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Design and Evaluation of Processes for Fuel Fabrication

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UNLV AAA UPP Proposal Year II
Design and Evaluation of Processes for Fuel Fabrication

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Estimated Cost: \$82,466 (Year 2)

Technical Focus Area: Fuel Development: Development of Production Scale Remote Fabrication Processes.

Date of Submission: May 31, 2002

Design and Evaluation of Processes for Fuel Fabrication Year II

ABSTRACT

The objective of this project is the design and evaluation of manufacturing processes for transmuter fuel fabrication. The large-scale deployment of remote fabrication and refabrication processes will be required for all transmutation scenarios. Current program emphasis is on a five-year effort to determine the feasibility of transmutation as a technology to limit the need for repository storage of spent commercial fuel. The evaluation of the fabrication processes will create a decision support data base to document design, operations, and costs. Fabrication processes required for different fuel types differ in terms of equipment types, throughput, and cost. Differential cost Implications of various fuel choices will be assessed. The ongoing year 1 project has been focusing on collecting information on existing technologies, equipment costs, and material throughput. Another aspect during year 1 has been the assessment of robotic technology and robot supervision and control, and the simulation of material handling operations using 3D simulation tools with view towards the development of a fully automated and reliable, autonomous manufacturing process. Such development has the potential to decrease the cost of remote fuel fabrication and to make transmutation a more economically viable process. An added benefit would be the potential for large reductions in dose to workers. This project is being conducted in close cooperation with the fabrication development group at Argonne National Lab.

Year 2 of the project will be devoted to developing further data and knowledge regarding the cost and feasibility of automated fuel manufacture in a hot cell. The manufacturing processes will be simulated as robotic operations supervised by remote operators. Both normal operations as well as failure scenarios will be investigated, analyzed, and simulated. The results of this study will be documented in detail. The results of the simulations will be used by AAA program personnel to perform sensitivity studies on the impact of different fuel types on ATW system operation. Conceptual designs for plant designs and the accompanying supervision and control systems will be developed. Impacts on transmutation system capital cost, economics of operation, estimates of process loss, and environmental and safety issues will be estimated in further detail, continuing the work from year 1.

1. Work Proposed for Academic Year 2002-2003, Goals, and Expected Results:

During year 2, we will perform the following:

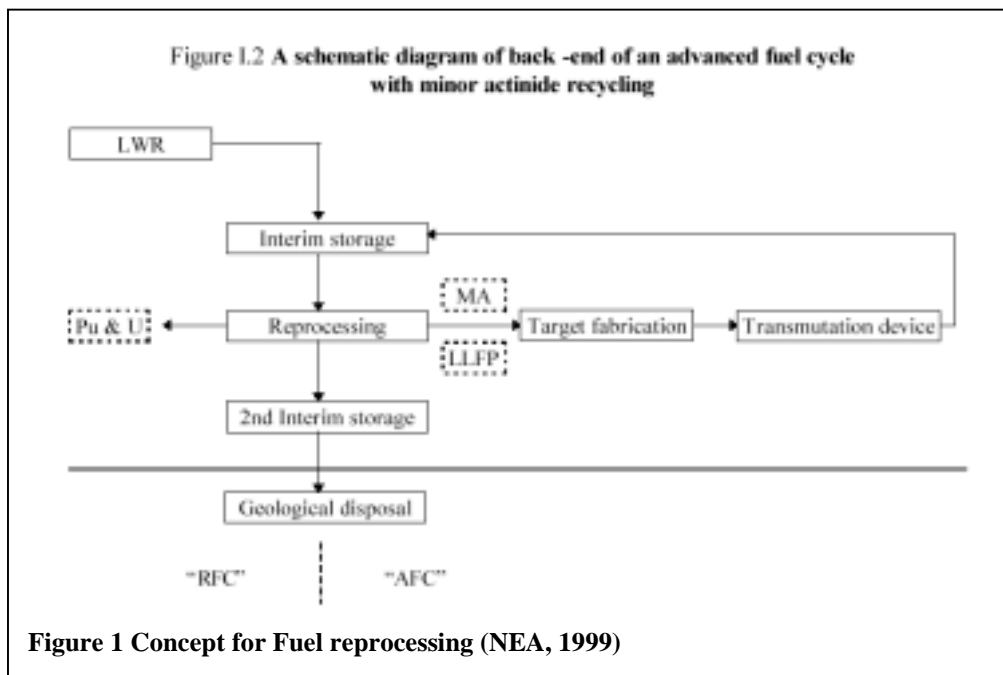
- Detailed evaluation of the fuel manufacturing processes for ceramic, metal, and dispersion fuels following criteria established by the AAA Fuel Development Program.
- Conceptual computer modeling of the manufacturing processes.
- Identification of areas where automated processes are crucial to maintain the required throughput rates.
- Conceptual design of key automated processes.
- Estimation of component and plant costs, maintenance requirements and plant life expectancy.
- Documentation of study results and recommendations for large-scale fuel fabrication.

Funding Profile:

Academic Year:	2001-2002	2002-2003	2003-2004
Total (K\$)	87	84*	88*

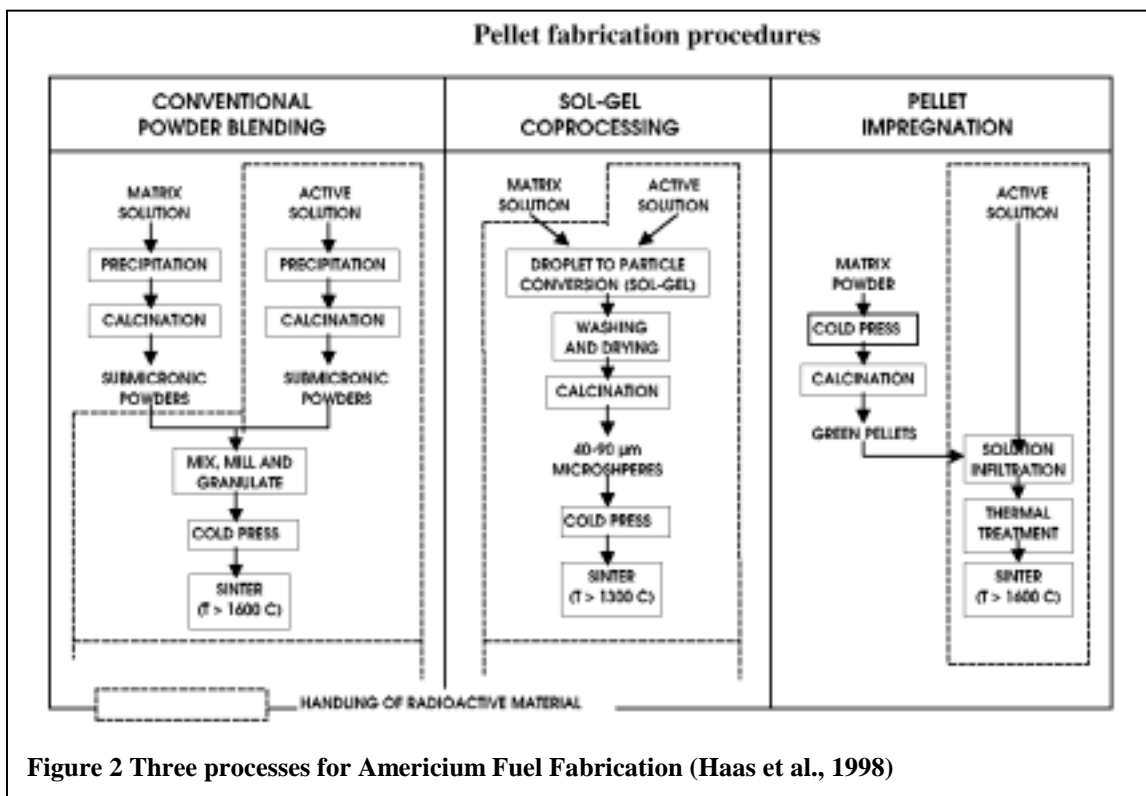
* Projection does not include lab equipment.

2. Summary of Results to Date



Partitioning and Transmutation (P&T) Concepts (Literature Survey)

P&T concepts are discussed widely in pertinent publications and conference proceedings. Examples of comprehensive discussions are found in NEA reports (1999 and 2001) and in a report of the scientific office of the French parliament (1997, in French). The paper by Boidron et al (2000) presents a survey of P&T research efforts. Fig. 1 illustrates the NEA concept of separating Pu and U from spent fuel and transmuting the minor actinides (MA). The report to the French senate (1997) estimates the initial costs for a separation plant based on the PUREX process at 5 Billion francs or approx. \$1 Billion, for a throughput of 850 tons of spent fuel annually. Haas et al. (1998) discuss the feasibility of the fabrication of Americium targets in a NEA conference paper using an infiltration process and the 'sol-gel' method developed at the Institute for Transuranic Elements



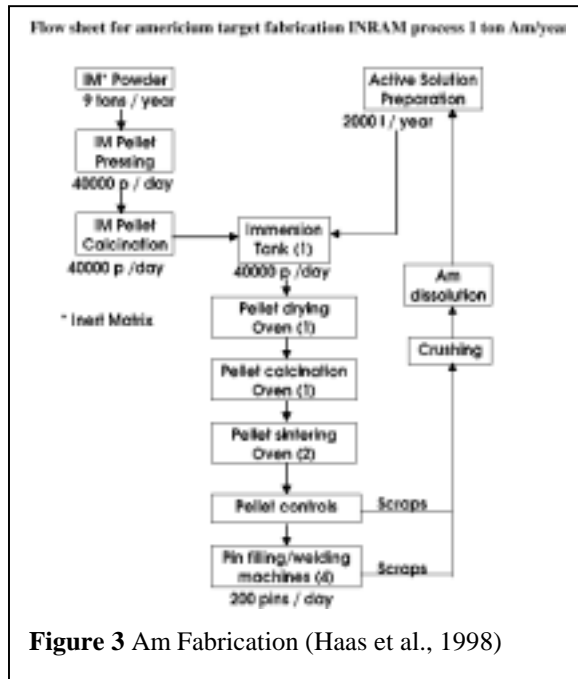
(ITU) in Karlsruhe, Germany. Fig. 2, quoted from Haas et al. (1998), compares both processes with established powder processing techniques. Fig. 3, quoted from Haas et al. (1998), illustrates the anticipated equipment needs for the fabrication of 1 ton of Am/year based on ITU's INRAM Process. V.V. Ignatiev et al. (1998) present a discussion of molten salt technologies and losses during manufacturing.

More detailed descriptions of powder manufacturing processes and equipment are found in Ganguly (1989) and Balakrishna et al. (1999). The fuels described here are generally based on U- and Pu- oxides and were manufactured in glove boxes.

While the technologies cited above generally employ wet chemical and powder processing methods, the Argonne National Laboratory (ANL) as well as other labs have

developed molten salt separations technologies (UIC 2001, Meyer 2001). Molten salt separations technologies appear to be most suitable for second tier recycling of fuel, with the benefit of avoiding the long cooling times associated with aqueous processes. The process for manufacturing fuel for the integral fast reactor (IFR) relied on remote 'injection' casting of metallic fuel slugs.

A comprehensive treatment of issues pertaining to Nuclear Waste is presented in the book "Nuclear Wastes: Technologies for Separations and Transmutation" published by the National Research Council (1996). The book also contains cost estimates for reprocessing plants.



Plant Cost Estimates – The goal of this task is to develop the database necessary to provide estimates of cost and differential cost for the various fuel manufacturing options. Preliminary cost figures for fuel manufacture from preprocessed materials (e.g. wet separation or molten salt electrolysis) were presented in Progress Report #2. These figures have been updated in Progress Report #3 (May 2002) to reflect recent findings.

Manufacturing Automation – The goal of this task is to develop simulations of

manufacturing processes to allow for plant sizing and to determine adequacy of current generation sensors and robotics and the need for development of new technology in this area. The progress reports # 1 and #2 for this project (Mauer, 2001 and Mauer, 2002) contain an assessment of generic equipment needs and a survey of commercially available manufacturing and robotic handling equipment. Robotic work cells would likely result in reduced cost of operation as well as increased reliability by reducing the potential for human error during materials handling operations. One graduate student working on the project, Mr. Richard Silva, is developing the 3-D manufacturing process simulation CAD models. Results to date exist in real time movie format. A set of sample movies has been forwarded to Dr. Hechanova for posting on the AAA web site. To date, simulations for several robot types have been developed and their proper kinematic configuration has been verified. A number of screen shots from these simulations are shown in the appendix at the end of this document. For the animations, please refer to the UNLV AAA web site (<http://aaa.nevada.edu/>)

Accurate process supervision will be essential for the reliability and safety of the fuels manufacturing process. This will likely be accomplished by a combination of process sensors and visual supervision. Machine vision can detect and analyze situations automatically, and camera images can be transmitted directly to supervising personnel. In addition, calibrated vision systems can perform and document automated dimensional

and surface quality measurements on the completed pellets as well as the completed fuel pins.

Graduate Students – Ph. D. student Jae-Kyu Lee presented a paper at the ANS Annual Meeting, student conference. Title: Transmuter Fuel Fabrication Processes. Jae-Kyu Lee and G. Mauer also presented a AAA Seminar. Title: Transmuter Fuel Fabrication Processes. Jae-Kyu also developed a Ph.D. thesis proposal based on the ongoing AAA research, where he will focus on the supervision and control of the automatic fuel manufacturing process. The tentative title of his Ph.D. thesis proposal is: “Object Recognition and Inspection For Remote Manufacturing Processes.” The preliminary examination before the Ph.D. committee will be held in July 2002.

M.Sc. student Richard Silva’s work on manufacturing simulation is ongoing, and reportable results are anticipated for the fourth quarter. Mr. Silva is not funded from AAA funds.

Year 1 Fourth Quarter Plans – The preliminary examination for Ph. D. student Jae-Kyu Lee will be held in July 2002. The topic of his Ph.D. thesis project is “Object Recognition and Automated Inspection for a Remotely Controlled Manufacturing Process.” Much of the recent R&D in the field of nuclear waste reprocessing has been conducted in countries of the European Union. Dr. Mauer plans to visit several European sites (ITU Karlsruhe, Advanced Nuclear Fuels GmbH fuel manufacturing plant Lingen, Centre de Cadarache) this summer in order to gain further information on manufacturing technologies.

3. Research Plan for Year II

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 fabrication line required for the U.S. transmutation with fuel to complete its mission 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 that are developed must allow the use of robust equipment that is readily maintainable. Attention must also be given to decommissioning during the design phase. All of these factors play a role in the feasibility of the transmutation process as a whole. Assessment of the state of the technology, potential problem areas, and an understanding of the scale at which shielded facilities must be deployed play an important role in determining the feasibility of the process as a whole. In addition, large differential costs associated with the adoption of any particular technology will be identified.

The conceptual fuel fabrication processes developed during year I for the candidate fuel types will be refined further in conjunction with ANL. Conceptual designs of the fuel fabrication processes will evaluate the issues of 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. The process 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 now under consideration.

In summary, the project will result in conceptual plant designs, simulations of manufacturing operations and throughput, cost data and estimates on plant maintenance and plant life time.

Research Areas

Methods and Processes - We will continue, in close cooperation with ANL, the literature survey and detailed analysis of the R&D pertaining to candidate processes for transmuter fuel manufacture. We will refine equipment, instrumentation, and control specifications, and assess the reliability and safety of operations using industry standards.

Process Simulation and Simulation Software R&D – The goal of this task is to model manufacturing processes to allow realistic assessment of plant layout, size, feasibility, and technology development required for large-scale remote fabrication of fuel. The candidate fuel manufacturing processes are being modeled using the MSC Visual Nastran and ProEngineer simulation software tools (see also the appendix.) Master's student Richard

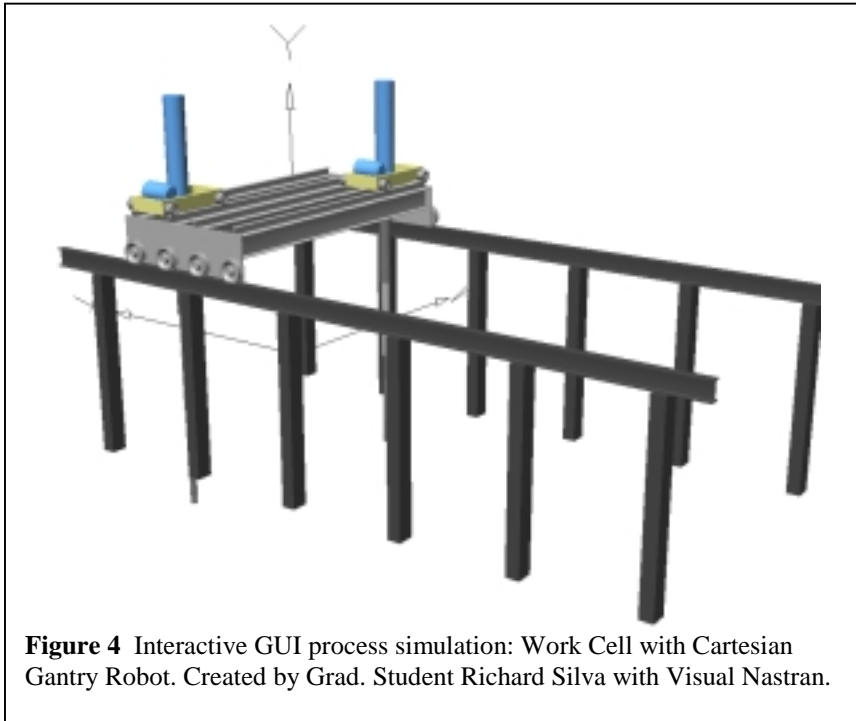


Figure 4 Interactive GUI process simulation: Work Cell with Cartesian Gantry Robot. Created by Grad. Student Richard Silva with Visual Nastran.

Silva is working on this effort. 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.

Fig. 4 shows an example of a gantry robot simulation in VisualNastran. VisualNastran Motion by MSC software (<http://www.mscsoftware.com/>) is a state of the art simulation tool. Results from the simulation are available as quantitative data as well as through animated graphics. In addition to the simulation of normal operations, the dynamic process model can simulate and analyze maintenance and troubleshooting situations, such as the removal and replacement of malfunctioning equipment components. Other simulation tools can evaluate the system control, materials flow, and diagnostics aspects of the plant:

The time-dependent flow of materials through the plant can be modeled with tools such as SimCad (<http://www.simulationsoftware.com/>). This and similar tools model the product stream and assist in defining the space and equipment needs for the required throughput. Bottlenecks to material flow can be identified, and requirements for automated equipment determined.

Processes and Equipment for Autonomous Manufacturing – The goal of this task is to develop an understanding of the cost and capability of current generation remotely operated equipment suitable for use in radiation environments. We will continue to monitor the market for equipment and components with regard to suitability for automated manufacturing under hot cell conditions. As mentioned, sensor systems, both those embedded in the equipment as well as additional sensors added for process supervision and control, must be insensitive to radiation or radiation hardened.

Sensors, Controls and Operational Safety – The goal of this task is to determine the adequacy of current technology and the need for development in sensor technology suitable for deployment in hard radiation environments. In remote manufacturing, it is crucial to be able to determine the exact locations of parts, points and surfaces where tools or objects need to be placed. The exact knowledge of the location and spatial orientation of all parts in the robot's work envelope, as well as the ability to position all material handling and troubleshooting equipment exactly at a desired location inside the work cell is crucial for the safety and reliability of any successful remote operation. The type and location of sensing equipment will determine the accuracy and repeatability of each respective operation, and therefore have a direct bearing on the quality and reliability of the fuel manufacturing process. To the extent that sensors and controls cannot be placed outside the hot cell, they must be radiation-hardened. The absence of suitable sensors would have a significant impact on plant operations and operating cost, since more human supervision would likely be required.

Cost, Feasibility, and Large Scale Deployment – The goal of this task is to use all information developed or collected on the topics listed above in order to evaluate assess the cost, feasibility, and suitability for large scale deployment of the candidate manufacturing processes. The results will be tabulated, and quantitative estimates regarding projected cost, reliability, and plant life time will be developed.

4. Expected Technical Results

This research will provide technical results in two areas, which are both germane to assessing the cost and feasibility of transmuter fuel manufacture. First, detailed process models will be developed that will allow the evaluation of the impact of fuel type on the fuel manufacturing process and the transmuter fuel cycle in terms of differential cost and potential for material loss. Secondly, manufacturing models for large scale production in a hot cell environment will be developed. These two results will 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 will be assessed.

Process models will be developed to better define the impact of fuel choice on the transmuter fuel cycle. In particular, the process models will be used to better define relative process losses, waste generation, and plant capital cost. These process models will allow a better definition of required plant size and number of plants needed to mesh with the fuel recycling line, as well as determining requirements for automation. Future fuel plant design efforts can rely on the groundwork laid here as a starting point for facility and process design.

Scientific advances in remote manufacturing technology required for efficient large-scale remote fuel fabrication will be identified. Besides hot cell compatible equipment, the supervision and control processes must rely on sensing technology that is both survivable as well as flexible in its usage, in order to address a wide variety of possible scenarios. Radiation hardened vision systems appear to be a promising technology: Vision systems can be adapted to a wide range of uses, from dimensional metrology (e.g. non-contact dimensional pellet inspection, determination of exact location and spatial orientation of parts) to supervision in process control, materials handling, and collision avoidance. We therefore propose to continue the vision systems R&D as a component of developing a system for flexible supervision and control of the autonomous manufacturing system. The manufacturing technology developed for the hot cell application will also be applicable to other, more general uses, where occupational hazards prevent human presence near processes.

The project will also result in advances in control and operation of manufacturing processes, will provide UNLV with a long-term research capability in machine intelligence and robotics, and will enhance the depth and attractiveness of its Ph.D. programs in computer science, mechanical and electrical engineering through broad student involvement in the project and through new advanced course offerings.

Ph.D. Thesis: Mr. Jae-Kyu Lee has been a Ph.D. student in UNLV's Department of Mechanical Engineering since the Fall of 1999. After nine months on the project, he has developed a detailed proposal for his Ph.D. thesis. The preliminary exam for approval of his thesis project will be held in July 2002. Continuation of the current funding will be essential

for resolving the fundamental need for reliable automated process supervision for remote hot cell manufacturing, as well as in ensuring the completion of J.K. Lee's Ph.D. thesis project.

Educational and Research Infrastructure - The project will strengthen our analytical and experimental research capability in the emerging field of remote process control. Over the three-year project duration, we will develop and demonstrate real time hardware and software capable of performing autonomous supervision, action planning and execution. In addition to the Ph.D. student, up to five undergraduate seniors annually will be participants in the project.

5. 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 (see Figure 9) 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 (see Fig. 6) which travels along an overhead rail. The cameras are installed in the forward pan unit, which can rotate about 350 degrees. The conditions inside the heated drift comprise temperatures up to 300 deg. C and high humidity. The communication with the remote monitoring station is via wireless transmitters installed in the thermally insulated container. We designed at UNLV all communication and control units, using commercial OEM components. All electrical motors, image and data acquisition, process control and data storage is performed automatically by a computer program written at UNLV in MS Visual basic. 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.
- Reduction of raw sensor data: image file sizes are substantially reduced through filters and spatial (e.g. Fourier and wavelet) transforms for image segmentation and extraction of characteristic object features. Data reduction is vitally important for the maximization of processor speed.
- Feature characterization: Descriptors, derived from transform and geometric properties, characterize object features. The feature detection is orientation-invariant and independent of the size of the detected feature. Pattern matching is performed by statistical comparison (e.g. minimum Euclidean distance between the observed feature set and a database containing all known features).
- Sensor Fusion and Feature Validation: By inspecting the corresponding region of the

range image (disparity image from stereo vision analysis) we determine the spatial location and visible portions of the candidate object's geometry, such as length or thickness. The additional information from range data has been shown to often resolve problems that cannot be resolved solely with plane vision, e.g. the spatial location of a reference plane viewed from an oblique camera angle, or the spatial positions of two objects when one object partially obscures the other.

- Verification and Tracking of target features: Using range data (e.g. from stereo vision or laser range imaging), a targeted feature's spatial dimensions and location are verified and mapped. The classification is corrected if necessary. The feature's spatial location, size, orientation and velocity vector (if moving) are computed, with the latter determined from the time series of two or more location vectors.
- Scene interpretation is based on the analysis of descriptor and geometric data. A coherent set of rules for descriptor evaluation and feature identification employs real time Artificial Intelligence (AI) methods. The AI unit tentatively classifies and groups each detected feature in a scene, rejects irrelevant features, and focuses only on the desired images elements, e.g. hand or face contours.

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 six refereed journal papers, three book articles, twenty one refereed conference papers, and 26 project reports during the past seven years. Dr. Mauer is currently working on project in which sensor based automatic tracking and recognition systems are being designed for mobile robotic vehicles.

Selected publications:

Georg F. Mauer: "An Interactive Control System Laboratory Using Visual Basic And Vissim," ASEE 2002 Annual Conference, Montreal.

Georg F. Mauer: An Interactive Visual Environment for Scientific Problem Solving, Proc. ASEE 2001 Annual Conference, paper#572, Albuquerque.

J.K. Lee and G. Mauer "Transmuter Fuel Fabrication Processes," Presentation at ANS Student conference in Reno, NV, Nov. 2001.

- Georg F. Mauer (1999) "Remote Controlled Imaging in an High Temperature Tunnel Environment," Proc. 20th IEEE Real-Time Systems Symposium, November.
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- Sureshkumar Devarajan and G. F. Mauer: "Object Classification through Descriptors and Expert System Analysis for Robotic Applications," published in: Proceedings of 1997 Conference on Artificial Neural Networks in Engineering, p. 497-502.
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- G. F. Mauer (1994) "Modeling and Experimental Validation of Torsional Crankshaft Dynamics," SAE Paper #940830.
- G. F. Mauer "Computer-Supported Controller Design with Model-Based and Fuzzy-Logic Methods," Proc. 1992 Coll. on Robotics, Duisburg, p. 151-162.

Mr. Jae-Kyu Lee has been a Ph.D. student in UNLV's Department of Mechanical Engineering since the Fall of 1999. He has completed his course requirements and prepared a thesis proposal on the topic of machine recognition for autonomous manufacturing workcells under the supervision of Prof. G. Mauer. The preliminary exam for approval of his thesis project will be held in July 2002. Mr. Lee is an accomplished C-programmer and has developed several image processing algorithms.

6. Project Timeline

The proposed research is planned to cover three years from the start in September 2001. A Ph.D. student (Mr. Jae-Kyu Lee) began work on the project in the Fall semester of 2001. As in year 1, the project will continue to utilize presently available computer equipment at UNLV (workstations and professional design software in the UNLV robotics and graphics laboratories).

Year 2 Effort: The Year 2 effort will focus on the completion of the four tasks listed below. The major components will be defined and identified in cooperation with ANL personnel.

Milestones

Task 1 Methods and Processes - We will continue, in close cooperation with ANL, the literature survey and detailed analysis of the R&D pertaining to candidate processes for transmuter fuel manufacture. We will refine equipment, instrumentation, and control specifications, and assess the reliability and safety of operations using industry standards. Project tasks will be executed concurrently.

Subtask 1.1 Processes and Equipment for Autonomous Manufacturing – The goal of this subtask is to identify manufacturing processes, industrial and custom equipment in nuclear research and production facilities, to allow realistic assessment of plant layout, size, feasibility, and technology development required for large-scale remote fabrication of transmuter fuel. We will continue to monitor the market for equipment and components with regard to suitability for automated manufacturing under hot cell conditions. As mentioned, sensor systems, both those embedded in the equipment as well as additional sensors added for process supervision and control, must be insensitive to radiation or radiation hardened.

Subtask 1.2 Sensors, Controls and Operational Safety – The goal of this subtask is to determine the adequacy of current technology and the need for development in sensor technologies suitable for deployment in hard radiation environments. In remote manufacturing, the ability to determine the exact locations of parts, points and surfaces where tools or objects need to be placed is crucial. Radiation hardened vision systems appear to be promising technologies: Vision systems can be adapted to a wide range of uses, from dimensional metrology (e.g. non-contact pellet dimensional inspection, determination of exact location and spatial orientation of parts) to supervision in process control, materials handling, and collision avoidance. We therefore propose to continue the vision systems R&D as a component of developing a system for flexible supervision and control of the autonomous manufacturing system.

Leads: J.K. Lee and G. Mauer

Duration: 12 months.

Task 2 Process Simulation and Simulation Software R&D – The goal of this task is to develop simulations of manufacturing processes to allow for plant sizing and to determine

adequacy of current generation sensors and robotics and the need for development of new technology in this area. The candidate fuel manufacturing processes will be modeled using the MSC Visual Nastran and ProEngineer simulation software tools. Master’s student Richard Silva is working on this effort. 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.

Leads: Richard Silva and G. Mauer

Duration: 4 months.

Task 3 Cost, Feasibility, and Large Scale Deployment – The goal of this task is to develop the database necessary to provide estimates of cost and differential cost for the various fuel manufacturing options. All information developed or collected on the topics listed above will be evaluated in terms of assessing the cost, feasibility, and suitability for large scale deployment of the candidate manufacturing processes. The results will be tabulated, and quantitative estimates regarding projected cost, reliability, and plant life time will be developed. This task will be carried out intermittently as progress warrants.

Lead: G. Mauer

Cumulative Duration: 1 month.

Task 4 Final Report

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

G. Mauer

Duration: 1 month.

Project Schedule Year 2

Task	Description	Month			
		1	4	9	12
1	Methods and Processes	-----			
2	Process Simulation	-----			
3	Cost and Feasibility Evaluations		-	-	---
4	Progress and Final Reports		-	-	---

Possible Tasks for year 3:

The objectives of year 3 will be defined towards the end of year 2 in cooperation with ANL.

Possible tasks include:

- Further 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.
- Plant sizing for 2-3 specific transmutation scenarios and capital cost estimates using a fixed set of assumptions.

- Assessment of differential plant capital and operating costs resulting from fuel choices (e.g. fuel composition, inert matrix materials, wet/dry processes for pellet production, sintering pressures and temperatures, frequency of defects, machining needs after sintering or casting)

Deliverables

Main Deliverable: At the end of year 2, a final report will document the findings, describing the relative merits and limitations of the various manufacturing processes. In addition to written documentation, animated computer simulations will be developed that will illustrate the flow of material and equipment operations from start to finish.

Other Deliverables: Refereed Journal Papers - Results will be published in refereed journals. We anticipate to publish papers on pattern recognition, decision and control, and on precision manipulation of targets acquired by the robotic sensors.

Education: The project will encourage qualified students towards studies of artificial intelligence and robotics. Two students are currently engaged in the project, thus we anticipate that one Ph.D. and one Master's degrees will be awarded as a direct result of the project. Additional students are expected to participate in graduate thesis and undergraduate senior design projects.

Undergraduate Students - We will actively recruit **undergraduate students** to participate in the research through design projects, experiments, and software R&D. Up to 5 undergraduate seniors annually will have the opportunity gain valuable research, design and experimentation experience.

Reports

- **Collaboration with DOE project:** Monthly communications (by phone or in person) with National 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 Project.
- **Progress Reports:** Brief reports indicating progress will be provided every quarter (to support DOE AAA quarterly meetings).
- **Annual Reports:** Written reports detailing experiments performed, data collected and results to date.
- **Final Report:** Written report detailing experiments performed, data collected, results, and conclusions to be submitted at the end of the project.

References

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Appendix

Selected Simulation Results

The simulations presented here were developed using ProEngineer solid modeling software in conjunction with MSC VisualNastran4D. Together, the software tools create realistic 3D animations, as well as accurate calculations of the dynamics of all components, loads, collisions, and other aspects of the hot cell operations. Animated simulations of the simulations depicted below have been submitted to the UNLV AAA web site (<http://aaa.nevada.edu/>) for posting.

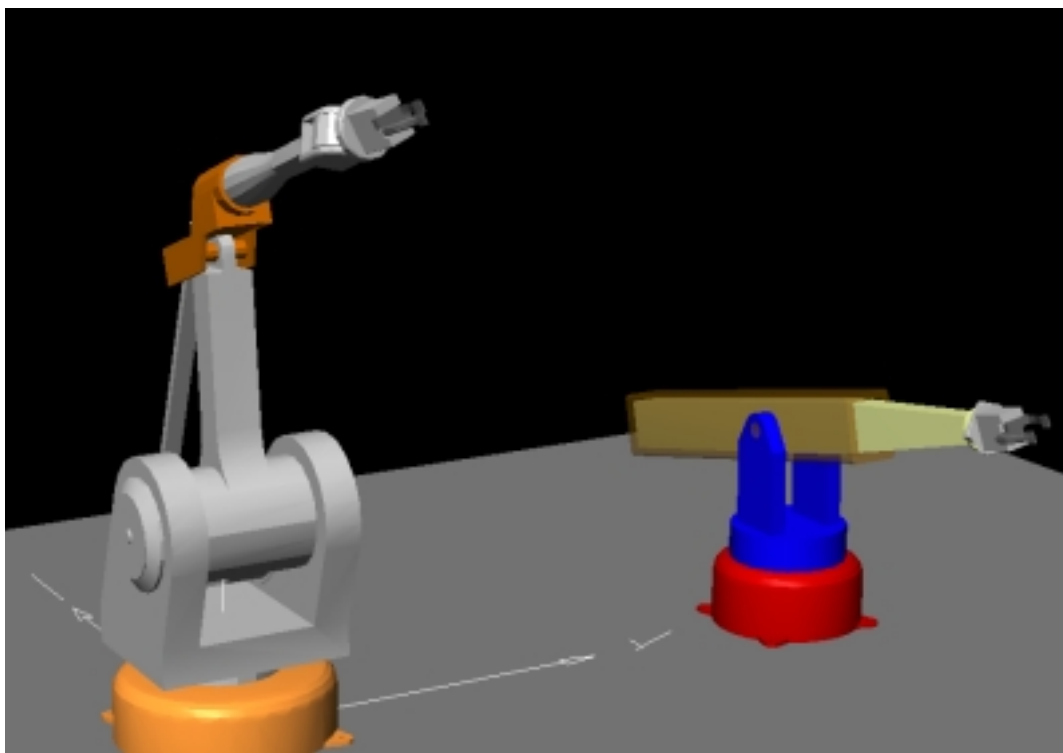


Figure A1 Interactive GUI process simulation: Two Robots ell. Created by Richard Silva with Visual Nastran.

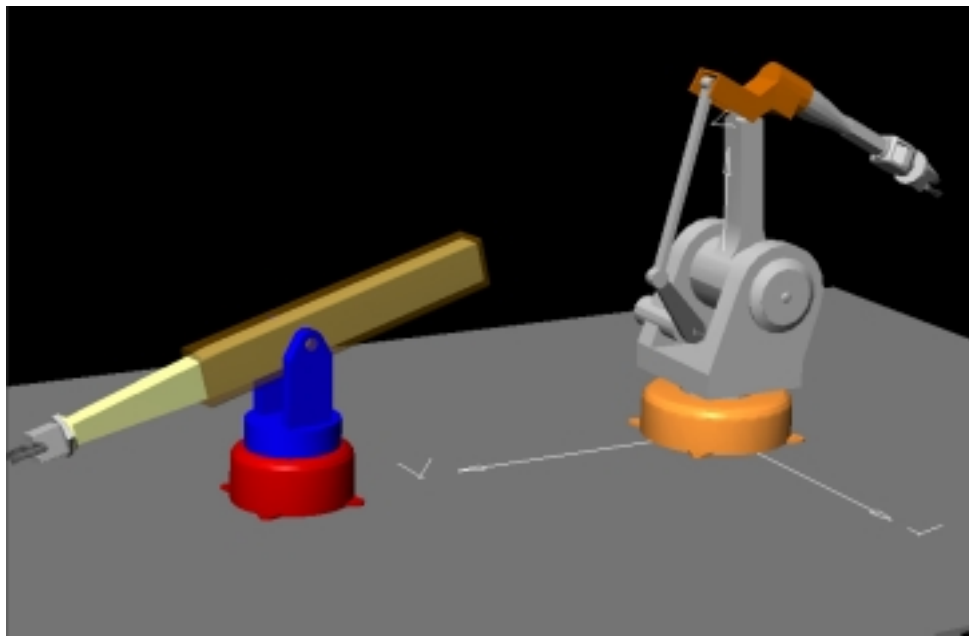


Figure A2 Interactive GUI process simulation: Two Robots ell. Created by Richard Silva with Visual Nastran.



Figure A3 Interactive GUI process simulation: The gripper of the revolute Robots of Fig. 2. Created by Richard Silva with Visual Nastran.