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Development of a Systems Engineering Model of the Chemical Separations Process

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Proposal

Development of a Systems Engineering Model of the Chemical Separations Process

Submitted to

UNLV Transmutation Research Program
Technical Focus Area: Separations
Chemical Separations Development Research
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$ 147,250

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May 16, 2003

Abstract

Two activities are proposed: the development of a systems engineering model and the refinement of the Argonne code AMUSE (Argonne Model for Universal Solvent Extraction). The detailed systems engineering model will be continuously focusing on the integrated approach to the analysis of the materials separations associated with the TRP Program. A second portion of the project will streamline and improve an integral part of the overall systems model, which is the software package AMUSE. AMUSE analyzes the UREX process and other related solvent extraction processes and defines many of the process streams that are integral to the systems engineering model.

Combining these two tasks is important in ensuring that calculations made in AMUSE are accurately transferred to the overall systems model. Additional modules with the work flowsheet will be developed to model pyrochemical process operations not treated by AMUSE. These modules will be refined as experiments are conducted and as more knowledge is gained in process steps. The software with an Object Oriented Programming (OOP) approach for all data input types will also be developed.

Integrating all aspects of the proposed separations processes will allow for detailed process analyses, trade-off studies or the evaluation of proposed process steps, complete material balances that include all potential waste streams, the impact of changes in feed streams, studies detailing the importance of process control and instrumentation, and the ultimate optimization of the process. The constraints of optimization provided by ANL-East will be implemented with single or multi-run.

Proposed Work

Two graduate student research projects are proposed. Both of these projects are inter-related and support the overall goal of developing a systems engineering model of the chemical separations portion of the TRP-UPP program. These students will work under the direction of the researcher associated with this project.

The first activity is the development of a systems engineering model. This will be the third year of the development effort. The activities for this project include refining process models for all unit operations (process and waste streams), continue the development of a detailed system model, and to demonstrate the utility of the modeling concept.

The second activity is the implementation of Object Oriented Programming (OOP) approach to the existing Graphical User Interface (GUI) and link to the AMUSE macros. Project tasks include the review/analysis of the code structure, the examination of other possible implementations, development of a verification plan, and the modification/improvement of the software, including a database to efficiently handle the data flow between AMUSE, Visual Basic and MATLAB.

1. Progress in Year 2 – First Part

Major advancements have been made in the project for Year 2. Work continued on both the development of the systems engineering model and on the graphical user interface for AMUSE.

Productive meetings were held with Argonne National Laboratory (ANL)-East to obtain their input on the project. These meetings were very useful and will make the research more useful for them. A Graphical User Interface (GUI) has been developed that connects to AMUSE. All the macros in AMUSE were studied and the data flow between the macros is understood. The GUI takes the input from the user and creates an export file. Export file serves as the input for AMUSE code.

Code within the GUI transfers the data given by the user in the interface to the export file. The export file is a Data Carrier which connects the VB-Interface to AMUSE. The data given by the user in the front-end must be transferred to the export file which then links the data to AMUSE for further calculations. The data includes the number of sections in the process, recycle organic, concentrations of TBP and CMPO and they are stored in the export file.

A template option was provided to the user, which enabled the user to just feed the data into the flowsheet. This development was very useful for new users. This option was removed at the suggestion of ANL-East.

The data given in the process blocks goes to the export file and AMUSE code is run. Each of the blocks physically represents a part of the uranium extraction process. The user will be able to define this data, or it will be passed to the AMUSE code in a data file when the AMUSE code is run as part of the overall systems engineering model.

New enhancements include the ability of the user to select a particular process type. Figure 2 shows the main form where the user selects the process type and different other parameters before creating the flowsheet. Once the user selects the process a template flowsheet is provided to the user. Here user selects solvent type, type of contactor, etc.

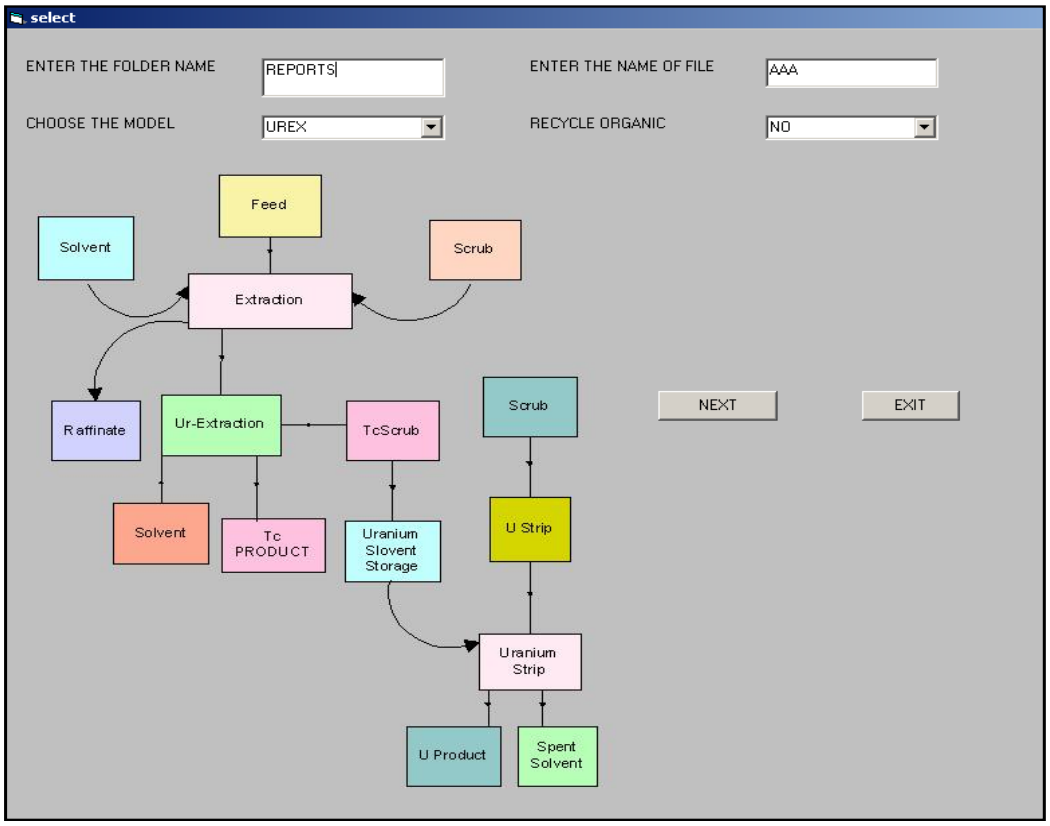


Figure 2 - GUI for user selection of predefined processes.

Once AMUSE has been run using the primitive data, it generates results files. The post processing section allows the user to view the results like concentration profiles, full reports, concise reports, etc. Figure 3 shows the example of concentration profile.

An interface for conducting multiple runs has been created. The GUI for this form is shown in Figure 4. It includes a list of variables, a range for those variables, all of which change the end result. All the input is validated with maximum and minimum values. When the parameters are changed a click on RUN button runs AMUSE and a click on EXIT button takes the user to the main form.

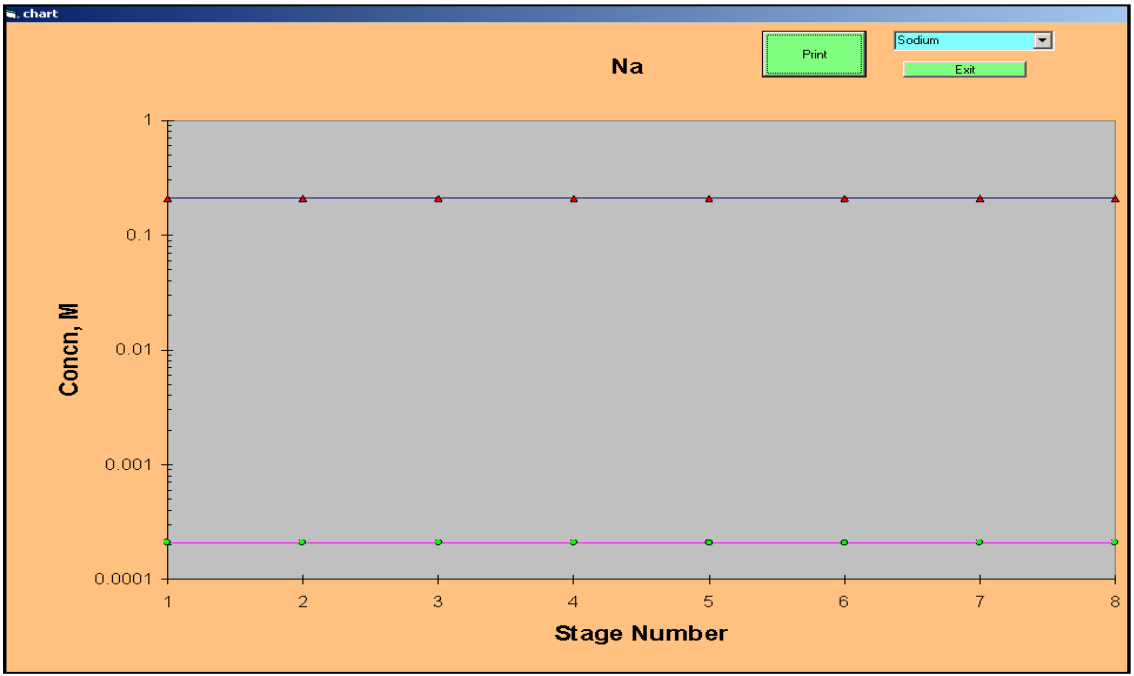


Figure 3 - Representative output for reporting chemical concentrations.

Open and Save options are created in the menu. This enables the user to open a similar file and make some changes to run AMUSE without again building a new flowsheet. Figure 5 shows the use of Open n Save options:

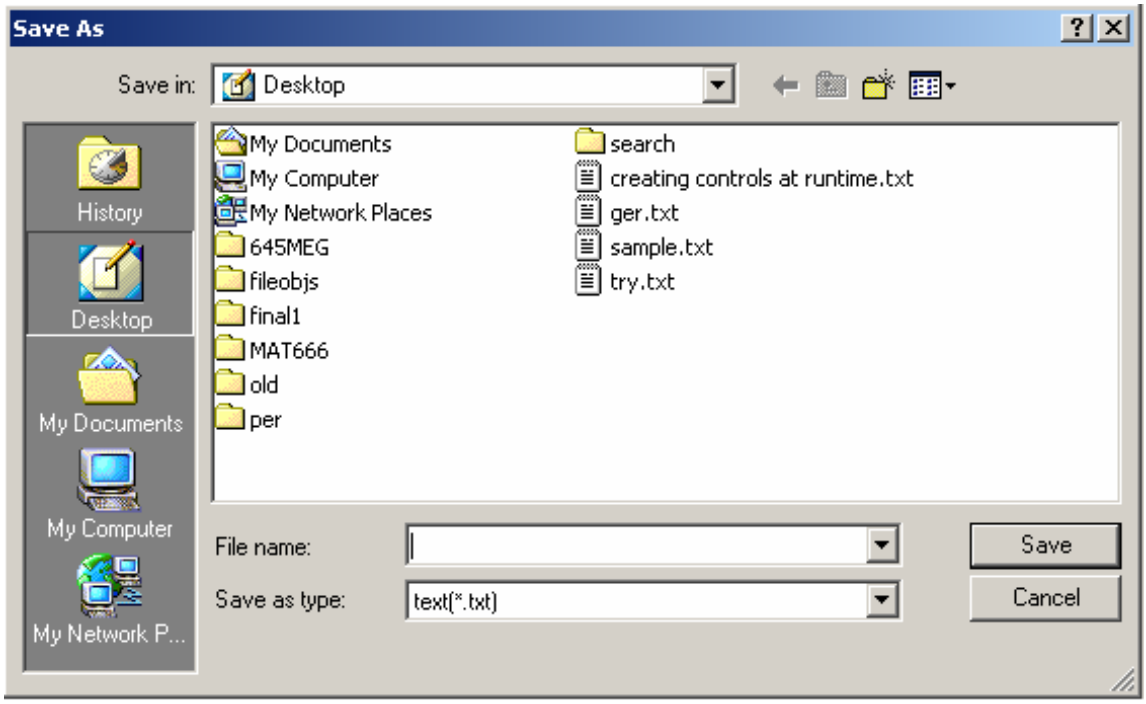


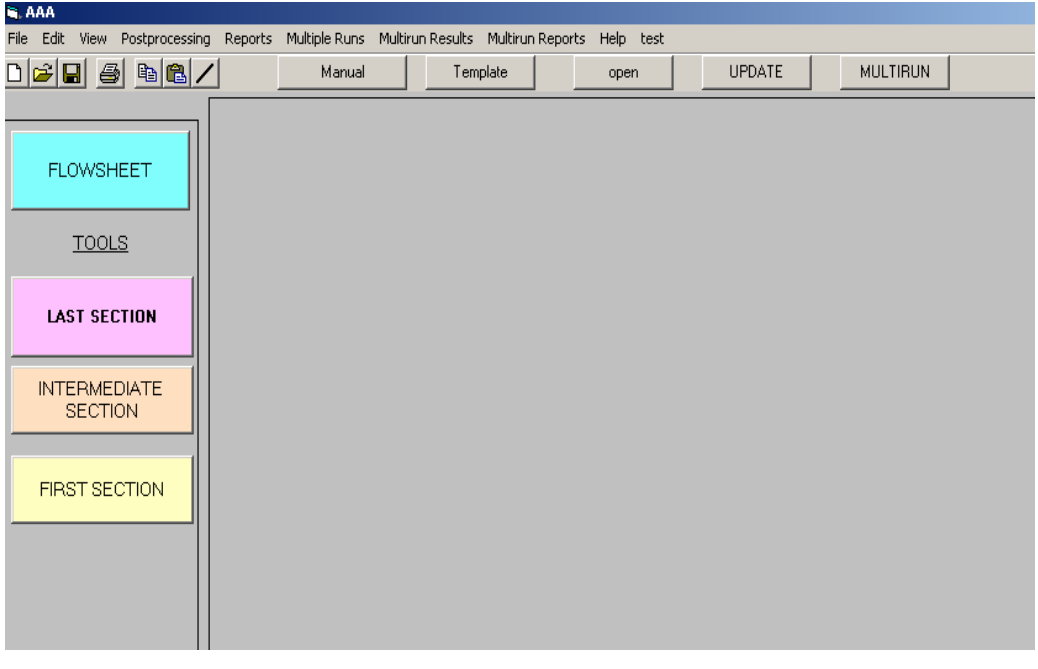
Figure 5 – Standard GUI interfaces have been developed for opening and saving files. These interfaces are standard Windows interfaces for user comfort.

A reports tab has been created to view the reports. ANL-East is making some changes in their report format and we will incorporate their changes in the reports as the project moves forward.

Feedback from ANL was very useful in deciding to develop the software with an Object Oriented Programming (OOP) approach for all data input types. The new interface with OOP looks like what is shown in Figure 6.

Figure 7 shows that the flowsheet object is used to give some input regarding solvent type, recycle organic, etc. Figure 8 shows the new tool, which is used to create the flowsheet.

The main form which is shown in Figure 9 will have flowsheet object and Tools to create the flowsheet and to give input. Connectors are removed because by default the streams go from one block to the consecutive block. Events are written for each object so that user can give input. Events are written for each object so that user can give input.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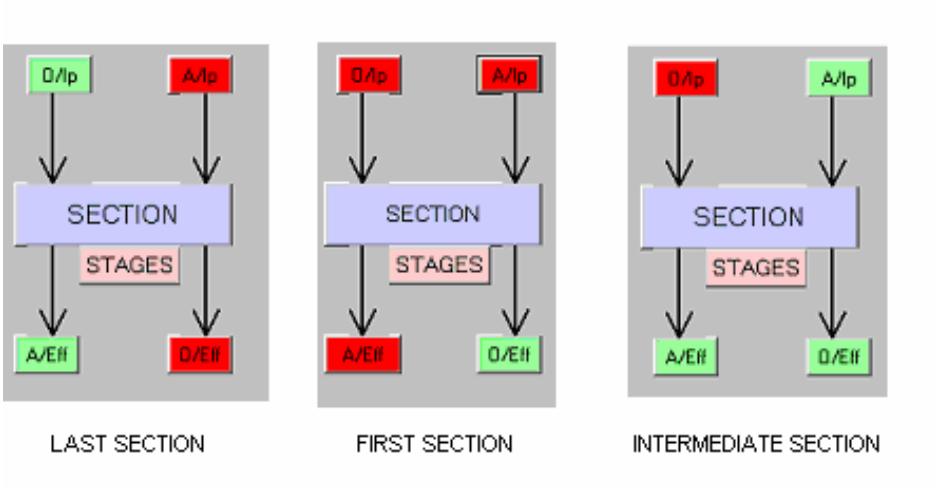


Figure 8 – New design for creating the flowsheet.

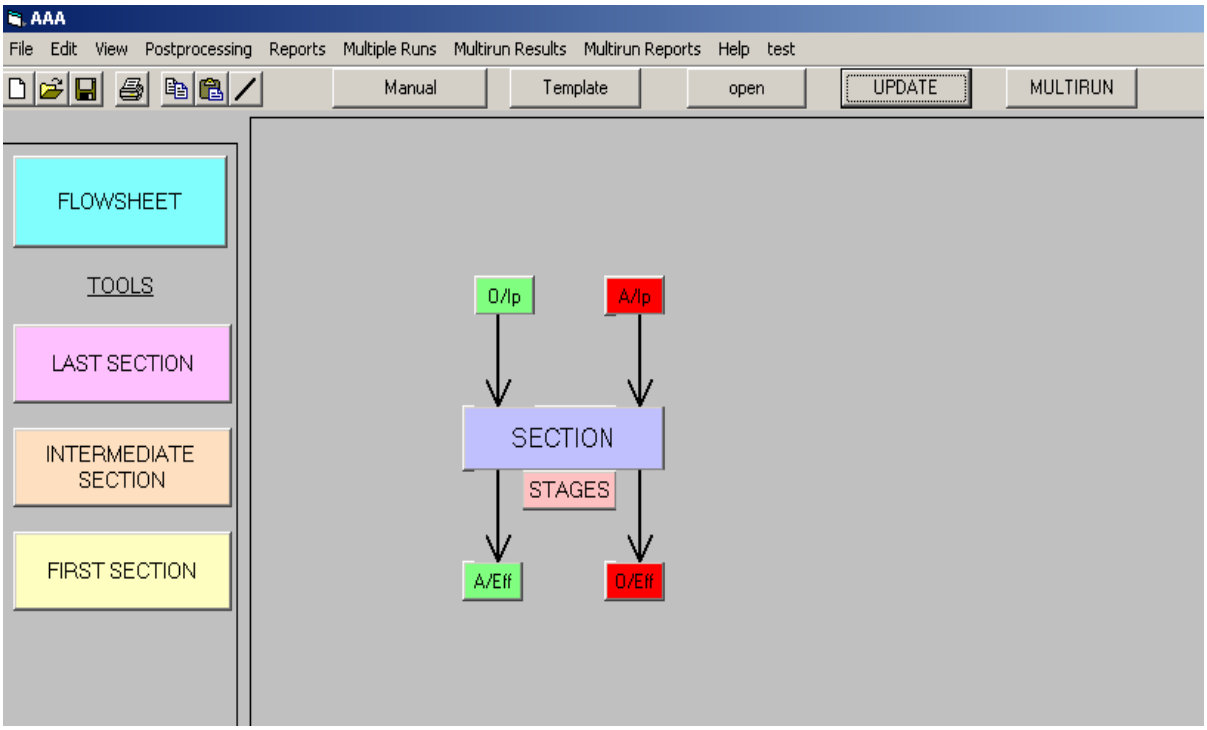


Figure 9 – Flowsheet object and tools to create the system flowsheet and to assign inputs.

Progress in Year 2 – Second Part

The second task of this project is the development of a systems engineering model for the chemical separations process. We have been applying general systems engineering techniques/tools to complex processes –TRP-UPP Chemical Separation Process:

- Development of a tool that allows process changes to be modeled on a system level, to have the ability to know what impact one change have on overall process
- Mass balance for all process streams
- Examine changes of input on waste streams
- Ability to optimize system such like cost, waste streams, etc.
- Detailed models of process components reactors, electro refining, chopping, separation, etc.
- Examination of different assumptions on process performance

The basic knowledge of system engineering have been studied at the very beginning. The different system engineering technology and approach have also been studied. We have inspected many aspects of system design process and many system design tools like QFD – Quality Function Deployment.

At the beginning of year 2 of this project, iSight has been used as the main development environment to build system engineering modal and perform the system analysis, trade-off study, optimization, etc. iSight is a generic software shell that improves productivity in design process. In iSight, design problems are specified, and simulation codes from multiple disciplines are coupled in a description file. After a description file is created, users can use the iSight interface to set up, monitor and analyze a design run.

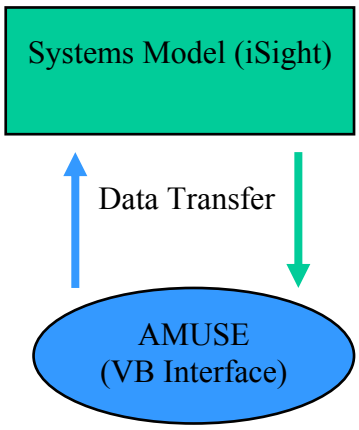


Figure 10 – Data transfer and interaction between the systems engineering model and AMUSE code.

Problem Definition: Before an optimization problem can be run, it must have a starting point, a goal and some boundaries. The type of parameters consists:

- Design variables - which will be perturbed by the optimizer
- Objectives – which will be maximized or minimized during optimization
- Constraints – define the limits, or boundaries, of your design space
- Objective function – a weighted sum of all of the parameters designated as objectives in design problem
- Feasibility – indicate the suitability of the current design point with respect to previous ones

Figures 11 and 12 show the UREX integration Models build in iSight.

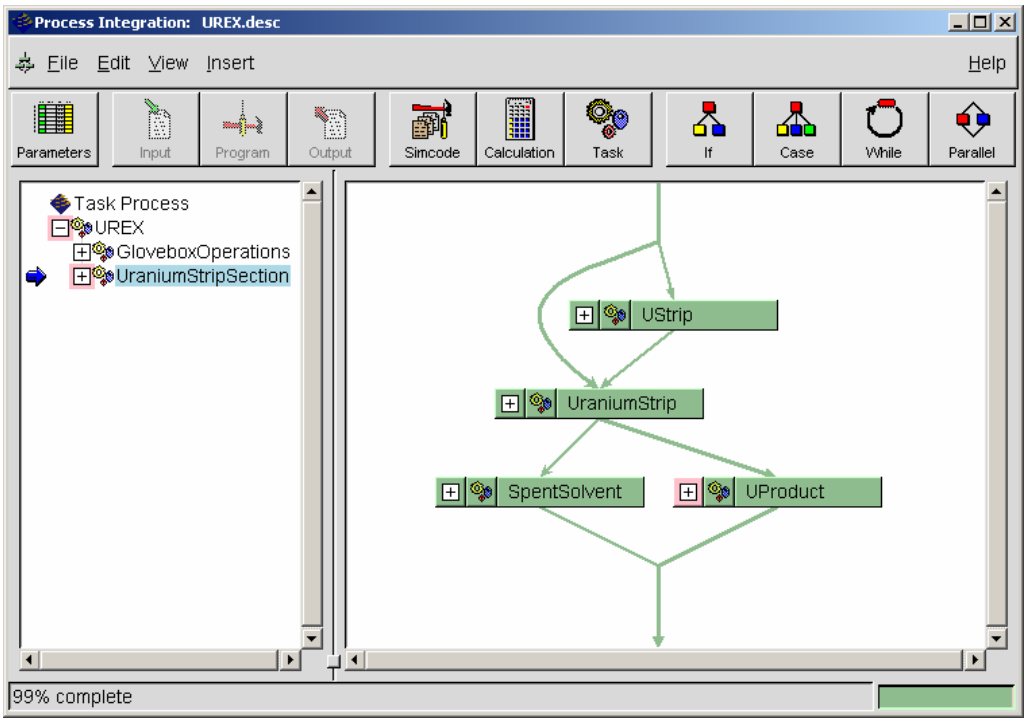


Figure 11 - AMUSE (UREX) integration.

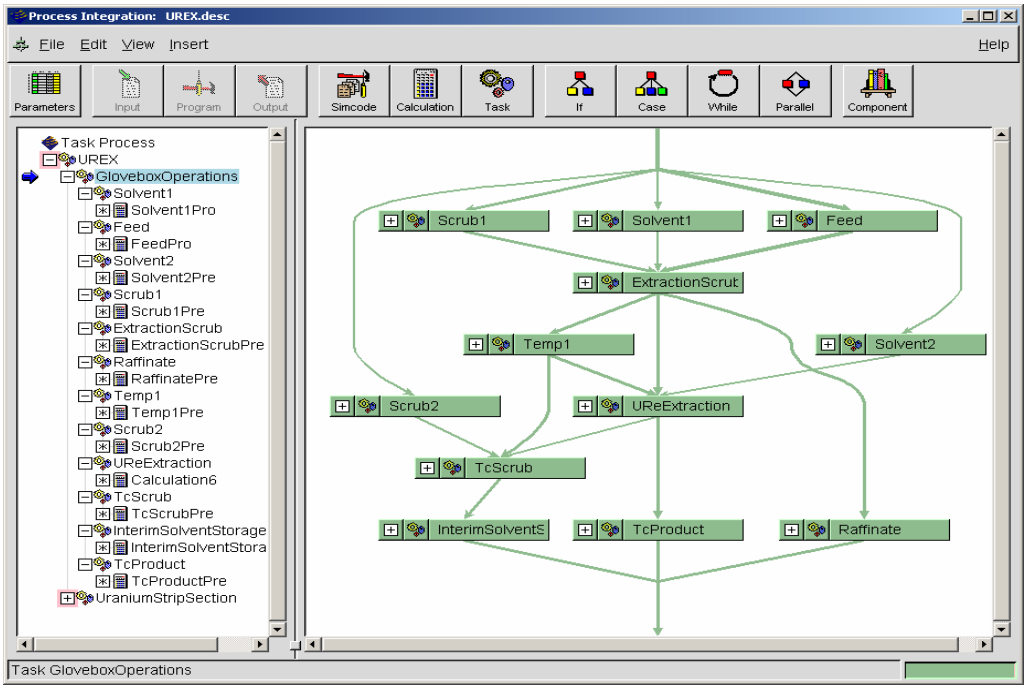


Figure 12 - AMUSE (UREX) Integration – Glovebox operation.

TRADE-OFF STUDY: In lieu of conduction an optimization, a standard engineering practice has been used to perform a trade-off study; that is, to evaluate a set of design points, analyze them and plot the results. Some of the important techniques for trade-off study have been studied, like Full – Factorial Design, Parameter Study, Data File, Orthogonal Arrays, Central Composite Design, Latin Hypercubes.

Design Matrix (Orthogonal Array): By using the above techniques, we could then create the design matrix, in which each row constitutes a separate design;

Basic on the above matrix, the trade off study could be performed, and the main effects were calculated from the set of data, and an analysis of variance (ANOVA) was conducted to determine the primary sources of variance in the response quantities.

iSight was initially selected as the development environment for the systems engineering model. During the second year, through discussions with ANL personnel it was decided to no longer pursue the use of this product. The reasons for not continuing on this path included the high lease prices for iSight, poor availability for universities, and the need for a product whereby work could continue in the future without incurring large expenses. Therefore, the combination of MATLAB, SIMULINK and OPTIMIZATION toolbox were chosen as the main software environment for the development of system engineering model. Figure 13 shows the main flow chart for current system development.

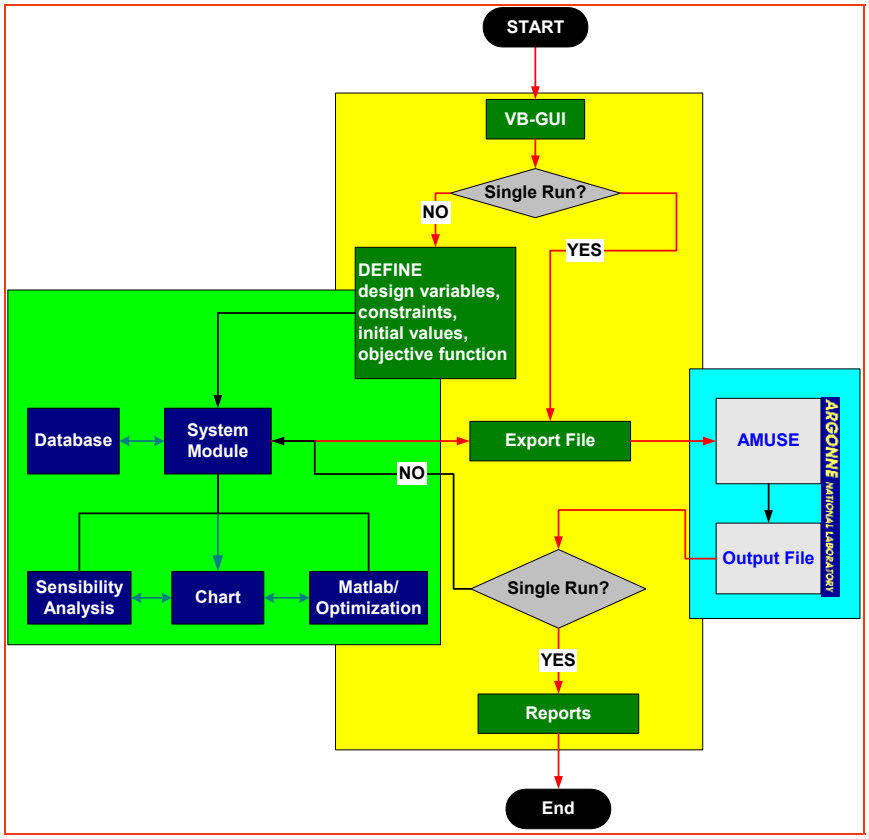


Figure 13 - Main flow chart for current system development.

Figure 14 shows the example of design matrix. Each row of the matrix constitutes a separate design evaluation. The example of system sensitivity analysis chart – Line Plot is shown in Figure 15. The example of system sensitivity analysis chart – Bar Plot is shown in Figure 16. In this chart, red color shows that it is a positive effect and blue color shows that it is a negative effect. From this chart we can identify the most influential factors in the design objective.

Assignment

Experiment Number	H	A	B	C	D	E	F	G	I
	1	2	3	4	5	6	7	8	9
1	1	250	175.0	20	150	25	4.5	1	75.0
2	1	250	175.0	20	150	35	5.5	2	125.0
3	1	350	250	30	200	25	4.5	1	75.0
4	1	350	250	30	200	35	5.5	2	125.0
5	2	250	175.0	30	200	25	4.5	2	125.0
6	2	250	175.0	30	200	35	5.5	1	75.0
7	2	350	250	20	150	25	4.5	2	125.0
8	2	350	250	20	150	35	5.5	1	75.0

Figure 14 – Design matrix.

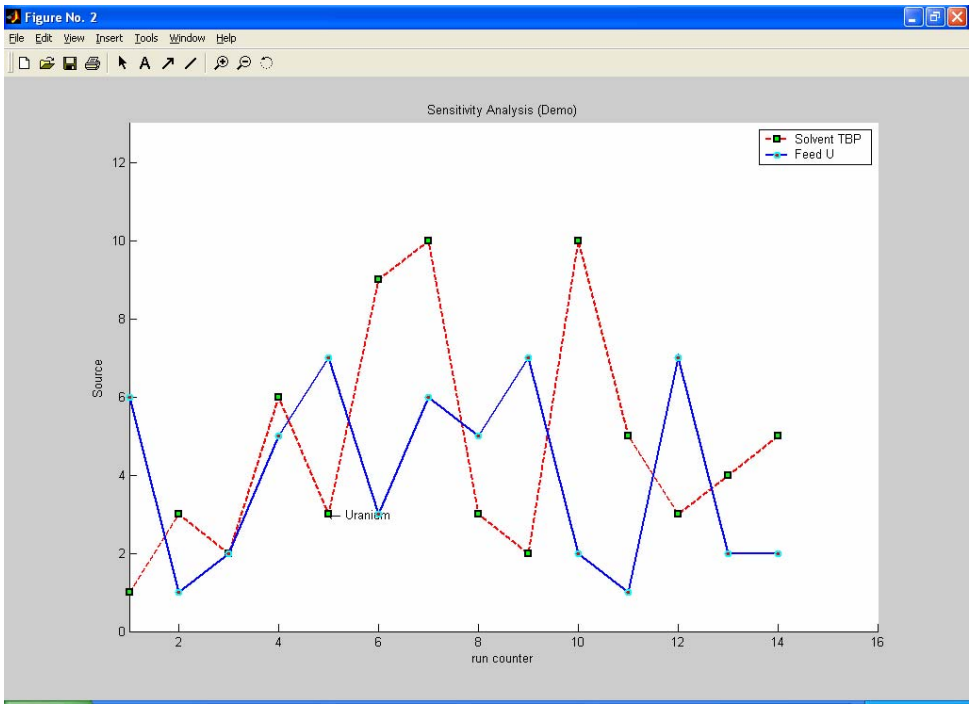


Figure 15 – System sensitivity analysis chart – Line Plot.

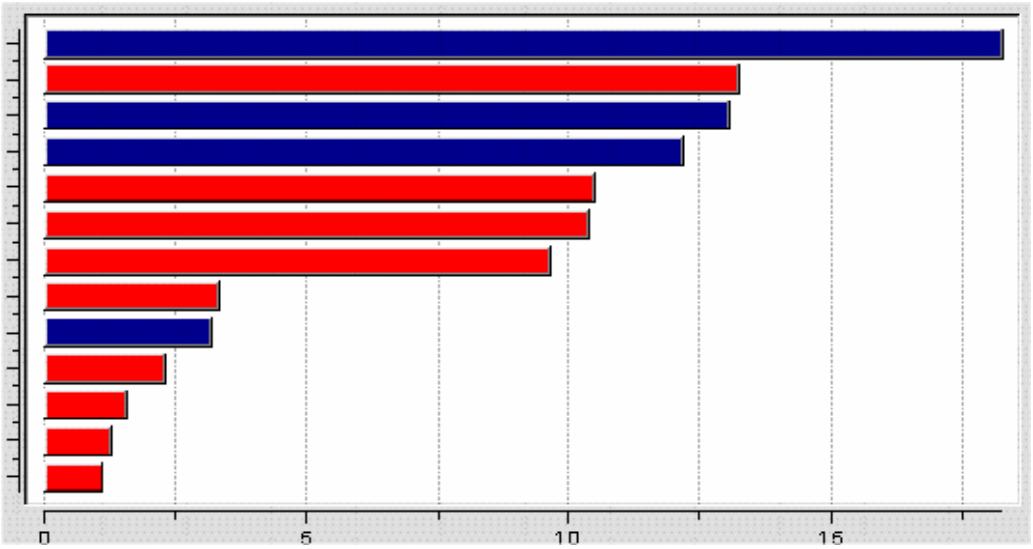


Figure 16 – System sensitivity analysis chart – Bar Plot.

2. Background and Rationale

The UNLV Transmutation Research Program is developing technology for the transmutation of nuclear waste to address many of the long-term disposal issues. An integral part of this program is the proposed chemical separations scheme. Figure 17 shows a block diagram of the current process as envisioned by Argonne National Laboratory (ANL) researchers. This is the same process as presented in year one and initially will be the model used for the systems engineering model. The modeling environment has the flexibility to allow the modeling of any process changes.

Nearly all issues related to risks to future generations arising from long-term disposal of such spent nuclear fuel is attributable to ~1% of its content. This 1% is made up primarily of plutonium, neptunium, americium, and curium (the transuranic elements) and long-lived isotopes of iodine and technetium created as products from the fission process in power reactors. When transuranics are removed from discharged fuel destined for disposal, the toxic nature of the spent fuel drops below that of natural uranium ore (that was originally mined for nuclear fuel) within a period of several hundred years.

Removal of plutonium and other transuranics from material destined for geologic disposal also eliminates issues related to long-term (centuries) heat management within geologic environments. The removal of neptunium, technetium, and iodine render negligible the possibility of radioactive material penetration into the biosphere far in the future. Finally, removal of plutonium negates any incentive for future intrusion into repositories driven by overt or covert recovery of material for nuclear proliferation.

The complete process considers existing LWR spent fuel, separation processes, fuel fabrication, transmutation, disposal as a low-level waste (LLW), and the reprocessing of fuel after transmutation. This is an involved process that can be varied in a number of ways. Any proposed change to the process can have impacts on the fuel design, amount of waste generated

by the process, number of cycles through the reactor, etc. In a nuclear growth scenario, the introduction of advanced thermal reactor designs will almost certainly result in changes in separations system requirements that must be met with optimized systems.

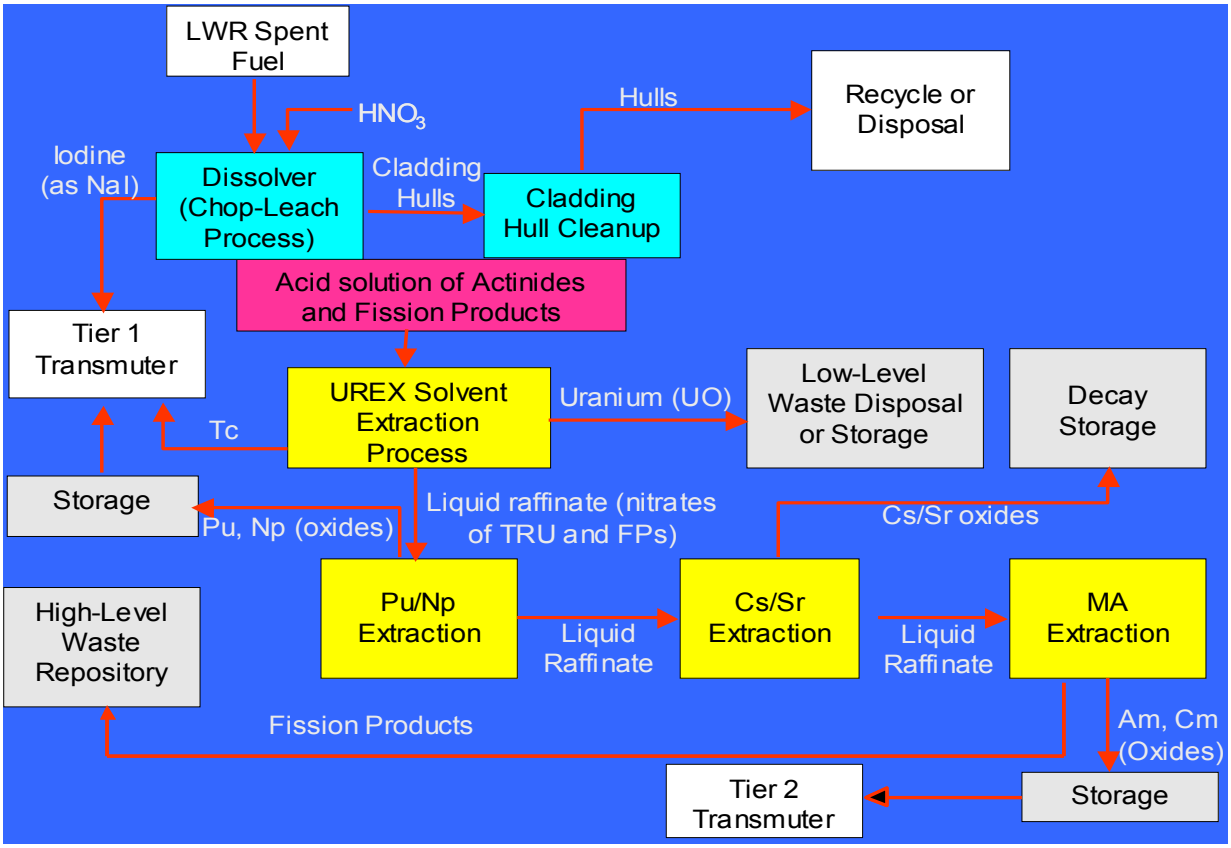


Figure 17 – Overall Chemical Separations System for AFCI Program. This figure depicts the fuel cycle scheme in which the transuranic elements and long-lived fission products from spent LWR fuel are sent directly to an accelerator-driven subcritical reactor for transmutation. Other schemes under consideration involve intermediate critical reactor steps; this would result in major changes in the design, development and analysis of separations systems. Systems engineering would enhance the ability to respond with such changes.

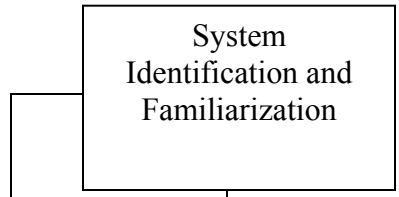
The development process is considered a multi-year task. Years 1 and 2 have laid the groundwork for the systems engineering model. The groundwork was discussed in Section 1 of this proposal. The third year's effort will continue to develop details of the process model and to modify the AMUSE code to streamline it's use and to make sure it interfaces nicely with MATLAB, SIMULINK and OPTIMIZAITON toolbox.

Developing a systems engineering model of the overall process would be beneficial to analyzing complex interactions between proposed process changes. All of this work will be conducted in conjunction with researchers at the national laboratories to insure its usefulness.

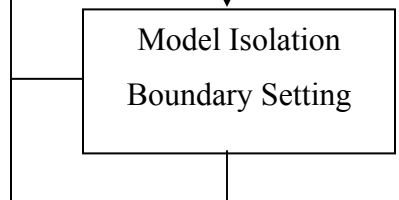
The beginning of any system study is the recognition of the rational system that is responsible for the inputs or outputs of interest. Often, identifying the essential components of the system that collectively undergo the cause and effect action associated with the system is obvious, such as the illness (the output) that results when a person (the system) consumes toxic food or water (the input). However, the identification and isolation of other systems, such as a study of the causes of inflation where the general system is the world economic system, is undoubtedly complex, diverse, and presents a serious modeling challenge. For this project, clearly defining the process flowsheet is a critical first step (UREX, PYRO-A, PYRO-B, etc.).

Table 1. Evolution of a Typical System Study

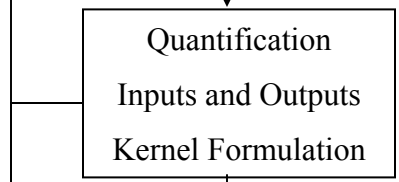
- Background information on actual system
- Observation and experimental data
- Determine system characteristics
  - -Continuous or discrete
  - -Determinant or stochastic
  - -Number and ranking of inputs and outputs



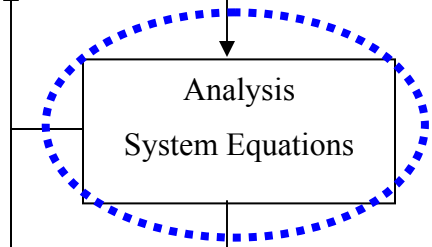
- Separation of system model and environment
- Distinguish between inputs and outputs
- Assessment of intrinsic and extrinsic feedback



- Measurement scheme for inputs and outputs
- Formulation of each kernel component
- Identification and evaluation of system parameters
- Use linear kernels if appropriate

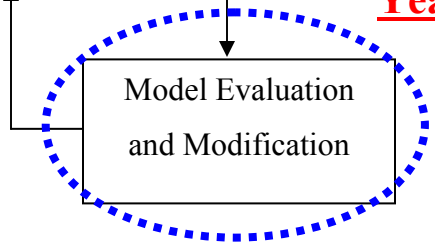


- Simplification and reduction
- Linearization and parameter minimization
- Analytical solution(s)
- Computer solution(s)



Year 3

- Evaluation of analysis
- Comparison with actual system
- Modification and iteration on steps as necessary



When the essential task of identifying and defining those input and output variables that will be employed for a given system model is completed, the system investigator or apprentice then must quantitatively formulate each kernel component for a given input and output. When the essential variables (inputs and outputs) have been identified for the given model, the next step is the quantification and formulation of the system kernel. The system investigator or apprentice, in formulating the system kernel, must seek to quantify each kernel component by determining those system variables and parameters that contribute to that system kernel component. Obviously, successful kernel formulation requires sound knowledge of the particular system and broad experience in system synthesis and analysis such as chemical separation process in UREX etc. Clearly, the integration of the AMUSE tool into the overall process is critical.

Table 1 provides a typical scheme for conducting a system study. The particular nature of each study phase and the efforts expended is, admittedly, system specific, but the study sequence is typical and will be used in developing a systems model for the chemical separations program.

A set of dashed ellipses in Table 1 indicates the stage of the project for year three. The work will continue to focus on defining the necessary data transfer between process models (mass balance of important constituents) and the definition of models or relationships for each of the process blocks. These process models may be individual software packages, or they may be simple assumptions relating to assumed mass balances. The model evaluation and modification will also be studied after the constraints are provided from ANL-East.

3. Research Objectives

The follow objectives remain the same from years one and two of the project. Meeting these objectives will lead to a concrete and useful systems engineering model.

- Develop a framework and environment for a systems engineering analysis of the chemical separations system for the TRP-UPP program with OOP approach.
- Establish a baseline systems engineering model from which modifications and improvements can be made.
- Refine the existing AMUSE program that gives a detailed examination of the UREX process, a critical component of the overall separation scheme.
- Include a database to handle data efficiently between AMUSE, VB and MATLAB.

4. Technical Impact

A comprehensive systems engineering model of TRP-UPP chemical separations processes can greatly facilitate the evaluation of overall systems options. This capability will be become increasingly important as it becomes necessary to down-select reactor types, fuel types, and multi-recycle modes. Systems analysis will make it possible to present decision-makers with concise evaluations of system options and their characteristic features.

In year three, as the level of sophistication of the systems engineering model is increased and the optimization constraints are provided, it will conceivably be possible to make relative

comparisons of process options with regard to waste generation, proliferation resistance, throughput capabilities, facility requirements, and cost. With confidence in the models, the decision-making process can be given greater objectivity and technical credibility.

5. Research Approach

The two proposed research activities have been broken down into several tasks. These tasks are outlined below.

Activity 1: System Engineering Model

1. *Refine Process Models Needs* – Work will continue during this 3rd year to refine the process models. At present, some of the models are very basic and need to be refined. Discussions will be held with ANL and other national laboratory personnel to clearly define appropriate process models. This will include the important task of defining the inputs/outputs from each model and how it is passed to the other process steps.

    - Specify input streams associated with typical spent fuel.
    - Determine all inputs and outputs for each process block.
    - Select key components to monitor throughout process.
    - Document key individuals or organizations for each process block.

2. *Refine All Unit Operations* – Each group of process blocks represents a set of operations. These operations need to be refined in order to realistically represent a "real" process, not just a theoretical process on paper. Communications between UNLV, ANL, and other researchers will be conducted to insure that the process is modeled as realistically as possible.
3. *Continued Testing of Development Environment* – Work will continue to streamline the development process within MATLAB. These activities will center on including optimization, incorporating detailed process models in a transparent manner to the user (FORTRAN, C++, VB, etc.), and the development of general process blocks.
4. Refinement of System Model – The overall system model is evolving as the TRP Project continues. UNLV will work to incorporate changes to the overall process as time advances.
5. *Demonstrate Modeling Concept* – Perform system analyses/simulations using the basic model that has been developed. Determine deficiencies and troubleshoot any possible errors that are found in the model.

Activity 2: Improvement/Automation/Modernization of AMUSE

1. *Review/Analyze Code Structure* – Each year this review activity is carried out to make sure we are still on tract and developing a useful product for the national laboratories. This work insures that all input data is properly stored within the existing AMUSE environment and that the output from AMUSE is easily accessed and analyzed.
2. *Define Year 3 Software Tasks* – Plans will be made in conjunction with Task 1 of Activity 2 to insure the necessary software is planned for that meets all of the program objectives.

3. *Verification Activities* – All changes to the code will be verified numerically. A set of test problems or other plan will be developed to demonstrate the numerical accuracy of the actual software changes. These results and test cases will be developed in conjunction with ANL researchers. This task will continue in year three because software verification is critical in insuring the new environment works properly.
4. *Modify/Improve Software* – Make changes to the software that allows it to be used as a part of the overall systems engineering model and that allows it to be used as a stand-alone process model. Determine what modifications would be necessary to allow the optimization of the process.
5. *Systems Analaysis* – Use the software to analyze a variety of proposed configurations (input from Argonne National Laboratory Collaborators).

Dr. Chen's efforts have centered on developing a framework and environment for a systems engineering analysis of the chemical separations system. He also establishes a baseline systems engineering model from which modifications and improvements can be made. Dr. Chen's and Dr. Clarksean's work have been crucial in developing Visual Basic interface and the use of the Excel spreadsheet that properly represents the AMUSE. They refine the existing AMUSE program that gives a detailed examination of the UREX process, a critical component of the overall separation scheme

In addition, Drs. Chen and Clarksean will develop and implement the measurement scheme for inputs and outputs, formulation of each kernel component, identification and evaluation of system parameters, use linear kernels if appropriate, simplification and reduction, linearization and parameter minimization, analytical solution(s), and computer solution(s) in phase III project.

6. Capabilities at UNLV and DOE Labs

Dr. Yitung Chen is Research Associate Professor of the Department of Mechanical Engineering and Interim Director of the Nevada Center for Advanced Computational Methods (NCACM) at the University of Nevada, Las Vegas, and would serve as Principal Investigator. He received his B.S. degree in Chemical Engineering in 1983, and his M.S. and Ph.D. degrees in Mechanical Engineering in 1988 and 1991, respectively, from the University of Utah. He also has a minor degree in Nuclear Engineering. He was a consultant for several engineering companies from 1991 to 1993. Dr. Chen is an expert in experimental and computational aspects of momentum, heat, and mass transfer. His research interests include chemical kinetics modeling, high level radioactive waste repository design, design and analysis for melt casting metallic fuel pins incorporating volatile actinides, niobium cavity design, atmospheric sciences, magnetohydrodynamics modeling, ground water transport, energy conservation, and biomedical engineering. He also has a strong background in organic chemistry, biochemistry, polymer chemistry, and physical chemistry. His research experience includes being PI and co-PI on many projects involving the study of flow and heat transfer and species transport in unsaturated porous media and fuel fabrication funded by DOE, the burning of rocket motors under the Joint Demilitarization Technology (JDT) program funded by DOD, and atmospheric modeling funded by the NOAA Cooperative Institute for Atmospheric Sciences and Terrestrial Applications. He was also co-PI on an EPA project dealing with environmental monitoring for public access and a groundwater modeling project funded by DOE.

Dr. Pepper is Interim Dean of College of Engineering at the University of Nevada, Las Vegas. Dr. Pepper would serve as Co-Principal Investigator. He has been actively involved in the generation, development, and use of hybrid, multi-dimensional algorithms for environmental transport and CFD applications for many years, and has developed atmospheric models for the NRC, NOAA, and DOE (OHER; NVOO). His previous work experiences at the Savannah River Site (E. I. Du Pont de Nemours), the Marquardt Company, and Advanced Projects Research, Inc., have resulted in numerous publications and presentations. Dr. Pepper organized and directed the first modeling workshop for the DOE-OHER on mesoscale atmospheric transport modeling. He served on a NRC project to assess consequences of natural phenomena on various reactor sites and fuel fabrication facilities located within the U.S., and has developed 3-D dispersion models for the NRC and DOD. Dr. Pepper is the co-author of three textbooks on the finite element method, co-editor of two books on environmental modeling, and directs the AIAA Home Study Courses and ASME short courses on finite elements. He is a Fellow of ASME and Associate Fellow of AIAA.

Dr. Randy Clarksean's experience in system modeling, programming, and system optimization provides him with an ideal background to guide the development of this comprehensive System Model. Dr. Clarksean would serve as Co-Principal Investigator. He has taught programming classes, performed system optimization studies, and is knowledgeable of the issues associated with spent fuel processing from his work at Argonne National Laboratory. Dr. Clarksean completed his Ph.D. at the University of Utah in 1990, with an emphasis on computational methods in the thermal and fluid sciences. In 1990, he started work for Argonne National Laboratory at their Idaho facilities. He worked on a number of different process and safety projects while with Argonne National Laboratory. Since 1995, Dr. Clarksean has worked on a number of projects independently. These projects have involved materials processing, spent nuclear fuel storage, system optimization, electronics cooling, phase change, and other general heat and mass transfer processing. Funding for these projects have come from the D.O.E., D.O.D., private industry, international research organizations, and the State of California. He is an expert in the analysis of engineering systems and has numerous publications in heat transfer and fluid mechanics.

Researchers in the Chemical Technology Division of Argonne National Laboratory have been involved in the development of chemical separations technologies for the nuclear industry since formation of the division in 1948. Argonne is leading the development of chemical processing technology for the Advanced Fuel Cycle Initiative (AFCI) program and, along with the Savannah River Technology Center and the Oak Ridge National Laboratory, is actively involved in the conception and experimental confirmation of advanced separations processes for a variety of spent fuel types. Two senior scientists with Argonne's Chemical Technology Division, Drs. Laidler and Vandegrift, will provide support to this project. Dr. Laidler is currently responsible for all U.S. work on the development of chemical separations technology for the AFCI program, and Dr. Vandegrift has over two decades of experience in the development of solvent extraction processes for chemical separations. Dr. Vandegrift is the developer of the GTM code that was recently renamed AMUSE.

7. Project Timeline with Milestones and Deliverables

The proposed schedule for all tasks and significant meetings is shown on the following page.

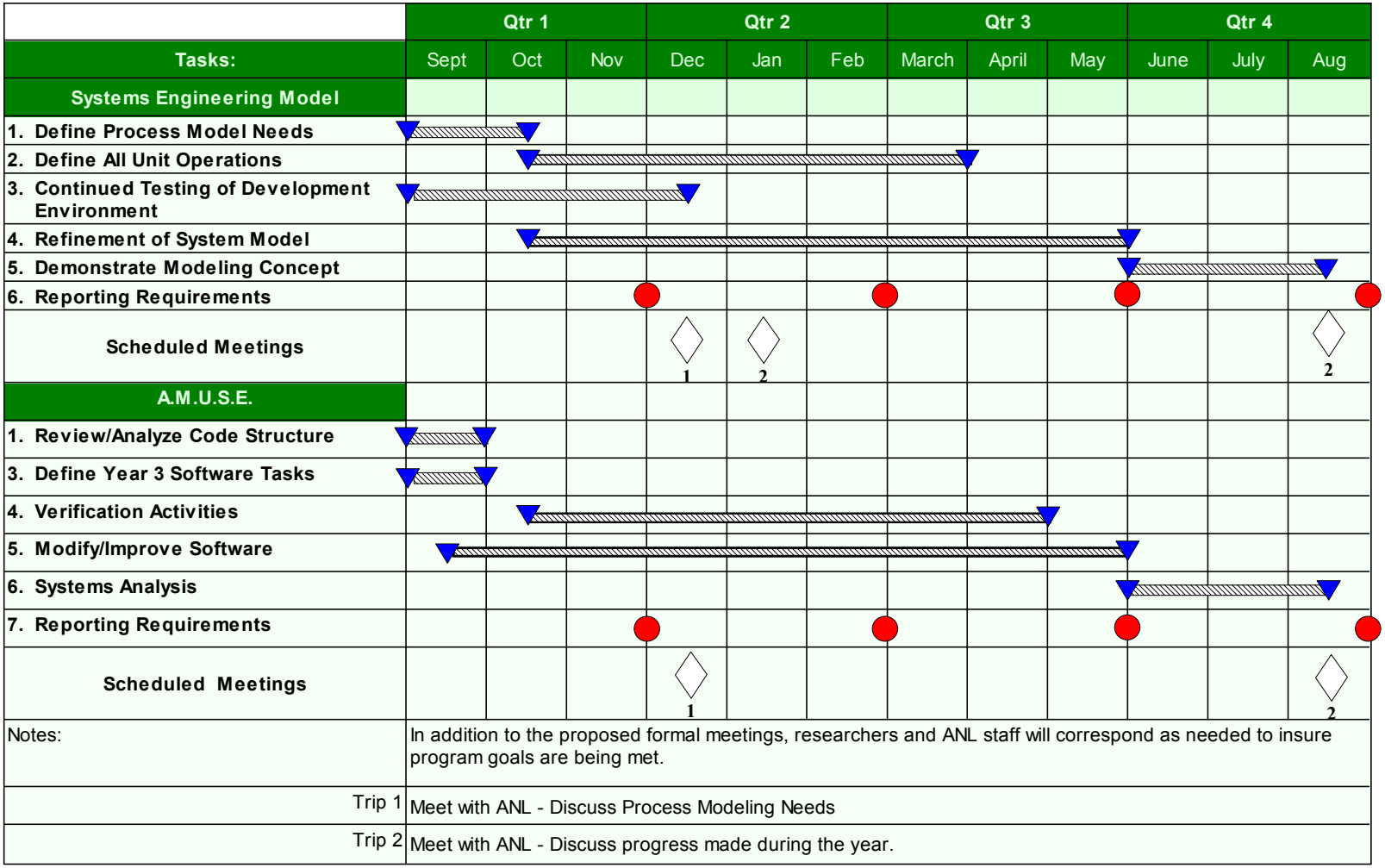


Figure 18 - Proposed Timeline for Research Tasks.

Work is assumed to commence on September 1, 2003. Additional travel may be necessary for interactions relating to other specific tasks.

ARGONNE NATIONAL LABORATORY
CHEMICAL ENGINEERING DIVISION BUILDING 205
9700 SOUTH CASS AVENUE, ARGONNE, ILLINOIS 60439-4837

TELEPHONE: 630-252-4513
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E-MAIL: VANDEGRIFT@CMT.ANL.GOV

May 16, 2003

Dr. Anthony Hechanova
Harry Reid Center
University of Nevada Las Vegas
4505 Maryland Parkway
Las Vegas, NV 89154

SUBJECT: Proposal Endorsement

Dear Dr. Hechanova:

This letter is being written to strongly endorse the proposal entitled "Development of a Systems Engineering Model of the Chemical Separations Process" submitted by Drs. Chen, Pepper, and Clarksean. I have read their proposal and feel that:

1. The proposal accurately describes the significant progress they have made.

2. The quality of the work described is of very high caliber.

3. They have been supportive of our programmatic requirements and suggestions.

4. The product of their proposed work will be extremely valuable to our efforts at Argonne National Laboratory and to the success of the Advanced Fuel Cycle Initiative (AFCI).

5. The proposed activities and schedule for the upcoming year are well thought out and will lead to success.

I am glad for the opportunity to express my appreciation for the efforts of the UNLV team involved with this program. It was clear from the beginning that their objective was to provide a useful, high-quality product to the AFCI, and I am still thrilled by the responsiveness we continue to receive. The AMUSE code will be a far more useful tool once we attach the graphical user interface (GUI), and the proposed systems engineering model will be useful for optimizing the entire processing scheme.

I heartily encourage the continuation of this work. We are counting on the products being developed.

Sincerely,

George F. Vandegrift, Head
Process Chemistry and Engineering Department
Chemical Engineering Division

GFV/vts