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# The Environmental Control and Life Support System Advanced Automation Project

Phase 1 - Application Evaluation

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## Abstract

The Environmental Control and Life Support System (ECLSS) is a Freedom Station distributed system with inherent applicability to advanced automation primarily due to the comparatively large reaction times of its subsystem processes. This allows longer contemplation times in which to form a more intelligent control strategy and to detect or prevent faults.

The objective of the ECLSS Advanced Automation Project is to reduce the flight and ground manpower needed to support the initial and evolutionary ECLS system. Our approach is to search out and make apparent those processes in the baseline system which are in need of more automatic control and fault detection strategies, to influence the ECLSS design by suggesting software hooks and hardware scars which will allow easy adaptation to advanced algorithms, and to develop complex software prototypes which fit into the ECLSS software architecture and will be shown in an ECLSS hardware testbed to increase the autonomy of the system.

This report covers the preliminary investigation and evaluation process, aimed at searching the ECLSS for candidate functions for automation and providing a software hooks and hardware scars analysis. This analysis will show changes needed in the baselined system for easy accommodation of knowledge-based or other complex implementations which, when integrated in flight or ground sustaining engineering architectures, will produce a more autonomous and fault tolerant Environmental Control and Life Support System.

## Domain Overview

For development purposes, the ECLSS has been divided into six subsystems:

1. Temperature and Humidity Control (THC)
    - Condensate Removal
2. Water Recovery Management (WRM)
    - Potable Water Recovery
    - Urine Water Reclamation Pre-treatment
    - Hygiene Water Recovery
3. Air Revitalization (AR)
    - Carbon Dioxide Removal
    - Carbon Dioxide Reduction
    - Oxygen Generation
    - Trace Contaminant Control
4. Atmosphere Control and Supply (ACS)
5. Waste Management (WM)
6. Fire Detection and Suppression (FDS)

The first three (THC, WRM, and AR) have components which interact to cycle water and air for the crew as illustrated in figure 1. The air revitalization and water recovery management functions introduce new technology to NASA programs; extensive analysis and pre-flight testing is being performed at MSFC to insure proper operations and procedures necessary to control these cycles. One control objective is to isolate the operations of the subsystems such that these subsystems can be operated independently without analysis of their overall fluid loops. NASA ECLSS hardware and control engineers have expressed concern that the control and fault detection methods planned for the baselined ECLSS do not take into account the overall air and water generation loop interactions. Stable control of these loops will be difficult if not impossible to achieve by simply adjusting knobs in the test environment, scheduling setpoint adjustments of the process control components.

The control and software architecture to manage the ECLSS is hierarchically, physically, and functionally divided as illustrated in figure 2. The lowest level of control is that of real-time process control systems which perform the actual chemical transformations. The next higher level is the ECLSS element supervisor, which monitors and maintains those process controllers physically contained inside a Freedom Station Element, such as the Laboratory. The highest level of ECLSS control is the ECLSS Station Manager. It performs those functions which require knowledge from across element boundaries. It also interacts with the Operations Management Application (OMA) to perform distributed system resource allocation and consumption management with the rest of the Station distributed system managers, such as the Electrical Power System (EPS) manager.

In Phase 1 of the ECLSS Advanced Automation Project we are in the process of analyzing both the functional interactions of the regenerative processes and the software control architecture in search of candidate applications for advanced automation.

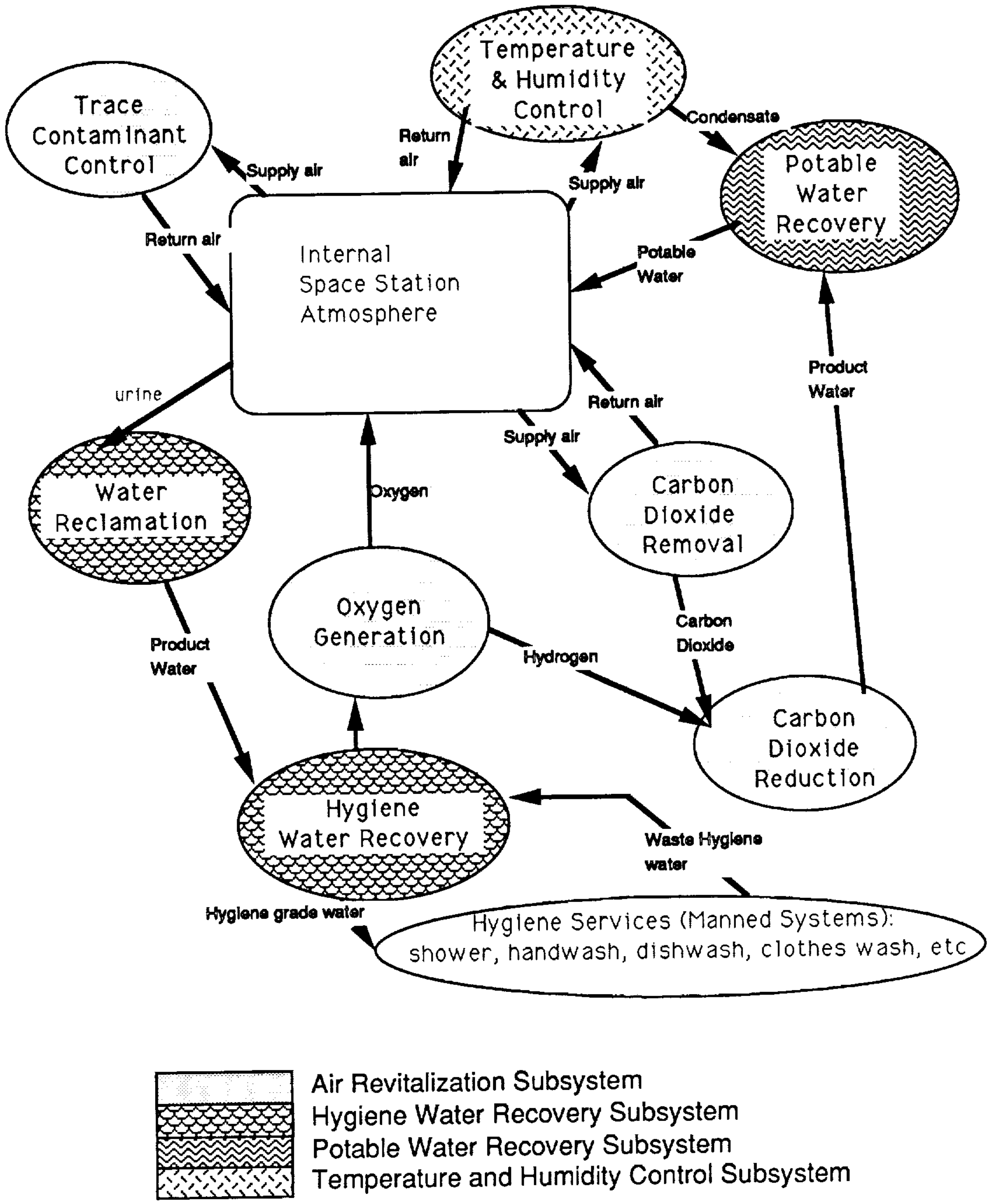


**Figure 1 - Regenerative ECLSS Functional Interfaces**

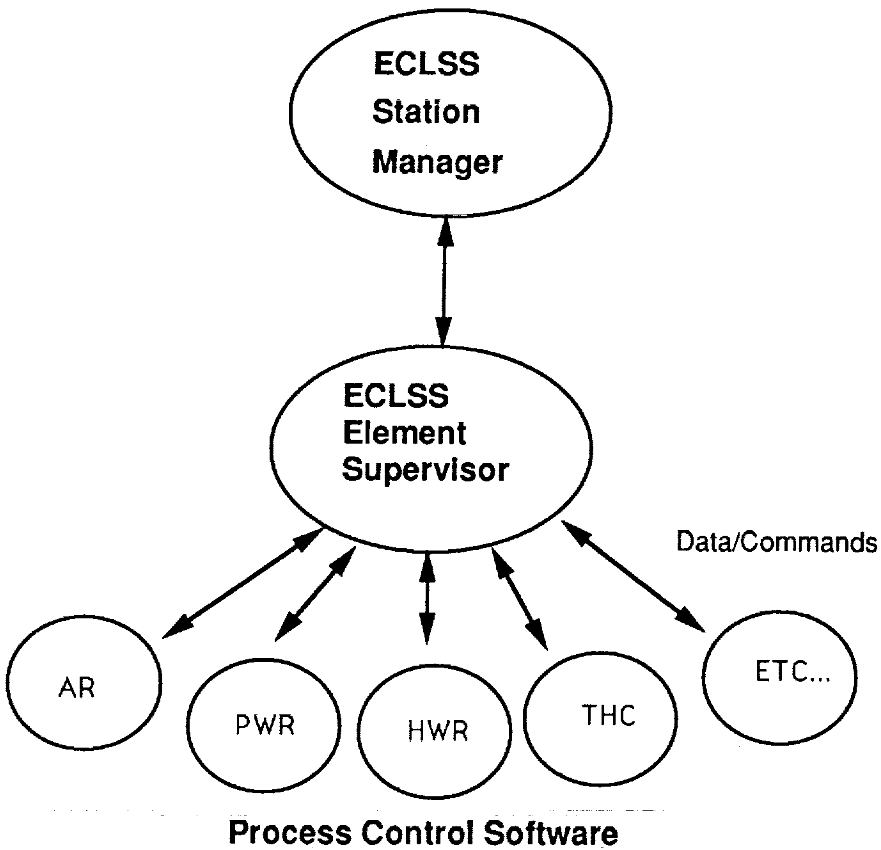


**Figure 2 - ECLSS SOFTWARE FUNCTIONAL SCHEMATIC**

## Application Evaluation / Hooks and Scars Analysis

The preliminary research task, performed by the University of Alabama in Huntsville (UAH), has the main goal of laying the foundation for more extensive analysis and prototyping later, and to drive out software hooks[1] and hardware scars[2] early. It is expected to be an iterative task as the design and testing of ECLSS continues.

Application Evaluation / Hooks and Scars Analysis (figure 3) begins by analyzing the ECLSS domain . As the ECLSS is currently in the preliminary design stage, our knowledge is generated from three general sources:

- Applicable Space Station Freedom documentation such as the ECLSS, DMS, OMS, Architecture Control Documents (ACD's), Contract End Item Specifications, ECLSS component test plans, etc.

- Conference reports on environmental control using knowledge based systems, plus papers describing other past work in automation of environmental control systems

- Interviews with ECLSS test and design engineers, scientists, and doctors

Our initial task was to gather and analyze promising documentation. The UAH application/hooks and scars analysis team, consisting of environmental, chemical, process control, and artificial intelligence engineers, then analyzed each document, determining areas in need of advanced automation and the resulting hooks and scars.

The ECLSS integration support contractor, McDonnell Douglas of Huntsville has been instrumental in supporting NASA ECLSS engineers to develop test plans and simulations for ECLSS components. As part of Phase 1 of this project, McDonnell Douglas was also employed to deliver ECLSS simulations and also write a brief report covering ECLSS instrumentation and possible knowledge based applications. This document was folded into the Domain analysis.

A "divergent thinking" approach was used in the initial listing of candidate applications (1). All the software functions found in ECLSS were listed in order to insure that all were considered. Boeing, the MSFC prime contractor for ECLSS, derived data flow diagrams in their software requirements generation. These were used to list and describe the functions of the baselined system. A preliminary application candidate list is shown in figure 4.

Also, new applications were added which were derived from interviews with ECLS system engineers and scientists. This list will serve as a broad groundwork for future iterations of application analysis.

[1] **software hooks** - an alteration to the Initial Operating Configuration software which will allow easier (less expensive) transition to more advanced software at a later date.
example: providing visibility of all ECLSS subsystem sensor data at the Global ECLSS Manager

[2] **hardware scars** - an alteration to the IOC hardware which will allow easier transition to more advanced hardware and automation capabilities at a later date.
example: providing a connection for a water quality monitor (to be added in the future) at the THC condensate output to isolate bugs in the water to a THC component.

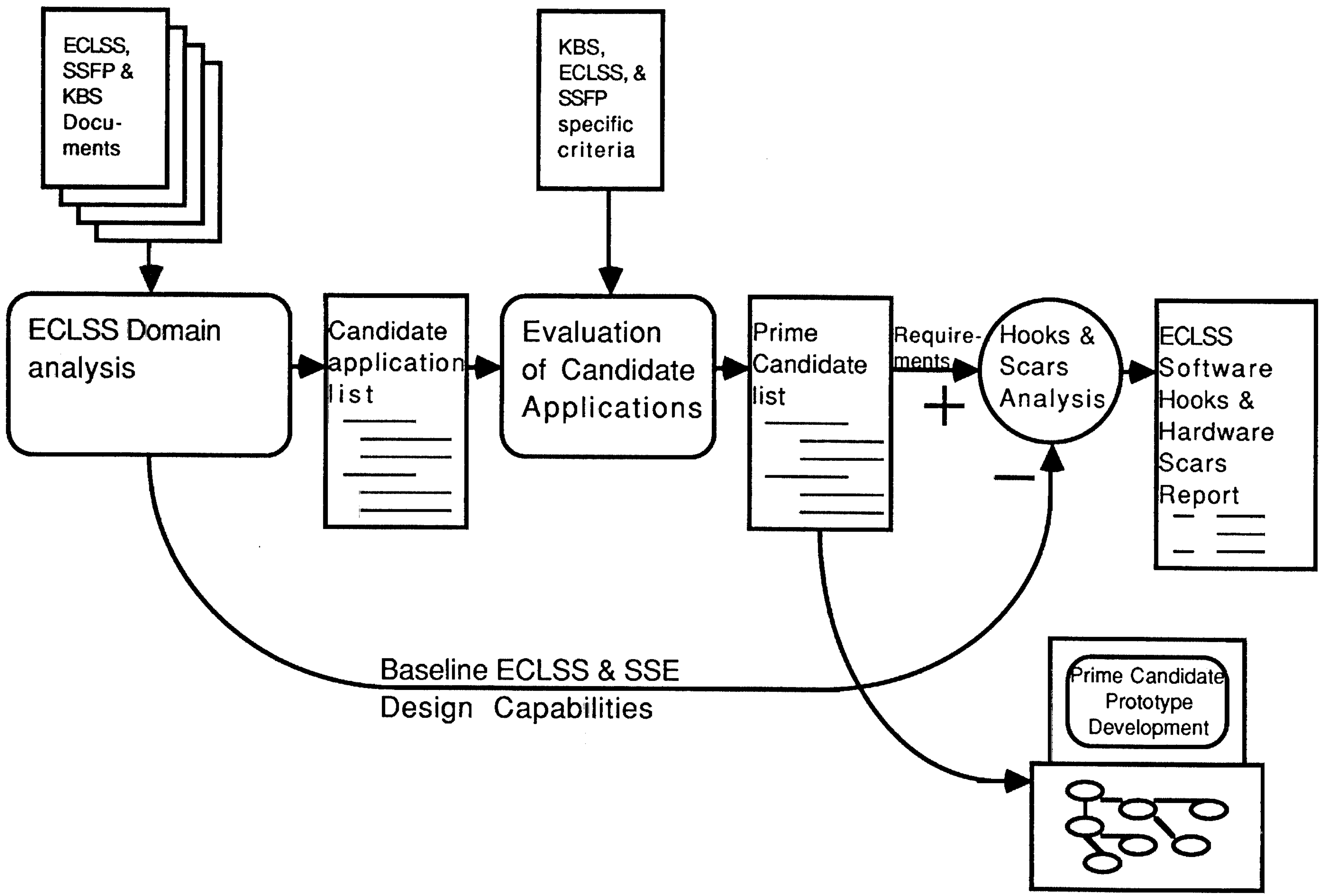


Figure 3 - Application Evaluation / Hooks and Scars Analysis Functional Schematic

**I. ECLSS Station Manager**

ECLSS system level control and FDIR software

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**II. ECLSS Element Manager**

A. ECLSS Element Support Software
  1. Fault Detection and Isolation
  2. Performance and Trend Analysis
  3. Verify Commands
  4. Inhibit Commands
  5. Activate Processes
  6. Process Display Data

B. Temperature and Humidity Control (THC) Subsystem Software

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C. Air Revitalization (AR) Subsystem Software

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D. Atmosphere Control and Supply (ACS) Subsystem Software

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E. Fire Detection and Suppression (FDS) Subsystem Software

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F. Waste Management (WM) Subsystem Software

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G. Water Recovery and Management (WRM) Subsystem Software
  1. Process Potable Water
    a. Monitor Subsystem Status
    b. Monitor and Control Recieving Tank and Pump
    c. Monitor and Control the Purification Process
    d. Monitor and Control Potable Water Storage
    e. Monitor the Water Quality
  2. Process Water Quality Sensor Data
  3. Process Hygiene Water
  4. Process Urine
  5. Set WRM Limits

**III. Real-time Process Control Software**

A. Potable Water Processing Control

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**Figure 4 - Overview of Preliminary Candidate List**

Evaluation criteria was derived for input into the prime candidate evaluation phase. Criteria for evaluation of knowledge based system (KBS) applications are well defined (1). An example of this KBS criteria is: "Is there an expert available? " These were used, but we have not limited ourselves to KBS implementations of advanced automation. We generated more evaluation criteria in the areas of: 1) ECLSS significance (ex: "has the need for advanced automation in this area been voiced by ECLSS engineers?"), and 2) Feasibility ("do we have enough time and money to complete a convincing demo of this application, or should we just analyze this application for later consideration?"). These criteria were used to select the prime candidate applications for which hooks and scars analysis will be performed. An outline of our prime candidate list, which we are in the process of developing, is given in figure 5.

Although the application evaluation plan (figure 3) calls for comple evaluation of all candidate applications before beginning a hooks and scars analysis, we found the best approach was to follow this procedure with one application at a time. For instance, some of our researchers at UAH are chemical and process control experts working on the Water Recovery Management's Potable Water Recovery (PWR) function. We found it best to explore the potable water loop in detail, finding prime candidate applications for advanced automation in this area and getting a good set of hooks and scars Little automation is currently planned in PWR. We will go back for a closer look into Hygiene Water Recovery and Air Revitalization later in Phase 1, after doing our procedural groundwork with PWR.

Having completed our domain analysis, we have done extensive analysis of application evaluation and hooks and scars for the Potable Water Recovery function. We plan to continue work on application analysis for the rest of the ECLSS regenerative functions, with more detail and hooks and scars requirements. Figure 6 is an illustration of the overall plan steps, pointing out our present position.

After phase 1 is complete (scheduled completion is the end of October), an engineering firm will develop prototype advanced automation software, picked from the prime candidate list and using the described requirements of phase 1. We will prove our automation concepts using system hardware and a software structure modeled on that of baselined ECLSS.

## Application Examples

Two areas in which the ECLSS could be more autonomous are in process control and fault detection/prevention, and at the system level - supervising the overall operation of the regenerative loops. Advancement of the automation concepts in these two areas of ECLSS are illustrated. First, the potable water recovery system will be described along with a plan for increased automation. Second, the Meta-regenerative FDI function will be overviewed. These examples have not been picked for prototyping, but are prime candidates in our evaluation.

1) Water Recovery and Management (WRM) Subsystem Software
- Potable Water Recovery
  1. Fault Detection and Isolation
     Input: Process Description: Output: Requirements:
  2. Performance and Trend Analysis
     Input: Process Description: Output: Requirements:
- Hygiene Water Recovery
  1. Fault Detection and Isolation
     Input: Process Description: Output: Requirements:
  2. Performance and Trend Analysis
     Input: Process Description: Output: Requirements:
  3. Monitor the Water Quality
     - Performance and Trend Analysis
       Input: Process Description: Output: Requirements:

2) Air Revitalization (AR) Subsystem Software
  1. Fault Detection and Isolation
     Input: Process Description: Output: Requirements:
  2. Performance and Trend Analysis
     Input: Process Description: Output: Requirements:

3) Fire Detection and Suppression (FDS) Subsystem Software
  1. Fault Detection and Isolation
     Input: Process Description: Output: Requirements:
  2. Performance and Trend Analysis
     Input: Process Description: Output: Requirements:

4) Meta-Control of Water/Condensate Loops
   Input: Process Description: Output: Requirements:

**Figure 5 - Structure of Prime Candidate List**

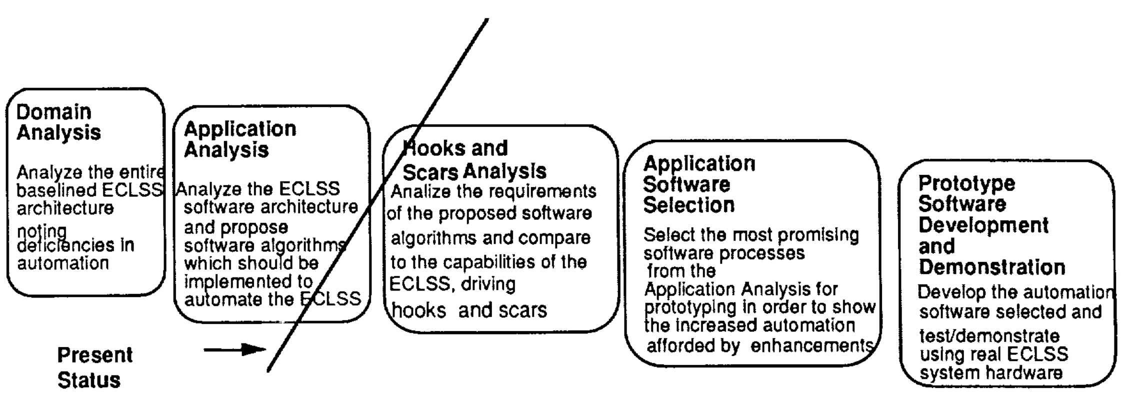


**Figure 6 - Overview of Entire Task with Present Status**

## Potable Water Recovery Advanced Automation

The potable water recovery system, its control algorithm, and an overview of its advanced control algorithm is illustrated in figure 7. The system input is an inlet tank which gets its water from two sources, the THC condensate and the water by-product of the BOSCH carbon dioxide reduction subsystem.

This water is sent through a multifiltration device to an outlet tank which is checked using three monitoring methods for impurities:

1. The Process Control Water Quality Monitor checks in real time for levels of Iodine, Total Organics, PH, and Temperature.

2. A batch qualitive assessment is performed by the crew using a sample taken from the product water storage tank.

3. A batch qualitive assessment is performed on the ground using a sample brought back in the logistics module.

As the Potable Water Recovery components are being developed, so will the control scheme. Described in figure 7 is the baselined control scheme which uses the Water Quality Monitor data to determine in real time if the water is fit to drink. If its measurements meet specifications, the water is used, otherwise, it is sent back through multifiltration. The batch crew assessment is only to be used in off-nominal situations when there is not enough time to allow the ground assessment. The ground assessment will be used to match the readings of the WQM with the actual constituents of the water.

This control algorithm relies heavily on nominal processing of the water by the multifiltration device. This method may be sufficient for the initial operations of the Space Station Freedom, but advanced automation algorithms must be employed to reduce the crew and ground maintenance time. For instance, if an anomaly (a bug or foriegn chemical) gets in the water which multifitration cannot remove, the water must be removed from the loop and it will be very difficult to determine its origin.

A general advanced control algorithm should not only use more knowledge in feedback decision but should attempt, if the water is contaminated, to determine the source of the contamination. Connection graphs, simulations, and trend data may be used to increase the intelligence of the control and fault detection algorithm. Also an expert system could be used in the ECLSS ground sustaining engineering facility to help correlate the sensor readings from the water quality monitor to the batch qualitive analysis of the water (2). This expert system would reduce analysis time on the ground and store valuable knowledge which will be acquired from a medical doctor or chemist working on ECLSS sustaining engineering.

The hygiene and air revitalization process control systems will be inspected for insufficient control algorithms and fault detection/isolation in a similar manner. We will drive higher fidelity control algorithms and hooks and scars for their later implementation.

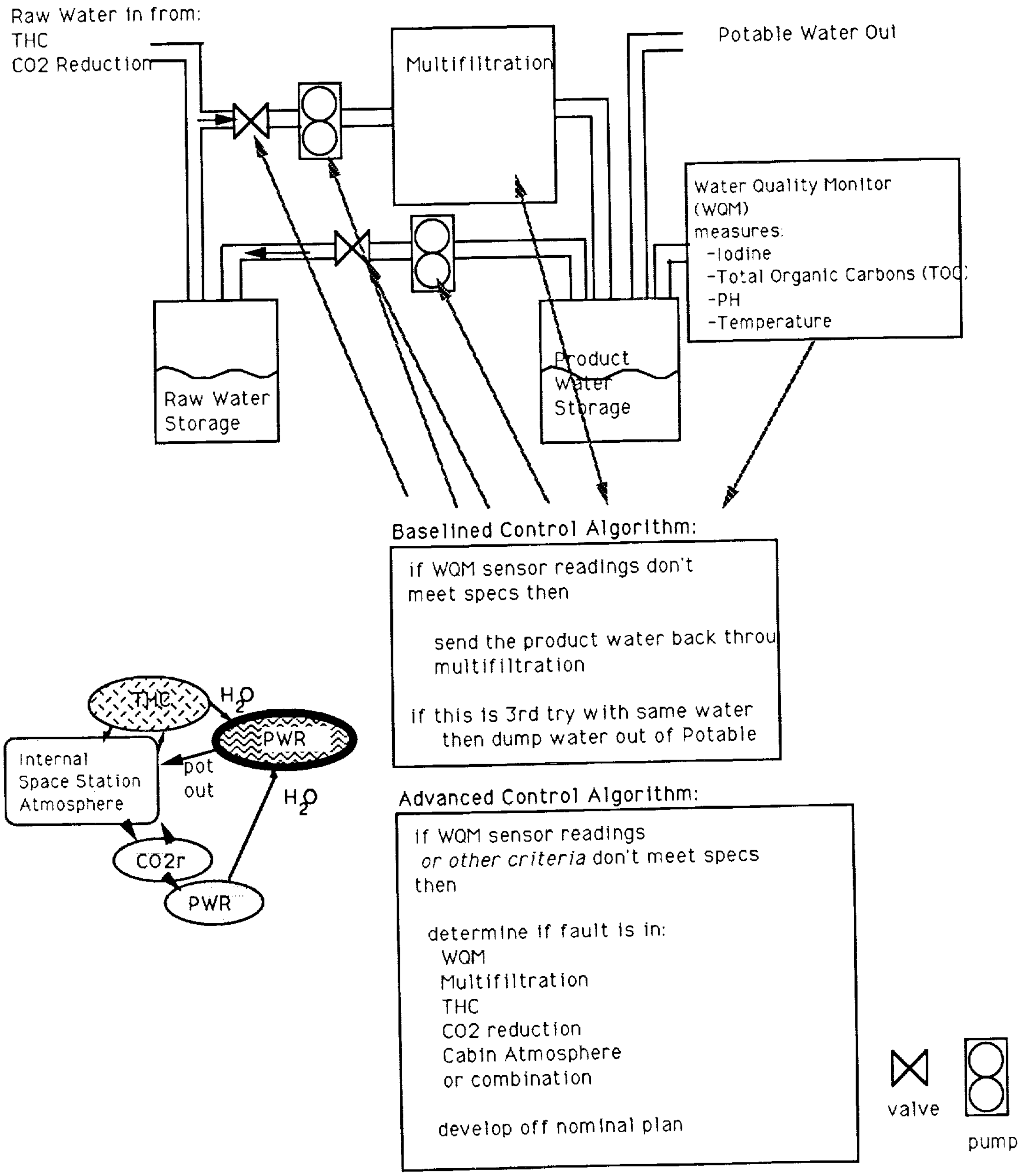


**Figure 7 - Potable Water Recovery Advanced Automation**

## Meta-Regeneration Automation

The Meta-Regeneration Automation function is illustrated in figure 8. It will take as inputs the necessary data from the flight and ground analysis functions, and influence the control scheme in order to detect/predict/prevent a fault. A portion of the baseline software will most likely be used to serve this function, but as of yet it is not called out in the design. The ECLSS developers currently maintain that the subsystems are isolated enough that such an overall control intelligence is unnecessary, or at least minimal. In ECLSS extended testing, these system level requirements will become apparent - even though each subsystem is working nominally, instabilities may occur in a water or air regeneration loop. The initial operating configuration (IOC) of ECLSS may depend heavily on sustaining engineering analysis to detect these conditions and update the operating configuration. Hooks and scars in the IOC design should allow easy implementation of advanced automation software in this area.

This advanced software may take the form of a blackboard system or knowledge base system which has access to all the required data. These design decisions, and an operating prototype may be developed and tested in ECLSS subsystem testing. This system should be able to grow as more knowledge concerning the interaction of these processes is accumulated.

## Conclusion

We developed a straightforward plan for advancing the automation of the Environmental Control and Life Support System. It was found that our group has expertise in a particular area of the ECLSS, the potable water recovery (PWR) subsystem, so we went into more detail in this area, using it as a case study for finding prime candidate applications and hooks and scars. We have yet to complete our application analysis for the entire ECLSS regeneration systems, and produce a hooks and scars analysis for these systems.

We have determined two examples of where the automation of the ECLSS could definitely be improved. One area is in the low level process control algorithms, the other is in the higher level of overall ECLS system automation. The baselined control algorithms of these systems will most assuredly change during system testing, but the groundwork of phase 1 will continue to be a valuable resource in prototype development and demonstration phases.

This preliminary analysis will prove beneficial in phase II and III, where actual prototypes will be developed by the engineering contractor. When these prototypes are being tested against ECLSS hardware and prototype software, the groundwork developed in phase I will minimize data searches and tracing of requirements.

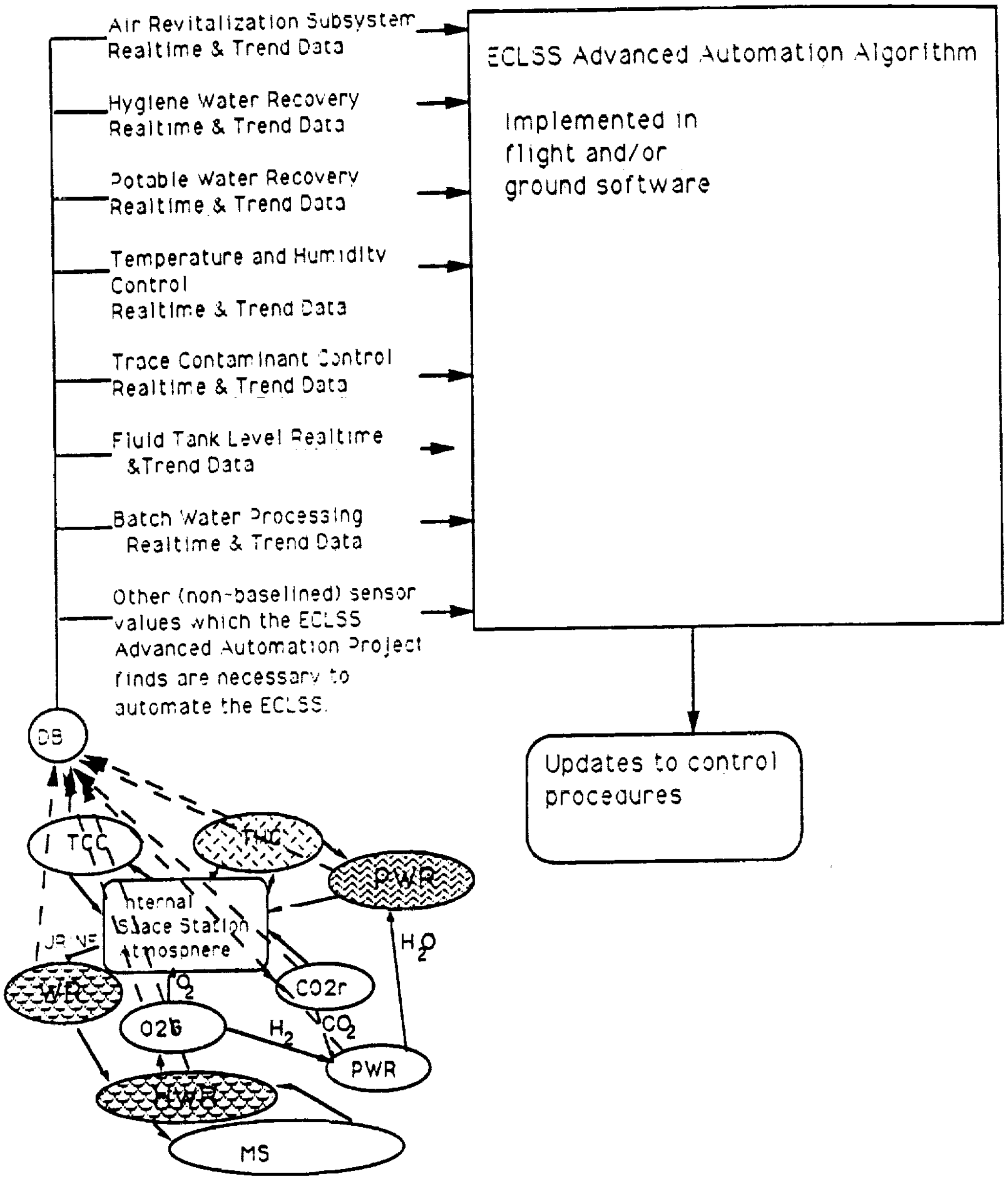


Figure 8 - Meta-Regeneration Automation

## References

In addition to the reports listed below, some forty documents have been accumulated during the ECLSS domain analysis which were not explicitly referenced in this paper. A summarized list of these documents will be made available at the workshop.


1. Slagle, James R. and Wick, Michael R., "A Method For Evaluating Candidate Expert System Applications," AI Magazine, Palo Alto, CA, Winter 1988, pages 44 -53.

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4.Architectural Control Document - Environmental Control and Life Support System, SSP 30262, February 15, 1989