

**Project Title:**

**Design and Evaluation of Processes for Fuel Fabrication**

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**First Year Request:** \$86,533 (out years comparable)

**Technical Focus Area:** Fuels

**Note:** Dr. Yue Guan of ASTM, Inc will be funded directly by ANL.

## Design and Evaluation of Processes for Fuel Fabrication

### Abstract

The objective of this project is the design and evaluation of manufacturing processes for transmuter fuel fabrication. A detailed design description for the manufacturing of each candidate fuel type would support the informed selection of fuel for a transmutation system. We will collect pertinent manufacturing and process-related information and create an information database that will document the design, operations, and cost implications of various fuel choices. Fabrication processes for different fuel types will likely differ in terms of equipment types, throughput, and cost. The project will be conducted in close cooperation with the fabrication development group at Argonne National Lab (ANL) and with Dr. Yue Guan of ASTM, Inc., who will consult with ANL on the modeling of transuranic material handling systems. Year 1 of the project will be devoted to the analysis and assessment of the multiple steps required in the manufacture of different fuel types. This research will accomplish two tasks: First, comprehensive process definitions and requirements will be developed that will aid in the identification of issues, costs, impacts of the impact of fuel type choice on the fuel manufacturing process and the transmuter fuel cycle as a whole. Secondly, preliminary requirements for large-scale fuel production in a remote environment for a network of transmutation systems will be defined. The results of this study will be documented in detail.

Following Year 1, the manufacturing processes would be simulated as operations supervised by remote operators. Both normal operations as well as failure scenarios would be investigated, analyzed, and simulated. The simulation results would assist AAA program personnel in performing sensitivity studies on the impact of different fuel types on AAA system operation, and in the estimation of transmutation system capital cost, economics of operation, process loss, and environmental and safety issues.

### Funding Profile:

Academic Year:	2001-2002	2002-2003	2003-2004
Total (K\$)	85	86*	87*

\* Projection does not include lab equipment that might be identified during Year 1.

### 1. Work Proposed for Academic Year 2000-2001, Goals, and Expected Results:

During Year 1, we will perform the following:

- Survey of candidate transmutation fuels
- Detailed evaluation of the identified proposed fuel manufacturing processes following criteria established by the AAA Fuel Development Program.
- Conceptual computer modeling of one manufacturing process.
- Identification of areas where automated processes are crucial to maintain the required throughput rates.

- Cost estimates.
- Documentation of study results and recommendations for large-scale fuel fabrication.

## **2. Background**

The development of fuels for higher actinide transmutation systems presents many technical challenges. Fuel must behave in a benign manner during core off-normal events, maintain integrity to high burnup, lend itself to low-loss recycling processes, and be easily fabricated in a remote environment. A transmutation system cannot function effectively without a fuel that meets these criteria. This proposal concentrates on identifying and resolving issues in fuel fabrication, an important issue in the transmuter fuel cycle.

Little data is currently available on which to base selection of a fuel type for an accelerator-driven transmutation system, and several general fuel types are under consideration. In this project we will consider the fuel types and manufacturing processes under consideration within the DOE national program. The candidate processes outlined below (ceramic fuels, metallic fuels, and dispersion fuels), presently under consideration by the manufacturing group at ANL West, may serve to illustrate the distinctions among manufacturing processes. Each fuel type requires the development of a distinct remote fabrication process. The basic process steps underlying fabrication of each of the 3 broad categories of fuel types are outlined below.

### **(a) Manufacturing Sequence for Dispersion Fuels:**

1. Manufacture spherical fuel particles by wet chemical process or direct reaction and attrition
2. Coat the particles (process not yet determined, but Nb is a candidate coating material)
3. Mix fuel particles with matrix metal
4. Press fuel and matrix blend into a cylindrical compact
5. Assemble billet
6. Extrude billet at ~800 C. The resulting rods would be approximately 2 m long and will have a diameter of approx. 6.5 mm
7. Finishing of fuel rods by trimming ends
8. Inspection of rods (radiography, dimensional, bonding, and clad defects)

### **(b) Manufacturing Sequence for Ceramic Fuels:**

1. Manufacture particles by wet chemical process or direct reaction (1 to 30 um dia.)
2. Compaction of particles into pellet form. Optional: Debinding
3. Sinter the pellets resulting from Step 2 at 1400 –1800 C
4. Inspection of pellets
5. Assemble pellets into cladding tube
6. Add bonding material (He or Na)
7. Seal weld cladding tube
8. Inspect assembled fuel pin (radiography, dimensional and clad defects)

### (c) Manufacturing Sequence for Metallic Fuels:

1. Cast fuel slugs. Pins are 4 to 5mm dia. and 0.8 m to 1.5 m long
2. Insert fuel slugs into cladding tube
3. Add bond phase (Na) in cladding tube
4. Seal cladding tube by welding end fitting onto the tube
5. Inspect fuel pin (radiography, dimensional, and clad defects)

Each of these manufacturing processes have differences in complexity, throughput rate, capital cost, process loss, maintainability, environmental impact, and secondary waste generation. The impacts of these different fabrication processes on the transmuter fuel cycle are not well known. A detailed design of each of these or any other remote processes will enable a more informed selection of fuel candidates for the AAA system. Design and modeling of industrial scale fabrication lines will identify factors that may disqualify a fuel on the basis of the factors listed above, and should be done early in the process of transmuter system definition.

### 3. Research Approach

**General Requirements:** The entire manufacturing process for any fuel type must take place in a shielded hot cell environment, with operators/supervisors observing and intervening only through remote interaction with any part of the process. The scale of the required fabrication line is very large, and overall throughput rates are high for a remote operation. Equipment will be required to perform over a time scale of forty to sixty years, and the processes must allow the use of robust equipment that is readily maintainable. Attention must also be given to decommissioning during the design phase.

**Concepts and Definitions:** conceptual fuel fabrication processes for the fuel types will be developed in conjunction with ANL. Submodels may be developed to differentiate between process steps required for oxides and nitrides. Conceptual designs of the fuel fabrication processes will take issues of maintainability, robust design, and throughput rate into account, and lead to identification of areas where improvements in technology are required to meet the goals of the transmutation system. The models will allow ANL AAA personnel and consultants to determine the sensitivity of the processes to changes in fuel isotopic feed and mass throughput rates for the different system scenarios (dual strata vs. single strata) now under consideration. Secondly, areas will be identified where advances in remote manufacturing technology are required in order for transmuter fuel fabrication to proceed at a throughput rate commensurate with AAA program needs.

Dr. Yue Guan of ASTM, Inc. will consult with ANL on the modeling of transuranic material handling systems. Her work will be funded directly by DOE, and will not require support from the AAA project at UNLV.

**Fuels Survey and Process Analysis:** In close cooperation with ANL, a survey of candidate fuels and detailed analyses of the candidate processes will be conducted. Preliminary equipment,

instrumentation, and control requirements will be defined, and the reliability and safety of operations using industry standards will be assessed. This will be the major focus of the project during the first year.

**Process Simulation and Simulation Software R&D:** Process simulation software will be used to model one fuel manufacturing process towards the end of Year 1. Realistic simulations permit the prediction, analysis and elimination of potential problems such as collisions and unreachable locations before the actual execution of a programmed sequence. An accurate process simulation will aid in sizing fuel manufacturing hot cells, and help to model process losses. The often time-consuming task of developing a solid 3-D sequential process model is greatly reduced by employing software tools that automate many tasks, such as the generation of the process kinematics and control algorithms, and the creation of a graphical user interface for the simulation of equipment and materials motion. Towards the end of Year 1, we will begin preparing 3-D models of equipment and parts at appropriate levels of detail using customary software, such as ProEngineer™ or Solidworks™. The solid models will be embedded in the 3-D dynamic process model. Geometric data from the CAD model will be ported to motion analysis software for testing in a virtual environment that accurately reflects the physical world. The simulation of assembly motions will comprise the analysis of loads in mechanical joints and load bearing parts, as well as collision detection. We will also be able to simulate and evaluate failure scenarios. The dynamic system simulation will detect inconsistencies and possible design flaws. The simulation will thus allow timely modifications to previously unsuspected problem areas.

**Issues in Remote Manufacturing Operations:** There are several considerations necessary in order for a fabrication process to approach the efficiency of common, non-remote industrial scale processes. Some issues are common to all the candidate fuel manufacturing processes. Identification of generic areas for improvements in remote process technology will lead to further research in Years 2 and 3 of the project.

#### **4. Expected Technical Results**

First, we will conduct a survey of the possible transmuter fuel types, and of the requirements for manufacturing these fuels. Detailed process models will be developed thereafter that will aid in the identification of issues, costs, and impacts of each fuel type on the fuel manufacturing process and the transmuter fuel cycle. Preliminary requirements for large-scale fuel production in a remote environment for a network of transmutation systems will be defined. One fuel manufacturing process will be modeled with process simulation software towards the end of the first year.

In Years 2 and 3, remote manufacturing technologies required for efficient large-scale remote fuel fabrication would be identified and analyzed. Process models developed in the project would be available to AAA program personnel for a more accurate definition of the impact of fuel choice on the transmuter fuel cycle. In particular, the process models could better define relative process losses, waste generation, and capital cost for the 3 potential fuel types. These process models would allow the early identification of issues that may disqualify a fuel type for

consideration in a transmutation system in the system specification process. These models will also allow more accurate definitions of required plant size and of the number of plants needed to mesh with the fuel recycling line, as well as the determination of requirements for automation.

Some key technologies may be implemented on a laboratory scale during the second year and third years. Technological advances and automation will result in reduced human exposure risk, enhanced reliability and reductions in operations cost. The manufacturing technology developed for this hot cell application will also be applicable to other uses, where occupational hazards prevent human presence near processes.



Figure 1. Robotic Hot Cell Unit in UNLV's Robotics Lab. This large work cell (approx. 20 x 20 ft floor space) features two large gantry robots with 1- and 2-ton lifting capacities. The large robot is equipped with a tool changer for various attachments, including a remotely controlled master-slave dual arm end effector.

## 5. Capabilities at UNLV

- **UNLV Laboratory Facilities:** State of the art equipment and software is presently used in UNLV's robotics and computer graphics laboratories headed by Dr. Mauer (see Figures 1 and 2). The UNLV robotics laboratory is equipped with a new RWI B-14 mobile robot, 3 stationary robots, several CCD cameras and frame grabbers, several ultrasound range sensors, a stereo range camera, and a six-axis force/torque measurement system. We developed, installed, and tested a mobile inspection and data collection system for the Yucca Mountain "heated drift" project. The "heated drift" project was begun at Nevada's Yucca Mountain Project in 1998 in order to explore experimentally the effects of high-level nuclear waste emplacements in Yucca Mountain at the Nevada Test Site.



Figure 2. Dual slave arm end effector in the UNLV Robotic Hot Cell Unit. The master is configured identically, and is guided by a human operator.

## 6. Related R&D and Key Personnel

**Related R&D:** Dr. Mauer and graduate students have been developing robotic solutions for various applications using image and range based sensors for since 1992, with an experimental project for robot control successfully completed in 1996. Recently completed projects include the following:

- G. Mauer (PI): "Mobile Robot R&D for Remote-Controlled Environmental Remediation in Open Terrain," Funded by DOE-Nevada Operations, Jan. 97 to Dec. 98. \$120,000.
- G. Mauer: "Design and Testing of Remote Imaging Apparatus for a High Temperature Environment," TRW Inc. Jan. 97 to Sept. 98, \$163,600.

In these projects, we have successfully implemented the following components:

- Design and Manufacturing of a Custom Robotic Application – The heated drift remote inspection system at Yucca Mountain comprises a camera system travels along an overhead rail. The cameras are installed in the forward pan unit, which can rotate about 350 C. The conditions inside the heated drift comprise temperatures up to 300 C and high humidity. A graphical user interface permits the console operator to monitor the progress of the image and data acquisition in real time, and to visually program the sequence of operations.
- Image processing, feature characterization, and pattern matching.
- Verification and Tracking of target features, and visual scene interpretation. A coherent set of rules for descriptor evaluation and feature identification employs real time Artificial Intelligence (AI) methods.

**Key Personnel:** Dr. Georg F. Mauer will direct the project. He has an extensive background in automatic control, robot control, instrumentation and software development, and applications. At UNLV, Dr. Mauer has worked on several research projects on robot control, non-contact sensors, and image analysis. Dr. Mauer is currently working on a DoD funded project in which sensor based automatic tracking and recognition systems are being designed for mobile robotic vehicles. Presently, our pattern recognition software, based on CCD-vision and range cameras, can identify and classify distinct objects irrespective of scale and orientation. The software also computes the exact location, size, and orientation of all objects relative to the camera for reliable grasping with a robot arm. Before moving to Las Vegas, Dr. Mauer was Assistant Professor at the University of Washington, Seattle, WA (1982 to 1985). Total funding for his projects exceeded \$1,200,000 since joining UNLV in 1986. Funding for these projects has been provided by the Department of Defense, NSF, and the Department of Energy. Dr. Mauer holds two patents on capacitive sensing awarded in 1989 and 1990. Dr. Mauer received a Doctor of Engineering degree (summa cum laude) in Mechanical Engineering from the Technical University of Berlin, West Germany, in 1977. He is a member of ASME. In addition to the patents, Dr. Mauer has published 6 refereed journal papers, 3 book articles, 21 refereed conference papers, and 26 project reports during the past seven years. Dr. Mauer is currently working on a project in which sensor based automatic tracking and recognition systems are being designed for mobile robotic vehicles.

**Mr. Jae-Kyu Lee** has been a Ph.D. student in UNLV's Department of Mechanical Engineering since the fall of 1999. He has been working on the completion of his course requirements (expected to be completed at the end of spring 2002 semester) and on machine recognition, including stereo vision, under the supervision of Prof. Mauer. Mr. Lee is an accomplished C-programmer and has developed several image processing algorithms. This experience will likely enable him to make rapid progress in the proposed research.

## 7. Project Timeline

The proposed research is planned to cover 3 years, starting in September 2001. A Ph.D. student (Mr. Jae-Kyu Lee) is ready to begin work on the project in the fall semester of 2001. The Year 1 effort will focus mostly on the completion of Tasks 1 and 2. The major components will be defined and identified in cooperation with ANL personnel.

## **Milestones:**

### **Task 1. Survey of Candidate Fuel Types**

In cooperation with the ANL fuel development group, Dr. Yue Guan of ASTM, Inc. and other researchers in the field, we will determine the scope of possible fuel options, and define their manufacturing, processing, and handling requirements.

Duration: 2 months.

### **Task 2. Detailed Study of Manufacturing Process Options**

We will evaluate the proposed fuel manufacturing processes following criteria established by DOE and ANL, again in close cooperation with ANL West and Dr. Yue Guan of ASTM, Inc. The equipment required for the different manufacturing steps will be defined, as well as throughput, preliminary cost estimates, waste streams, and required floor space.

Duration: 8 months.

### **Task 3. Conceptual Modeling of a Sample Manufacturing Process**

We will develop a 3-D solid model of a sample process, its flow of materials, and of the equipment required to handle the material flow as discussed above. This model will demonstrate the utility of realistic 3-D animated modeling for the definition of a process, including the evaluation of requirements and processes in the case of abnormal events, and serve to define future work in years 2 and 3, during which more detailed modeling could be conducted.

Duration: 1 month.

### **Task 4. Final Report**

A detailed documentation of analytical results and recommendations will be submitted at the end of the project.

Duration: 1 month.

### **Possible Tasks for Years 2 and 3:**

The objectives of Years 2 and 3 will be defined towards the end of Year 1 in cooperation with ANL. Possible tasks include:

- Detailed animated solid modeling of manufacturing processes and material flows, including simulation of abnormal events and recovery procedures.
- Design of production, materials handling, control and sensor systems including radiation shielding.
- Setup and experimental testing of remote materials handling and assembly processes at UNLV, using inert materials.
- Development of AI-based real-time remote control and diagnosis software for process supervision, diagnostics, and documentation.

## Project Schedule

Task	Description	Month		
		1	6	12
1	Fuel Types	----		
2	Detailed Study of Processes.	-----		
3	Conceptual Modeling		---	
4	Final Report			---

## Deliverables

In addition to written reports discussed below, animated computer simulations will be developed that will illustrate the flow of material and equipment operations through computer animations. Results will also be published in refereed journals as appropriate.

## Reports:

- **Collaboration with DOE project:** Monthly communications (by phone or in person) with National AAA Project collaborator and/or technical lead to update on progress, discuss problems, and allow for re-focusing if necessary to address shifts in direction by the National AAA Project.
- **Progress Reports:** Brief reports indicating progress will be provided every quarter (to support DOE AAA quarterly meetings).
- **Final Report:** This report will document the findings, describing the relative merits and limitations of the various manufacturing processes

## Bibliography

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## Selected Simulation and Robotics References on the World Wide Web (Vendors and Research Laboratories)

- Dynamic process Modeling: <http://www.workingmodel.com/>  
<http://www.kinematics.com/>  
<http://www.simulationsoftware.com/>
- General Info Robotics: <http://www.ifi.unizh.ch/groups/ailab/links/robotic.html>
- GUI Robot Design Software: <http://www.kinematics.com/index.htm>
- Motion Controllers: <http://www.texonics.com/Specs/motioncontrol.htm>
- Laser range scanners: <http://cyra.com/cyrax.html>  
<http://www.sick.de>

July 11, 2001

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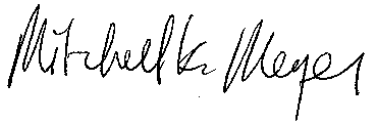
Dear Dr. Mauer:

I am writing in support for your UNLV AAA University Participation Program proposal "Design and Evaluation of Processes for Fuel Fabrication." Successful completion of this proposal will provide valuable information to the AAA program, and aid in the down-selection of transmuter fuel candidates for further development and irradiation testing.

The success of an accelerator-driven transmutation system in reducing the total quantity of plutonium and minor actinide waste pivots on the successful development of the transmuter fuel cycle. The components of the fuel cycle must mesh effectively in order to efficiently reduce the total waste volume. Because of the multiple passes required to achieve a high transmutation fraction, fuels must be amenable to recycle and refabrication in addition to exhibiting good irradiation performance. The fabrication/refabrication process must produce minimal secondary radioactive waste, be economically viable, have a reasonable initial capital outlay, and be maintainable over the transmuter core life cycle. Achieving these goals is complicated by the necessity for remote processing inside of a hot cell and by the volatility behavior of americium during thermal processing. These issues greatly escalate the difficulty and complexity of fabrication, and require considerable study and design effort. Fuel fabrication and refabrication are thus an important consideration in the transmuter fuel cycle, and an aspect that has not yet been studied in detail.

Detailed information on the design of fabrication processes required for proposed transmuter fuel types will allow for more informed selection of candidate fuels. Successful completion of the proposed research will be an important component in defining the transmutation fuel cycle. I offer my enthusiastic support your proposal and wish you success in this important research endeavor.

Sincerely,



Mitchell K. Meyer  
Group Leader, Fabrication Development  
Nuclear Technology Division

MKM:smr  
pc: RF