# Nuclear Engineering Applications Utilizing Additive Manufacturing

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## Introduction

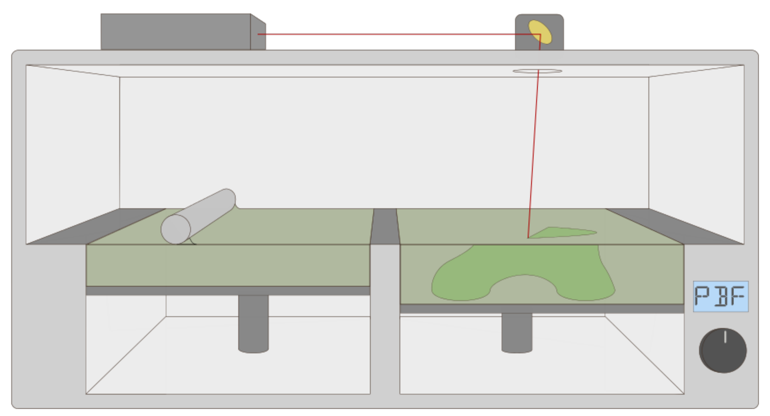
Additive manufacturing (AM) opens the door to many complex part and assembly designs that can not be obtained via traditional manufacturing techniques. Many industries such as automotive, aerospace, and medical device have began utilizing the advantages of additive manufacturing for innovation in their fields. Additive manufacturing has also been identified as a technology that can lead innovation in the nuclear industry and ground level research has begun in this area. This poster reviews the different additive manufacturing techniques and the nuclear applications they could positively impact in the near future.

## Powder Bed Fusion (SLS, SLM)

Bulk Material Type:
- Powder

Process Type:
- Laser Melting

Available Materials:
- Metals & Alloys (SLM)
- Polymers (SLS)
- Ceramics (SLS)




| Process Advantages | Process Disadvantages |
|---|---|
| High feature resolution (80-250 μm)<br>Dense parts<br>Great mechanical properties<br>Multi-Material capable | Slow process<br>Expensive compared to other AM<br>Post-processing required for ceramics |

Current research using powder bed fusion:

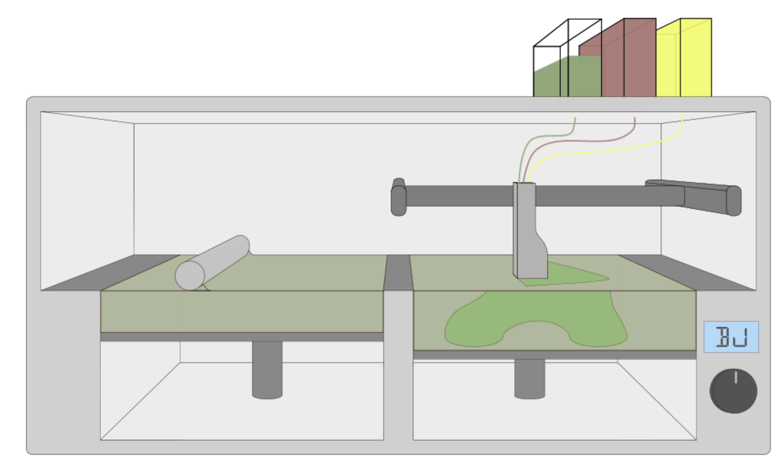
- Idaho National Lab (INL) has began development of a printed $U_3Si_2$ fuel. Cerium, zirconium, and hafnium were explored as surrogates to uranium in the PBF process [2].

## Binder Jetting (BJ)

Bulk Material Type:
- Powder

Process Type:
- Material Jetting (binder)

Available Materials:
- Metals
- Polymers
- Ceramics




| Process Advantages | Process Disadvantages |
|---|---|
| High feature Resolution (80-250 μm)<br>Good mechanical properties<br>Multi-Material capable | Expensive compared to other AM<br>May lead to porous parts<br>Requires post-processing |

Current research using binder jetting:

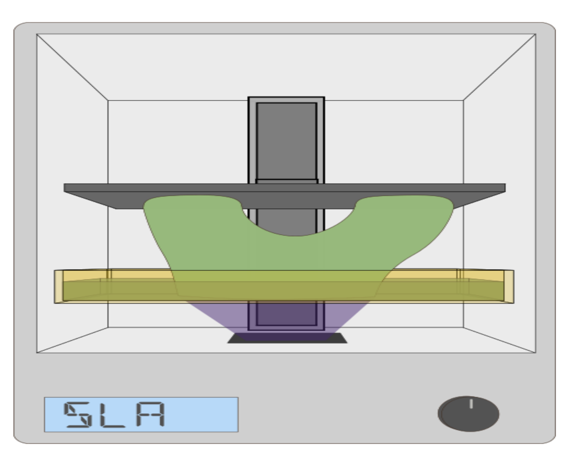
- Oak Ridge National Laboratory (ORNL) used binder jetting AM to produce a SiC complex capsule that could house TRISO fuel particles [3].

## Stereolithography (SLA)

Bulk Material Type:
- Liquid

Process Type:
- Laser Polymerization

Available Materials:
- Resins with photo-active monomers
- Hybrid polymer-ceramics




| Process Advantages | Process Disadvantages |
|---|---|
| Best feature resolution (10 μm)<br>Good mechanical properties | Limited materials<br>Expensive compared to other AM<br>May require support material |

Current research using stereolithography:

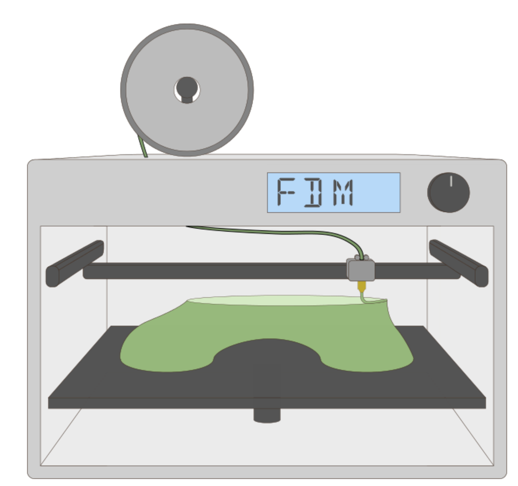
- INL used SLA to explore printing thorium-oxide ($ThO_2$) which could be used as nuclear fuel [4].

## Fused Deposition Modeling (FDM)

Bulk Material Type:
- Solid Filament

Process Type:
- Thermal Extrusion

Available Materials:
- Thermoplastic polymers
- Fiber-reinforced polymers
- Metals*




| Process Advantages | Process Disadvantages |
|---|---|
| Low cost<br>High speed<br>Simple process<br>Multi-Material capable | Weak mechanical properties<br>Limited materials<br>Poor surface finish<br>Requires support material<br>Metals require post-processing |

Current research using fused deposition modeling:

- Los Alamos has began initial research into printing insensitive high explosives (TATB), and conventional high explosives [5].

## Potential Nuclear Applications Utilizing Additive Manufacturing [1]

**Reverse Engineering** – AM can allow for fabrication of aging reactor/weapons parts where the supply chain is no longer available.

**Integrated Sensors** – Sensors can be embedded inside parts allowing for communicating operational status, predictive maintenance, and autonomous operations. Multi-Material AM will help enable this.

**Nuclear Fuel** – AM may allow for a simplified fuel production process making fuel production cheaper, quicker, and easier.

**Nuclear Fuel Assemblies** – Using AM may allow for customizable fuel assemblies, optimized fuel locations, better fuel margins, and a reduced supply chain.

**Part Qualification** – In-process monitoring techniques can allow for quicker part qualification by verifying microstructure during production.

**Radioisotope Production** – May allow for radioisotope production in new/ cheaper ways, or eliminating the use of sensitive material (HEU).

**Warhead Components** – AM could lead to beneficial geometries for hypersonic application, decreased manufacturing time, and reduced cost.

**High Explosives** – Using AM would allow better control of the voids inside the explosive making unwanted detonation less likely.

## Nuclear Materials of Interest for AM [1]

**Beryllium** – Can act as a neutron reflector in explosive devices.

**Multi-Material Parts** – Parts consisting of more than one material could optimize many nuclear processes .

**Bulk Metallic Glasses** – These can possess unique combinations of metallic, magnetic, and chemical properties.

**High-Entropy Alloys –** Alloys containing four or five elements. Specific applications still need to be investigated.

**Specialized Materials** – Such as materials formulated by the USAF (AF96 Steel) and NASA (GRCop-42) with special applications.

## References

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

[2] Rosales, Jhonathan, van Rooyen, Isabella J., & Parga, Clemente J. *Characterizing surrogates to develop an additive manufacturing process for U3Si2 nuclear fuel*. United States. doi:10.1016/j.jnucmat.2019.02.026.

[3] Trammell, Michael P., Jolly, Brian C., Richardson, M. Dylan, Schumacher, Austin T., Terrani, Kurt A. *Advanced Nuclear Fuel Fabrication: Particle Fuel Concept for TCR*. United States.

[4] Andrew Bergeron, Brent Crigger, and Cathy Thiriet, "Early Progress on Additive Manufacturing of Nuclear Fuel Materials," 2018, Canadian Nuclear Laboratories

[5] Explosiv3Design: 3D-printing technology is booming and could revolutionize the design of high explosives, 1663 Magazine, Los Alamos National Laboratory, March 8 2016. https://www.lanl.gov/discover/publications/1663/2016-march/_assets/docs/1663_26_explosive-3d-design.pdf

[6] Ngo, T.D., Kashani, A., Imbalzano, G., Nguyen, K.T.Q., Hui, D., 2018. Additive manufacturing (3D printing): a review of materials, methods, applications and challenges. Compos. B Eng. 143, 172e196.https://doi.org/10.1016/j.compositesb.2018.02.012