SAND2018-2784PE

In situ analysis of consolidation and flow phenomena in selective laser sintering of metals

PRESENTED BY

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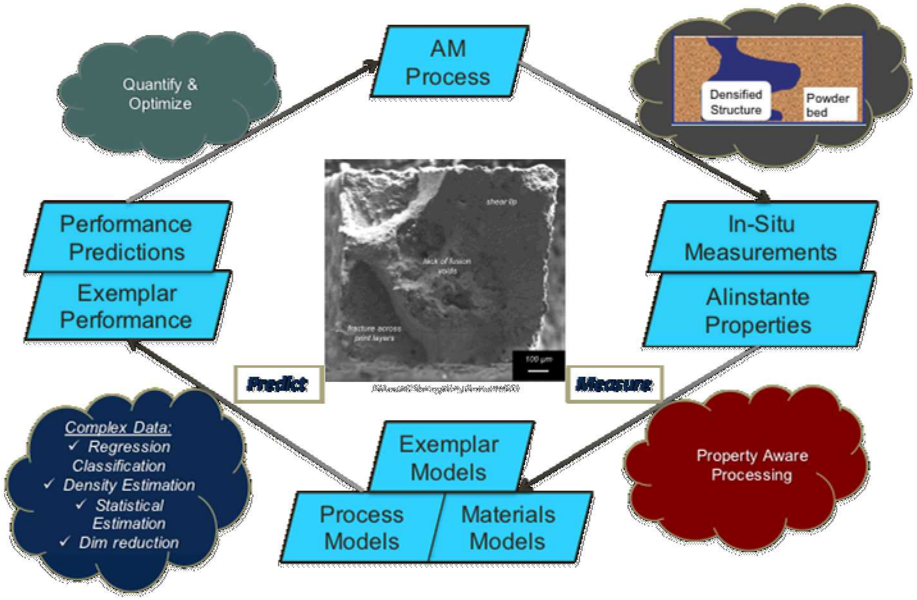
Born Qualified Overview & Vision

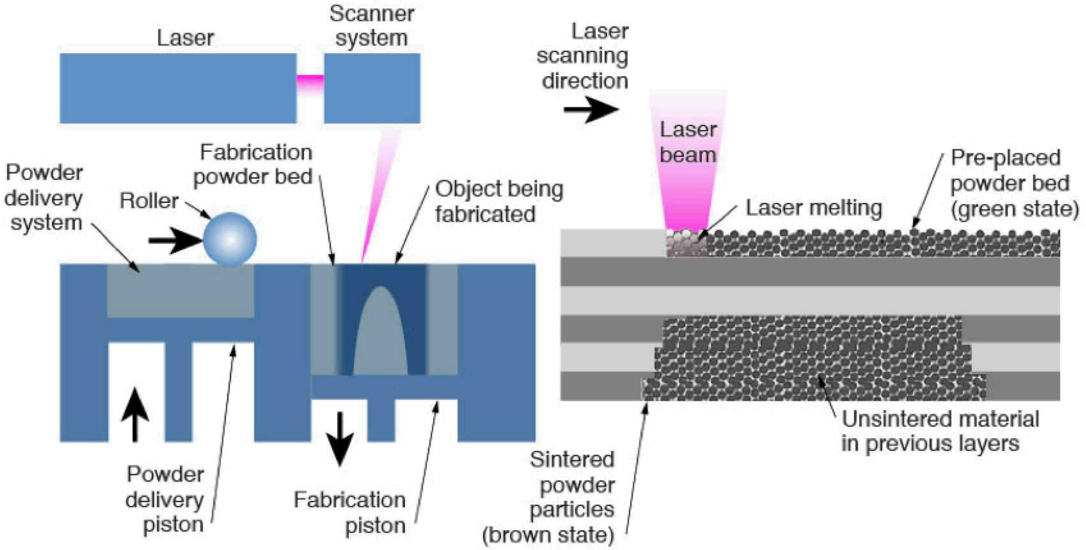
- ***Goal:*** Combine promise of **additive manufacturing** with **deep materials & process understanding** to revolutionize design, manufacturing, & qualification paradigms
  - Materials, designs, and ultimately components are "*Born Qualified/Certified*"
- Achieving the born qualified vision is estimated to be a 15-year process, and this Grand Challenge Lab Directed R&D (GC-LDRD) project is meant to lay the foundation over a period of 3-years
- ***Why Additive Manufacturing (AM) as driver for design, manufacturing, and qualification revolution?***
  - Disruptive technology that allows simultaneous creation of optimized part geometries and materials-by-design
  - Ability to tightly control and monitor manufacturing processes
  - AM is ideal for low volume, high value, high consequence, complex parts
  - Inherently flexible and agile
  - Ability to create near-net shape parts

Approach to Paradigm Change

- Drive revolution in part qualification by:
  - Predicting performance probabilistically
  - Tightly controlling process parameters
  - Accelerated cycles of learning
- Integrate validated, predictive capability with real-time and ex-situ diagnostic tools to create the Capability Base to realize UQ driven qualification of design and process
- Utilize Capability Base and Diagnostic Artifacts to verify materials and process assurance



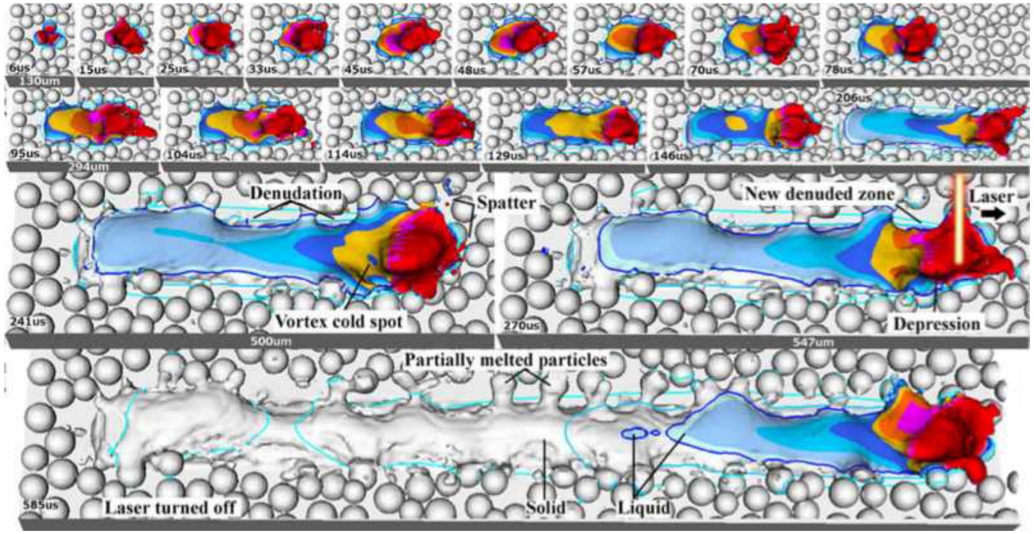
Principles of metal selective laser melting (SLM)

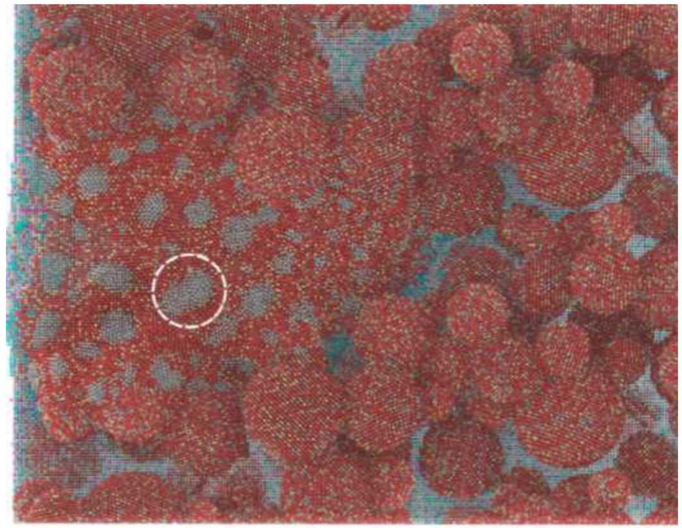


- Layer-by-layer bottom-up manufacturing approach for creating metal parts.
- High power lasers raster at m/s speeds over powder bed, melting powder particles and solidified material below.

Problem: Unpredictable part performance from defects induced by repeated melting/solidification has prevented widespread use of SLM (more generally, AM).

Importance of melt pool flow and consolidation in metal SLM





- Models/simulations have begun to establish criteria for flow-based defect formations in melt pools – ***limited in situ experimental validation***.
- High process temperatures and ***rapid*** melting/solidification rates (10^4-10^5 Ks^{-1}) make in situ imaging of melt pool difficult.

We propose to use pRad to establish rapid, in situ observation of melting and solidification of particle beds to inform development of predictive models

Goals of proposed pRad experiments

Provide support to Born-Qualified program through high temporal-resolution in situ imaging of a melt pool in metal SLM using proton radiography.

Objectives:

1. Observe and characterize melt pool formation, including defects and non-uniformity, during solidification using SLS ***at time intervals as fast as 200 ns.***

2. Determine validity of existing assumptions about melt pool characteristics at varying beam exposure time and power density/flux.

3. Assess scalability of physics models used to describe melting/solidification in a melt pool – ***connect mesoscopic-to-atomistic simulation results.***

4. Validate this experimental imaging method as a fundamentally new route for investigating melt pool flow dynamics in metal AM processes.

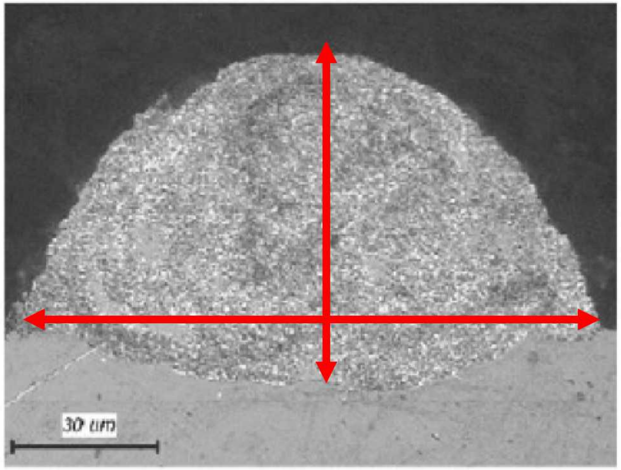
FY18/Phase 1 – feasibility assessment of pRad (w/ x7 magnifier)

- ***Benchmark pRad as in situ diagnostic tool using static shots with x7 magnifier in the air gap:*** Characterize previously consolidated SS304L beads.

- These beads were processed using a range of powder layer thicknesses (60 – 300 µm), laser powers (200 – 1500 W) and speeds (0.2 – 1 m/s).
  - Bead geometries ***ranging from 0.1 – 1 mm*** in size will be targeted.
  - Density differences of ~43% for build plate and beads, > 26% for powder and beads.

- Based on this data we will down-select build parameters for the in situ pRad experiments (Phase 2).

- Beam time required: 1 day (by Oct. 2018)



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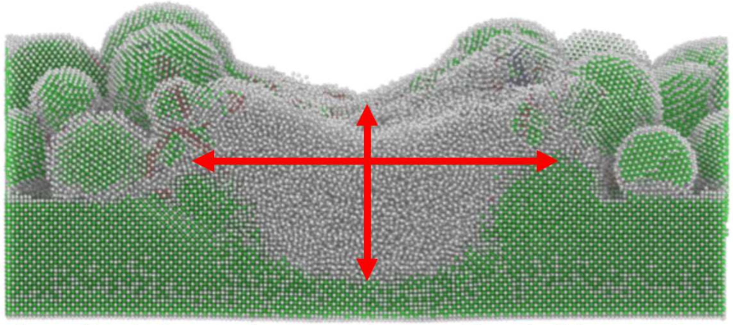
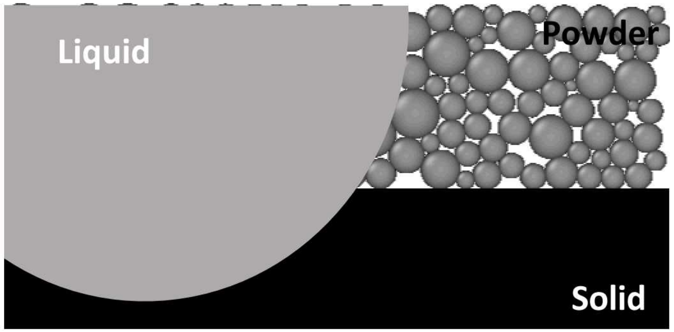


Wilson (SNL/BQ-LDRD) – green is crystalline (solid), gray is amorphous (liquid).

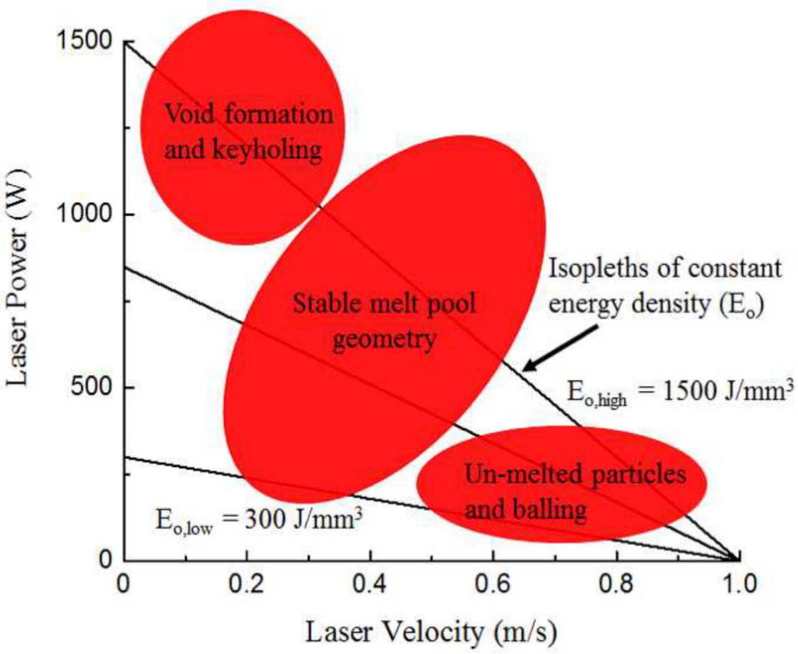
FY18/Phase 2 – in situ imaging of powder bed melt pool (w/ x7 magnifier)

- With the down-selected processing matrix from Phase 1, we will perform in situ pRad experiments using custom powder bed test cell (under development at SNL) with x7 pRad magnifier and air gap.

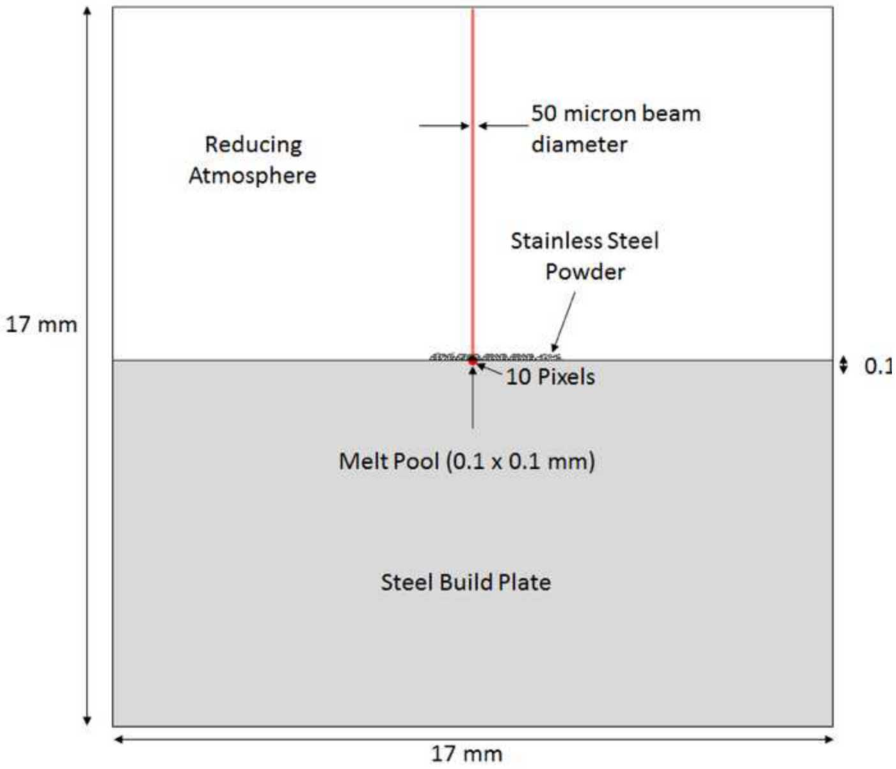


- Our experiments will examine:
    - Solid-liquid interfaces of melting powder with a stationary laser – propose to use 200 ns and 5 µs snapshot time intervals.
    - Dynamic melt pool characteristics with moving laser – propose to use 10 and 45 µs snapshot time intervals.

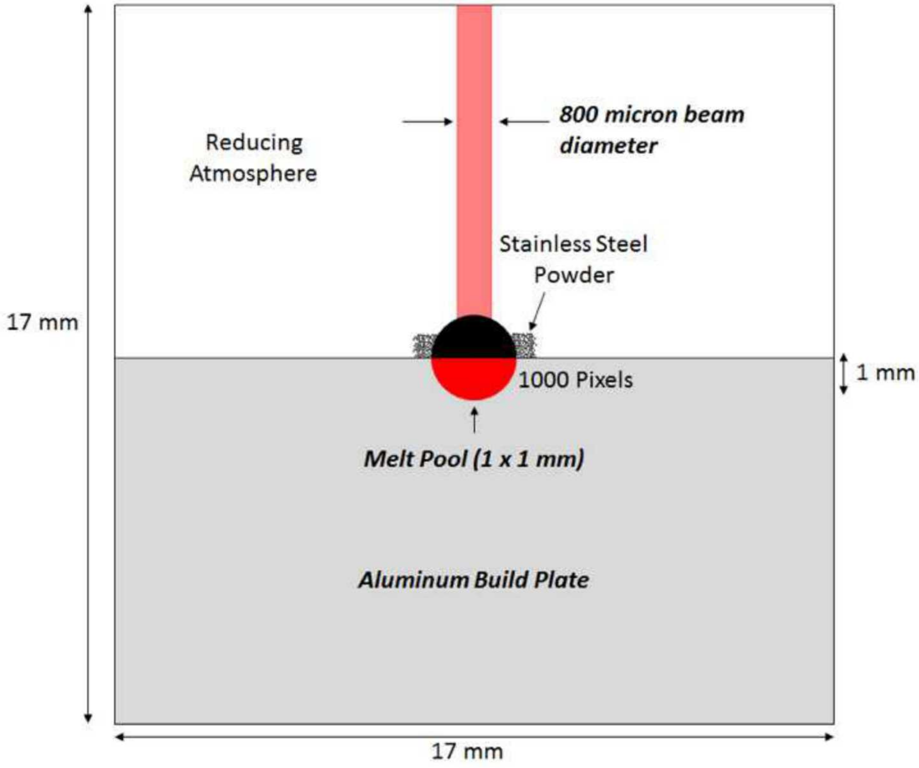
- Estimate 5 days of beam time (tentatively by Sept. 2019).



FY18/Phase 2 – representative scaled views of melt pool in pRad w/ x7 magnifier



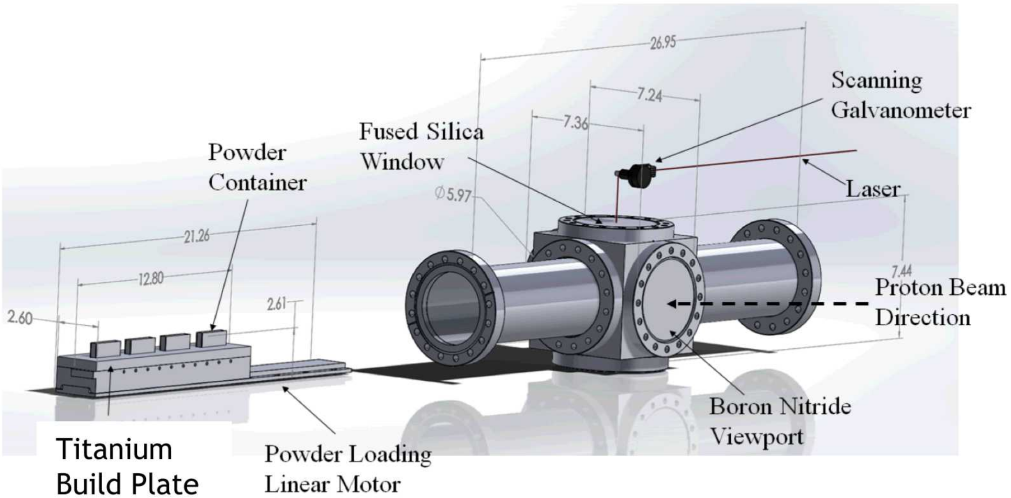
Conventional powder bed (200 W)



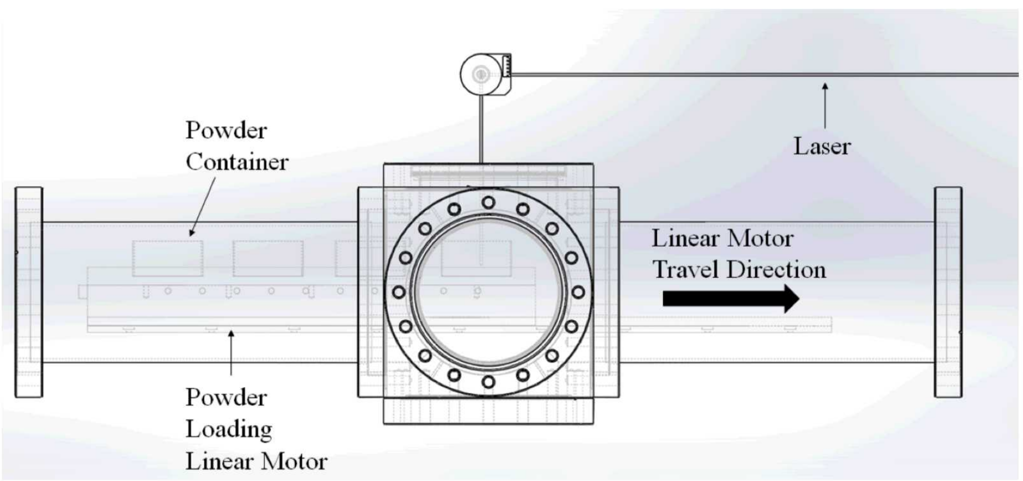
Proposed powder bed (> 1 kW)

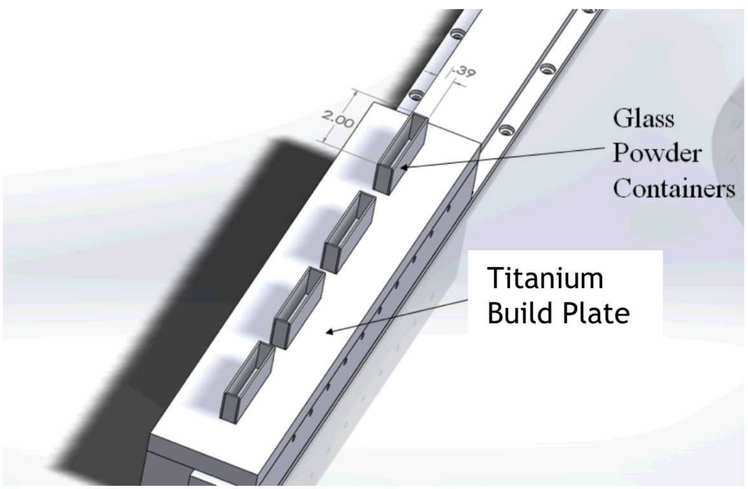
- Conventional powder bed yields small melt pool geometry (~ 10 pixels of data).
- We propose to scale up melt pool (~ 1000 pixels of data) and use Ti build plate to promote large density difference (~43%) at bead/build plate interface.

FY18/Phase 2 – components of custom powder bed test cell



- Test cell components:
- $20-30k off-the-shelf commercial components made ready to assemble
- Melting laser:
  - Possibilities of using one from SNL (Dave Keicher) or other orgs.
  - Available lasers from LANL
  - Renting/loaning from IPG photonics





End of Project Deliverables

Phase 1 (by Oct. 2018):

Static pRad images using x7 magnifier in air gap of existing SLM beads under varying conditions.

Down-select process parameter matrix for phase 2.

Phase 2 (by Sept. 2019):

Perform in situ pRad analysis using custom powder test cell.

Inform model development and provide simulation validation for metals SLM, and obtain high-rate images of transient melt pool evolution.

Total requested days - 6