Constructive reuse (versus degradation) of plant biomass residuals with braided twine, rope, hammocks, baskets, etc.
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Message from the Center Director

Dear Friends and Colleagues of the ALS NSCORT:

As the NASA Specialized Center of Research and Training (the ALS NSCORT) approaches the end of its second year of operations, the entire Advanced Life Support community of NASA finds itself in a particularly exciting climate of anticipation, starting with the Presidential announcement of the Space Exploration Initiative last January. A vision of crewed and robotic space missions, first back to the Moon, then on to Mars, and subsequently beyond, gives a unifying charge to the space agency that has been lacking since the Apollo era. A sustainable human presence off the home planet not only will be required to support the science effort needed to answer the long-standing question “Are we alone?”, but will be needed to pave the way for permanent, independent human outposts in space in preparation for a time when Earth no longer can support humanity.
The concept of humans living sustainably outside of Earth’s biosphere is an age-old vision that borrows from ever-growing knowledge of closed-loop life support within Earth’s biosphere. Researchers within the ALS community attempt to mimic, or even improve on, the natural bioprocesses that allow Earth to operate as a life-support system closed with respect to mass but open with respect to energy. The analogous human life-support system for Luna and Mars will be a materially closed, pressurized habitat, likely powered primarily by portable nuclear reactors and compensating for hostile surface environments by locating below ground. Early-generation planetary habitats likely will close life-support loops incrementally, as technology development evolves to accommodate bioprocess flows reliably, efficiently, and affordably. Life-support loops likely will be closed in order of the resupply costs of the heaviest and most life-support-critical components. Thus, water and air-revitalization loops will be closed the earliest, while the food loop may be closed more gradually. NASA sources indicate that it costs about $10,000 to launch a pound of anything into low-Earth orbit; about 7 times that amount to launch mass direct from Earth to Moon; and it presently is estimated to cost about $140,000 per pound to launch mass from Earth’s surface to Mars’ surface. At such resupply cost rates, regeneration strategies for life-support consumables will play strongly into ALS strategies for long-term human life support beyond low Earth orbit.

As a member of the ALS community, the mission of the ALS NSCORT is to synergistically research novel concepts that could mature into advanced life-support technologies to reduce future mission costs. The term “advanced” refers to technologies beyond what are being used on space station. The title of the proposal submitted by Alabama A & M, Howard, and Purdue Universities in response to the year 2000 NRA for the Regenerative Life Support NSCORT competition was “Minimizing Equivalent System Mass for an Advanced Life Support System by Optimizing Kinetics and Energetics of Major Bio-Processes”. At the heart of the Center’s approach to help NASA reduce launch and operational costs of maintaining crewed habitats on Luna or Mars is the concept of “equivalent system mass”. Several parameters in addition to mass contribute to the infrastructure of a planetary habitat including volume, power, thermal control, crew time, and mission duration. A linear additive model expresses the equivalency to mass of those other parameters, and overall ESM is calculated as
ESM = M + (V \cdot V_{eq}) + (P \cdot P_{eq}) + (C \cdot C_{eq}) + (CT \cdot D \cdot CT_{eq}),

where M, V, P, C, T, and D are the mass, volume, power, cooling, crew time, and mission-segment duration for a particular mission scenario, respectively. The ESM components figure logically into the overall cost of any space mission. The sub-eq coefficients are factors that convert the non-mass parameters to mass equivalencies. There is considerable discussion worldwide regarding the numerical values of mass-equivalency factors, and how valid they are for different mission architectures, but no one can argue against the importance of the ESM parameters per se.

Since the ALS NSCORT has been tasked to investigate novel concepts and principles to help NASA reduce ESM for advanced life-support processes, we work in many cases at lower technology-readiness levels involving proof of concept for candidate technologies. The major components of closed-loop advanced life support are represented in the Center, including crop and edible biomass production, food technology and safety, hazard analysis, resource recovery from air, water, and solid wastes, and systems analysis to integrate components into a sustainable life-support system. NSCORT researchers are working to make their candidate technologies lighter, smaller, more energy efficient, and more automated. They discover many catch-22s while trying to optimize all ESM components simultaneously, because reciprocal tradeoffs lurk in the details that make overall ESM resistant to change, unless the novel concept truly is more efficient. For example, a candidate technology to reduce electrical power consumption for one bioprocess may require an increase in crew time in the same or a different ALS sub-system. Thus, the NSCORT systems-analysis group plays a crucial role in helping NSCORT laboratories understand the impacts of their candidate technologies on an entire ALS system. In some cases, calculation of ESM is still a ways off in technology development, but the systems group has adopted the ethic of “sensitivity analysis” for ESM components so that investigators researching for greater efficiency in their own sub-system also are considering opportunities and impacts in other sub-systems. ALS NSCORT researchers are now in their second year of working in the multidisciplinary ALS field. They are being encouraged to become “students of ALS” and to develop a “systems conscience” in terms of what they do, how it impacts, and how it is impacted.
Although the component parameters of ESM are of obvious importance to ALS, and NASA has committed to reduce the ALS ESM three-fold by 2010 relative to that of space station, other issues also must be considered in making decisions regarding which sub-system technologies will be used for different missions, and those considerations don’t presently fit into any equation. For example, the power and energy costs of growing plants for food have caused NASA to put crops on the back burner for now, in favor of early “camping trips” using stored food. However, recent information regarding psychological needs of Antarctic crews living in isolation for long periods of time and how the presence of non-human living things benefits human emotional health may have immeasurable value for future space-mission architectures. Work on crops, fish, and mushrooms within the NSCORT may not always trade well in some mission scenarios by traditional ESM analysis, but their presence in an ALS may be demanded by Mars crews for emotional support as well as for nutritional and resource-recovery purposes. The NSCORT systems-analysis group has been challenged to do trade studies to determine how much other heterotrophic life can be accommodated to support human crews in an ALS without serious competition for common resources.

The three partner universities of the ALS NSCORT not only bring synergistic academic creativity to NASA’s ALS Program Element, but also help NASA in other ways. Each project is staffed with one or more trainees who not only do most of the actual research, but who represent a potential future intellectual resource for NASA. Having been engaged in synergistic, multidisciplinary research for several years, each graduate student and post-doctoral research associate who has been part of the ALS NSCORT will be a totally different kind of professional in the future than if they had not ever been part of the Center. Potential future careers as civil servants, as NASA contractors, or as university PIs funded by NASA are among the employment scenarios that will help those future professionals implement the Space Exploration Initiative. The Lunar outpost and the Mars base both are within the career horizons of NSCORT trainees, and NASA’s support of the ALS NSCORT not only is an investment in future life-support technology, but also in human capital for the space agency.
Another way in which NSCORT helps NASA is through public relations. The Center’s dynamic Education and Outreach program is impacting K-12 students during their most formative years and winning the grassroots support of adult taxpayers and voters. NSCORT Outreach is effective and aggressive, attracting outside funding to supplement Center support. The E & O program engages students in their classrooms, brings them to campus, trains their teachers, seeks out underrepresented groups, and works collaboratively to install space education in the curriculum, nationwide. Theme-based ALS topics involving space life sciences are being piloted in many schools, and a cadre of teachers is being trained to deliver the hands-on curriculum following a training period. The most-often heard term in connection with the NSCORT Education and Outreach program is “excitement”. A Center-wide distance-education course also trains NSCORT and other students in the fundamentals of advanced life support.

The reports of individual NSCORT projects and activities chronicled in the remaining pages of this volume reflect a growing level of collaboration both within the Center as well as with entities outside the Center. Maturing NSCORT researchers are learning to leverage modest budgets between disciplines and projects to achieve synergistic results. The Center is receptive to suggestions for ongoing improvement in its operations, be it research, training, or outreach. We at the ALS NSCORT consider it a privilege to contribute to the ALS Program Element of the Advanced Human Support Technology Program and to help NASA achieve its life-support goals.

Best wishes,

Cary A. Mitchell, Director
ALS NSCORT
3.0 ALS NSCORT
Composition, Infrastructure and Personnel

5 - year grant with NASA
- 1 Dec. 2002 - 30 Nov. 2007
- $2.0 Million in funding for Year 2
- $0.2 Million cost share supported by Purdue University for Year 2
- 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 Deschusses  University of California – Riverside
Alan Drysdale  Boeing/NASA Kennedy Space Center
Les Grady  Clemson University
Morton Barlaz  North Carolina State University
Hua Wang  The Ohio State University
Ray Wheeler  NASA Kennedy Space Center
Desmond Mortley  Tuskegee University

Ex officio NASA:
Dan Barta  NASA Johnson Space Center
Mark Kliss  NASA Ames Research Center

NASA Observers:
Jitendra Joshi  NASA Adv. Human Support Tech Program

Executive Committee

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<td>Pete Dunn</td>
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### ALS NSCORT Co-Primary Investigators by Focus Area

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ALS NSCORT Graduate Students by Focus Area for 2004

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<td><a href="mailto:dwhitaker@purdue.edu">dwhitaker@purdue.edu</a></td>
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4.1 Education and Outreach Program

Executive Summary

The NSCORT 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.

The Education and Outreach program focuses on two thrust areas: Technical/Higher Education which includes the Summer Fellowship Program and ALS/NSCORT Distance Learning Course and 2) K-12 Education which includes Key Learning Collaborative Project, Mission To Mars and Equivalent Systems Mass Analysis of Plant Growth.

Technical/Higher Education has grown significantly. The Summer Fellowship Program trained 7 undergraduate fellows in the Summer 2004. Included in the fellowship were two elementary education students from Alabama A& M who received intensive training on the K-12 programs of Education and Outreach. Funding was allocated to employ these students during the 2004-2005 school year in Alabama, extending the reach of NSCORT into the Alabama schools. ALS/NSCORT Distance Learning Course was offered for the first time in the Spring 2004. Thirty students were enrolled in the course.
K-12 Education grew exponentially. Key Learning Collaborative Project developed significant research programs on-going in the school laboratory. The project was expanded to include an “Explore Mars” summer camp which provided 150 Key Learning students the opportunity to spend 3 days/nights on the Purdue University campus, interacting with NSCORT researchers and graduate students. The camp was financed with funds of over $20,000.00 which were obtained through grants written by NSCORT Outreach manager. Lafayette School Corporation funded ($4,000) and piloted the Mission To Mars program in four elementary schools in 2004. Numerous professional development programs were offered throughout Indiana as well. Two significant proposals have been submitted to date for the funding of professional development workshops and nationwide dissemination of the Mission To Mars program. Equivalent Systems Mass (ESM) Analysis of Plant Growth project was funded by a $25,000 SBIR grant to develop an 18 week curriculum module for high schools involved with Project Lead the Way. This module incorporates BPES growing systems and students’ analysis of calculated ESM values. A pilot program is on-going to date with an expanded pilot program planned for January 2005. Project Lead The Way will incorporate this module into their national network in June 2005.

This year, ALS/NSCORT Education and Outreach K-12 programs alone have reached 516 teachers and 16,177 students.

Julia Hains-Allen
Education and Outreach
4.2 PROJECT SEVENTEEN: EDUCATION AND OUTREACH

**Principal Investigator**  Julia Hains-Allen, Outreach Manager, Purdue University

**Co-Investigators**  M. Katherine Banks, Purdue University

**Project Goals and Objectives**
- Increase the number of students/educators who are involved in NASA related education opportunities.
- Increase the scientific literacy of K-12 educators, students and general public, fostering public awareness and the earth benefits of NASA research.
- Increase the number of students directly engaged in NASA research.
- Increase the number and diversity of students who pursue graduate degrees and research careers in NASA related science, engineering and technology fields.
- Increase higher education research capability and opportunities that attract and prepare students for NASA related careers.

**Cumulative Research Progress to Date**
Education and Outreach program focuses on two major areas: 1) Technical/Higher education, and 2) K-12 education.

**Technical/Higher Education**

**Summer Fellowship Research Program:**
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. Summer Fellowship applicants indicate a preference for a particular faculty member and NSCORT site. Fellowships are awarded according to faculty choice and project compatibility.

ALS/NSCORT provides round trip transportation, room at the research institution plus a $3600 stipend for the eight-week research opportunity. A two-day scientific symposium culminating the summer research experience is held at one of the research institutions in August, allowing each summer fellow to present their work to their peers in a scientific presentation.

In addition to the data gathered from the 2003 program, the ALS/NSCORT Education and Outreach Group consulted numerous sources on “best practices” for summer fellowship programs to gather information on redesigning portions of the program. The following changes were made to the 2004 Summer Fellowship Program:
1. Funding included room and transportation to/from the research institution.
2. Fellowships were offered in Education/Outreach increasing the geographical contact area for outreach. Only Alabama A&M and Howard students were eligible.
ALS NSCORT Summer Fellowship Undergraduate Students: (L-R) Lenwood Purce, AAMU; Asha-Dee Celestine, Howard University; Shandra Stafford, AAMU; Andy Hai Ting, Howard University; Preciaus Heard, AAMU; SURF Undergraduate Students, Rebecca Lattyak, Purdue University; Stephen Clark, Purdue University.
In 2004, seven fellowships were offered. Four students from Howard University and three students from Alabama A&M participated in the program. Two of the students from Alabama A&M received fellowships in Education/Outreach, creating a new program within the fellowship program. In addition to the 8 week summer research, this new addition allows the Alabama students to continue the fellowship and present Education/Outreach programs in Alabama during the 2004-2005 school year. The program will significantly increase the reach of ALS/NSCORT Outreach into the Alabama educational community.

**Space Advanced Life Support Distance Course (see James Alleman’s section for report)**

**K-12 Education**

**Key Learning Community Project**

In the fall of 2003, the ALS/NSCORT Center 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. Key Learning Community Collaborative Project provides exposure, mentoring and research opportunities for 9-12th grade students at Key Learning Community. The collaboration will focus on developing successful 9th-12th grade outreach strategies for ALS/NSCORT.

In a science laboratory at Key Learning is an actual prototype bioreactor designed by Purdue Engineering researchers to remove surfactants from gray water in the Mars habitat. Key students are performing research on this bioreactor, including reactor performance assessment with liquid influent. In addition, Key students are raising Tilapia, the fish that will serve as a bioreactor of nutrient species thus reducing Equivalent Systems Mass (ESM) in the ALS/NSCORT space habitat design. Hydroponics plant growth research was added in July 2004.

Purdue University researchers and graduate students provide mentoring for the students during the research period via email communication, classroom visits, university trips and a summer camp experience. This collaborative project provides Key Learning Community teachers and students with an arsenal of experiences that make learning science, technology, and engineering exciting without sacrificing rigor.
Explore Mars Camp

Expanding the collaborative relationship, a summer camp experience was added in August 2004. One hundred and fifty Key Learning high school students stayed on Purdue’s campus from August 4th to August 6th. The camp experience provided some students with an expanded opportunity to conduct research in other areas of ALS/NSCORT while other students will increase the depth of the present research on-going in the school. Further ensuring the success of the camp program, students self-selected the research area in which they wished to work during the camp experience. Key students were also exposed to other areas of engineering provided by a new partner, Department of Engineering Education, on Purdue’s campus. This cutting-edge department ran short courses for the Key students during camp, focusing on topics such as Nosecone Simulation, Radio-Controlled Engines, Space Materials and Engineering a Sneaker.

An important component of the camp experience was the opportunity for some students to create and produce a documentary on Explore Mars and the on-going research. A select group Key Learning communication students worked on this product in lieu of the laboratory research. The result of this will be a 10 minute video that can be used by ALS/NSCORT outreach in the future, showcasing the collaborative program. Over $20,000 in funds from partners were leveraged for this camp experience.

In addition, the Explore Mars Camp integrated the Summer Fellowship program into the camp experience. Undergraduate students participating in the Summer Fellowship Program served as mentors and counselors in the dorms while graduate students and researchers advised students in the laboratory research.
Mission to Mars

Education and Outreach has developed and pilot tested a standards/inquiry-based module, introducing 5th-8th grade students to the complex issues involved with living in a habitat on Mars. The module includes laboratory exercises revolving around the study of plant growth, ecosystems, water and waste treatment, recycling and food production.

The “Mission to Mars” module provides teachers with a collection of standards-based, multi-disciplinary hands-on activities that are easily used in classrooms and after school programs. In keeping with the National Science Education Standards (NRC, 1996) and Inquiry in the National Science Education Standards (NRC, 2000), the “Mission to Mars” module facilitates science instruction that actively involves students in meaningful experiences that provide opportunities to develop inquiry abilities and understanding to promote scientific literacy. Module activities are based on cutting-edge research that is ongoing in the ALS/NSCORT. These direct links with research and current events serve to build teacher expertise in cutting edge science, while stimulating student interest by connecting learning to real-life challenges.

The “Mission to Mars” module includes the background information teachers need to understand the science content, eleven comprehensive 5-8th grade standards-based activities, teacher guides and material lists along with implementation instructions. Macon Fish, ALS/NSCORT graduate student, has developed a content and attitudinal assessment tool which is being piloted in 15 classrooms during October-December 2004.

Formal (1-2 day) professional development programs in FY04 trained one hundred and twenty three (123) 5th-8th grade teachers and Extension educators. Those formal professional development programs are indicated by an asterisk in the Projects/ Presentation section of this report. Evaluation materials have been given to all educators participating in professional development programs to date. Data obtained from the evaluation clearly demonstrates that the “Mission To Mars” program is: a) highly applicable to their classroom and b) contains a large amount of standards/based science content they can easily integrate into their curriculum.
Response to this program has been overwhelming. The pilot program in FY04 resulted in the participation of 100 Lafayette School Corporation students. In FY05, Lafayette School Corporation has requested the program be offered to 250 students, expanding the program from after-school to intersession classrooms. Funds of $8,000 from LSC will be used for this request. A professional development program offered in the fall 2004 was filled the first week following an email solicitation. 15 teachers are on the waiting list for the next professional development program.

**Project Lead The Way**

NASA Advanced Life Support has joined with Orbital Technologies to design Biomass Production Educational Systems (BPES), a research grade plant growth chamber that can be used in high school classrooms across the country. ALS/NSCORT Education and Outreach, lead by Julia Hains-Allen, has designed learning modules integrating the BPES and ESM analysis. Students will use the research grade plant growth chambers and design experiments that investigate:

- Variables needed for plant health, determining best conditions for optimum growth
- Species and varieties best suited for space travel
- Design improvements to plant growth chambers

Using experimental results from the BPES and statistical analysis, students calculate ESM values on all variables, species and design improvements. Data provided by NASA allows students to compare their experimental results (ESM values) and determine the feasibility of their experimental designs. A website will be developed, serving as a student depository of data, student resource, and student collaboration center. This is a collaborative project between the ALS/NSCORT team and Project Lead The Way. The ALS/NSCORT team will be responsible for the development/revisions of the learning module and Project Lead The Way will be responsible for the implementation and dissemination of the module within their national network.
Background

In February 2004, Project Lead The Way (PLTW) contacted Julia Hains-Allen for assistance in the development of a new sequence of learning modules for Biotechnical Engineering. In response to the request, a team consisting of Julia Hains-Allen, Gus Koerner, Ross Remiker, Gioia Massa, George Applequist and Macon Fish designed a skeleton framework for a module *Equivalent Systems Mass Analysis of Plant Growth*. This module was presented to Indiana Department of Education Project Lead The Way team in March and was accepted into the Project Lead The Way National Biotechnical Engineering sequence. Project Lead The Way Inc. (PLTW) is a national program forming partnerships among Public Schools, Higher Education Institutions and the Private Sector to increase the quantity and quality of engineers and engineering technologists graduating from our educational system. Early on, PLTW became partners with the High Schools That Work initiative of the Southern Regional Educational Board (SREB) with schools in 27 states. Currently, PLTW offers its program in 31 states from New York to California.

Module Development

- June 1, 2004 Orbital Technologies delivered three BPES systems to ALS/NSCORT for the initial development of the learning module *Equivalent Systems Mass Analysis of Plant Growth*. Macon Fish, Agriculture Education graduate student, lead a team in the development of the learning module. The team consisted of Macon Fish, Julia Hains-Allen, Jeff Martin, Project Lead The Way teacher in Indianapolis and Carol Martin, Math teacher in Lakeland, FL. Funding for the module development was provided by a $25,000 Orbitec sub-contract via a NASA SBIR grant.
Project Lead The Way (Continued)

Key concepts addressed in the module are:

- Factors that effect plant health and optimum growth
- Analysis factors required for ESM value calculations and systems applications
- Plant varieties and species to be used in space travel
- Statistical analysis of data
- Investigating unprecedented problems

Benefits of space research to Earth agriculture systems August 1, 2004 module development was completed and the initial pilot testing began at McKenzie Learning Center, MSD Washington Township School Corporation, Indianapolis. This pilot is lead by Jeff Martin, Project Lead The Way teacher at McKenzie. A second pilot testing period is planned in January 2005. This testing period will include 10 teachers throughout Indiana and Florida. At the completion of this pilot period, the learning module will be integrated into the Project Lead The Way curriculum.

Indiana Department of Education Project Lead The Way will be financially responsible for the professional development and initial implementation into the Project Lead The Way national network. National implementation will be the financial responsibility of Project Lead the Way national organization. ALS/NSCORT team will serve as consultants and resources during the first and second pilot period. Julia Hains-Allen will serve on the Project Lead the Way team as the lead consultant and liaison between the ALS/NSCORT development team and Project Lead the Way National throughout the entire module testing, implementation, professional development, and subsequent national dissemination to ensure NASA missions and goals are met.
Future Research Directions

Summer Fellowship Program

Fall 2004  Evaluation of 2004 program and program changes
Spring 2005  Begin application process for 2005 summer program
Summer 2005  Summer Fellowship Program

Key Learning Community

Fall 2004  Continuation of research projects in Key Learning Science Lab
Fall 2004  ALSNSCORT/Key partnership on submission of Indiana Commission of Higher Education Grant.
Spring 2005  Expand collaborative project to include 2nd-8th grade students via professional development on “Mission To Mars”
Fall 2005  Implementation of “Mission To Mars” into Key Learning 2nd-8th grade curriculum

Mission To Mars Program Dissemination

Fall 2004  Mission To Mars module launched on www.spaceplace.org
Fall 2004  Alabama “Mission To Mars” dissemination
December 2004  Mission To Mars Thesis pilot program completed
January 2005  Begin thesis evaluation of Mission To Mars program
August 2005  Macon Fish Graduate Thesis completed: “Mission To Mars: Evaluating a 9 week Inquiry Based Program”
FY 2005  Local/Regional professional development
        IVY Tech professional development
        Home school educators workshop
        4-H Extension educators workshop
        Alabama Professional Development workshop
        Regional conventions extended day professional development workshops

Project Lead The Way

Fall 2004  First pilot period for module “Equivalent Systems Mass Analysis of Plant Growth”
January-May 2005  Second pilot period
Pilot Teachers
  •  Jeff Martin, Lead Teacher, McKenzie Career Center
  •  Ralph Neth, Key Learning Community
  •  Carol Martin, Math Consultant, Columbia High School
  •  5 additional teachers (to be announced)
July 2005  Professional development for 12-15 teachers on the learning module
August-Dec 2005  Third pilot period testing of learning module.
Trainees
Macon Fish, Agriculture Education, Masters in Agriculture Education
Lenwood Purce, Elementary Education, Bachelor of Science in Elementary Education
Shandra Stafford, Elementary Education, Bachelor of Science in Elementary Education

Research Collaboration

**Internal NASA Partners**
ALS/NSCORT Researchers
NASA Biological Sciences
NASA AHST
ALS Education and Outreach Working Group
Space Ag in the Classroom
NASA Ames – AstroVenture
Ned Penley, JSC
Marybeth Edeen, JSC
Space Grant Consortium
NASA Nanotechnology Center

**External NASA Partners**
Alabama A&M Department of Education
Indiana Department of Education
Project Lead The Way
Key Learning Community
Department of Curriculum/ Instruction, Purdue University
Lafayette School Corporation
Orbitech Technologies
Imagination Station
Department of Engineering Education
Department of Agriculture Education, Purdue University
Challenger Learning Centers
4-H Extension Educators
IVY Tech
NLIST
Brownsburg Community School Corporation
MSD Washington Township School Corporation
MARC/AIM Program
NSF Nanotechnology Center, Purdue University
Great Lakes Chemical Company
Dow AgroSciences
Bioanalytical Systems, INC.
Projects and Presentations To-Date:

Hains-Allen, Julia, Neth, Ralph, “Key Learning Research” November 2003-June 2004
Teachers: 1 Students: 100

 Teachers: 4 Students: 125

Massa, Gioia, “Mission To Mars” NLIST Conference November 21-22, 2003
State Sciences Supervisors: 35

Hains-Allen, Julia, Neth, Ralph, “Key Learning Research” OBPR Conference, January 2004

Hains-Allen, Julia, “Mission To Mars” HomeSchool Association of Tippecanoe County, January 21, 2004
Teachers: 15 Students: 50

Hains-Allen, Julia, “Mission To Mars” Orchard School February 25, 2004
Teachers: 2 Students: 25


Gardner, Guy, Fish, Macon “Mission To Mars” ESTME Expo March 16, 2004
Teachers: 30

*Hains-Allen, Julia, “Mission To Mars”, Hammond City School Corporation March 16, 2004
Teachers: 20 Students: 2,000

*Hains-Allen, Julia, Fish, Macon “Mission To Mars” 4-H Extension Educators March 31, 2004
 Extension Educators: 30 Teachers: 300 Students: 9,000

Hains-Allen, Julia, Fish, Macon, Martin, Jeff “Equivalent System Mass Analysis” Project Lead The Way, May 21-22, 2004

Hains-Allen, Julia, Fish, Macon “Summer Fellowship” June 9-July 31, 2004
Students: 2

*Hains-Allen, Julia, Fish, Macon “Mission To Mars” Agriculture Teachers June 9, 2004
Teachers: 30 Students: 900

Hains-Allen, Julia, Fish, Macon, Martin Jeff, “Project Lead The Way” June 15-August 15, 2004

Hains-Allen, Julia, Neth, Ralph, “Key Learning Research”, July 2004-June 2005
Projects and Presentations To-Date: (continued)

*Hains-Allen, Julia “Mission To Mars” IVY Tech July 7-8, 2004
Teachers: 6  Students: 600
Coulter, Gary, Hains-Allen, Julia “Mission To Mars” Space Foundation Teachers,
July 13, 2004
Teachers: 30  Students: 200 (limited workshop exposure)
Banks, Katherine, Hains-Allen, Julia “NSCORT Outreach, ICES”, July 14, 2004
Kotterman, Dave, Hains-Allen, Julia “Summer Fellowship Symposium”, August 2-3, 2004
Students: 18
Hains-Allen, Julia “Explore Mars Camp”, Key Learning Community, August 4-6
Teachers: 15  Students: 150
*Hains-Allen, Julia, Fish, Macon, “Mission To Mars” Challenger Learning Center Teachers,
August 12, 2004
Teachers: 30  Students: 450 elementary 2000 middle
Hains-Allen, Julia, Fish, Macon, Martin, Jeff, “Project Lead The Way Pilot”, August-December 2004
Teachers: 1  Students: 25
*Hains-Allen, Julia, Fish, Macon, “Mission To Mars” Thesis study training, September 17-18, 2004
Teachers: 17  Students: 300  Note: this workshop will have teachers (5) already
involved in program.
Hains-Allen, Julia, Quimpo, Robert, “Mission To Mars” After-school/intersession program
September 2004-April 2005
Teachers: 8  Students: 250

Totals
Teachers: 516 (teacher numbers in italic are projected reach, determined by workshop
capacities)
Students: 16,177 (student numbers in italic are projected reach, determined by teacher
class size)
**Education & Outreach**

Note: Numbers are based on potential reach of educators trained. Extension Educators have the potential for the largest reach as they each work with approximately 10 teachers, primarily in elementary school. Therefore, the number of teachers reached through the Extension Educators is significant.

The teachers trained in the ALS/NSCORT programs varied in grade level; therefore the student projected reach is not calculated on an average. Middle school teachers have approximately 100 students in their classrooms, while elementary teachers average 25 students in their classrooms.

In addition, the projected reach was based on evaluation materials, not direct contact with the teachers after the professional development. Follow up contact is planned for the Spring FY05 to gain insight into classroom implementation of professional development material.

**FY04 Roadmap**

Education and Outreach activities are outlined in the roadmap on the following page. The activities are categorized in groups with specific milestones listed. The individuals responsible for or participating in the activity are listed using colors that respond to the institution where they are located. In addition, the names are listed in a key at the bottom of the page along with the institutions’ color representation.

The significance of this roadmap is that minority institutions’ participation has increased extensively in FY04 as compared to a FY03 roadmap that would have been predominantly blue. Another substantial increase in minority institutions’ participation in ALS/NSCORT Education and Outreach is planned for FY05 as indicated by the October/November column on the roadmap. Dissemination of Mission to Mars throughout Alabama is just beginning and will continue throughout FY05. Key Learning Community and Project Lead The Way will both experience considerable minority participation, indicated on the road map by planning/strategizing sessions between Purdue, Howard and Alabama A&M occurring in October and November. John Trimble at Howard University and Julia Hains-Allen will lead the integration of System Dynamics software STELLA (Systems Thinking Experimental Learning Laboratory Animation) software into the Key Learning Community Project and Project Lead The Way. A student at Howard University will be intricately involved as well. Project Lead The Way will also be integrated into Alabama A&M as Caula Beyl will have a BPES chamber in her laboratory and do pilot studies with the chamber in the Spring of FY05.
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‘Space Advanced Life Support’ Distance Course : Jim Alleman

Our Spring 2004 ALS/NSCORT Distance Learning ‘Space Advanced Life Support’ course was developed and presented on an experimental basis to 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 graduate and undergraduate students either directly working with, or academically curious about, our ALS research mission. The course was managed by Jim Alleman on a Tues-Thurs 75-min schedule basis, with 15 total guest speakers covering various classes during the entire semester’s 30-class schedule. Student enrollment included 26 local students and 5 remote students, and another 4-5 NSCORT staff typically listened in via the Web during most classes. The volunteer speaker roster was largely composed of NSCORT faculty, as well as doctoral-level graduate students and NSCORT center personnel and post-doctoral research assistants. In addition, the class greatly enjoyed lectures by former and current NASA personnel, including astronaut Guy Gardner (STS-27 and STS-35) and Karen Ross (the Manager for Space Food Processing with United Space Alliance), and a number of field tours to ongoing NSCORT project sites.
Both real-time local and remote, plus post-presentation video, access to the course lectures was provided using state-of-the-art Web-based systems. In general, the content of the course offered a state-of-the-art introduction to the complex challenge of life support for astronauts working in space (i.e., during lunar, Mars, etc. missions) covering each of the major interdisciplinary aspects. As can be seen in reviewing the syllabus given on the following page, the following interdisciplinary aspects were addressed:

- water supply and closed-loop recycle
- waste processing and high-level water/nutrient recovery
- air rejuvenation and bioregenerative oxygen resupply
- water, waste, and air disinfection
- food packaging and preservation
- bioassay assessment of critical life support via molecular biology tools
- energy-efficient crop production

In retrospect, this course provided yet another creative opportunity for ALS/NSCORT researchers to participate in, and contribute to, a team-building process that synergistically contributes to our center’s success as a whole. Yet another benefit to the course.
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33- ALS NSCORT ANNUAL REPORT 2004
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Two edible biomass research projects are supported by 10% of the NSCORT budget. One project bridges between biomass production and resource-recovery sub-systems. A third project funded within solid-waste management bridges to the edible biomass area. The two bridging projects involve either fungi that grow on inedible crop residue, with fruiting bodies that are exotic edible mushrooms, or tilapia fish with some capacity to digest crop tissues that humans cannot. Thus, both projects potentially extend the harvest index of crop production by converting lignocellulose to substrates for growth of intermediate organisms that can be eaten by humans. Fish, of course, could provide balanced protein and calcium to supplement a mostly vegetarian ALS diet, and mushrooms could psychologically augment crew diets through texture, flavor, some nutrition, and interest. The main benefit of white-rot fungi, however, might be to pre-treat and “soften” vegetation that fish have a hard time digesting. If tilapia find fungal-treated crop residue to be palatable, a positive synergism could occur between the two bridging projects and the crop-production project of the NSCORT. Since both “processor organisms” also are heterotrophic, the systems group, in collaboration with the fish, fungal, and crop labs, are calculating how much fish and fungal biomass production can be accommodated in an ALS before the benefits to humans are superceded by competition for resources such as oxygen.

The crop-production project focuses primarily on reducing costs of plant-growth lighting. Greenhouses are not a viable option for growing plants on the moon or Mars. Lack of a geomagnetic field to divert cosmic-galactic and solar radiation puts life on the Lunar or Martian surfaces at risk. Glass, plastic, cloth, or metal do not adequately shield organisms on the surface against genetic or somatic damage from incident radiation, but several meters of regolith does. The loss of geomagnetic field likely caused the solar wind to gradually blow away most of the Martian atmosphere, and today UV-C and micrometeorites encounter little resistance reaching the surface. If Mars habitats are located underground or are bermed over with regolith, plants within them cannot receive solar radiation, unless it is piped below ground. Airborne dust and sandstorms further cloud the reliability of solar radiation, even as an indirect source of energy for plant growth. Electrostatic dust even threatens the cooling fins of surface nuclear power generators, which could limit their efficiency.
The crop-production project is combining a novel architecture for distribution of photosynthetic radiation together with low-power, solid-state radiation sources that closely match absorption spectra of photosynthetic pigments. A major goal of the project is to reduce ESM for crop production in ALS by at least an order of magnitude. Secondary goals include introduction of fruit species with high anti-oxidant content to help mitigate radiation damage to humans, to reduce crew time in managing hydroponic nutrient solutions, and to develop cultural methods for reducing the growth area of vining crops.

Cary A. Mitchell, Group Leader
Crop/Biomass Focus Area
5.2 PROJECT ELEVEN: MINIMIZING ESM FOR ALS CROP PRODUCTION

**Principal Investigator**: Dr. Cary Mitchell, Professor of Plant Physiology, Department of Horticulture and Landscape Architecture, Purdue University

**Project Goals and Objectives**

- **Primary Goal**: Reduce ESM for crop lighting sufficient to reintroduce plants into ALS.
  -- Objective: Develop and validate two light-distribution systems combining solid-state, low-power sources with narrow-spectrum emissions matching absorption maxima of plant pigments and incremental switching involving tissue sensing.
- **Secondary Goals**:
  -- Reduce crew time for management of hydroponic nutrient solutions.
  -- Introduce fruit species with anti-oxidant and desirable organoleptic qualities.
  -- Restrict vining crops to limited growth volume.
  -- Provide crop biomass and nutrient solutions to other NSCORT laboratories.

**Cumulative Research Progress to Date**

- The first intracanopy LED array has been designed, constructed, and tested. Mounting of the lightcicles has been completed and initial testing of light uniformity and the development of voltage vs. intensity curves are underway. Hydroponics systems have been fully tested, and environmental conditions for growth of cowpea, the first intracanopy test crop, and lettuce, the first close-canopy test crop, have been established. Plant residue from these trials has been used by our collaborators.

- Design and testing have been performed on a pH control system for the hydroponics systems by Moeed Mukhtar, under the mentorship of Dr. George Chiu. Development of the system involved extensive comparisons of existing technologies, as well as custom development of modeling software. Acid and base control of hydroponic solution pH have been established, without plants, and the changes due to plants are being tested.
The day-neutral strawberry cultivars ‘Tristar’, ‘Tribute’, ‘Seascape’, and ‘Fern’ have been examined. Productivity has been measured under three pruning strategies and different fertilization regimes. All cultivars had higher productivity if runners were removed. ‘Tribute’ produced the largest number and mass of berries in the interval between 3/4/04 and 8/20/04. However, ‘Seascape’ plants produced the largest individual berries. Currently, plants of each cultivar are in growth chambers at three different temperature regimes, and productivity will be compared with that of greenhouse plants.

Four cultivars of low-bush blueberry (‘Top Hat’, ‘Brunswick’, ‘Northstar’, and ‘Patriot’) and one cultivar of cranberry (‘Stephens’) were obtained. Growth media have been tested, and fertilizer, temperature, and lighting regimes were selected to promote growth. Current work emphasizes plant hormone treatment to produce fruit without pollination, propagation from cuttings, and development of a hydroponic growth system.

A variety of pruning, defoliation and cultivation experiments were performed using the sweetpotato cultivar TU-82-155. Proximate composition and Vitamin A analyses were conducted on sweetpotato roots using different container volumes and pruning regimes. No significant effect of cultivation practice was detected. Small root containers have been selected for high yields, and space-managing practices involving coiling of vines are being investigated.
Eight cultivars of basil were grown and pruned in several different ways. Current data demonstrate that bush basil varieties, such as ‘spicy globe’ are suited for ALS production. Rooting from stem-tip cuttings and hydroponic growth also were successful.

The crops group has engaged in a variety of education outreach activities including several tours to student and community groups, and participation in the ALS summer camp, running a module for students entitled “Building a Hydroponics System!”, which taught high school students the fundamentals of hydroponic plant growth, trained them to build their own system, and sent system supplies and suggestions for experiments back with the students to the classroom. In addition, we have been involved in planning activities for the “Project Lead The Way” program designed by Julia Haines-Allen.

A website was created for Dr. Mitchell’s lab. This site has information about the projects and the people engaged in them, as well as links to other relevant information. [http://www.hort.purdue.edu/hort/research/mitchell/](http://www.hort.purdue.edu/hort/research/mitchell/)
Future Research Directions

An SBIR proposal was submitted to NASA in collaboration with Orbitec in September, 2004 to develop software for automated plant tissue sensing coupled to on/off switching of LEDs on individual light engines of intracanopy and close-canopy lighting arrays. This project will add a further degree of sophistication to the overall efficiency of both light-distribution systems by creating a capability to switch on light engines only when plant tissues have grown in front of or below them, thereby avoiding waste of photons by lighting empty space. Automated sensing will control switching without manual input, thereby saving crew time, electrical energy, and improve efficiency of photon absorption. This activity will occur during years 3 and 4.

During the remainder of year 2, a second LED array configured for close-canopy (CC), planar lighting (an overhead horizontal lamp bank) will be constructed by Orbitec and delivered to Purdue. This array will be used as an overhead lighting control for intracanopy (IC) lighting with separate, vertical strips hanging within closed canopies of planophile crops (leaves perpendicular to overhead light). Both IC and CC arrays can be reconfigured for use either with planophile or erectophile (leaves parallel to plane of overhead radiation) crops.

During year 3, one additional IC array and one additional CC array will be constructed, incorporating upgrades from experience gained from working with the first two arrays. The two additional lighting arrays will be mounted within whole-canopy cuvettes equipped for temperature control, atmospheric flow, and CO₂ gas analysis. Crops will be evaluated for real-time photosynthetic and transpirational responses to changes in light intensity, light quality, and CO₂ level, as well as longer-term changes in growth, morphology, and yield.

During year 3, the secondary objective projects will be brought to the level of publication. Focus for the remainder of the project will be on crop studies with the IC and CC lighting systems.

Trainees

- Dr. Gioia D. Massa—Post-Doctoral Research Associate
- Mercedes Mick—Senior Undergraduate in Horticultural Science
- Richard Kennedy—Junior Undergraduate in Landscape Horticulture and Design
- Erin Christ—Junior Undergraduate in Landscape Architecture
- Javier Campos—Junior Undergraduate in Horticultural Production and Marketing
Research Collaboration

- Collaboration with the NSCORT laboratory of Dr. George Chiu (Mechanical Engineering, Purdue University) to automate pH control within recirculating hydroponics systems growing crops in growth chambers. ME Graduate student Moeed Mukhtar is developing a system that will eliminate 1.5 to 2 hours per day of crew time otherwise required for manual adjustment of nutrient solutions, and which likely will result in more productive crop growth because daily pH swings will be eliminated.

- Collaboration with Orbital Technologies Corporation, of Madison, WI in developing intracanopy and close-canopy lighting systems based upon printed-circuit LED technology.

- Collaboration with Dr. Robert Joly, Department of Horticulture and Landscape Architecture, Purdue University, in measuring photosynthetic rates of sweetpotato leaves of different ages along vines as a strategy for base-up defoliation to maintain compact, coiled vines without mutual shading losses of productivity.

- Collaboration with Dr. Desmond Mortley, Tuskegee University Space Life Support Center and the NSCORT lab of Dr. Lisa Mauer, Food Science Department, Purdue University, to determine effects of different sweetpotato pruning, defoliation, and training practices on yield, proximate composition, and beta-carotene content of sweetpotato roots.

- Service function to prepare and provide crop-residue biomass and nutrient solutions to the NSCORT labs of Dr. Caula Beyl, Alabama A & M University (fungal substrate); Dr. Jim Alleman, Civil Engineering, Purdue University (solid-waste bioreactor feedstock); Dr. Paul Brown, Forestry and Natural Resources, Purdue University (fish feed); Dr. Kathy Banks, Civil Engineering, Purdue University (waste-water bioreactor feedstock); Dr. Lisa Mauer, Food Science Department (wheat production), and Dr. Bruce Applegate, Food Science Department, Purdue University (hydroponic solution as a potential bacteriostat for pathogens).

- Collaboration with Dr. Yang Yang, Department of Horticulture and Landscape Architecture, Purdue, and Dr. Jonathan Frantz, USDA-ARS, University of Toledo, OH, on the development of gas-exchange systems for optimization of LED lighting arrays.

- Service function to ASAE in organizing Session 37 (Biomass Production), securing reviews, and accepting/rejecting papers for the 2004 ICES conference.

- Service as Senior Editor for Human Support Technology for the Habitation Journal, selecting Associate Editors, and assigning manuscripts to specific review editors.
Publications and Presentations To-Date:


Pending Research Milestones and Benchmarks

- Initial testing and crop cycle using lightcicles to be completed December, 2004.
- Second array for use as overhead control - complete January, 2005.
**5.3 PROJECT TWELVE: SOLID WASTE PROCESSING USING EDIBLE FUNGI**

**Principal Investigator**  
Dr. Caula Beyl, PhD., Professor, Department of Soil and Plant Science, Alabama A & M University

**Co-Investigators**  
Dr. L.M. Nyochembeng  
Dr. R.P. Pacumbaba

**Project Goals and Objectives**

One of the hallmarks of NASA’s successful extended space explorations will be the crew’s ability to produce their own food and recycle residual wastes, thus minimizing mass and eliminating costly replenishment of supplies. Edible fungal species have been used to degrade lignocellulosic material in plant tissue, converting it directly into fungal protein suitable for human consumption. Lignin, the most recalcitrant component of the plant cell wall to degrade, has been shown to be susceptible to degradation by edible white rot fungi such as *Pleurotus ostreatus* and other species (Sarikaya and Ladisch, 1997b). Our goal is to optimize use of edible white rot fungi for degradation and recycling of solid wastes such as inedible crop biomass, food waste and biosolids with ultimate production of an edible product (mushrooms) that will add diversity to the restrictive diet of the astronaut. Edible mushrooms therefore are a vital component of sustainability within the Advanced Life Support (ALS) system of the spacecraft. To maximize the biodegradation of crop residues and recycling of other solid wastes using edible white rot fungi, key factors influencing the biological process will have to be controlled. These include a judicious selection of species and strains of edible white rot fungi, cropping patterns used, nitrogen requirements, light and temperature requirements. The objectives of our effort are to evaluate and select most efficient species and strains to optimize solid waste degradation, recycling and fruiting body production, determine most efficient cropping patterns for maximizing biomass degradation and fine tuning environmental factors of light, temperature, nutrient (C/N) for improved fungal colonization and fruiting.
Cumulative Research Progress to Date

Experiments were conducted to determine the suitability of various sources of nitrogen in enhancing growth in select strains of shiitake and maitake and to investigate strains of shiitake demonstrating greater tolerance to higher concentrations of food waste in culture medium. Significant growth differences were observed between maitake strains in media supplemented with either KNO$_3$ or NH$_4$Cl as sources of N. These compounds were also more favorable to growth of the strains than urea. In shiitake, strains showed significant differences for their preference for source of N, however, neither KNO$_3$ nor NH$_4$Cl enhanced growth better than the control. Increasing the concentration of food waste in the culture medium reduced the growth of the four shiitake strains. Only strain LE002 grew in media amended with up to 50% food waste. There is a need to further screen additional strains of edible white rot fungi which will allow growth and basidiocarp production on media amended with food waste. They also underscore the importance of strain selection for use in long term space missions and the need to expand the test to higher percentages of incorporation, more shiitake strains and evaluate basidiocarp development.

Biodegradation of single, and dual substrate combinations of inedible crop biomass using select fungal species and strains

Less than 2 mm particle size inedible residues of tomato, wheat, rice, basil, sweet potato, soybean and cowpea were moistened, autoclaved and placed as single crop residues or as 1:1 combinations with either rice or wheat straw to make 100 g in 750 ml transparent food containers. The substrates were aseptically inoculated with two shiitake strains (LE001 and LE002). Seeded cultures were incubated at 25°C for growth and colonization of the substrate and subsequent fruiting. Initial growth and colonization by the two strains was rapid in the legume substrates and their combinations with rice or wheat straw. Growth and colonization of LE001 was slow in tomato, basil and their combinations with wheat or rice straw, but was completely suppressed in sweet potato. Strain LE002 outperformed LE001 in the difficult substrates exhibiting better colonization in tomato, basil and sweet potato. In order to improve the efficiency of degradation of the difficult substrates, more aggressive colonizers such as oyster mushroom (P. ostreatus) were evaluated. P. ostreatus ‘Grey dover’ was tested on 2 mm particle size inedible residues of wheat, rice, tomato, basil, sweet potato, soybean and cowpea placed singly or mixed in a 1:1 ratio with either rice or wheat straw in 750 ml transparent food containers. also improves shiitake growth. Simple single crop substrates may not be the best approach to efficient degradation.
Growth of *P. ostreatus* on wheat and rice straw amended with STAR effluent

We have also begun incorporating food wastes and STAR sludge from Dr. Jim Alleman’s group (Purdue University) in our substrate mixes for recycling. Previous research in our laboratory had shown that at least two strains of shiitake tolerated up to 50% (v/v) concentration of food waste supplemented in artificial culture medium. *P. ostreatus* ‘Grey dover’ was inoculated on approximately 80g of autoclaved wheat straw supplemented with 0, 20, 40 and 60 % (v/v) dilutions of STAR effluent in 750 ml food containers. Initial mycelial growth (diameter of surface spread from center of substrate) was rapid covering 8 cm in 7 days. The rate of initial colonization was not affected by concentration of STAR effluent in the substrate mixture suggesting that at least 60% of STAR effluent is supportive to *P. ostreatus* growth and that higher concentrations of the STAR effluent may be tolerated and effectively recycled by this strain. Further experiments using up to 100% concentration (undiluted) of STAR residue in rice straw have been initiated. Preliminary data shows the undiluted sludge to be most supportive of mycelial growth in strains of *P. ostreatus* (Pohu, Grey dover and Blue dolphin).

Cropping spent mixed crop substrate with strains of shiitake, oyster and maitake

To minimize residual undegraded crop substrate following initial cropping, it is imperative to identify species and strains of edible fungi that can further colonize the non-degraded portion of previously cropped biomass. This will ensure continued and advanced degradation and recycling of the residual crop biomass in ALS system. Spent wheat straw, rice straw, sweet potato, basil, tomato, cowpea and soybean including those contaminated by competing fungal species were thoroughly mixed, autoclaved and seeded separately with *Pleurotus* spp, *L. edodes* and *G. frondosa*. Quantitative assessment of mycelial colonization showed that *Pleurotus* species colonize most rapidly compared to *Lentinula* and *Grifola*. Growth of *G. frondosa* in these media was completely repressed. *P. eryngii* was the most effective colonizer.

Enhancing growth and fruiting of edible fungi on wheat straw using urea

Two strains each of the edible fungal species *Lentinula edodes* (LE001, LE002) and *Pleurotus ostreatus* (Grey dover, Blue dolphin) were grown in...
fine wheat straw amended with urea at 0.0, 0.001, 0.01, 0.05 and 0.1M as N source. The objective of the study was to determine optimal concentrations of N for growth and fruiting, and to compare the relative growth and fruiting of the fungal species on the enriched wheat straw. Major differences were observed between the strains in growth and colonization of the substrates and fruiting. *P. ostreatus* (Grey dover) was most responsive both in mycelial growth and fruiting, whilst urea at 0.001M was most favorable to mycelial colonization. Other parameters being evaluated include changes in pH and C/N ratio over time.

**Future Research Directions**

Continuing with the wheat/legume, rice/legume, basil/legume, and sweet potato/legume paired ratio tests. October-December, 2004

Incorporation of STAR effluent for recycling and enhancement of fruiting in wheat and rice straw as well as in the other crop substrates. August-December, 2004

Evaluate the more aggressive species and strains of *Pleurotus* and other edible fungi (*Hericium, King Stropharia*) on basil and sweet potato biomass and their paired combinations with the legumes or wheat or rice straw. November, 2004-April, 2005

Examine the effect of light duration and temperature on a) growth of mycelium, b) appearance of fruiting initials, and c) development of edible mushrooms for *Pleurotus* and the other species. October, 2004 – March, 2005.

Examination of Hericium (Lion’s mane) and King Stropharia species as primary decomposers to enhance degradation of solid wastes and biomass October, 2004-May, 2005.

Leaching of wheat straw to enhance its ability to sustain fungal growth. This was suggested through discussions with Field and Forest, Peshtigo, WI. This will include analysis of N:C ratios for putative critical threshold. November, 2004-February, 2005

Sequential cropping of strains of edible fungi on various substrates. January – December 2005

Comparison of single and paired crop substrates for growth and fruiting of *Pleurotus*. December, 2004 – May, 2005
Evaluation of growth and fruiting of fungal species on first generation expended substrate December, 2004 – December, 2005

Trainees

Kavita, Manohar-Maharaj, undergraduate, Howard University. ALS/NSCORT Summer Undergraduate Fellowship research project entitled “Growth of shiitake and oyster mushrooms on processed wheat straw modified with varying concentrations of urea.

Research Collaboration

Collaborations with Drs. Jim Alleman’s group, Cary Mitchell and Paul Brown-all of Purdue University, are ongoing. Dr Alleman’s laboratory is the source of the biosolid (STAR sludge) we incorporate in crop mixes for recycling with edible fungi. Dr Mitchell provides residual plant biomass while we furnish Dr. Paul Brown with fungal predigested composted inedible plant biomass for his fish project.

Collaboration is also being sought with Dr. Trotman at Tuskegee University on the construction of a simple chamber for measurement of respiration (CO₂ monitoring) and water vapor dynamics for various strains of white rot fungi grown on different substrates and/or combinations.

Publications and Presentations To-Date


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Pending Research Milestones and Benchmarks

Mycelial growth and colonization of *P. ostreatus* strains in rice straw amended with undiluted STAR residue is prolific. It would be interesting to see how they also fruit in this substrate.

*Pleurotus eryngii* is exhibiting a high tendency to effectively colonize and degrade first generation spent substrate and is being observed and evaluated as a potential candidate to be used as the last colonizer in sequential cropping patterns.

References:

Fig 1. Shiitake growth in culture media amended with increasing concentrations of food waste
Fig 2 and 3. Fruiting of Pleurotus on rice straw in the laboratory

Fig 4. Pleurotus growing on wheat straw amended with STAR sludge in food containers in the laboratory
Fig 5 and 6. Outgrowths of Pleurotus Basidiocarps
In an ALS, the food subsystem is an integral part of the mission. Purdue and Alabama A&M Universities are continuing to address key components of food processing, food safety, energy requirements, and the effect of long term exposure of food to radiation. Currently there are three major efforts addressing these food related issues for a potential NASA mission to Mars or establishment of a lunar base. It is also important to consider that the research, although space based, has terrestrial benefits as well. To address food safety, research is ongoing in both specific detection of pathogens and prevention of contamination in food processing. By continuing to identify potential areas of contamination and control strategies using an integrated HACCP (hazard analysis and critical control points) approach key parameters are being identified from harvest through processing and consumption. The HACCP approach has also been recently expanded to evaluate the ALS system as a whole for identification of key parameters and possible points of contamination from the various waste processing regimes, hydroponics, and tilapia waste water. Research has also shown proof in principle experiments of a phage based immunoassay allowing signal amplification by exploiting phage amplification in a bacterial host. This approach will allow a simple test for pathogen detection which can be implemented with minimal equipment and training and has potential for impacting food safety and biosecurity in a terrestrial application. Research on effects of radiation on foods has also begun to understand impacts of prolonged exposure on quality of food including the nutritional and sensory aspects.

Bruce Applegate
Focus Area Group Leader – Food Safety and Processing
Project Nine: Bioamplification Using Phage Display for the Multiplexed Detection of Pathogens in Potable Water and Food

Principal Investigator: Dr. Bruce Applegate, PhD., Assistant Professor, Department of Food Science, Purdue University

Co-Investigators: Dr. Michael Ladisch

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 assay will provide an alternative to current culturing methodology and nucleic acid amplification technology which are time, labor, and equipment intensive. 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.
Cumulative Research Progress to Date

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. Primers were utilized to amplify the tailspike protein from P22 with the appropriate His modifications. We are currently adding the appropriate promoter configurations to allow repressed expression of the His modified tailspike protein in the preparative host strain. The preparative host strain repressor gene cassette was constructed for insertion into the preparative host strain genome. Initial work was begun on inserting the modified tailspike gene in the previously constructed P22 recombination vector. Appropriate promoter and terminator configurations were added to the modified tailspike protein to allow repression of expression of the His modified tailspike protein in the preparative host strain. Preparative host strain containing the *lacI* repressor gene cassette was constructed. The strain is currently being evaluated for sufficient repression activity using a *lac-lux* fusion.

The resultant recombination construct was utilized to facilitate a development of a detection system utilizing bacteriophage pathogen-specificity and a bacterial bioluminescent bioreporter utilizing the quorum sensing molecule from *Vibrio fischeri*, *N-(3-oxohexanoyl)-homoserine lactone* (3-oxo-C6-HSL) for the detection of *Salmonella* sp. The assay exploits phage host specificity coupled with a modified phage genome to reprogram the host cell to express acyl-homoserine lactone synthetase (*luxI*) leading subsequent production of 3-oxo-C6-HSL. The 3-oxo-C6-HSL molecules diffuse out of the target cell resulting in induction of bioluminescence from a population of 3-oxo-C6-HSL inducible bioreporters (RO/lux). Assays utilizing the *luxI/ROlux* based phage system for the detection of *Salmonella enteriditis* showed detection limits of 1000 bacteria in approximately 6 hours using a portable luminometer.
**E. coli O157:H7 bacteriophage:** Phage based detection of *E. coli* O157:H7 will be accomplished using bacteriophage $\phi V10$. *Bacteriophage $\phi V10$* was originally isolated by R. Khakhria and has been shown to specifically 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. To determine the specificity of $\phi V10$, a previously characterized library from pathogenic *E. coli* outbreaks responsible for disease was screened for $\phi V10$ susceptibility. 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 $2 \times 10^{-3}$ plaque forming units per mL. Using this assay, 187 strains of *E. coli* were tested. Of these samples, 106 were known to be isolates of *E. coli* O157:H7 and 81 were not. Results showed 93 positives and 81 negatives. The data correlated with the previous identifications. However 13 of the previously identified positives did not form plaques and were investigated further and found to be contaminants. No false positives were detected.

Total DNA was isolated from the phage and a genomic library for sequencing the entire phage genome was generated. The library was sequenced providing data which will allow a more deliberate construction of the recombinant phage avoiding the use of transposon mutagenesis. (Note: An anomaly in the previously reported sequencing data suggests a unique DNA packaging requirement for *phi V10* which is being investigated. It appears the phage may have a tripartite genome. If this is the case it would allow large insertions of foreign DNA.) Preliminary sequencing generated two contigs of 22 kb and 15 kb. Sequence analysis showed high homology to the Enterobacterial phage epsilon 15 and numerous *E. coli* O157:H7 bacteriophage. The final sequencing is currently being performed to resolve ambiguities in the genome along with completing the annotation of the genome.

A similar recombination system for insertion of foreign DNA into the phage genomes as described for the P22 above was developed for the modification of the *E. coli* O157:H7 bacteriophage $\Phi V10$. This was accomplished by isolating a $\Phi V10$ lysogen of *E. coli* O157:H7. The lysogen was further characterized and shown to be inducible for the lytic phenotype. The strain was subsequently transformed with pKD46 which contains an arabinose inducible integrase. This system allows the electroporation of linear DNA containing foreign genes flanked by DNA sequences from regions of the phage genome. This allows insertion of reporter genes into specific regions of the phage genome. Initial work has identified regions for modification, allowing insertion of reporter genes which do not affect the phage life cycle. Although designated for reporter gene insertion we are also utilizing the system for analysis of the unknown open reading frames found in the genome of bacteriophage $\Phi V10$. Key parameters were determined for optimization of the recombination system for reporter gene insertion and gene inactivation.
Primers were designed to begin the systematic evaluation of the unknown open reading frames. Amplicons were constructed for the systematic disruption of identified open reading frames in phi V10. We are currently beginning the recombination and lysogen rescue experiments.

**Listeria monocytogenes bacteriophage:** Preciaus Heard (Summer Fellowship Student) began initial screening of a *Listeria monocytogenes* library to isolate a lysogenic bacteriophage. Preliminary results suggest she was successful and we are currently further evaluating the isolated bacteriophage and continuing to screen the library.

**Future Research Directions**
We are continuing the development of the various bacteriophage and are beginning initial work on lateral flow assays for the development of the kit based system for pathogen detection. The long term effort will adapt the developed pathogen detection test strip for integration into food packaging material with Dr. Lisa Mauer. Validation of the test strip for use in monitoring water quality will be preformed to allow utilization in the HACCP program developed for the system.

**Trainees**
Udit Minocha, Department of Food Science, Doctor of Philosophy
Melinda Shroyer; Department of Food Science, Doctor of Philosophy

**Research Collaboration:**
*External collaborations:* 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 has been completed and ambiguities of the sequence data are being resolved for tentative submission of a manuscript by the end of the year.

*Internal collaboration:* Dr. Applegate is also collaborating with Dr. Mauer and Dr. Williams to develop a general HACCP plan for the integrated system to identify key control points related to potential bacterial contamination in the waste/water processing system. In collaboration with Dr. Banks and Dr. Mitchell we have developed a bioluminescent based assay to evaluate the bioavailability of carbon in the various water sources in the system to determine potential pathogen growth areas. Dr. Applegate is also working with Dr. Williams providing bioluminescent pathogens for studies of control interventions for pathogen elimination.
Leveraged funding:

Dr. Applegate received a grant from the Purdue University TRASK fund to support the development of a food based assay utilizing phage based detection the synergy between the ALS NSCORT project and this effort will should allow the reduction to practice and the filing of a Utility patent on the technology platform being developed in this effort.

Publications and Presentations To-Date:


Patents:

Pending Research Milestones and Benchmarks

Completion of Recombinant Bacteriophage

Development of lateral flow assays
6.3 Project 13: Novel Food Processing and Packaging Operations

Principal Investigator Dr. Lisa Mauer, PhD., Assistant Professor of Food Science, Purdue University

Project Goals and Objectives

Food must be safe, nutritious, and acceptable throughout a long duration mission. 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. 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.). 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.

Based on discussions and recommendations from the external advisory committee review in November, 2003, the focus of projects will shift from an applied emphasis on ESM of the food system to a basic research emphasis on quality of foods and effects of radiation on foods.

Cumulative Research Progress to Date

- Equivalent System Mass (ESM) Estimates for Commercially Available, Small-Scale Food Processing Equipment (work completed and presented at the ICES annual meeting)

One of the challenges NASA faces today is developing an Advanced Life Support (ALS) system that will enable long duration space missions beyond low earth orbit (LEO). This ALS system must include a food processing subsystem capable of producing a variety of nutritious, acceptable, and safe edible ingredients and food products from pre-packaged and re-supply foods as well as salad crops grown on the transit vehicle or other crops grown on planetary surfaces. However, designing, building, developing, and maintaining such a subsystem is bound
to many constraints and restrictions. The limited power supply, storage locations, variety of crops, crew time, need to minimize waste, and other ESM parameters influence the selection of processing equipment and techniques. Several researchers have calculated ESM of select types of food processing equipment to compare ESM for individual food types; however, a complete survey of ESM parameters for currently available food processing unit operations has not been completed. In order to direct NASA’s research and technology efforts related to the food subsystem, the technologies available on Earth for food processing, preservation, 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 available food processing equipment and evaluating feasibility for use in an ALS system. Once the ESM has been estimated for available equipment, modifications can be suggested to improve efficiency and reduce ESM. The objective of this study was to compile ESM-parameter information (mass, volume, and power) for currently available, small-scale food processing equipment and to provide average, high, and low ESM values for each class of equipment (hand-held and bench-top mixers, etc.) that performs the following unit operations: mixing, size reduction, heat transfer (heating and cooling), and extraction (water, oil, and juice). In this study, each piece of equipment was assumed to perform a single task, the power required for cooling was set equivalent to the power needed to operate the equipment, and the crew-time was not considered in the preliminary ESM estimates. ESM (non-crewtime) estimates were also provided for different mission scenarios. A database of this information has now been created and is available for further development and updates. The data and ESM estimates presented will provide a starting point for the minimization of the ESM of food processing equipment for a long term mission. This work was done in collaboration with Dr. Michele Perchonok at JSC.

- Equivalent System Mass of Producing Yeast and Flat Breads From Wheat Berries, A Comparison Of Mill Type (work completed and presented at the ICES annual meeting)

This work built on a study presented at the 2003 ICES meeting entitled “Comparison of Equivalent System Mass (ESM) of Yeast and Flat Bread Systems”. Wheat is a candidate crop for the Advanced Life Support (ALS) system, and cereal grains and their products will be included on long-term space missions beyond low earth orbit. While the exact supply scenario has yet to be determined, some type of post-processing of these grains must occur if they are shipped as bulk ingredients or grown on site for use in foods. Understanding the requirements for processing grains in space is essential for incorporating the process into the ALS food system. The ESM metric developed by NASA describes and compares individual system impact on a closed system in terms of a single parameter, mass. The objective of this study was to compare the impact of grain mill type on the ESM of producing yeast and flat breads.
Hard red spring wheat berries were ground using a Brabender Quadrumat Jr. or the Kitchen-Aid grain mill attachment (both are proposed post-harvest technologies for the ALS system) to produce white and whole wheat flour, respectively. Yeast bread was made using three methods (hand+oven, bread machine, mixer with dough hook attachment + oven). Flat bread was made using four methods (hand+oven, hand+griddle, mixer+oven, mixer+griddle). Data on all inputs (active time, passive time, mass and volume of ingredients and equipment, power) were measured and used to calculate ESM. Assumptions were based on data in NASA documents. Data were analyzed using PC-SAS with significance at $P < 0.05$. Grain mill type significantly ($P < 0.05$) influenced the ESM of making both bread types; and the Brabender Quadrumat Jr. contributed significantly ($P < 0.05$) more mass than the Kitchen-Aid grain mill to the ESM for producing both types of bread. Additionally, the approach used for measuring ESM for a food production scenario can be used for evaluating ESM of producing any food and can be a useful template for future investigations. This work was done in collaboration with Dr. Michele Perchonok at JSC.

- Characterization of wheat cultivars intended for growth during long-term space missions and comparison to select common terrestrial cultivars (preliminary study presented at the IFT annual meeting)

Cereal grains and their products will be included in long-term space missions beyond low earth orbit. Wheat is a candidate crop for the Advanced Life Support system and will likely be grown with other crops to provide food, oxygen, and water purification during extended planetary research missions. Apogee and Perigee are hard red spring wheat cultivars with dwarf and super-dwarf heights, respectively. These wheat varieties were developed at Utah State University for growth in space. Unique characteristics of these cultivars include: short height at full maturity, high edible bio-mass production per unit area, and elevated protein levels. The chemical and physical characteristics of these wheat cultivars important for functionality in foods have not been thoroughly investigated. The objective of this study was to characterize Apogee and Perigee wheat cultivars and compare them to common terrestrial wheat varieties using chemical and physical assays. Apogee and Perigee were grown hydroponically and in the field at Utah State University. Yecora Rojo, Parshall, and Yavaros 79 were purchased from commercial seed suppliers. Yecora Rojo and Parshall are hard red spring wheats, while Yarvaros 79 is a durum wheat. Chemical assays conducted on all wheat varieties were: proximate analysis, non-protein nitrogen, nitrate content, free-amino acid content, insoluble polymeric protein content, and total antioxidant capacity. The physical assay conducted on all wheat varieties was the Farinograph. Wheats were compared by wheat type, growth media (field vs. hydroponic), and flour type (whole-wheat vs white) for these assays. Wheat grown hydroponically exhibited higher protein levels than field grown wheat. Non-protein nitrogen was not accumulated as urea or ammonia. Proximate composition, nitrate levels, insoluble polymeric protein content, and total antioxidant capacity varied between varieties and growth conditions. Based on preliminary results, Perigee would be the best wheat variety for growth in space because of its short stature and high protein levels; however replication of this study is
needed for statistical evaluation of the data. This work was done in collaboration with Dr. Bruce Bugbee at Utah State University and Dr. Michele Perchonok at JSC.

- **Educational Outreach Activities:**
- **Developed laboratory activities to be used for the August 5 Key Learning Camp**

Activities included: 1) Discussion of the space food system and why foods for space will be different than many common "Earth" foods. 2) What is vacuum packaging and why do we use it? All students vacuum packaged M&M's and labeled them with ISS labels to take with them. 3) What is freeze drying and why is it used for space foods? All students viewed the freeze drying process in the pilot plant and sampled a variety of freeze dried foods (ice cream, carrots, bananas). 4) What happens to foods in a vacuum? Students examined effects of vacuum on a variety of foods. 5) Why do astronauts eat tortillas? Students made tortillas from scratch and discussed dehydration, heat transfer, and frying.

- **Prepared a course module for Wabash Area Lifetime Learning Association Continuing Education Program**
- **Prepared a lecture on space foods for the NASA-NSCORT graduate-level course taught at Purdue in Spring semester 2004**

**Future Research Directions**

- **Effects of space-relevant radiation doses radiation on food oils, antioxidants, and wheat**

Because irradiation of foods does affect food quality and nutrition, it will be essential to characterize effects of radiation on foods in order to assure a continuous supply of foods for the entirety of a mission. Effects of space-relevant radiation doses on a variety of foods and food ingredients have not been characterized, even though dietary countermeasures are proposed for mitigating cancer risks. The long-term goal of this work is to optimize food quality (in terms of nutrition, acceptability, safety, etc.) for a mission to Mars, including identifying levels of radiation that might be a concern for various food types and developing countermeasures to ensure the quality of the food supply for up to 5 years. The specific aims of this research project are to identify threshold levels of radiation that affect foods. Once these levels are identified for each food type, countermeasures can be developed to maintain quality and/or slow degradative reactions in the foods. This information will enable the selection and design of appropriate foods for use in extended missions beyond LEO.
Future Research Directions (continued)

A selection of foods and food ingredients (wheat, oils, antioxidants, and mixtures of oils and antioxidants) will be exposed to gamma radiation at levels (0, 0.25, 0.5, 0.75, 1, 1.5, 2, 3, 5 Gy and higher). These radiation levels encompass the range of radiation exposure expected on a Mars mission (6—8 month transit and 600 day surface stay). Appropriate accelerated shelf-life testing procedures will be used for 0 to 6 months. Analysis of quality parameters will include: chemical analyses (peroxide value, TBARS, FAME-GC analysis, antioxidant capacity, and wheat composition and protein profiles (SDS-PAGE) and functional properties (mixograph analysis of wheat protein functionality). Appropriate experimental design with replication of treatments will be analyzed for significance of effects. The no effect dose, the threshold of dose effect, and the effects of higher doses will be identified along with importance of the impact of these effects on quality and nutrition of the foods and ingredients.

We have gained access to a Cobalt 60 radiation source at Purdue, and the two MS students working on this project have been trained on proper operating procedures (training completed in August). We have sources for oils with a variety of chain lengths and degrees of saturation, both of which are important factors in the lipid oxidation reaction, and natural and synthetic antioxidants. Preliminary studies on radiation of soybean oils began in September and we are working on appropriately modifying the TBARS and FRAP methods for the sample types under investigation. These studies will be expanded to include at least 5 oil types and 4 antioxidant types and will be completed by November, 2005. Select varieties of wheat have been ordered and should arrive in November, 2004. The graduate student, who began in July, is currently learning the methods he will use (PAGE, mixograph, proximate analysis, TBARS, FRAP) for his studies. He is also growing Apogee and Perigee wheats in the greenhouse at Purdue for replication of the characterization of wheat cultivars project described previously. The wheat cultivar characterization study will be completed in November 2005, along with preliminary wheat-radiation studies.

• Food Packaging Options for Space Foods
  An undergraduate student has begun compiling data related to the current food packaging system used for foods on ISS and other possible packaging systems available and will continue this work through 2005. A comparison of traditional packaging materials and potential for use of biodegradable and “edible” packages will be made and impact of options on ESM of food storage scenarios determined.
ESM of Producing Pasta
An undergraduate student has begun compiling data related to production of pasta, shelf-life of various types of pasta, unit operations needed for pasta production, and wheat-protein profiles recommended for pasta products. She will gather ESM parameter information needed to characterize ESM for pasta production scenarios in space through 2005.

Trainees
Ilan Weiss, completed M.S. degree May 2004, Thesis titled: “Characterization of equivalent system mass (ESM), chemical, and physical properties of select wheat products and cultivars intended for long-term space missions”
Jake Gandolph, began M.S. degree January 2004
Adam Stoklosa, began M.S. degree July 2004
Libby Snuffin, B.S.
Dina Romano, B.S.

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, Dr. Bruce Bugbee at Utah State University related to wheat varieties he has developed for NASA (Apogee and Perigee), and Dr. Lester Wilson at Iowa State University on radiation of foods for space. Additionally, a NASA SBIR Phase I grant has been submitted (9/04) in collaboration with Triple F and researchers at Purdue (Drs. Osvaldo Campanella and Martin Okos in the Agricultural and Biological Engineering Department at Purdue) and an NRA grant for ground-based studies for radiation biology is being written (submission 11/04) in collaboration with Drs. Michele Perchonok, Steve French, and Lester Wilson. Other collaborations include:

- Organoleptic study on effects of basil in the diet of tilapia on acceptability of fish fillets consumed after baking (Dr. Paul Brown)
We have developed a general approach for data collection using CompuSense 5 software and plan to conduct the sensory study this fall. The fish-feeding study is currently in progress. New regulations at Purdue will require Dr. Mauer and students working on the project to undergo a workshop (Sept. 21) and a CITI certification exam prior to receiving approval for human subjects testing needed for this project.

- Sweetpotato study (Dr. Cary Mitchell, Dr. Desmond Mortley at Tuskegee)
We are investigating the effects of growth conditions on yield and composition of TU-82155 sweet potatoes with the intent to submit this work to a peer reviewed journal. Three replicates of sweetpotato growth/analysis have been completed and a paper drafted.
Publications and Presentations To-Date:

Proceedings Publications:

Poster Presentations at National Meetings:

Invited Talks:
Pending Research Milestones and Benchmarks

- A major upcoming research milestone is characterization of effects of space-relevant radiation levels on food oils, antioxidants, and wheat. This information is essential not only for designing a food system that will maintain quality for up to 5 years, but also for ensuring that the foods/antioxidants intended as dietary countermeasures for mitigating cancer risks are stable and not adversely affected by expected radiation exposure. We are designing an experimental approach that can be expanded to include other food and radiation types in future investigations.

- Another milestone will be the characterization of composition and functionality of Perigee wheat, a super dwarf wheat developed at Utah State University. It is important to ensure that crops developed for space-growth constraints are also functional for food use.

- We are also excited about an upcoming collaboration with Dr. Cary Mitchell and Dr. Gioia Massa on characterization of antioxidant capacity of berries.
6.4 PROJECT FOURTEEN: OPTIMAL FOOD SAFETY IN ADVANCED LIFE SUPPORT

Principal Investigator  Dr. Leonard Williams, PhD., Research Assistant Professor - Food Microbiology and Safety; Immunochemistry, Alabama A & M University

Co-Investigator: Lloyd Walker, Professor of Food Science Department of Food and Animal Sciences

Significance of Project to ALS
The potential for prevalent outbreaks of human infections caused by consumption of raw produce was considerably recognized during the summer of 1996 in Japan. More than 6000 cases of *E. coli* O157:H7 infections were reported (Gutierrez, 1997). The largest outbreak resulted in more than 4000 school children in and around Sakai City. Raw radish sprouts that had been prepared in the main kitchens appear to have transmitted the pathogen. In the United States, between 1995 and 1999, there were nine outbreaks of food borne illness caused by *Salmonella* or *E. coli* O157:H7 due to consumption of fresh vegetable (NACMCF, 1999). These outbreaks involved more than 1,234 cases in Missouri, Michigan, California, Washington, Arizona, and Nevada, most cases fresh salad crops were implicated as the initial inoculum source.

Washing of raw agricultural products with water is practiced in industry, however, washing alone does not render the products completely free of pathogens, therefore, effective methods of reducing or eliminating pathogens in fresh fruits and vegetables are important to the successful implementation of Hazard Analysis Critical Control Points (HACCP) programs by both the food industry and NASA for the establishment of critical control points during the processing and harvesting of salad crops.

Project Goals and Objectives
The primary goal of this project is to develop a HACCP system which can be used for the validation and testing of food products for ALS mission and determine the critical points in processing and production of packaged products provided from plants produced by Purdue and AAMU researchers, and develop a HACCP and food safety system to monitor and validate the effectiveness of reducing any hazards in these packaged products. In turn, the associated objectives would be as follows:

1. Develop a sampling plan in coordination with Purdue researchers (Mauer and Applegate) at each critical point in processing and packaging products.
2. Define the monitoring, critical limits and corrective actions of pathogenic organisms (*L. monocytogenes, Campylobacter jejuni, Salmonella, E. coli* O157:H7) isolated from food systems.
3. Develop integrated HACCP plans for potable water and foods to validate the effectiveness of objective 1 and 2.
4. Develop an integrated HACCP system into novel food safety and HACCP plans for non-food safety and microbiology personnel.

Research Progress:
Research has begun on objective one and two of the above section, development of sampling plans, validation and monitoring plans for pathogenic bacteria. Lettuce, carrot and tomatoes are currently being used to determine the efficacy of commonly used sanitizers and antimicrobials for reducing or eliminating spoilage and pathogenic bacteria at both pre and post harvest and to increase the shelf-life of each salad crop.

**Efficacy of sanitizing agents on reduction of Salmonella on the surface of tomatoes:** To determine the role of sanitizing agents on reduction of an high inoculum of *Salmonella* spp. on surfaces of tomatoes, we decided to used several sanitizers that are generally recognized as safe (GRAS). Four sanitizers, peracetic acid, hydrogen peroxide, chlorine and Proscan®, a commercially available product were all chosen based on their potency, FDA approval for use and its ability to leave behind limited amounts of chemical residues. Two stains of Salmonella were used in this study to determine the ability of biofilm formation, increased ripening or spoilage and their storage at room temperature on short period of time (up to 6 days of storage). All strains were provided by the AAMU Food Microbiology Laboratory and each were cultured separately in tryptic soy broth (TSB) at 37°C for 24 h with agitation, washed, and resuspended into 0.1% peptone water. In this project, we decided to optical density of 0.5 at 640 nm (representing approximately $10^9$ CFU/ml). Six dipping trials on tomatoes were conducted, each with single test pH within the range of 4 to 9. In each trail, 50 tomatoes were divided into groups. Each group consisted of 6 samples, 2 as controls and 4 sanitizer treatments. Group 1 and 6 was used without sanitizer treatment to determine the visual color changes of tomatoes after treatment. Groups 2, 3, 4 and 5 were inoculated with *Salmonella* spp. to determine the reduction of individual disinfectants on survival of Salmonella due to treatments. Samples were dried under laminar flow hood to dry surface for 1 h. For treatment of tomatoes, samples were dipped into a 2 L sterile sample bag containing 800 ml of each sanitizer for 3 min at 25°C. Treatment temperatures were achieved by storing samples in temperature controlled incubator.

**Microbial enumeration:** Each control and treatment were suspended in 225 ml of 0.1% buffered peptone water in a stomaching bag, and gently agitated for 120 s. Stomaching waters of each control were collected, diluted and plated onto 100 mm plates, while the stomaching waters of each treatment were plated directly onto tryptic soy agar and incubated overnight. For better recovery of injured cells, colonies were counted again after incubation after incubation for another 24 h.
Evaluation of the color of tomatoes: the color of the tomatoes on the outer surfaces and ripening (softening) were measured by using a colorimeter and by visual inspection.

Data can be summarized as follows: the numbers of Salmonella bacteria recovered from tomato samples were dramatically reduced by 0.91 CFU/tomato log reductions from the initial population when observed at 2 days of storage at room temperature (Table 1).

**Table 1.** Log10 reductions in Salmonella viability on tomatoes during 2 and 4 days of storage (25 °C) following treatment with sanitizers

<table>
<thead>
<tr>
<th>Sanitizer</th>
<th>Day 2</th>
<th>Day 4</th>
<th>Day 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proscan (1%)</td>
<td>0.91</td>
<td>0.15</td>
<td>NR</td>
</tr>
<tr>
<td>H2O2 (5%)</td>
<td>-</td>
<td>-</td>
<td>NR</td>
</tr>
<tr>
<td>Peracetic Acid (1%)</td>
<td>1.15</td>
<td>1.45</td>
<td>NR</td>
</tr>
<tr>
<td>Chlorine (200 ppm)</td>
<td>0.71</td>
<td>0.20</td>
<td>NR</td>
</tr>
</tbody>
</table>

NR- No reduction
However, at 4 d of storage, the survival of *Salmonella* on the surface of tomatoes increased with an increase in the storage time. Suggesting that *Salmonella* acquired the ability to adjust to the changes in the pH of the sanitizers, recover and eventually start attaching to the surfaces of the tomatoes (Figure 1).

![Graph showing survival of Salmonella spp. on whole tomatoes after exposure to sanitizers (25°C) for 3 min](image-url)
No obvious color changes of tomatoes were visually observed after sanitizer treatment (Figure 2.)

Day 0

Day 6
Future Direction of Research: 1. Development of monitoring and validation steps for detecting coliforms in gray water and hydroponically grown salad crops. 2. Determine role of biofilms on salad crops using bioluminescence strains developed in Bruce Applegate Lab (Purdue). 3. Determine the effects of irradiation on color changes, sprouting and germination of salad crop seedlings.

Trainees: M.S. Candidates— Tyrico English
Aretha Clisby (unfunded)

Research Collaboration: This project has several collaborative aspects. First, Proscan® sanitizer was provided by Dr. Lopes of Microcide, Inc. in collaboration with NASA Food Technology Commercial Space Center at Iowa State University.

Publications and Presentation to date
No publications have been generated on this project.

Pending Milestones and Benchmarks
There are two upcoming, presenting presentation at local middle school (invited) science club and an abstract presented at the upcoming Food Safety Conference in Orlando, Florida 2004.

References


7.1 2004 ALS-NSCORT ‘Solid Waste’ Group Report Overview
by
James E. Alleman, Solid Waste Group Leader

Team Integration, Collaboration, and Startup
Our NSCORT ‘solid waste group’ members have all maintained productive levels of individual research activity and collaborative interaction over the past year, and the critical process of securing timely distribution with representative STAR-product (both scrubber condensate and residual solids) has been now been reasonably well worked out in terms of delivery mode and sample volume. While prior collaborative visits to the Howard campus had been made during the course of our NSCORT operation, a particular highlight for FY2004 was a visit to Dr. Beyl’s ‘mushroom growth’ lab at Alabama A&M. Admittedly, Dr. Beyl’s particular project is considered a ‘plant growth’ center activity, but given the fact that STAR-residuals comprise a primary waste substrate with their mushroom growth an on-site visit was quite helpful in terms of comparing notes on overlapping research issues and concerns.

Significant Project Highlights

1) STAR Solid Waste Processing (Jim Alleman @ Purdue)
Extended testing with two different ‘hydraulic retention times’ (HRTs) (i.e., 11 and 16 days) and influent solids concentrations (i.e., 3 and 6%) was completed over the past year, and the latter, higher HRT run was conducted at a higher temperature (~60°C) such that sizably higher levels of solids degradation and fecal coliform loss were observed. In addition, an off-gas scrubber system was installed such that a realistic off-gas condensate stream could be obtained for subsequent evaluation with respect to zeolite sorption of ammonia.

2) STAR Off-Gas Processing (Charles Glass @ Howard): Dr. Glass’s research team has completed an extensive series of batch zeolite sorption studies, including a series of runs with actual post-scrubber STAR off-gas condensate. In one such study, where there was no detectable NH$_3$-N for approximately 40 bed volumes, a ‘commendable’ performance assessment appeared warranted given that BREATHe would not be expecting any significant incoming ammonia-nitrogen loading.
3) **STAR residuals post-processing with Tilapia** (Paul Brown @ Purdue): The accompanying photograph was taken during a site-visit to Purdue’s aquaculture research facility made by students enrolled in our Spring 2004 ‘distance learning course’, with John Gonzalez giving the group a first-hand introduction to the challenge of Tilapia growth in relation to STAR residuals post-processing. Over the past year, Dr. Brown’s research team has continued their efforts with complementary development of the involved fish species, as well as working on various technical methods for dewatering of the STAR product (e.g., centrifuging, screening, etc.). The underlying concern which has proven to be quite significant is that STAR residuals contained an elevated ammonia level which then mandates separation of the bacterial solids prior to addition to the fish growth chambers.

4) **STAR residuals post-processing and water recovery with plants** (Jeff Volenec and Brad Joern @ Purdue): After an initial phase of plant growth trials (using various clover and grass options, as well as wheat, tomato, and pepper varieties), the conclusion was reached that all of the test species grown in STAR exhibited reduced growth and enhanced senescence. In turn, a second plant growth study was conducted using another candidate plant group, including: cattail, rush, Kopu II White Clover, Reed Canarygrass, and Super Dwarf Rice. The latter study showed that cattail was the only species observed to have roots actively growing in STAR effluent, while senescence of roots occurred in STAR effluent for all other species. Upcoming testing will focus on plant growth substrate optimization and species selection.
5) STAR residuals post-processing with edible fungi (Caula Beyl): Dr. Beyl's research group has noted that *Pleurotus ostreatus* 'Grey dover' inoculated on approximately 80g of autoclaved wheat straw supplemented with 0, 20, 40 and 60 % (v/v) dilutions of STAR effluent in 750 ml food containers produced rapid mycelial growth, with approximately an 8cm diameter surface spread within one week. Furthermore, the rate of initial colonization did not appear to be affected by the STAR concentration in the substrate mixture. In fact, experiments using up to 100% concentration (undiluted) of STAR residue in rice straw have been initiated and preliminary data has shown that the undiluted STAR residual is most supportive of mycelial growth in at least three different strains of *P. ostreatus*, including Pohu, Grey dover and Blue dolphin.
7.2 PROJECT ONE: SOLID-PHASE THERMOPHILIC AEROBIC REACTOR (STAR) PROCESSING OF FECAL, FOOD AND PLANT RESIDUES

Principal Investigator Dr. James E. Alleman, Purdue University

Project Goals and Objectives

The primary goal of this project is to develop a novel high-temperature solids digestion system for processing biodegradable wastes within a sustainable closed-loop ecosystem. The pathogen-free residuals streams generated by this process would 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 (1). Associated objectives are:

1- To create a thermophilic STAR reactor system mechanically able to suitable mix and aerate high input solids levels at an expected range of 6-10% solids,

2- To maximize STAR’s positive ESM-enhancing attributes in terms of gas transfer rates to maximize performance, solids shear to reduce particle size, solids and organic destruction performance to reduce waste volume and enable further recovery of water, nutrients and carbon, and pathogen pasteurization to prepare the product for further use or storage (2,3),

3- To minimize STAR’s ESM-degrading attributes, in regard to mass and volume, crewtime, noise generation, vibration, energy consumption, and heat loss,

4- To evaluate the STAR system’s performance utilizing a long-term mission waste stream including human fecal, paper, food residuals, and plant materials,

5- To evaluate the complementary use and operational performance of a vacuum waste collection system, particularly in regard to high-solids waste transfer, and

6- To provide collaborative support for subsequent post-processing NSCORT research projects, including those of Charles Glass (off-gas air processing and condensate processing), Paul Brown (residuals uptake via fish), Jeff Volenc and Brad Joern (residuals water separation via plants), and Caula Behl (nutrient and water recovery via mushroom growth).
Research Progress

In the past year, significant progress was made toward the goals of the STAR system. Further advances in the engineering aspects have been made, resulting in better performance of the system. A project plan for research goals and deadlines was developed in January, and since that time the research has remained on track.

At the beginning of the year, a trial run began on STAR using dog food as a fecal simulant, toilet paper, and food residuals. This study allowed evaluation of the physical aspects of the system, enabling operation to work out any issues not readily apparent before full operation without the inherent issues of including human fecal matter. This study also allowed evaluation of such things as the volume rate of the pumping system, the response to the solids content, relationship of flush water volume and toilet performance, and airflow issues. Initial plans were to introduce all wastes into the system through the toilet. However, it was found that due to the angle of the piping and the speed of the flush, higher solids content feedstocks were adhering to the sidewall of the tank. It was then decided to use the toilet system only for fecal matter and the necessary associated toilet paper, and introduce all other feedstock components directly into the reactor.

Following the successful completion of that initial trial, the dog food was replaced with human fecal matter, and a run with a solids content of 3% and an HRT of 11 days was begun. Data collected on this run included solids degradation, pH, ORP, pathogen inactivation utilizing fecal coliform as an indicator organism, and various metals and nutrients. The analyses chosen were compiled based on enabling assessment of the system and by consulting with the various groups receiving STAR effluent.
Results of the first full run were promising. Total solids degradation was 43%. Partial pathogen inactivation occurred, though not to desired levels. The parameters analyzed responded as expected for this type of treatment system. Several engineering issues came to light and were corrected. Fecal coliform levels were much higher than expected, due to the poor performance of the heating coil. Supplemental heat was required, since the system, though autothermal, has several heat sinks as designed. The heating coil was replaced with a band heater. Tank placement had been problematic during the run, as foam generated during operation built up within the tank, so the tank was relocated. Additionally, the datalogger was programmed to control the pump to shut off for 4 minutes every half hour to minimize foam accumulation. A feeding port was added to simplify the addition of feedstock components into the reactor. Evaporation was higher than expected, resulting in significant condensation within the off-gas piping. A collection area was added with ports to allow sampling of the condensate for evaluation and distribution to the ammonia removal study. The revised configuration is shown at right.

In April, another study began implementing the design changes. This run had an HRT of 18 days and a solids content of 6%. This run showed significant improvements in performance. Solids degradation was increased from the initial 43% to 74%. Temperature was consistently maintained above 55°C. Fecal coliform levels were reduced 100-fold over the previous study, though still higher than expected. This result is believed to have been caused by the sampling procedure, rather than the performance of the system, and is believed to be a false indication of actual pathogen inactivation. Changes in the sampling port design occurred based on this study.
Over the summer, STAR was operated continually using the same 6% solids feedstock, enabling significant data collection over this time period. Multiple thermocouples were installed to allow evaluation of the temperature gradient and heat loss within the system. The off-gas scrubber was fully installed and operational. Additional analytical studies began, including volatile fatty acids and ammonia in both the sludge effluent and condensate.

Additional improvements to the structure of the STAR system were made in early fall. A slight redirection of piping was made to improve oxygen transfer, and “quick-connects” were installed to allow easier maintenance. CO₂ and O₂ online monitoring was connected into the datalogger allowing continual monitoring and data collection. Also, procurement of food residuals from cafeteria wastes was abandoned in favor of a controlled “recipe”, eliminating variability in this part of the feedstock.

Another run was started in late September, including salad machine inedible biomass in the feedstock. Salad machine biomass is estimated at 0.07 kg/CM·d in the BVAD (4). The influent solids percentage for this run was 9%, with an HRT of 14 days. This run was not complete at the time of this report, and therefore no results are included.

A significant alteration in the solids treatment plan occurred in early fall. Based on the inedible plant biomass generated by the all-crop diet, 6.7 kg of inedible plant biomass would be generated per person per day (4). This is an enormous quantity of plant matter, and presents extreme difficulty with regards to treatment in the STAR system. It was therefore decided to add an additional chamber specifically for the treatment of inedible plant matter beyond that of the salad machine crops for this type of scenario. Day-to-day operation of the STAR reactor would include human fecal matter, toilet paper, food residuals, and the inedible biomass generated by the salad machine crops. The additional chamber would only be utilized for treatment of large quantities of crop biomass.

This treatment chamber would be filled on harvest events, and seeded with thermophilic bacteria from the sludge effluent produced in normal operation of the STAR system. Thermophilic aerobic conditions would be maintained. These conditions, together with a higher initial pH such as that in STAR effluent, have been shown to increase the degradation of lignin and cellulose components of compost, and thereby achieve better results than other composting scenarios (6). Depending on the characteristics of the resultant products, effluents from this system may be incrementally introduced into the main STAR system for further degradation, utilized as a growth medium for plants, mushrooms, and/or fish, or otherwise processed for resource recovery or storage.
A preliminary study was started in the early fall. This study consisted of 6 small bioreactors maintained at thermophilic temperatures in a water bath. Two types of plant inedible biomass were studied, wetted with STAR effluent at two different solids percentages. The reactors were turned periodically by an automated motor to allow mixing, and aeration was provided intermittently to maintain aerobic conditions while minimizing drying of the material. The degradation was evaluated based on off-gas analysis of CO₂ production, and volume and solids reduction. This study was not complete at the time of this report, and therefore no results are included.

**Future Research Directions**

Operation of the STAR system will continue to be optimized to achieve better results while reducing ESM. Pathogen inactivation will be further evaluated by incorporating testing of additional indicators. The product quality of the sludge effluent can be manipulated based on downstream uses. Parameters that fall into this category include volatile fatty acid content, solids percentages, and oxygen demand, among others.

The online off-gas analysis will be supplemented by gas chromatography analysis of ammonia, hydrogen sulfide, and mercaptans. A mass balance study is planned in January, utilizing data from the sludge, condensate, and off-gas analyses.

Parameters that will continue to be evaluated in the operation of the system include oxygen transfer, with a planned evaluation of an alternative aeration method, and influent solids percentages. Statistical validity of results will be significantly improved over the next year.

Scale-up of the plant inedible biomass treatment is planned for late fall. A wider variety of plants will be included, at the ratios provided in the BVAD (4). Cellulose and lignin degradation will also be quantified, and evaluated as a means of maturity indication.

**Trainees**

| Post-Doctorates | None |
| PhD Candidates | Dawn Whitaker, Purdue University (0.5 Research Assistant) |
| MS Candidates | Neepa Shah, Purdue University (unfunded) |
Research Collaboration

Extensive collaboration within the NSCORT occurred this year, particularly due to the positioning of STAR as the initial treatment of solids which is followed by multiple treatment technologies. There is much interaction within the solids group to discuss issues, collaborate on analytical work, and distribute effluent. STAR effluent was distributed to the mushroom growth group, dewatering group, tilapia group, and ammonia removal group. Also, collaboration with the BREATHe system group occurs on a regular basis regarding off-gas issues. STAR has been assigned to YanFu Kuo, a systems group graduate student, for modeling and ESM evaluation.

Additionally, STAR researchers participate in SIMA telecons, and the Solid Waste group telecons. Contributions have also been made to the Solid Waste Requirements effort.

Publications and Presentations To-Date

A presentation on the STAR system was made at the Habitation Conference in January 2004. An ICES paper titled “Solids Thermophilic Aerobic Reactor for Solid Waste Management in Advanced Life Support Systems” was published (5), and a corresponding presentation was made at the ICES conference in July. There was also significant interaction with the outreach group.

The STAR project has received much media attention this year, with articles appearing in campus and local papers as well as internationally circulated papers such as the New York Times. Television coverage included local news, ABC sports, and CBS news.

Additionally, STAR was presented at the EAC meeting in May, and at various other internal NSCORT meetings.
Pending Research Milestones and Benchmarks

Results of the preliminary plant study will be complete in this winter. At that time scale-up will begin on this part of the STAR system. Additionally, once sufficient data is gathered using the gas-stream on- and off-line analyses, sludge effluent data, and condensate analyses, a mass balance study will be enabled. This is anticipated to begin in January.

References


7.3 PROJECT TWO: NITROGEN CYCLING IN ADVANCED LIFE SUPPORT

Principal Investigator  Dr. Charles C. Glass, PhD., Assistant Professor of Environmental Engineering, School of Civil Engineering, Howard University

Project Goals and Objectives
The primary objective of this research project is to effectively treat ammonia rich wastewaters from various process streams and convert it into a form that is amenable to uptake by plants in order to complete the nitrogen cycle throughout ALS. The sources of ammonia will include the condensate from 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.

The objective of effectively treating an ammonia rich wastewater will be met by constructing a zeolite system. At this point we believe that the use of a zeolite is the most efficient method to remove the concentrated ammonia from water, with the lowest equivalent system mass, and to remove the ammonia in a form that can be used as a possible input to plant growth systems inside NSCORT.

Cumulative Research Progress to Date
Over the past year we evaluated six different zeolites in batch tests with varying pretreatment regimens for their maximum capacity. Batch tests have been completed with varying ammonia concentrations (100, 200, 300, 400, 500, 1000 mg/L-N), using one gram of zeolite and 100 mL of solution at 20.0°C. Variations of pretreatments included: heating for 1, 2, or 3 hours; soaking in hydrochloric acid or sodium hydroxide; loading with sodium chloride or potassium chloride. Each zeolite was analyzed for its removal capacity and compared using the Freundlich isotherm. In the literature a range of maximum capacities can be found for ammonium adsorption, from 7- 43 mg NH₄⁺/g of zeolite. The variation in the maximum capacity may be due to pretreatment of the zeolites.
Table 1: Maximum Capacity of Ammonia Adsorption in the Literature

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>System</th>
<th>Equilibrium Time</th>
<th>Pretreatment type</th>
<th>Initial concentration NH$_4^+$ - N mg/L</th>
<th>Max. NH$_4^+$ Ion exchange capacity (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jorgensen et al.</td>
<td>1979</td>
<td>Batch</td>
<td>8 days</td>
<td>Salt (Na$^+$)</td>
<td>133.037</td>
<td>16</td>
</tr>
<tr>
<td>Jorgensen</td>
<td>2003</td>
<td>Batch</td>
<td>4-6 days</td>
<td>Salt (Na$^+$)</td>
<td>400</td>
<td>29</td>
</tr>
<tr>
<td>Klieve and Semmens</td>
<td>1980</td>
<td>Column</td>
<td>20 BV/ h</td>
<td>Salt (Na$^+$) and Acid</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>Rožić et al.</td>
<td>2000</td>
<td>Batch</td>
<td>2 hours</td>
<td>Untreated</td>
<td>500</td>
<td>13</td>
</tr>
<tr>
<td>Demir et al.</td>
<td>2002</td>
<td>Batch</td>
<td>30 mins</td>
<td>Untreated</td>
<td>80</td>
<td>7</td>
</tr>
<tr>
<td>Demir et al.</td>
<td></td>
<td>Column</td>
<td>75 BV/ h</td>
<td>Untreated</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Semmens and Martin</td>
<td>1988</td>
<td></td>
<td>2 days</td>
<td>Untreated</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Langella et al.</td>
<td>2000</td>
<td>Batch</td>
<td>3 days</td>
<td>Salt (Na$^+$)</td>
<td>8000</td>
<td>43</td>
</tr>
<tr>
<td>Cincotti et al.</td>
<td>2001</td>
<td>Batch</td>
<td>1 day</td>
<td>Salt (Na$^+$)</td>
<td>200</td>
<td>12</td>
</tr>
</tbody>
</table>

At this point a chabazite (ZS500RW/H) has shown the highest ammonia removal capability. In Table 2 a listing of the results for the batch experiments is shown. Although the maximum capacity of ammonium adsorption in the literature varies between 7 and 43 mg NH$_3$ - N/g of zeolite, our highest adsorption capacity measured with no pretreatment is 50 mg NH$_3$-N/g of zeolite, with an initial concentration of 400 mg/L. Experiments that we performed with ammonia concentrations higher than 400 mg/L showed higher adsorption capacities, but the ammonia did not remain attached to the zeolite and was constantly released and reattached. We will continue to evaluate the capacity of new zeolites as we make contact with more vendors and scientists around the world. We believe that ZS500RW/H, ZS403H, and ZS403TM show the greatest capacity and perform well enough to move on to column experiments.
Table 2: Summary of all of the Batch Experiments

<table>
<thead>
<tr>
<th>Zeolites</th>
<th>Concentration (mg NH₃ – N/L)</th>
<th>Maximum capacity (mg/g)</th>
<th>Equilibrium capacity (mg/g)</th>
<th>Pretreatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZS403H</td>
<td>100</td>
<td>11.21</td>
<td>11.21</td>
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</tr>
<tr>
<td>ZS403TM</td>
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<td>12.74</td>
<td>8.85</td>
<td>Untreated</td>
</tr>
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<td>ZS500RW/H</td>
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<td>10.9</td>
<td>Untreated</td>
</tr>
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<td>21.49</td>
<td>17.21</td>
<td>Untreated</td>
</tr>
<tr>
<td>ZS403H</td>
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<td>200</td>
<td>24.14</td>
<td>19.34</td>
<td>Base</td>
</tr>
<tr>
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</tr>
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<td>8.73</td>
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</tr>
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<td>ZS403TM</td>
<td>200</td>
<td>28.21</td>
<td>15.96</td>
<td>Base</td>
</tr>
<tr>
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<td>18.64</td>
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<td>15.51</td>
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</tr>
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<td>26.77</td>
<td>23.41</td>
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</tr>
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<td>4.72</td>
<td>3h Heat + KCl</td>
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<td>9.78</td>
<td>1h Heat + KCl</td>
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<td>Untreated</td>
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<td>24.92</td>
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<td>28.75</td>
<td>Acid</td>
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<td>Zeolites</td>
<td>Concentration (mg NH$_3$ – N/L)</td>
<td>Maximum capacity (mg/g)</td>
<td>Equilibrium capacity (mg/g)</td>
<td>Pretreatment</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------</td>
<td>-------------------------</td>
<td>----------------------------</td>
<td>----------------------</td>
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<tr>
<td>ZS403H</td>
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<td>ZS500RW/H</td>
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<td>Untreated</td>
</tr>
<tr>
<td>ZS403TM</td>
<td>1000</td>
<td>54.33</td>
<td>26.55</td>
<td>Untreated</td>
</tr>
<tr>
<td>ZS500RW/H</td>
<td>1000</td>
<td>103.89</td>
<td>35.63</td>
<td>Untreated</td>
</tr>
</tbody>
</table>
In Figure 1 an example of the experiments performed for each of the six zeolites is presented for one of the three zeolites that will be used in continuing column experiments.

Figure 1  Zeolite ZS403H, a Clinoptilolite, Capacity with respect to Time

<table>
<thead>
<tr>
<th>Pretreatment</th>
<th>Adsorption Capacity (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid</td>
<td>40</td>
</tr>
<tr>
<td>Untreated</td>
<td>20</td>
</tr>
<tr>
<td>Base</td>
<td>10</td>
</tr>
<tr>
<td>1h Heat</td>
<td>5</td>
</tr>
<tr>
<td>1h Heat &amp; KCl</td>
<td>2</td>
</tr>
<tr>
<td>3h Heat &amp; KCl</td>
<td>0</td>
</tr>
</tbody>
</table>

We have received our several 1 L shipments of condensate from the condensate produced by the off-gas from the STAR system and are evaluating its chemistry and its treatment through the three selected zeolites. In preliminary column studies presented in Figure 2, we have shown that two of our three selected zeolites performed well with synthetic water. The chabazite (ZS500RW/H) showed the highest capacity for ammonium adsorption in the preliminary column experiment.
We have received 10 liters of STAR condensate with an average concentration of 550 mg/L NH\textsubscript{3}-N during the last 6 months of this annual report. The organic carbon concentration measured as COD, was approximately 1100 mg/L. The condensate was pumped through a column filled with 200 g of zeolite from our third best untreated zeolite (the top two were depleted when the condensate arrived). The results from the first column experiment with STAR condensate showed fluctuating results. The effluent from the column had no detectable NH\textsubscript{3}-N for approximately 40 bed volumes. In communication with the Project 6 team (BREATHeII), this early result is commendable as they are not expecting a significant amount of nitrogen in the effluent from the zeolite treatment.
Future Research Directions

With the conclusion of batch experiments the evaluation of the performance of our three best zeolites with both synthetic and actual condensate water from the STAR system continues. The capability of the Chabazite: ZS500RW/H is still out performing the Clinoptilolite: ZS403TM and (Clinoptilolite: ZS403H). However, all of our selected zeolites perform better with synthetic feed with a higher ammonium concentration that the condensate water from the STAR system. We believe this is due to organic carbon and possibly other cations that are present in the condensate water and are taking steps to confirm this fact.

Experiments that were performed with Heat for 1, 2, or 3 hours, with soaking in KCl overnight showed no improvement in capacity for our top three zeolites. In addition, pretreatment with strong acid or base did not show any improvement in performance in batch tests. Consistently, however, equilibrium was reached in a shorter amount of time with the pretreatment processes and adsorption seemed to be more stable (less fluctuation in the sorbed concentration of ammonium). The advantages of K⁺ as the exchange cation may outweigh the loss of performance in the capability of the zeolites, but we are not pursuing that line of questioning at this time. The focus for the next year will be to continue to evaluate the capability of the three zeolites selected for treatment of the actual STAR condensate that is shipped to Howard University from Purdue University on a bi-monthly basis.

Trainees

Ms. Ressa Chee Wah (finishing Masters Student)
Mr. Wendell Khunjar (undergraduate assistant for two years, now at Virginia Polytechnical University)

Dr. Radha Vippagunta (incoming Post-Doctoral Fellow)
Mr. Hugh-Berk Sinclair (current undergraduate assistant)

Research Collaboration

- This project works directly with both Project #1 (Dr. Alleman) and Project #6 (Dr. Banks), the upstream and downstream projects.
- Dr. Glass assisted Dr. Alleman in the presentation of the Advanced Life Support Class to four Howard University graduate students in the Spring 2004 semester.
Publications and Presentations To-Date:

Pending Research Milestones and Benchmarks
The next phase of this research project is to continue to evaluate the three selected zeolites in column studies with synthetic feed and actual feed from STAR condensate. From preliminary research with STAR condensate we believe that the zeolites selected will not work as well with the condensate as they have with the synthetic wastewater because of the presence of other cations and organic matter. Identification of the cations that cause interference and mitigation of their impact on the zeolite process will be critical.

When column experiments are complete the regeneration of the zeolite with brine created from urine treatment or reverse osmosis reject from water treatment will be investigated.

References:
7.4 PROJECT THREE: BIOSOLIDS DEWATERING OF SOLID-PHASE THERMOPHILIC AEROBIC REACTOR (STAR) EFFLUENT USING VARIOUS PLANT SPECIES

Principal Investigator  Dr. Jeff Volenec, PhD., Professor of Agronomy, Department of Agronomy, Purdue University

Co-Investigator  Dr. Brad Joern, PhD., Professor of Agronomy, Department of Agronomy, Purdue University

Project Goals and Objectives
- Identify biomass specie(s) best suited for dewatering and capturing nutrients in STAR waste effluent.
- Develop a cropping system that utilizes the dewatered biosolids form the STAR reactor to grow crops for food, mushroom growth and fish feed.
- Investigate plant growth substrates for STAR effluent dewatering process.

Cumulative Research Progress to Date

Experiment I

Candidate species for dewatering of STAR effluent in Experiment I include the following grasses, legumes, and food crops:

<table>
<thead>
<tr>
<th>Grasses</th>
<th>Legumes</th>
<th>Food Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palaton canarygrass Reed</td>
<td>Endura Kura Clover</td>
<td>USU Apogee Wheat</td>
</tr>
<tr>
<td>Dakotah Switchgrass Tall</td>
<td>Kopu II White Clover</td>
<td>Micro-Tina Tomato</td>
</tr>
<tr>
<td>Millennium Fescue Tall</td>
<td>Jumbo Ladino Clover</td>
<td>Triton Pepper</td>
</tr>
<tr>
<td></td>
<td>Big Trefoil</td>
<td>USU Perigee Wheat</td>
</tr>
</tbody>
</table>
Three plants of each eleven candidate species was established in 1 L pots containing a sand substrate and provided nutrient solution for four weeks. Pots were placed in a greenhouse set to control temperature (25°C±5°C) and photoperiod of 15 h with artificial lighting. Plants growing in 1 L pots were then placed in a second 1 L pot for submersion into the treatment (Fig. 1). Three plants of each specie were assigned one of three treatments (STAR, Nutrient solution, and water). All three treatments were delivered via a tube inserted into the bottom 1 L pot. Treatments were delivered daily to each plant specie, recording volume for water use and efficiency data. Experiment run commenced at day twenty five with destructive plant harvesting. Each plant was divided into herbage, crown and root components and then analyzed for B, Ca, Cu, Fe, K, Mg, Mn, N, NO₃, Na, P, S, and Zn composition.

Fig. 1. Super Dwarf Rice plants planted in “double boiler” system. Plants initiated in top pot for four weeks followed by immersion into bottom pot containing treatment.
Water transpiration increased as plant mass increased for water and Hoagland’s treatments as shown in figures 2 and 3, but not with the STAR treatment (Fig. 4). All species grown in STAR effluent exhibited reduced growth and enhanced senescence. Hoagland’s nutrient solution generally increased tissue concentrations for most elements tested. Tissue sodium concentrations of plants grown with STAR effluent were significantly greater than that observed with the other treatments (Fig. 5).

Fig. 2. Water use during final week for all species treated with water.

Fig. 3. Water use during final week for all species treated with Hoagland’s Nutrient solution.
Fig. 4. Water use during final week for all species treated with STAR effluent.

**Herbage Sodium Composition**

![Graph showing herbage sodium tissue concentrations for all three treatments.]

Fig. 5. Herbage sodium tissue concentrations for all three treatments.
Experiment II

Candidate species for dewatering of STAR effluent in Experiment II include the following,

- Cattail
- Rush
- Kopu II White Clover
- Reed Canarygrass
- Super Dwarf Rice

Three plants of each five candidate species was established in 1 L pots containing an illite-montmorillonite-silica substrate (Turface) and provided nutrient solution for four weeks. Pots were placed in a greenhouse set to control temperature (25°C±5°C) and photoperiod of 15 h with artificial lighting. Plants growing in 1 L pots were then placed in a second 1 L pot for submersion into the STAR effluent. Each of the three species was then assigned one of two treatments (STAR and Nutrient Solution). Treatments were administered in the same fashion as in experiment I. After one week, the STAR treatment was substituted with deionized water due to limited STAR effluent availability. Experiment II commenced at four weeks with plant harvesting. Plants were divided into herbage and root components. Herbage and root dry weights were analyzed for differences.

Dry weight analysis resulted in no significant differences between treatments across all plants. Plant dry matter weights were significantly different from each other. Cattail was the only specie that outperformed the control (nutrient solution) treatment in terms of total dry weight as a percentage of total control weight of that same specie. All other species were observed to have total dry matter weight less than that of the control treatment (Fig. 6).

![Total Weight Percentage of Control](image)

Fig. 6. Total dry matter weight of STAR treatment expressed as a percentage of control (nutrient solution).
Fig. 7. Herbage and dry matter weight of STAR treatment expressed as a percentage of control (nutrient solution).

Fig. 8. Rush root development in STAR and nutrient solution treatment. Root senescence occurred in STAR effluent (left), while root proliferation continued into treatment for nutrient solution treatment (right).
Fig. 9. Cattail root development in STAR and Nutrient Solution treatment. Roots observed in both treatments.

**Future Research Directions**

Near term research will focus on plant growth substrate optimization and selection. Courser substrates such as illite-montmorillonite-silica blends (Turface), glass beads and basaltic lunar and Martian simulants will be investigated. Mineral and water mass balance studies investigating dewatering efficiency and nutrient recovery of these species will also be initiated. Additional types of plants will be included in future studies, including transgenic species such as tomato and rice containing sodium antiporter genes to reduce hyper-accumulation of sodium.

**Trainees**

Shane Howard (M.S. Student)
Also assisting:
Amy Berg (M.S. Student)
Kess Berg (Ph.D. Student)
Suzanne Cunningham (Research Physiologist)
Kali Frost (Undergraduate Student)
Research Collaboration

- Dr. James E. Alleman (Project 1) Solid-Phase Thermophilic Aerobic Reactor (STAR) Processing of Fecal, Food, and Plant Residues.


Publications and Presentations To-Date:

Pending Research Milestones and Benchmarks
See Future Research Directions
7.5 PROJECT TEN: WASTE TREATMENT USING TILAPIA

Principal Investigator  Dr. Paul Brown, PhD., Professor of Forestry and Natural Resources, Department of Forestry and Natural Resources, Purdue University

Co-Investigators

Project Goals and Objectives

- Evaluate ability of tilapia to reduce equivalent system mass
- Evaluate quality of tilapia as food when fed waste products

Cumulative Research Progress to Date

Our research required collaboration from colleagues as we were evaluating wastes generated in their portion of the projects. As such, there was a lag phase as they completed initial phases of their evaluations. This lag phase allowed us to acquire the desired strain of tilapia (Nile) from collaborators in Canada, transport those animals to Purdue, and establish the requisite aquaculture systems for future research. Specifically, we established a broodstock holding and spawning system, fry rearing facilities and growout systems. Additionally, we established our primary experimental system for feeding trials and preliminary integrated aquaponics systems. These systems allow us to spawn and grow fish to fit the needs and timing of the project.

Waste products were acquired from collaborators (wheat bran, ATAD waste, basil, etc. etc. etc), dried to approximately 8% moisture, then pelleted in a 98:2 ratio of waste:binder. All waste products were offered to juvenile tilapia and all waste products were consumed, resulting in positive weight gain in all treatments. Initial and final samples of fish were collected for determination of mass balance. Further, nutrient content of all waste products was thoroughly evaluated.

We sampled two size categories of tilapia for evaluation of nutrient content. Dry matter, crude protein, fat, ash, carbohydrate, minerals, vitamins, fatty acids and amino acids were determined from whole fish and fillets. Filleted carcass nutrient concentrations were determined by difference.

As a prelude to future evaluations, we also conducted the first evaluation of all-plant diets fed to first feeding tilapia and presented those results at an international meeting. Weight gain and conversion of feed was within 85-90% of the growth observed in fish fed a positive control diet, thus demonstrating the potential of feeding tilapia larvae waste products generated in an Advanced Life Support System.
In our preliminary aquaponics systems, we have identified nutrient deficiencies in several species of plant under evaluation for Advanced Life Support. We are conducting an initial evaluation of nutrient intake in fish, absorption in the gastrointestinal tract, excretion and solubilization of excreted minerals, then uptake by plants.

**Future Research Directions**

We are currently acquiring composted fibrous wastes from collaborators to evaluate the utility of reducing those wastes through tilapia. We will conduct another feeding study using the same general methods, and thoroughly characterize the feed inputs and mass balance within the fish. It appears that evaluation will begin in calendar year 2005.

We will enter the nutrient concentrations from all waste products into a feed formulation software program and begin developing a nutritional complete diet for tilapia. Once those data are evaluated, along with any new wastes developed in other portions of the project, we will establish several potential ingredient combinations and evaluate mass balance through tilapia fed mixtures of waste products. We will also evaluate these combinations of wastes as feeds for first feeding tilapia and broodstock, characterizing growth and retention of nutrient in fry and quality of eggs produced in adults.

Once we quantify mass balance of fish fed various waste products and combinations of waste products, our next step is to integrate fish and plant production and conduct system mass balances, examining the interactions of wastes, fish, their excretions and uptake by plants.

**Trainees**

John Gonzales, Ph.D., Aquaculture  
Megan Rosinski, B.S., Fisheries and Aquatic Sciences

**Research Collaboration**

- J. Alleman, STAR/ATAD waste  
- J. Volenec, wetlands grass wastes  
- C. Mitchell, food plant wastes  
- C. Beyl, composting of wetlands grass wastes  
- L. Mauer, food wastes
PROJECT TEN: WASTE TREATMENT USING TILAPIA

Publications and Presentations To-Date:


Pending Research Milestones and Benchmarks
November 2004, initiate second feeding study examining composted waste
December 2004, completion of chemical analyses of fish from initial study
December 2004, initiate second study on all-plant diets for first feeding fish
January 2005, completion of composting study
March 2005, Initiate study on adult fish fed wastes and their ability to reproduce
March 2005, complete chemical analyses from composting study
June 2005, complete adult feeding study
June 2005, initiate larval feeding study using wastes

References:
Below: Graduate Student John Gonzales displays Tilapia, representative of one of many varied dietary treatments.
Providing clean water and air for long-term exploration missions is a top priority for the NSCORT research team. The Air and Water Research Group is focusing on development of innovative technology for wastewater treatment and recycling, drinking water treatment and safety, and removal of trace contaminants from air. Highlights from our research efforts include:

**Potable Water Disinfection Subject to Extended Space Travel Constraints.** A numerical method for prediction of UV disinfection process efficacy has been developed and experimentally tested. Experimental results indicate that the model provides a reasonably accurate representation of disinfection efficacy in the UV reactor system, and the fundamental physical behavior that governs performance. Analytical methods for the detection of various iodine species have been identified. Our developed iodine speciation model allows the concentration of various iodine species to be determined using information such as pH and total iodine concentration.

**Liquid Freeze-Thaw (LiFT) Urine and RO Brine Processing for Advanced Water Recovery and Salt Separation.** Collaborations with a freeze concentration company have resulted in a planned pilot plant study of water extraction recovery rates and cleaning capabilities of a model urine solution. The study will consist of two phases. Phase I involves off-site testing located at the company’s pilot plant. Upon completion and process verification, Phase II will include on-site testing of urine samples at Purdue using the company’s freeze concentration unit.
Membrane Processes in Advanced Live Support. Ion rejection was evaluated from modified and unmodified membranes. Increased electrostatic interactions near the membrane surface increased ion rejection from these membranes. Low salt flux indicates high ion rejection. The next goal is to verify these results for other membranes and determine if NF membranes can compete with RO membranes for ion rejection. Positive results would indicate that NF membranes can be modified to have high monovalent ion rejection, but with much lower operating pressures.

Bio-Regenerative Environmental Air Treatment for Health (BREATHe): Integrated STAR Off-Gas, Cabin Air, and Grey Water Processing. Respirometry has been successfully used to provide general information about the biodegradability of target surfactants. Carbon dioxide production was used as a measure of ultimate biodegradation and both surfactants were found to be readily biodegradable. A test run of the proto-type BREATHe reactors was successful. Through mathematical modeling, we found that surface area of packing material, gas velocity, and liquid velocity were the most sensitive experimental parameters.

Gas Phase Revitalization Using Biofilters in ALS. Programming all simulation models for predicting biofiltration performance and ALS indoor air quality has been completed. Although the general framework for modeling the biofiltration process has been completed, the chemical kinetics and equilibrium equations for microbial degradation will be added to the models after initial experiments. The indoor air quality simulations are being conducted by commercial programs for computational fluid dynamics. In addition, construction of 24 biofilters is complete.

Trainees from our research programs included nine graduate students and five undergraduate students. Our NSCORT group interacts often through teleconferencing meetings. Collaboration with NASA researchers has occurred in several of the research projects. Significant progress is being made toward our objective of optimizing treatment efficiency while significantly reducing ESM.
8.2 PROJECT SIX BIO REGENERATIVE ENVIRONMENTAL AIR TREATMENT FOR HEALTH (BREATHe): INTEGRATED STAR OFF-GAS, CABIN AIR, AND GREY WATER PROCESSING

Principal Investigator: M. Katherine Banks, PhD, PE

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 the NSCORT 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. 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. 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.

PROJECT GOALS AND 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 bio-trickling filter 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

Target Contaminant Degradation. The ALS research community has recently focused on two surfactants, sodium laureth sulfate (SLES) and disodium cocoamphoacetate (DSCADA). These are the surfactants present in Pert Plus for Kids, which has been identified as a likely candidate soap for hygiene purposes during long duration human space missions. Oxygen uptake during microbial degradation of these surfactants can be measured by respirometry and further used to determine Monod kinetic parameters. Respirometry has been successfully used to provide general information about the biodegradability of SLES and DSCADA. Carbon dioxide production was used as a measure of ultimate biodegradation and both surfactants were found to be readily biodegradable (Figures 1 and 2).

![Figure 1. CO₂ produced during degradation of DSCADA (3 replicates for each concentration tested).](image)

![Figure 2. CO₂ produced during degradation of SLES (3 replicates for each concentration tested).](image)
To more effectively track the presence of surfactant degradation byproducts, metabolic pathways should be identified so that relevant metabolites can be recognized. Figure 3 depicts the structure for the target surfactants. Of note is that DSCADA often exists as a mixture of homologues sometimes containing monoacetate (3b) and other times diacetate (3c). Several researchers have studied the biodegradability of SLES and DSCADA for ALS applications, but possible degradation byproducts have not been identified or studied. Nonionic surfactants will also be important within an ALS water regeneration system because they are commonly found in laundry and dish wash detergents, with the most common in commercial products being polyalcohol ethoxylates (PAEs). The general structural formula for PAEs, or alcohol polyglycoethers, is \( R(OCH_2CH_2)_nOH \). Published degradation pathways are shown in Figures 4 and 5. No information exists in the literature regarding specific degradation pathways for DSCADA or any member of the alkylamphoacetate group to which it belongs. However, amphoteric surfactants are known to be readily biodegradable due to their structural similarity to proteins.
Reactor Operation. The reactor design is shown in Figure 6. Peristaltic pumps were used to provide graywater simulant to the bench scale BREATHe I reactors at 5 L/day and to recirculate water through the reactors at 100 L/day. Waste gas simulant will be supplied to the reactors through pressurized gas cylinders, although in this first study, we chose to have an air gas stream influent to allow us to evaluate a best case scenario. In the future, gases will not be precombined in gas cylinders, instead there is a separate gas cylinder for each component (air, ammonia, hydrogen sulfide, and carbon dioxide). The gases will be combined in a mixing box equipped with four flow meters to regulate the amount of each gas coming in. Reactors were packed with 1" Tri-pack packing material (Jaeger Products Inc.). The material has a specific surface area of 85 ft²/ft³ and 90% void space.
The top layer of the reactor was packed with 1 square inch foam packing material (Zander, Type TM2340) to evenly distribute water through the reactors. Reactors after 30 days of biofilm growth are shown in Figure 7. Summary results from the BREATHe first run with replicates is shown in Figure 8.

**Figure 7.** Reactor operation after 30 days.

**Figure 8.** Percent TOC removal during the first test operation of the BREATHe system, using air as the influent gas stream.
Identification of Surfactant Degraders. Experiments were conducted to isolate SLES and DSCADA degrading bacteria by operation of a chemostat with the surfactants as the sole carbon source. It became apparent after several experiments that the bacteria responsible for the initial attack on the surfactants could not be isolated on LB plates. When processed samples were run on agarose gel, bands appeared in the chemostat samples not present in the isolates (Figure 9), verifying the presence of nonculturable bacteria in chemostat samples.

Figure 9. Agarose gel electrophoresis patterns formed for isolates (#1 & #2) and bacteria in chemostat samples after digestion with Hha I enzymes.
Mathematical Modeling. A model for BREATHe I was written using a model developed by other researchers (Ockeloen et al., 1996). The Runge Kutta fourth order (RK4) function was applied to solve the set of ordinary differential equations. A preliminary sensitivity analysis was performed. The model was found to be most sensitive for surface area of packing material, gas velocity, and liquid velocity. We conclude that increased packing material surface area will improve both liquid and gas phase removal of contaminants. A lower gas velocity will result in shorter length requirements for the biotrickling filter. It also appears that liquid contaminant removal is faster when gas velocity is low. Finally, a lower liquid velocity should result in better removal in the liquid phase but does not appear to have a significant effect on gas phase contaminant removal.

FUTURE RESEARCH DIRECTIONS

- Confirm the ability to simultaneously treat graywater and a waste gas contaminated with hydrogen sulfide, ammonia, and carbon dioxide.
- Determine optimal flow scheme for operation of BREATHe I.
- Determine a maximum loading capacity for both NH₃ and H₂S gases at which an increase in contaminants becomes detrimental to reactor performance.
- Challenge the BREATHe reactor with a urine stream to determine the affect on effluent contaminant characteristics.
- Provide information to the systems group about how BREATHe performs under a variety of conditions.
- Generate data for models to determine how BREATHe I should be operated and pretreatment requirements for waste streams.
- Assess biokinetic parameters for surfactant degradation to be used in models to predict and optimize operation of BREATHe I.
- Quantify equilibrium conditions between gas and liquid contaminants in the presence of high concentrations of surfactants.
- Isolate surfactant degrading bacteria which will provide information about pathways and metabolites during biological removal of surfactants.
- Optimize performance of BREATHe I while minimizing important ESM parameters.

TRAINEES

PhD Students: Sybil Sharvelle and Yong-Sang Kim
Undergraduate Students: Katherine Graham, Erin Malony, Chris Ghattas, Joi Dunham, Rebecca Lattayak, Stephan Clark
RESEARCH COLLABORATION

- Banks co-chaired the 2004 ICES session on “Biological Treatment for Water Recycling” with Jay Garland from KSC. Due to the large number of papers submitted to this session, two periods, morning and afternoon, were devoted to this topic.
- Kennedy Space Center – Jay Garland is a member of Sybil Sharvelle’s PhD committee. Sybil has traveled to KSC several times for research interaction.
- Johnson Space Center – Banks has communicated with researchers at JSC and Texas Tech. to provide updates on NSCORT progress with BREATHe.
- Banks attended the NASA Biological Water Treatment Workshop held in Houston, TX.
- Banks visited the University of Florida’s NASA Commercialization Center.
- Monthly BREATHe meetings are conducted with Al Heber’s and K. Banks’ research groups.
- Monthly Water Group Telecons are conducted with PIs and students from Purdue and Howard.
- Sharvelle presented a BREATHe experimental plan at the NSCORT Systems Group Retreat.
- Sharvelle is collaborating with Bruce Applegate, an NSCORT food area researcher to identify surfactant degraders.
- Banks hosted Kim Jones’ student in her laboratory to develop methods for an experimental project to determine the effect of biofouling on reverse osmosis efficiency.

PUBLICATIONS


PRESENTATIONS
Presented at the University of Florida Seminar Series, Gainesville, FL.
“Testing biofilters for advanced life support.” Poster presented at the Habitation Conference, Orlando, FL.
Presented at the NSCORT Summer Symposium, Purdue University, West Lafayette, IN.
Clark, S. (2004), “Operation and Maintenance of BREATHe,” Presented at the NSCORT Summer Symposium, Purdue University, West Lafayette, IN.
Kim, Y. S. (2004), “Gas/Liquid Phase Equilibrium in BREATHe,” Presented at the NSCORT Summer Symposium, Purdue University, West Lafayette, IN.
Maloney, E. (2003), “Design of BREATHe Reactors,” Presented at the NSCORT Summer Symposium, Purdue University, West Lafayette, IN.
Graham, K. (2003), “Biodegradation of Surfactants in BREATHe,” Presented at the NSCORT Summer Symposium, Purdue University, West Lafayette, IN.
8.3 PROJECT FIVE: MEMBRANE PROCESSES IN ADVANCED LIFE SUPPORT

Principal Investigator
Dr. Kimberly L. Jones, Ph.D., Associate Professor, Department of Civil Engineering, Howard University

Rationale
A typical water-reclamation unit for a space mission would consist of a series of biological and physical-chemical treatment processes. Membrane processes such as reverse osmosis are typically utilized in such a treatment train, as wastewaters (grey water, urine) processed via biological processes will require final polishing to meet stringent potable/reuse drinking water standards mandated by NASA and EPA. Reverse osmosis (RO) membranes are well suited to remove contaminants from water and have been evaluated for use as a critical part of the treatment process in wastewater recycle during space missions (Pickering et al., 2001; Campbell et al., 2003). However, reverse osmosis membranes suffer from fouling, low flux, and high pressure requirements, especially during use for wastewater recycling. In fact, fouling has been identified as the major problem for the application of RO membranes to wastewater recycling applications for space missions (Lee and Lueptow, 2001, Pickering et al., 2001).

In this project, microfiltration (MF) or ultrafiltration (UF) membranes will be used as pretreatment to RO or nanofiltration (NF) membranes in an integrated polishing process. These systems will be investigated separately to optimize for fouling, flux and rejection, then operated integrally to estimate overall membrane system flux, rejection and recovery. The focus of year 2 was to determine the effect of membrane properties on organic fouling and solute rejection.

Project Goals and Objectives
The goal of recent work in membrane processes for NSCORT involves quantifying fouling mechanisms and rejection properties of both membrane systems in an effort to link physical chemical characteristics of the membranes to solute attachment on the membrane surface and solute rejection. Objectives of this project are to

- Evaluate suite of membranes for flux and contaminant rejection.
- Quantify fouling mechanisms in MF/UF system.
- Increase ion rejection for RO/NF system.
Impacts of the research plan and expected outcomes on ESM

- High flux, low fouling membranes will reduce the power of the system by reducing necessary energy. As membranes become fouled, higher pressures are required to maintain an acceptable permeate flux and product recovery. Low fouling membranes will minimize the pressure increase, greatly reducing transmembrane pressure and energy.

- Prudent choice of a membrane array will reduce the footprint of the membrane systems, which will reduce volume of the system. A well known advantage of membranes when compared to other polishing steps (e.g., conventional filters) is the compactness of the membrane system. High surface area of membranes can be achieved by utilizing a high surface area configuration such as spiral wound or hollow fiber membranes.

- Low-fouling membranes will result in low frequency of backwashing, which reduces crew time and power. As membranes become irreversibly fouled, they have to be chemically cleaned or replaced. Robust membranes will reduce volume by reducing the need for extra membranes and cleaning solution on the shuttle. Once flux has degraded to some low threshold value (constant pressure systems) or when transmembrane pressure has increased to unacceptable levels (constant flux systems), system has to be either backwashed (MF/UF) or chemically/hydraulically cleaned (RO/NF).

If membranes can be developed and operated with minimal fouling, backwashing and cleaning frequency will be reduced, which will reduce the amount of operational attention. Also, there will be a reduction in power resulting from reduced backwash flow.

Cumulative Research Progress to Date

Fouling of MF/UF Membranes. The suite of MF/UF membranes tested for flux/rejection of target contaminants is shown in Table 5.1. A Sepa crossflow unit was used for all experiments to simulate hydraulics typical of spiral wound units (Figure 5.1).

<table>
<thead>
<tr>
<th>Membrane</th>
<th>Pore Size</th>
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<tr>
<td>PVDF UF</td>
<td>30000 MWCO</td>
</tr>
<tr>
<td>Polysulfone UF</td>
<td>30000 MWCO</td>
</tr>
<tr>
<td>Cellulose Acetate UF</td>
<td>20000 MWCO</td>
</tr>
<tr>
<td>Polyethersulfone UF</td>
<td>20000 MWCO</td>
</tr>
<tr>
<td>PVDF MF</td>
<td>0.1 μm</td>
</tr>
<tr>
<td>Polyethersulfone MF</td>
<td>0.1 μm</td>
</tr>
<tr>
<td>Polycarbonate MF</td>
<td>0.1 μm</td>
</tr>
<tr>
<td>Polyethersulfone MF</td>
<td>0.22 μm</td>
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</tbody>
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Table 5.1. MF/UF membranes to be used in this study. Membranes were chosen to be representative of different pore sizes and materials.
The operating pressures for the MF system range from 10 – 50 psi. Based on flux profiles (not shown), polyethersulfone (PES) and polycarbonate (PC) MF membranes were chosen for further study.

Flux decline was measured through the 0.1 micron PES and PC membranes using three different organic materials as feed solutions (Figure 5.2): 1 g/L bovine serum albumin (BSA), 25 mg/L Suwannee River Humic Acid (SRHA) and 25 mg/L Aldrich Humic Acid (ALD). These organics materials were chosen based on the pore size/solute ratios for the membranes. Fouling mechanisms were elucidated for each different organic.

Fouling mechanisms (pore plugging, etc) can be elucidated by quantifying the flux decline and resistance of the membrane and cake layer. Internal fouling can be described by standard blocking or pore blocking models, while external fouling can be described by cake filtration models. Data such as that shown in Figure 5.2 can be fit to models to determine fouling mechanisms. The protein formed a cake layer on the (cake filtration model) membrane surface, while the humic acid layer formed inside the membrane pores (standard blocking model), effectively decreasing the membrane pore size. In future studies, these fouling mechanisms will be linked to cleaning strategies for the membranes. Surface (cake filtration) fouling is often easier to reverse than internal (pore) fouling.

Ion Rejection from RO/NF Membranes. The first consideration for RO/NF membranes is rejection of target contaminants, since this process is the final one before disinfection and reuse. Thus, ion rejection from a suite of RO and NF membranes was studied (Table 5.2). Typically, NF membranes do not have a high rejection of monovalent ions, but rejection of divalent ions can be significant. However, since NF
membranes operate at lower operating pressures than RO membranes and have cheaper operating costs, it would be desirable to increase the rejection of all ions (including monovalent ions) from NF membranes to increase the efficiency of NF membranes and substitute these lower pressure membranes for RO in this application. A cellulose acetate NF membrane was modified by implanting fluoride ions into the active surface layer of the membrane, thus increasing effective membrane charge, as shown by streaming potential measurements across the membrane (Figure 5.3). This technique has been developed elsewhere (Mukherjee, et al., 2004; Abitoye, 2004).

Ion rejection was evaluated from the modified and unmodified membranes (Figure 5.4). Increased electrostatic interactions near the membrane surface increased ion rejection from these membranes. Results shown are for sodium rejection from an influent feed of 1m M NaCl. Low salt flux indicates high ion rejection. The goal is to verify these results for other membrane materials and determine if NF membranes can compete with RO membranes for ion rejection. Positive results from those experiments would indicate that NF membranes can be modified to have high monovalent ion rejection (similar to RO), but with much lower operating pressures.

Table 5.2. RO/NF membranes evaluated for flux and ion rejection. First three membranes are low pressure RO membranes, last two membranes are NF membranes.

<table>
<thead>
<tr>
<th>Material</th>
<th>Rejection</th>
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<tr>
<td>Cellulose Acetate</td>
<td>97% NaCl</td>
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<tr>
<td>Polyamide</td>
<td>99.5% NaCl</td>
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<tr>
<td>Thin Film Composite</td>
<td>98.2% NaCl</td>
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<tr>
<td>Cellulose Acetate</td>
<td>92% Na2SO4</td>
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Figure 5.4. Salt flux of monovalent ion (Na+) across polyamide membrane. Results shown are for a low F- dose (1 x 10^{10} atoms/cm^2) and a high F- dose (5 x 10^{6} atoms/cm^2)
Future Research Directions

- Modify commercially available membranes. After physical-chemical influences on fouling are determined, membranes will be modified to reduce adsorption of organics on membrane surfaces. BREATHe effluent will be filtered through the membrane to determine fouling mechanisms.
- Evaluate biofouling of membranes. Biofilm attachment on MF/UF membranes will be evaluated by exposing membranes to BREATHe effluent and performing a heterotrophic plate count on membranes to determine biofouling potential.
- Operate system with integrated disinfection. A UV lamp will be sent to Howard University so that disinfected water can be fed directly to RO/NF unit (see Collaboration within NSCORT, below).
- Evaluate cleaning techniques. Once fouling resistance has been quantified, appropriate cleaning strategies will be evaluated. Backwash, hydraulic cleaning, alkaline cleaning, and chemical cleaning are all possible cleaning strategies for membranes. A mechanistic approach will be taken to evaluate the percentage of fouling resistances remaining after progressive cleaning techniques for each membrane.

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<td>Modify commercially available membranes</td>
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<tr>
<td>Continue organic fouling and rejection of modified membranes</td>
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<tr>
<td>Evaluate biofouling of modified membranes</td>
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<td>Operate system with integrated disinfection</td>
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<td>Evaluate cleaning techniques</td>
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Trainees
- Joshua Abitoye (MSChE)
- Samantha LaHee (MSCE)
- Joffrey Leevy (MSCE)
- Asha-Dee Celestine (Summer Fellowship Student, BSME)
- Ravindra Revanur (Postdoctoral Researcher)
Research Collaboration

**Collaborations within NSCORT**

Membrane processes (Project Five) will be completely integrated with BREATHe reactors (Project Six) and Disinfection (Project Eight). The schematic of the integrated projects is shown in Figure 5.1:

Each integrated system will be constructed at Howard University and Purdue University. Collaborators (Banks, Blatchley) at Purdue will purchase Osmonics crossflow membrane units to be integrated with their existing biological and disinfection systems. The membrane units will be operated under constant flux conditions, with the primary goal of disinfecting permeate directly from membrane units instead of having to ship water between universities.

Similarly, collaborator (Jones) at Howard University will receive a UV lamp to place between the MF/UF and RO/NF units in order to simulate disinfection of the permeate.

In order to further facilitate collaboration, a summer fellowship student from Howard University traveled to Purdue to work with Bank’s group on characterizing biofilm growth on MF/UF membranes.

**Collaborations outside of NSCORT**

The PI recently presented results from this study at the 2004 ICES conference, where she met with Jay Garland (KSC) and discussed collaborations regarding the development of membranes with targeted biofilm growth. Specifically, Jones’ group is developing bacterial-resistant membranes; Garland’s group would like to develop bacteria-attractive membranes. The collaboration would entail a study of the specific factors of membranes that encourage or prohibit bacterial growth and the synthesis of membranes that are tunable to bacterial growth.
Publications and Presentations To-Date:


Pending Research Milestones and Benchmarks

- Modify commercially available membranes
- Continue organic fouling and rejection of modified membranes
- Evaluate biofouling of modified membranes
- Operate system with integrated disinfection
- Evaluate cleaning techniques

References:


8.4 PROJECT EIGHT: POTABLE WATER DISINFECTION SUBJECT TO EXTENDED SPACE TRAVEL CONSTRAINTS – (IODINE, CHEMICAL) COMPLEMENTARY WATER DISINFECTION

Principal Investigator: Ernest R. Blatchley III, PE, PhD., Professor, School of Civil Engineering, Purdue University

Project Goals and Objectives

Four research goals for investigating UV and iodine disinfection are listed below.

- Determine whether complementary disinfection using UV radiation and iodine will provide more effective microbial inactivation than either method alone.
- Develop a chemical actinometer that can monitor the UV disinfection process, in addition to providing sufficient quantities of iodine to achieve residual disinfection. The dual purpose of the chemical actinometer may reduce chemical restock requirements.
- Investigate whether the microbial check valve (MCV), which was developed in the 1970s by NASA, can be used to store and deliver the photochemically-produced iodine.
- Evaluate the effectiveness of using Vitamin C to remove iodine from potable water, while providing a beneficial residual for the astronauts.

Cumulative Research Progress to Date

Analytical methods for the detection of various iodine species have been developed. Specifically, effort has been placed on the determination of molar absorptivity of various iodine species. These values were derived by direct measurement using a spectrophotometer, in addition to the iodine speciation model, which was previously developed as part of this research. The iodine speciation model allows the concentration of various iodine species to be determined using information such as pH and total iodine concentration.

NASA has indicated severe restrictions on the use of mercury in space missions. As such, mercury-containing lamps, which are the most common and most efficient sources of germicidal UV radiation cannot be used in these systems. Therefore, alternative UV sources are needed.
Excimer lamps represent a possible alternative to conventional mercury lamps. Through an agreement with USHIO America, Inc., our group has acquired two excimer lamps for use in this research. These lamps, based on KrCl and XeBr excimers, yield nearly monochromatic UV output at characteristic wavelengths of 222 nm and 282 nm. In addition, it is possible that a third lamp based on a XeI excimer may become available; the XeI excimer develops output that is nearly monochromatic at 253 nm. As a substitute for this source, experiments are being conducted with an existing Hg lamp (characteristic wavelength – 254 nm).

The iodide/iodate actinometer will be used as both the source of oxidized iodine for chemical disinfection and a tool for monitoring of UV process performance. The photochemical quantum yield of the iodide/iodate actinometer was determined for three different UV wavelengths (222 nm, 254 nm and 282 nm) using the radiation sources described above (see Figure 1).

Complementary disinfection is based on the hypothesis that the application of two disinfectants that accomplish microbial inactivation via fundamentally different mechanisms will be more effective than either process alone. To test this hypothesis, it is necessary to quantify the dose-response behavior of representative microorganisms against the individual disinfectants. The dose-response relationship of
Bacillus subtilis spores when subjected to iodination was investigated for pH=5. Figure 2 shows the experimental results.

Two capillary flow reactors have been constructed by Purdue University for use at Howard University. It is anticipated that the capillary flow reactors will be used to investigate biofouling of membrane filters. A photograph of one of these devices is provided below.

Figure 1: Quantum Yields for the Iodide/Iodate Actinometer
Future Research Directions

- Conduct additional dose-response experiments with iodine and *B. subtilis* at near neutral pH (November 2004).
- Conduct additional dose-response experiments with UV radiation (222 nm and 282 nm) and *B. subtilis* (December 2004).
- Determine the benefit of complementary disinfection (January 2005).
- Investigate the feasibility of using the MCV (or similar device) to deliver photochemical produced iodine for residual disinfection purposes (February 2005).
- Evaluate using Vitamin C in the iodine removal process (March 2005).

Trainees

Kelly Pennell, PhD Candidate
Research Collaboration

- Two non-mercury UV sources were donated by USHIO America, Inc. (Cypress, CA) for research relating to bacterial inactivation and photochemical kinetics.

Upon receipt, each lamp was configured within a flat-plate collimator. Collimated radiation consists of parallel rays of radiation with uniform intensity. Without a collimated source of radiation, the radiation emanating from a tubular UV source is emitted non-uniformly in radial directions.
Purdue and Howard Universities are working to investigate biofouling of membranes using pre- and post-irradiated wastestreams.

In order to deliver a uniform UV dose to the water, a capillary flow reactor was constructed. Water to be irradiated flows through the capillary tube at a predetermined distance from the UV lamp. The effluent water will then be treated by membrane filtration. Biofouling of the membrane will then be evaluated.
NSCORT Summer Undergraduate Fellowship Program.
Andy Hai-Ting of Howard University investigated bacterial inactivation kinetics as part of the NSCORT Summer Undergraduate Fellowship Program. His research included UV radiation and iodination of *B. subtilis* spores.

Publications and Presentations To-Date:


8.4 PROJECT EIGHT: POTABLE WATER DISINFECTION SUBJECT TO EXTENDED SPACE TRAVEL CONSTRAINTS – UV IRRADIATION (PHYSICAL)

Principal Investigator: Ernest R. Blatchley III, PE, Ph.D., Professor, School of Civil Engineering, Purdue University

Co-Investigators
Dennis A. Lyn, Associate Professor, School of Civil Engineering, Purdue University

Project Goals and Objectives
ESM calculations for the Mars surface mission (duration 600 days) were performed for the proposed UV disinfection reactor, resulting in an overall ESM estimate of 117 kg. Figure 1 is a schematic representation of the UV disinfection reactor geometry that the ESM values were based upon. Figure 2 represents ESM partitions based on individual components. The greatest contribution to the ESM value comes from the power consumption by the UV lamp. It should be noted that alternative reactor designs will be investigated as part of this project that are likely to alter the ESM estimate described above.

The greatest contribution to the ESM value comes from the power consumption by the UV lamp. It is expected that power consumption can be reduced by increasing the efficiency of the UV lamp. Crew time can be decreased by reducing the maintenance requirement, and mass reduction can be achieved if the reactor is constructed out of a material lighter than stainless steel. All these possibilities are being investigated as part of the alternative reactor design mentioned above.

Cumulative Research Progress to Date
A numerical method for prediction of UV disinfection process efficacy has been developed and experimentally tested based on existing hardware. The model simulates the microbial inactivation process that takes places within an annular UV disinfection reactor, with the chosen target microorganisms being *Bacillus subtilis* spores. The experimental set-up with the model UV disinfection reactor is presented in Figure 3. The internal length of the reactor is 75.5 cm and internal diameter is 9.56 cm. The reactor contains a centrally positioned low-pressure mercury lamp which has a length of 75.5 cm and an outside diameter of 2.54 cm. Two sets of flow-through experiments were conducted. The first set of operating conditions included tap water that had been subjected to pretreatment through a reverse osmosis system and had a transmittance of 99.38%. The second experiment was conducted under lower transmittance conditions of 64.85%. This was achieved by adding decaffeinated instant coffee to the aquatic matrix. For both experiments, $10^7$ colony forming units/L of *Bacillus subtilis* spores were added to a 350 L tank of water. This aqueous suspension was then drawn from the tank with a pump and passed through the
UV reactor at four different measured flow rates. Samples of the suspension were collected from the tank and at the outlet of the reactor at all flow rates under steady-state operating conditions. These samples were then vacuum filtered through 0.45 μm membrane filters and the membranes were transferred to nutrient agar plates for 24 hours of incubation at 37ºC. Individual colonies on the filters after this period of incubation were assumed to be attributable to a single viable spore in the original water sample that was passed through the membrane filter. Inactivation achieved at all four flow rates was measured by comparing the initial number of viable spores and the number of viable spores in the irradiated effluent at all flow rates.

In UV disinfection theory, microbial inactivation predictions are expressed as the inactivation ratio, \( \frac{N}{N_0} \), where \( N \) is the number of viable microorganisms after UV radiation exposure and \( N_0 \) is the initial number of viable microorganisms. The inactivation ratio can be correlated to the UV radiation dose, \( D \), imposed on the microorganisms. The UV dose, \( D \), is defined as the integral of UV radiation intensity history, \( I(t) \), over the period of exposure, \( \tau \). Therefore, to numerically determine the inactivation ratio for a certain microorganism, information is needed on the dose, \( D \), delivered by the UV system and the value of \( \frac{N}{N_0} \) corresponding to each dose, \( D \). The relationship between \( \frac{N}{N_0} \) and \( D \) for \textit{Bacillus subtilis} spores was determined by cultivating a large number of spores in the laboratory and exposing known concentrations of them to a range of representative UV doses. Spore suspensions were irradiated using a collimated-beam device and a shallow, well-mixed batch reactor. The collimated-beam apparatus used in this research were based on low-pressure or low-pressure high output mercury lamps; these devices yield highly uniform, nearly monochromatic output beams at 254 nm. The resulting inactivation curve, the relationship between the dose imposed on the microorganism and the achieved degree of inactivation, is presented in Figure 4 for \textit{Bacillus subtilis} spores.

Due to turbulent flow conditions achieved in the UV reactor, each microorganism will traverse the reactor following a different trajectory. This condition, together with the non-uniform radiation intensity field in the reactor, determines that a distribution of UV doses will be delivered by an UV reactor, as opposed to a unique dose delivered to all the microorganisms. An estimate of the dose distribution can be developed by simulation of the UV intensity field with a numerical method known as line source integration, and simulation the flow field and microbial (particle) trajectories through the reactor with commercially-available computational fluid dynamics software, FLUENT. An example of 4 microorganisms traversing the modeled reactor is shown in Figure 5, and the dose distribution delivered by the reactor at four different flow rates is presented in Figures 6 and 7, for the 99.38% and 64.85% water transmittance cases, respectively.

These dose distributions were then linked to the dose-response relationship determined experimentally for \textit{Bacillus subtilis} spores, thereby allowing prediction of the inactivation responses of these organisms for each operating condition. These numerical results, along
with the measured results from the flow-through experiments described previously, are presented in Figure 8. The results are in good agreement; these results indicate that the model provides a reasonably accurate representation of disinfection efficacy in the UV reactor system, and the fundamental physical behavior that governs its performance.

**Future Research Directions**
Future efforts will be directed towards investigating reactors with alternative UV radiation sources which do not contain mercury, such as excimer lamps. Different reactor geometries will be investigated with the developed numerical method for their inactivation efficiencies. The most efficient candidate geometry will be chosen and operating conditions will be optimized with the help of the numerical simulations.

**Trainees**
Zorana Naunovic, Environmental Engineering, Doctorate Degree

**Research Collaboration**
- Ondeo Degremont Inc, Richmond, Virginia provided the model UV reactor for experimental research
- USHIO Inc, Cypress, California provided two excimer lamps as non-mercury UV sources

**Publications and Presentations To-Date:**
- Zorana Naunovic, “Ultraviolet Water Disinfection for Long-Term Space Missions,” Space Advanced Life Support Class Lecture, School of Civil Engineering, Purdue University, West Lafayette, Indiana, April 2004.
- Zorana Naunovic, "Potable Water Disinfection for Long-Term Space Missions", Oral presentation, Hydraulics/Hydrology Civil Engineering Seminar, Purdue University, West Lafayette, Indiana, October 2003.

**Pending Research Milestones and Benchmarks**

**References:**
Figure 1. Schematic of UV disinfection reactor with relevant dimensions defined in centimeters

Figure 2. ESM partitions based on its components
Figure 3. Experimental set-up for the flow-trough experiment with model UV disinfection reactor.

Figure 4. Dose-response relationship (Inactivation curve) for *Bacillus subtilis* spores based on irradiation under a collimated beam device.
Figure 5. Example of four microbial trajectories through the reactor as simulated by particle-tracking algorithm in FLUENT.

Figure 6. Dose distribution based on 1000 particles traversing the reactor at different flow rates (T=99.38%).
Figure 7. Dose distribution based on 1000 particles traversing the reactor at different flow rates (T=64.85%)

Figure 8. Inactivation measurements with experimental method and inactivation predictions with numerical method for *Bacillus subtilis* spores

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8.5 PROJECT SEVEN: GAS-PHASE REVITALIZATION USING BIOFILTERS IN ADVANCED LIFE SUPPORT

Principal Investigator  Dr. Albert J. Heber, PE, Ph.D.  
Professor of Agricultural and Biological Engineering, Purdue University

Co-Investigator: Dr. M. Katherine Banks, Ph.D.  
Professor of Civil Engineering, Purdue University

Project Goals and Objectives

Our goal is to develop bio-regenerative air cleaning systems to efficiently remove the gas phase contaminants that will be generated in the cabin during long term space missions. The Bio-Regenerative Environmental Treatment for Health (BREATHe) has been proposed as an alternate system to decontaminate cabin air using biofiltration. Our ultimate research goal is to optimize design and operation of air biofiltration in the ALS indoor air system. The goal is to minimize the ESM burden and to maximize biofilter performance simultaneously. The ESM reduction may be achieved by optimizing gas/water loading and biofilter depth, and selecting biofilter media with a large surface area. Our approach is to optimize design and operation based on theoretical modeling first, and then to verify model results by experimentation. Specific goals are as follows.

1. Simulation of biofiltration and indoor air quality in the ALS system
   - Develop mathematical models to study the effects of biofilter design and operation on air cleaning performance.
   - Simulate the airflow and the indoor air quality in an ALS cabin using computational fluid dynamics and mass transfer programs and predict air purification by biofiltration.
   - Apply simulation results to design and control of experimental and full-scale biofilters.

2. Experimental setup of the BREATHe II system
   - Compare results with biofiltration process modeling.
   - Experimentally observe effects of media depth, media type, microbial growth, media clogging, gas residence time, and using of condensate on biofiltration performance.
   - Evaluate microbial degradation of several gaseous contaminants.
Cumulative Research Progress to Date

1. Simulation of biofiltration and indoor air quality in the ALS system

A simulation of biotrickling filtration processes was developed to predict the removal efficiency of the gas phase contaminants in the ALS cabin during long term space missions. Biotrickling filtration has been known to be effective in removing organic and some inorganic gas pollutants using microbial degradation. However, the mechanisms of biofiltration are so complicated that development of a theoretical model is needed to understand the reaction mechanisms. In this simulation, the influences of physical, chemical, and biological parameters on the elimination of gaseous contaminants were estimated using models modified from previous studies. As a result, we can describe the gravity effects on overall reaction and water flow behavior by incorporating the wetting phenomena of media surfaces. Consequently, this model can provide optimal values of water loading in the ALS space cabin. Fig 1 and Fig 2 show gaseous contaminant removal as influenced by biofilter filter depth and water loading rate respectively.

In addition, we are estimating the air flow and contaminant transport in the ALS cabin environment with an operation of a biofilter (or biotrickling filter). The network flow models are applied to simulate air flow and convective transport of gas phase contaminants emitted from contaminant sources. Using the model, we can predict the air flow patterns and the concentration of each gas phase contaminant in the ALS cabin.

Fig 1. Gas concentration as a function of media depth when re-circulated water flow rate is 10 L/hr (167 ml/min).
2. Biofilter lab setup for testing the BREATHe II system

We have completed the construction of 24 biofilters (Fig. 3). The liquid pumping system is operating continuously and liquid, currently water only, is added regularly to keep the media wet. Nutrient solutions are being selected to add into the biofilter to meet both moisture and nutritional requirements. Meanwhile, biofilters are being observed daily to troubleshoot operational problems, such as the frequency of liquid addition, the lifetime of pump tubing, and leakages. The air is supplied by an air compressor and evenly distributed by a pressure regulated manifold into the 24 biofilters.

A design was developed for the gas injection system and potential reactions between test gases were investigated. The gas injection system will have the capability of mixing up to 8 different gases into the air entering the manifold. A custom commercial system was considered but, due to cost, we will build it ourselves.

We performed ammonia calibrations with the FTIR spectrometer. Programmed concentrations of ammonia using a gas diluter were measured. The gas diluter was set up to deliver ammonia at 10 to 100% of cylinder concentrations. We are setting up permeation ovens to generate n-butanol, acetone and formaldehyde. For example, refillable n-butanol permeation tubes were installed in a KIN-TEK Model 571C permeation ovens, and once setup, the concentration of the generated gas will be measured by FTIR.

Fig. 2. Output gas contaminant removal as a function of water flow rate under dry and wetting surface presence.
A steam generator was obtained for the pre-humidification system and is being set up. Three types of media, compost, perlite and plastic foam were selected for the biofilters (Fig. 3). Filters were installed in the water distribution line to prevent clogging. Gas analyzers were repaired and the data acquisition and gas sampling hardware were set up to sample from the biofilters. Water distribution and nutrient addition systems were designed and constructed for each biofilter.

Fig. 3 Temperature-controlled chamber for testing 24 biofilters and biotrickling filters (BREATHe 2).

Future Research Directions

**Simulation of biofiltration and indoor air quality in the ALS system**

Before the end of this year, we will complete programming all simulation models for predicting biofiltration performance and ALS indoor air quality. Although the general framework for modeling the biofiltration process has been completed, the chemical kinetics and equilibrium equations for microbial degradation will be added to the models after the initial experiments. The indoor air quality simulations are being conducted by commercial programs for computational fluid dynamics. The mass transfer and chemical variations of humidity, water condensate, carbon dioxide and other chemicals will be incorporated in the simulation in the future. Next year, these simulations will be conducted repeatedly with parameter variation according to experimental data or other requests. The optimization of design and operation can be estimated based on ESM calculations and model-based parametric control simulations.
Biofilter test lab for the experimental testing of the BREATHe II system

We will test 24 biofilters, continuously in test runs, each lasting several weeks. Removal effectiveness will be optimized while considering cost and ESM reductions. First, we will write a complete Quality Assurance Project Plan for the biofilter tests which will include standard operating procedures, data quality objectives and criteria, and lab safety. We will evaluate synthetic vs. biological media; treatment of air vs. treatment of air and water; airflow rate, liquid flow rate, contaminant feed rates, and EBRT (Empty Bed Resident Time). We will monitor biofilter airflow rate, gas concentrations of each contaminant, liquid pH, temperature and relative humidity of supply air and biofilter exhaust air, and probe and supply air manifold pressures. The water flow rate will be measured daily.

Trainees

Sang-hun Lee, Air Quality, Ph.D Student, Agricultural and Biological Engineering, Purdue University

Hong Huang, Air Quality, Master’s Student, Agricultural and Biological Engineering, Purdue University

Research Collaboration

- Please emphasize the collaboration between projects WITHIN the ALS NSCORT as well as those with which you have worked outside the ALS NSCORT.
  1. Collaboration with Research Project #6 on development and discussion of biofiltration system and modeling.
  2. Collaboration with Research Project #15 group on calculation of ESM values.

Publications and Presentations To-Date:


Pending Research Milestones and Benchmarks

1. Commission biofilter test lab.
2. Complete pilot test of biofilter lab.
3. Complete ALS air quality model
4. Complete biofilter model

References:

8.6 PROJECT FOUR: LIQUID FREEZE-THAW (LIFT) URINE AND R.O. BRINE PROCESSING FOR ADVANCED WATER RECOVERY AND SALT SEPARATION

**Principal Investigator**
Dr. James E. Alleman, PhD., Professor of Environmental Engineering, School of Civil Engineering, Purdue University

**Co-Investigators**
Jeff Schmidt, Doctoral Student, Environmental Engineering, Purdue University

**Project Goals and Objectives**
- The primary goal is potable water extraction from urine; however, additional waste streams will be tested based on the same principle technology.
- Research geared towards reduction of ESM compared to existing water recovery technologies. i.e. VCD and VPCAR

**Cumulative Research Progress to Date**
At the start of 2004 LiFT research focused on the feasibility of a sublimation system for urine water processing. The third LiFT sublimation system was completed and initial tests began; however, research goals were changed as a result of an ESM analysis of a sublimation process. During collaborations with our systems analyst YanFu Kuo, the energy usage of a sublimation process was proven to be a large energy consumer with not much advantage over the current urine processor, the VCD. From that point, the initially proposed freeze-thaw extraction technique was again studied and thus reintroduced as the method of choice for potable water extraction from urine. Energy requirements for a freeze thaw technique are much less than those for sublimation and distillation as noted in Table 1.

**Table 1: Energy Comparison of Urine Treatment Techniques**

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<tr>
<th>Freeze-Thaw Latent Heat of Freezing</th>
<th>Distillation Latent Heat of Vaporization</th>
<th>Sublimation Latent Heat of Sublimation</th>
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<tr>
<td>334 kJ/kg</td>
<td>2260 kJ/kg</td>
<td>2800 kJ/kg</td>
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This change was also reborn because during sublimation system testing, observations were made in the freezing and thawing of urine that resulted in an obvious separation of salts and organics. A simple initial experiment was performed to prove this concept based on the conductivity of urine pre- and post-freezing. The results of this experiment showed that a concentrated salt solution is formed during freezing and could perhaps be physically removed from the sample as a pre-treatment step. The concept of this experiment was based on the melting temperature of salt solutions being lower than that of pure water.
An intensive literature search was performed in order to determine the most practical freeze-thaw process for urine considering aspects ranging from energy consumption to process location requirements. There were a few possible options. One included a spray freeze concentration technology that utilizes the technique of salt separation from water during freezing. In colder regions of the world this technology is an economically feasible choice for drinking water treatment of salt laden waters. The process is relatively simple. Salt water is sprayed into the air during below freezing temperatures. As a result, ice crystals form and a concentrated brine solution is wasted. This method is capable of removing 70% of water from salt solutions. Based on this idea, an experimental set up was constructed consisting of an upright freezer modified with input/output points for waste treatment and collection. Experiments were conducted to determine the feasibility of this technology based on urine conductivity measurements. Although theoretical treatment levels were not achieved, this was not the main reason that a spray-freeze-thaw process was discarded. In essence, the process would be difficult if not impossible to control in a microgravity environment, plus a 70% water recovery rate was low compared to other options.

Another freeze-thaw option studied was a freeze concentration method of water extraction from urine. Literature suggests that this is the optimal method for solid-liquid extraction in the freeze-thaw regime. Freeze concentration is a process that focuses on the nucleation of pure ice crystals followed by a ripening effect of those crystals and subsequent washing to achieve high extraction efficiencies. Figure 1 below represents the basic process. Through collaboration with the leader in the freeze concentration industry, a theoretical water recovery value of approximately 90% has been determined based on the eutectic points of urine constituents.

**Figure 1:** Freeze Concentration Process Schematic (Niro 2004)
Small scale versions of freeze concentration have been attempted, see Figure 2 below, but lack the high water recovery due to insufficient design parameters; however, initial results are very promising with water recovery rates reaching approximately 30%. COD tests were also performed on the product water however we were working with a minimum detectable limit of 20 mg/L. Results of these tests determined COD values being below this minimal value. The basis of freeze concentration lies in the fact that pure ice crystals are formed thus crystallization removes virtually all impurities leaving a ‘pure’ water product. Our initial testing has confirmed this idea.

Collaborations with a freeze concentration company have resulted in a planned pilot plant study of water extraction recovery rates and cleaning capabilities of a model urine solution. The study will consist of two phases. Phase I involves off-site testing located at the company’s pilot plant. Upon completion and process verification, Phase II will include on-site testing of urine samples at Purdue using the company’s freeze concentration unit. Phase I studies will be completed the last week of September; if positive results are obtained, Phase II will follow after transportation and operation requirements are completed.

Figure 2: Bench scale freeze concentration experimental setup
Future Research Directions

As mentioned above, a pilot plant freeze concentration study will be performed in late September, after this report is printed, and will then be followed by on-site experiments, upon favorable results, of numerous waste streams including ersatz formulations and urine samples. Results will focus on water recovery rate, conductivity, and TOC. Further research will focus on the integration of freeze concentration with other water recovery processes such as VPCAR. The basis of this research lies in the fact that the energy consumption of freeze concentration is much less than that of VPCAR; however, only 90% water recovery is attained. Therefore, the concentrated brine from freeze concentration will have to be further processed.

Research Collaboration

- Collaborations with our systems analyst YanFu Kuo has resulted in significant advances in our research as mentioned above. ESM reduction being the main goal of the Purdue University NSCORT, he helps keeping us on our objective.
- We have worked quite a bit with Niro Inc. of the Netherlands in studying the benefits of freeze concentration in the effect that a long-term relationship with them is almost certain in developing a urine processor.

Publications and Presentations to Date


Pending Research Milestones and Benchmarks

Results from the freeze concentration pilot plant studies will be in by the time this report is sent. Our hopes are high, and chances are very likely, that these results will be quite favorable thus resulting in future experiments with multiple waste streams.

References

9.1 SYSTEMS GROUP EXECUTIVE SUMMARY

The principal investigators, postdoctoral staff, graduate students, and technical staff have continued to engage in several projects and events. A dynamic human model and a crew cabin atmosphere model have been built. A prototype SIMulation based OPTimization (SIMOPT) framework is being used to enable identification of the optimal strategies to control the overall ALSS behavior. A Plant-Scheduling model has been developed to determine the best planting schedules to minimize ESM. ESM analysis is being conducted on all subsystems, and has initial computations have been completed on several subsystems – UV water disinfection, BREATHe II, STAR, LiFT, Zeolite, biomass production chambers and food production subsystems. ESM sensitivity analysis is also being conducted. A process model of all mass flows in a life support system relying uniquely on proposed NSCORT technologies has also been developed.

A system dynamics model using Stella software was developed for the Membrane System for ALS Wastewater Recycle. Another prototype high-level ‘qualitative’ system dynamics model of a complete bioregenerative life-support system was also built using Stella. These models are also being incorporated into the senior level Systems Management Course at Howard University.

Near-term future work will involve continued interaction with the members of all the NSCORT systems to refine and extend the models being developed and the ESM calculations.

Guy Gardner
Integrated Systems Group – Focus Area Lead
Principal Investigator  Dr. Joe Pekny, PhD., Professor, Chemical Engineering, Purdue University

Co-Investigators  
Dr. Yuehwern Yih, PhD., Professor, Industrial Engineering, Purdue University,  
Dr. George T-C. Chiu, PhD., Professor, Mechanical Engineering, Purdue University,  
Dr. Bin Yao, PhD., Professor, Mechanical Engineering, Purdue University.

Project Goals and Objectives  
- Develop a SIMulation based OPTimization (SIMOPT) framework to study the dynamics of advanced life support system.  
- Evaluate ESM of technologies developed in ALS NSCORT. Determine the technology performance by comparing with the ISS assembly complete technologies ESM.

Cumulative Research Progress to Date  
ALS/NSCORT systems group research activities in its second year are aligned with the November 2003 External Advisory Committee meeting recommendations and can be grouped in three major categories: Model Development Activities, ALS/NSCORT Process Map Development and ESM estimations of ALS/NSCORT technologies.  

Model Development Activities  
A dynamic human model is built to evaluate the crew members’ inputs and outputs by hour. In this model, users can freely assign crewmembers’ gender, age, weight, and activity schedules to find out the hourly energy expenditure, heat production, oxygen requirement, carbon dioxide and respiration water productions, as well as the diet composition. Waste generation is computed in proportion of the total oxygen, food and potable water consumed. Meanwhile, hygiene water inputs and outputs are extracted directly from Baseline Values and Assumptions Documents, 2002. Some of the data and formula applied are not as sensitive as others with respect to crewmember’s gender, age, weight and activity schedules (e.g. hygiene water consumption). This is mainly due to the lack of existing formula and data available. However, this shortcoming is not a hurdle in developing the dynamic model, as the use of Excel spreadsheet in computing these attributes allows users to easily update formula and data later.  

Apart from the human model, crew cabin atmosphere is modeled as well. In the crew cabin atmosphere, the habitat volume, total cabin pressure, air temperature and mass of oxygen, carbon dioxide, water vapor, and nitrogen by difference are considered.
Using Matlab, these two subsystems are combined together to evaluate the effects of crewmembers’ activities toward the cabin atmosphere. To this date, the oxygen depletion and increase of carbon dioxide, water vapor and temperature in the cabin are successfully modeled.

A SIMulation based OPTimization (SIMOPT) approach is used to study the dynamics of Advanced Life Support System (ALSS). The SIMOPT architecture uses a Deterministic Optimization (DO) algorithm to optimize the overall ALS behavior by minimizing the re-supplies which are difficult to procure or transport, in conjunction with a simulation model which introduces uncertainty, i.e. randomness, to the system. A prototype SIMOPT framework is studied. For this purpose, a simple dynamic simulation of the ALSS using an aggregate mass balance model is developed to represent reality with uncertainty. The ranges of acceptable values of strategic decisions, e.g. safety buffer for oxygen, in a given ALSS scenario are determined using time series data mining methods performed on the information gathered within the timelines, which are generated by the ALSS simulation. These buffer values impose constraints to the optimization model (DO algorithm) which is an aggregate steady state mass balance model. This model determines the optimal values for the degrees of freedom of the ALSS used in the simulation. It should be noted that the random events introduced through the simulation may result in a difference between the predicted values of the variables by optimization model and values generated by the simulation (a trigger event). As the number of trigger events increases the data mining algorithm examines the timelines to infer the system behavior and updates the desired safety buffer values. These new values are used in the optimization model within the proposed SIMOPT architecture. Therefore, SIMOPT framework enables us to identify the optimal strategies to control the overall ALSS behavior. This work has been presented in International Conference on Environmental Systems (ICES) 2004.

Additionally, a Plant-Scheduling module is developed. Given the demands of the ALSS crops over a period of time (which can be specified by the user of the module), it determines the best planting schedule that will optimize the system behavior, i.e. the one that would minimize ESM. The formulation is an MILP and coded in Java, the equations are solved using CPLEX, which is a widely used commercial optimization package.

**ALS/NSCORT Process Map Development**

A process model of all mass flows in a life support system relying uniquely on proposed NSCORT technologies is developed. The purpose of this activity was to answer the question whether the ALS/NSCORT technologies can act as a system or not (see appendix for the current ALS/NSCORT process map). The model has an Excel interface to unify all specifications of process connectivity, stream compositions, mass and concentration values, reaction stoichiometry, phase equilibria, and other relations. The underlying code solves a linear program currently having 947 variables and 711 equations. The model finds feasible solutions including operation of all air, water, and waste recovery processes, growth of 15 crops, edible fungi, tilapia, and six biosolids dewatering plants. The air and water loops are evidently closed, and food is mainly supplied based on the current choice of costs for supply vs. growth. Biomass production is minimized in general.
**ESM estimations of ALS/NSCORT technologies**

ESM analysis is conducted to evaluate the performance of ALS/NSCORT technologies. As most of the technologies are still under development, appropriate assumptions and educated guesses from subsystem experts are considered into the analysis. This ESM analysis focuses on a hypothetical device, instead of the anticipated technology that is system flight proven in mission operations, because many ALS/NSCORT technologies are at low TRL levels. To add more flexibility into the ESM calculation, sensitivity analysis is introduced to include all the ESM possible values. In addition, this method allows the identification of the most critical factor that can reduce the ESM significantly. So far, the ESM evaluation on UV water disinfection, BREATHe II, STAR, LiFT, Zeolite, biomass production chambers and food production subsystems are completed. Initial ESM estimation and sensitivity analysis for the NSCORT ALS subsystems are performed for Mars surface mission scenario. The estimations based on BVAD requirement and consider the physical/chemical constraints of each subsystem as well as preliminary experimental data provided by the subsystem development team. Sensitivity analysis of the estimated ESM provided information for the subsystem development team to optimize system design and reduce ESM for the entire advance life support system. Moreover, the established mission scenarios documented in the RMD are used to analyze the impact of mission scenario on subsystem design for certain ALS/NSCORT technologies. The purpose of this analysis is to explore the impact of the various ESM equivalencies of different missions.

**Future Research Directions**

The ALS/NSCORT systems group envisions continuing to work effectively in these three major activity threads in the upcoming year.

**Model Development Activities**

After building the human and cabin atmosphere model, crop model will be constructed and then incorporated with the two models mentioned. At this point of time, the modified energy cascade available in BVAD 2004 is selected as a "candidate" to model the crop. It is anticipated that the crop model will be able to capture the daily oxygen production, daily carbon gain, daily canopy transpiration rate, total biomass and edible biomass, among others. For simplicity purpose, a hypothetical crop is considered at this time. The hypothetical crop will possess the average properties of dry bean, lettuce, peanut, rice, soybean, sweet potato, tomato, wheat and white potato, which are the crops that have the most complete data for use in the modified energy cascade.

Currently a diet optimization module which will determine the best diet cycle that minimizes the ESM of the overall ALSS is being developed. Given the activity schedule of the crew members, the model will be able to calculate the necessary nutritional requirements of the crew members using a dynamic human model. A diet cycle (20-30 days cycle) will be constructed that meets these requirements while minimizing the ESM. This model will also be able to give the necessary biomass amount required to construct this diet. This study will be completed by the end of 2004.
Necessary biomass amounts calculated by this module will be fed into the plant-scheduling module as the demands. The diet optimization and plant-scheduling modules will be integrated into the SIMOPT framework to study their effects on the overall system behavior and to represent the ALSS more realistically.

We will analyze the supply requirements and waste generations of three different scenarios, i.e. camping trip approach in which everything that is need for life support is shipped to Mars, a more evolved base including pysico-chemical systems for resource recovery and finally a complete base with biomass production via the plant growth chambers, for Mars surface missions. The system trade of studies will be done on the architecture level using ESM values as well as in terms of waste generation by the system. This work will be submitted as a manuscript to a special issue of International Journal of Environment and Pollution (IJEP) in January 2005.

**ALS/NSCORT Process Map Development**

The process map developed will be a living effort which will be updated and modified as more detailed data and information is evolved from ALS/NSCORT projects to investigate integration issues such as, but limited to, load compatibility, transient behavior, and fault/error handling. The result of the investigation will provide sub-system developer more reliable information on interconnect behavior and fault/exception handling requirements. This analysis will be able to provide feedback to the sub-system researchers regarding system integration and cost trade-offs and ensures that the sub-system will be able to function in an integrated life support system. Sensitivity analysis is can be applied to the ESM result to identify aspect of the system that will provide most significant improvement.

**ESM estimations of ALS/NSCORT technologies**

ESM analysis will also be conducted on BREATHe I, iodine water disinfection, reverse osmosis/ nano filtration, biosolids dewatering plants, fish/tilapia and edible fungi growth subsystems. After that, the performances of each subsystem will be evaluated through comparison with the ISS assembly complete technologies. As ISS assembly complete technologies are expected to have lower closure or higher re-supply than ALS technologies, not all ALS NSCORT technologies will be able to find a compatible ISS subsystem to compare its performance with. This challenge remains to be addressed.

The ESM of a complete ALS system will be estimated after a mission scenario specific NSCORT ALS design has been finalized. The total system level ESM estimation, in addition to subsystem ESM, needs to include system integration, interface and control functionalities. The result will be compared to the ISS or other similar ALS systems.

**Trainees**

Chit Hui Ang, Industrial Engineering, Master’s program
Selen Aydogan, Chemical Engineering, PhD program
Tze Chao Chiam, Industrial Engineering, PhD program
YanFu Kuo, Mechanical Engineering, MSME
Research Collaboration

- Systems group works with all of the project teams within ALS/NSCORT to:
  - Estimate ESM of each ALS/NSCORT technologies.
  - Develop, improve and maintain ALS/NSCORT process map.
  - Aid project planning.
- Organize quarterly half day workshops where each project team reports their progress and updated project plans to all of the ALS/NSCORT researchers.
- In order to compare the ESM of ALS and ISS technologies, the Systems group contacted Mike Ewert, Tony Hanford, Molly Anderson, Michael Flynn and Alan Drysdale to obtain ISS technologies ESM breakdown.
- System group contacted Dr. Jean Hunter to receive the recipes that are developed for ALSS diet which will be used as the starting point of the diet optimization module.
- During Spring 2004 semester Dr. Pekny challenged senior Chemical Engineering students at ChE 450 (Design and Analysis of Processing Systems) course to expand “Zeroth Order Model” by using Physical-Chemical technologies and analyze their proposed system performance as a short course project.

Publications and Presentations To-Date


Selen Aydogan, Seza Orcun and Joseph F. Pekny, “Title to be determined”, Invited paper to a special issue of International Journal of Environment and Pollution (IJEP) (due January 2005).

NSCORT Reports:
- Initial ESM estimation for solid-phase thermophilic aerobic rector in ALS system
- Initial ESM estimation for urine water recovery via vacuum sublimation in ALS system
- Initial ESM estimation for zeolite in ALS system

Pending Research Milestones and Benchmarks

Manuscript in preparation:


Selen Aydogan, Seza Orcun and Joseph F. Pekny, “Title to be determined”, Invited paper to a special issue of International Journal of Environment and Pollution (IJEP) (due January 2005).
References


9.3 PROJECT FIFTEEN: SYSTEMS MODELING OF ADVANCED LIFE SUPPORT

Principal Investigator  
Dr. George T-C. Chiu, PhD., Associate Professor, Mechanical Engineering, Purdue University  
Dr. Bin Yao, PhD., Associate Professor, Mechanical Engineering, Purdue University

Cumulative Research Progress to Date

- **Subsystem ESM estimation and analysis:**  
  Initial ESM estimation and sensitivity analysis for the NSCORT ALS subsystems, STAR, LIFT, and Zeolite under Mars surface mission scenario is completed. The estimations based on BVAD requirement and consider the physical/chemical constraints of each subsystem as well as preliminary experimental data provided by the subsystem development team. Sensitivity analysis of the estimated ESM provided information for the subsystem development team to optimize system design and reduce ESM for the entire advance life support system.

- **Provide mission scenario and project planning support:**  
  The established mission scenarios documented in the RMD are used to analyze the impact of mission scenario on subsystem design. The system group inspects the impact on sub-systems due to the various ESM equivalencies of different missions. The analysis results are fed back to the sub-system groups in order to help reduce subsystem ESM.

Future Research Directions

- **System integration:**  
  We will begin to integrate individual NSCORT ALS technologies and investigate integration issues such as, but limited to, load compatibility, transient behavior, and fault/error handling. The result of the investigation will provide sub-system developer more reliable information on interconnect behavior and fault/exception handling requirements. This analysis will be able to provide feedback to the sub-system researchers regarding system integration and cost trade-offs and ensures that the sub-system will be able to function in an integrated life support system. Sensitivity analysis is can be applied to the ESM result to identify aspect of the system that will provide most significant improvement.

- **ESM estimation for NSCORT ALS:**  
  The ESM of a complete ALS system will be estimated after a mission scenario specific NSCORT ALS design has been finalized. The total system level ESM estimation, in addition to subsystem ESM, needs to include system integration, interface and control functionalities. The result will be compared to the ISS or other similar ALS systems. Lunar space missions have been proposed to be the first to investigate.

Trainees

YanFu Kuo, Mechanical Engineering, MSME

Research Collaboration

- Solid waste group in NSCORT
- Water treatment group in NSCORT
- Molly Anderson, JSC, ESM analysis and VCD information.
- Michael Flynn, NASA Ames, ESM estimation for VPCAR. (No response yet)

**Publications and Presentations To-Date: (proposed format)**

- **NSCORT Report:**
  - Initial ESM estimation for solid-phase thermophilic aerobic rector in ALS system
  - Initial ESM estimation for urine water recovery via vacuum sublimation in ALS system
  - Initial ESM estimation for zeolite in ALS system

- **Manuscript in preparation:**
  - Y.F. Kuo, G.T. Chiu, and J. Alleman, Systems analysis and initial ESM conduction on solid wastes degradation via solid-phase thermophilic aerobic rector in a life support system

**Pending Research Milestones and Benchmarks**

**References: (proposed format)**


9.4 PROJECT FIFTEEN: SYSTEMS MODELING OF ADVANCED LIFE SUPPORT

Principal Investigator  Dr. Yuehwern Yih, PhD., Professor, Industrial Engineering, Purdue University

Project Goals and Objectives
- Develop a dynamic model to investigate the overall system performance.
- Evaluate ESM of technologies developed in ALS NSCORT. Determine the technology performance by comparing with the ISS assembly complete technologies ESM.

Cumulative Research Progress to Date
A dynamic human model is built to evaluate the crew members’ inputs and outputs by hour. In this model, users can freely assign crewmembers’ gender, age, weight, and activity schedules to find out the hourly energy expenditure, heat production, oxygen requirement, carbon dioxide and respiration water productions, as well as the diet composition. Waste generation is computed in proportion of the total oxygen, food and potable water consumed. Meanwhile, hygiene water inputs and outputs are extracted directly from Baseline Values and Assumptions Documents, 2002. Some of the data and formula applied are not as sensitive as others with respect to crewmember’s gender, age, weight and activity schedules (e.g. hygiene water consumption). This is mainly due to the lack of existing formula and data available. However, this shortcoming is not a hurdle in developing the dynamic model, as the use of Excel spreadsheet in computing these attributes allows users to easily update formula and data later.

Apart from the human model, crew cabin atmosphere is modeled as well. In the crew cabin atmosphere, the habitat volume, total cabin pressure, air temperature and mass of oxygen, carbon dioxide, water vapor, and nitrogen by difference are considered.

Using Matlab, these two subsystems are combined together to evaluate the effects of crewmembers’ activities toward the cabin atmosphere. To this date, the oxygen depletion and increase of carbon dioxide, water vapor and temperature in the cabin are successfully modeled.

ESM analysis is conducted to evaluate the performance of NSCORT technologies. As most of the technologies are still under development, appropriate assumptions and educated guesses from subsystem experts are considered into the analysis. This ESM analysis focuses on a hypothetical device, instead of the anticipated technology that is system flight proven in mission operations. To add more flexibility into the ESM calculation, sensitivity analysis is introduced to include all the ESM possible values. In addition, this method allows the identification of the most critical factor that can reduce the ESM significantly. So far, the ESM evaluation on UV water disinfection and BREATHe II subsystems are completed.
Future Research Directions

After building the human and cabin atmosphere model, crop model will be constructed and then incorporated with the two models mentioned. At this point of time, the modified energy cascade available in BVAD 2004 is selected as a “candidate” to model the crop. It is anticipated that the crop model will be able to capture the daily oxygen production, daily carbon gain, daily canopy transpiration rate, total biomass and edible biomass, among others. For simplicity purpose, a hypothetical crop is considered at this time. The hypothetical crop will possess the average properties of dry bean, lettuce, peanut, rice, soybean, sweet potato, tomato, wheat and white potato, which are the crops that have the most complete data for use in the modified energy cascade.

ESM analysis will also be conducted on BREATHe l, iodine water disinfection, and reverse osmosis/ nano filtration subsystems. After that, the performances of each subsystem will be evaluated through comparison with the ISS assembly complete technologies. As ISS assembly complete technologies are expected to have lower closure or higher re-supply than ALS technologies, not all ALS NSCORT technologies will be able to find a compatible ISS subsystem to compare its performance with. Due to this reason, a different method may need to be devised to analyze NSCORT technology performance.

Trainees

Chit Hui Ang, Industrial Engineering, Master’s program
Tze Chao Chiam, Industrial Engineering, PhD program

Research Collaboration

- In order to compare the ESM of ALS and ISS technologies, the Systems group contacted Mike Ewert, Tony Hanford, and Alan Drysdale to obtain ISS technologies ESM breakdown.
- The System group co-operates with Water/Air group to obtain essential information and educated guesses for ESM computation.
9.5 PROJECT SIXTEEN: A SYSTEM DYNAMICS APPROACH TO MODELING THE ADVANCED LIFE SUPPORT SYSTEM

Principal Investigator  Dr. John Trimble, PhD., Associate Professor of Systems and Computer Science, College of Engineering, Architecture and Computer Sciences, Howard University

Co-Investigators:

Project Goals and Objectives

- One objective of this project is to identify and apply critical developments in knowledge management to the knowledge engineering tasks of the overall NSCORT effort. This emphasis of knowledge management is designed to facilitate ESM identification and reduction.
- The second broad objective focusing on the application of the system dynamics methodology to the study and analysis of the Advanced Life Support (ALS) system as a whole as well as its subsystems. This approach is designed to provide both conceptual models and quantitative computer simulation models that will facilitate further understanding of the dynamics involved in the ALS system

Cumulative Research Progress to Date

Charita Brent developed a high level membrane system incorporating all membrane subsystem 0th order parameters. This was done using a system dynamics approach and Stella software. She set up scenarios for each RO/NF membrane (6) selected by the Membrane Group using projected rejection rates at maximum pressure levels. She ran simulations using different backwash intervals and experimented with various recursive algorithms to match subsystem water recovery activity. Different knowledge elicitation processing exercises were developed to archive project knowledge. A combination of techniques including interviews, task analysis and process tracing were used.

John Trimble developed a prototype high-level ‘qualitative’ system dynamics model based on the “bioregenerative life-support system (modified from Hoff et al. 1982)” that is presented in the Introduction of our research plan description. This model is built using Stella. It will be used to illustrate the general causal relationships between components of the ALS system and develop a better understanding of the precise quantitative relationships in play as our complex system evolves.
John Trimble has modified the Systems and Computer Science senior level Systems Management Course to include components that utilize the system dynamics models build for the NSCORT project. The course will use both the ‘Water subsystem’ models developed by Dr. Trimble and extended by Charita Brent over the past year and the recently developed ‘prototype high-level’ model. This course is a required course of all systems and computer science majors at Howard University and presents an opportunity to involve a wider range of students in our project and also identify potential graduate students with an interest in the systems component of ALS.

Interviews of the Howard University investigators were conducted to access the utilization and usefulness of the ALS-NSCORT web portal. These interviews and discussion with other team members is the basis of the development of a survey questionnaire to be completed by all faculty and student investigators to further access the web portal usefulness and utilization. The intent is to determine ways to make the portal and the associated project communication processes more effective.

Work over the summer was conducted by students in conjunction with Dr. Keeling to investigate semantic web developments and related tools. This effort is designed to provide insights into how to incorporate the semantic web capabilities into a future web-based knowledge repository for the project.

**Future Research Directions**
Assessment of the web portal and associated tools will lead to recommendations on revisions to the portal and additional training for the investigators on portal utilization.

The focus of the immediate future research will be the further development of the system dynamics model to

1. Extend the modeling effort to reflect the 1st order model developments
2. expand the flight simulation interface to make the conceptual model more useful
3. Develop various quantitative scenarios with an emphasis on models that generate subsystem ESM.
4. Training of other investigators on system dynamics model development and utilization
Research Collaboration

- This past year Charita Brent (MS student in computer science) worked closely with the Membrane Processes group led by Dr. K. Jones to gather information about the experiments with hypothetical water flow increases to prevent frequent water recovery process (backwashing). This information was used to run various simulation scenarios. Collaboration will be extended to other groups, so they can assist in system dynamic model development and utilization.

Publications and Presentations To-Date:
Brent, Charita, Trimble, J, “Applying Knowledge elicitation Techniques to Construct Membrane Flight Simulation” National Technical Association Annual Conference, September 2004

Pending Research Milestones and Benchmarks
October 2004 – complete interviews and survey assessing the utilization the ALS-NSCORT web portal and associated tools
November 2004 – complete the first set of system dynamic subsystem models with ESM calculations

References:
Media Activities Log for the ALS NSCORT 2004


1. WRTV Channel 6       1/22/04
   a. Cary Mitchell Interviewed in light of President Bush’s exploratory vision announcement

2. WLFI Channel 18      1/22/04
   a. Cary Mitchell Interviewed in light of President Bush’s exploratory vision announcement

3. Indianapolis Star,    1/27/04,
   a. “Space needs drive research”
   b. Written by Marcella Fleming
   c. Purdue Campus
   d. Interviewed 10 people
   e. IPS students help Purdue with projects that may become part of planned moon base.

4. Chicago Tribune Kathleen Johnston  2/17/04
   a. Purdue preps children hoping for trip to Mars
   b. Phone Interview Cary Mitchell

5. Purdue Exponent
   a. ALS NSCORT Article       2/26/04
   b. Christina Nethercutt
   c. Cary Mitchell and Dave Kotterman Interviewed

6. Optimist Club         3/4/04
   a. “Artificial Closed Eco-Systems for Human Habitation of Space”
   b. MCL Cafeteria
   c. 35 people
   d. Dave Kotterman presenter

7. Industrial College of the Armed Forces  3/18/04
   a. “Artificial Closed Eco-Systems for Human Habitation of Space”
   b. Pfendler Hall, Purdue
   c. 40 people
   d. Dave Kotterman presenter

8. Karen Ross            4/6/04
   a. Space Advanced Life Support Class
9. Purdue Forever Club 4/16/04  
   a. “Artificial Closed Eco-Systems for Human Habitation of Space”  
   b. Dave Kotterman presenter  
   c. Purdue Memorial Union  
   d. 60 Purdue alumni

    a. “Planning for a Return to Space”  
    b. Written by Marc B. Geller  
    c. Cary Mitchell interviewed

11. Kiwana Noontime Kiwanis Club 7/27/04  
    a. “Artificial Closed Eco-Systems for Human Habitation of Space”  
    b. Kiwana United Methodist Church  
    c. Kiwana Indiana  
    d. 50 business people  
    e. Dave Kotterman presenter

12. Purdue Agricultures Magazine Spring 2004  
    a. Spot Light Section “Mission to Mars”  
    b. Written by Jennifer Cutraro  
    c. Cary Mitchell Interviewed

13. Purdue Alumnus Magazine May/June 2004  
    a. Feature Article: “Creating Tomorrow’s World”  
    b. Written by Ellen Yazbec  
    c. Cary Mitchell, Kathy Banks and Dave Kotterman Interviewed

    a. Summer 2004, Vol.3 No. 3  
    b. Feature Article in Education and Outreach  
    c. “Staying Alive: On Mars – and on Earth”  
    d. Julia Hains-Allen interviewed

15. Purdue Exponent, Front Page Article with Pictures, 8/25/2004  
    a. “Waste No More”  
    b. Written by Liz Bower, Campus Editor  
    c. Jeff Volenec, Jim Alleman, Shane Howard Interviewed

    a. “Purdue knee-high in NASA’s waste-not plans”  
    b. Written by Tanya Brown  
    c. Jeff Volenec, Shane Brown, Jim Alleman and Cary Mitchell Interviewed
18. Optimist Club 9/29/04
   a. “Artificial Closed Eco-Systems for Human Habitation of Space”
   b. MCL Cafeteria
   c. 35 people
   d. Dave Kotterman presenter

18. Chicago Talk Radio Q-101 10/21/04
   a. Radio interview about mission to Mars research.
   b. Cary Mitchell interviewee
Creating Tomorrow's World

The discovery of water on Mars and President George W. Bush's pledge to chart a new course for the nation's space program have created focus and excitement for a Purdue center aimed at developing an environment that would sustain human life on other planets.

Though still in its early stages, the research being done on Purdue's West Lafayette campus could make the prospect of living in outer space a reality. A NASA Specialized Center of Research and Training for Advanced Life Support (ALS/NSCORT) created at Purdue is focused on developing technology that would sustain human life on the moon, Mars and beyond.

Established in 2002, the center was created with a $10 million, five-year grant and includes researchers from Purdue, Howard University in Washington, D.C., and Alabama A&M in Normal, Ala. Researchers from disciplines such as engineering, food science, horticulture, agronomy and forestry and natural resources are involved.

The University operated a similar program in the early 1990s, but when the five-year program was opened for bidding by NASA, it was awarded to Rutgers University, says Cary Mitchell, ALS/NSCORT director and professor of horticulture. Once the center returned to Purdue, the research focus had shifted to finding a way to use both biological and chemical processes to make life outside of Earth's atmosphere possible, says Mitchell.

Dave Kotterman, ALS/NSCORT operations manager, says research develops ways to sustain a closed-loop system to support extended human space presence. House all over Purdue's campus, as well as at Howard and Alabama A&M, researchers have created parts of a contained environment that simulate conditions outside Earth's atmosphere.

On Earth, there are "buffers" that clean the air and water, the atmosphere filters radiation from the sun. Oceans and plantlife add moisture and oxygen to the air. On the moon and Mars, those buffers don't exist, so the purpose of the center is to simulate an Earth-like environment.

The goal for the center is to design a self-sustaining environment for future space colonies. Residents would grow their own crops and live inside enclosed habitats in which all wastes are continually recycled and purified. Plants would provide food and oxygen, microbes would break down waste, and technology currently in development would purify the air and water.

"We have to make it as bio-regenerative as possible," says Mitchell. "We need to use less energy to convert biomass.

"For example, if you've grown a crop for food and have inedible parts left over, you could dry out and burn those parts and create carbon dioxide, but that takes a lot of energy and you have to worry about pollutants. With microbial bioreactors, you can put hydrated waste in it and let the microbes work on them. It's similar to the human digestive system," he adds.

EVERYTHING IS USEFUL

Research is under way in four major areas: environmental management (i.e. solid waste, water and air revitalization plus related resource recovery), food production and safety, systems engineering and complementary outreach activities. All areas are combined in the advanced life support system. Researchers in each area have to consider how their findings will affect the other areas in the system.

The systems analysis team creates models of each situation in the center, says Mitchell. They look at all of the inputs and outputs and try to find potential stumbling blocks. Through the models, researchers see how an increase in one
variable affects the whole system.

For example, on the moon, daylight lasts for two weeks at a time, says Korteman. Researchers have to find out how the increase in light on plants over those two weeks would affect the plants’ growth and the oxygen level in the system. If a model can be created that answers these types of questions, Purdue’s center would be the first in the Advanced Life Support community to do so.

The waste materials must be collected and converted because there isn’t an option to just open a window and throw things away in a space environment, says Korteman.

Kathy Banks, associate director of the center and a professor of civil engineering, says civil engineering got involved in the project because of the focus on water, air, and solid waste recycling. Banks is taking a two-pronged approach to her work with the center.

“You have to gather the information related to the overall process,” she says. “But you also have to consider your technology independently. NASA could choose only one aspect of the technology you’ve developed. You have to work together, but you also have to stand alone. It’s equally important to add to the overall systems and develop independent technology, and let NASA decide how it wants to use them.”

Banks and her research team have developed a system called the Bio-Regenerative Environmental Air Treatment for Health (BREATHe). The system would contain two biotower reactors that treat air and water at the same time, allowing for a more efficient treatment. There are two BREATHe reactors, labeled I and II. BREATHe I treats grey water (i.e., bath water or dish water) using high water and low air levels during the process. BREATHe II treats cabin air and condensate with high air and low water levels.

“We’re looking at real-time changes and gathering information to set our parameters and move forward,” says Banks. “We’re trying to find a low-energy process that will recycle water from grey water and clean the air.”

Before the development of the BREATHe system, there were two systems for water and air treatment. Previously, researchers didn’t have to consider ways to clean both air and water at the same time because they were thinking in terms of Earth processes—air and water are in
ample supply in most areas on Earth.

"We think the BREATHe system could be used in any system with contained air and water, particularly closed habitats," says Banks. The system's potential isn't limited only to outer space use.

Banks hopes to spend the next year and a half gathering baseline data, then the group will begin focusing on potential stressors to the environment and how those could affect the water/air system.

"It takes an enormous amount of energy to grow plants," says Mitchell, who also heads the crop group. Rather than using hot overhead lights to grow plants, the group is experimenting with strips of colored lights using light waves the plants will absorb most effectively.

The diet would be mainly vegetarian. People living in space could grow crops such as legumes, wheat, rice and possibly eventually herbs or potatoes.

Researchers also are investigating the use of tilapia fish as a protein source and to eat the plant wastes.

"The first trips will probably be like a camping trip," says Mitchell. "They'll take most of their food and maybe grow salad or other vegetables. Eventually we could try to grow the protein, fat and carbohydrate."

DETERMINATION

President George W. Bush's announcement in January about the future of the space program validated the work at ALS/NSCORT, says Mitchell. Bush seeks to shift NASA's long-term concentration from the space shuttle and international space station to the creation of a manned space vehicle that would be flying with a crew in 10 years and returning humans to the moon in 16 years.

Bush has proposed spending $12 billion over the next five years on the effort, with $1 billion toward an increase in NASA's budget. Bush hopes to use a return to the moon as a catalyst for deeper space exploration -- namely, Mars.

Kotteman says the hope is to have the first human mission to Mars between 2020 and 2030.

The discovery of water on Mars could be a great help to supporting human life there, says Kotteman. In March,
NASA’s Opportunity rover found that rock at its landing site had been chemically altered in the presence of soaking amounts of water. NASA scientists said the rock was infused with "enormous amounts" of salt, which on Earth occurs when salts precipitate out of water over time, particularly when water evaporates.

Purdue’s ALS/NSCORT is the only one of its kind in the nation. Now that the research has begun, results are coming in, says Kotterman. The center will be up for renewal in 2007.

"There is a collaboration of many disciplines," says Kotterman. "The final product isn’t known yet, but we know the center’s research will be used. This research has purpose and many potential earth benefits as well. This could have a great impact — the center continues Purdue’s legacy as a cradle of astronauts."

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**On a mission to Mars**

Purdue alumnus Bill O’Neil (AAE ’61) could claim to be one of the first to land on Mars.

In 1971, O’Neil was chief of navigation for the Mariner 9 spacecraft, the first spacecraft to successfully orbit Mars. His work with the Mariner spacecraft prepared him to be chief of navigation for the Viking Project, the first U.S. landings on Mars.

“Our mission was to seek life on Mars,” says O’Neil. “The results were ambiguous.”

O’Neil led the navigation team that in 1976 guided the landers to Mars and performed landings on its surface. At the time, the United States and Russia were competing for dominance in the space race, and Russia previously had had a lander that operated on Mars’ surface for only seconds, producing no useful results, says O’Neil.

The Viking orbiter was planned to take the Mariner orbiter design and enlarge it so it could carry the Viking lander into the orbit of Mars.

“We’d orbited Mars using high-resolution cameras to survey landing sites,” says O’Neil. “Our plan was to land on July 4, 1976, but when we got into orbit and started surveying the area, the scientists decided it was too hazardous and too likely we’d land on a rock. So we had to abandon the July 4 landing and look for other sites.”

Using the images, the crew found a safer area and landed on July 20, 1976 — the same day the Apollo astronauts had landed on the moon in 1969. It was the first mission to successfully land on the surface of another planet.

O’Neil says the landings were somewhat like the recent landings on Mars. “We had another vehicle on the heels of the first one, and it was to go to a higher latitude site. The second lander went directly to its originally specified site on schedule. All the vehicles worked beautifully.”

It was one of the most sophisticated missions of the time and remains so today, says O’Neil. The landers conducted three biology experiments looking for signs of life. They found chemical activity in Mars’ soil, but there wasn’t evidence of living microorganisms in the soil.

O’Neil’s work on the first Mars landing has helped pave the way for this year’s landings. “The big effort now is that NASA will become an exploration organization and stop flying the shuttle by the end of the decade,” says O’Neil.

“All things will have a clear connection to how to get humans to Mars and what the science objectives, plus research into how to make sure what the environment is like and what humans will need when they’re outside their vehicles.

“There is no reason technically that we couldn’t get humans to Mars and back by 2025,” he adds.
Mission to Mars

NASA taps Purdue to develop life support systems for future space travel

I t takes real foresight to envision technologies that won’t be used for another 20 years—let alone those that won’t even be used on Earth. But that is the mission of staff at Purdue University’s NASA Specialized Center of Research and Training in Advanced Life Support (ALS-NSCORT), a multidisciplinary research center where the goal is to develop technologies to support long-term human survival during a mission to Mars.

The Mars mission came one step closer to reality last winter, when President Bush announced plans to establish a lunar base as a way station for future interplanetary travel. NASA doesn’t expect to return to the moon until 2015 at the earliest, and the target for the first human mission to Mars is 2030. Purdue researchers are in the early stages of developing the systems necessary for life support beyond Earth’s atmosphere. Those systems will be tested first on the moon. “It’s a logical step to return to the moon before going to Mars,” says Cary Mitchell, ALS-NSCORT director. “Establishing a base on the moon will give us more practice in space and the opportunity to test out the technologies we develop.”

Mitchell oversees a team of food scientists, horticulturists, aquaculture specialists and engineers at Purdue and ALS-NSCORT partner institutions Alabama A&M University and Howard University who are working together to resolve the many challenges of life in an extraterrestrial habitat.

“We’re trying to mimic what goes on in nature by designing an artificial, closed ecosystem for human habitation in space,” Mitchell says. That means Mitchell and his colleagues need to develop systems to provide energy; recycle and circulate air, water and nutrients; decompose and recycle solid wastes; control temperature and humidity levels; grow crops; and even protect astronauts from cosmic radiation, to which they will be exposed once they leave Earth’s protective atmosphere and magnetic field.

Purdue competed against several other top research institutions to secure the $10-million, 5-year NASA grant, which established the center in 2002. The grant is a confirmation of Purdue’s strong base in science and engineering research, says Dave Kotteman, ALS-NSCORT operations manager. “Purdue provides fertile ground for the center, given our strong background in science, engineering and systems modeling,” he says. “Having the center associated with Purdue’s Discovery Park was also a very attractive setup from NASA’s point of view.”

Another NASA priority in establishing the center at Purdue was to ensure that ALS-NSCORT provides outreach and education opportunities to the K-12 school community. To meet that goal, Julia Hains-Allen, ALS-NSCORT outreach coordinator, has been working with public schools in both Lafayette and Indianapolis to bring the science of NSCORT to the classroom as the first steps in developing a curriculum for schools around the country.

Through her program, students have the opportunity to visit NSCORT labs on Purdue’s campus, interact with faculty and graduate students, and conduct research in their own classrooms. “Lack of exposure is three-quarters of the reason why students don’t see the excitement in science, engineering and technology,” Hains-Allen says. “This program is an opportunity for students to see and do some exciting things.”

Contributing writers: Molly Brock, Jennifer Cutraro, Maggie Issler, Steve Leer

Horticulture professor Cary Mitchell leads a team of Purdue researchers who are designing an artificial, closed ecosystem to support human life on NASA’s planned mission to Mars. The research is funded by a $10-million NASA grant.
Planning for a return to space

By Marc B. Geiger

Just days after the President's Commission on the Moon, Mars and Beyond delivered a report to the White House recommending a much larger role for private industry in space operations, a rocket built by billionaire Microsoft co-founder Paul Allen became the first privately funded, non-governmental manned spacecraft.

But at least one NASA veteran, Purdue University's Jim Lengsfield, has doubts about private industry being a major player in getting humans to Mars.

The U.S. space-exploration vision President Bush outlined last week and elaborated by the same commission calls for returning the space shuttle to flight, completing the International Space Station and planning out the space shuttle program by 2010, in about 2018.

In addition, it calls for sending a robotic orbiter and lander to the Moon, sending a human expedition to the moon as early as 2015, but no later than 2020, conducting robotic missions to Mars in preparation for a future human mission, and maintaining robotic exploration across the solar system.

The commission believes the US government need not shoulder the entire cost for the initiative, and suggests that NASA needs to engage competitive private firms.

NASA / A3

Capers' spacecraft needs the gravity of Saturn

Lengsfield

LOOKING AT SPACE: Vice President Dick Cheney (second from right) meets with members of the President's Commission on implementation of United States Space Exploration Policy, led by chairman Pete Aldridge (seated from left) in the Roosevelt Room of the White House. The commission presented its report with its findings to the vice president and NASA Administrator Sean O'Keefe (third from right).
SPACE

Professor still sees funding as a problem

Having tourism as part of suborbital flights or Earth-orbital flights, I think that’s probably possible and that may happen. But I don’t think that putting people to Mars is going to be done by the private sector.”

Langaske believes it will take “large-scale government funding” to get people to the moon or Mars.

“But hey, let them prove me wrong,” he said. “It would be good to have the market, and I’m open to that possibility. I just have no doubts that that’s the answer to all problems. Let the private sector do it. If Kennedy said, ‘Let’s be the private sector in space,’ I would have gotten down on one knee.”

Though Langaske is disappointed that the commission did not recommend a specific, aggressive schedule for putting humans on the moon, he remains concerned that there is not enough funding to support the vision, he agrees with the report’s emphasis on human safety and approves of its suggestion that NASA make the development of a heavy-lift launch vehicle a priority.

Purdue alumnus Doug Adams, a member of the engineering staff in the Spacecraft Structures and Dynamics Group at NASA’s Johnson Space Center and Population Laboratory, has worked on the Mars Exploration Rover project and also gave the commission’s report a mixed review.

One of the report’s important elements, he said, was the conclusion that it is practical to send humans back to the moon and put them on Mars. If they don’t do that, it would have presented a significant obstacle for the overall manned Mars initiative.

The report does summarize a good approach toward further space exploration, he said. “One of the commissioners I heard in listening to the presentation was it was mentioned several times that not having time pressure was a good thing.”

But from historical perspective, he said, it seems like programs that are forced to meet aggressive schedules not only meet their objectives but do so quicker. And it’s a big deal when you’re talking about something that could ultimately be promoted for a reason period of time and cost a tremendous amount of money if you’re allowed to delay.

He’s also concerned about the commission’s recommendation that NASA centers be reinvigorated as federally funded research and development centers, the same research model as JPL, and he said pursuing international partnerships may be more easily said than done.

JPL is such a federally funded center “and it works extremely well,” he said. “It may be that some centers would function better if they were not.”

Adams said international cooperation can add more complexity to an already difficult problem in missions, as demonstrated by some of the challenges in constructing the International Space Station.

“International export of technology is regulated,” he said. “And that can be a tripping stone for international cooperation.”

Cary Mitchell, a Purdue professor of aerospace, is director of the university’s NASA Specialized Center of Research and Training in Advanced Life Support or ALS-NSCORT.

Working with partners at Alabama’s A&M and Howard universities, Purdue researchers are figuring out how to maintain an extended mission’s growth crops, recycle water, air and water, and avoid deadly cosmic radiation.

He called the report “fairly inspirational” and consistent with President Bush’s announcement in January that a human presence on the moon by 2020.

“I thought it was very high-level, philosophical... ,” he said. “I think we’re going to see more in this plan to begin building out the NASA people.”

Mitchell noted the report’s assertion that “sustaining the long-term exploration of the solar system requires a robust space industry that will contribute to national economic growth, produce new products through the creation of new knowledge and lead the world in invention and innovation.

This space industry will become a national treasure.”

He said that amounts to “a lot of flag-waving,” but he also agrees it’s important to create a public rallying point at the grassroots level.

They said all the right things in this non-report, much more artfully done than the president did,” Mitchell said.

But he added it’s not good for everybody who has been involved in NASA research.

“They might lose their funding or they might get reduced, or things will be, as NASA likes to say, ‘glide on the back burner’ which they always do,” he said of projects not in line with the initiative. “It’s a politically driven agency.”

Mitchell said the report is good news for ALS-NSCORT, the NASA center at Purdue.

“Not really what we’re all about,” he said. “What we are all about is developing the necessary and the principle of how to support human life on the moon or on Mars without resupply.”

168- ALS NSCORT ANNUAL REPORT 2004
Waste no more

As soon as 10 years from now, astronauts could be drinking their purified urine and feces in space.

Water accounts for 90 percent of the life-sustaining supplies astronauts need in space. NASA wants to minimize the mass that is on board spacecrafts in order to keep mission costs down. Preventing the need for thousands of gallons of water would help make a mission to Mars more affordable. Research teams at Purdue have found a method to lessen the water load.

James Allenman, professor of civil engineering, and others have found a way to separate water from urine and feces, which are donated by volunteers.

From a NASA-provided toilet — similar to those on airplanes that use a vacuum instead of water — the urine goes down one pipe and the feces go to a storage tank that is actually a small beer keg. Then researchers add other wastes that the astronauts would dispose of. The feces and other wastes are in the keg for 10 to 12 days.

The thin, pudding-like liquid is transferred to Jeff Volene, professor of agronomy, Brad Joern, assistant professor of agronomy, and Shane Howard, a graduate student of purification.

The liquid is 97 percent water and 3 percent solids.

“We use plants to remove the water and the solids left behind fertilize the plants,” Volene said.

Although all plants do not

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Liz Bower □ Campus Editor
tolerate the “fertilizer,” Volenc and the team are closer to finding plants that survive and would be useful to the astronauts. Right now they are hoping rice continues to be successful.

The researchers purify the water by passing it through plant roots to the leaves and then the water vapor is released through the plant’s pores. The vapor condenses upon contact with cold pipes, producing clean, recycled water.

Volenc said there is another purification step that uses ultraviolet radiation.

“You have fairly pure water ready to go,” Volenc said. “I would drink it without any hesitation.”

Urine goes through a separate process. It is chilled to the point of ice crystal formation.

“The urine resembles a slushie,” Alleman.

The researchers then harvest the ice crystals. The ice crystals can then be used as water.

“The water we make from urine is actually better quality than the water from tap,” Alleman.

The NASA Specialized Center of Research and Training in Advanced Life Support, in which Purdue is the lead research university, is funded for five years with $10 million. The center is working with NASA to help support astronauts in space.

Waste treatment is one aspect of the center’s research.

“In space there is no giant ecosystem and space is tight (in the space craft) so there is a need to reuse materials,” said Alleman, who is also the associate director of the center.

To test this research, NASA would first go to the moon to ensure that the water purification system works properly, and then take the technology to Mars.

“We are talking about going to the moon in about 2015 and 2020s or 2030s for Mars,” said Alleman.
By Tanya Brown

Harvesting drinkable water from urine and plants fed on sewage may seem like an unsavory project, but it could mean the difference between life and death for astronauts on long missions.

Researchers at Purdue University are working in conjunction with NASA and two other universities to create an extreme form of recycling meant to make life outside of Earth feasible.

The NASA Specialized Center of Research and Training has been operating on Purdue's campus for about a year and a half. NSCORT operates under a $10 million total, five-year grant from NASA.

Launching a pound of anything to Mars costs an estimated $140,000.

"Water is heavy. If you can recycle it there, you can save a lot of launch costs," said Cary Mitchell, NSCORT director and Purdue professor of horticulture.

Other than the cost, the physical constraints of space travel also limit astronauts. Jeff Volene, a Purdue crop physiologist, estimates that only about 1,000 gallons of water per astronaut will be transported on a mission.

"The typical household's two-day supply is all they can take," said Volene, who is working with assistants on harnessing the wetlands' power to recycle water for space. "Wetlands are very effective at scavenging out nutrients."

Clean water

Volene used corn as an example. Corn uses 500 pounds of water to grow one pound of weight. If Volene and his team can condense water vapor from plants, they can harvest clean drinking water.

The plants are being grown with a treated sewage-based sludge recycled from human fecal matter, a natural waste that astronauts would need to dispose of anyway. It is composed of 97 percent water and 3 percent solids.

Part of the problems the researchers face include growing plants with a lack of oxygen. Many food-producing plants do not flourish in the sludge.

"We're looking at rice, which is used to growing in flooded areas. We're also examining cattails and reeds," Volene said.

To get a trust-to-life result, his team must also try to replicate the diet of astronauts, which differs greatly from earthly fare.

See WASTE NOT, Beck Page
Education & Outreach

Staying Alive: On Mars — and on Earth

A specialized NASA center for research in advanced life support for missions to Mars — a cooperative venture of three universities — is exciting the younger generation by involving students from middle school through college in real-world research.

Hungry? Go to the nearest restaurant or grocery store. Thirsty? Fill a glass of water from the faucet. Need some fresh air? Take a walk outdoors. Got trash? Switch on the garbage disposal, flush the toilet, or put a bag out on the curb.

In our modern society, the necessities of life (food, water, and air) and waste disposal are so smoothly provided by stores, plumbing, green plants, and sanitation trucks that we scarcely give them thought. But on a round-trip mission to Mars, astronauts will have to live within entirely closed systems for several years while growing crops, cleaning air and water, and recycling waste into usable foodstuffs. How they will carry out all these tasks necessary to human survival has not yet been determined.

Purdue University (West Lafayette, Indiana) heads a university consortium that operates a NASA specialized center with the goal of developing advanced life support technologies for a mission to Mars while engaging college undergraduates and high school students in the fundamental research and middle school students in defining the basic challenges. "It’s part of our mission to inspire and excite the next generation of explorers," explains Julia Hains-Allen, outreach coordinator for the NASA Specialized Center of Research and Training (NSCORT) in Advanced Life Support (ALS), commonly known as ALS/NSCORT and headquartered at Purdue.

Innovative research on life support

ALS/NSCORT — one of about a dozen NSCORTs founded since 1990, each focusing on a major interdisciplinary challenge related to long-duration space missions — is the only center in the nation devoted to advanced life support. Began in 2002 with a 5-year grant of $10 million from NASA, ALS/NSCORT consists of 24 researchers from a consortium of three universities: Purdue, Alabama A&M (Normal), and Howard University (Washington, D.C.). NASA wanted consortia competing for the grant to include at least one minority university with essential expertise. Purdue selected not one but two minority universities — Howard for its engineering researchers and Alabama A&M for its food scientists and agriculturalists.

Growing plants in a spacecraft or on Mars will be more complicated than on Earth, not only because of confined growing space but also because of sunlight considerations. The Sun’s rays would be far stronger everywhere outside of Earth’s atmosphere (because ultraviolet rays would not be filtered), and the light would be less bright on Mars than on Earth (because of Mars’ greater distance from the Sun). Researchers at Purdue are thus investigating energy- and space-saving ways to provide light sources for food crops. Instead of conventional incandescent or fluorescent lighting, vertical strips of colored, light-craving diodes might hang among crops. The colors would match the wavelengths absorbed by the plants’ photosynthetic pigments, and the diodes would be cool enough that they can touch leaves without damage.

In waste-recycling projects, Alabama A&M horticulturalists are experimenting with growing edible mushrooms from the roots, stems, and leaves of other plants as a method of recycling inedible plant waste. Howard engineers are researching membranes to filter waste water into gray water (suitable for showering, laundry, or dishwashing) or even into drinking water (which would require further sterilization). Meanwhile, Purdue scientists are studying the usefulness of the whitefish tilapia, a bottom feeder, in eating plant, human, and food waste and adding variety to astronauts’ largely vegetarian diet. They also have observed that tilapia become sluggish and hide in response to environmental changes (e.g., in oxygen levels or water quality) and are trying to determine how such behavioral signals could make the fish useful as the equivalent of miners’ canaries in warning of deteriorating conditions well before human astronauts might be endangered.

Getting college students to reach out

Equally important to ALS/NSCORT’s advanced life support research is its commitment to educate students from middle school through college. Today, ALS/NSCORT conducts three unique programs: 8-week summer fellowships in education and outreach for college undergraduates; a cooperative program with a high school in Indianapolis, Indiana, to engage students in fundamental NASA research; and an 11-week program to encourage elementary and middle school students to think through the challenges of living on Mars — and what those challenges mean for Earth.

In 2003, ALS/NSCORT inaugurated the summer fellowships program in which six undergraduate students from the three universities work alongside researchers on some of the consortium’s 19 projects (See Table 1, page 26). At the end of the summer, the students present their research in an ALS/NSCORT symposium. This program continues in 2004.

One major innovation for 2004 is the introduction of two additional 8-week undergraduate summer fellowships for education and outreach, awarded to two students who are majoring in elementary or secondary education. The students learn about various science hands-on activities that can be taught in the classroom and are counseled on “how to teach teachers, 4-H extension educators, and kids about those activities,” Hains-Allen says.

Surprisingly, getting the word out about ALS/NSCORT, even to undergraduates
at Purdue’s partner universities, has “been a big problem,” Hains-Allen reports. “But within the directives of NASA outreach has been elevated to the importance of research. We are doing the same here at ALS/NSCORT.” Therefore, each undergraduate education major who completes a fellowship and returns to Howard or Alabama will “serve as the ALS/NSCORT outreach person at the home university as well as do outreach in local schools.”

One important benefit to the undergraduates in the outreach fellowships is that they will learn about science. “Education majors often have very little science background, in part because they themselves may have been turned off to it in school,” Hains-Allen points out. “So we teach them the science they’ll need for NASA outreach—but not in the way it was likely presented in school. If it’s chemistry about acids and bases, we don’t teach them balancing equations or stoichiometry. We teach them fundamentals using household objects such as pennies and lemons and challenge them to design experiments to answer fun questions that relate to everyday life, like ‘Why does Alka-Seltzer fizz?’ Experiments are simple dump-put-explain activities yet are inquiry based, like real science. When fellowship participants understand the concepts, they feel successful and can convey that thrill to both their students and other teachers.”

Mars inspiring younger students

Another outreach activity is the Explore Mars pilot program being conducted at ALS/NSCORT and Key Learning Community in Indianapolis. The Key Learning Community is an innovative public school that has been teaching kindergarten through grade 8 in inner-city Indianapolis for two decades and now also includes high school. Its educational approach of teaching the whole child is premised on psychologist Howard Gardner’s theory that each person has seven types of intelligence, which include five (musical, spatial, bodily-kinaesthetic, interpersonal, and intrapersonal) in addition to the verbal-linguistic and logical-mathematical types that are the focus of most schools.

Located in Key Learning’s science laboratory is a prototype bioreactor designed by Purdue’s researchers to remove surfactants (sudsing agents) from gray water in the Mars habitat. “Key Learning students are doing actual ALS/NSCORT experiments in cleaning water, mirroring research at Purdue,” Hains-Allen explains. “This is authentic, relevant research, not a simulation,” she adds.

New in August 2004 will be an Explore Mars Camp on the Purdue campus, where Key Learning students in grades 9–12 will have additional opportunities (still being defined) to learn about and conduct research in other areas of ALS/NSCORT. They also will produce a 10-minute documentary film about ALS/NSCORT and Explore Mars to use in education and outreach efforts.

For students from other schools, ALS/NSCORT has been pilot testing an 11-week program called Mission to Mars at the Imagination Station family science center in Lafayette, Indiana. Aimed at students in grades 3 through 5 but also accessible to gifted and talented children in grades 3 and 4), the program challenges children to think about what astronauts would need to live on Mars. Children first consider the necessities people must have to live on Earth, then explore how some of those needs could be adapted for Mars. “The program is structured around four concepts: producers, consumers, decomposers, and energy, all within the big picture of an ecosystem,” Hains-Allen explains. “Every week [students] are asked a central question, such as ‘What will we drink?’ Then they are challenged to design a water-cleaning system from household supplies and test the system with simulated gray water.”

Although the Mission to Mars program meets defined educational standards, “our goal is not to deliver content,” Hains-Allen cautions. “Our goal is to fulfill NASA’s aim to ‘inspire and excite the next generation of explorers’—a difficult

continued on page 26
Table 1. Research projects and faculty involved in the NASA Specialized Center of Research and Training in Advanced Life Support (ALS/NSCORT) program

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Notes: ALS, Advanced Life Support; BREATHe, Bio-Regenerative Environmental Air Treatment for Health; ESM, Equivalent Systems Mass; K-12, kindergarten through grade 12; LIFT, Liquid Freeze-Thaw Treatment; SIMOPT, Simulation Optimization Model; STAR, Solid-Phase Thermophilic Aerobic Reactor.

Source: ALS/NSCORT