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Assessing Nuclear Proliferation Capability in Additive Manufacturing

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Background

- Additive Manufacturing (AM):
  - Generate Complex Geometries
  - Work with Ceramics/Polymers/Metals
    - Includes **Nuclear Materials**
  - Requires a "Blueprint"
- Nuclear proliferation:
  - Spread nuclear weapon materials/fuel and tech illegally
- **Mitigation: Export controls**
  - 10 CFR Part 110
  - Atomic Energy Act of 1954
  - Nuclear Suppliers Group
  - **AM is not subject to same export controls**

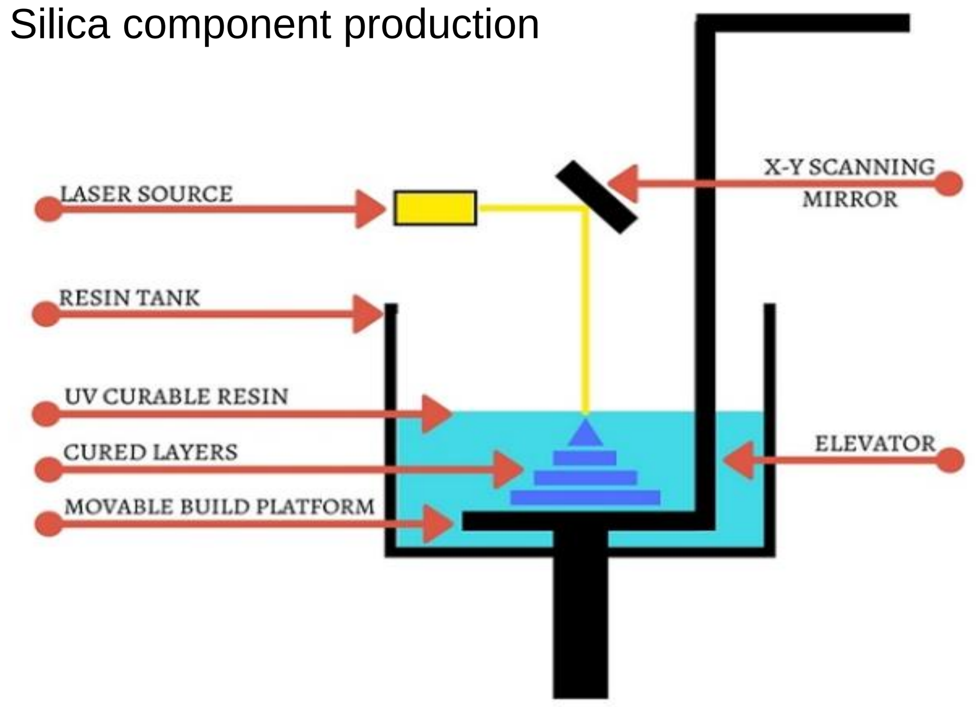
Threat

- Proliferators do not need specialists
- Need a (stolen) blueprint for components
- Accelerates civilian nuclear programs
  - Widespread Nuclear Material
- Obtain key technologies from multiple nuclear cycle
  - Printing enrichment centrifuges
  - Printing Nuclear Fuel
- Manufacture conventionally complex components for weapons of mass destruction [2]
- Technology is becoming rapidly widely available
- Unknown side channel information leakage

AM Capabilities

Stereolithography:

- Printed Aluminum Ceramics
  - Colloidal Mixture with Ceramic Powder
- Novel method for production of thorium dioxide using STL
- Volumetric Manufacturing (non layer-by-layer method)
- Resin solutions properties can be tailored
- Silica component production



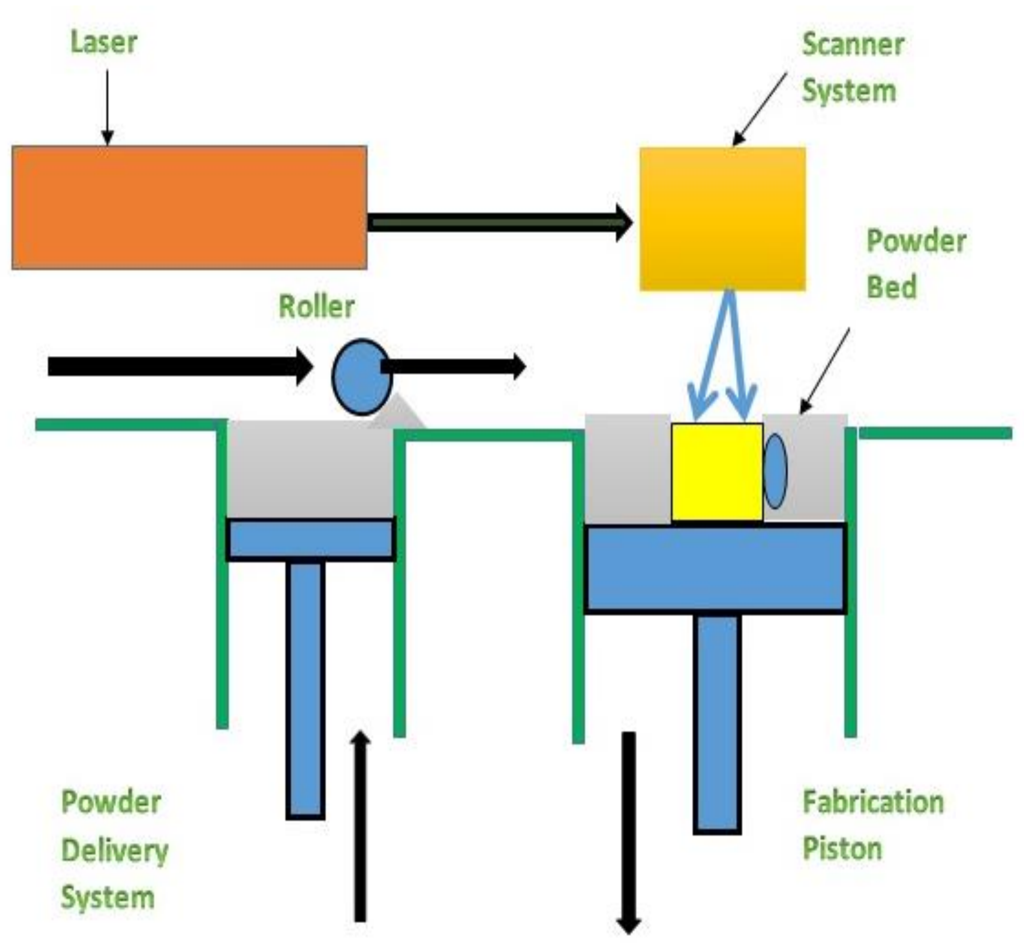
Stereolithography [3]

Fused Deposition Modeling (FDM):

- Generated Filaments embed with ~55 vol% ceramic material
- Thermoplastic Filaments (Conventional 3D printing)

Selective Lasering/Electron Beam Melting and Sintering:

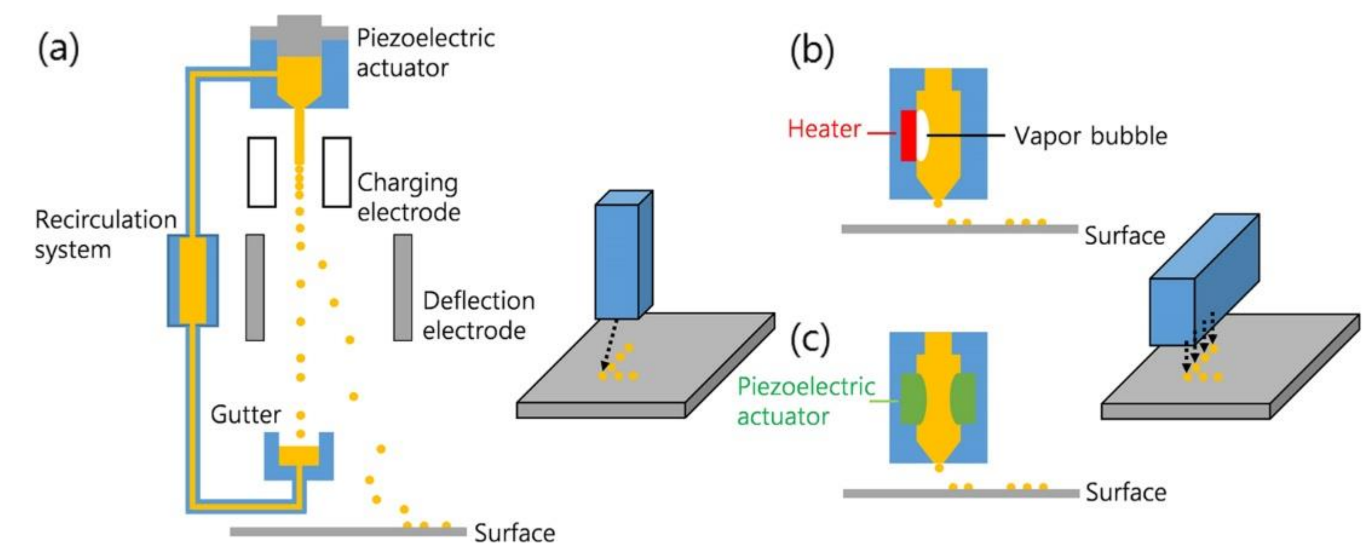
- Printed Nuclear Grade Alloys (V-6Cr-6Ti)
- Printed Super Alloys (Ti-6AL-4V)
  - "Refined Microstructures"
- Resolution of beam creates "extra-fine" microstructures
- Capable of producing materials with superior mechanical properties
- Physics models and simulations are being developed



Selective Laser Sintering [3]

Inkjet Printing

- Continuous drop
- Drop on demand
  - Printed Titanic Dioxides and tailored binder material resulted in 50 vol% ceramic green body



3D Inkjet Printing: a) magnetic deflection continuous drop, b) Thermal based drop-on-demand, c) piezoelectric drop-on-demand

[4]

Laser Powder Bed Fusion

- Spattering formation investigations
  - Splat and cause of defects
- Laser qualification through machine learning based monitoring

Materials in Use:

- Many AM relevant materials are cited on materials controls list [6]

AM Technologies

- Stereolithography
- Selective Lasering Sintering
- Selective Laser Melting/Electron Beam
- Fused Deposition Modeling
- Laser Chemical Vapor Deposition
- Focused Ion Beam Direct Writing
- Electrochemical Fabrication Process
- Binder Jet
- Drop-Based and Continuous flow Direct Write

Future Work

- Develop data acquisition for extrusion-based printers
  - **Investigate instrumentation for data collection**
  - Utilize suitable software
- Print varying distinct geometries
- Examine data collected to discern difference in signatures
  - **Machine Learning for analysis of trends**

References

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[2] Daase, Christopher, Grant Christopher, Ferenc Dalnoki-Veress, Miles Pomper, and Robert Shaw: "WMD Capabilities Enabled by Additive Manufacturing," NDS Report 1908, Negotiation Design and Strategy 2019, Jupiter, FL / Monterey, CA.

[3] manufactur3dmag.com

[4] Dong-Woo Cho, Jung-Seob Lee, Jinah Jang, Jin Woo Jung, Jeong Hun Park and Falguni Pati: "Inkjet-based 3D printing " Published October 2015 Copyright © 2015 Morgan & Claypool Publishers Pages 3-1 to 3-7

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[6] "Control List of Dual-Use Chemical Manufacturing Facilities and Equipment and Related Technology and Software," Common Control Lists (2017).

National Nuclear Security Administration

Consortium for Enabling Technologies & Innovation