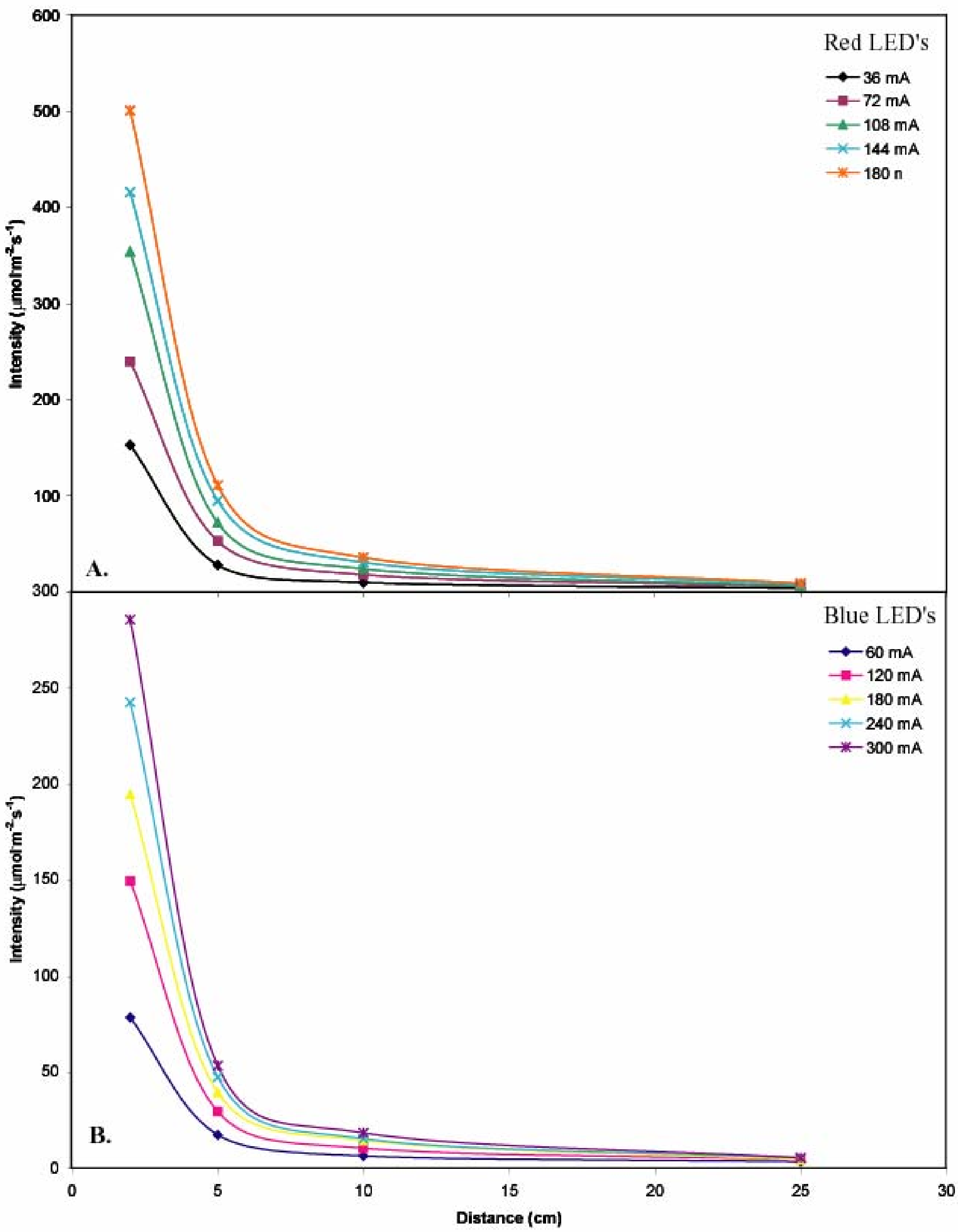


Fig. 2 Effects of variable current on light intensity at distances from the surface of **A**. Red LEDs and **B.** Blue LEDs.

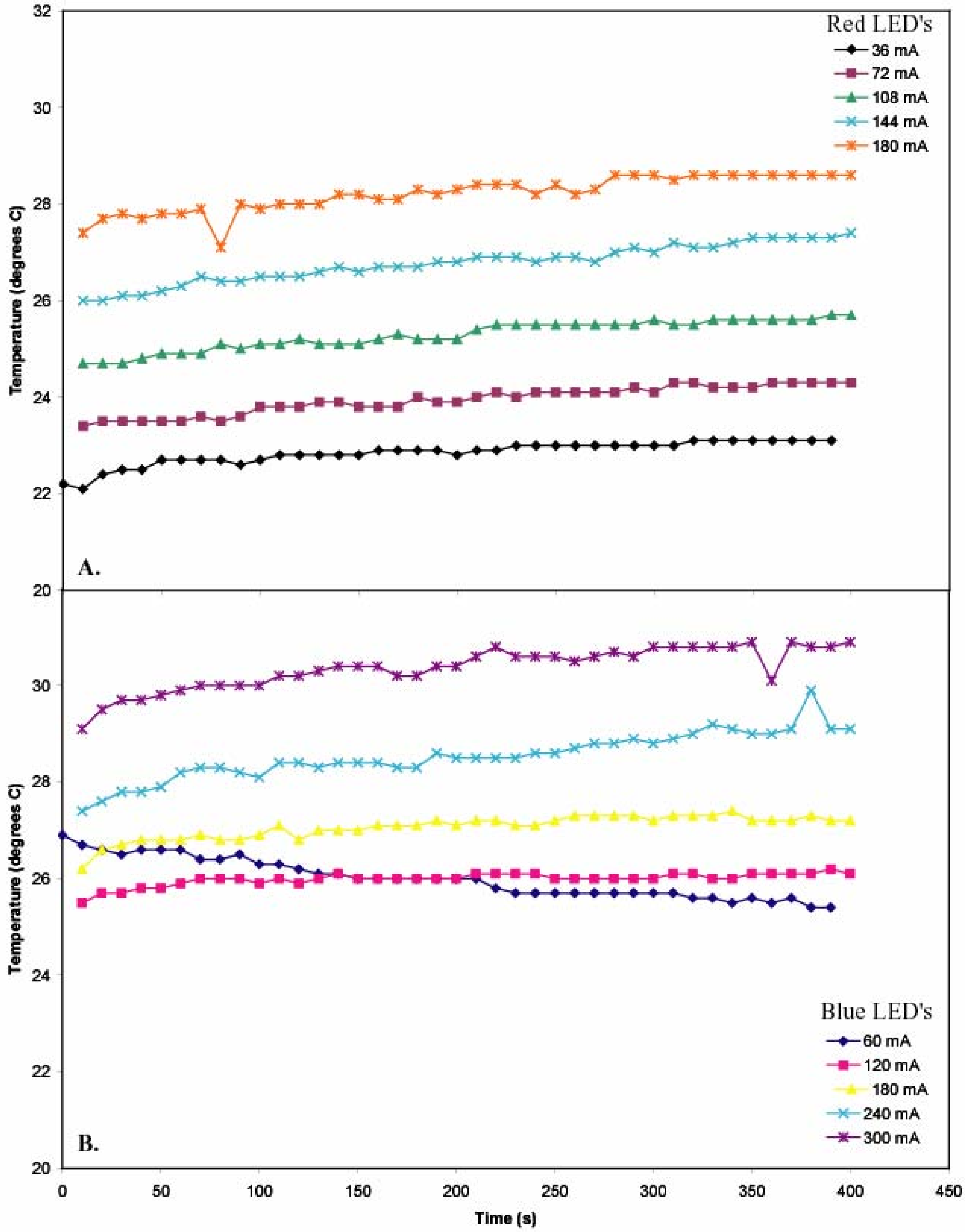


Fig. 3 Effects of variable current on temperature over time of **A.** Red LED's and **B.** Blue LED's.

Fig. 4 Photograph of greenhouse showing ALS target crop cultivation.

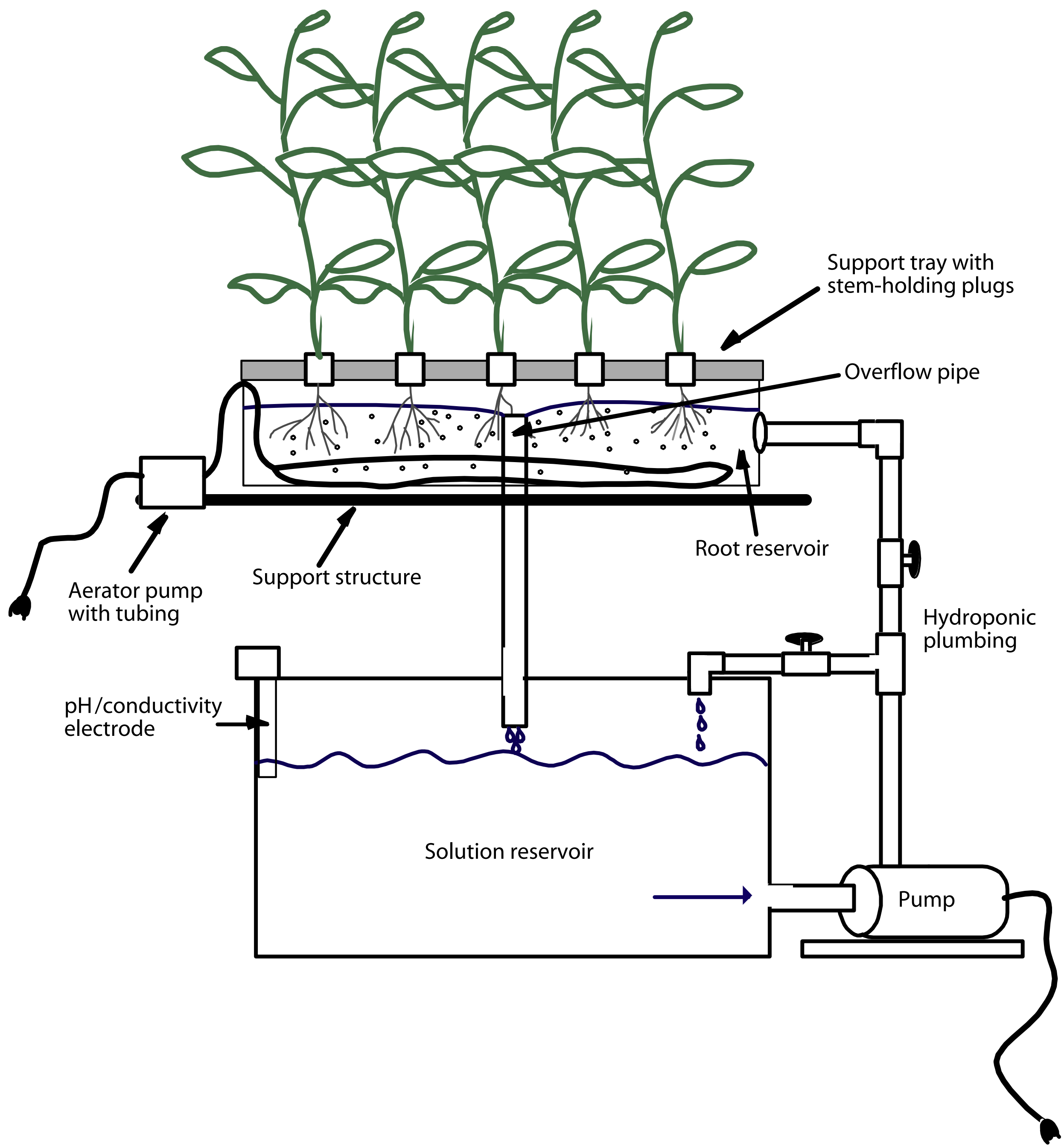


Fig. 5 Schematic of hydroponic system. Four identical hydroponic arrays have been constructed in the EGC growth chamber.

Table 1. Spectroradiometric analysis of red and blue LED's from a hex array. L, M, and H indicate Low, Medium and High current, respectively. Values represent applied or measured parameters for clusters of 30 LED's.

Proportion (Red:Blue)	Red Current	Red Voltage	Red Peak	Blue Current	Blue Voltage	Blue Peak
	(mA)	(V)	(nm)	(mA)	(V)	(nm)
L:L	30	9.2	625-675	60	8.52	450-500
L:M	30	9.3	625-675	150	8.82	450-500
L:H	30	9.3	625-675	300	9.12	450-500
M:L	90	10	625-675	60	8.49	450-500
M:M	90	10	625-675	150	8.8	450-500
M:H	90	10.1	625-675	300	9.11	450-500
H:L	180	11.1	625-675	60	8.49	450-500
H:M	180	11	625-675	150	8.8	450-500
H:H	180	11.1	625-675	300	9.09	450-500

References

Brown C, Schuerger A, Sager J (1995) Growth and photomorphogenesis of pepper plants under red light-emitting diodes with supplemental blue or far-red lighting. J. Amer. Soc. Hort. Sci. 120: 808-813.

Bula R, Morrow R, Tibbitts T, Ignatius R, Martin T, Barta D (1991) Light-emitting diodes as a radiation source for plants. HortScience 26: 203-205.

Frantz J, Chun C, Joly R, Mitchell C (1998) Intracanopy lighting of cowpea canopies in controlled environments. Life Support & Biosphere Sci. 5: 183-189.

Frantz J, Joly R, Mitchell CA (2000) Intracanopy lighting influences radiation capture, productivity, and leaf senescence in cowpea canopies. J. Am. Soc. Hort. Sci. 125: 694-701.

Frantz J, Joly R, Mitchell CA (2001) Intracanopy lighting reduces electrical energy utilization by closed cowpea stands. Life Support & Biosphere Sci. 7: 283-290.

Goins G, Yorio N, Sanwo M, Brown C (1997) Photomorphogenesis, photosynthesis, and seed yield of wheat plants grown under red light-emitting diodes (LEDs) with and without supplemental blue lighting. J. Exp. Bot. 48: 1407-1413.

Goins G, Yorio N, Sanwo-Lewandowski M, Brown C (1998) Life cycle experiments with *Arabidopsis* grown under red light-emitting diodes (LEDs). Life Support and Biosphere Sci. 5: 143-149.

Hoenecke M, Bula R, Tibbitts T (1992) Importance of blue photon levels for lettuce seedlings being grown under red-light-emitting diodes. HortScience 27: 427-430.

McKay C (2002) Why, from a life sciences perspective, this mission to mars? Proceedings of the XXVIth International Horticultural Congress: Toronto, Canada, pp 38.

Mitchell CA, Dougher TAO, Nielsen SS, Belury MA, Wheeler RM (1996) Costs of providing edible biomass for a balanced vegetarian diet in a controlled ecological life-support system. In: H Suge ed. Plants in Space Biology. Tohoku University Press. Sendai, Japan, pp 245-254.

Ohler T, Mitchell CA (1995) Effects of carbon dioxide level and plant density on cowpea canopy productivity for a bioregenerative life-support system. Life Support & Biosphere Sci. 2: 3-9.

Ono E, Cuello J, Jordan K (1998) Characterization of high-intensity red and blue light-emitting diodes (LEDs) as a light source for plant growth. Life Support & Biosphere Sci. 5: 403-413.

Tennessen D, Singsass E, Sharkey T (1994) Light-emitting diodes as a light source for photosynthesis research. Photosynthesis Res. 39: 85-92.

This page intentionally left blank.

8.3 Use of Edible White Rot Fungi to Enhance Cellulose, Hemicelluloses, and Lignin Degradation of Crop Residues

Principal Investigator: Caula A. Beyl

Leopold M. Nyochembeng[1], Caula A.Beyl[2], R.P. Pacumbaba[2] and G.C. Sharma[2]

[1] Postdoctoral Fellow, and [2] Professors, Department of Plant and Soil Science, Alabama A&M University, Normal, AL 35762

Significance of Project to ALS

Astronaut survival during extended space travel and in long term space habitats will depend on successfully growing food and recycling residual biomass including human biosolids in the space vehicle. The use of edible white rot fungi to degrade the inedible biomass component of the crop production system is advantageous in that cellulose, hemicellulose and lignin are further degraded yielding edible products in the form of mushrooms. Lignin, the most recalcitrant component of the plant cell wall, has been shown to be susceptible to degradation by white rot fungi such as *Pleurotus ostreatus* (Sarikaya and Ladisch, 1997b) and shiitake (*Lentinula edodes*), which typically grows on highly lignified substrates and produces enzymes associated with lignin depolymerization in other fungi (Buswell et al., 1996). It is believed that human waste can be recycled and used as an amendment to inedible crop wastes for the production of various white rot mushrooms including *Lentinula edodes, Grifola frondosa, Pleurotus ostreatus, Ganoderma lucidum,* etc. The shiitake mushroom for example is a rich source of proteins and vitamins (Matilla et al., 2001), and has demonstrated medicinal attributes as well (Breene, 1989; Hokama and Hokama, 1981; Sugano et al., 1982; Suzuki et al., 1979; Takazawa et al., 1982; Takehera et al., 1981; Tokita et al., 1972; Tsunada and Ishida, 1969).

Project Goals and Objectives

Crops such as wheat, beans, peanut, potato, rice, soybean, tomato, etc. will be grown in controlled ecosystems in which all non-edible residual waste including human biosolids will be degraded and recycled. The goal of this project is to use white rot fungi to degrade and recycle inedible crop residues and astronaut waste in the Advanced Life Support (ALS) system. The specific objectives of this effort are 1) to evaluate strains of edible mushrooms for their ability to convert the inedible biomass from the biomass production system (BPS), and 2) to evaluate each crop residue independently to determine its specific suitability as a substrate for certain fungal species under optimal conditions.

Research Progress

Our collection of white rot edible mushroom species was enhanced through the acquisition of additional strains of shiitake (54), maitake (12), oyster (8), reishi (2). Two projects were completed by ALS/NSCORT undergraduate minority fellowship trainees this summer, in which they examined shiitake growth and basidiocarp production on human biosolid amended culture media in the laboratory, wheat straw of three textures exposed to different heat treatments, and fine wheat straw amended with different concentrations of poultry litter.

1. Shiitake Growth on Culture Media Amended with Two Concentrations of Human Biosolid

One way to recycle the biosolid waste of astronauts beneficially is to incorporate it into the medium for growing shiitake (*Lentinula edodes* [Berk] Pegler) and/or other exotic mushrooms. These include *Grifola frondosa* (maitake), *Pleurotus ostreatus* (oyster), *Ganoderma lucidum* (reishi), *Cantharellus cibarius* (golden chanterelles), *Hericium coralloides* (tooth fungi), *Polyporus spp*. (shelf and bracket fungi), *Caprinus comatus* (thorny mushroom), etc. Since the astronaut's main diet will be vegetarian, shiitake and other exotic mushrooms tasting like meat will serve as suitable substitutes and add needed variety to the diet. This investigation sought to 1) determine shiitake growth on culture media (Pacumbaba and Pacumbaba, 1999a; 1999b; Pacumbaba et al., 1999) amended with two concentrations of human biosolid waste in the laboratory and 2) to determine if development of fruiting initials is influenced by the addition of human biosolid wastes. Four strains of shiitake, LE001 (ATCC #20546), LE002 (ATCC #20635), LE2 (ATCC #48861), and LE3 (WW 44, Lot 34A Unit 8 of Forest Products, Prestigo, WI) were tested on the medium amended with three concentrations (0%, 20% and 40%) of human biosolids. LE002 exhibited the greatest tolerance to the addition of human biosolids, growing well even on the 40% amended-medium (Fig. 1). The strains of shiitake reacted differently on the media in response to the two treatments which contained biosolids at 20% and 40%. Increasing the concentration of human biosolids in the medium was unfavorable to the mycelial growth and production of basidiocarps for strains LE2, LE3 and LE001 (Table 1). However, biosolid waste was more favorable to the formation of basidiocarp initials of LE002, hastening the onset of basidiocarp formation as early as 15 days after inoculation (Fig. 2). These results indicate that there is a need to screen additional strains of *L. edodes* and select those which sustain growth and basidiocarp production on media amended with human biosolids. This also underscores the importance of strain selection for use on long term space missions or in non-terrestrial habitats and the need to expand the test to higher percentages of incorporation, a greater number of shiitake strains, and to evaluate not only mycelial growth but also basidiocarp development.

2. Growth of Two Strains of Shiitake on Wheat Straw in Response to Texture, Heat Treatment and Amendment with Chicken Manure

This study explored the efficiency of chicken waste as a nitrogen source in promoting shiitake growth and basidiocarp development. Successfully utilizing chicken waste to augment inedible crop wastes could also help assess the feasibility of raising fowl as a food component in a space-based environment since this method will recycle bird waste in the controlled ecosystem. In addition, this study evaluated whether the chicken waste could be added to the crop wastes, which cannot be digested by humans, to facilitate recycling. The objectives of the investigation were to determine the effect of particle size (coarse, medium, fine) of wheat straw, heat treatment and amendment with chicken manure, on the growth of two strains of shiitake and to determine if shiitake basidiocarps coulc be initiated on a substrate amended with varying concentrations of chicken manure. Two experiments were performed to determine how the texture of wheat straw and heat treatment affects mycelial growth and initiation of basidiocarps on substrate amended with poultry manure. In Experiment I, three textures of wheat straw (coarse, medium and fine) were each amended with 20% (v/v) chicken manure in GA7 containers and the media were either autoclaved, microwaved to 150°F or not heat-treated (control). The mycelial growth of two shiitake strains, 'Eastwind' and 'Westwind', was evaluated on the amended media using a scale of 0-7, with 0 = no growth and 7 = excellent growth. Of the samples demonstrating the most growth, 80% were 'Eastwind' relative to 20% of 'Westwind', 80% were fine wheat straw relative to 20% of medium and 0% of coarse. The least amount of contamination occurred in autoclaved media (6.7%), followed by microwaved (33.3%) and the control (43.3%). In Experiment II, 'Eastwind' and 'Westwind' were studied in fine wheat straw amended with chicken manure at 0, 10, 20, 30, 40 and 50% (v/v). Both strains exhibited good and similar growth on fine wheat straw without chicken manure, however, there was a progressive decrease in growth with increasing concentration of chicken manure, indicating that neither of the two strains could tolerate higher concentrations of chicken manure as a medium amendment in fine wheat straw.

Table 1. Growth of shiitake strains in media amended with two concentrations of human biosolid waste ten days after inoculation[X]

Shiitake Strain	Shiitake growth (Diameter in cm)[Y] -----Treatments-----		
	Control	20% Amended	40% Amended
LE2	7.65±0.24a	4.75±0.53c	0.0±0.0a
LE3	7.58±0.44a	3.08±0.67b	0.0±0.0a
LE001	7.50±0.01a	0.0±0.0a	0.0±0.0a
LE002	8.70±0.00b	7.13±0.48d	5.75±0.35b

[X]Each strain of shiitake tested per concentration was replicated four times.
[Y]Means in the same column with the same letter are not significantly different according to Tukey's studentized range test at *P=0.05*.

Current Projects

Current projects in our laboratory include 1) the screening and evaluation of several shiitake spawn strains on artificial medium amended with astronaut biosolids to look for tolerant strains that can fruit under the higher concentrations, and 2) evaluation of different nitrogen sources on growth performance of shiitake strains in culture media.

Research Collaboration

Collaboration on outreach is being explored with Dr. Rudy Pacumbaba Jr. to augment an already planned display on gravitropism with a demonstration of the technology to recycle nonedible crop residues for long term Mars habitats to be used by the Space and Rocket Center, Huntsville, AL.

Future Directions of the Research

The current laboratory projects should be completed within the next three months. In the 12 months following that period, our major thrust will be to conduct experiments to determine which of four mushroom species (shiitake, maitake, oyster and reishi) works best on residue from two of the ten crop species (wheat, soybean, white potato, sweet potato, tomato, rice, peanut, lettuce, spinach and dry beans). In this first year, wheat and soybean will be grown hydroponically to simulate loosely the systems that will be used in the BPS. The crops will be harvested and processed into edible and inedible components. The residual inedible components will serve as substrates for growing the mushrooms.

Trainees Involved in the Study

Our research currently supports one full time postdoctoral position with a twelve month appointment. This summer, two trainees from Howard University and Purdue University completed summer projects under the ALS/NSCORT Minority Fellowship Research Program, in our laboratory.

Publications and Oral/Poster Presentations

Oral presentations were given by our two summer trainees at the ALS/NSCORT Summer Fellowship Symposium, that took place at Purdue University from July 30-31, 2003. The titles of the presentations were:

A) Growth of Two Strains of Shiitake on Wheat Straw in Response to Texture, Heat Treatment and Amendment with Chicken Litter
B) Shiitake Growth on Culture Media Amended with Two Concentrations of Human Biosolids.

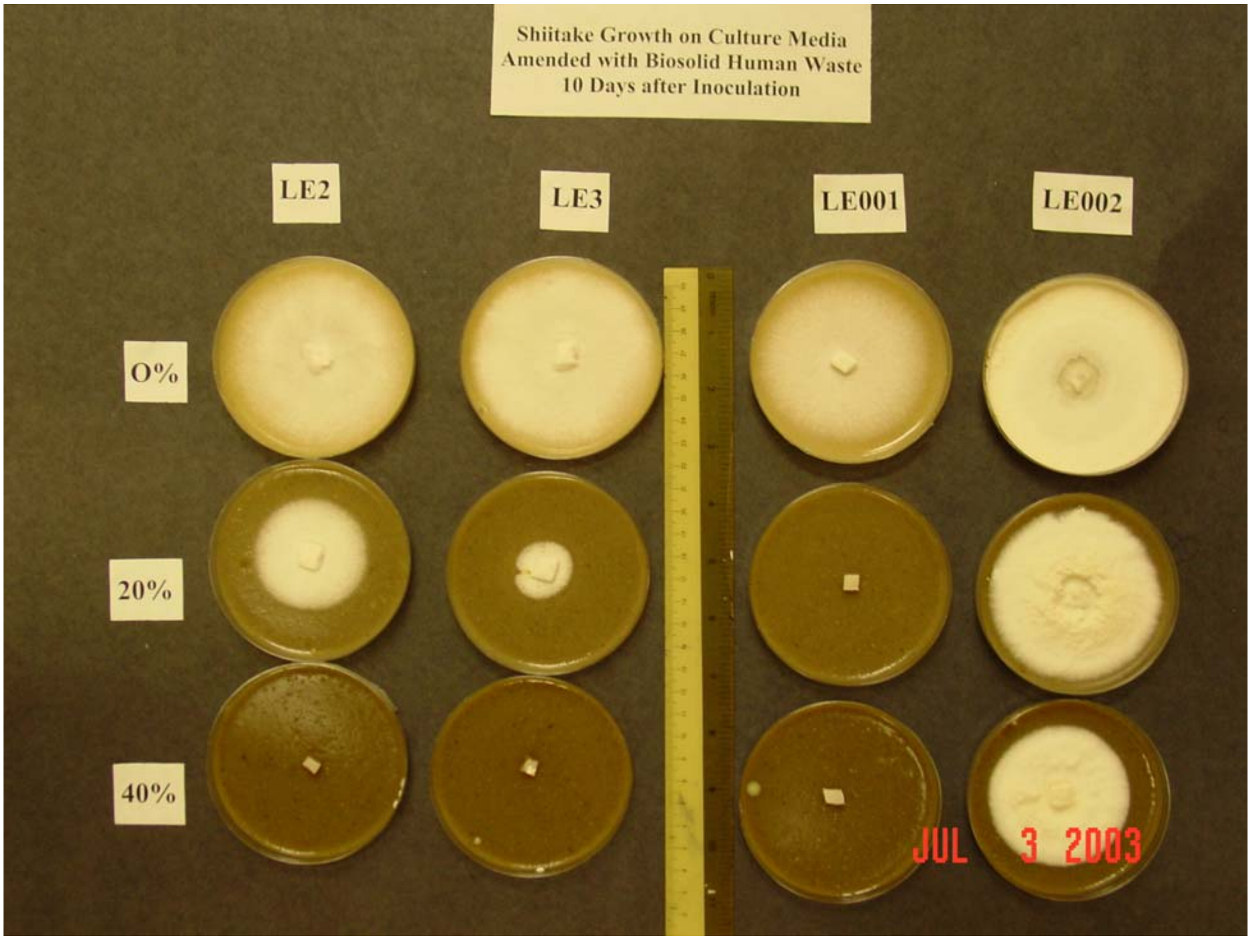
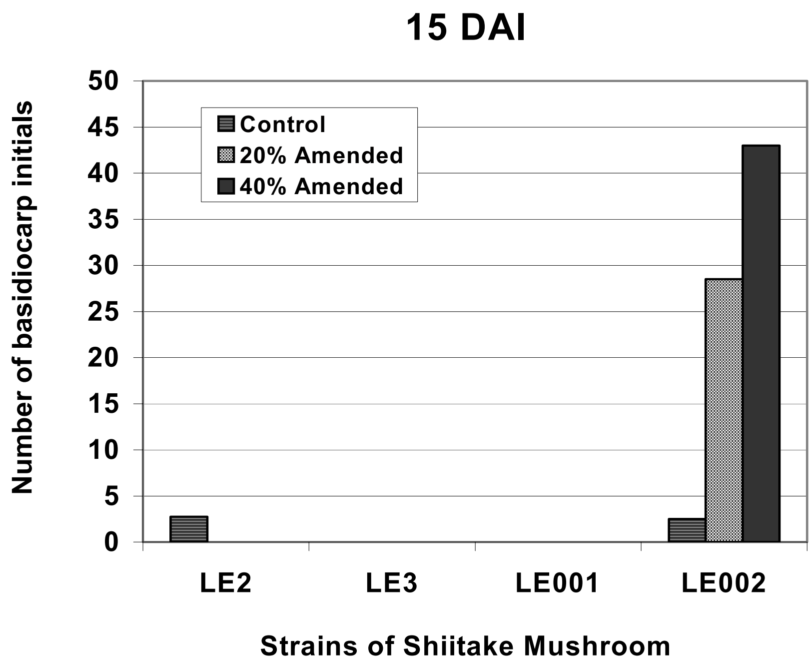


Fig. 1. Growth of the four strains of shiitake at 10 days after inoculation on the amended-media with two concentrations of biosolids waste.



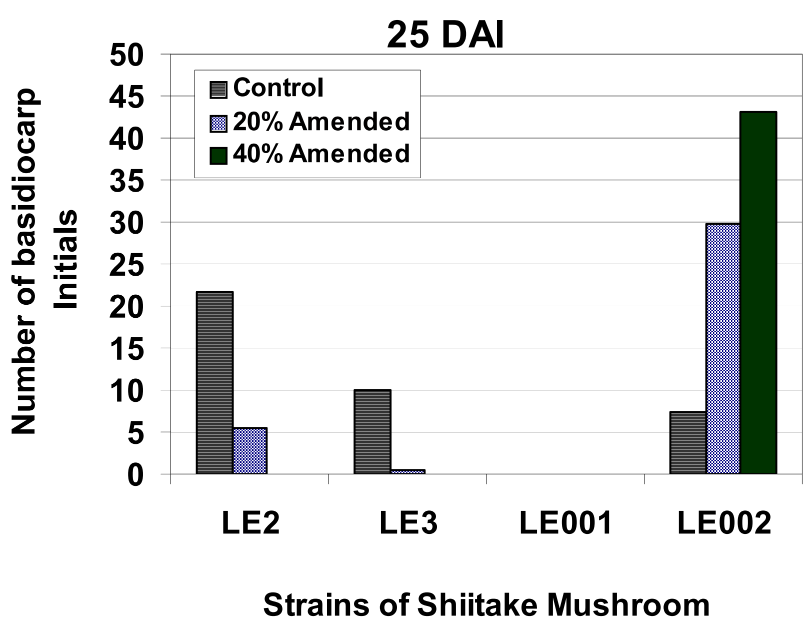


Figure. 2. Production of basidiocarp initials in four shiitake strains inoculated on standard medium (control) or biosolid amended (20% and 40%) medium at 15 days after inoculation (15 DAI) or 25 days after inoculation (25 DAI).

References

Breene, W. M. 1989. Nutritional and medicinal value of exotic mushroom. Proceedings of the National Symposium and Trade Show, May 3-5, 1989. St Paul, MN. Pp 87-112.

Buswell, J.A., Y.J. Cai, S.T. Chang, J.F. Peberdy, S.Y. Fu, and H.S. Yu. 1996. Lignocellulolytic enzyme profiles of edible mushroom fungi. World Journal of Microbiology and Biotechnology 12:537-542

Hokoma, Y., and J. L. R. Y. Hokoma. 1981. In vitro inhibition of platelet aggregation with low dalton compound from aqueous dialysate of edible fungi. Res. Commu. Chem. Path. Pharmacol. 31:177-180.

Matilla, Pirjo., Konko, Karoliina., Eurola, Merja., Pihlava, Juha-Matti., Astola, Jouni., Vahteristo, Liisa., Hietaniemi, Veli., Kampulainen, Jorma., Valtonen, Meli., and Piironen, Vieno. 2001. Contents of vitamins, mineral elements, and some phenolic compounds in cultivated mushrooms. J. Agric. Food Chem. 49:2343-2348.

Pacumbaba, R. P., and Pacumbaba, R. O., Jr. 1999a. Shiitake mushroom growth on the formulated culture media, production of spawn, and basidiocarps in the laboratory. HortTech. 9:85-90.

Pacumbaba, R. P., and Pacumbaba, R. O., Jr. 1999b. Growing shiitake mushroom on hardwood sawdust in the greenhouse. HortTech. 9:91-94.

Pacumbaba, R. P., Beyl, Caula A., and Pacumbaba, R. O., Jr. 1999. Shiitake mycelial leachate suppresses growth of some bacterial species and symptoms of bacterial wilt of tomato and lima bean in vitro. Plant Disease 83:20-23.

Sugano, N., Hibino, Y., Choji, Y., and Maeda, H. 1982. Anticarcinogenic actions of water-soluble and alcohol-soluble fractions from culture medium of *Lentinus edodes* mycelia. Cancer Letters 17: 109-114.

Sarikaya, A. and M.R. Ladisch. 1997b. An unstructured mathematical model for growth of Pleurotus ostreatus on lignocellulose material in solid state fermentation systems. Appl. Biochem. Biotechnol. 62:71-85

Suzuki, F., Suzuki, C., Shimomura, E., Maeda, H., Fuji, T., and Ishida, N. 1979. Antiviral and interferon-inducing activities of a new peptidomannan, KS-1, extracted from culture mycelia of *Lentinus edodes.* J. Antibio. 32:1336-1345.

Takazawa, H., Tajima, F., and Miyashita, C. 1982. An antifungal compound from shiitake (*Lentinua edodes*). Jour. Pharmacol. Soc. Japan. 102:489-491.

Takehera, M., Mori, K., Kuida, K., and Hanawa, M. A. 1981. Antitumor effect of virus-like particles from *Lentinus edodes* (shiitake) on Ehrlich ascites carcinoma in mice. Archives Virol. 68:297-301.

Tokita, F., Shibukawa, N., Yasumoto, T., and Kaneda, T. 1972. Isolation and chemical structure of the plasma-cholesterol reducing substances from shiitake mushroom. Mushroom Science 8:783-788.

Tsunada, A., and Ishida, N. 1969. A mushroom extract as an interferon inducer. Annals NY Acad. Sci. 173:719-726.

Appendix 9.0

9.1 Education and Outreach

9.1.1 ALS NSCORT Summer Symposium Absracts

9.1.2 Distance Learning Course Outline

9.1.3 Lafayette School Corporation After-School Program

Simultaneous Treatment of Air and Water Using Biotrickling Filter Technology in an Advanced Life Support System

Presenter: Sybil Sharvelle, Graduate Student, Civil Engineering, Purdue University
Faculty Sponsor: M. Katherine Banks, Civil Engineering, Purdue University
Sponsoring Program: NSCORT

Abstract

An important function of life support systems developed for a long duration human mission to Mars is the ability to recycle water and air. The Bio-Regenerative Environmental Air Treatment for Health (BREATHe) is part of a multicomponent life support system and will simultaneously treat wastewater and air. The BREATHe system will consist of packed bed biofilm reactors. Model waste streams will be used for experiments conducted during the design phase of the BREATHe system. This paper summarizes expected characteristics of water and air waste steams that would be generated by a crew of six during a human mission to Mars. In addition to waste air and water generation rates, the chemical composition of each waste stream is defined. Specifically, chemical constituents expected to be present in hygiene wastewater, dishwater, laundry water, atmospheric condensate, and cabin air are presented. Because air and water will be treated simultaneously, it will be essential to examine the partitioning of chemicals between the gas and liquid phases in waste streams.

Water Disinfection for Long Term Space Missions

Presenter: Kelly Pennell, Grad Student, Civil Engineering, Purdue University
Faculty Sponsor: E. R. Blatchley, Civil Engineering, Purdue University
Sponsoring Program: NSCORT

Abstract

For closed-loop water recycle systems, stringent performance standards are required of disinfection processes because the disinfection process is not only the "final" barrier before consumption, but it can also be considered the first process in a the entire water treatment process. The disinfection process included in this research will include a two-pronged approach: ultraviolet (UV) radiation to act as the primary (physical) disinfectant, and iodine to serve as the secondary (chemical) disinfectant.

The UV portion of the research will focus on developing a computational method that will model the disinfection reactor and predict the dose of UV radiation absorbed by pathogenic microorganisms. A commercial computational fluid dynamics (CFD) code, FLUENT, will be used to perform flow simulations. This will provide a time-efficient process of testing different reactor geometries and finding the optimal reactor. The second part of the research will focus on iodine. An iodine species (iodide) will be used as a chemical actinometer to perform real-time monitoring of the UV system. Iodide, when exposed to UV radiation is converted to triiodide, which can be used as a metric to estimate UV dose. After the iodide has been converted to triiodide it will then be converted into another iodine species capable of disinfection to serve as the secondary disinfectant. Prior to consumption, the iodine will be recovered from the water for re-use in the disinfection process.

Human Life Support in a Closed Loop System

Presenter: Chit-Hui Ang, Graduate Student, Purdue University
Faculty Sponsor: Yuehwern Yih, Industrial Engineering, Purdue University
Sponsoring Program: NSCORT

Abstract

It is essential to understand the human biological system in order to ensure that all the life support systems operate under optimal conditions. This topic will present summary of collected data and information regarding human, with emphasis on crewmembers living in a closed loop for an extended period of time. Subtopics presented include body mass, energy intake, water consumption, nutritional requirements, sleep duration and its quality, energy expenditure and balance, noise, air temperature and humidity, air pressure and its composition, hypo gravity, crew time allocation, and thrash generation. These data and information are categorized into inputs, outputs, control variables and constraints. The interactions and relationships between factors that affect human biological system are discussed. In addition, the application of these data and information on the design of advanced life support system will be presented as well.

Evaluation of Nile tilapia (*O. niloticus*) as a Component Within an Advanced Life Support (ALS) Integrated System

Presenter: John M. Gonzales, Jr., Graduate Student, Forestry & Natural Resources, Purdue University
Faculty Sponsor: Paul B. Brown, Forestry & Natural Resources, Purdue University
Sponsoring Program: NSCORT

Abstract

Sustaining life on Mars is currently hampered by an inability to develop an advanced life support (ALS) system incorporating bio-regenerative and physical-chemical processes that can reduce equivalent system mass (ESM). Such a system needs to incorporate food production techniques with waste management practices in an integrated system to sustain life on Mars. Furthermore, past space missions have shown:

1) Bone degeneration and weight loss occur in astronauts living in space;
2) Astronauts grow tired of consuming an all vegetarian diet and have requested the inclusion of animal protein; and,
3) Physiological stressors associated with living in space has resulted in high usage of pharmaceuticals which may adversely affect the ecology of an ALS.

Nile tilapia will be evaluated as means of reducing ESM by serving as a bioreactor of nutrients by reducing carbon inputs via consumption of thermophilic bacteria and various waste products; thereby increasing the availability of nutrients for plant production. Metabolic waste, specifically CO_2, will further aid such production. Furthermore, Nile tilapia will serve as a source of high quality protein, n-3 fatty acids essential for bone growth, and act as a means to alleviate physiological stress imparted on humans living in space.

Nile tilapia production will be evaluated by means of comparative slaughter trials to determine its potential in an ALS system for sustaining life on Mars. Research objectives are:

a) Evaluation of Nile tilapia production fed various combinations of potential foods, i.e. thermophilic bacteria, plant waste, and food waste products;
b) Evaluation of fish reproduction and successive offspring production in such a system,; and,
c) Evaluation of the success of Nile tilapia as a bioreactor transforming nutrients in waste into readily accessible nutrients for hydroponic plant production

Experimental design will be completely randomized, evaluating production at multiple age classes, i.e. larval, fingerling, sub-adult, and adult. At every level, growth rate, survival rate, nutrient retention, nutrient excretion and optimum stocking rates will be analyzed. Additionally, gonadal development will be analyzed at the adult stage. Analysis will include quantification of nutrient discharge, and proximate analysis of feed, feces and whole body composition. Results from this research will determine the optimum stocking density for the production of Nile tilapia in an ALS system and aid in determining stocking densities for plant production in such a system.

Knowledge Acquisition Framework Implementation for ALS NSCORT Program

Presenter: Charita Brent, Graduate Student, Howard University
Faculty Sponsor: John Trimble, Systems and Computer Science, Howard University
Sponsoring Program: NSCORT

Abstract

General comprehension of individual subsystems by all research participants in a multi-discipline program is essential for the progression of a collaborative project. The framework for the Advanced Life Support NASA Specialized Center of Research and Training (ALS NSCORT) Knowledge Elicitation technique was designed to improve communication between the different subgroups, which in turn will assist in reaching the goal of developing an efficiently integrated ALS System. The framework includes a series of interviews; structured and semi-structured, and task analysis exercises directed for the principle investigators (PI) of each subgroup. At the fundamental level, each PI will identify all tasks, prerequisites, inputs/outputs, control variables and constraints of their subsystem. The data will be found in representational formats such as structured trees and dependency graphs linking the dynamics of each subsystem in the ALS System. The raw data will be archived in ALS NSCORT media for future reference by any research participant. The ALS NSCORT Knowledge Elicitation framework will serve as a precursor for more sophisticated knowledge elicitation techniques, exercises and modeling.

Food System for ALSS: Objectives and Challenges

Presenter: Ilan Weiss, Graduate Student, Food Science, Purdue University
Faculty Sponsor: Lisa Mauer, Food Science, Purdue University
Sponsoring Program: NSCORT

Abstract

The foods group of the ALS NSCORT has the distinguished opportunity to develop novel processes and technologies to provide a safe, nutritious, and tasty food supply for long-term space missions. Specific objectives relating to food processing include: develop foods with a 3-5 year shelf-life, examine the processing of raw materials into foods, and minimize ESM. Food safety in space poses an extremely important issue. Factors to consider include: the remote nature of space travel necessitates prevention as opposed to treatment, confined environment, and physical and mental stress may lower susceptibility level to pathogens. Traditional microbiological techniques are time and labor intensive. Development of a rapid, highly specific test to determine the microbial safety of foods intended for long-term space travel is of utmost importance.

Ammonium Removal by Ion Exchange Using Different Types of Zeolites

Presenter: Ressa Che Wah, Graduate Student, Howard University
Faculty Sponsor: Charles Glass, Civil Engineering, Howard University
Sponsoring Program: NSCORT

Abstract

Zeolites are crystalline alluminosilicates and are known for their ability to remove ammonium (NH_4^+) from wastewater because of their preferential selectiveness for the ion (NH_4^+). They have three-dimensional frameworks arising from a honeycomb arrangement of corner-sharing $(SiO_4)^{4-}$ and $(AlO_4)^{5-}$, which allows water to move freely in and out while retaining its rigidity. Zeolites are a popular group of minerals with important industrial functions due to their following properties. Structurally they contain large vacant spaces in the form of a crystalline cage. These cavities allow for cations such as sodium (Na^+), potassium (K^+), barium (Ba^{2+}) and calcium (Ca^{2+}) and even large molecules such as ammonium (NH_4^+) and water (H_2O) to infiltrate and exchange. Consequently, not all zeolites are the same. There are nearly 50 different types of zeolites, each with its own physical and chemical properties. The major differences between zeolite groups are crystal structure and chemical composition. One important difference is the composition of the exchangeable cations residing in the zeolite. Clinoptilolite and chabazite, $(Na_3K_3)(Al_6Si_{40}O_{96}) \bullet 24H_2O$ and $(Na_6K_6)(Al_{12}Si_{24}O_{72}) \bullet 40H_2O$ respectively, belong to the group of naturally occurring zeolites. Both zeolites have many practical chemical applications due to its ability to selectively absorb nitrogen as ammonium ions. For this particular study the selectivity of these two zeolites as a mineral ion exchangers for ammonium ions will be explored in direct relations to regenerative processes. The ultimate aim of this study is to utilize an ammonia rich effluent from a STAR - Gas Scrubber and extract nitrates, to supplement plant growth.

Design Of A High Flux, Low Fouling Membrane System For Use In Space Missions

Presenter: Joffrey L. Leevy, Graduate Student, Civil Engineering, Howard University
Faculty Sponsor: Kimberly Jones, Civil Engineering, Howard University
Sponsoring Program: NSCORT

Abstract

An available supply of drinking water for the protracted Mars mission is an indispensable requirement. Due to volume constraints, it is essential that the wastewater be recycled and treated to potable NASA water standards. BREATHe and LiFT systems have been proposed to treat grey water, urine and atmospheric condensate. Effluent from BREATHe will subsequently be sent to a membrane system for polishing before final disinfection.

The goals of this research are threefold: (1) to test the hypothesis that pretreated wastewater can be recycled and treated to acceptable drinking water standards via a high flux membrane system; (2) to design a low pressure reverse osmosis (LPRO) or nanofiltration (NF) system with minimal input of membranes, expense, and time; and (3) to produce satisfactory and consistent experimental results which show minimal membrane fouling, minimal concentrate volume, and maximum flux.

A versatile lab-scale unit that simulates cross-flow filtration will be employed for the pressure-driven membrane process. Inserts can be reverse osmosis, nanofiltration, ultrafiltration, or microfiltration flat sheet membranes. The instrument allows for easy and reliable control of pressure and flow parameters over the membrane surface. Contaminants of concern that should be reduced to potable standards include urea, creatinine, ammonium carbonate, surfactant, sodium chloride, and trace organics. Contaminants in the membrane influent that exceed NASA potable standards include ammonium ion and total organic carbon. The target percentage reductions for these two contaminants are 99% and 97% respectively.

Determination of Antioxidant Capacity of Advanced Life Support Crops and Other Food Ingredients For a NASA Mission To Mars

Presenter: Deidra Carr, Undergrad Student, Biology, Howard University
Faculty Sponsor: Lisa Mauer, Food Science, Purdue University
Sponsoring Program: NSCORT

Abstract

The National Aeronautics and Space Administration (NASA) is working towards future long duration space flights which may last as long as two and a half years and which will include exploratory missions on a planetary surface, such as Mars. The need to provide the crew with a varied, palatable, nutritious, easy to prepare and safe food system while on a Mars mission is of paramount importance to NASA. During long duration space missions the body and mind undergo physiological and psychological stresses that may lead to severe health problems. These physiological effects include weight loss, dehydration, constipation and calcium loss; while, crewmembers can undergo psychological changes, such as sleep disorders, loneliness, depression, irritability and anxiety. These problems can lead to low morale and less efficient teamwork, poor concentration and lack of productivity. Exposure to cosmic radiation has become an additional concern for astronauts, some of who reside in space for periods of up to one year. Radiation causes an increase in free radicals in the body which results in a condition called oxidative stress. Antioxidants alleviate oxidative stress by neutralizing these free radicals, thereby preventing them from doing damage to the body's tissues. Choosing a diet high in antioxidants may become increasingly important to counteract the effects of this radiation exposure. This project aims to: 1) Determine the antioxidant capacity for all advanced life support candidate crops 2) Identify other food ingredients that meet mission constraints (3-5 year shelf life) and have high antioxidant capacity and 3) Summarize methods currently used to determine antioxidant capacity.

Determining the Specificity of *Escherichia coli* O157:H7 Bacteriophage ϕV10

Presenter: Rachael Jennings, Undergrad Student, Food Science, Purdue University
Faculty Sponsor: Bruce Applegate, Food Science, Purdue University
Sponsoring Program: NSCORT

Abstract

There are numerous strains of *Escherichia coli*, of which only a small percent is *E. coli* O157:H7. *E. coli* 0157:H7 is infected by bacteriophage ϕV10. The parent phage attaches to the surface of the host at a specific receptor and subsequently injects its DNA into the host. Inside the host, the phage replicates its genome, produces its protein coat, forms progeny phage followed by lysis, releasing hundreds of progeny. It has been shown that ϕV10 is specific to *E. coli* O157:H7. In this project, the specificity of ϕV10 will be examined using a standard plaque assay. The assay consists of adding test cultures to 10^6 and 10^7 plaque forming units of ϕV10 in a top agar and overlayed on LB agar plates. If the appropriate virus is present, resultant infection and lysis of cells produces plaques. We plan to utilize this assay to screen numerous environmental and food isolates of *E. coli* which contain both O157:H7 and non O157:H7 strains. This is an important step in using ϕV10 for detecting food-borne *E. coli* O157:H7 as it will ascertain the specificity of the phage. Phage based methods are simple, inexpensive, and require minimal equipment. Although developed for use in space these techniques will have earthbound applications since *E. coli* O157:H7, is estimated to cause 73,000 illnesses and 61 deaths in the United States each year. Infection results from eating insufficiently cooked meats, infected sprouts, lettuce, salami as well as unpasteurized milk and juice.

Growth of Two Strains of Shiitake on Wheat Straw in Response to Texture, Heat Treatment and Amendment with Chicken Litter*

Presenter: Christen A. Tibbs, Undergrad Student, Biological Sciences, Purdue University
Faculty Sponsor: Caula A. Beyl and R. P. Pacumbaba, Alabama A&M University
Sponsoring Program: NSCORT

Abstract

Incorporating shiitake mushrooms into a space-based environment will contribute to the survival of astronauts, whose vegetarian diet will most likely consist of wheat, beans, potatoes, corn, peanuts and other nutritionally sound crops. Non-edible waste products from these crops will need to be degraded and recycled. Shiitake, a wood rotting fungus, performs this action while producing the tasteful, nutritional Shiitake mushroom. Two experiments were performed to detect how the texture of wheat straw affects mycelial growth and to determine if shiitake basidiocarps can be initiated on poultry litter amended substrate. In Experiment I, three textures of wheat straw (coarse, medium and fine) were each amended with 20% (v/v) chicken litter in GA7 containers and the media were either autoclaved, microwaved or not heat-treated (control). The mycelial growth of two shiitake strains, 'Eastwind' and 'Westwind', was evaluated on the media on a scale of 0-7, with 0 = no growth and 7 = excellent growth. Of the samples demonstrating the most growth (ratings of 5-7), 80% were 'Eastwind' relative to 20% of 'Westwind', 80% were fine wheat straw relative to 20% of medium and 0% of coarse. In autoclaved media, all samples showed growth as opposed to no growth for the microwaved and non heated-treated media. In Experiment II, 'Eastwind' and 'Westwind' were studied in fine wheat straw amended with chicken litter at 0, 10, 20, 30, 40 and 50% (v/v). Both strains exhibited equal growth on fine wheat straw without chicken litter, however, there was a progressive decrease in growth with increasing concentration of chicken litter, indicating that neither of the two strains could tolerate higher concentrations of chicken litter as a medium amendment in fine wheat straw.

Shiitake Growth on Culture Media Amended with Two Concentrations of Human Biosolids*

Presenter: Kavita Manohar-Maharaj, Undergrad Student, Arts & Sciences, Howard University
Faculty Sponsor: Caula A. Beyl and R. P. Pacumbaba, Alabama A&M University
Sponsoring Program: NSCORT

Abstract

Astronauts traveling in space for long periods will have to raise their own food. The space vehicle or the long term space habitat will function as a controlled ecosystem where even human waste and crop residues are a resource to be used and recycled. Crops like wheat, beans, peanuts, potato, rice, soybean, tomato, and their nonedible biosolid waste can become substrate components for the further growth of food. Biosolids generated by the astronauts' waste, will also be recycled and used to augment inedible crop residues to support the growth of edible white rot fungi such as shiitake mushroom. The present investigation sought to 1) determine shiitake growth on culture media amended with two concentrations of human biosolid waste in the laboratory and 2) to determine if development of fruiting initials is influenced by the addition of human biosolid wastes. Four strains of shiitake (LE001, LE002, LE2, and LE3) were tested on the medium-amended with two concentrations (20% and 40%) of human biosolids. LE002 exhibited the greatest tolerance to the addition of human biosolids, growing well even on the 40% amended-medium. LE002 at 15 days after inoculation also exhibited significantly more basidiocarp initials at 20% and 40% amended-medium compared to the control. These results underscore the importance of strain selection for use on long term space mission or on non-terrestrial habitats and the need to expand the test to higher percentage of incorporation, a greater number of shiitake strains, and to evaluate not only mycelial growth but also basidiocarp development.

Efficacy of Chlorine, Hydrogen Peroxide and Heat Treatment on Reduction of *L. monocytogenes* Scott A on Carrot Seeds during Growth and Sprouting*

Presenter: Joi Dunham, Undergrad Student, Food Science, Purdue University
Faculty Sponsor: Leonard Williams, Alabama A&M University
Sponsoring Program: NSCORT

Abstract

Listeria monocytogenes is a Gram-positive bacterium, which has a great resistance to low temperatures, heat, and drying. The objectives of this study were to determine the efficacy of chlorine, hydrogen peroxide and heat treatment in killing *L. monocytogenes* Scott A inoculated onto carrot seeds, the retention of viability of *L. monocytogenes* on dry seeds as affected by storage temperatures of 8^{o}C and 21^{o}C, and the behavior of *L. monocytogenes* on carrot seeds subjected to conditions commercially. The method used for inoculation was suspending the carrot seeds in a solution of 0.1% peptone water and a 24 hour culture of *Listeria monocytogenes* Scott A. The inoculated seeds were divided and held at 8^{o}C for one and six week periods and for a four week period at 8^{o}C and 21^{o}C. The portions were treated with hydrogen peroxide at 0.5%, 5%, and 10% and a chlorine solution at 100, 300, 500, 1000 and 2000 ppm. Additionally, inoculated seeds were germinated and samples were plated to determine the incidence of *L. monocytogenes* on carrot sprouts. Samples were extracted from the treatments and spirally plated onto plate count agar. The plates were incubated at 37^{o}C for 48 hours and then colonies were counted with a plate reader. The chemical treatments established that the trend reduction of *L. monocytogenes* was greater with the 5% and 10% hydrogen peroxide solutions and the 500, 1000 and 2000 ppm chlorine solutions. These results are significant to hazard control of the pre-harvested preliminary stages of food production.

Biological Nutrient Removal in a Multistage attached Growth System

Presenter: Wendell O. Khunjar, Undergrad Student, Howard University
Faculty Sponsor: Charles Glass, Civil Engineering, Howard University
Sponsoring Program: NSCORT

Abstract

This study will present preliminary results on the effect of various loading rates on nitrification of industrial strength ammonia wastewater in a biofilm reactor. The study will be carried out using flow bench scale fixed-film reactors operated under fully submerged conditions. The reactor system consists of 3 glass columns 36 in by 2.5 in (in diameter) with 1.80 L empty volume operating in series with completely mixed, fully aerated conditions in the first stage and plug-flow anaerobic conditions in the second stage. Nitrification will occur in the first stage (aerated state) followed by denitrification (anaerobic stage). Nitrification is the process by which ammonia is oxidized to nitrite and then nitrate. Denitrification is the process by which nitrate is then converted to N_2 gas. Nitrification is the primary process being studied and acclimatization of nitrifying bacteria to industrial strength ammonia wastewater is currently being investigated. Nitrifying bacteria are extremely sensitive organisms and as such, optimum conditions for each loading rate are being investigated. Both the aerator and deoxygenation units will be operated at 1/3 full to represent a liquid volume less than 10% of the reactor void volume. The system will be operated over a period of 3 months during which influent, effluent and biological conditions will be monitored. The current study aims to provide laboratory experience for students in the short-term while being the first step towards a more detailed study of biofilm structure. The study ultimately seeks to provide information to assist with biological regeneration of zeolites.

Understanding Mechanisms of Enhanced Bacterial Cell Adhesion on Novel Nanophase Alumina Sterilization Filters

Presenter: Christian Ghattas, Biological Sciences, University of California-Irvine
Faculty Sponsor: M. Katherine Banks, Civil Engineering, Purdue University
Sponsoring Program: Mark Aim

Abstract

Development of innovative methods for the removal of pathogenic microorganisms from potable water and indoor air is essential for the protection of public health. New technological advancements in the area of nanotechnology have been developed. Advancements include the utilization of materials and systems whose structures and components exhibit novel and significantly changed physical, chemical and biological properties through the manipulation of structures and devices at the atomic, molecular, and supramolecular levels. This may result in new devices that can be used to improve our air and water quality. Although many advanced properties for materials with grain sizes less than 100nm- nanophase materials- have been observed for catalytic, mechanical, magnetic, and electrical applications, few advantages for the use of these materials for applications involving interactions with living cells have been explored [Siegel, 1996; Siegel, 1994; Siegel and Fougere, 1995a and b]. Nanophase materials hold promise for biological applications since all natural materials are composed of nanometer structures. It is speculated that ceramics with greater numbers of atoms at the surface (as would occur for nanophase compared to conventional materials) will alter interactions with proteins that mediate microbial adhesion. In addition, since all proteins are nanostructures, materials with nanometer surface roughness values, or with many nano-surface "bumps," will manipulate absorbed protein conformation to a larger extent than conventional or microstructured surfaces. Nanostructured surfaces may therefore promote exposure of select cell-adhesive epitopes in absorbed proteins to increase cell adhesion; it is not possible to influence absorbed protein conformation (and, thus, exposure of select cell-adhesive epitopes that mediate cell adhesion) on material surfaces in this manner with surface characteristics in the micron regime. For these reasons, it is the central hypothesis of the proposed study that nanophase materials will increase bacterial adhesion and, thus, the design of more effective point-of-use sterilization filters may lead to the more efficient adhesion and consequent removal of bacteria in many applications.

Examination of Biological Growth Rate Kinetics on Commercial Detergents

Presenter: Katherine Graham, Undergrad, Purdue University
Faculty Sponsor: M. Katherine Banks, Civil Engineering, Purdue University
Sponsoring Program: SURF

Abstract

The mission to Mars will be a mission of extended duration in which everything, including water and air, must be recycled in order to limit the amount of materials that are taken on the mission. The water that is taken must be treated well enough that it can be reused countless times throughout the duration of the mission. Part of the treatment plan involves the use of a biological reactor to degrade surfactants, an essential component of detergents, in graywater (shower, laundry, and dish water). NASA has not yet made decisions about detergents to use during long duration space missions. Because biological systems will be used for surfactant removal, it makes sense to use detergents that are most readily biodegradable. The purpose of this study is to determine biological growth rate kinetics for several commercially available detergents. Knowledge of biological growth rate kinetics will allow us to effectively model expected reactor performance and these models will further allow us to maximize reactor efficiency. Tests were performed using a constant concentration of sludge from the local wastewater treatment plant as a bacterial source and varying concentrations of surfactant. Samples were taken several times per day and the data was analyzed to obtain the bacterial growth rates, COD reduction, and microbial concentrations in each surfactant concentration. The results of these growth rate experiments will be presented at the symposium.

Design and Operation of an Air/Water Treatment System for Gray Water

Presenter: Erin Maloney, Undergrad, Purdue University
Faculty Sponsor: M. K. Banks, Civil Engineering, Purdue University
Sponsoring Program: SURF

Abstract

A crucial aspect of supporting life on a long duration human mission to Mars is the ability to recycle cabin air and water supplies. The Bio-Regenerative Environmental Air Treatment for Health (BREATHe) is a part of the multi component life support system that has been proposed by NSCORT at Purdue. The BREATHe system focuses on recycling wastewater and air for reuse. The system will consist of two biological trickling filter reactors that will treat wastewater and waste gas simultaneously. BREATHe I will treat graywater and gas from another component of the life support system, the Solid Phase Thermphilic Aerobic Reactor (STAR), while Breathe II will treat habitat air and atmospheric condensate. The size of the BREATHe I reactor is critical because it must enable the most efficient treatment of water and air possible while minimizing mass, volume, and required power input due to the nature of the environment that it will be used in. The small volume of water that will be treated daily compared to municipal wastewater treatment plants has posed problems in terms of sizing the BREATHe I reactor. Typical assumptions and calculations used for designing biotrickling filters apply to large scale systems, while the BREATHe I reactor will be required to clean only about 55 L/day of graywater. Therefore, size of the reactor was determined by comparing sizes, flow rates, and recycle rates used for bench scale and pilot scale trickling filters found in the literature. Based on the information compiled during the literature search, we propose that the BREATHe I reactor will be approximately 55 L with an average flow rate of 55 L/day. The bench scale reactor currently in use is 5L with a flow rate of 5L/day and a recycle ratio of 10. Experiments are being conducted to determine if the size of the reactor is sufficient to biologically degrade surfactants in the influent solution. Our goal is to achieve 90% removal of chemical oxygen demand (COD). The results of these experiments will be presented at the symposium.

9.1.2 ALS/NSCORT Distance Learning Course Outline

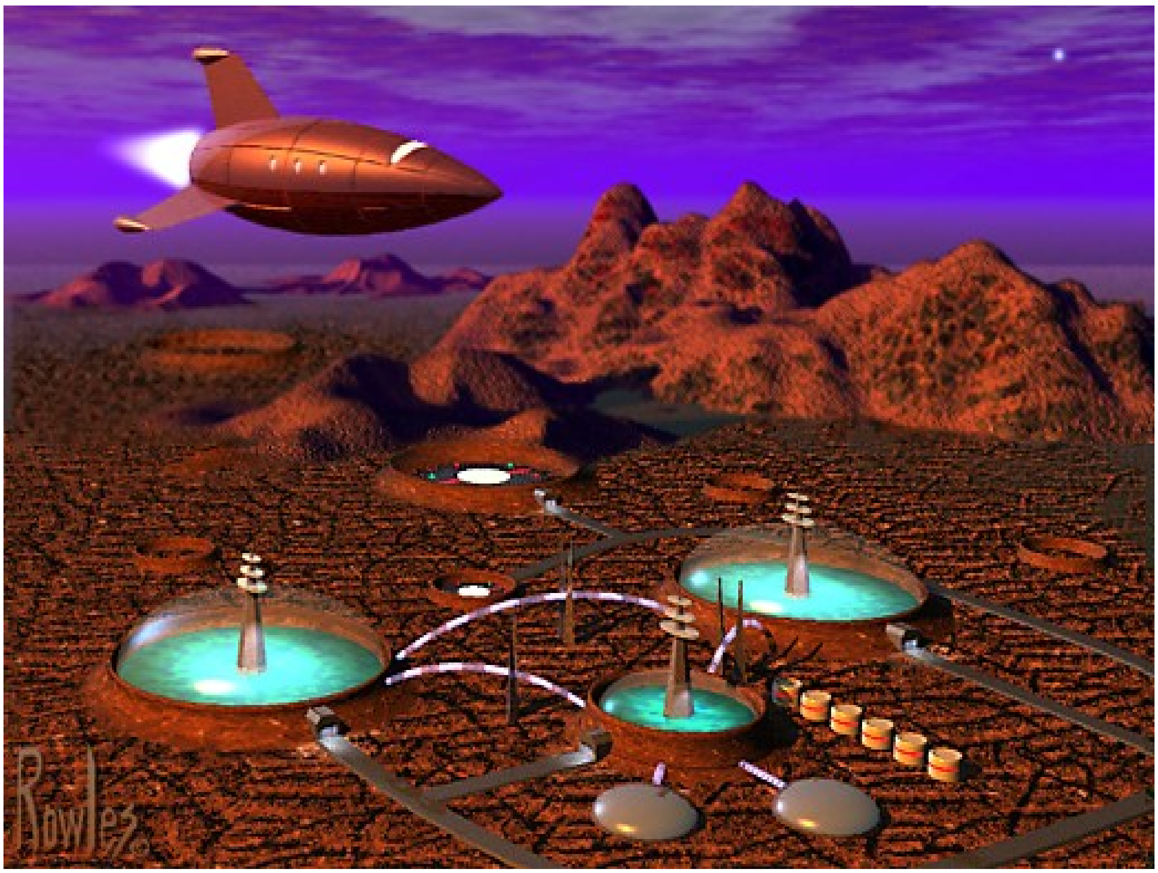
Draft NSCORT Distance Learning Class Listing	
Topic	**Speaker(s)**
Water/Air - BREATHe - 2	Al Heber
Molecular Biology & Food Safety Applications	Bruce Applegate
Bioregenerative Life Support '101' (Retrospective, Current, Prospecti	Cary Mitchell
Extraterrestial Plant Systems '101'	Cary Mitchell
Plants - Lighting	Cary Mitchell
Plants - Shiitake	Caula Beyl
Solids - STAR off-gas	Charles Glass
Water disinfection	Chip Blatchley
Solids - Dewatering	Jeff Volenec & Brad Joern
Welcome & Mars Basics '101' plus 'micro' vs 'low' gravity	Jim Alleman
BVAD…'sinks and sources' basics '101'	Jim Alleman
Habitat '101' - design, protection, volume, energetics, etc.	Jim Alleman
Solids - STAR	Jim Alleman
Systems basics '101'	Joe Pekny & George Chiu
Water/Air - BREATHe - 1	Kathy Banks
Water processing (membranes)	Kim Jones
Food protection	Leonard Williams
Food sources, consumption, packaging, residuals	Lisa Mauer
Solids - Fish	Paul Brown
Martian soil regolith	Steve Fritz
Systems - 2	Yuehwern Yi & Bin Yao

21 classes
3 'field' trips
3 exams

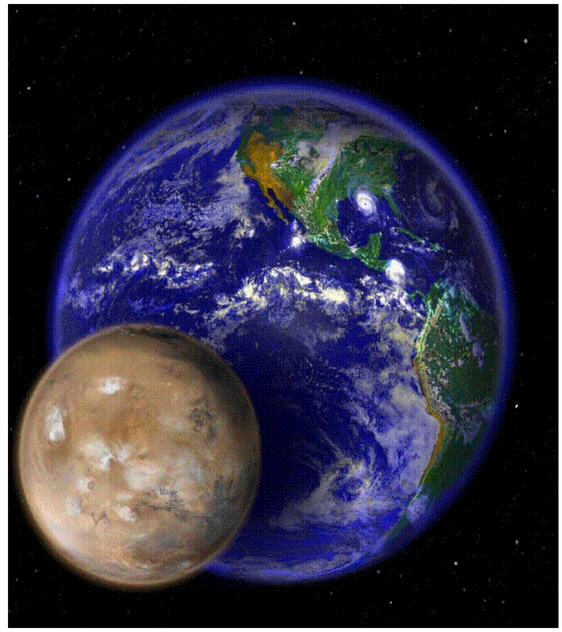
9.1.3 Lafayette School Corporation After-School Program

Mission to Mars After-School Program

Welcome to the After-School Program. You are about to begin the journey of a Mission to Mars, investigating the dangers and challenges that are encountered by visitors on this harsh planet. We are going to learn the "what's and how's" about survival on Mars. At the end of this journey, you will have a new understanding of life in space and on Earth. Have fun!!!!!!



Introduction



Activities

- Earth and Mars: As Different As They Are Alike
  Reference Source: NASA, ALS/NSCORT
- Living in Space
  Reference Source: NASA

.

Ecosystems

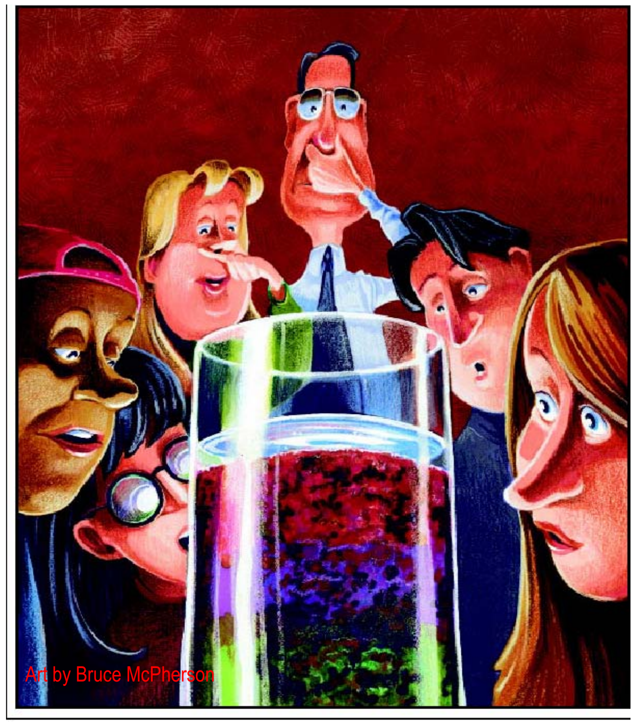
Activities

- Astro-Venture Junior Biology Academy Training.
  Reference Source: NASA Astro-Venture
- Guppy Ecosystem.
  Source: ALS/NSCORT Julia Allen
- Chemistry In A Ziploc Bag
  Source: ALS/NSCORT Julia Allen
- Water Testing in the Ecosystem
  Source: ALS/NSCORT Julia Allen

Waste Treatment – Space Landfills

Activities: ALS/NSCORT adaptations of the following will be used.

- Building a Soda Pop Bottle Reactor:
  Reference Source: Cornell Univ.
- Mud Microbiology.
  Reference Source: NASA
  Winogradsky Column



Water Treatment

Activities: ALS/NSCORT adaptations of the following will be used.

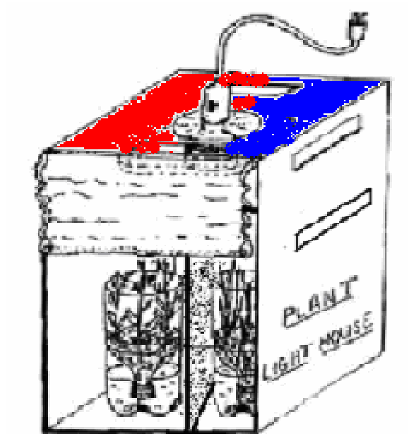
- Biofilms- Microbial Slime
  Reference Source: National Biology Teachers

- Cleaning Gray Water
  Reference Source: Eco-Lab
- Clean Water…Where does it come from in Space?
  Reference Source: NASA

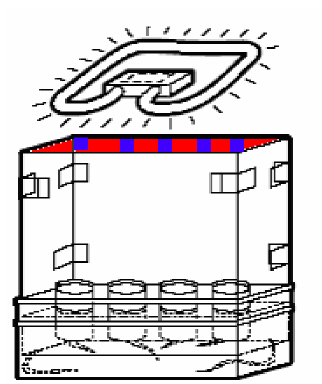
Plants

Activities: ALS/NSCORT adaptations of the following will be used.

- Growing Space Growth Chambers
  Reference Source: Farming in Space NASA



- Investigating Plants In Space
  Reference Source: NASA



Appendix 9.2

Subject Plants: Used in solids separation research

Jeff Volenec