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Design and Evaluation of Processes for Transmuter Fuel Fabrication

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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

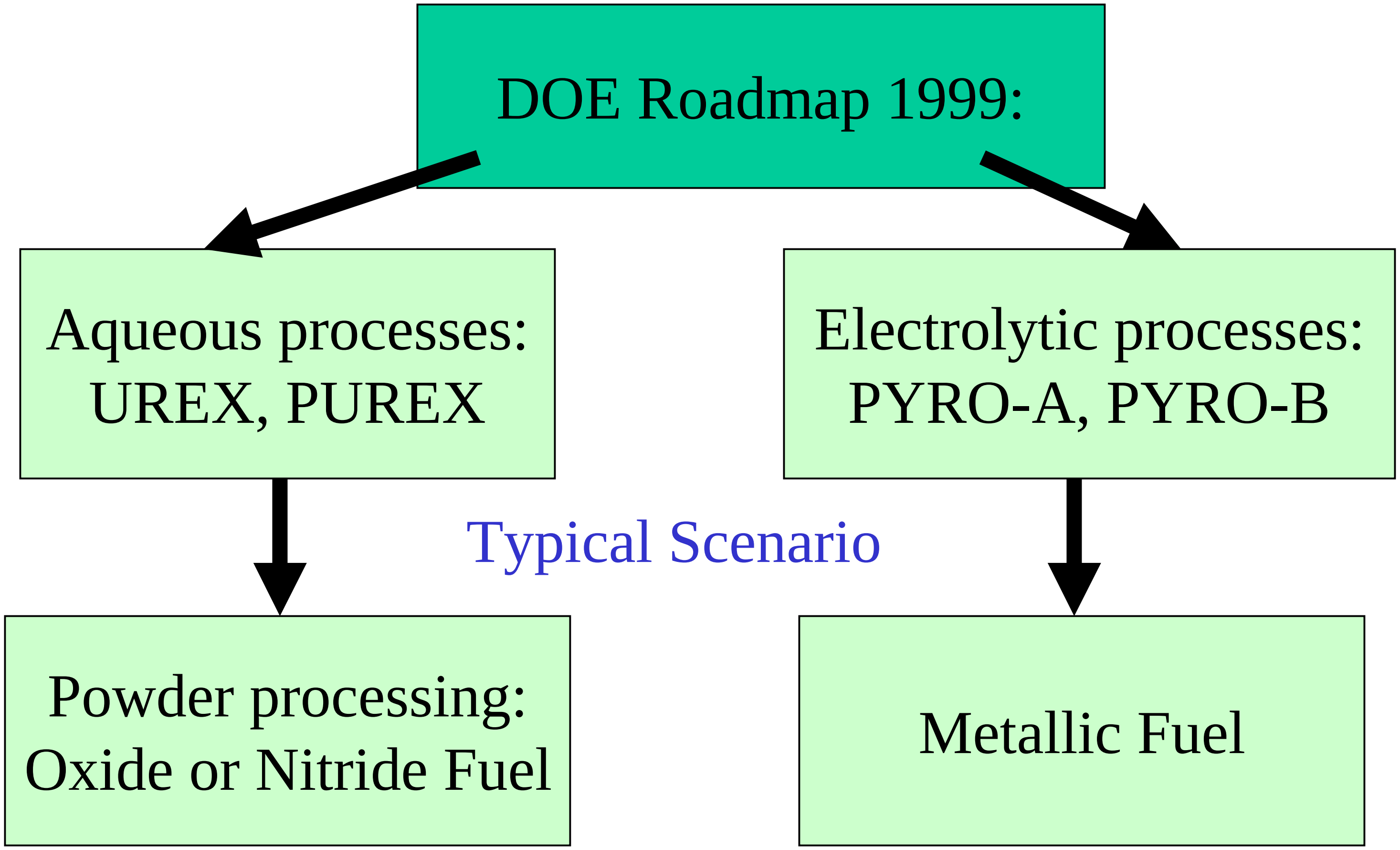
• Benefit to DoE: decision support for the selection of the most suitable manufacturing process.

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 long-lived fission products (mostly Pu and actinides such as Am, Cm, Tc, I).

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

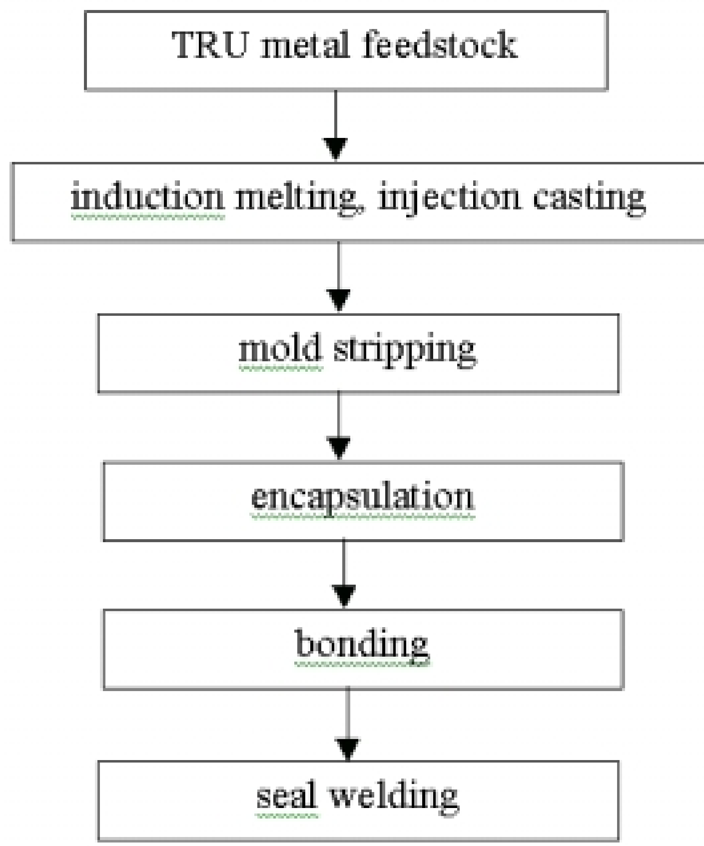
Fuel Fabrication Processes

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



Broken Mold = Waste!

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

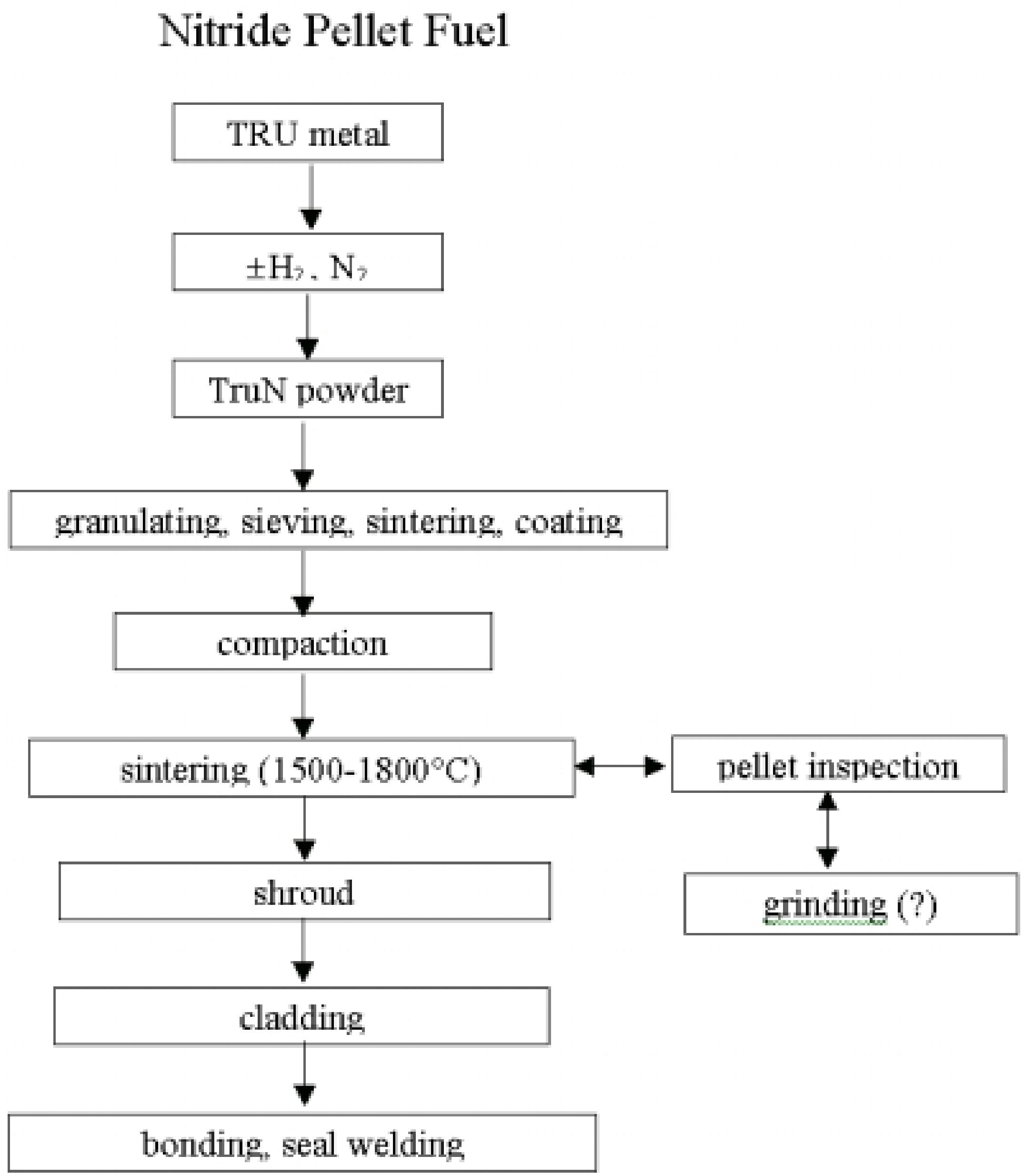
Ceramic Fuels

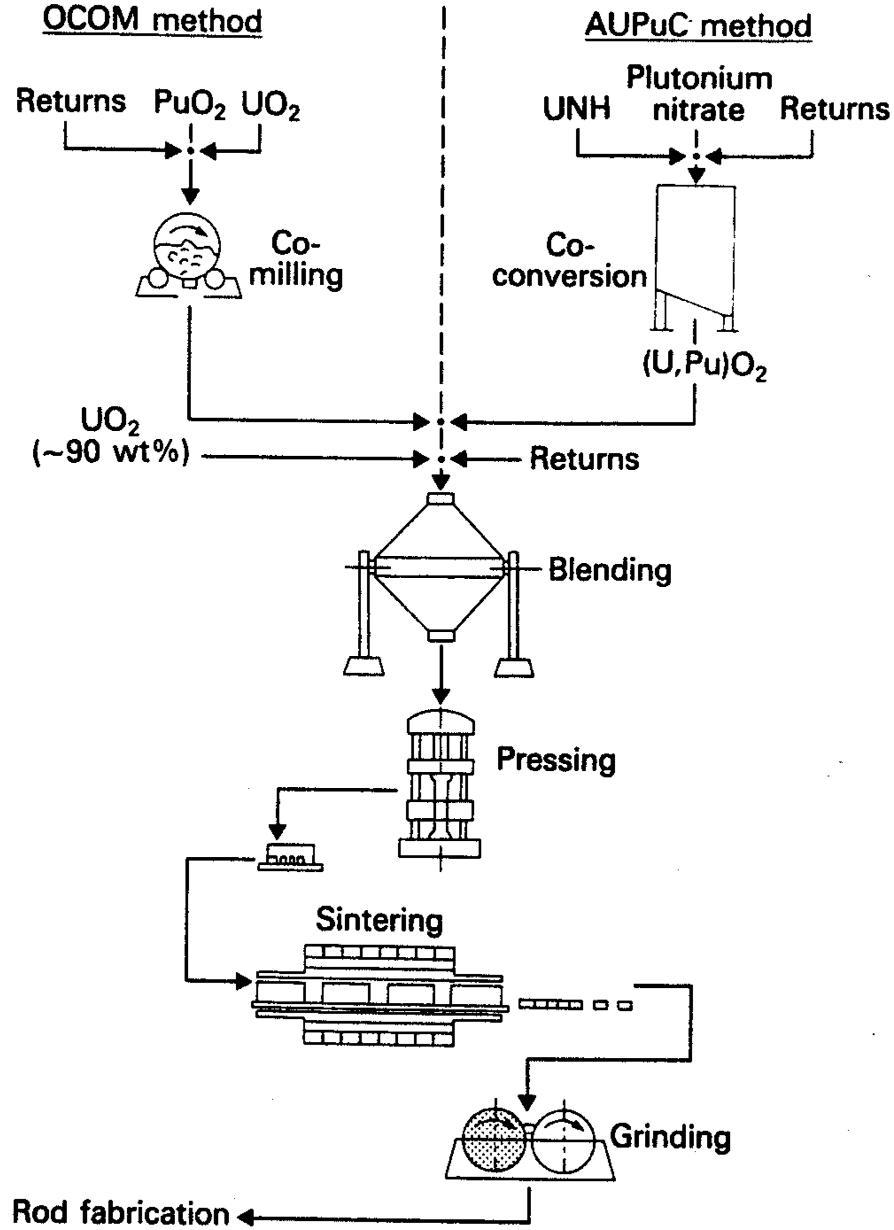
Manufacturing Sequence for Ceramic Fuel :

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)

Fuel Fabrication Processes

ANL Concepts





MOX Fabrication Process (Siemens)

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

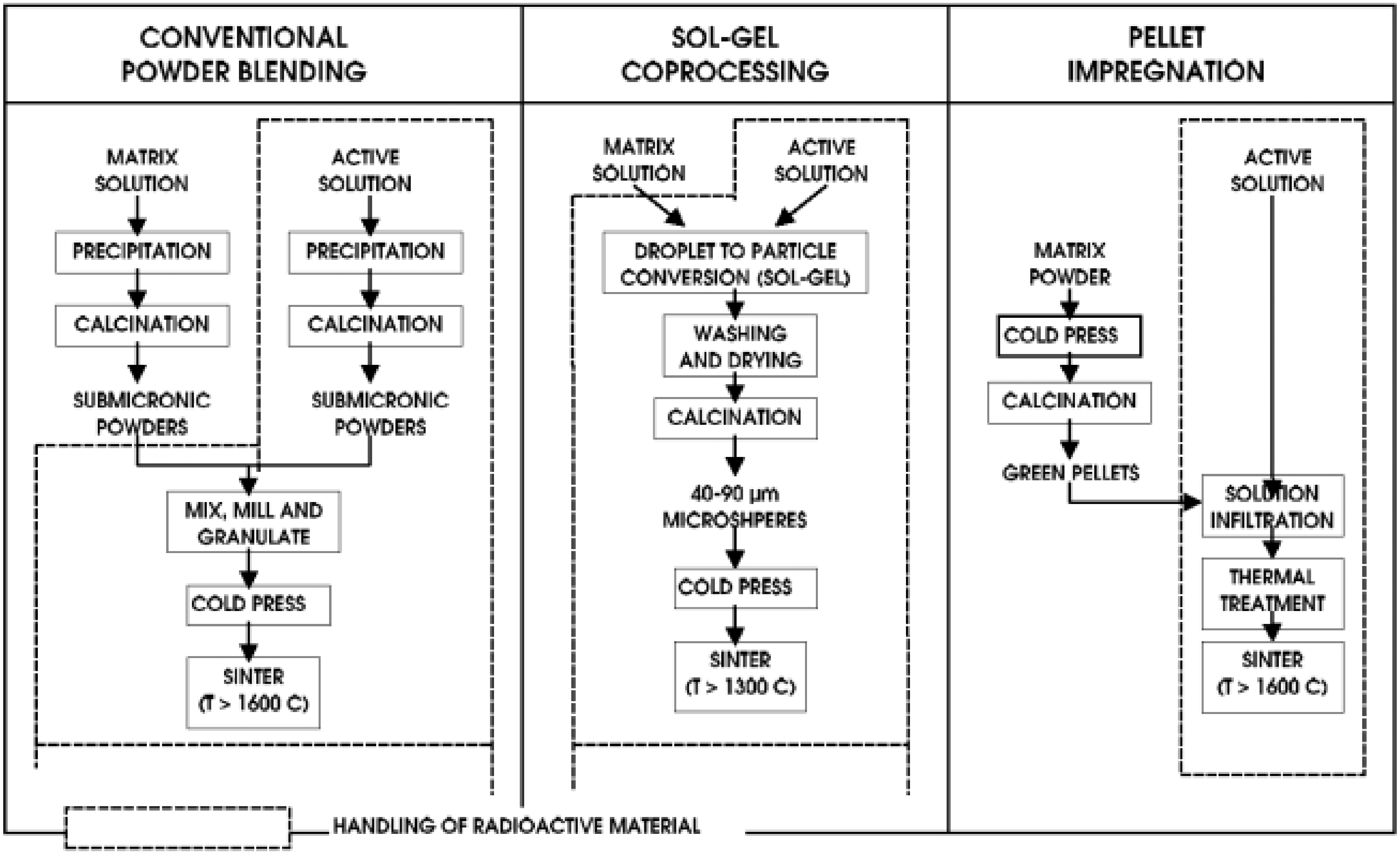
Powder Processing Disadvantages

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

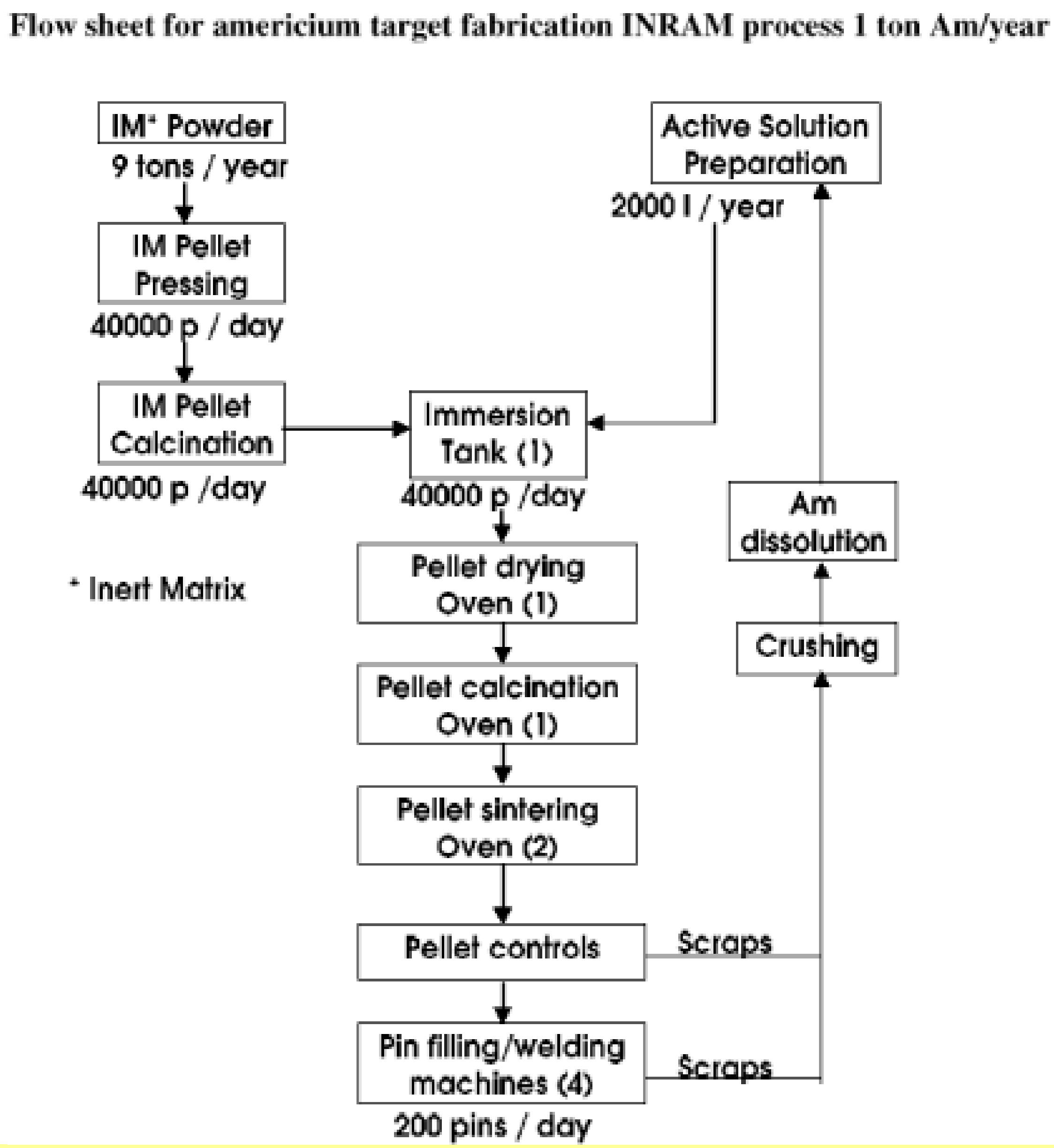
Transmuter Fuel Fabrication Issues:

- 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

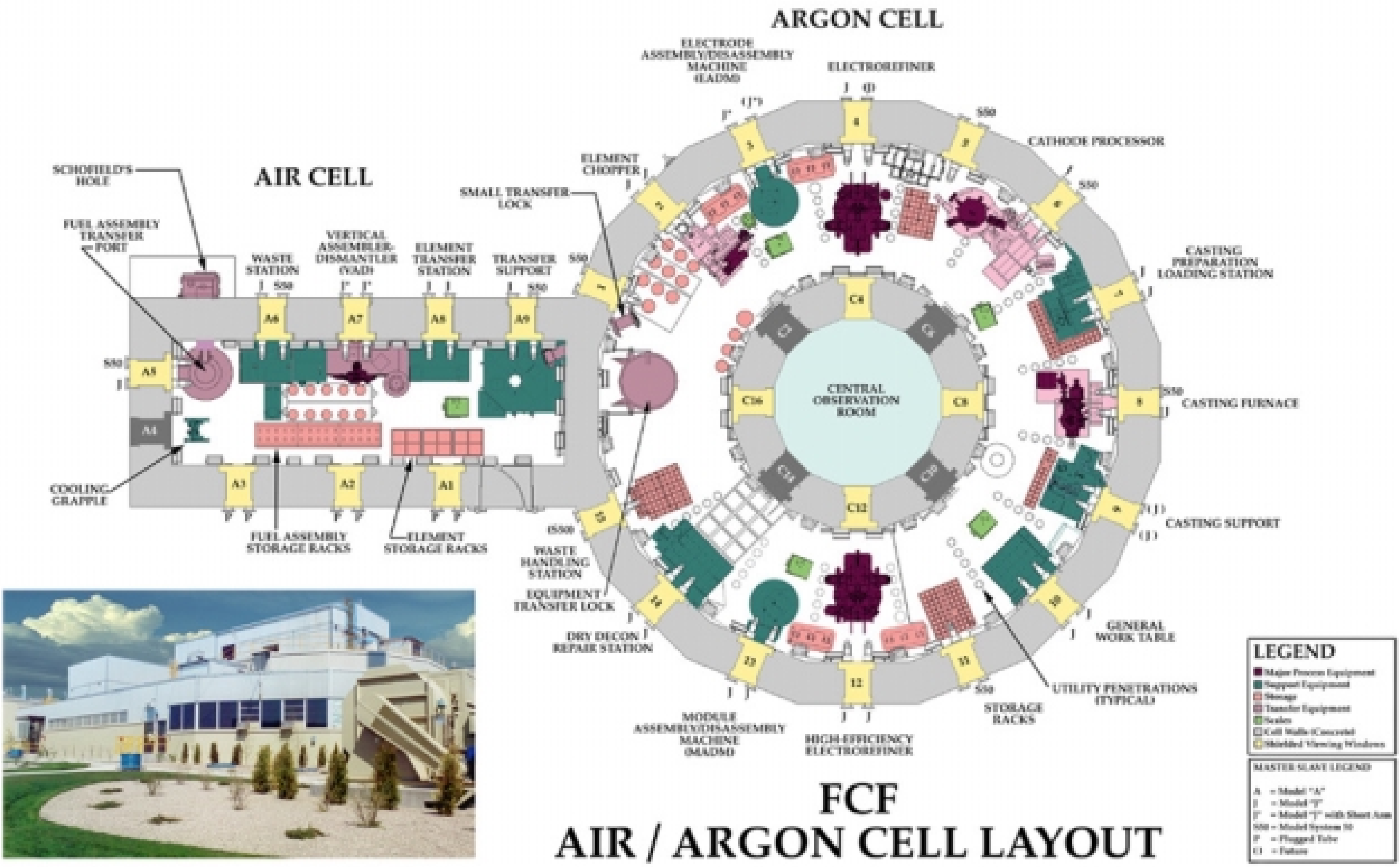


Three processes for Americium Fuel Fabrication (Haas et al.), 1998



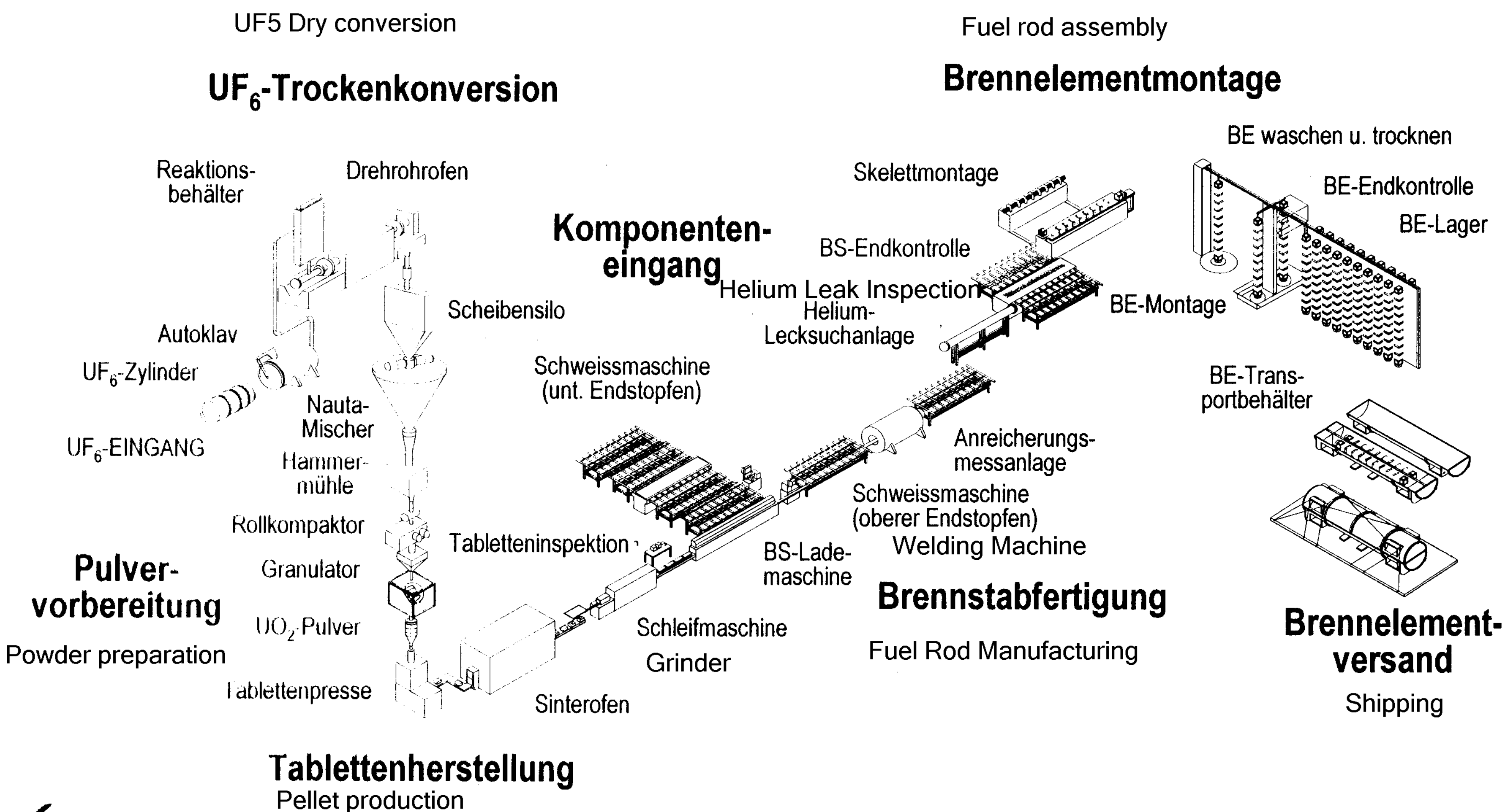
Americium Fuel Fabrication for 1 ton of Am/year (Haas et al.), 1998

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

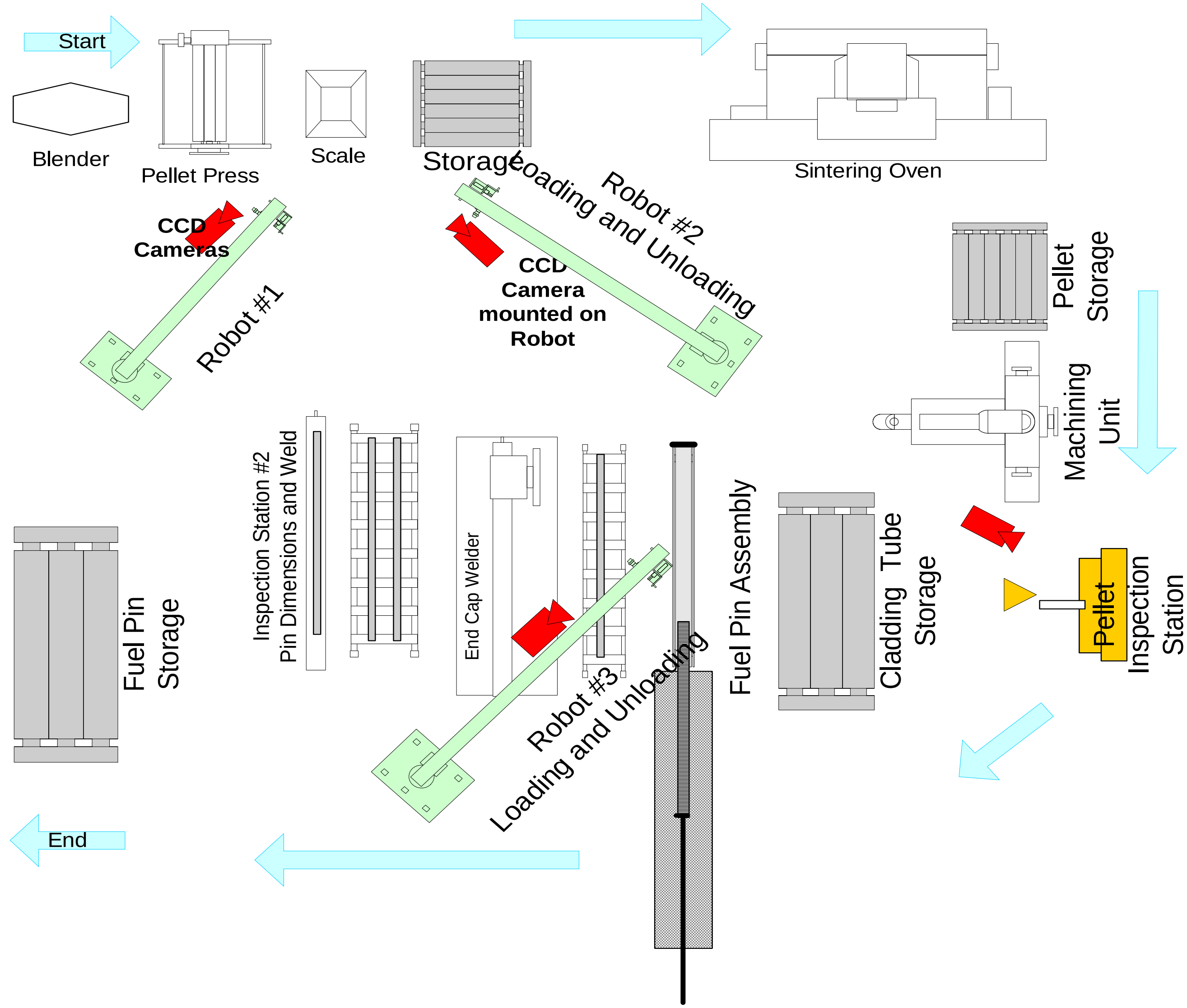


Fertigungsprozess im Brennelementwerk der ANF Lingen

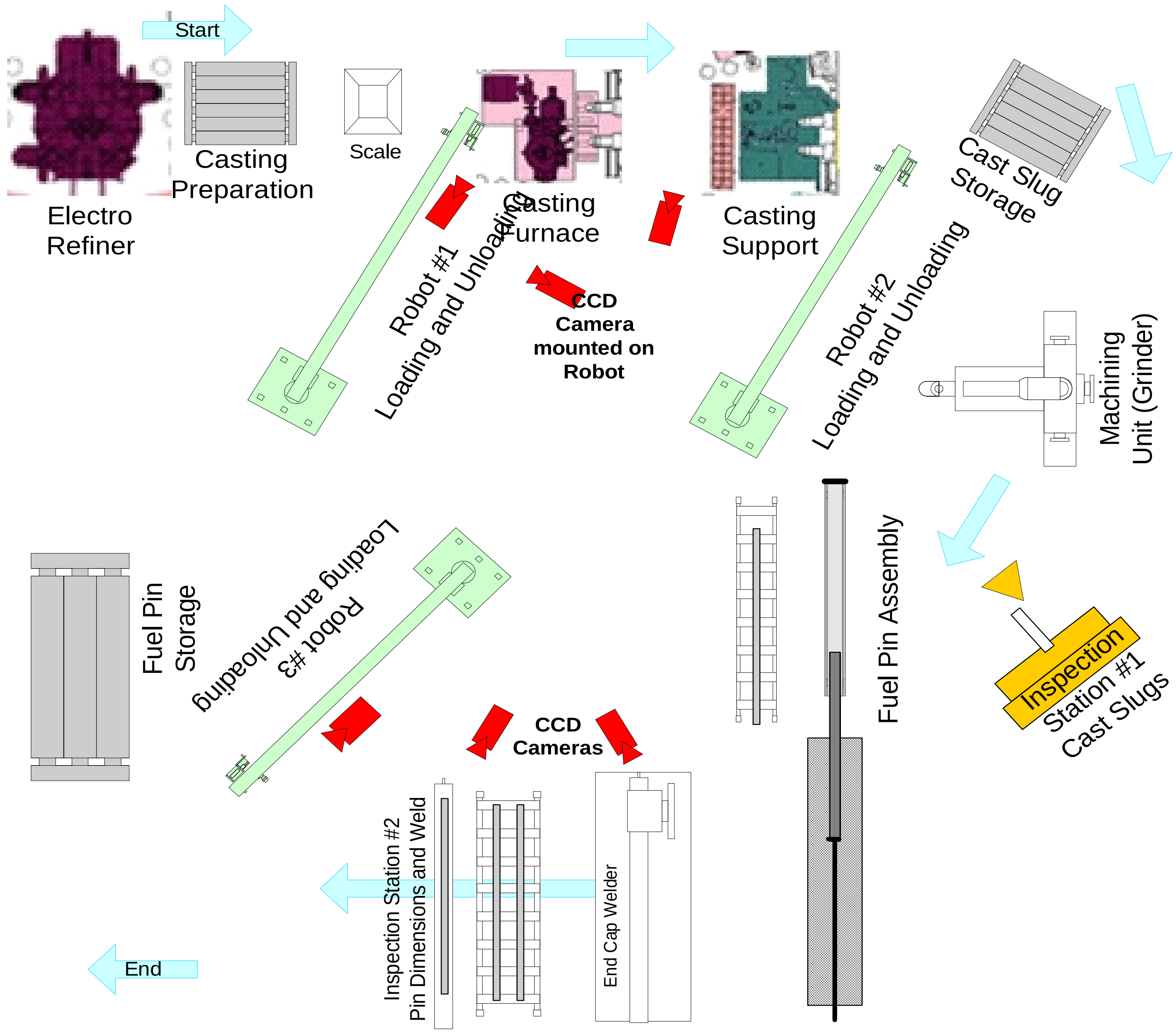
Manufacturing Process Diagram ANF Lingen



ADVANCED NUCLEAR FUELS
FRAMATOME



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



Possible Configuration for Metallic Fuel Fabrication Work Cell

Preliminary Cost Estimates, Metallic Fuel Fabrication.

Equipment	Estim. Cost US $	Estimated Area requirement ft^2	Comments
Induction furnace + 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	**$9 Million**	**240 sq.ft.**	

Preliminary Cost Estimates, Powder Processing

Equipment	Estim. Cost in US $	Estimated Area requirement ft^2	Comments
Blender	50K	10	
Pellet press	500K	20	
Sintering oven	1.5Million	100	Custom equipment
Machining Center (Grinder)	500K	20	Custom equipment. Dust seal and dust 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 ft^2**	

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^2 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. \$17.85 Million.

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)

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

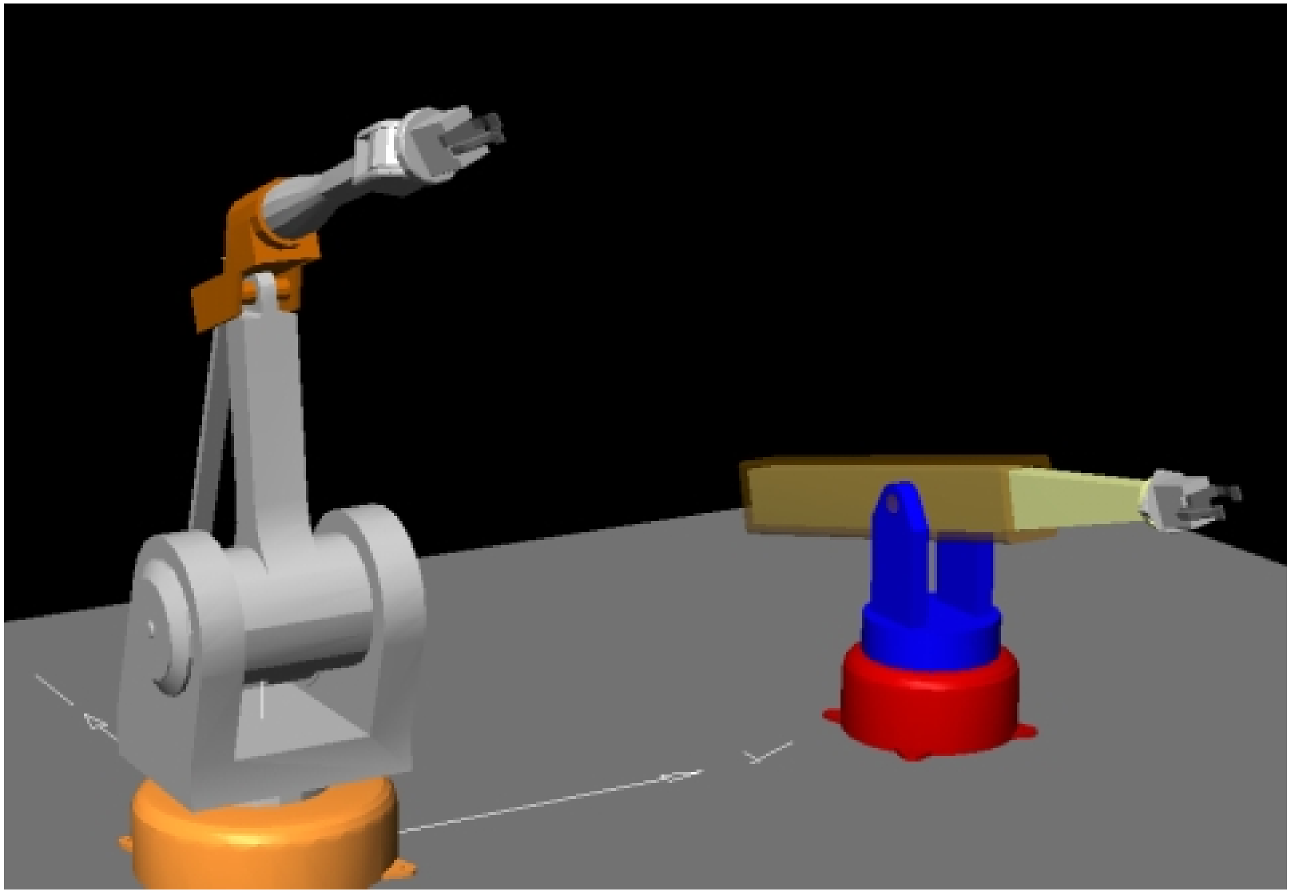
Solid Modeling of Processes

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

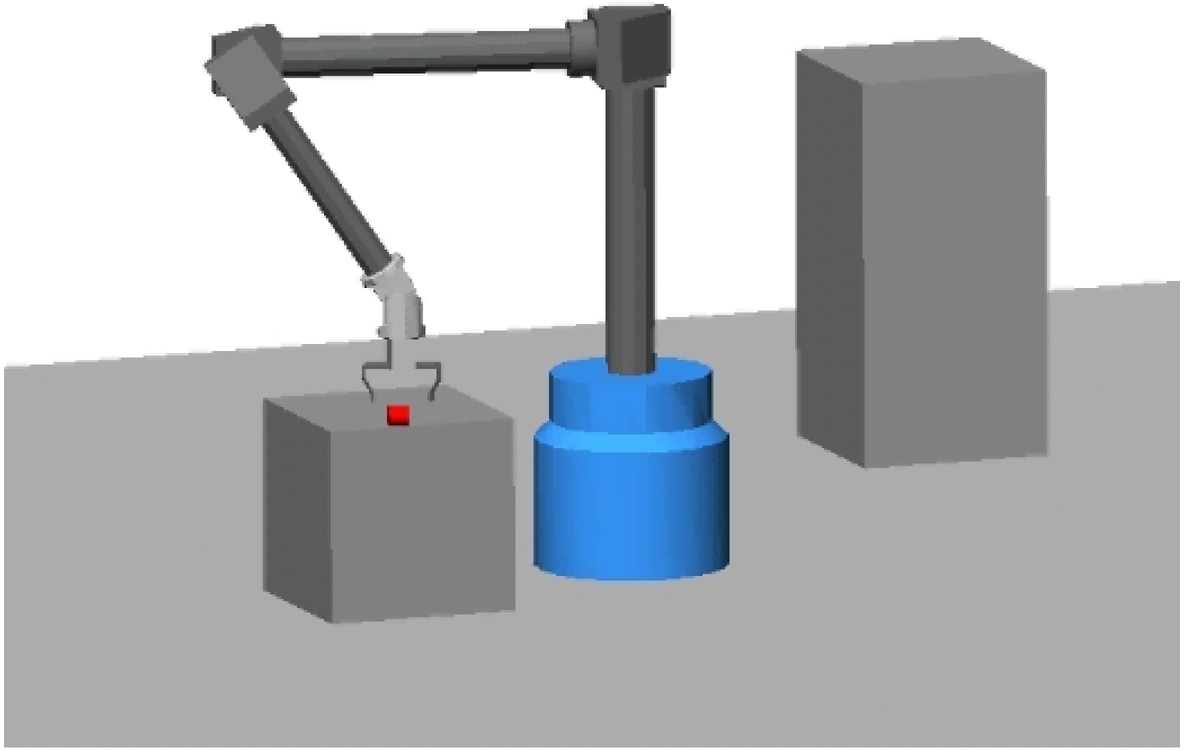
Simulation example



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

Solid Modeling of Processes

Simulation example



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

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