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Design and Evaluation of Processes for Fuel Fabrication: Quarterly Progress Report #3

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Design and Evaluation of Processes for Fuel Fabrication

QUARTERLY PROGRESS REPORT #3

UNLV AAA University Participation Program

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Design and Evaluation of Processes for Fuel Fabrication

Summary

The third quarter of the project covered the following:

- Literature Search: The process of evaluating the pertinent literature continued. Results are summarized below.
- Mr. Richard Silva, developed an initial work cell simulation with two robots. Rich will continue to develop detailed 3-D process simulation models as his M.Sc. thesis project. Rich is employed with Bechtel at the Yucca Mountain project.
- The equipment detail and estimates were refined based on the literature survey results for different manufacturing plant design options.
- Concepts and Methods for Vision-Based Hot Cell Supervision and control (Ph.D. Student Jae-Kyu Lee)

Figure 1 Concept for Fuel reprocessing (NEA, 1999)
1. 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.


**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. Updated estimates are presented below to reflect recent findings.

**Manufacturing Automation** – The goal here 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. The candidate fuel manufacturing processes are being modeled using the MSC Visual Nastran and ProEngineer simulation software tools (see also the appendix.) One graduate student working on the project, Mr. Richard Silva, is developing the 3-D manufacturing process simulation CAD models. To date, several

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**Figure 3 Am Fabrication (Haas et al., 1998)**

![Flow sheet for americium target fabrication INRAM process 1 ton Am/year](image-url)

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robot simulation models have been developed and their correct performance has been verified. 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. To date, Richard has developed three basic robot models (prismatic, revolute, and the Cartesian gantry robot shown in Fig. 4. Please see the appendix at the end of this document for additional simulation screenshots.

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 without physical contact, 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.

1. Equipment for Fuel Fabrication Processes

**Design Constraints:** As described in report #1, criticality concerns mandate fabrication in small batch sizes. Limitations of batch sizes vary with fuel composition. 

**Generic Equipment Needs:** Depending on the process, dedicated equipment such as induction furnaces, V-blenders, Sintering presses, and Arc welders will be required. The transport of the material being processed can be performed using dedicated designs ("hard automation") or

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**Figure 4** Interactive GUI process simulation: Work Cell with Cartesian Gantry Robot. Created by Grad. Student Richard Silva with Visual Nastran.
robots equipped with suitable end effectors. Hard automation (e.g. conveyors, part feeders) can be advantageous in simple transport applications. Normally, however, such equipment cannot recover from unusual events such as part misfeeds or blockages. Robots are more complex, but can be programmed and operated flexibly so that normal operation as well as a wide range of possible contingencies can be covered. By changing a robot’s end of arm tools, the same robot can be equipped to perform multiple tasks, such as material handling and inspection.

1.1 Equipment for Metallic Fuel Manufacture

ANL West developed a custom furnace for its fuel conditioning facility, at an approximate cost of $2 Million. Source: Dale Wahlquist, ANL West.

The ANL casting process employs vacuum casting into an array of quartz tubes. The tubes are broken after casting and must be disposed as waste. A casting process employing reusable molds will be required in order to reduce the quartz waste stream. Evaporation of Am from the liquid phase is a major drawback at present. Dr. Yitung Chen is presently investigating methods to recover the Am-vapor, possibly by deposition on a cold surface, so that the Am can be returned to the fuel stream. Am losses reach up to 40% in the ANL vacuum casting process.

The completed fuel pins must be inspected and inserted into a cladding tube. A Na bond phase must be added. An end cap welder seals the tube. The final inspection completes the process.

Cost estimates: The estimates listed below are tentative. Although commercial equipment prices are available, the adaptation of such equipment to hot cell requirements can increase the cost 10 fold or more. Some equipment is based on custom development, and therefore cost estimates are difficult to obtain or may not exist. The cost estimates presented below are most reliable with regard to metallic fuels due to the ability to contact scientist at ANL West’ directly. Estimates for powder processing are indirect at this time and will be concretized as additional information is gained.
Work Cell Layout – Fig. 5 shows schematically a possible work cell for metallic fuel production. The function of the electrorefiner shown in Fig. 5 is separation. It is included here to illustrate the compactness of the metallic fuels concept. The icons in the upper row are copied from the ANL West illustration of its fuel conditioning facility. With reusable molds, the fuel pin dimensions may deviate from design specifications. A machining unit was therefore added. The two inspection stations would quantify the dimensions of the cast slugs and inspect the completed fuel pins. Two stationary robots would likely suffice to meet all material handling demands. Fig. 5 shows five cameras, one attached to a robot arm. At this time, the intent is merely to illustrate potential camera uses. The exact number and placement of cameras would result from a determination of the supervision and measurement needs in the hot cell. The table below reflects the updated estimates for plant and equipment cost and space requirements.

Figure 5 Possible Configuration for Metallic Fuel Fabrication Work Cell
Updated cost estimates, **metallic fuel fabrication**.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Estim. Cost in US $</th>
<th>Estimated Area requirement ft²</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction furnace+ Preparation Area</td>
<td>2.0 Million</td>
<td>50</td>
<td>Source: ANL West</td>
</tr>
<tr>
<td>Reusable Mold</td>
<td>500K</td>
<td></td>
<td>No standard process exists. Conventional methods have not been adapted to hot cell use.</td>
</tr>
<tr>
<td>Fuel Pin Assembly Unit (Encapsulation and bonding)</td>
<td>2.0 Million</td>
<td>20</td>
<td>Custom equipment</td>
</tr>
<tr>
<td>Automatic Welder</td>
<td>1.0 Million</td>
<td>20</td>
<td>Custom equipment</td>
</tr>
<tr>
<td>2 Robots, approx. 1.5 m work envelope at 270 deg. range</td>
<td>1.0 Million</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Inspection stations 1 and 2 (10 sq.ft. ea.)</td>
<td>100K</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Machining Unit</td>
<td>1 Million</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Supervision (cameras and controllers)</td>
<td>500k</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Product storage</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>$8.1 Million</strong></td>
<td><strong>180</strong></td>
<td></td>
</tr>
</tbody>
</table>

A single manufacturing cell would require approx. 180 sq. ft of hot cell space at a cost of approx. $30,000/ft² or $5.4M for the hot cell space. Total installation cost approx. $13.5Million.

**Productivity** – Criticality concerns limit the batch size to approx. 3 kg, according to Dr. Mitchell Meyer at ANL West. The longest time constant in the metallic fuel fabrication process is likely the casting and subsequent cooling of the metallic slugs. Assuming a cycle time of two hours for this process, the inspection, assembly, and welding functions will likely be completed below two hours. Assuming a down time of 1/3 of the total operation and 24 hour production, 8 batches at 3kg each could be produced daily. Assuming 360 days of operation annually, approx. 8500 kg of metallic fuel could be produced annually.
2.2 Powder Processing Equipment

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. The conventional pellet manufacturing process is dry, and would not require the drying ovens listed in Fig. 3. The number of required sintering presses depends on the duration of the process. The cost of the sintering press varies with the process parameters, all yet to be identified. Literature data indicate wide variations in sinter pressures (vacuum to hundreds of MPa pressure, and temperatures (1400 to 1700 deg. C.)

The table below assumes a need for three sintering ovens, and for four pin filling/welding machines in analogy to Hass et al., 1998. A machining center to ensure consistent pellet dimensions is also listed.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Estim. Cost in US $</th>
<th>Estimated Area requirement ft²</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-blender</td>
<td>50K</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Pellet press</td>
<td>500K</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Sintering ovens (3)</td>
<td>3Million</td>
<td>60</td>
<td>Custom equipment</td>
</tr>
<tr>
<td>Pellet Inspection Station</td>
<td>1Million</td>
<td>10</td>
<td>Custom equipment</td>
</tr>
<tr>
<td>3 Robots, approx. 1.5 m work envelope ea. at 270 deg. range</td>
<td>2 Million</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Pin Assembly Unit (Pellet insertion, Encapsulation and bonding, welding)(4)</td>
<td>8Million</td>
<td>80</td>
<td>Custom equipment</td>
</tr>
<tr>
<td>Machining Center</td>
<td>2Million</td>
<td>20</td>
<td>Custom equipment</td>
</tr>
<tr>
<td>Supervision (cameras and controllers)</td>
<td>500K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product storage</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Final Inspection station</td>
<td>100k</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17.15M</td>
<td>220 ft²</td>
<td></td>
</tr>
</tbody>
</table>

A single manufacturing cell would require approx. 220 sq. ft. of hot cell space at a cost of approx. $30,000/ft² or $6.6M for the hot cell space. Total installation cost approx. $24Million. Fig.6 shows the conceptual fabrication cell layout.
Additional information regarding powder processing equipment design, cost, size and throughput will be collected this summer.
Conclusion

During the third quarter, project needs and issues were detailed further. The present effort is focusing more on collecting more detailed information on the cost and space requirements for powder processing equipment. The floor space requirements will be detailed further through the 3-D manufacturing simulation.

Management Issues: Expenditures were generally as planned in the proposal. Ph. D. student Jae-Kyu Lee was funded throughout the reporting period. An undergraduate engineering student, Mr. Timothy Atobatele, has been recruited on an hourly basis to provide support services.
References


for Transmutation Systems,” Presentation to the AAA project, Las Vegas, NV, June
http://aaa.nevada.edu/pdffiles/Meyer6_21_01.pdf

National Research Council (1996) “Nuclear Wastes: Technologies for Separations and
Transmutation,” Committee on Separations Technology and Transmutation Systems, National Research Council
National Academy Press, ISBN # 0-309-05226-2, online at:
http://search.nap.edu/books/0309052262/html/

Transmutation,” http://www.nea.fr/html/pt/docs/1999/neastatus99/Phase1_report.html and
and

Targets and Fuels Dedicated to the Minor Actinides Transmutation in the Frame of the Cadra
programme” Proc. GLOBAL ’99 Conference.

Conference.

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. They also permit accurate calculations of the dynamics of components and 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.

![Interactive GUI process simulation: Two Robots ell.](image)

**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.