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## April 2004 Report of Progress

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1 Jim Alleman

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

- **STAR Reactor Configuration Modification**

The STAR reactor was rebuilt in March 2004 in order to provide a larger internal volume that would accommodate higher waste loadings. In addition, we completed the installation and startup of a real-time data acquisition system for tracking pH, ORP, and reactor temperatures, and started the development of a controller program to manipulate reactor mixing intensity based on feedback ORP loop.



- **STAR Reactor Operation**

The STAR reactor was started with real 'human fecal' residuals loading, plus representative food residuals input, and then maintained at an HRT of 11 days for one HRT cycle. During this initial operating period, we maintained real-time (on-line) monitoring plus off-line solids conversion testing throughout the cycle, and this data confirmed an average 42% solids destruction. In addition, we secured external analysis of effluent residuals composition, including organic, inorganic, and biological parameters (e.g., including a diverse suite of nutrient content, mineral content, fecal coliform, etc. tests). The fecal coliform levels were below expected levels due to reduced operating temperatures (i.e., slightly below 50°C which would have been expected to provide complete pasteurization of reactor residual materials). Post-discharge supplemental sterilization was then provided for all collected residuals, and these materials were then distributed to other NSCORT 'solid waste' group project members. The reactor was then stopped after completing this initial 'human fecal' run at the low HRT level, to reconfigure mixing and off-gas zones with the intent of negating previously experienced reactor foaming events, as well as to reconfigure reactor heating and insulation strategy. Following these renovations, the reactor was then restarted on a second testing run, again using 'human fecal plus waste food' loading. This new reactor configuration is presently holding significantly higher temperature (above 60°C) which will provide desired coliform reduction. We intend continue this mode of reactor operation for the upcoming 2 to 3 months, with continued distribution of product residuals to other NSCORT projects. Lastly, and working in consort with started interaction with NASA JSC statistician, we developed a basic mass-balance model of our blended waste stream characteristics and composition, with which we can then conduct subsequent assessments of STAR operational parameters (e.g., HRT, C:N ratio, solids content, etc.).

- **Upcoming Revisions Expected with STAR Operations**

We intend to start supplemental addition of plant residuals feedstocks to the STAR feed at the end of this summer (i.e., mid-August), and will be working to initiate a new set of on-line off-gas analyses for oxygen and carbon dioxide at much the same time.

**NOTE:** Further details and images relative to this project can be found in the 'STAR' project's April 2004 monthly report available on the Purdue Discovery Park NSCORT 'Waste' portal section

**2 Charles Glass**

**Nitrogen Cycling in ALS**

- **Optimum Zeolite for Ammonium Adsorption**

Over the past six months an evaluation of 4 different zeolites in batch tests have been performed to select the optimum zeolite for further study. Batch tests have been completed with varying ammonia concentrations (100, 500, 1000 mg/L-N), using one gram of zeolite and 100 mL of solution at 20.0°C. Each zeolite was analyzed for its removal capacity and compared using the Freundlich isotherm.

- **Limitation of Zeolite Adsorption**

At 500 and 1000 mg/L -N the capacity of one gram of each of the four zeolites was exceeded. In the literature the maximum capacity of ammonium adsorption is 11.0 mg NH<sub>4</sub><sup>+</sup>/g of zeolite (110 mg/L NH<sub>4</sub><sup>+</sup> in solution). Ammonia concentrations higher than the maximum results in oscillations between release and retention of ammonia.

- **Procurement of Various Zeolites and STAR Off-gas effluent**

At this point a chabazite has the highest ammonia removal capability. In an effort to obtain the best zeolite possible, 6 more different zeolite providers have been identified and are being acquired including potential adsorption synthetic zeolites. In addition, we have received our second shipment of effluent off-gas from the STAR system and are evaluating its chemistry.

**3 Jeff Volenec**

**Solids Separation Water Removal from STAR Biosolids Effluent Using Plants**

- The first replicate of the bio-solid dewatering experiment with human fecal waste from the Solid-Phase Thermophilic Aerobic Reactor (STAR) has been completed. Experiment involves three treatments, STAR effluent, Hoagland's nutrient solution, and water, applied to eleven different plant species. Second replicate of these treatments is currently underway.
- Tests to determine if STAR effluent aeration reduces high BOD and reducing conditions in root zone are in progress.
- Plant biomass and elemental tissue concentrations from first replicate harvest are being analyzed to determine effects of STAR effluent on tissue composition. Water use data will be used, along with biomass and tissue concentrations, to determine plant specie suitability for dewatering STAR effluent.

**4 Jim Alleman**

**Liquid Freeze-Thaw (LiFT) Urine & RO Brine Processing for Advanced Water Recovery and Salt Separation**

- **Sublimation Freeze-Thaw Water Recovery Element**

Our 3<sup>rd</sup>-generation LiFT system is now in the finishing stages of being constructed and is currently being tested for leakage, feasibility, operation requirements, and procedures. This third version was quickly constructed after the preceding version was unable to hold the required vacuum for sublimation, and the original version was not adequately able to provide sufficient water vapor transport. The newest, 3<sup>rd</sup> generation design is not yet optimized with respect to water capture efficiency, but it will still be suitable for product water and solids residue characterization experiments. Upon completion of system setup, the first round of experiments will focus on the fate and survival of microbial indicators.

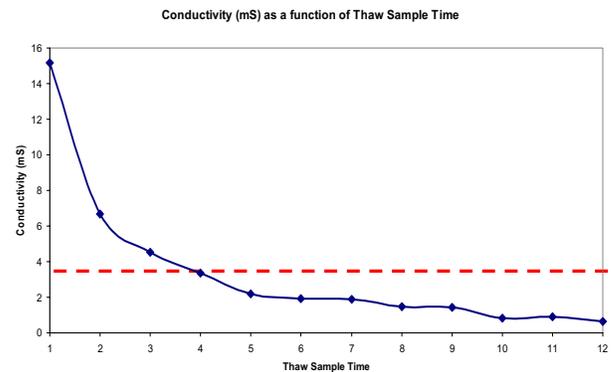
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These tests will determine whether *E. coli* is transferred to the product water via sublimation transport processes. In addition, *E. coli* will be tested in the solids residue to determine inactivity. Normally, urine is a sterile waste product; however, in cases of urinary tract infections *E. coli* is the main culprit approximately 80% of the time. We hypothesize that no transfer of microbials will take place into the product water and that a high degree of inactivation will occur in the solids residue.

- **Ambient Pressure Freeze-Thaw Water Recovery Element**

This 'ambient pressure' research element represents the second major phase of our experiments with urine freeze-thaw processing. Although our preliminary testing with this approach in 2003 was not promising, we have since revisited the strategy with unexpectedly positive results and have decided to essentially resurrect this original element of our original line of research. Indeed, we now believe that ambient pressure freeze-thaw salt separation may be included as a urine pre-treatment step before the concentrated salt solution is then sublimated.

This hypothesis is based on our completion of a urine freeze-thaw sequence which showed that a concentrated salt solution was 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. Forthcoming experiments will focus on conductivity measurements for different rates of freezing on standard NaCl solutions and on urine, and on urea and ammonia concentrations. Due to recent developments, the LiFT process model will slightly change to account for freeze-thaw experiments.



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**NOTE:** Further details and images relative to this project can be found in the 'LiFT' project's April 2004 monthly report available on the Purdue Discovery Park NSCORT 'Waste' portal section

5 Kim Jones

### Membrane Processes in ALS

Progress report not available for April

6 Kathy Banks

**Treatment of Grey Water Using Gas Biofilters**

- **Addition of gas phase contaminants to closed vials containing water resulted in an increased pH after equilibrium was reached**

The effect of gaseous constituents expected in BREATHe I on pH was investigated. Ammonia, hydrogen sulfide and carbon dioxide was injected to 45 ml vials containing the same volume ratio of water to gas. The concentrations of ammonia, hydrogen sulfide and carbon dioxide used in this study were 600 ppm, 60 ppm and 7200 ppm respectively. The experiments were carried out in a constant temperature room at 25°C. A rotating system was used at 60 rpm to ensure homogeneity throughout the vials. The initial pH of the solution was 6.01. After one hour, each sample had a similar pH. The ammonia solution was around pH 7.5, hydrogen sulfide was around pH 7.3, and carbon dioxide was around pH 6.7.

- **Addition of gas contaminants to vials containing surfactants in solution resulted in discernible pH changes**

The effect of surfactants on pH was investigated. Two surfactants, STEOL (sodium laureth sulfate) and Miranol (disodium cocoamphodiacetate) were used in this study. The concentrations of surfactants were 1000 ppm each. Air, 300 ppm of ammonia, 20 ppm of hydrogen sulfide were injected at the same volume vials containing each surfactant. Vials were shaken on a rotating system. The temperature was 25 °C and initial pH was 5.9, 6.9 and 8.4 for water solution, STEOL solution and Miranol solution. After shaking for one day, solution pH changes were observed and found to be dependent on the characteristics of solutions and gaseous constituents. After shaking, ammonia and water solution showed pH 9.5, ammonia and STEOL solution was at pH 8.8 and ammonia and Miranol solution was at pH 8.6. On the contrary, solutions with hydrogen sulfide showed relatively little pH changes with the exception of the solution containing Miranol. The pH of the hydrogen sulfide and water solution was 6.7, the STEOL solution was 7.4 and Miranol solution was 8.4. The results showed that the change of pH is highly affected by gaseous constituents and the characteristics of surfactants.

- **Isolated two strains of bacteria that play prominent role in surfactant degradation**

A chemostat reactor was established with surfactant as the only carbon source. Surfactants were added to a minimal salts medium (MSM) at 0.56 g/L disodium cocoamphodiacetate and 0.85 g/L sodium laureth sulfate. Samples were taken from the chemostat weekly and plated on laurel broth (LB) medium. After three weeks of operation, samples from the chemostat contained only two strains of bacteria. Each isolate was gram stained and observed under a microscope. Both were found to be gram negative rods. A thick biofilm formed during the course of the chemostat run and the bacteria present within the biofilm were the same strains as the bacteria present in solution. An attempt was made to culture each bacterial species on Pseudomonas selective medium (PIA). Neither bacteria grew in the medium, thus indicating that neither of the strains are Pseudomonas. DNA from each isolate was amplified by PCR and gel electrophoresis was performed. DNA from both strains eluted near 1600 bp.

7 Al Heber

**Gas-Phase Revitalization Using Biofilters in ALS**

- **Biofiltration Model**

A first order biodegradation reaction equation was added to the biofiltration model. The overall mass transfer coefficient, previously assumed to be

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constant, was made a function of water and gas flow rates, wet surface area, media surface tension, gravity, Henry's law coefficient, and water and gas densities and viscosities. The sensitivity analysis was rerun using the modified model. The results were summarized and included in a report submitted to the EAC.

- **Cabin Air Quality Model**

A simple CFD model was constructed using PHOENICS and COMTAMW. The location of contamination sources were roughly estimated for now.

- **Biofilter Testing**

Fifteen biofilters have been constructed and four of them have been mounted on a bench and tested operationally. Filters were purchased and installed in the water distribution line to prevent clogging. Nine other biofilters are currently under construction. Fittings to assemble all 24 biofilters have been selected and ordered. Programmed concentrations of ammonia using a gas diluter have been measured with the FTIR gas spectrometer. The gas diluter was set up to deliver ammonia at 10 to 100% of cylinder concentrations.

### 8 Chip Blatchley

#### Potable Water Disinfection Subject to Extended Space Travel Constraints

- **UV and Membrane System Collaboration**

Purdue University in the process of building two UV reactors for use at Howard University. In a teaming effort, Howard University will assist in setting up a membrane system at Purdue. The main objective is to have parallel membrane and UV systems at both institutions. Discussions between Water Group members at monthly meetings have highlighted the need for this collaborative effort because of the interconnected fashion by which the membranes and UV/iodine achieve disinfection. To date, the UV reactors have been assembled. UV lamps and ballasts have been ordered for the reactors, but have not been received. Once the lamps have been received, Kelly Pennell (of Purdue University) will travel to Howard University to set-up and test the UV reactors.

- **Analytical Method Development**

This month significant effort has been placed on the development of analytical methods for the determination of various iodine forms and ascorbic acid. It is proposed that iodine will be detected spectrophotometrically, while ascorbic acid (which is proposed for use in the iodine removal process) will be detected using mass spectrometry, in addition to spectrophotometry. Over the past month, effort has been placed on the determination of molar absorptivity values for three different forms of iodine ( $I^-$ ,  $I_2$  and  $I_3^-$ ). Prior to the determination of these values, molar absorptivity values as reported in published literature were used. Most of the published values were determined without the use of a speciation model (such as the one developed by K. Pennell as part of this research). In addition to iodine molar absorptivities, a method to identify ascorbic acid using electro-spray ionization mass spectrometry (ESI/MS) was also developed this month. Additional efforts will focus on increasing the detection limits for ascorbic acid using ESI/MS.

- **Ultraviolet numerical model verification employing *Bacillus Subtilis* spores**

Preparations were made for experimental verification of numerical estimates of the UV dose distribution delivered by a continuous-flow UV reactor. A setup including the model UV reactor was assembled for flow-through experiments. Inactivation achieved by the reactor will be studied employing *Bacillus subtilis* spores. These spores were propagated using well-established methods and their response to UV radiation was examined under collimated beam UV radiation. The dose-response data was fitted to a series-event kinetic model and will be used to evaluate experimental and numerical results.

- **Presentations at the ESEI Symposium**

Presentations were given at the annual Environmental Science and Engineering Institute (ESEI) Symposium, 4/9/04 by Zorana Naunovic and Kelly Pennell.

9 Bruce Applegate  
Mike Ladisch

**Bioamplification Using Phage Display for the Multiplexed Detection of Pathogens in Potable Water and Food**

- **Preliminary work was begun using the previously constructed recombination system for the modification of the *E. coli* O157:H7 bacteriophage.**

Primers were designed to amplify the *recET* gene from the *E. coli* O157:H7 lysogen containing phiV10. The *recET* was subsequently amplified and sequenced providing additional confirmation of the lysogen. A *recET* deletion containing a kanamycin marker was constructed for initial gene replacement experiments. The deletion construct was sequenced confirming appropriate modifications. (This work will be presented at the annual meeting of the American Society of Microbiology in New Orleans May 24, 2004 and was chosen to be highlighted in the press room by the abstract review committee)

- **Preliminary genome annotation of *phi V10* was performed and a preliminary map was constructed.**

Initial genome analysis showed significant similarity to the *Salmonella* bacteriophage epsilon 15. Of the thirty open reading frames identified seven of these could be assigned a putative function with reasonable certainty. Thirteen open reading frames showed some similarity with previously published sequences coding for known proteins. A manuscript on the sequencing and annotation of the genome is in the early stages of preparation.

- **Initial work was begun to insert a unique binding epitope in the tailspike protein of the *Salmonella* spp. bacteriophage P22.**

Primers were designed to facilitate the insertion of the his tag in the tailspike protein of P22. Further characterization of the previously constructed P22 reporter phage demonstrated the promoter chosen provided significant expression of the inserted gene. Therefore we will utilize the same promoter when inserting the second copy of the tailspike gene into the P22 genome.

10 Paul Brown

**Waste Treatment Using Tilapia**

- **Waste Products Ground and Pelleted.**

Waste products that are potential food for fish were acquired from collaborators (Alleman and Mitchell), ground and pelleted. Six Wastes will

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be evaluated in a formal study beginning May 17.

- **Plant Diet Experiments Completed and Reported.**  
 Experiments were completed using all plant diets fed to larval tilapia and results reported at an international conference. These data indicate that wastes from ALS can potentially meet the needs of this critical life history stage.
- **Nutrient Analysis Completed.**  
 Nutrient analyses have been completed with several of the wastes and laboratories have been identified that will analyze wastes and fish upon completion of the next study.
- **Mass Balance Study Underway.**  
 Preliminary studies are underway evaluating the mass balance of ingested dietary minerals within a fish and the mass balance of fishes within an integrated aquaponics system.

### 11 Cary Mitchell

#### Minimizing ESM for ALS Crop Production

- **Update on first Intracanopy LED array**  
 Our collaborative partners, Orbitec, have sent detailed schematics of the LED lightcycles for approval and have begun fabrication of the first array. The Purdue Crops group is designing a mounting framework for the array that will support the weight (estimated 46 lbs for 16 lightcycles) yet still allow versatility and ease of reconfiguration.
- **Growth chamber hydroponics**  
 Testing in the growth chamber continues in preparation for LED based lighting. Different germination strategies (transplant versus direct seeding) are being examined for cowpea, the first target crop for LED testing. Additionally, basil and pepper are being tested in the hydroponic system for future lighting studies.
- **Cultivar analysis in the greenhouse**  
 Strawberries have begun fruiting and data collected for berry number, size, shape, and color for four different cultivars. Blueberry and cranberry cultivation continues to be refined with different media types. Plants appeared to be getting too warm and were moved closer to the cooling unit. A student in the lab received a summer scholarship and will work with blueberries and cranberries, and will design an appropriate hydroponic system for berry culture. Basil trials are continuing, with several cultivars being grown and basil productivity in response to pruning measured.

### 12 Caula Beyl

#### Solid Waste Processing Using Edible Fungi

**Objective: To evaluate biodegradation in single, and dual substrate combinations of inedible crop biomass by select fungal species and strains**

- Milled (2 mm particle size) inedible residues of tomato, wheat, rice, basil, sweet potato, soybean and cowpea were placed singly or in a 1:1 combination with either rice or wheat straw in 750 ml transparent food containers. The dry weight of each substrate or combination was approximately 150 g. The substrates were sufficiently moistened by adding

250 ml of distilled water, prior to autoclaving at 121°C and 1.1kg cm<sup>-2</sup> for 40 min. The cooled cultures were each aseptically inoculated with an agar block of mycelial spawn from two shiitake strains (LE001 and LE002) at the center of the substrate. 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. Further tests using more aggressive colonizers such as oyster mushroom (*P. ostreatus*) will be carried out on the difficult substrates.

- Acquisition of additional species and strains of *Pleurotus ostreatus*. One prolific substrate colonizer capable of degrading a broad range of ligninaceous substrates is the oyster mushroom (*Pleurotus spp*). Four strains belonging to three species [*P. ostreatus* (Grey dover oyster, Blue dolphin), *P. cornucopiodes* (Golden oyster), *P. eryngii* (King oyster)] were obtained from Field and Forest Products Co., Wisconsin. The spawns have been multiplied in the laboratory and are being used for solid waste degradation involving single and combined (1:1, rice or wheat/legume) processed substrates, and recycling STAR sludge.
- We have also begun incorporating food wastes and sludge from STAR at 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.

13 Lisa Mauer

#### Novel Storage and Packaging Operations

- **Tracking down sources, estimating prices for different dosage levels**  
For irradiation at \$1600 per box careful planning is a must.
- **Received oil samples to be used in the irradiation testing**
- **Completed preliminary sensory tests acceptability of rancid oils in salad dressings**
- **Submitted and received reviews for two ICES papers and resubmitted one for review after some slight modification.**

14 Leonard Williams

#### Optimal Food Safety in ALS

- **Determination of critical points**  
AAMU Graduate Student has completed preliminary work on determination of critical points in pre-harvest salad crop production.
- **Determination of Biofilms on Salad Crops**  
Graduate student continue work on biofilm formation on salad crops and microenvironments or "niches" created by spoilage and pathogenic bacteria.

15 J. Pekny, G. Chiu,  
Y. Yih

#### Systems Modeling of ALS

- **The NSCORT Systems Group is implementing the research strategy developed with the External Advisory Committee during their last visit.** In particular, the following specific progress has been made.
- **Implementation of an ALS/NSCORT technology mass balance model:** The process map now has about 90% of the information needed based on the additional meetings with subtask leads this month and the information they have presented in the ALS class lectures. Modeling data collected by

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graduate students is being merged into a unified model under development which allows for process connectivity, flow quantities and compositions, reactions, phase equilibria, and other relations.

- **Meetings of systems members with Bruce Bugbee**  
During his visit April 8-9, Dr. Bugbee helped the group to better understand crop growth and start to reconcile the data we have.
- **Other services**  
Reviews of ICES papers were completed. Dr. Seza Orcun gave the April 1 lecture on systems and simulation in the ALS course.

### 16 John Trimble

#### A System Dynamics Approach to Modeling the Advance Life Support System

- **Developed a high level membrane system incorporating all membrane subsystem 0<sup>th</sup> order parameters**  
Set up scenarios for each RO/NF membrane (6) selected by Membrane Group using projected rejection rates at maximum pressure levels
- **Working closely with membrane subsystem experiments to gather information about**  
Experimenting with hypothetical water flow increases to prevent frequent water recovery process (Backwashing)
  - Past simulations used daily backwash intervals, which is detrimental to membranes. Expedites membrane flux decay and material wear.
 Modifying water recovery process by altering its original (hypothetical) equation by incorporating new variables and hypothetical pressure.
  - Experimenting with various recursive algorithms to match subsystem water recovery activity
 Modifying the simulation runs
  - Taking Human Activity information to explore membrane system operation times to prevent overflowing of water reservoirs
    - Plan to batch water to UV Disinfection in simulation at specified time instead of constant flow
    - Lacking information of hypothetical water tank storage capacity
 Incorporated new knowledge elicitation processing exercises for developing subsystem artifacts for project knowledge archiving

### 17 Julia Hains-Allen

#### Outreach

- **What:** Spring Fest
- **When:** April 17-18, 2004
- **Where:** Purdue University

ALS/NSCORT will participate in the two-day annual Spring Fest sponsored by Purdue University School of Agriculture. This event will showcase the science of flight and food. ALS/NSCORT will have a plant growth chamber in the booth along with instructions for children to build their own chamber. Apogee Dwarf Wheat seed provided by Bruce Bugbee, Utah State University, will be handed out to interested children for home experiments.

- **What:** Space Advanced Life Support Distance Learning Course
- **When:** April 20, 2004
- **Where:** Purdue University

Julia Hains-Allen presented an overview of Education/Outreach to the undergraduate/graduate ALS/NSCORT Space Advanced Life Support Distance Learning Course. Students received information on all the outreach programs and participated in a hands-on activity included in the Mission to Mars module.

**18 Dave Kotterman**

**ALS NSCORT Center Activities**

- **Bruce Bugbee Seminar & Meetings**  
Dr. Bugbee from Utah State University spoke at a jointly sponsored seminar between Purdue's Department of Horticulture and Landscape Architecture and ALS NSCORT on April 8, 2004. Dr. Bugbee also met with all program graduate students and members of the Systems, Water, Food, Crops, and Administration during his stay on April 9, 2004.
- **Purdue Alumni Association – Forever Class Presentation**  
Dave Kotterman was the after-dinner speaker at a Purdue Alumni Association presentation on April 16, 2004. An overview presentation was given on the ALS NSCORT program.
- **Spring 2004 Distance Learning Class Ends**  
The last SpaceClass lecture was delivered on Thursday, April 29. This concluded our first distance learning class through ALS/NSCORT. Archives of the course lecture are available on the website.
- **Morton Barlaz was named to the External Advisory Council**  
Dr. Barlaz is from North Carolina State University and will be the EAC advisor for solid waste management.
- **Karen Ross Lectures to Space Advanced Life Support Class**  
Karen Ross, project leader at Space Food Systems United Space Alliance lectured to the class on April 6<sup>th</sup> covering food and diet topics of the astronauts in the shuttle and ISS programs.
- **Combined Executive Committee and Research Council Meeting**  
Occurred on April 7<sup>th</sup>. During the EC, the annual External Advisory Committee meeting was discussed and during the RC, Food Technology and Safety research progress was discussed in an open, round-table format.
- **Kathy Banks traveled to University of Florida and met with Bill Sheehan**  
Topics discussed were related to her Air/Water focus area.