DESIGN AND LAYOUT CONCEPTS FOR
COMPACT, FACTORY-PRODUCED, TRANSPORTABLE,
GENERATION IV REACTOR SYSTEMS

December 15, 2002

Professor Fred R. Mynatt

QUARTERLY REPORT

FOR PERIOD AUGUST 15, 2002 TO NOVEMBER 15, 2002

APPLICABLE FIELDS OF RESEARCH

Generation IV Nuclear Power Systems,
Improved Proliferation Resistance of Reactor Systems and Fuel Cycles

Submitted by

University of Tennessee
Nuclear Engineering Department
Industrial Engineering Department
And
Massachusetts Institute of Technology
Nuclear Engineering Department

In collaboration with

Northrop Grumman Newport News
Westinghouse Electric Company
Oak Ridge National Laboratory
Design & Layout Concepts for Compact, Factory-Produced, Transportable, Generation IV Reactor Systems

Status Summary of NERI Tasks – Phases 1-3:

**Phase 1:**

<table>
<thead>
<tr>
<th>Milestone/Task Description</th>
<th>Org.</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Evaluate designs and requirements for IRIS and other LWRs</td>
<td>UT</td>
<td>Feb 15, 2001</td>
</tr>
<tr>
<td>1.2 Evaluate designs and requirements for modular Pb-Bi LMRs</td>
<td>UT</td>
<td>Feb 15, 2001</td>
</tr>
<tr>
<td>1.3 Evaluate designs and requirements for modular HTGRs</td>
<td>MIT</td>
<td>Feb 15, 2001</td>
</tr>
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**Phase 2:**

<table>
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<tr>
<th>Milestone/Task Description</th>
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<tbody>
<tr>
<td>2.1 Develop designs and layout concepts for IRIS</td>
<td>UT</td>
<td>Oct 15, 2001</td>
</tr>
<tr>
<td>2.2 Develop designs and layout concepts for modular Pb-Bi LMR</td>
<td>UT</td>
<td>Oct 15, 2001</td>
</tr>
<tr>
<td>2.3 Develop designs and layout concepts for modular HTGR</td>
<td>MIT</td>
<td>Oct 15, 2001</td>
</tr>
<tr>
<td>2.4 Review IRIS design and layout concepts with industry</td>
<td>UT/Westinghouse/NNS</td>
<td>Feb 15, 2002</td>
</tr>
<tr>
<td>2.5 Review modular Pb-Bi LMR design and layout concepts with industry</td>
<td>UT/IPPE/NNS</td>
<td>Feb 15, 2002</td>
</tr>
<tr>
<td>2.6 Review modular HTGR design and layout concepts with industry</td>
<td>MIT/ORN/L/NNS</td>
<td>Feb 15, 2002</td>
</tr>
<tr>
<td>2.7 Complete IRIS design and layout concepts</td>
<td>UT</td>
<td>Aug 15, 2002</td>
</tr>
<tr>
<td>2.8 Complete modular Pb-Bi LMR design and layout concepts</td>
<td>UT</td>
<td>Aug 15, 2002</td>
</tr>
<tr>
<td>2.9 Complete modular HTGR design and layout concepts</td>
<td>MIT</td>
<td>Aug 15, 2002</td>
</tr>
</tbody>
</table>

* Westinghouse review not performed
** IPPE review not performed
Phase 3:

<table>
<thead>
<tr>
<th>Milestone/Task Description</th>
<th>Org.</th>
<th>Completion Date</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td>Planned/Actual</td>
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<tr>
<td>3.1 Complete preliminary factory simulations</td>
<td>UT</td>
<td>Feb 15, 2003</td>
</tr>
<tr>
<td>3.2 Review of factory simulations</td>
<td>NNS</td>
<td>Apr 15, 2003</td>
</tr>
<tr>
<td>3.3 Final project report</td>
<td>UT</td>
<td>Aug 15, 2003</td>
</tr>
</tbody>
</table>

Narrative:

The objectives of this project are to develop and evaluate nuclear power plant designs and layout concepts to maximize the benefits of compact modular Generation IV reactor concepts including factory fabrication and packaging for optimal transportation and siting. The project will utilize and build upon the work of others including both previous work and early Generation IV work. This project utilizes the results of a previously funded NERI project to develop standards and guidelines for cost effective layout and modularization of nuclear power plants.

This interdisciplinary project is comprised of three university-led nuclear engineering teams identified by reactor coolant type (water, gas, and liquid metal). The University of Tennessee (UT) leads the teams for two types (water and liquid metal) and the Massachusetts of Technology (MIT) leads the team for the gas cooled type. The industry and laboratory participants are Westinghouse Science and Technology for the LWR team and Oak Ridge National Laboratory for the HTGR team. Northrop Grumman Newport News (formerly Newport News Shipbuilding) will participate with all three teams. A fourth UT-led industrial engineering team will address computer simulation and optimization of the factory fabrication processes for the three reactor concepts. Each team consists of a Professor (ten percent time) and a graduate student (half time) who will perform most of the effort with review and consultation by industry and laboratory partners. This interdisciplinary arrangement maximizes the opportunity to satisfy DOE objectives for advancing state-of-the-art nuclear technology while at the same time strengthening nuclear science and engineering infrastructure in the U.S.

In the first two years of the project, the three reactor concept teams each developed a compact power plant design and layout concept. The teams obtained and analyzed relevant reactor concepts, utilized layout standards and guidelines currently being developed, and captured relevant industry experience to produce power plant design and
layout concepts which can be produced primarily in a factory environment. The national laboratory and industry participants reviewed these concepts and provided advice, feedback, and critical input, which were used to improve and finalize the design and layout concepts. The Industrial Engineering (IE) professor (UT) also reviewed the design and layout concepts, and provided feedback as needed to the three NE design teams during the first two years.

**Overall project status:**

This project was funded as a grant to the University of Tennessee and subgrant to the Massachusetts Institute of Technology with a starting date of August 15, 2000. Following the grant processing and assignment of students, work began on the first tasks, acquisition and reviews of available designs and requirements for each reactor type. The first phase has been completed. Work on computer modeling of the reactor systems and plant layout concepts began around February 15, 2001 and was completed on October 15, 2001. The review of the modular HTGR (modular PBR) by ORNL has been completed.

The reviews of all three reactor types by NNS were completed on August 1, 2002. The review of the IRIS concept by Westinghouse has not been completed. All of these entities were encouraged to complete their efforts so that the overall Phase 2 effort could be completed by August 15, 2002. The development of concepts by UT and MIT were completed by August 15, 2002. With DOE approval the subcontract with Westinghouse was extended into this fiscal year and they are working on optimization of the balance of plant (BOP) and related systems and structures.

Work on the third phase is in progress. A detailed simulation of the fabrication of our reactor concepts is impossible. The fabrication process data do not exist and, if the data existed, a simulation would require a level of effort many times larger than our study. In order to study the fabrication issues of our modular reactor concepts we are taking two approaches. The first is to perform a detailed fabrication process simulation of a ubiquitous reactor component, a heat exchanger. This component is representative of steam generators, heat exchangers and condensers. The study of the fabrication process will address component size and the effects of quantity of production. This will address some issues of mass production of modular reactors compared with construction of large plants. The second approach is to address the question, “Does modularity work?” This effort will look at the logical issues of modularization and suggest ideas for more cost effective plant fabrication and construction.
Task 1.1 Evaluate designs and requirements for IRIS and other LWRs
Task 1.2 Evaluate designs and requirements for modular Pb-Bi LMRs
Task 1.3 Evaluate designs and requirements for modular HTGRs

1. Task Status. These tasks are complete.
2. Issues/Concerns. None

Task 2.1 Develop designs and layout concepts for IRIS
Task 2.2 Develop designs and layout concepts for the modular Pb-Bi LMR
Task 2.3 Develop designs and layout concepts for modular HTGR

1. Task Status. These tasks are complete. The teams worked in a coordinated and cooperative fashion. There are, however, differences. The HTGR effort is part of a larger program at MIT and benefits from the companion efforts. The IRIS effort is also part of a larger program led by Westinghouse and having several partners. The Pb-Bi LMR effort is more independent but has benefited from the UT NE design class which chose to work on this concept. The degree of evolution of all three concepts was substantial.
2. Issues/Concerns. None

Task 2.4 Review IRIS design and layout concepts with industry
Task 2.5 Review modular Pb-Bi LMR design and layout concepts with industry
Task 2.6 Review modular HTGR (MPBR) design and layout concepts with industry

1. Task Status. The starts of these tasks were delayed due to a three month delay by UT administrative offices in processing subcontracts for Westinghouse and Newport News Shipbuilding. ORNL completed their review of the MHTGR by April, 2002. NNS completed their review of all three reactor types by August 1, 2002. The LWR review by Westinghouse has been delayed by Westinghouse. Our effort has benefited from interaction with the Westinghouse IRIS project team and this has provided substantial input. The IPPE review of the Pb-Bi concept (funded from UT funds) has not been done due to contractual difficulties between UT and IPPE.
2. Issues/Concerns. The lack of timely reviews by Westinghouse and IPPE is unfortunate but did not delay the overall tasks. UT has requested a no-cost extension for the Westinghouse review and this has been approved by DOE. The subcontract has been extended. The contractual difficulties between UT and IPPE are still unresolved.

Task 2.7 Complete IRIS design and layout concepts
Task 2.8 Complete modular Pb-Bi LMR design and layout concepts
Task 2.9 Complete modular HTGR design and layout concepts

1. Task Status. These tasks are complete.

Task 3.1 Complete preliminary factory simulations

1. Task Status. This task was started on August 15, 2002.
2. Issues/Concerns. A full detailed simulation cannot be performed. As described above a detailed simulation of a representative component (heat...
exchangers) is being performed. The results will be used to address mass production compared with large-scale plants.

**Task 3.2 Review of factory simulations**

1. **Task Status.** This task has not yet started.
2. **Issues/Concerns.**

**Task 3.3 Final project report**

3. **Task Status.** This task has not yet started.
4. **Issues/Concerns.**

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**Computer Simulation and Optimization of Factory Fabrication**

Jacob Fife  
Professor Rupy Sawhney

The following report pertains to the status of the Industrial Engineering efforts as of the end of the first quarter, which ended November 15, 2002. The goal of this portion of the project is to provide costing information on the mass production of heat exchangers through the use of simulation modeling.

A. Accomplishments

We have been able to define the components, processes, and much of the standard time needed in order to simulate the manufacturing of the heat exchangers described in “Conceptual Design and Layout of the Balance of Plant for a Generation IV Nuclear Power Plant Using the Westinghouse International Reactor, Innovative & Secure (IRIS)”. These heat exchangers vary in diameter and length, but are similar in design thus needing the same processes for manufacturing.

**Job Shop vs. Flow Shop**

Stan Kitchens of Steeltex, Inc, a heat exchanger company in Tulsa, Oklahoma, provided many details into the processes needed. Currently, Steeltex and most other heat exchanger companies operate as a Job Shop type production facility. In a Job Shop similar processes are grouped together (i.e. Weld Shop, Machine Shop, and Assembly Area). Job Shops are typically used in facilities creating a high variety of products as do most heat exchanger manufacturers. This production paradigm is not made for the effective flow in mass production. Part of the goal of this project is to use the information gathered on current production layouts to generate a Batch production line,
which will be more suited for the higher volume of products. Below is a figure showing how moving down the diagonal of production systems reduces the unit cost of a product.

<table>
<thead>
<tr>
<th>Low Volume, One of a Kind</th>
<th>Multiple Products, Low Volume</th>
<th>Few Major Products, Higher Volume</th>
<th>High Volume, High Standardization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Job Shop</strong></td>
<td>Commercial Printer French Restaurant</td>
<td>Heavy Equipment Coffee Shop</td>
<td>Flexibility (High) Unit Cost (High)</td>
</tr>
<tr>
<td><strong>II. Batch</strong></td>
<td></td>
<td>Automobile Assembly Burger King</td>
<td></td>
</tr>
<tr>
<td><strong>III. Assembly Line</strong></td>
<td></td>
<td>Sugar Refinery</td>
<td></td>
</tr>
<tr>
<td><strong>IV. Continuous Flow</strong></td>
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</tbody>
</table>

**Standard Time**

We have also been able to gather standard time data associated with two out of the three major phases of the manufacturing. The manufacturing of a heat exchanger is made of three components. This includes machining, welding, and assembly. The machining is made up of drilling, milling, turning, tapping, etc. These standard times are published for different grades of steel. Welding standard times are published and available as well.

**Simulation Modeling**

The simulation modeling of the manufacturing facility is being done with the software ARENA version 3.0. Currently, we have only been able to simulate a small portion of the facility. The goal of the second quarter is to finish the simulation while adding costing information into the computer model.

**B. Problems Encountered**

The only real problems have been the lack of standard time data associated with the different assemblies within the manufacturing facility. Most of this data is not published so we must heavily rely upon information provided by different companies.
C. Planned Activity

The goal of the second quarter is to finish the simulation model as stated above and begin inputting economic information into the model. We will attempt to verify the current state simulation with any companies that would review our model. Then, we will attempt to generate a Flow Shop design rather than the Job Shop. This will help in optimizing the facility based on a determined demand. Since the plant design is 300 MWe and many plants today are 1000 MWe, this means that we must produce multiple smaller plants in order to meet the output of the larger ones. This creates a higher demand for the smaller plants thus we will analyze this economies of scale issue and see how mass production impacts the cost.

LWR (IRIS) Concept

Martin Williamson
Professor Larry Townsend

The Tennessee Valley Authority has funded UT to do a parametric study of LWR Balance of Plant concepts using as a point of departure the IRIS BOP previously developed under this grant. Work has been performed under UT funds to correct errors found in the condenser design. The continuing work funded by TVA will help in the optimization of the IRIS BOP.

Under their subcontract Westinghouse will do the following:

* Review, comment, and finalize the turbine-generator-condenser-heater-steam/feedwater equipment in a barge-mounted BOP layout that includes consideration of equipment repair, pull-spaces, and replacement.

* Extend the above layout concept to include additional steam/feed equipment, including: the condenser circulating water intake and discharge, main circulating water pumps, component cooling water system (with interface to the reactor barge), steam bypass valves and piping, a full-flow feed water polishing system, the feed water storage tank, the generator hydrogen cooling system, auxiliary boiler, HVAC equipment, and all the associated
motor control and instrumentation cabinets.

* Provide at least a conceptual plan for integrating the BOP with other plant modules: (e.g., the reactor building, a control and electrical building that contains the main control room and all the I&C; a power input/output area that contains all the transformers and switchyard equipment, and the non-safety diesel generators; a heat rejection system that could contain all the cooling towers, circulating water pumps, water treatment equipment.

* Interface with Newport News to get their input on the above, as they are able.

Due to the limits on manpower and funds some of these efforts may be conceptual rather than a final design - but it would be beneficial to at least keep an overall plant concept in mind.