

## Task 22

# Design Concepts and Process Analysis for Transmuter Fuel Manufacturing

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## 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 have been 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 have also been 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 operations of robotic equipment and the sensor technology required for safe and reliable robot control have been evaluated through simulations in three-dimensional space. The manufacturing technology developed for hot cell applications is also applicable to other, more general uses, where occupational hazards prevent human presence near processes.

The research work performed was divided into several tasks:

### 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 performed using the MSC.visualNastran and ProEngineer simulation software tools. To date, the modeling of dispersion and TRISO fuels has been completed. A parametric study to determine the process reliability and possible reliability improvements for various fuel types and equipment configurations is in progress.

### Cost, Feasibility, and Large Scale Deployment

This task is to develop the database necessary to provide cost estimates and differential cost for various fuel manufacturing options. Cost estimates regarding projected capital cost, reliability, and plant life have been developed and are being refined as additional knowledge is developed.

### Automated Vision-Based Image Acquisition and Robot Control

This task explores and demonstrates strategies for the reliable and flexible control of the material handling robots inside the hot cell by means of automated vision systems. Since the cameras can be positioned outside the hot cell, such systems would have significant advantages over sensors inside the hot cell, resulting in potentially reduced system maintenance and increased system reliability.

## RESEARCH ACCOMPLISHMENTS

A fabrication process simulation model with several Waelischmiller robots in a hot cell was developed and coupled with MatLab control software. Matlab provides the interface with the robot and is used to control the system. The simulation 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.

The simulations are numerically extensive, and a single simulation can require hours to complete, depending on the complexity of the model. The speed of the simulation has been increased substantially through continuous equipment upgrades, which were essential in enabling more detailed model refinements without undue elongation of simulation run times.

### Analysis of Fabrication Plant Reliability

Given the large quantities of transuranic waste to be transmuted, an automated manufacturing process will likely be required for transmuter fuel fabrication. An analysis and simulation of various design configurations is conducted on a robotic powder-process manufacturing hot cell which had been designed and analyzed previously. Work cell layouts with redundant robots, and reliability analyses of the resulting alternative layouts directly effect production operations and costs by reducing plant down times, compared to a hot cell manufacturing plant without redundancy. Methods for the assessment of plant reliability and optimization strategies for optimizing the work cell layout with redundant robots were investigated. An analysis of different plant configurations as well as quantitative decision criterion for plant selection by means of a cost function that considers both plant reliability and capital cost were conducted. The performance of various selected layouts was simulated in order to

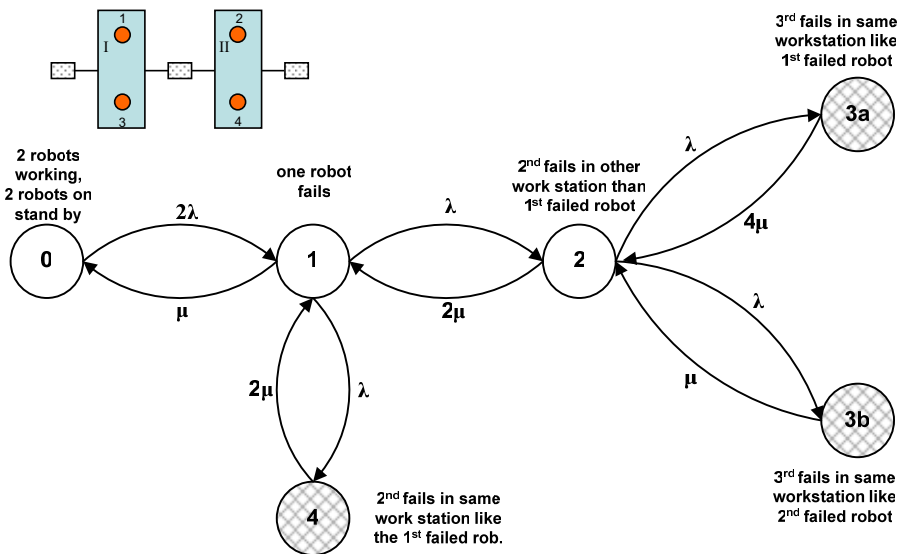
verify the overall plant performance and to study conceivable accident scenarios.

Randomly occurring robot failures and their subsequent repairs are modeled as Markov processes. This is a system with two possible states, operating or failing, and system availability and reliability can be calculated.

### Plant Layout Options

Both powder and metallic processing methods of transmuter fuel manufacturing will likely require two robots for material handling inside the work cell. Redundancy is introduced by adding one or more robots. When adding one robot, it must be configured to assume two distinct alternate base positions, so that it can assume the functions of the failed device.

In a four robot configuration, two robots are placed on standby. The redundant robot takes over for the failed robot in the case of one failing robot at any one location. If the replacement robot fails at the same work station as the first failure (before completion of repair the first failed) the entire system fails. Assuming that the robots do not fail while on standby, the availability and resulting reliabilities of the four robot work cell over a time period can be calculated.



Markov Model of Hot Cell Layout with two redundant robots.

## ACADEMIC YEAR HIGHLIGHTS

- ◆ G.F. Mauer and J. Renno, "Reliability Analysis of a Robotic Workcell for Transmuter Fuel Fabrication," *Proc. American Nuclear Society Winter Annual Meeting*, November, 2005.
- ◆ Student Andreas Roderburg, visiting from RWTH Aachen, completed and defended his Diploma thesis in Mechanical Engineering (January 2006). Thesis title: "Design Optimization Of Robotic Manufacturing Work Cell For Transmuter Fuel – Analysis And Simulation Of Robotic Manufacturing In A Hot Cell Environment."

### Cost Function

The plant's availability is a function of each robot's failure rate and its repair rate. The annually hot cell costs result from the sum of annual investment costs and operating costs. By computing the net throughput of the production system and its capital cost, the unit costs (e.g. cost per fuel pin) can be determined by a corresponding cost function. The cost model was implemented as an interactive simulation in Matlab Simulink that permits the evaluation of multiple alternative scenarios.

### Automated Vision-Based Image Acquisition and Robot Control

A remote-controlled surveillance camera (Sony EVI-D30) is operated from a computer. Image acquisition is performed by a frame grabber in the computer. The camera functions (pan, tilt, zoom, and focus) are controlled through a serial connection between camera and PC. The frame grabber transmits the image to Matlab for processing.

Object recognition is performed by identifying the object's contour, and by then matching the detected contour to those of known objects.

## 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 candidate manufacturing processes. Artificial intelligence concepts will be developed further with respect to reliable vision-based object identification and hot cell dynamics simulations.

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