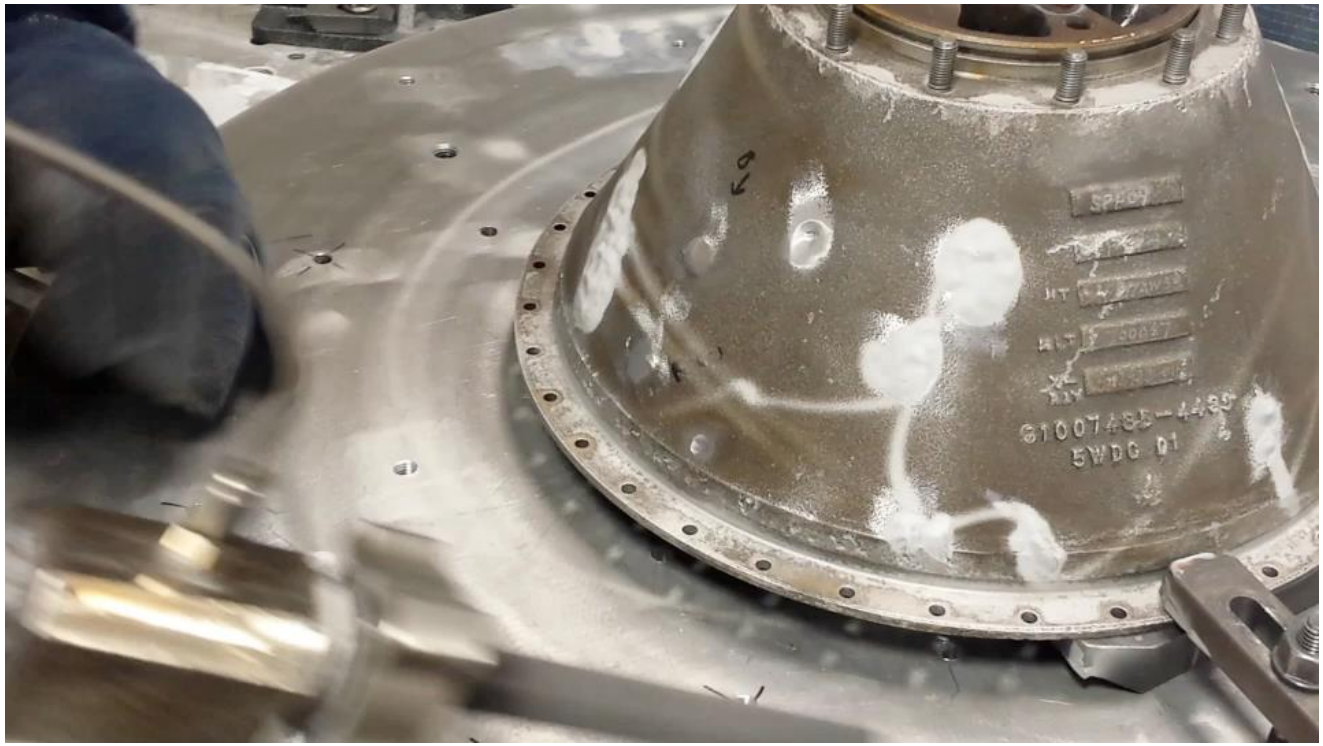


"Advanced Cold Spray System Development for DoD"

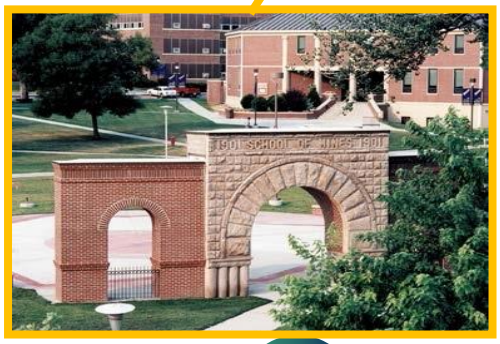
VRC METAL SYSTEMS & SD Mines

Christian Widener, Ph.D.

OUTLINE

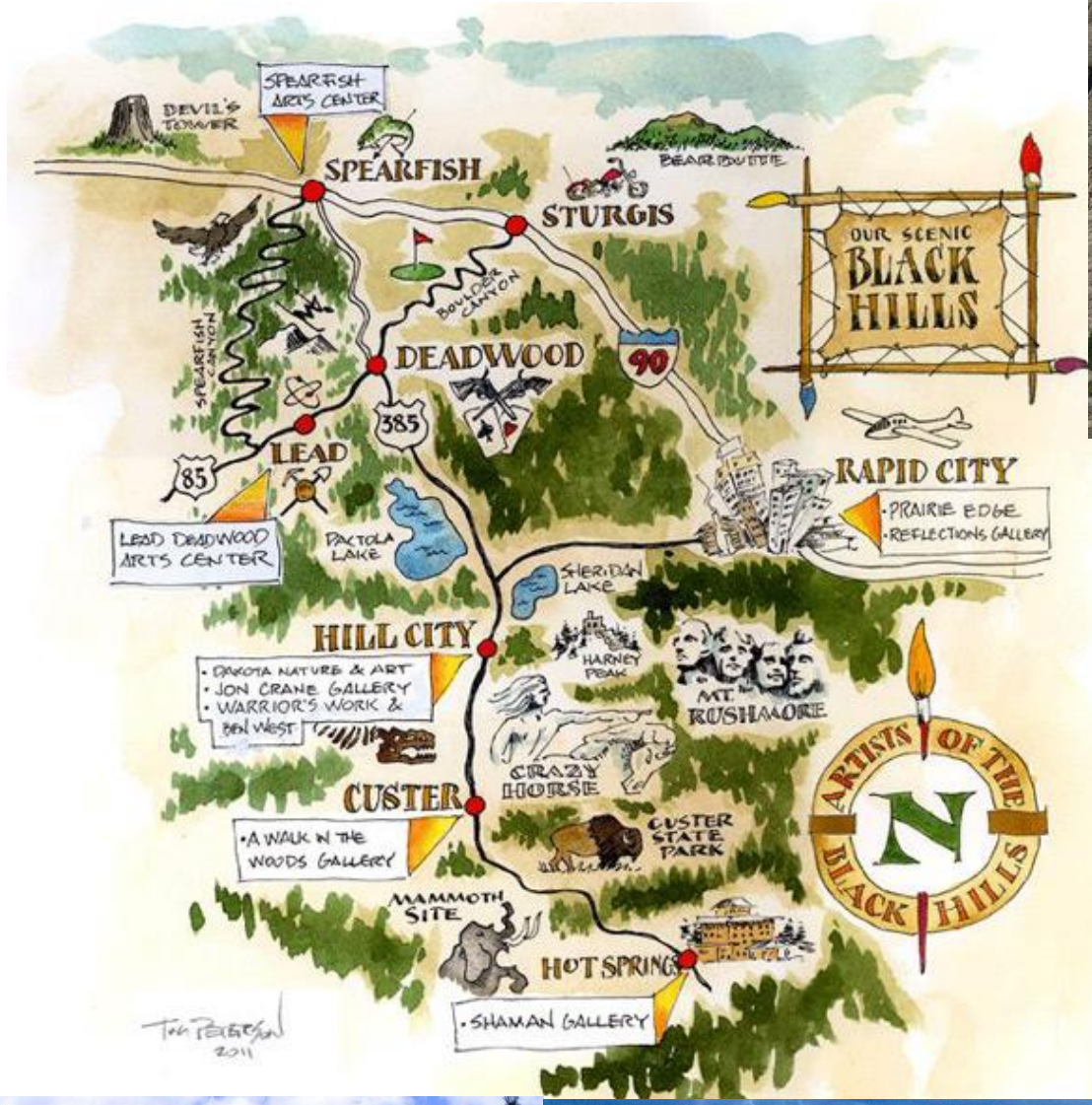
- SDSM&T & VRC Metal Systems Overview
- DoD Development Efforts
  - High Pressure Equipment
  - Hybrid Manufacturing
  - Advanced Motion Systems
  - Process Development
  - Repair Development
  - Cost Reductions
  - Qualification
  - Training
- Conclusions

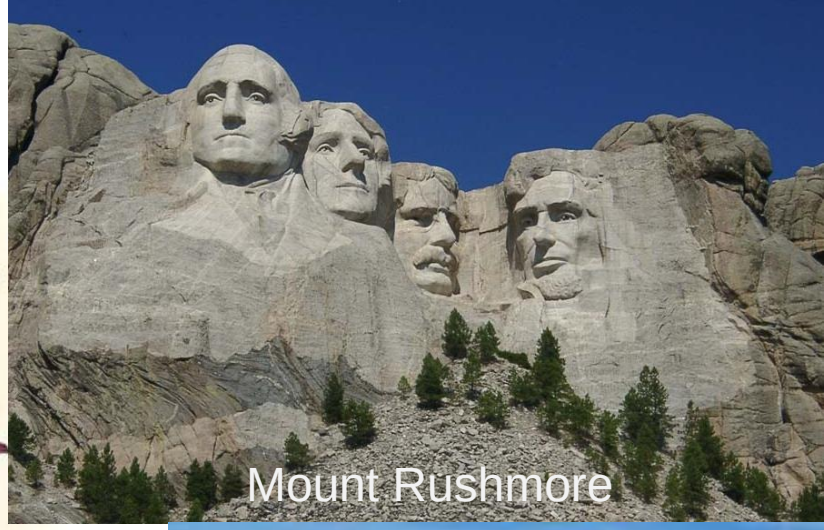
SCHOOL OF MINES AND TECHNOLOGY
ENGINEERING
TECHNOLOGY
1885
SCIENCE
SOUTH DAKOTA

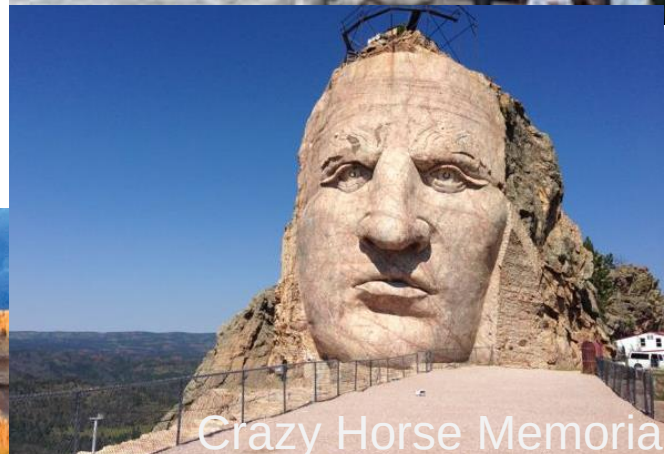


VRC METAL SYSTEMS

SCHOOL OF MINES & TECHNOLOGY


DEVIL'S TOWER
SPEARFISH ARTS CENTER
SPEARFISH
BEAR BUTTE
STURGIS
OUR SCENIC BLACK HILLS
BOULDER CANYON
SPEARFISH CANYON
DEADWOOD
90
385
85
LEAD
LEAD DEADWOOD ARTS CENTER
PACTOLA LAKE
RAPID CITY
• PRAIRIE EDGE
• REFLECTIONS GALLERY
SHERIDAN LAKE
HILL CITY
• DAKOTA NATURE & ART
• JON CRANE GALLERY
• WARRIOR'S WORK &
HARNEY PEAK
MT. RUSHMORE
CRAZY HORSE
CUSTER
• A WALK IN THE WOODS GALLERY
CUSTER STATE PARK
ARTISTS OF THE BLACK HILLS
N
MAMMOTH SITE
HOT SPRINGS
• SHAMAN GALLERY


Mount Rushmore


Crazy Horse Memoria


Needles Highway


Badlands National Park

Arbegast Materials Processing & Joining Laboratory

Technologies in the Lab

1. Cold Spray
2. Friction Stir Welding
3. Laser Powder Deposition
4. Plasma Transfer Arc Wire Deposition
5. Fused Deposition Modeling 3-D Printing
6. Stereo Photo Lithography 3-D Printing
7. Plasma Electrolytic Oxidation
8. Direct Write Printing w/ Photonic Curing
9. Atmospheric Plasma Nano-Spray
10. Tungsten Filament Physical Vapor Deposition

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

VRC Metal Systems

- >50 Employees in 5 locations
- Equipment Sales
- Consumables
- Training
- Turkey System Design & Installation
- Process Development
- Specialty Manufacturing
- Service and Support Agreements
- Licensing & Strategic Partnerships

January 2017

DoD Development Efforts for High Pressure Cold Spray

- High Pressure Equipment
- Hybrid Manufacturing
- Advanced Motion Systems
- Cold Spray Modeling
- Application Development
- Qualification
- Training

Achieving Reliability & Repeatability…

System Development Collaborators

ARL

MOOG

United Technologies Research Center

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PENNSTATE ARL

Quantum technology
Custom industrial gas solutions since 1981

Together ahead. RUAG

WPI

MISSOURI S&T

UND UNIVERSITY OF NORTH DAKOTA.

DEPARTMENT OF DEFENSE MANUFACTURING TECHNOLOGY PROGRAM

VRC METAL SYSTEMS

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Benefits of High Pressure

1. **Structural Properties**
   w/ **higher particle velocities**
   - ✓*Supersonic expansion with greater gas density*
2. **Cost Savings**
   w/ **higher deposition rates**
   - ✓*More lbs/hr of powder can be carried by the gas*

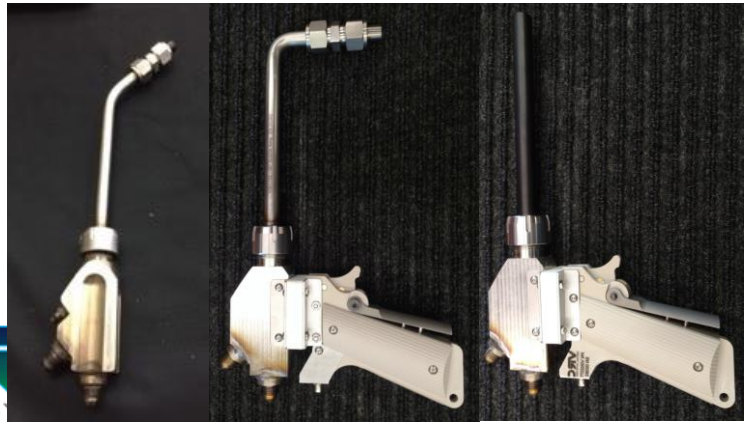
VRC Cold Spray Systems

VRC Gen III™
&
VRC Gen III Max™

15/45 kw
69 Bar
800C

Remote Heater & Powder Feeder Cart

Cold Spray Applicators



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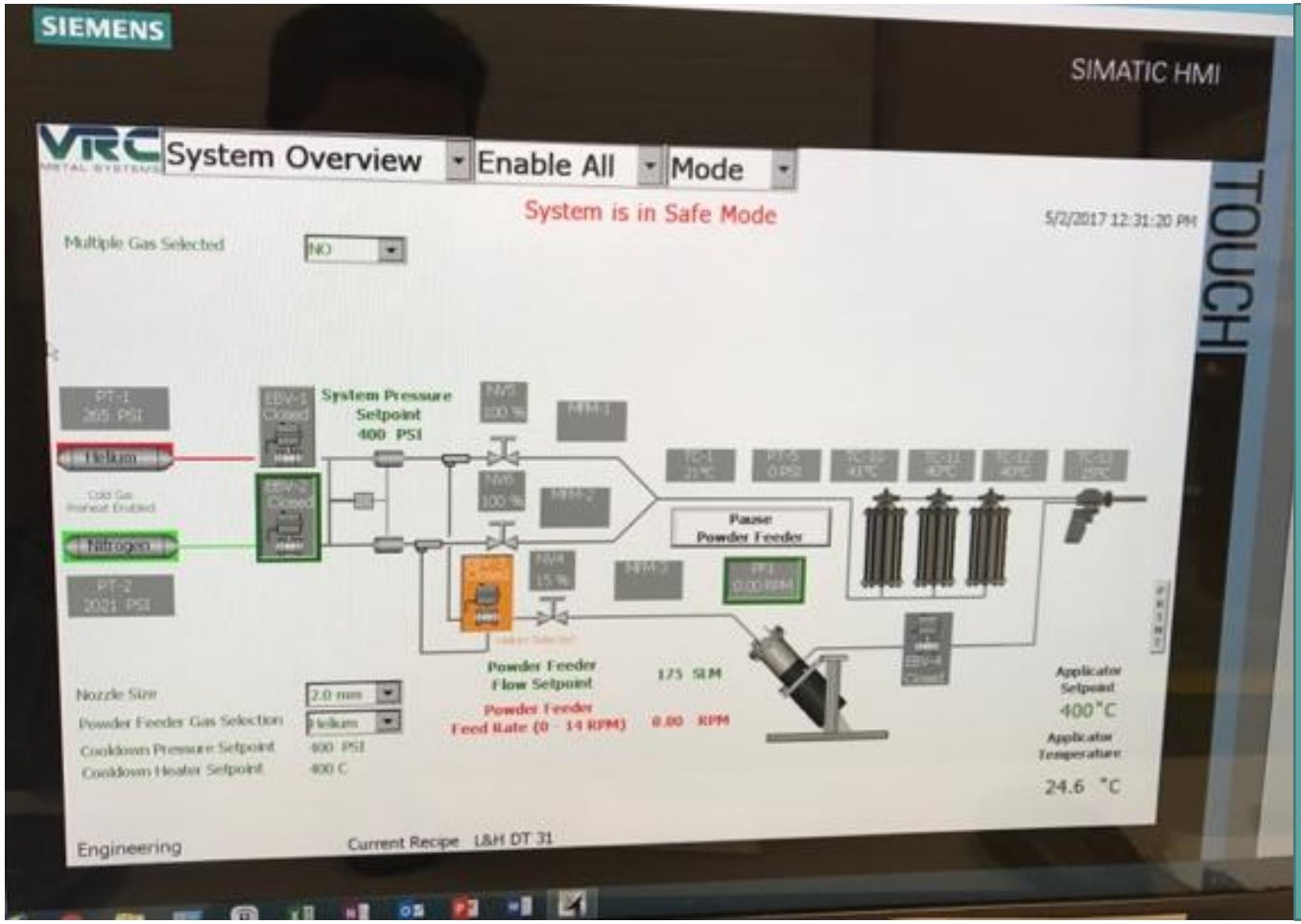
VRC Control System

Upgraded HMI

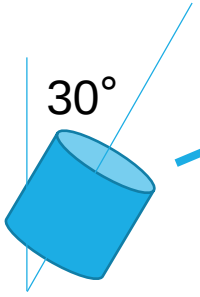


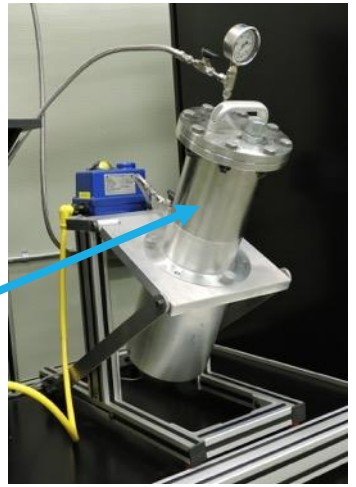
FEATURES

1. Data Logs
2. Recipes
3. Alarms
4. Gun Temp Control
5. Remote Monitoring & Troubleshooting

VRC Gen III Capabilities Enabling Growth of Repair Applications

- Smallest cold spray applicator
- Hand-held or Robotic Mounting
- Highest Pressure on the Market
- Completely Mobile Cart
- Extended Reach (>50ft) from Cart
- Many patent-pending features
- Unique Rotating Drum Powder Feeder
- Licensed technology from SDSM&T, ARL, and United Technologies





VRC METAL SYSTEMS

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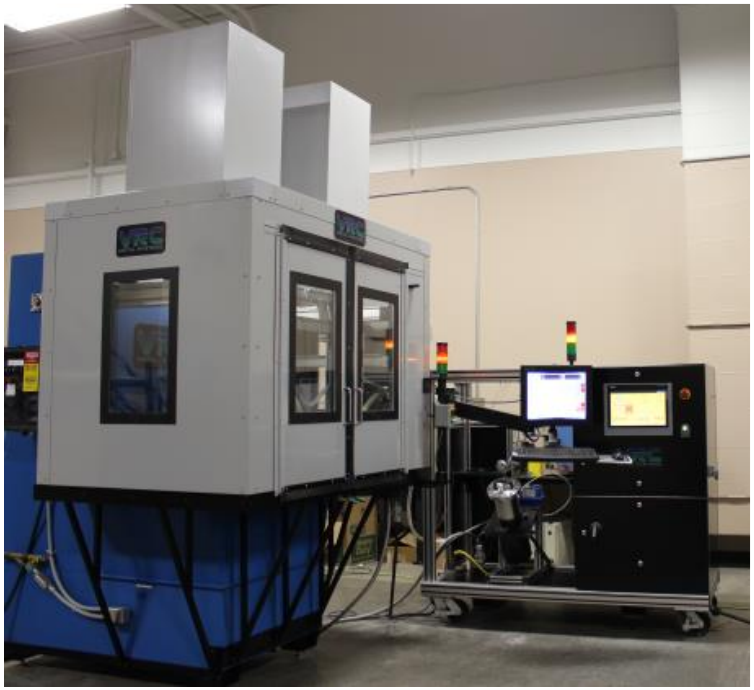
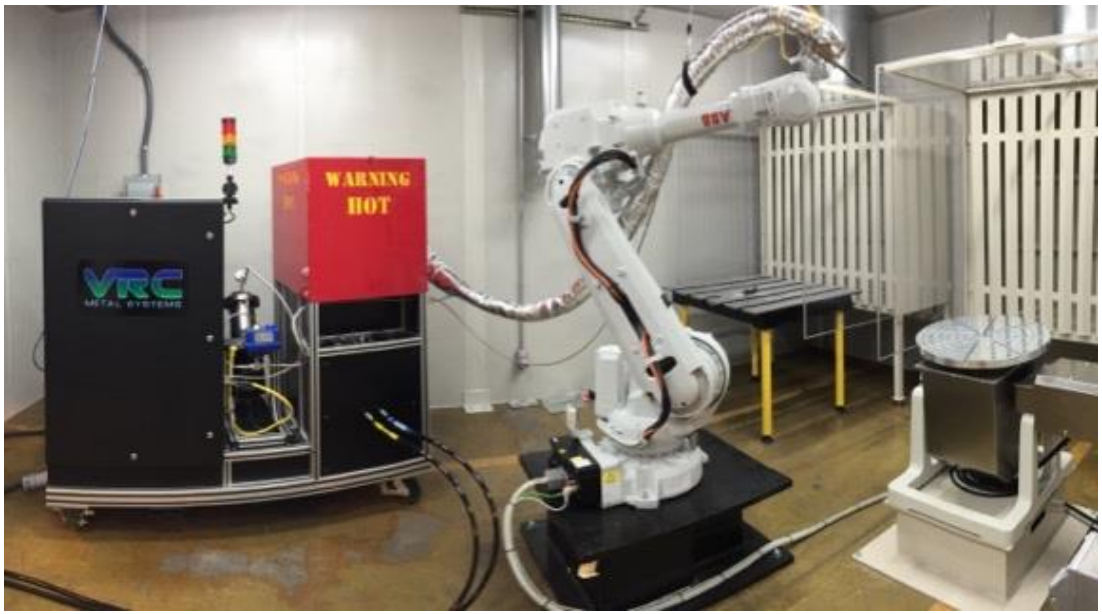
Integrated Systems

VRC Viper™
Development System



VRC Turnkey Cold Spray
Booth & Motion System



VRC METAL SYSTEMS

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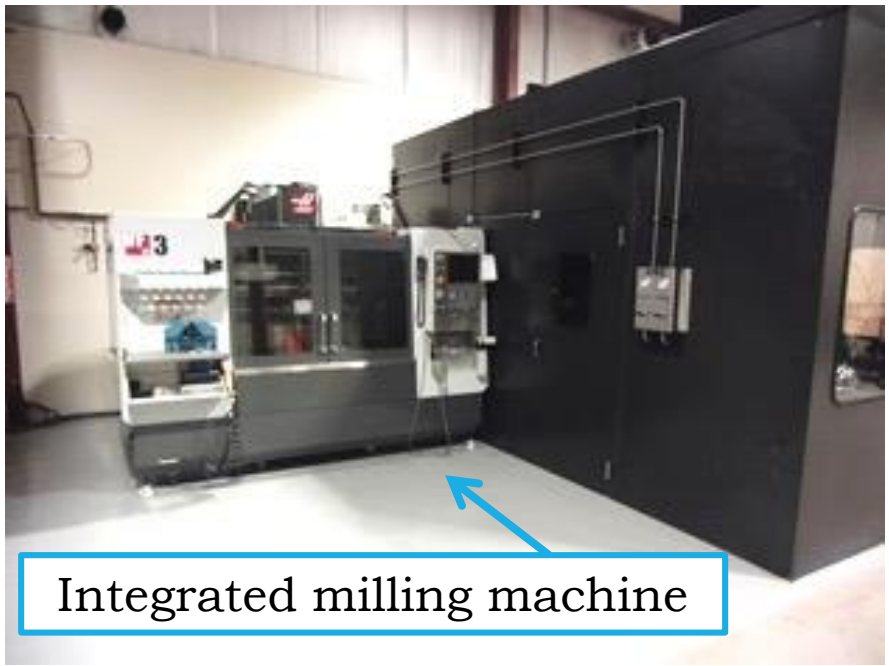
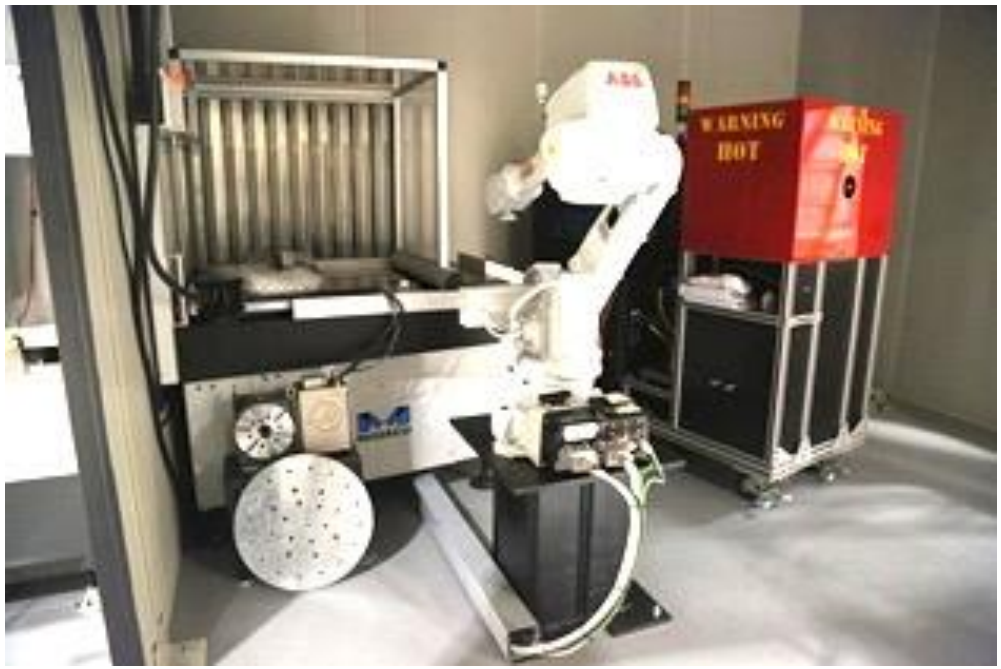
Hybrid Manufacturing Systems

VRC Paladin™
Cold Spray Additive Manufacturing System

Allows machining and cold spray on the same platform





VRC METAL SYSTEMS

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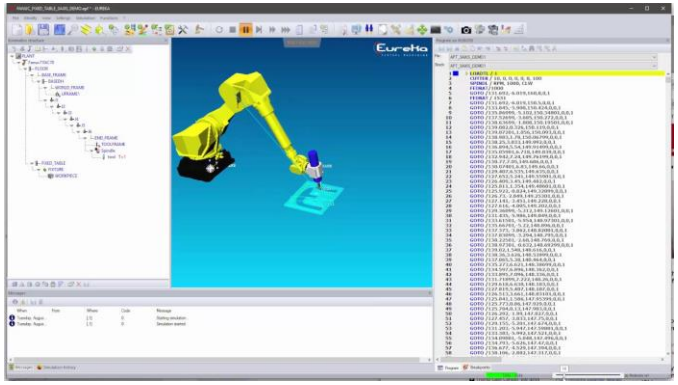
Advanced Path Planning

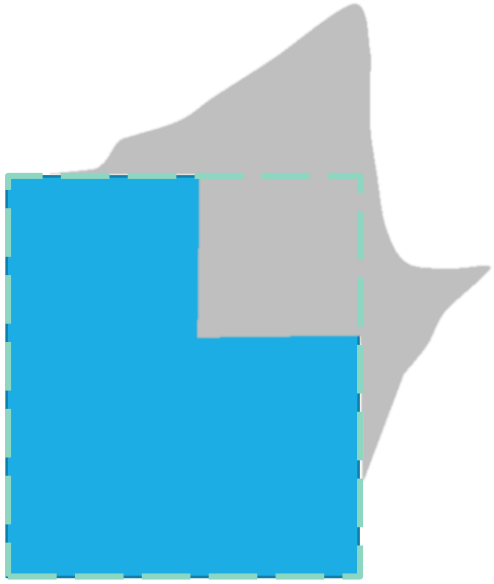
- Integrated CAD/CAM software is needed for path planning for AM and to minimize overspray.



Eureka VIRTUAL MACHINING

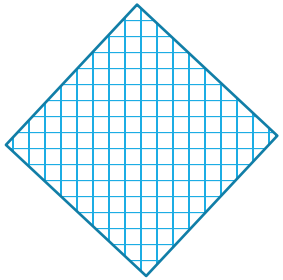
SOLIDWORKS

SolidCAM



Low Deposition Efficiency and Overspray can lead to losses of >50% of the powder…

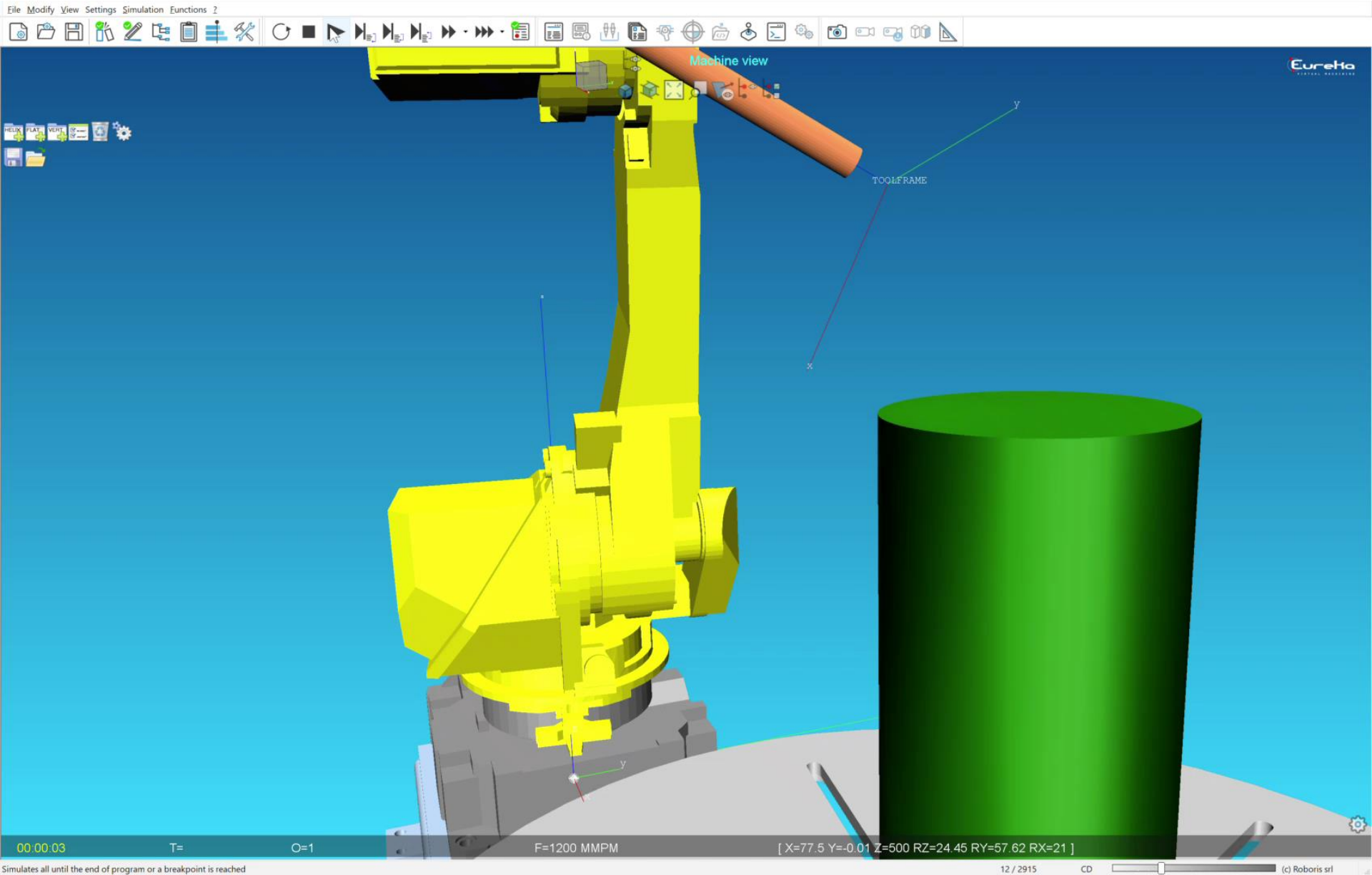
Thick Deposits Need to be Thought of as a 3-D Printed Feature not a Coating…



VRC METAL SYSTEMS

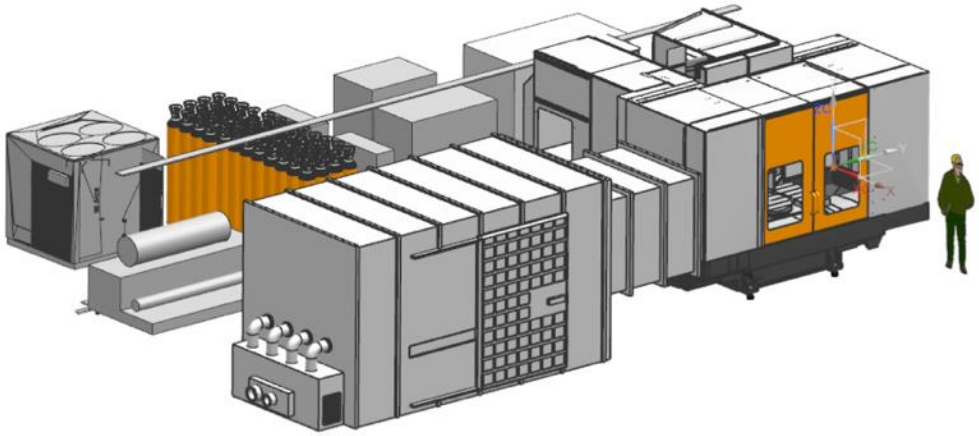
SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

Working towards direct visualization and manipulation for path planning



Helium Recovery

- Invest Capital to Reduce cost per m^3 of gas…
  1. **1 to 5 year ROI depending on volume**
  2. **Expands opportunities for structural repair with helium…**
  3. Can be coupled with onsite N_2 generation or Air compression
  4. **Helium Recovery System commercialized through VRC & Quantum**



Quantum technology

Custom industrial gas solutions since 1981

VRC METAL SYSTEMS

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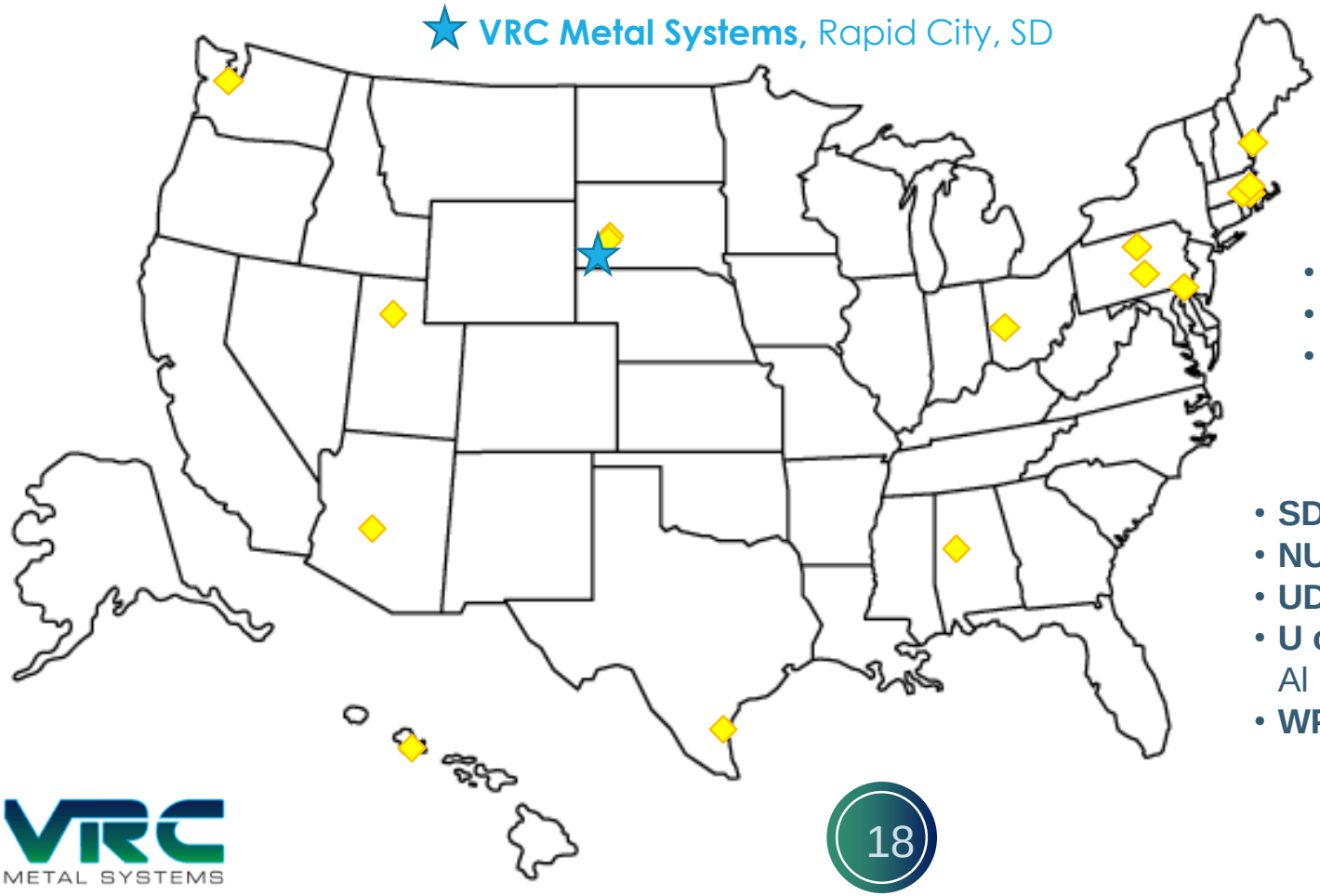
VRC Installations: DoD & DoD Collaborators

ARMY
- **ARL,** Aberdeen PVG
- **Corpus Christi Army Depot**
- **Letterkenny Army Depot**

NAVY
- **Penn State - ARL**
- **Pearl Harbor NSY**
- **Puget Sound NSY**
- **Portsmouth NSY**

AIR FORCE
- **Ellsworth AFB**
- **Hill AFB**



Commercial
- **MOOG,** Webster, MA
- **UTRC,** Hartford, CT
- **Honeywell,** Phoenix, AZ

Academia
- **SDSM&T,** Rapid City, SD
- **NU,** Boston, MA
- **UDRI**, Dayton, OH
- **U of Alabama**, Tuscaloosa, Al
- **WPI**, Worcester, MA

VRC METAL SYSTEMS

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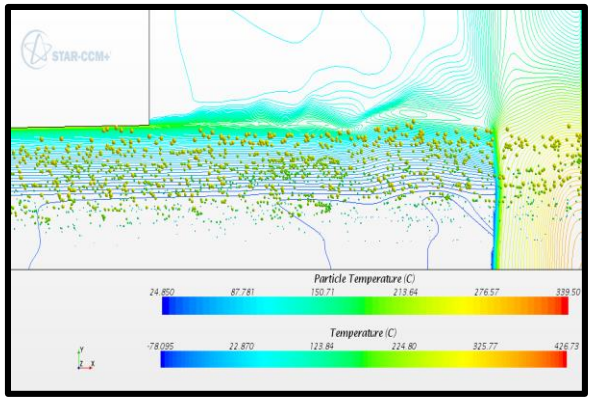
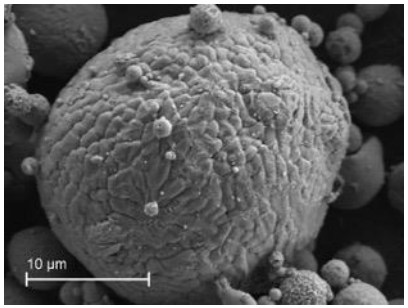
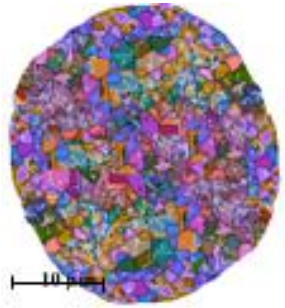
Improved Process Understanding

- **Modeling Improvements**
  - 1D to 3D
  - Ability to analyze multiple factor interactions
  - Presented by Dr. Ozdemir (a.m.)

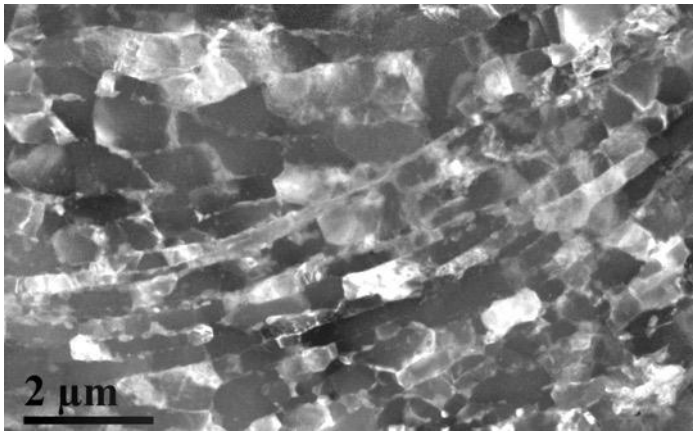


- **Powder Processing**
  - Metallurgy of the powder is important
  - Microstructures are preserved





- **Bonding Mechanisms**
  - Mechanical Interlocking vs. Recrystallization
  - Adhesion vs. Cohesion



VRC METAL SYSTEMS

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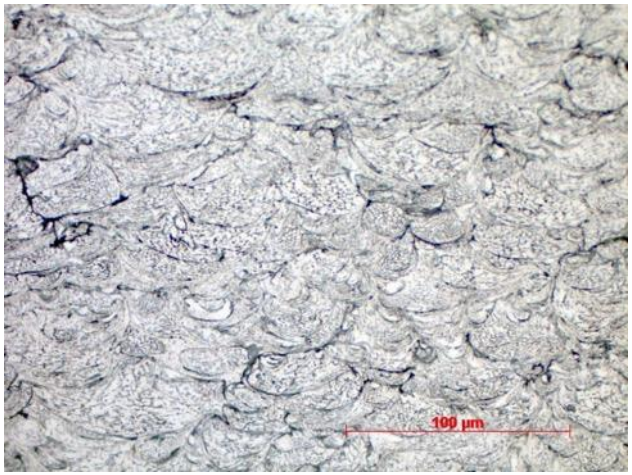
Example of Powder Processing Results

- Al 6061 Powder Process 1 – As-received + Dried @ 120C for 1 hr.
  48.3 ksi ± 3.1 ksi
  [333 Mpa ± 21.4 MPa] 3.2% ± 1% Elongation

- Al 6061 Powder Process 2 – Annealed
  42.1 ksi ± 2.5 ksi
  [290 Mpa ± 17.2 MPa] 5.1% ± 1.5% Elongation



VRC METAL SYSTEMS

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Timeline of a Cold Spray Repair

2012 — Aircraft Panel Problem Identified

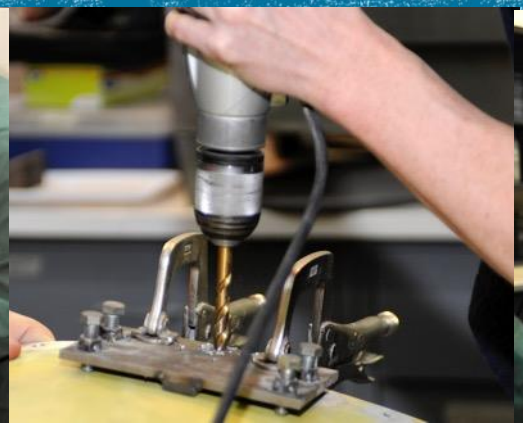
2013 — Repair Procedure Developed & Approved for Single Use

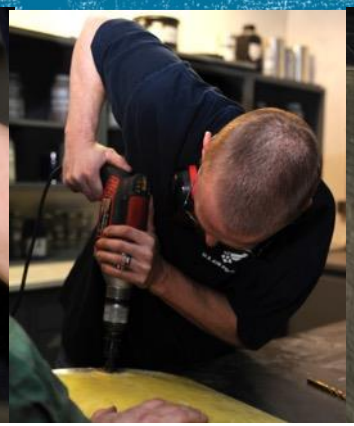
2014 — Proposal Funded to Develop Qualification Pathway

2015 — Formal Approval Process Review Initiated

2016 — Material Testing Complete

2017 — Full Approval Expected in 2017…





VRC METAL SYSTEMS

Total Effort: $3.3M over 5 years
Expected Savings: >$50M

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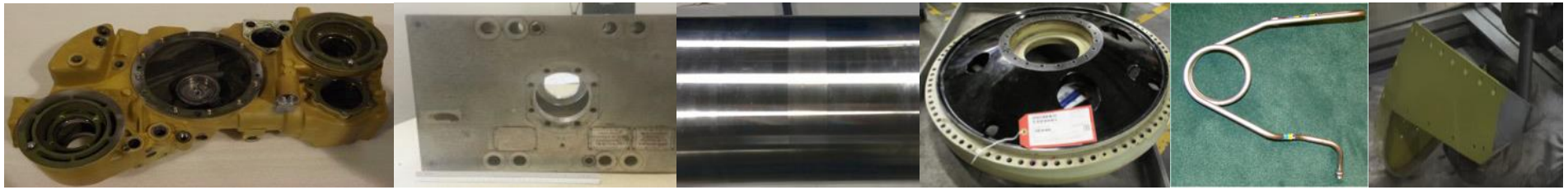
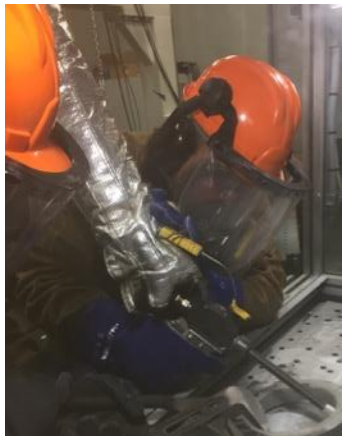
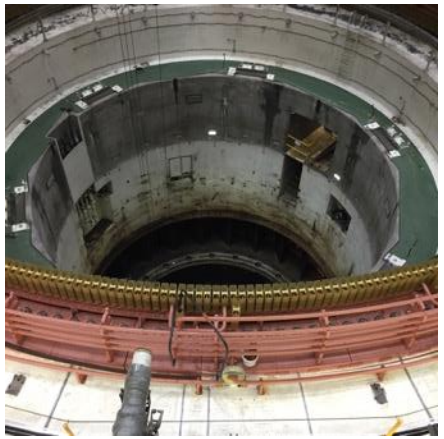
Applications Under Consideration

- Aerospace & Defense
  - Planes, Helicopters, Ships, Submarines, Ground Vehicles, etc.
  - Primary Use: Restoring wear & corrosion damage to extend part life



- Power Generation
  - Power Turbines, Valves, Boilers, Condensers, Separators, Nuclear Containment, etc.
- Heavy Industry, Mining, Oil & Gas
  - Shaft journals, Bushings, Bores, Seals, Castings, Mating Surfaces, etc.
  - Dissimilar Metal Coatings





Suggested Definition of "Structural Repair"

- *A structural repair* **adds measurable strength** *to a substrate that can be* **repeatably controlled** *to remain* **above minimum values**, *such that a designer can count on those values and* ***take credit for them*** *in calculating* ***design margins***.

VRC METAL SYSTEMS

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

A Structural Repair Does Not

- Need to match exactly to the substrate properties in every way…

Why?

- It's about restoring safety margins

Safety Margins – A simple example…

6,000 lbf whole
5,400 lbf @ max. limit

Safety Margins are compromised below max. wear limit

Safety Margins

5,400 lbf

Damage reduces the load carrying capability of the part.

Safety Margins

5,400 lbf

Damage less than the max. wear limit can be blended out and the part reused, but the safety margin has been reduced to the lowest acceptable level.

Safety Margins

However, additional damage at the same site will fail the part…

Safety Margins

5,400 lbf

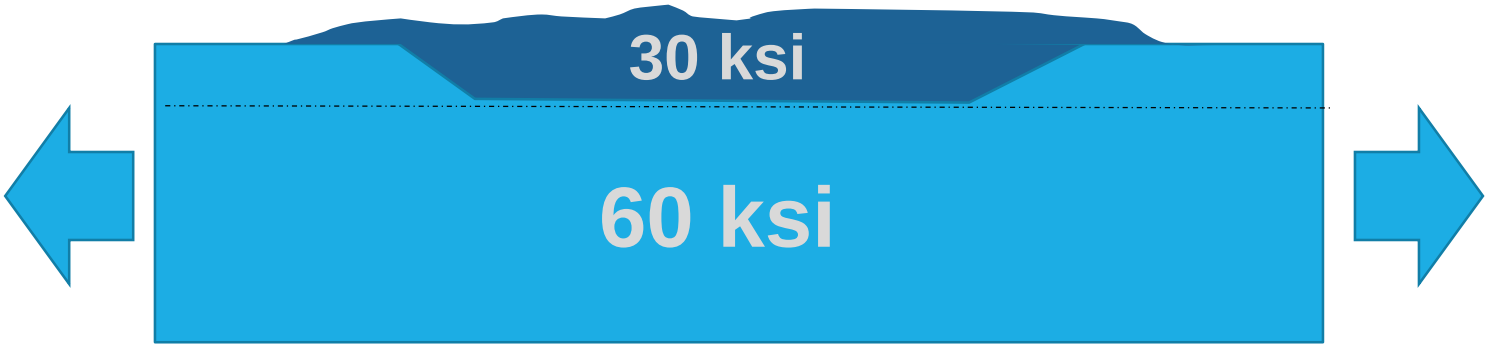
There is an alternative with cold spray…

Safety Margins

5,400 lbf

Blend out the damage

Safety Margins



Cold Spray the blended area

Safety Margins

Machine or grind back to part dimension.

Even if the cold spray is not as strong as the base metal, additional strength can be added to the part to restore safety margins.

Safety Margins

If the part is damaged again at the same location, additional damage will be protected.

Safety Margins

5,700 lbf

And the part can be repaired again.

Safety Margins

Additionally, if the part is damaged beyond repairable limits, the part may still be repairable...

Safety Margins

The area can be blended out and then cold sprayed.
If geometric constraints allow, the area can be overbuilt to restore full strength.

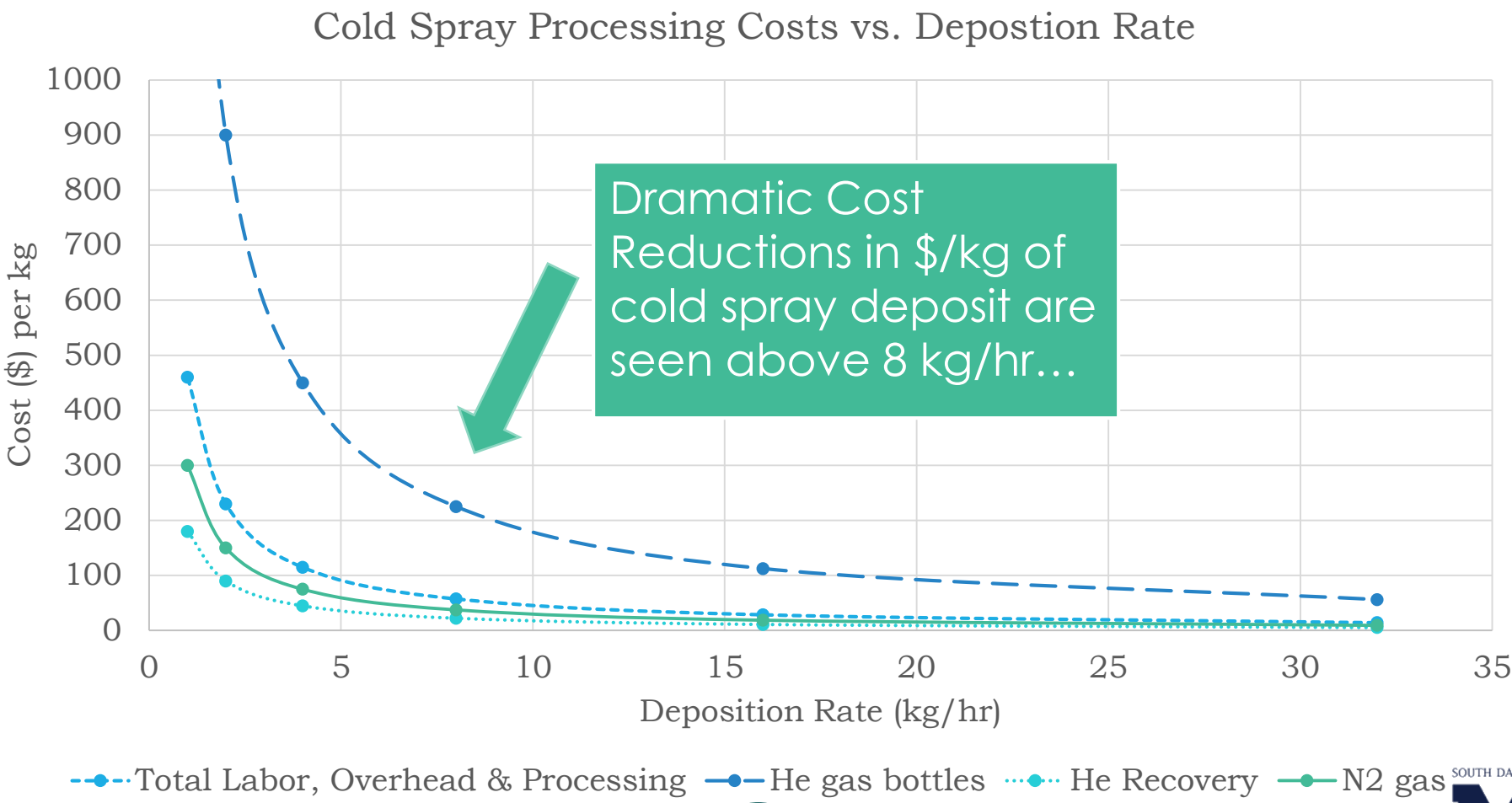
Safety Margins

Or simply re-machined, and evaluated to determine if safety margins have been restored to an otherwise unrepairable asset.

Cost Estimating

- Property & Quality Requirements
- Gas Type
  - (Air, N_2, He, other?)
- Gas Source
  - (Bottles, Liquid, Generator, Recovery, etc.)
- Deposition Rate & Efficiency
- Percent Overspray
- Powder Cost
- Powder Processing Cost
  - (Sieving, Drying, Heat treating, Milling, Packaging, other?)
- Setup, Post-Processing, and Clean-up Costs
- Labor and Facility Costs
- License Fee
  - (Possible license for use of patented process)

Cold Spray Cost Chart



Ways to Reduce Costs – Process Optimization

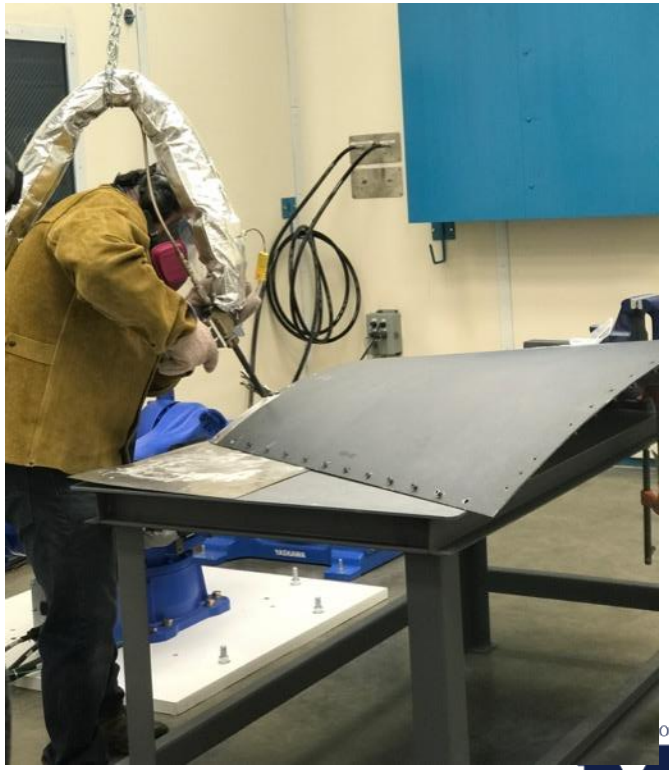
- **Optimize Cold Spray Parameters for Cost not Properties**
  1. **Increase powder deposition rates**
     - Powder feed rates can be increased at the expense of Vcr
  2. **Spray at 90° when possible**
     - To maximize deposition efficiency
  3. **Use a bond coat to increase adhesion**
     - Many coatings can fail by adhesion, when cohesion is high
     - Use He and/or 45-60° for the 1st pass
  4. **Implement helium recovery**
     - Lower cost than bulk nitrogen

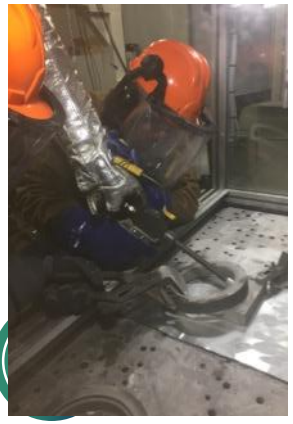
Qualification

- VRC Metal Systems and SDSM&T have been involved in numerous qualification efforts with cold spray.
- Air Force Rapid Innovation Fund (RIF)
  - Processes:
    - ✓FEB Panel & CET (Change Evaluation Team)
    - ✓Reported on yesterday by AFRL
  - Installations:
    - ✓Ellsworth site setup and qualification for AF
- Additional Efforts Now Underway
  - Army RIF
  - Navy RIF

Cold Spray Training

- ASM Thermal Spray Management Certificate
- VRC Cold Spray Operator Training Program
  - Includes a custom curriculum with hands-on instruction





SCHOOL OF MINES & TECHNOLOGY

Conclusion

- **Cold Spray is beginning to make a significant impact across the DoD**
- Developments are driving towards total **RELIABILITY** and **REPEATIBILITY**
- This requires work from POWDER TO PATH PLANNING in:
  1. **EQUIPMENT DESIGN & CAPABILITIES**
  2. **PROCESS QUALIFICATION**
  3. **TRAINING**

Thank you for your attention!

- **Acknowledgements**
  - We gratefully acknowledge the support of the **Army Research Lab** and **Victor Champagne** through contract #W911NF-15-2-0034.

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