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Design and Evaluation of Processes for Fuel Fabrication

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Task 9

Design and Evaluation of Processes for Fuel Fabrication

G. Mauer

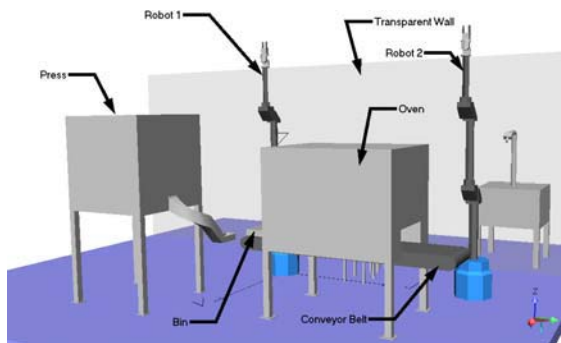
BACKGROUND

The safe and effective manufacturing of actinide-bearing fuels for any transmutation strategy requires that the entire manufacturing process be contained within a shielded hot cell environment. To ensure that the fabrication process is feasible, the entire process must be designed for remote operation. The equipment must be reliable enough to perform over several decades, and also easy to maintain or repair remotely. The facility must also be designed to facilitate its own decontamination and decommissioning. In addition to these design factors, the potential viability of any fuel fabrication process will also be impacted by a number of variables, such as the current state of technology, potential problem areas, deployment scaling, facility safety, and cost.

RESEARCH OBJECTIVES AND METHODS

The goal of this research project is to provide technical support to process designers working on the development of the fuel cycles for transmutation applications. Detailed process models are developed to better define the impact of fuel choice on the transmuter fuel cycle, including relative process losses, waste generation, and plant capital cost. These process models provide insight regarding required plant size and number of plants needed to mesh with the fuel recycling line. They also determine requirements for automation.

Manufacturing models for large-scale production in a hot cell environment are also developed. Combined, these two models allow the assessment of plant layout, and provide the framework for estimation of plant capital and operating cost estimates, and for feasibility in general. The need for development in the areas of robotic and sensor technology is assessed. The manufacturing technology developed for hot cell applications is also applicable to other, more general uses, where occupational hazards prevent human presence near processes.



Simulation Model of Hot Cell Manufacturing Plant for Oxide Fuels

The research work was divided into several tasks and subtasks:

Methods and Processes – A literature survey and detailed analysis of the research and development pertaining to candidate processes for transmuter fuel manufacture continued. Industry standards were used to refine equipment, instrumentation, and control specifications, and assessed the reliability and safety of operations.

Simulations – This task modeled manufacturing processes to generate a realistic assessment of plant layout, size, feasibility, and technology development required for large-scale remote fabrication of fuel. Modeling of the candidate fuel manufacturing processes was initiated using the MSC.visualNastran and ProEngineer simulation software tools. The modeling of powder-processed fuels has been completed, and the modeling of other fuel types (metallic, TRISO etc.) is in progress.

Process and Equipment for Autonomous Manufacturing – This task developed an understanding of the cost and capability of current generation remotely operated equipment suitable for use in radiation environments. Monitoring of the market for equipment and components with regard to suitability for automated manufacturing under hot cell conditions continued.

Sensors, Controls, and Operational Safety – This task determined the adequacy of current technology and the need for suitable sensor technology development for deployment in hard radiation environments. A means to identify the precise location and spatial orientation of all parts in the robot's work envelope were implemented. The ability to position and handle materials along with trouble shooting techniques were evaluated. Radiation hardened vision systems appear to be promising technologies.

Cost, Feasibility, and Large Scale Deployment – This task developed the database necessary to provide cost estimates and differential cost for various fuel manufacturing options. Efforts began to tabulate and quantify estimates regarding projected cost, reliability, and plant life.

RESEARCH ACCOMPLISHMENTS

A simulation model with a Waelischmiller hot cell robot was developed and coupled with MatLab control software. Matlab provides the interface with the robot and is used to control the system. This renders a realistic simulation of the forces and torques present during robot motion. A 3-D manufacturing process simulation using CAD models and the Newtonian dynamics of the moving components has been developed.

Results exist in the form of movies, data sets, and images. Simulations for several robot types were developed and their proper kinematic configuration was verified. The simulations permit the detailed analysis of forces and torques in any modeled part or component.

While the simulation process generally worked flawlessly, the simulation time rose considerably as more details were added to the simulation. The speed of the simulation has been increased about 100-fold by moving to fast dual-processor computers.

Efforts to develop a vision-based methodology for locating and identifying objects within the robot's workspace have found a preliminary completion with the successful Ph.D. thesis defense of Mr. Jae-Hyu Lee, who was awarded a Ph.D. degree in December 2003. The Artificial Intelligence (AI) algorithm for object identification is presently being expanded by visiting scholar Caroline Wijek from the *Ecole Supérieure d'Ingénieurs en Electronique et Electrotechnique*, 93162 Noisy-le-Grand, France.

Another accomplishment involved the development of algorithms for knowledge based pattern recognition using IF (a set of conditions is satisfied) THEN (a set of consequences can be executed) routines. Other simulation variables established included pattern matching using clustered indexing vectors containing information about an object and feature vector indexing, where a 3-D object is segmented into a set of simple geometric features. Each feature is stored with its vector segmentation and geometry information (magnitude, inner angle, etc.).

FUTURE WORK

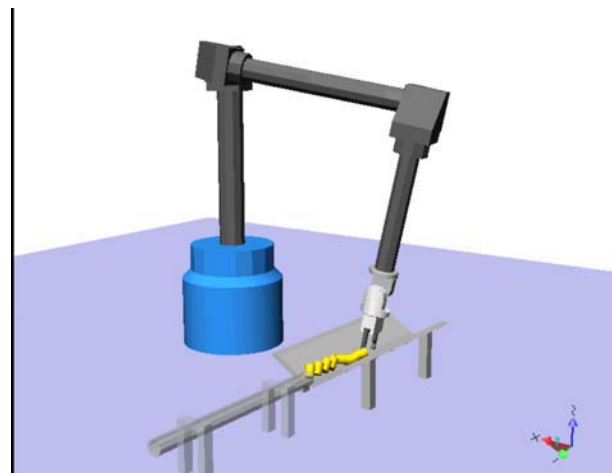
Further efforts will be devoted to increasing data and knowledge regarding the cost and feasibility of automated fuel manufacture in a hot cell by analyzing several additional manufacturing processes. Artificial intelligence concepts will be further developed with respect to object identification and hot cell dynamics simulations. Multiple robots have been placed into the hot cell and controlled simultaneously by a supervisory program. The placement of these robots is being evaluated with regard to optimizing their capability for redundancy in the event of equipment failures or maintenance.

The simulation environment will enable designers to create a virtual mock-up environment in which possible scenarios can be executed and analyzed at any desired level of detail. Normal operations and failure scenarios will be investigated, analyzed, and simulated.

HIGHLIGHTS

- ◆ Dr. Mauer visited CEA Cadarache and CEA Marcoule in France, the institute for transuranics in Karlsruhe, and the Framatome Manufacturing Plant in Lingen, Germany, during the summer of 2003.
- ◆ "Design and Analysis of Robotic Manufacturing Processes," Proceedings, American Nuclear Society Winter Annual Meeting, November 2003.
- ◆ Jae-Kyu Lee completed his Ph.D. in Mechanical Engineering (December 2003), thesis entitled "Three Dimensional Pattern Recognition using Feature-based Indexing and Rule-based Search."
- ◆ "Virtual Testing of Robotic Assembly Processes for Hot Cells," presented at the 10th International Conference on Robotics & Remote Systems for Hazardous Environments, March 2004.
- ◆ "Remote Transmuter Fuel Fabrication" presented at the ANS Student Conference, Madison, WI, April 1-4, 2004. Jamil Renno received a Best Presentation Award.

The results of the simulations will be used by APCI program personnel to perform sensitivity studies on the impact of different fuel types on transmutation system operation. Conceptual designs of the fuel fabrication processes will allow evaluations of issues related to maintainability, robust design, and throughput rate, and lead to identification of areas where improvements in technology are required to meet the goals of the transmutation system.



Oxide Fuel Manufacturing Accident Simulation: Analysis of Fuel Pin Loading Problems.

Research Staff

Georg Mauer, Principal Investigator, Professor, Mechanical Engineering Department

Students

Jae-Kyu Lee, Richard Silva and Jamil Renno, Graduate Students, Mechanical Engineering Department

Collaborators

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