NTRC | NANOTECHNOLOGY RESEARCH CENTER

Additive Manufacturing:
Observations, Hazards, and Opportunities

Gary Roth, MS, PhD

Health Scientist / Associate Service Fellow

Toxics Use Reduction Institute 2018 Spring Continuing Education Conference
Marlborough, MA
25 April 2018

CDC Workplace Safety and Health | NIOSH

The National Institute for Occupational Safety and Health

The U.S. Federal agency responsible for *conducting research* and *making recommendations* for the prevention of work-related injury and illness.

Mission: To *develop new knowledge* in the field of occupational safety and health and to *transfer that knowledge into practice*.

NIOSH & New Technologies

Legislative mandate

Section 20 (a) (4) of the Occupational Safety and Health Act of 1970:

..Conduct special research necessary to explore new problems, including those created by new technology……and develop new solutions

NIOSH response to advanced manufacturing

- First recognized nanotechnology as an Institute priority (2002)
- Chartered the Nanotechnology Research Center (NTRC) in 2004
- NTRC began investigating Advanced and Additive Manufacturing (2016)

Reasons for focusing on AM

- New processes and materials; little hazard and exposure data
- Rapidly evolving technology and capability
- Employees are among the first exposed to new technologies
- Increasing number of producers and customers
- Prior knowledge of hazards (air pollution, welding, dusts)
- NIOSH history of developing solutions for novel technologies

AM DIVERSITY

Materials & Feedstocks

Liquid Resin

Solid Plastic

Metal Powder

… or any permutation thereof.
… or something else entirely.

CDC Workplace Safety and Health NIOSH

NTRC NANOTECHNOLOGY RESEARCH CENTER

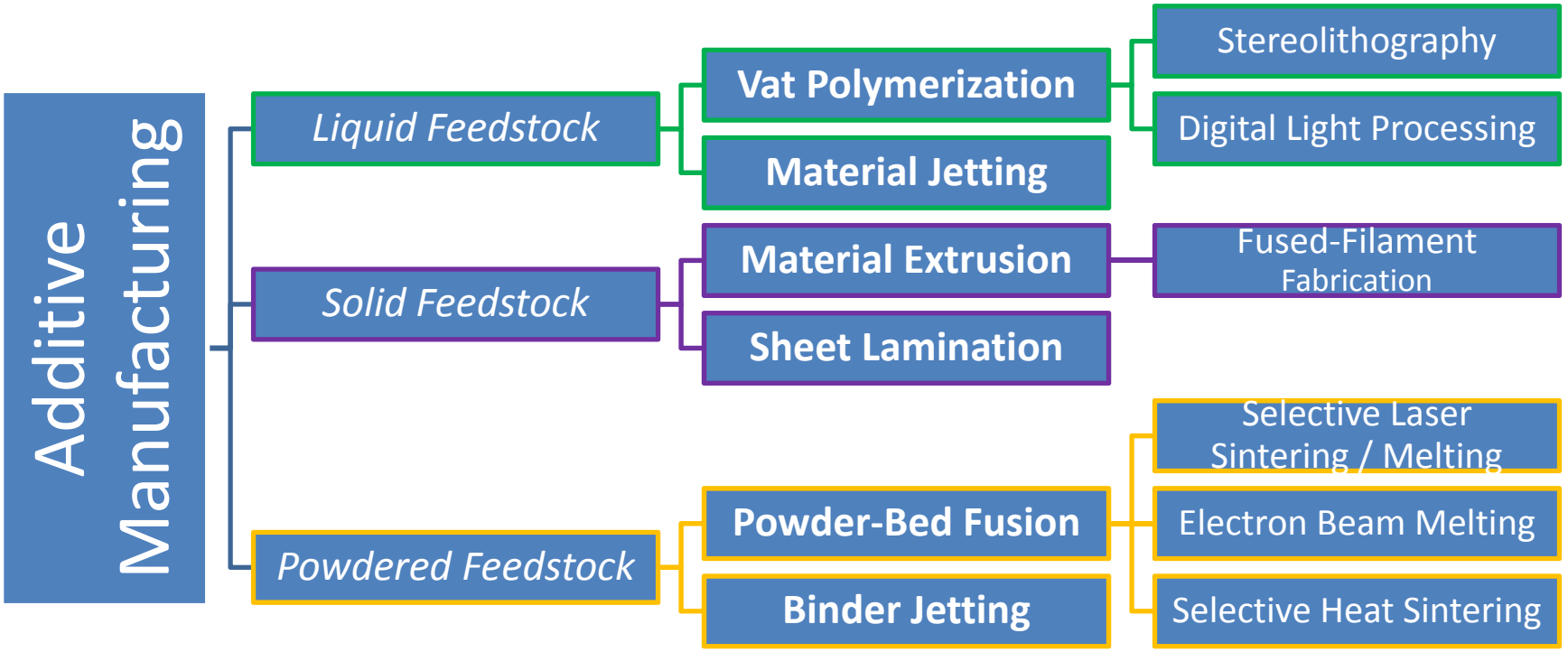
Binding/Joining Mechanisms

Curing

Heat/Cooling

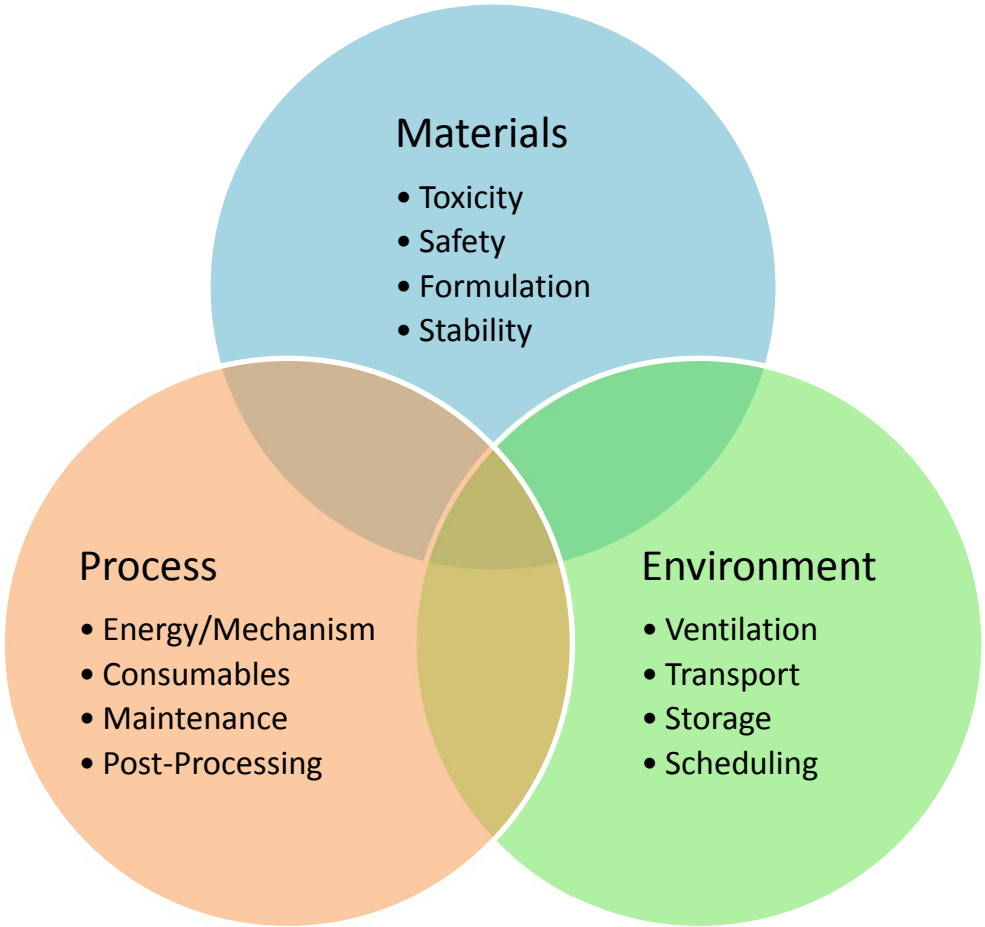
Cementing

Taxonomy


Additive Manufacturing
Liquid Feedstock
Solid Feedstock
Powdered Feedstock
Vat Polymerization
Material Jetting
Material Extrusion
Sheet Lamination
Powder-Bed Fusion
Binder Jetting
Stereolithography
Digital Light Processing
Fused-Filament Fabrication
Selective Laser Sintering / Melting
Electron Beam Melting
Selective Heat Sintering

AM HAZARDS

Holistic Perspective



Materials Hazards

- Toxicity (respiratory, dermal, etc.)
- Safety (Flammability, etc.)
- Formulation (coexposures)
- Process-Induced Changes

Example Materials

Polymers

- Acrylonitrile-butadiene-styrene
- Polylactic acid
- Propylene fumarate
- Poly(vinyl alcohol)
- Polycarbonate
- Polyethylene
- Polystyrene

Solvents

- Dimethyl fumarate
- Isopropanol
- Acetone
- Methyl Ethyl Ketone
- 2-Butanone

Metals

- Ti-6Al-4V
- IN 625 & IN 718 (Ni, Cr)
- 17-4 PH stainless steel
- Cobalt chromium

Nanomaterials

- nFe (steel sintering)
- nAg (sintering, conductivity)
- nCB, CNT (conductivity, stiffness, tensile strength)
- $nSiO_x$ (polymer strength)

Process Hazards

- Energy or mechanism for binding/joining
- Other reagents or consumables
- Maintenance, operations, & accessibility
- Post-processing

Example Process Hazards

Ergonomic	Noise	Shock
Fall/Impact	Burns	Fire/Explosion
Altered Materials & Byproducts	Compressed Gases	Laser/Radiation

Work Environment

- Transport
- Storage
- Ventilation
- Scheduling / Stress

AM Hazard Questions

Material-related	Is this material toxic? If yes, how?
	Is this material reactive? If yes, how?
	What are the likely exposure routes?
Process-related	What hazards originate from the material-binding process?
	What hazards originate from post processes?
	What worker activities are necessary to support the process?
Environment-related	How are materials/parts moved in/out/around the workspace?
	How and where are materials/parts stored?
	How are the workspace and worker activities organized?

Example Hazards

Material Extrusion	Vat Polymerization	Powder Bed Fusion	Binder Jetting
Material Toxicity	Material Toxicity	Material Toxicity	Material Toxicity
FP/UFP Emissions	VOC Emissions	Powder Inhalation/Contact	Powder Inhalation/Contact
VOC Emissions	Fires	Explosion	VOC Emissions
Post-Process Burns	Spills	Post-Process Exposure	Post-Process Exposure

FIELD STUDIES

NTRC Nano and Additive Manufacturing Field Studies Team

- Organized in 2006 as a component of the NTRC
- Has conducted over 130 site visits in a variety of workplaces
  - Expanding now to advanced and additive manufacturing
- Tasked with “seeing what’s out there”
- Attempting to fill knowledge gap on what is being used, how, and real-world potential worker exposures

Is there a release? To what extent?

Exposure Assessment Process

- Combines traditional industrial hygiene methods and new sampling techniques
- Based on Nanomaterial Exposure Assessment Technique (NEAT) 2.0
- Sampling strategy
  - Full-shift and task-based
  - Personal and area air sampling
    - Chemical and or gravimetric analysis
  - Electron microscopy (if engineered nanomaterial present)
    - Transmission electron microscopy (TEM) / scanning electron microscopy (SEM) sampling for identification, sizing and morphology
  - Data logging with real time aerosol instruments

NIOSH Nanoparticle Exposure Assessment Technique (NEAT) 2.0 Strategy

Pre-Assessment Prioritization	Field Measurements	Risk Management	Routine Monitoring
Gather Information •Work flows, staffing and tasks •Anticipated and recognized hazards •Nanomaterials used •Safety data sheets •Literature review •Other indicators of potential hazards and exposure situations	•Full-shift and task-based •Integrated filter sampling for elemental mass and microscopy •Direct reading instruments •Evaluation of ventilation and engineering controls •Advanced techniques or developmental methods as needed	•Evaluation of data for exposure-informed hazard assessment •Strategies to mitigate hazard and exposure potential based on results and utilizing the hierarchy of controls •Communications regarding potential occupational risks	•Confirmation of continued risk control •May indicate need for additional measurements or controls

Assessment considerations for:

Thermoplastics (FFF printing)

Type of filament

- VOCs associated with material
- Thermoplastic filament infused with engineered nanomaterial

Ultrafine particulate

- Dependent on the filament type?
- Nozzle and printing temperatures?

Printing environment

- Is the printing done in a small room with poor ventilation or large warehouse with a lot of air changes?
- Ventilation controls – local exhaust ventilation? Exhausted chambers?
- How many printers running?

Assessment considerations for:

Finely divided powders (SLS printing)

Types of powders

- Heavy metals – Dermal toxicity
- Explosion or fire potential?

Printing process

- Enclosed? Ventilated into the room or exhausted?
- What controls currently in place

Ergonomics

- Lifting kilograms of powder, equipment, printed parts
- Machine maintenance

Assessment considerations for:

Finely divided powders, cont.

Room ventilation

- Negative room pressure relative to other areas?
- Isolated system?

Worker practices

- Spreading heavy metal powders?
- Glove and other PPE habits
- Sticky mats used? Changed frequently?

Still investigating inhalation and dermal exposures

Early Recommendations

- Ventilation Controls
- Sticky Mats
- Improve PPE & Habits
- Isolating Activities
- Containment

Recommendations often (but not always) resemble those of existing manufacturing or nanotechnology practices!

CDC Workplace Safety and Health NIOSH

NTRC NANOTECHNOLOGY RESEARCH CENTER

AM SAFETY CULTURE (OPPORTUNITIES)

The Challenge: Agility

Product designers want to move fast.

Safety professionals don't know everything they need.

The tool users don't, either!

AM users and knowledge will vary

Large Enterprises

Small-to-Medium Enterprise

Service Locations

Hospitals

Schools

Libraries

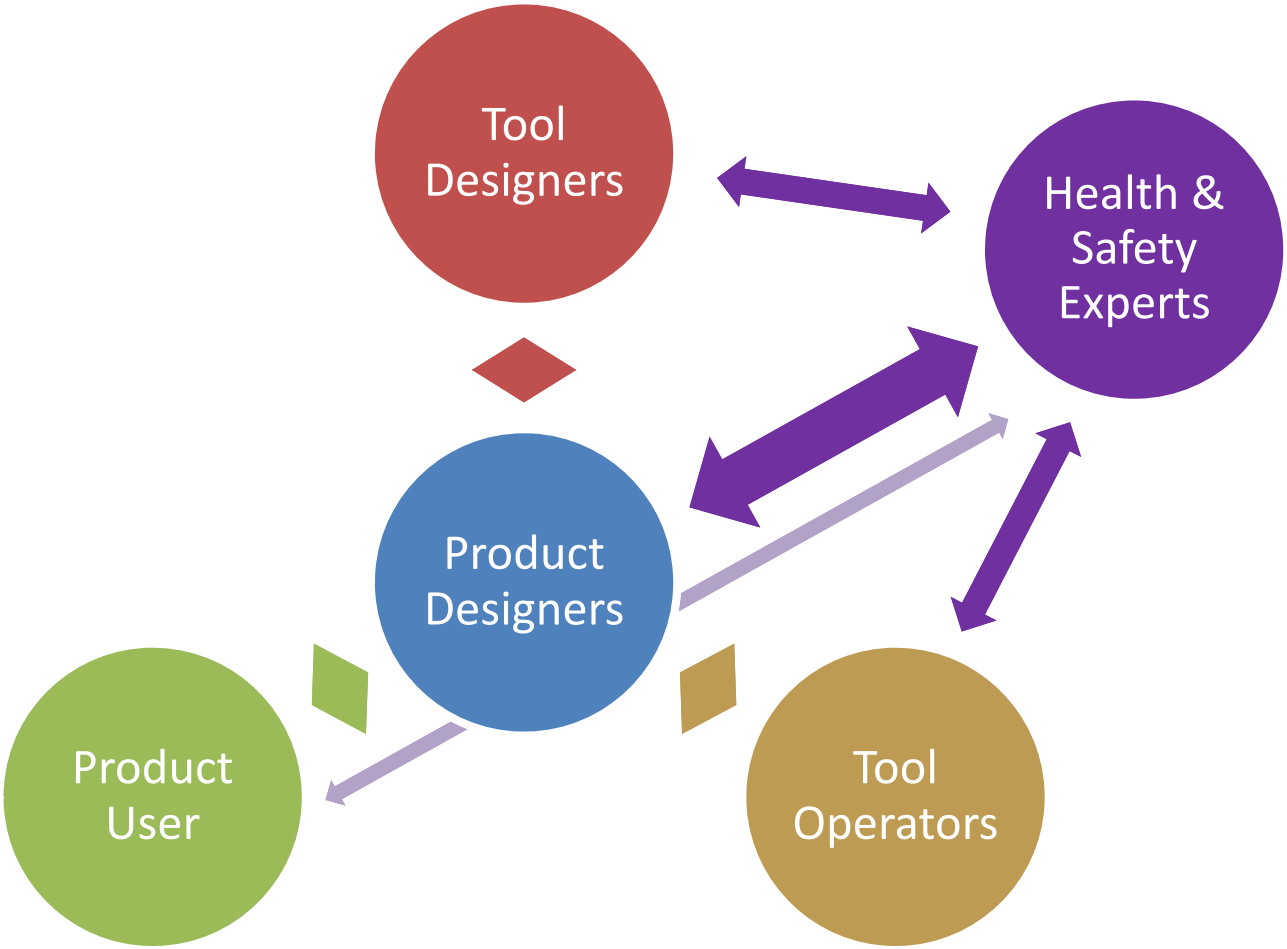
Users may differ in terms of …

- Budget for OSH activities (controls)
- Expertise (in both OSH and additive manufacturing)
- Synergistic exposures
- Communication preferences
- Decision-making structure
- Safety culture
- Demographics

CDC Workplace Safety and Health NIOSH

NTRC NANOTECHNOLOGY RESEARCH CENTER

Collaboration is Necessary



SUMMARY

Additive Manufacturing Hazards…

May affect substantial worker populations across multiple industries

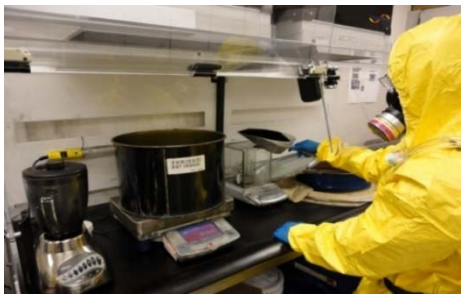
Vary based on particular materials, processes, and environments

Include many familiar hazards of manufacturing, and some less familiar ones

Provide an opportunity to change the dialogue on safety

NTRC Field Team is seeking more partnerships and collaborations!

- Over 130 visits (65 sites)
- Uses existing methods
- Evaluate processes & personal exposures
- Provide guidance and recommendations
- No monetary cost to partners



CDC Workplace Safety and Health NIOSH

NTRC NANOTECHNOLOGY RESEARCH CENTER

Thanks for your time!

groth@cdc.gov

Acknowlegments

- Charles Geraci
- Laura Hodson
- Kevin L. Dunn
- Eric Glassford
- Kevin H. Dunn
- Duane Hammond
- Aleksandr Stefaniak

References & Image Sources

- Bloomington Public Schools (2014) Poplar Bridge Elementary to incorporate 3D printing. URL: https://www.bloomington.k12.mn.us/node/3121478 (accessed 20-Nov-2017).
- Florida Public Library (2017) Our 3D Printer. http://www.floridapubliclibrary.org/news/our-3d-printer/ (accessed 20-Nov-2017).
- GE Additive (2017a) GE Additive takes bold moves in aerospace industry. https://www.ge.com/additive/press-releases/ge-additive-takes-bold-moves-aerospace-industry (accessed 20-Nov-2017).
- GE Additive (2017b) GE Additive to certify new production partners. https://www.ge.com/additive/press-releases/ge-additive-certify-new-production-partners (accessed 20-Nov-2017).
- Hewitt, Cooper (2014). Design Dictionary: Powder Bed 3D Printing. Youtube. URL: https://youtu.be/kBHsfNDsbCs (accessed 8-Feb-2017).
- O'Conner, Daniel (2013). Formlabs launch new Resin and win CES award. TCT Magazine. URL: https://www.tctmagazine.com/tct-events/formlabs-launch-new-resin-and-win-ces-award/ (accessed 13 Feb 2017).
- Open Biomedical Initiative (2016) Japanese medical insurance to cover cost of 3D printed organ models. URL: http://www.openbiomedical.org/japanese-medical-insurance-to-cover-cost-of-3d-printed-organ-models/ (accessed 20-Nov-2017).
- Pesce, Mauizio (2015). 3D Printing Materials. Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:3D_Printing_Materials_(16837486456).jpg (accessed 13 Feb 2017).
- Sęk, Matylda (2011). Crosslinker, UV Stratalinker 2400. Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Crosslinker_UV_Stratalinker_2400-1.jpg (accessed 13 Feb 2017).
- Sols Systems (2016) Mapp3D. http://www.sols.com/mapp3d/ (accessed 20-Nov-2017).
- Vít, Tomáš (2017). Selective Laser Sintering (or LaserCUSING) cycle. Youtube. URL: https://youtu.be/5-y8iep7jTk (accessed 8-Feb-2017).