# Transmuter Fuel Fabrication: Design and Analysis of Robotic Manufacturing Processes

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## Introduction

The large-scale deployment of remote fabrication and refabrication processes will be a requirement for the implementation of transmutation (Meyer, 2001). Fabrication processes for different fuel types differ in terms of equipment types, throughput, and cost. A comprehensive assessment of the issue is presented in NEA, 2000. Many aspects of manufacturing will be common to both powder-based and metallic fuels manufacturing. These comprise: fuel pin assembly, welding of the cladding tubes, and dimensional inspection of slugs, pellets, and completed fuel pins. The paper describes the design of robot arms, control strategies and end effectors for material handling in a hot cell, such as pellet insertion into fuel rods and fuel rod handling. The dynamics of the robots and the objects handled by them are analyzed in detail using state of the art software tools. In addition to the evaluation and testing of normal assembly operations, the simulation provides for a comprehensive analysis of forces and loads, including those occurring during atypical events such as collisions. The results are to form part of a decision support data base for the selection of the most suitable manufacturing process.

## Simulation of Fuel Fabrication

The simulations presented here were developed on a fast dual Xeon processor workstation using ProEngineer solid modeling software in conjunction with MSC VisualNastran4D and with Matlab Simulink for control. The CAD solid model is augmented in the VisualNastran4D environment by dynamic system parameters such as material properties and motion constraints such as joint definitions. The completed robot is actuated by forces and torques determined by the robot controller. The robot controller plans the required end effector trajectory using inverse kinematics (i.e. computing the required set of joint angles so that the end effector will arrive at the target location.) For each robot joint, smooth departures and arrival trajectories are generated. Fig.1 shows the trajectory of the resulting motion for the robot base (joint 1). 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. Fig. 2 illustrates a Waelischmiller 6-axes hot cell robot picking a part from a table. The robot's 6 axes are controlled from Matlab Simulink (one controller for each joint) using a PID algorithm.

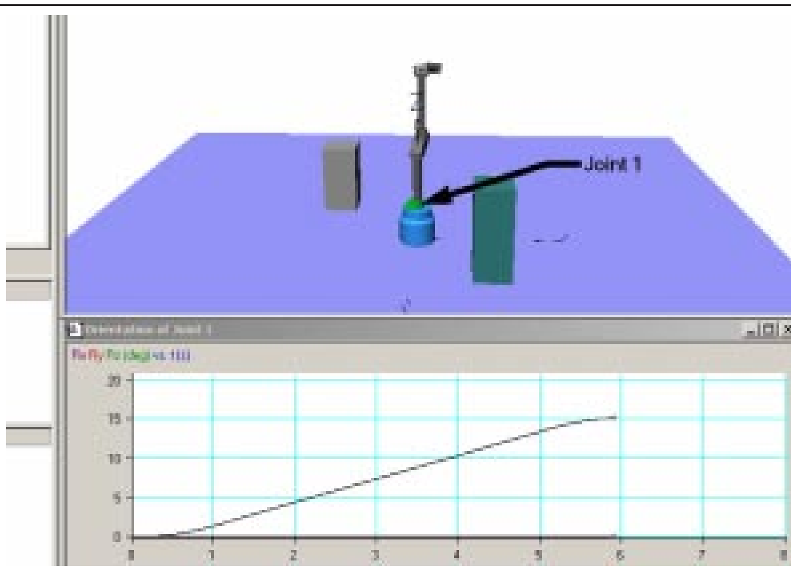


**Figure 1** Smooth *'Bang-Bang'* motion of Joint 1 (Rotation of Robot Base). Visual Nastran Simulation

The end effector design is crucial to all material handling: Incorrect grasping (typically resulting from misalignment) can easily lead to the robot dropping an object or propelling it away from the scene. The reliability of the assembly process can be improved through the design of compliant grippers and by the minimization of contact forces during grasping. Unusual events and accidents can occur. Good hot cell design must seek to avoid undesired events, and to recover from them after an occurrence. The simulation provides a capability for analyzing irregular events such as collisions and ejected parts. It allows for the comprehensive examination and testing of failure scenarios as well as recovery procedures, and thus for the iterative optimization of all mechanical hot cell components, ensuring maximum reliability and safety.

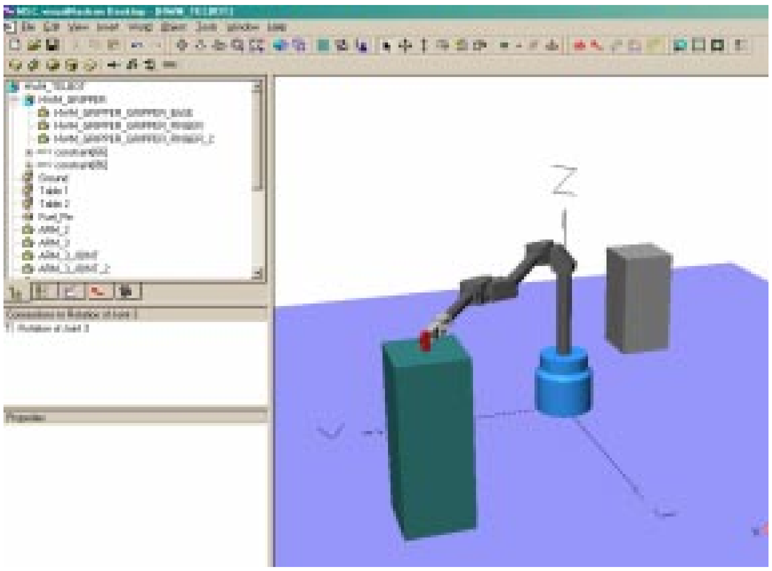


**Figure 2** Interactive GUI process simulation: Part grasping with Waelischmiller Hot Cell Robot.
Visual Nastran Simulation

Movie sequences illustrating aspects of assembly sequences and accident scenarios will be presented at the conference.

## References

**Meyer, M**. (2001) “The U.S. Program for the Development of Inert-matrix Fuel for Transmutation Systems,” Presentation to the AAA project, Las Vegas, NV, June http://aaa.nevada.edu/pdffiles/Meyer6_21_01.pdf

**NEA** (2000) “Status and Assessment Report on Actinide and Fission Product Partitioning and Transmutation,” http://www.nea.fr/html/ndd/docs/2001/nea3108-actinide.pdf, December.