#### UNIVERSITY LIBRARIES

Fuels Campaign (TRP)

Transmutation Research Program Projects

1-2003

#### Design and Evaluation of Processes for Transmuter Fuel Fabrication

Georg F. Mauer University of Nevada, Las Vegas, georg.mauer@unlv.edu

Follow this and additional works at: https://digitalscholarship.unlv.edu/hrc\_trp\_fuels

Part of the Nuclear Engineering Commons, Oil, Gas, and Energy Commons, and the Robotics Commons

#### **Repository Citation**

Mauer, G. F. (2003). Design and Evaluation of Processes for Transmuter Fuel Fabrication. 1-34. Available at: https://digitalscholarship.unlv.edu/hrc\_trp\_fuels/39

This Presentation is protected by copyright and/or related rights. It has been brought to you by Digital Scholarship@UNLV with permission from the rights-holder(s). You are free to use this Presentation in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Presentation has been accepted for inclusion in Fuels Campaign (TRP) by an authorized administrator of Digital Scholarship@UNLV. For more information, please contact digitalscholarship@unlv.edu.

# Design and Evaluation of Processes for Transmuter Fuel Fabrication

Georg F. Mauer, Professor Department of Mechanical Engineering University of Nevada, Las Vegas

*This work is funded by the UNLV Transmutation Research Program (U.S. Department of Energy Grant No. DE-FG04-2001AL67358)* 

UNIVERSITY OF NEVADA LAS VEGAS

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

# **Table of Contents**

Introduction

- •Survey of Existing Fabrication Processes
- Machinery for Manufacturing
- •Process Automation: Concepts and Methodology
- •Solid Modeling of Processes
- Conclusion

## **Summary**

• Project Objective : examine autonomous robotic fuel fabrication processes with regard to hot cell and equipment design, operations, and costs.

• Fabrication processes for different fuel types differ in terms of equipment types, throughput, and cost.

• Design options are restricted by the requirement to employ only radiation-hardened machinery and components

• Benefit to DoE: decision support for the selection of the most suitable manufacturing process.

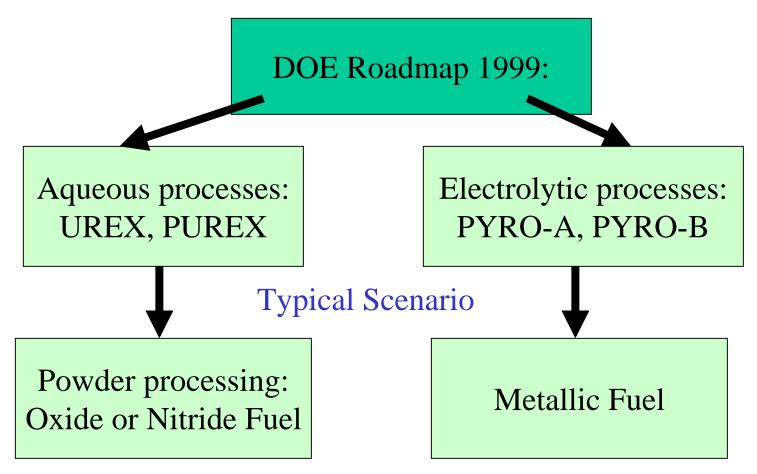
# **The Problem**

Nuclear waste reduction: Spent fuel quantities estimated at 86,000 metric tons must be safely stored for 10,000 years. Only about 1,000 tons are actinides and long-lived fission products.

**Transmutation:** Reduce the long term toxicity of longlived fission products (mostly Pu and actinides such as Am, Cm, Tc, I).

UNIVERSITY OF NEVADA LAS VEGAS

#### **Transmuter Fuel Fabrication**



#### **Fuel Fabrication Processes**

#### **Basic Manufacturing Options :**

1. Metallic Casting

2. Powder Processing, e.g. MOX fuels (several possible configurations)

# Fuel Fabrication Processes ANL Concepts

# **Potential Fuel Types**

# 1) Metal Alloy

- Casting or PM (Powder) fabrication
- High density
- Low smear density and gas plenum required for high burnup
- Requires liquid metal bond
- Behavior well understood, fuel performance model available

#### **Fuel Fabrication Processes**

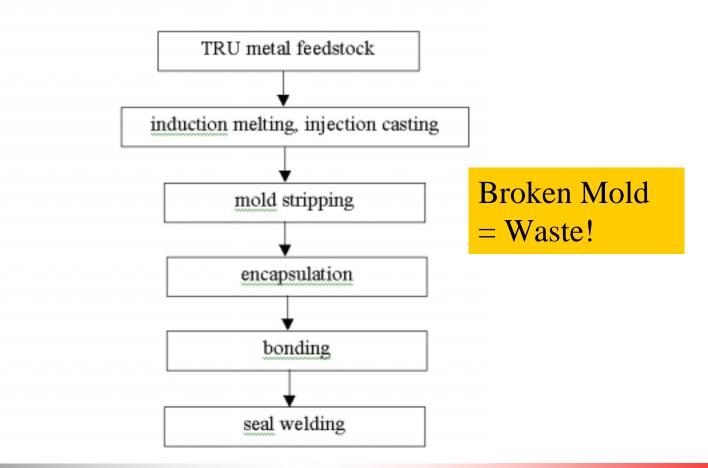
#### **Manufacturing Sequence for Cast Metallic Fuel (ANL):**

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)

# Fuel Fabrication Processes ANL Concepts

#### Metal Fuel by Injection Casting



#### UNIVERSITY OF NEVADA LAS VEGAS

# Fuel Fabrication Processes ANL Experience with Metallic Fuel Fabrication

- Simple, rapid production process
- Volatility of americium is problematic (Trybus, et. al. (1993))
- 40% **Am** loss
- Evaporation rate of  $\leq 5$  g/s from melt surface
- Ca, Mg impurities from Molten salt separation process caused eruptions

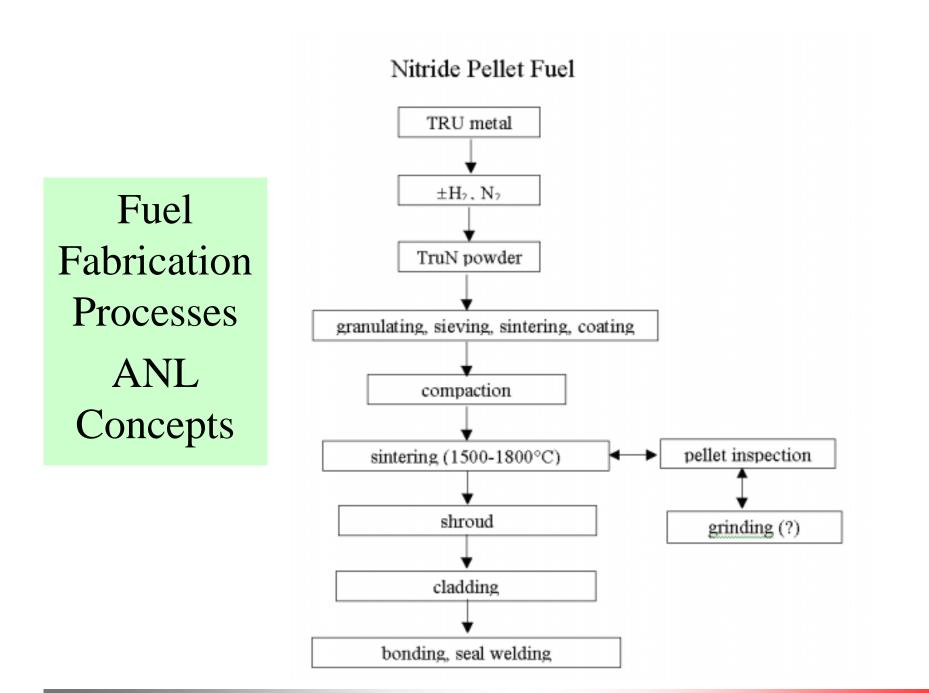
# Fuel Fabrication Processes

## **Ceramic Fuels**

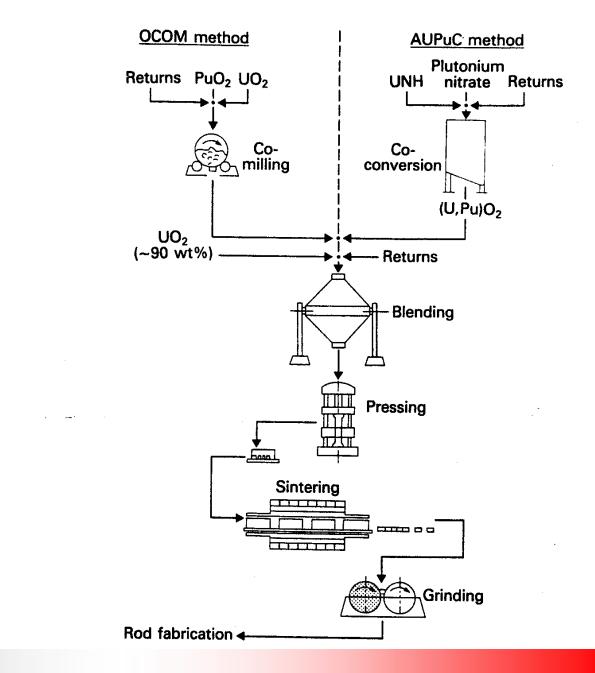
#### **Manufacturing Sequence for Ceramic Fuel :**

1. Manufacture particles by wet chemical process or direct reaction (1 to 30 um dia.)

- 2. Compaction of particles into pellet form.
- 3. Sinter pellets at 1400°-1800°C.
- 4. Inspect pellets
- 5. Assemble pellets into cladding tube
- 6. Add bonding material (He or Na)
- 7. Seal cladding tube by welding
- 9. Inspect assembled fuel pin (radiography, dimensional and clad defects)



#### UNIVERSITY OF NEVADA LAS VEGAS



#### MOX Fabrication Process (Siemens)

#### UNIVERSITY OF NEVADA LAS VEGAS

# Fuel Fabrication Processes ANL General Comments on Powder Processing

- Lower processing temperatures
- Densification of metals assisted by application of force
- Extrusion, swaging, drawing
- Densification of nitrides by thermally driven sintering process only (hot pressing is probably not practical)
- Dispersions and metal alloy fuels possible
- Powder processing is only viable route for nitride fuels
- Uniform distribution of components
- Diffusion barrier easily incorporated

Fuel Fabrication Processes ANL General Comments on Fuel Fabrication Routes

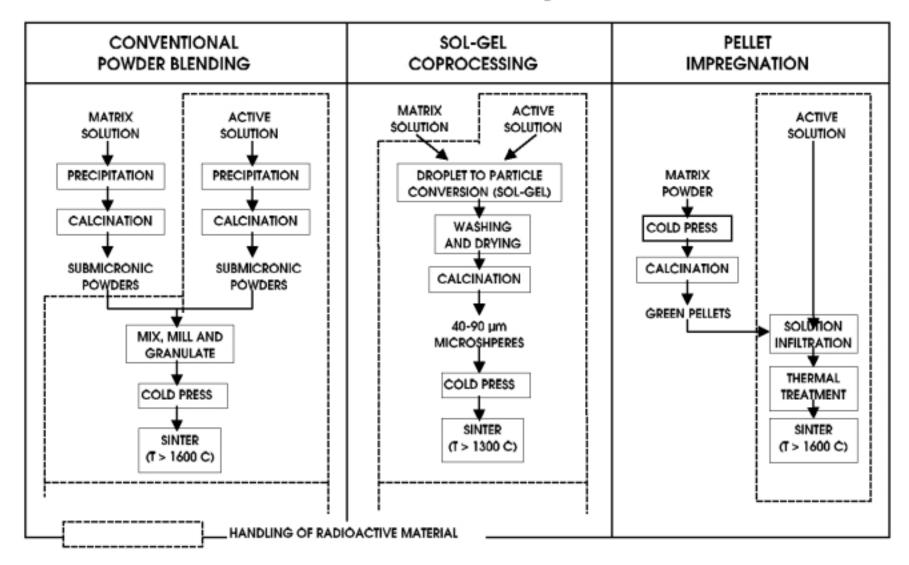
#### **Powder Processing Disadvantages**

- Requires formation and handling of fine powder
- Hydriding/dehydriding requires hydrogen
- Texturing possible on extrusion of metals

#### Transmuter Fuel Fabrication Issues:

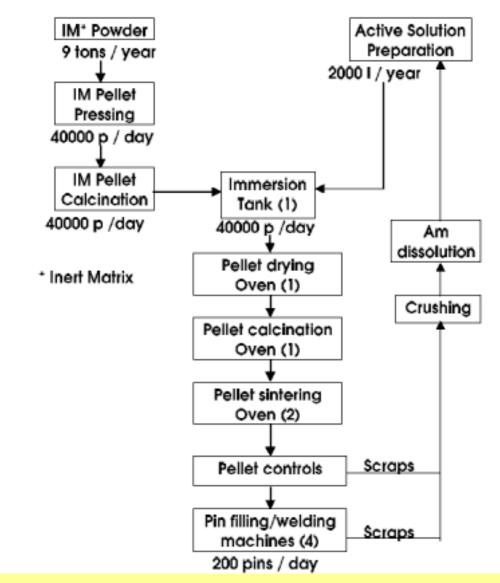
- Hot cell required
- Criticality concerns mandate small batch sizes
- Large fuel quantities suggest process automation
- Equipment for hot cell operation must be identified or developed.
- Material flow and operational sequence
- Long term reliability must be ensured
- Design must prove he ability to cope with a wide range of contingencies (e.g. equipment failures, spillage, breakage)

#### Pellet fabrication procedures



Three processes for Americium Fuel Fabrication (Haas et al.), 1998

UNIVERSITY OF NEVADA LAS VEGAS

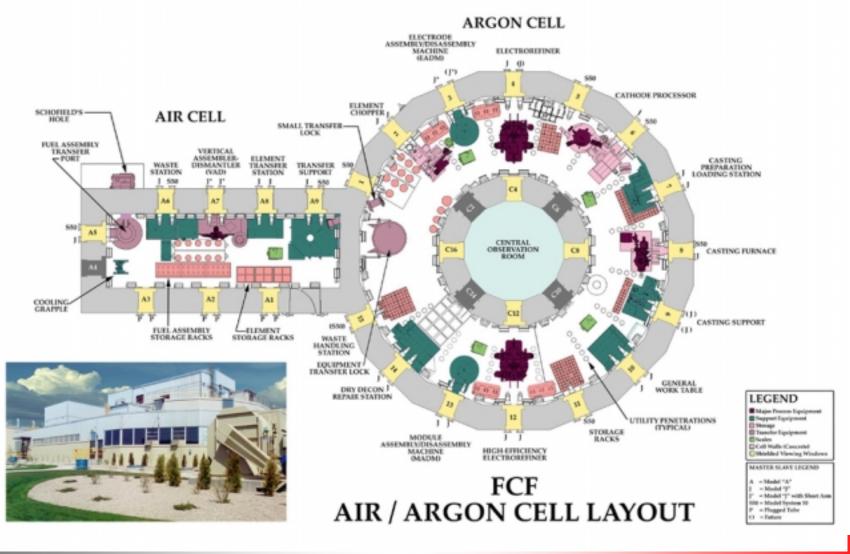


Flow sheet for americium target fabrication INRAM process 1 ton Am/year

Americium Fuel Fabrication for 1 ton of Am/year (Haas et al.), 1998

UNIVERSITY OF NEVADA LAS VEGAS

## Fuel Conditioning Facility at ANL West, Idaho Falls. Hot Cell Schematic.



UNIVERSITY OF NEVADA LAS VEGAS

# Fertigungsprozess Manufacturing Process Diagram ANF Lingen im Brennelementwerk der ANF Lingen

UF5 Dry conversion

**UF<sub>6</sub>-Trockenkonversion** 

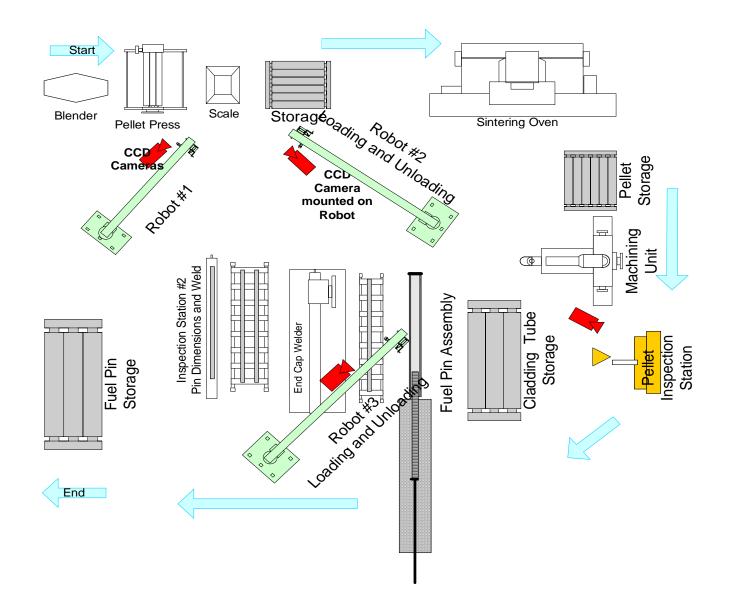
Fuel rod assembly

Brennelementmontage

#### BE waschen u. trocknen Reaktions-Drehrohrofen Skelettmontage **BE-Endkontrolle** behälter Komponenten-**BE-Lager BS-Endkontrolle** Helium Leak Inspection **BE-Montage** Scheibensilo Autoklav Lecksuchanlage Schweissmaschine UF<sub>6</sub>-Zylinder **BE-Trans-**(unt. Endstopfen) portbehälter Nauta-Mischer Anreicherungs-UF<sub>6</sub>-EINGANG messanlage Hammermühle Schweissmaschine (oberer Endstopfen) Rollkompaktor Tabletteninspektion • Welding Machine BS-Lade-Pulver-Granulator maschine Brennstabfertigung vorbereitung **Brennelement-**UO<sub>2</sub>-Pulver Schleifmaschine Fuel Rod Manufacturing Powder preparation versand Grinder **Lablettenpresse** Shipping Sinterofen Tablettenherstellung Pellet production

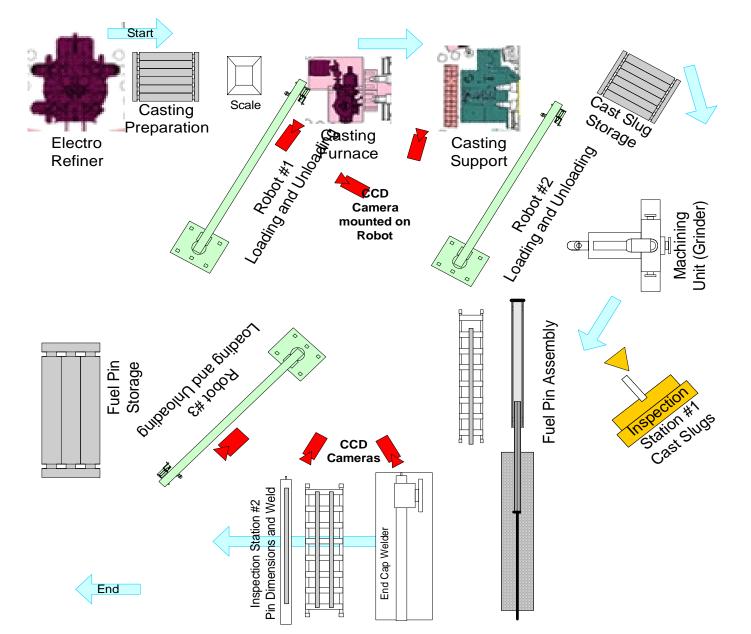
ADVANCED NUCLEAR FUELS

UNIVERSITY OF NEVADA LAS VEGAS



#### Possible Configuration for Powder Processing Fabrication Work Cell (e.g. Oxide or Nitride Fuel)

UNIVERSITY OF NEVADA LAS VEGAS



**Possible Configuration for Metallic Fuel Fabrication Work Cell** 

UNIVERSITY OF NEVADA LAS VEGAS

#### **Preliminary Cost Estimates, Metallic Fuel Fabrication.**

Equipment	Estim. Cost US \$	Estimated Area requirement $ft^2$	Comments
Inductionfurnace+Preparation Area	2.0Million	50	Source: ANL West
Reusable Mold	500K		No standard process exists. Conventional methods have not been adapted to hot cell use.
Fuel Pin Assembly Unit (Insertion, Encapsulation, bonding and welding)	2.0 Million	40	Custom equipment
3 Robots, approx. 1.5 m work envelope at 270 deg. range	1.5 Million	60	
Inspection stations 1 (slugs) and 2 (pins) (20 sq.ft. ea.)	2Million	40	
Machining Unit (Grinder)	500K	20	Provide for Dust Containment
Supervision (cameras and controllers)	500k	none	
Product storage		30	
Total Equipment	<b>\$9 Million</b>	240 sq.ft.	

#### **Preliminary Cost Estimates, Powder Processing**

Equipment	Estim. Cost		Area	Comments
	in US \$	requirement	$ft^2$	
Blender	50K	10		
Pellet press	500K	20		
Sintering oven	1.5Million	100	(	Custom equipment
Machining Center (Grinder)	500K	20	d v s	Custom equipment. Dust seal and lust suppression required. E.g.: wet process would reduce dust and surface temperatures during grinding.
Pellet Inspection Station	1Million	10	(	Custom equipment
Fuel Pin Assembly Unit (Pellet insertion, encapsulation and bonding, welding)	2Million	40	(	Custom equipment
3 Robots, approx. 1.5 m work envelope ea. at 270 deg. range	1.5 Million	60		
Supervision (cameras and controllers)	500k			
Product storage		30		
Final Inspection station (Fuel rod dimensions and weld)	1Million	20		
Total Equipment	\$8.55M	$310~\mathrm{ft}^2$		

#### UNIVERSITY OF NEVADA LAS VEGAS

# **Metallic Fuel Fabrication:**

A single manufacturing cell would require approx. 200 sq. ft. of hot cell space at a cost of approx. \$30,000/ft<sup>2</sup> or \$7.2M for the hot cell space. Total installation cost approx. \$16.2Million.

## **Powder Processing:**

A single manufacturing cell would require approx. 310 sq. ft. of hot cell space at a cost of approx.  $30,000/ft^2$  or 9.3M for the hot cell space. Total installation cost approx. 17.85Million.

### **Fuel Fabrication Processes**

#### **Generic issues common to all fuel types:**

- TRU Waste (e.g Am vapor, dust from powder)
- Dimensional Inspection, intermediate and final
- Heating or melting
- Assembly: e.g. placement of pins or pellets into cladding tube **Issues in Powder Processing:**
- Manufacture uniform particles
- Compact particles into some aggregate form (e.g. pellets)

#### **Other needs:**

Welding

Sintering

Injecting He or Na into cladding tube

Commercially available Equipment:

•Robots for Hot Cells
•Nuclear Manufacturing Equipment
•Camera Systems (CCD and GaAs)
•Wireless Communication Systems (GaAs)

UNIVERSITY OF NEVADA LAS VEGAS

## **Manufacturing Automation Modeling**

Support of the following elements of the plant design process:

Plant sizing, e.g. placement of equipment, determination of hot cell dimensions.

Determination of the adequacy of current generation sensors and robotics

Possible R&D needs for development of new technologies.

Capability for extensive simulations of contingency and accident simulations, resulting in shortened duration of mock-up experiments and enhanced reliability of plant operations.

#### Fuel Fabrication Equipment

Wälischmiller Robot:

- •Modular design
- •All drives and Sensors in Base
- •30 to 240 kg Load capacity



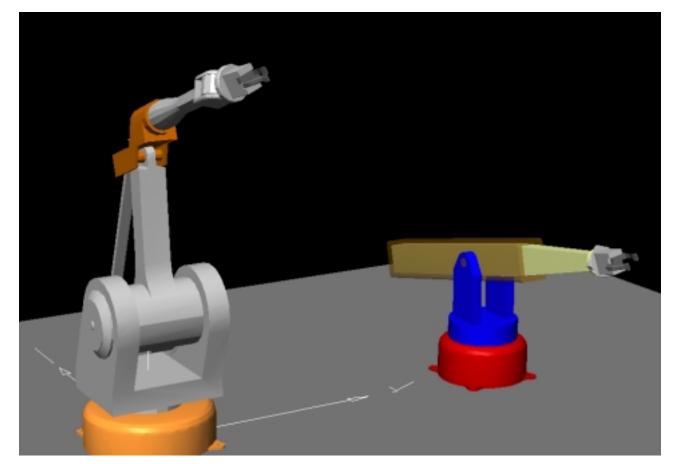
## Solid Modeling of Processes

The candidate fuel manufacturing processes are being modeled using the following simulation software tools:

- •MSC Visual Nastran (Dynamics)
- •ProEngineer (Solid Modeling)
- •Matlab (Control System)

### Solid Modeling of Processes

Simulation example

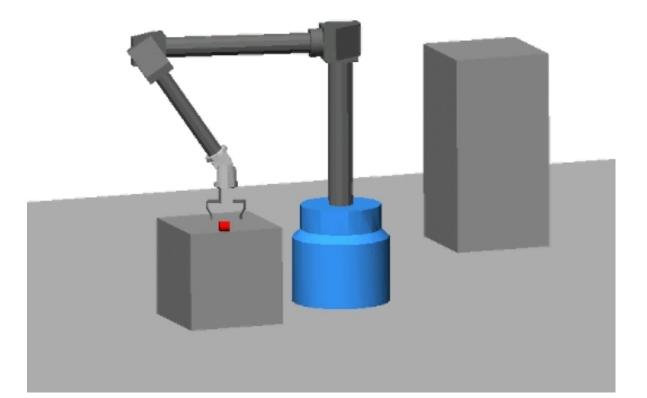


Interactive GUI process simulation: Two Robots Workcell. Created with Visual Nastran.

UNIVERSITY OF NEVADA LAS VEGAS

### Solid Modeling of Processes

Simulation example



Interactive GUI process simulation: Grasping a Pellet. Created with Visual Nastran.

UNIVERSITY OF NEVADA LAS VEGAS

# Fuel Fabrication Processes Conclusion

Transmuter fuels will likely be manufactured in automated hot cell facilities.

Our project objective is the conceptual design of automated hot cell manufacturing facilities for various fuel types.

We are in the process of developing a comprehensive solid model of workcell robotics and control, which will allow detailed simulations of process dynamics.

The design options will be compared in terms of complexity, reliability, and cost.

# Design and Evaluation of Processes for Transmuter Fuel Fabrication

End of Presentation

UNIVERSITY OF NEVADA LAS VEGAS