SAND2007-2512P

Thermal Spray Coatings & Sandia's Thermal Spray Research Laboratory (TSRL)

Dr. Aaron C. Hall
(505) 284-6964
achall@sandia.gov

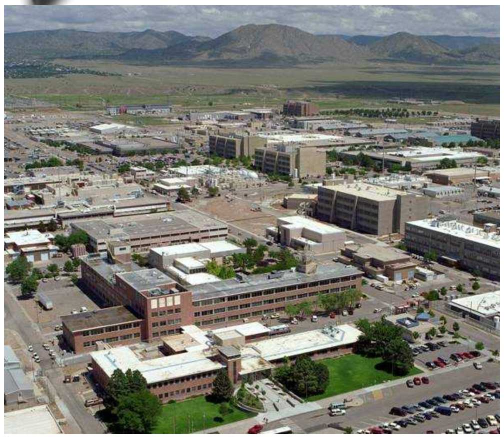
Dr. Rodney Williamson
(505) 284-8223
rodwill@sandia.gov

*Sandia is a multi-program laboratory operated by Sandia Corporation for the United States Department of Energy under contract DE-AC04-94AL85000.

Sandia National Laboratories

Sandia National Laboratories

Albuquerque, New Mexico



- More than 8,600 full-time employees
- More than 1,500 PhDs and 2,700 MS/MAs
- 2,200 on-site contractors
- $2.33 billion FY06 total budget

Yucca Mountain, Nevada

Kauai Test Facility, Hawaii

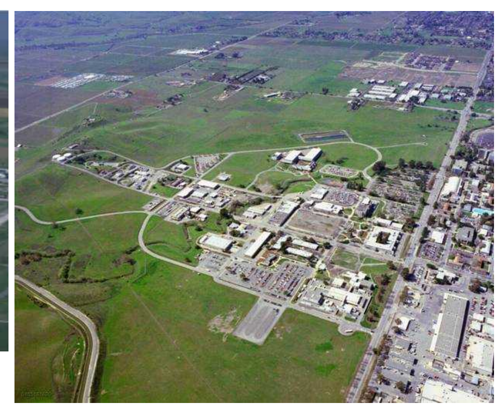
Tonopah Test Range, Nevada

National Nuclear Security Administration

LOCKHEED MARTIN

WIPP, New Mexico

Pantex, Texas



Livermore, California

"Exceptional Service In the National Interest"

Sandia National Laboratories

Sandia is a National Security Laboratory

We develop technologies to:

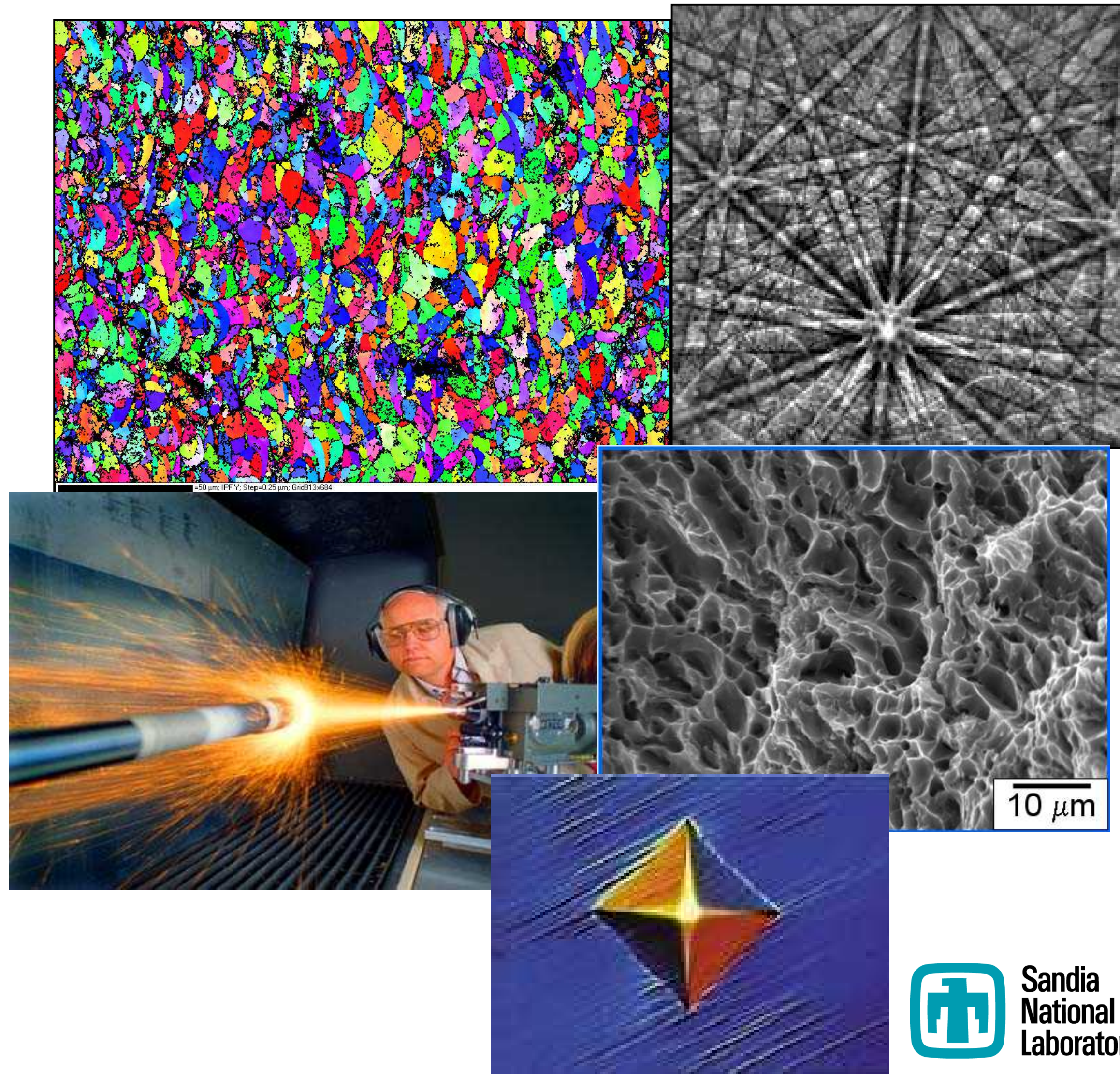
- Sustain, modernize, and protect our nuclear arsenal
- Prevent the spread of weapons of mass destruction
- Provide new capabilities to our armed forces
- Protect our national infrastructures
- Ensure the stability of our nation's energy and water supplies.
- Defend our nation against terrorist threats

"Exceptional Service In the National Interest"

Sandia National Laboratories

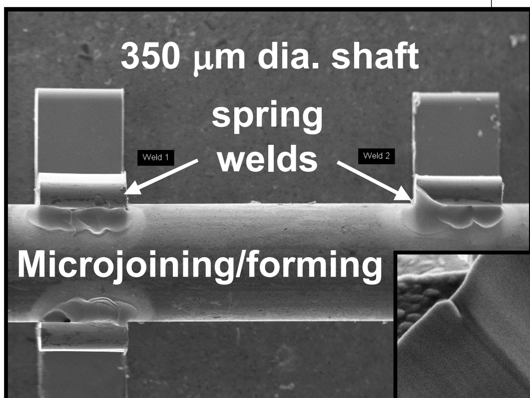
The Materials Science & Engineering Center supports Sandia's missions.

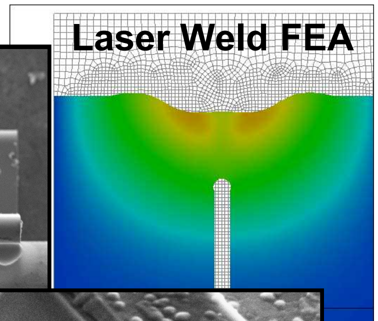
- ~ 250 people
- ~ 100 Ph.D.'s
- Polymers
- Ceramics
- Metals
- Advanced analytical techniques
- Atomistic & mesoscale modeling
- Mechanical metallurgy
- Process diagnostics
- Tribology
- Materials aging

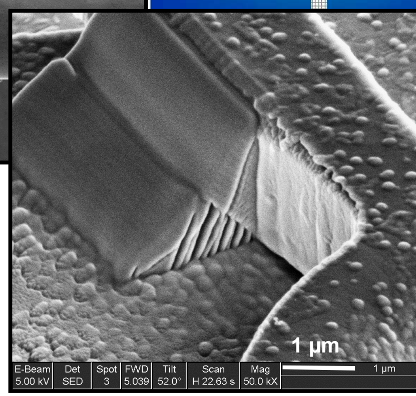


Joining & Coating Department (01813)

- ***Science-based engineering for reliable joining & thermal spray technologies***

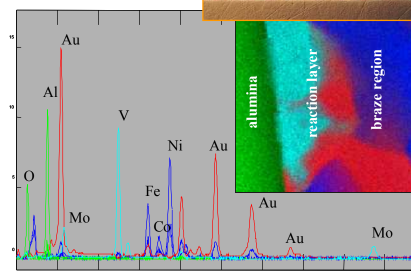


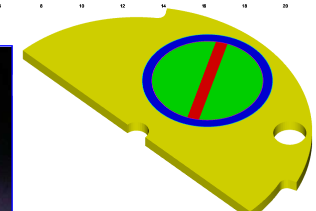


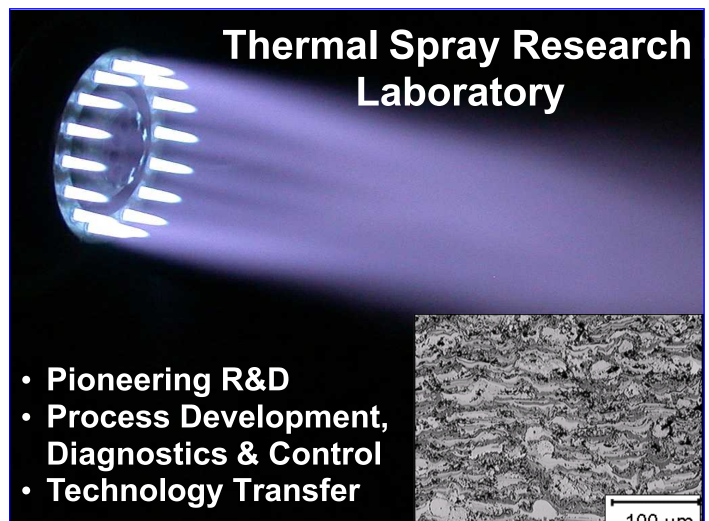


Focused Ion Beam Deposition Joining fillet on Si-MEMS device

Fundamental understanding of interfacial reactions & microstructures correlated to properties and performance







Providing Integrated Process & Physical Metallurgy Solutions

"Exceptional Service In the National Interest"

Sandia National Laboratories

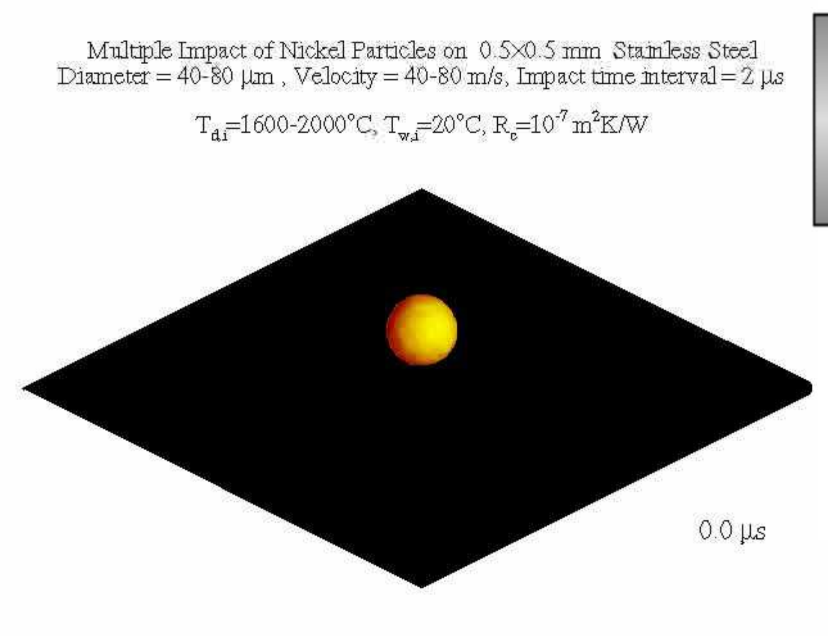
Sandia's Thermal Spray Research Laboratory (TSRL)

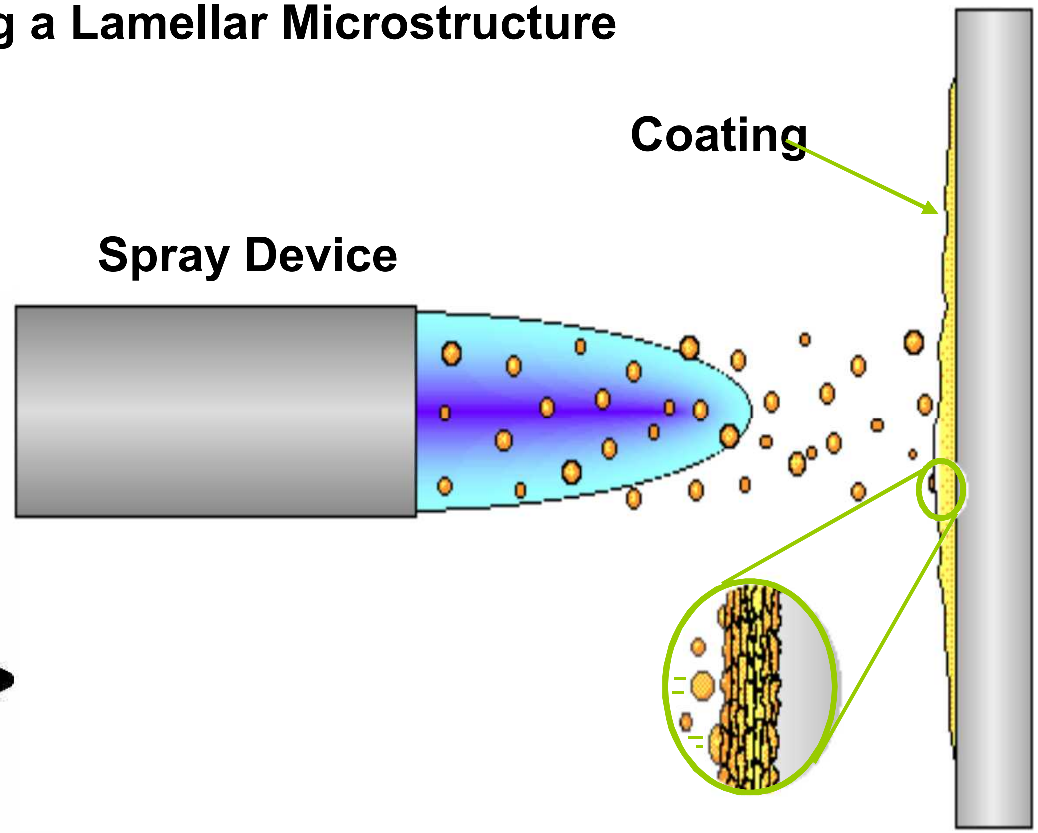
- **The TSRL provides:**
  - **Science-based process understanding for thermal spray**
  - **An engineering resource for materials & process development**
  - **Experience fielding thermal spray materials & processes in both the government & industrial sectors**

- **2 Ph.D Staff**
- **5 Engineers & Technicians**
- **1 Student**
- **1 Visiting Professor**

What is Thermal Spray?

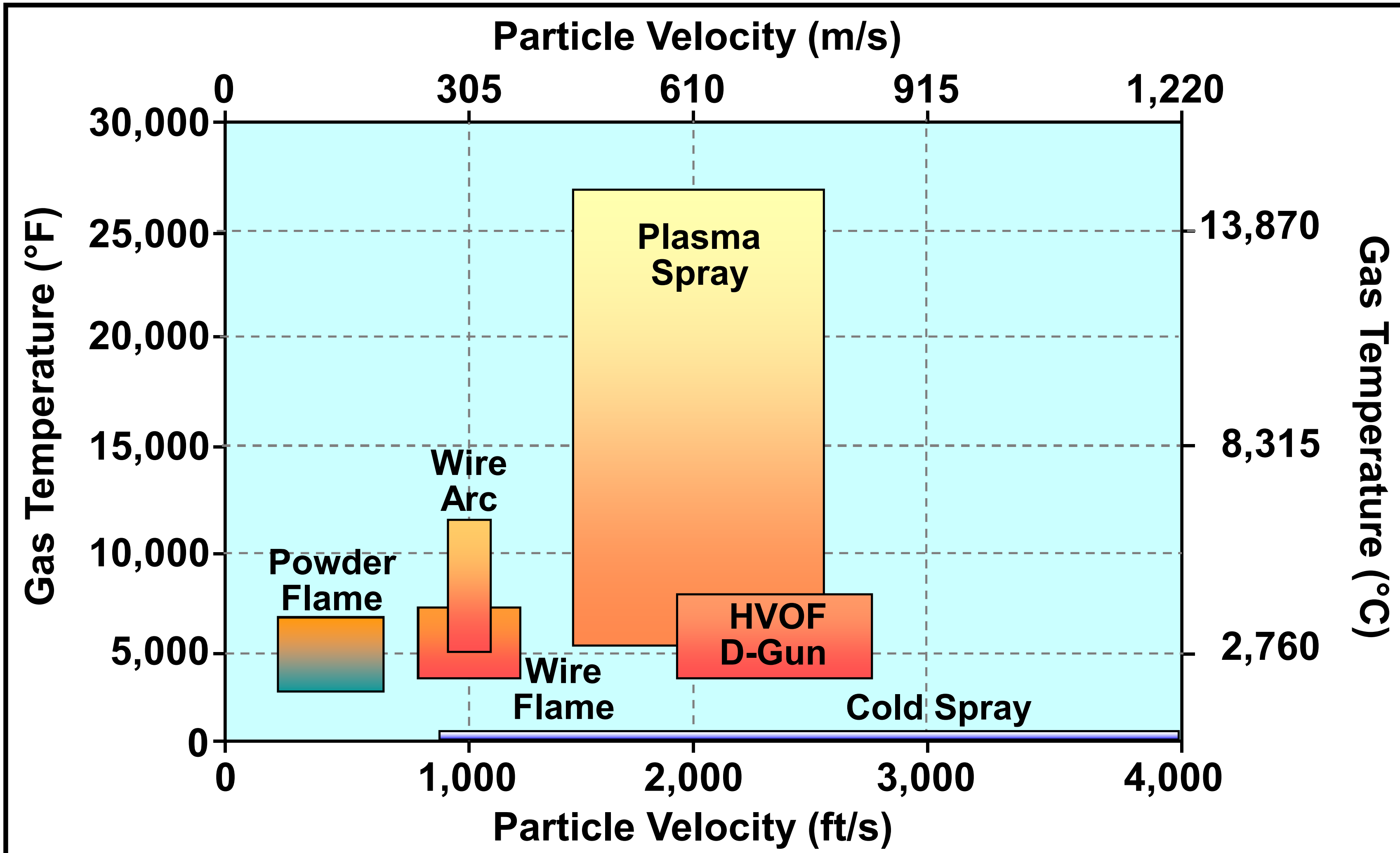
~ 10 - 100 µm Molten or Semi-Molten Droplets are Sprayed onto a Target Surface Where they “Splat” Cool at Rates up to 10^4 -10^8 K/sec Forming a Lamellar Microstructure





*Droplet Impact Simulation by Prof. J. Mostaghimi, et al, Univ. of Toronto, 1998.

Like welding processes, there are many different thermal spray processes.

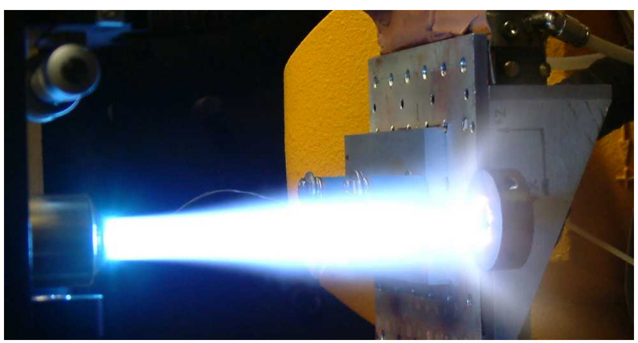


*Adapted from plots by R.C. McCune, Ford Motor Co. & A. Papyrin, Ktech Corp.

The TSRL currently operates at least one version of every major spray process in the world.

Atmospheric Plasma Spray

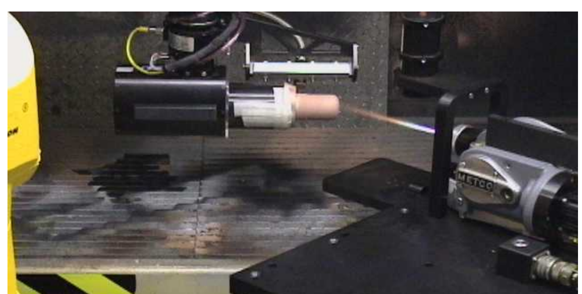
Twin Wire Arc Spray



Powder Flame Spray

Vacuum, low pressure, and very low pressure plasma spray

Cold Spray



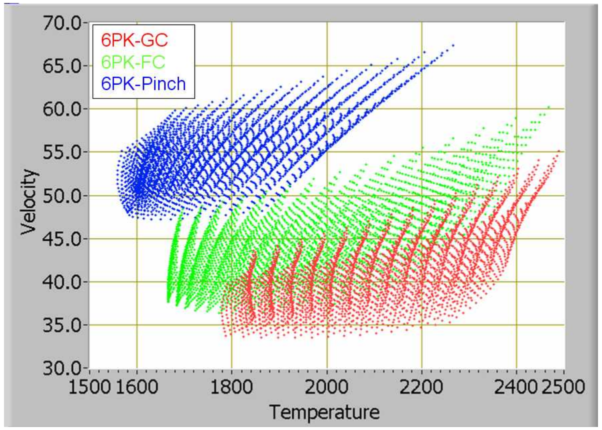
Wire Flame Spray

HVOF

"Exceptional Service In the National Interest"

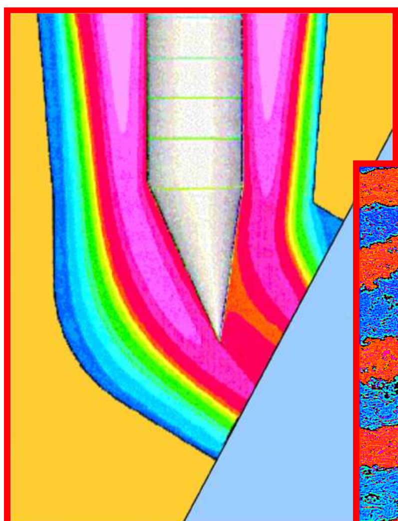
Sandia National Laboratories

What is Sandia's Thermal Spray Research Laboratory (TSRL)?

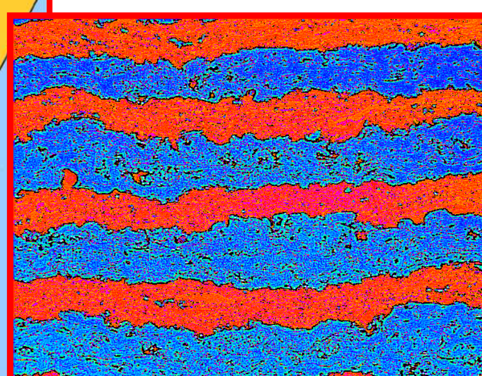


We focus on process diagnostics for thermal spray.

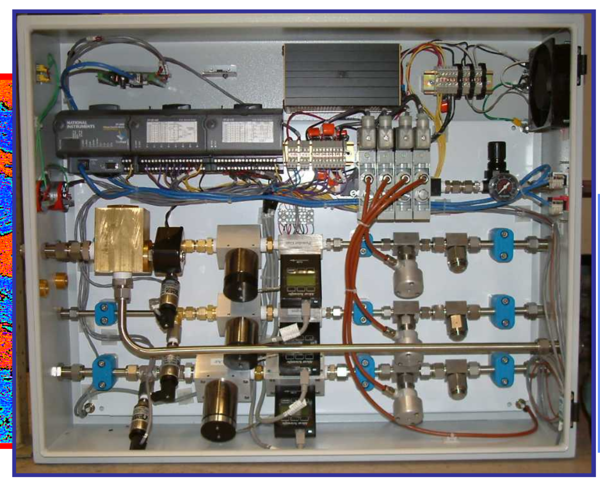
- Part of Sandia National Laboratories Materials Science and Engineering Center
- One the largest Thermal Spray R&D groups in the United States
- A team of scientists & engineers dedicated to understanding *process-microstructure-property* relationships in thermal sprayed coatings
- The largest *secure* thermal spray R&D facility in the United States



We team to model spray processes

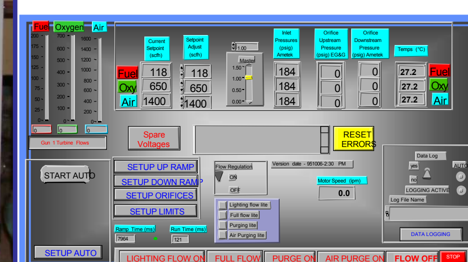


We design coatings & conduct materials R&D



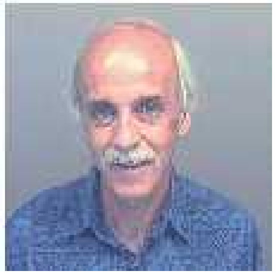
We develop custom control technology for spray applications

We support War Reserve Production for the Nuclear Weapons Stockpile



Sandia National Laboratories

Who is the TSRL?



F. Michael Hosking
M.S. Metallurgy UIUC
1813 Manager
(30+ years metals processing experience)

Dr. Mark F. Smith, FASM
TSRL Founder, Deputy Director 2400
25+ years Thermal Spray Experience
Member: Thermal Spray Hall of Fame

Dr. Richard Neiser
Former TSRL Lead, Manager 5918
15+ years Thermal Spray Experience

Aaron Hall
TSRL Lead
Ph.D. Materials Science UIUC
B.S. Mech. Engineering
7 Yrs metals processing, 5 yrs (TSRL)

Rod Williamson
Ph.D. Phys. Chem.
Univ. Wash.
22 Yrs metals processing experience

Dave Urrea
M.S. Info. Tech.
10 Yrs (TSRL)

Andy Mayer
B.S. Comp. Sci.
& B.S. Elec. Eng.
14 Yrs. (Ktech & TSRL)

Tim Roemer
M.S. Geophys. NMSU
27 Yrs (Ktech), 14 yrs (TSRL)

James McCloskey
Electrical/Mech Tech
5 Yrs. experience

Dave Beatty
Electrical/Mech
Tech. 29 Yrs.
(Ktech), 12 yrs
(TSRL)

Deidre Hirschfeld
Visiting Professor
NM Tech 20 Yrs

John Perovich
Student Intern
Physics – UNM

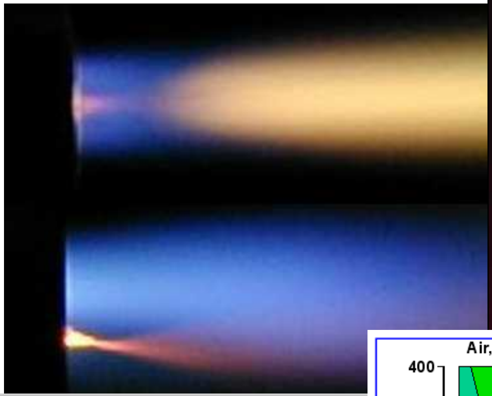
TSRL people:
- Have been active in Thermal Spray Community for ~ 30 years
- Currently have over 60 years of combined thermal spray experience

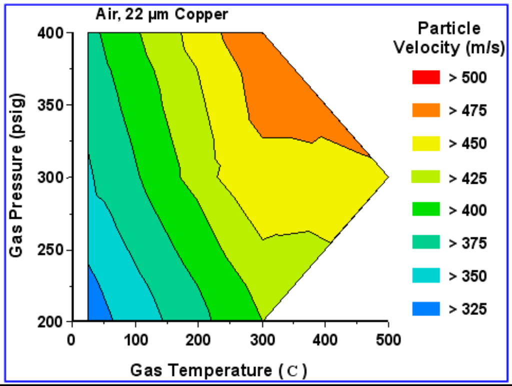
"Exceptional Service In the National Interest"

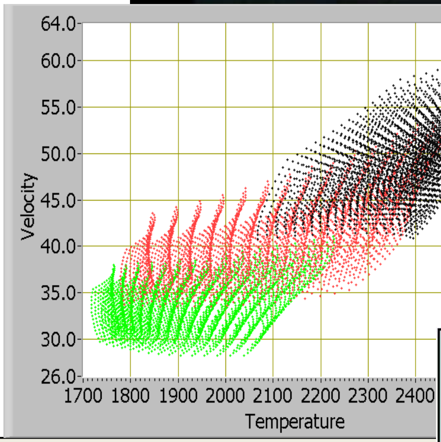
Sandia National Laboratories

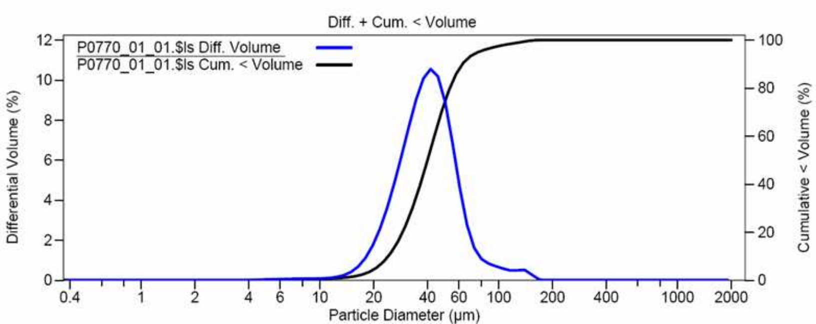
What makes the TSRL unique?

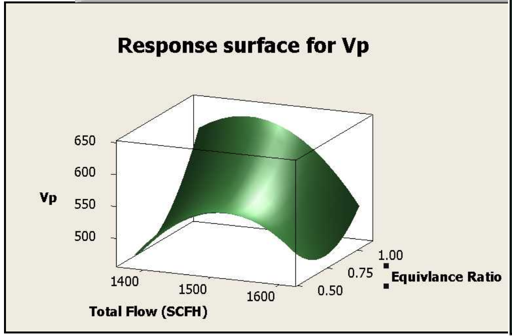
- Focus on Process Diagnostics for Thermal Spray
  - DPV-2000, Accura G3
  - L2F Laser Velocimeter
  - Control Vision
  - Spectroscopy
  - Xenon-Flash Thermal Diffusivity
  - Beckman Coulter Particle Size Analysis
- Materials Science Expertise and Analysis Capability
- Routine Calibration
- Modeling Support: Atomistic – Gas Dynamics
- LPPS® Thin Film & Cold Spray
- Experience supporting spray processes across entire technical readiness scale

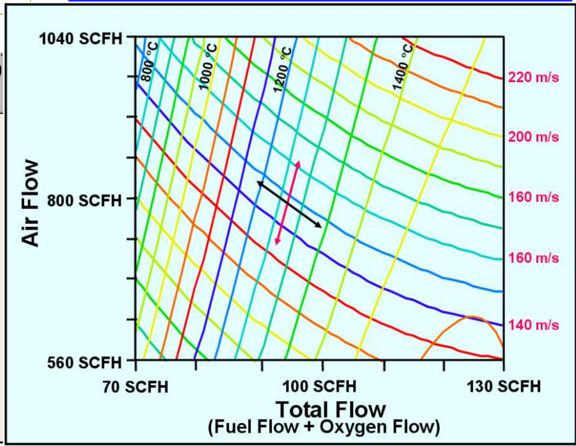






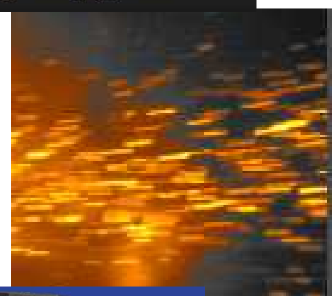


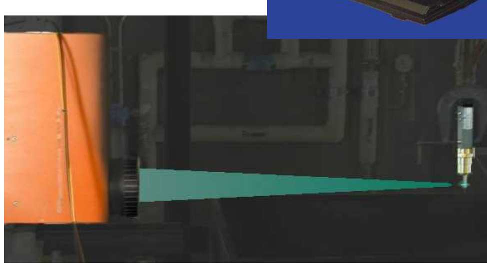


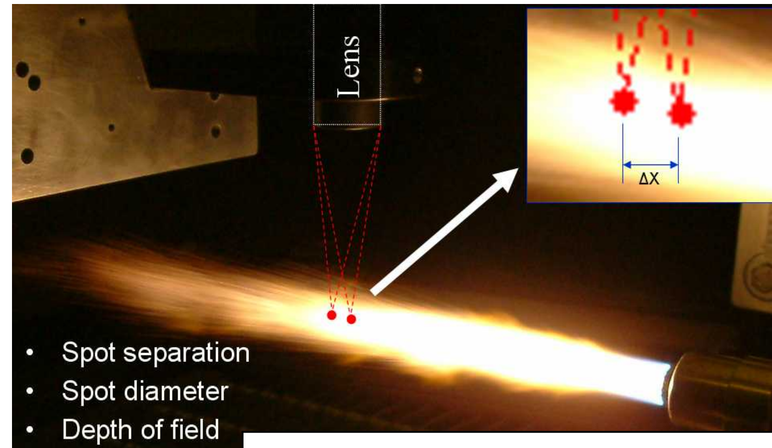


Commercial particle diagnostics equipment is readily available and widely used.

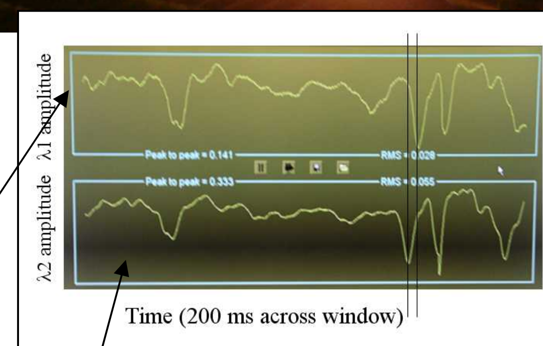
- Camera based
  - Stratonics
  - Spray Watch
- Sensor-based
  - Accura Spray
  - DPV
  - L2F

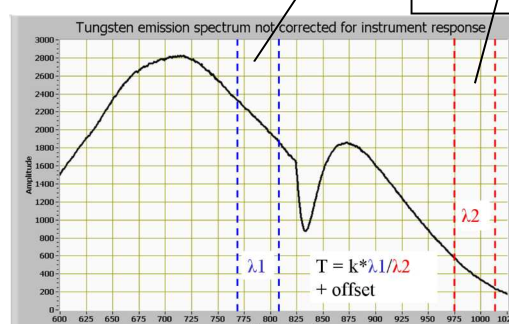






- Spot separation
- Spot diameter
- Depth of field

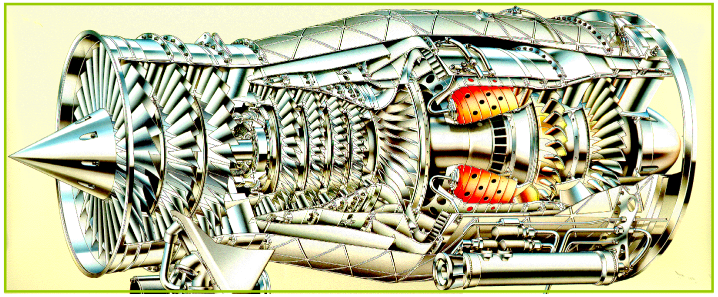




$$T_p \propto \lambda 1/\ \lambda 2$$

$$V_p = \Delta x\ /\Delta t$$

Many Unusual Matls. Are Thermal Sprayed

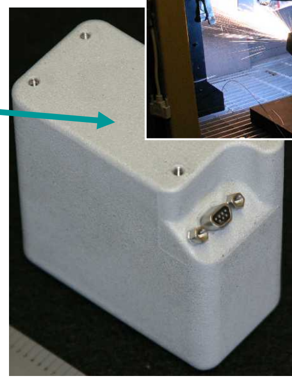


- **Pure metals and most alloys:**
  - Sn; Zn; Al; Cu; Ni; Fe; Mo; Ta; W
- **Most traditional ceramics:**
  - Al_2O_3; TiO_2; MgO; YSZ; ZrO
- **Composite abradable seal materials:**
  - Al-12Si-40Polyester; Ni-25Graphite; Al-9.5Si-20BN
- **Iron Based Alloy Coatings**
  - 316 Stainless; Fe-10Cr-7Al-5Mo-3TiO2 (grindable wear resistance)
- **Ni Base alloys**
  - Ni-14Cr-6Al-5Mo-2Co-1Ti-0.1Zr-0.01B (for use w/ Inconel)
  - Ni-16Cr-8Fe (machinable "stainless")
- **MCrAlY's:**
  - Co-32Ni-21Cr-8Al-0.5Y (high temp erosion, corrosion, & oxidation resistance in gas turbines)
  - Ni-22Cr-10Al-1.0Y (high temp erosion, corrosion, & oxidation resistance in gas turbines)
- **Blended cermets**
  - $MgZrO_3$+35NiCr; Al_2O_3 + 30(Ni-20Al) (abrasion & shock resistance)
- **Cobalt Based Alloys**
  - Co-25.5Cr-10.5Ni-7.5W-0.5C (abrasive wear and erosion in high temp environments)
  - Co-Ni-Cr-WC (surface restoration for combustors, airfoils, blades, and vanes in gas turbines)
- **Carbides & Metal / Carbide Composites**
  - MoC_3 , Cr_3C_2 , Cr_3C_2-NiCr (wear resistance & hard chrome replacement)
- **Tungsten Carbide Based Materials**
  - W_2C-12Co (hard chrome replacement)
  - (W_2C-12Co)+25(Ni Base Super alloy) Blend (hard chrome replacement in corrosive environments)

and many, many more…

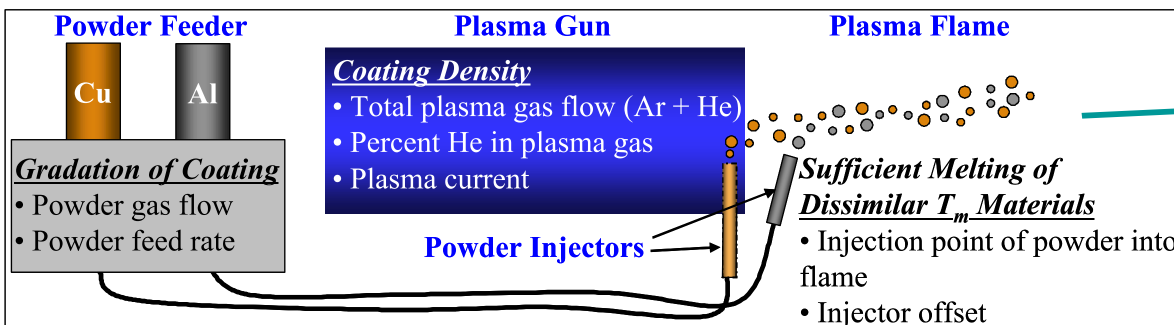
Examples of Spray-Deposited Coatings

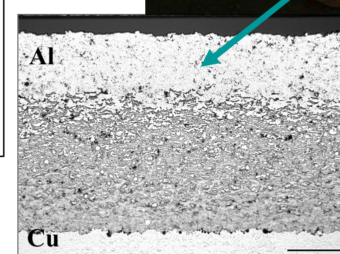
Flame Spray Process



Electromagnetic Shielding

Plasma Spray Process





Graded Al-Cu

Sandia/GM Jointly Develop Enhanced Spray Technology for Lightweight Auto Engines

Saturn with Sprayed Engine
Driven Detroit-Albuquerque-Detroit

GM Commercialization Hindered Due to:

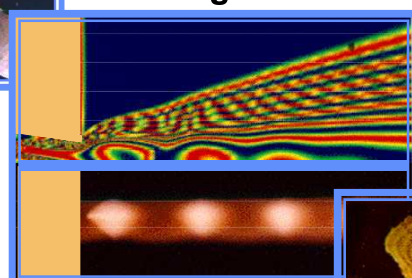
- Inadequate throughput/spray gun service lifetime
- Non-uniform macro/micro deposition
- Inadequate control of composition/microstructure

Diagnostics

Solution:

- Use SNL diagnostics/models to ID root process/materials issues
- Proper understanding led to successful solutions

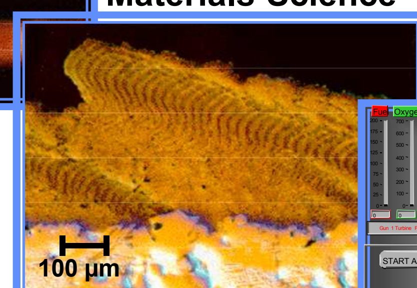
Modeling



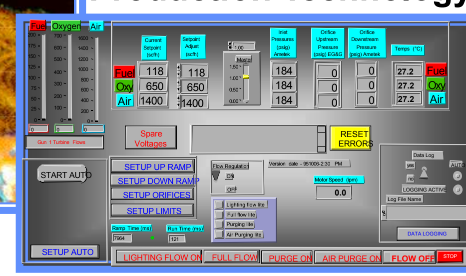
Results:

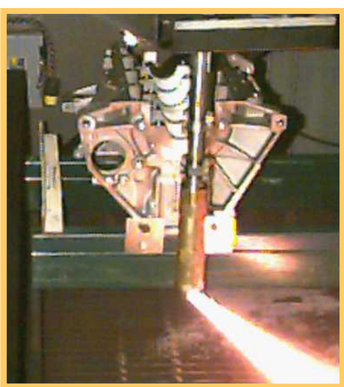
- > 200% throughput increase
- ~ 50% capital cost reduction
- > 1000% greater spray gun service life
- Desired uniformity/microstructure
- Outwears cast iron in lab tests

Materials Science



Production Technology





Preparing to Coat a Test Engine at SNL

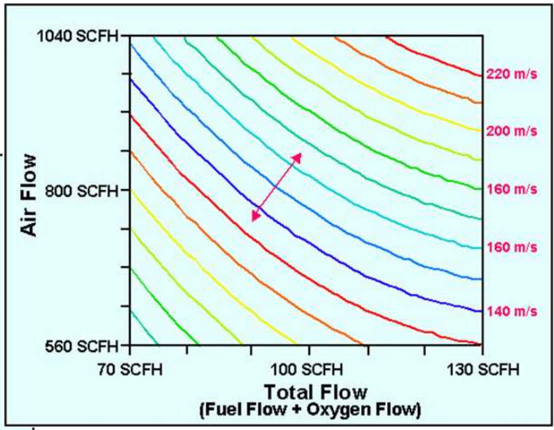
NW Production Flame Spray Coating:
Critical NW Technology Developed by TSRL

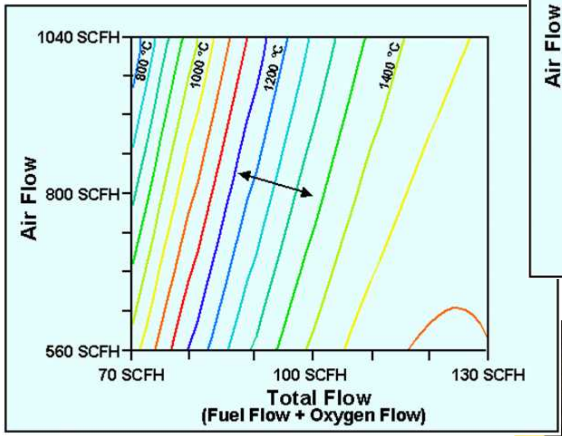
- SNL operates three production flame spray systems
- Mistakes are costly: 95% (~$75K) of component value built in when coating is applied.
- Critical requirements for coating thickness and microstructure.

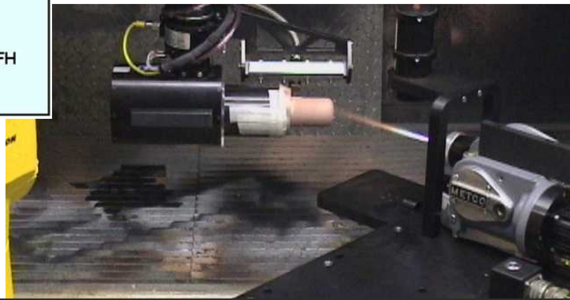
TSRL Accomplishments

- Coating Design & Metallurgy
- Process-Microstructure-Property Understanding
  - Process Mapping
  - Microstructure / Property Modeling
  - Experimental Testing
- Process Specification
- Complete Spray System Design
- Fabricated & Installed Custom Process Control Equipment
- WR Qualified System in Production for ~ 5 years @ SNL

Years of basic R&D work on flame spray coatings at Sandia have resulted in a science-based process understanding







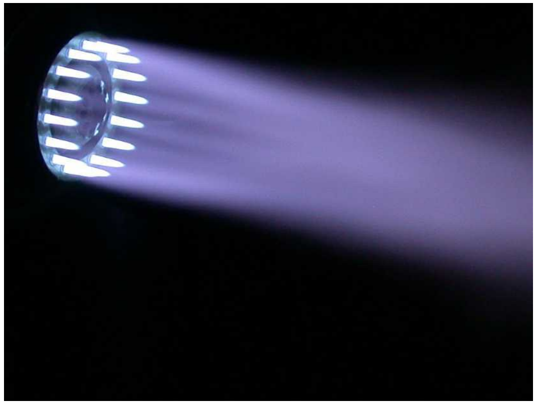
"Exceptional Service In the National Interest"

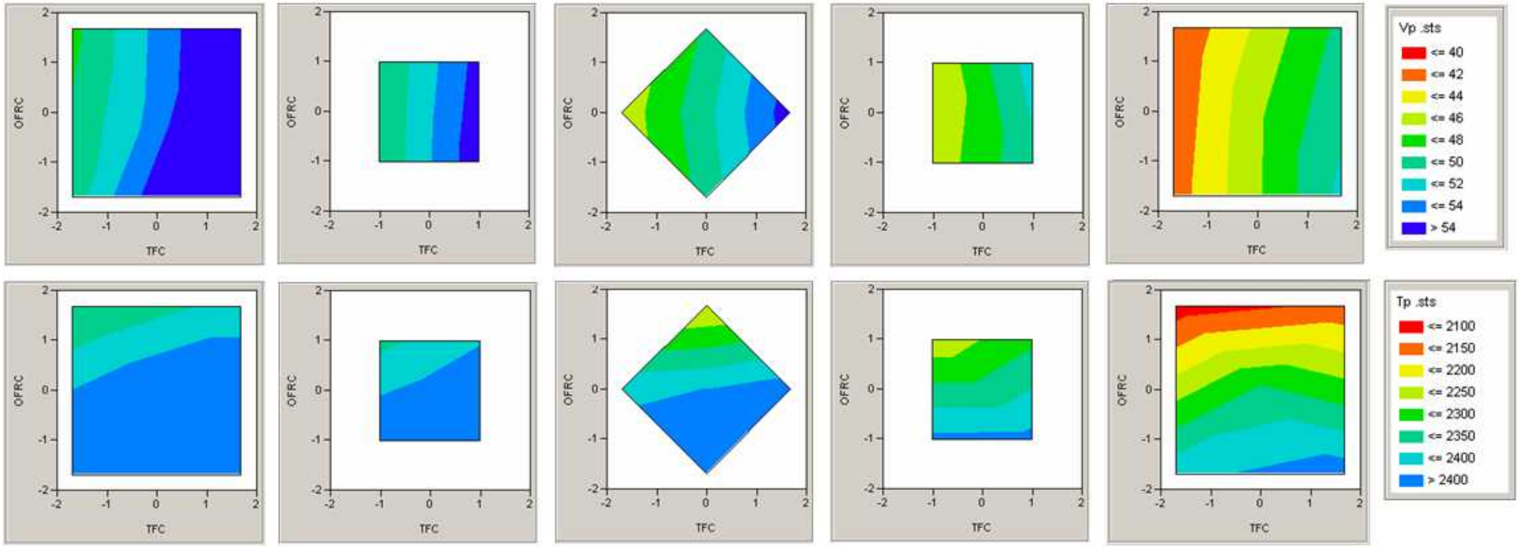
USAF Powder Flame Spray Program

- 4 year ~ $7M process development effort
- 1000 – 10,000 parts coated annually
- Critical to multiple U.S.A.F systems
- Currently in production at multiple U.S. manufacturers

TSRL Delivered:

- Science-based process definition
- Selection & pre-qualification of new materials
- Improved production equipment & quality control tools
- Government owned materials specification
- Support for transition to production



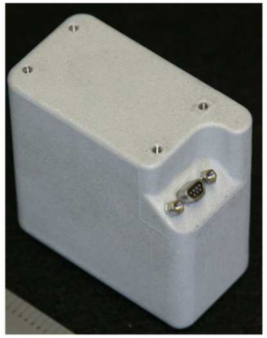


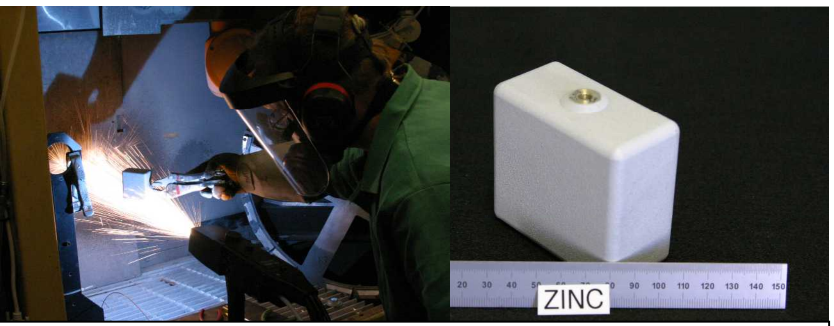
-1.682 -1 0 1 1.682

Standoff Distance

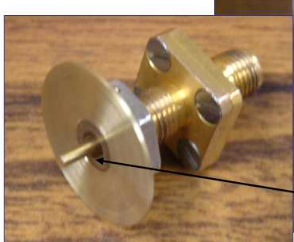
"Exceptional Service In the National Interest"

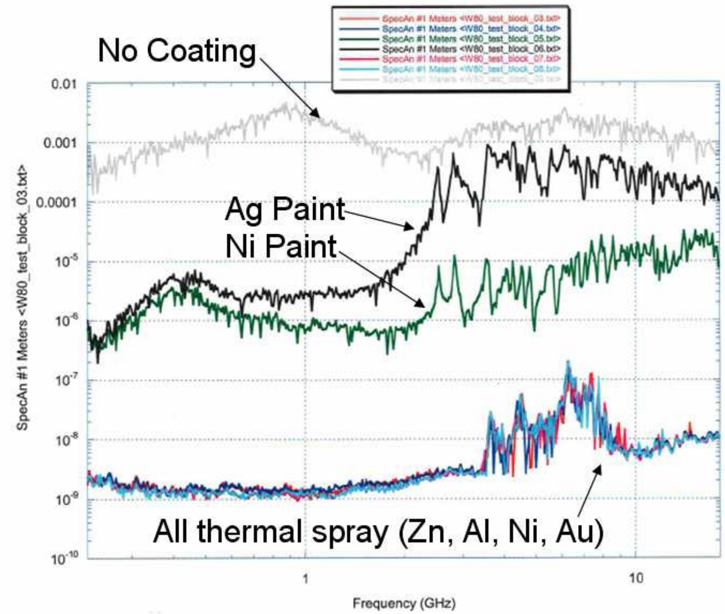
MC 4677 (Power Assembly) Electromagnetic Shield





- Nylon block with monopole antenna
- Allows relative comparisons between coatings





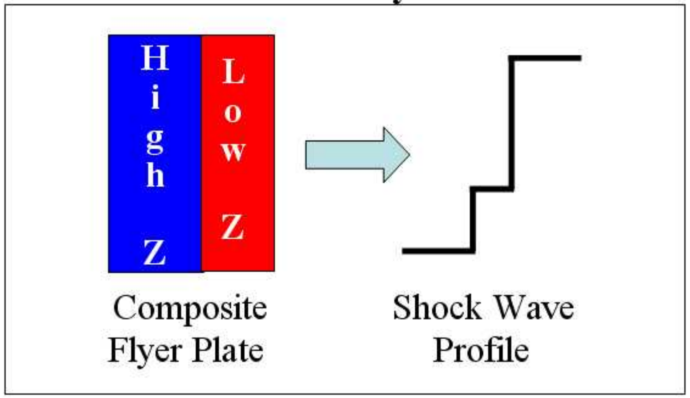
- **Specified and ordered spray equipment for production vendor:**
  - **Spray equipment & Acoustic enclosure**
  - **Robotics, Dust collector, etc…**
- **Work with production vendor to install equipment and meet OSHA safety requirements.**
- **Developed spray procedures**
- **Developed material specifications**
- ***Weapon program postponed prior to fielding coating.***

"Exceptional Service In the National Interest"

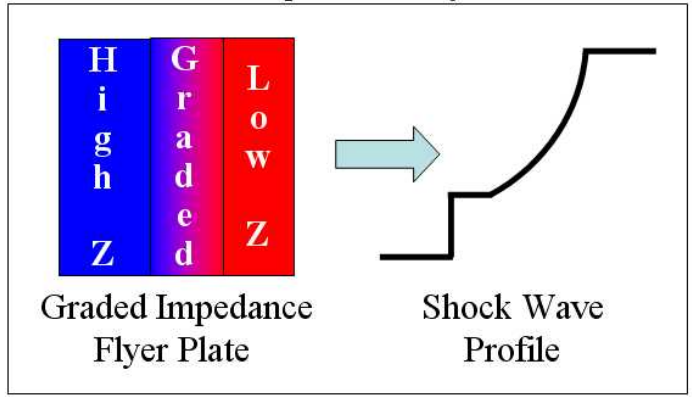
Sandia National Laboratories

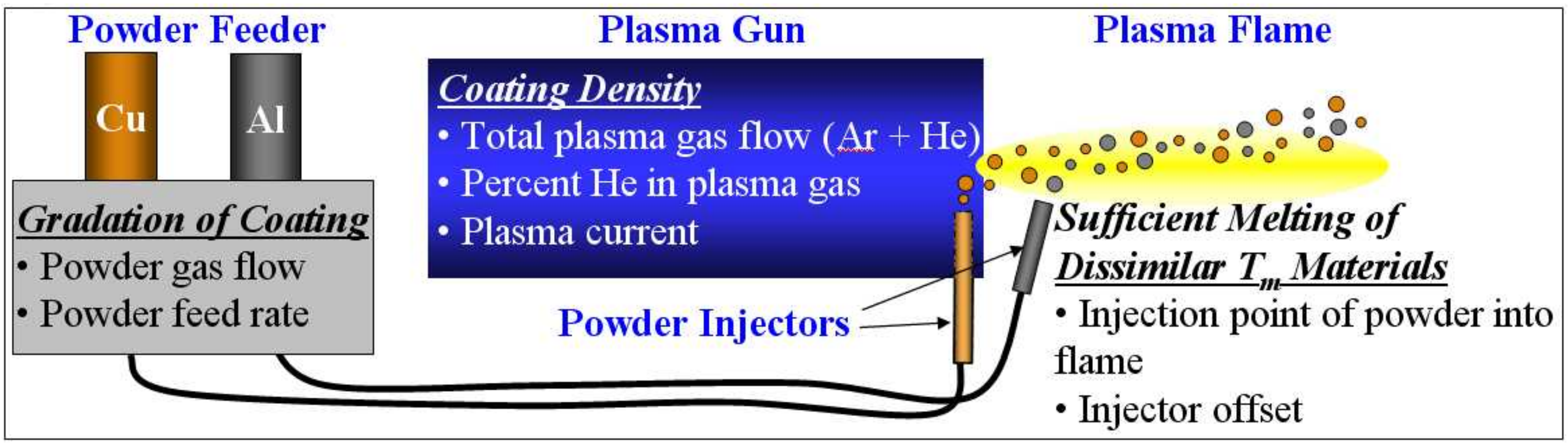
Graded impedance flyer plates are needed by the shock-physics community.

Conventional Flyer Plate



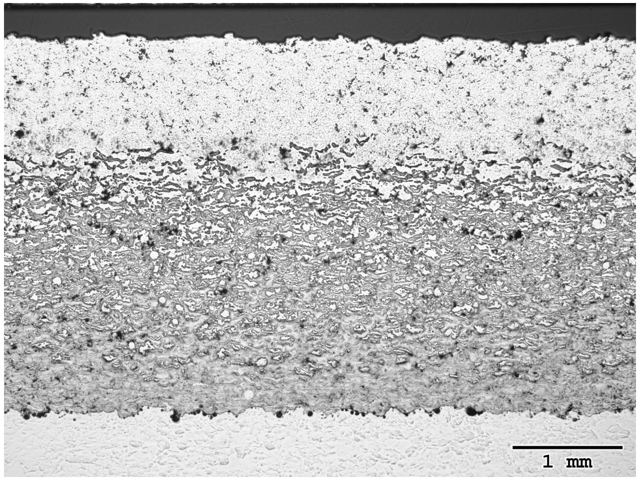
Graded Impedance Flyer Plate

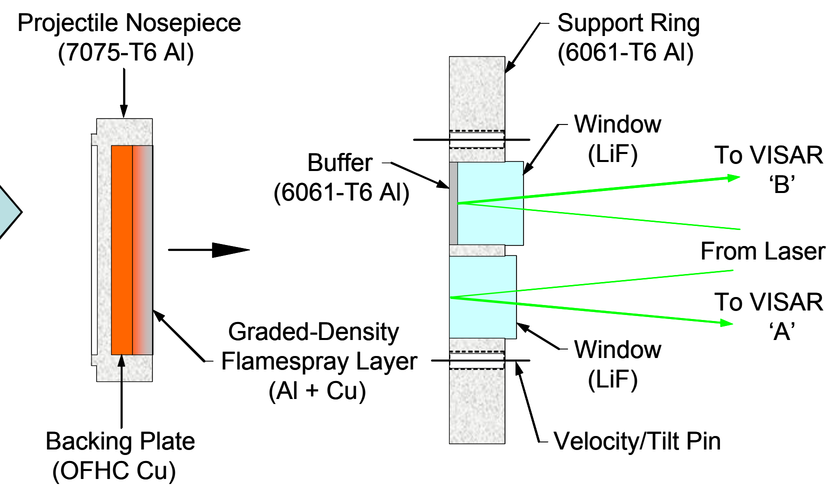


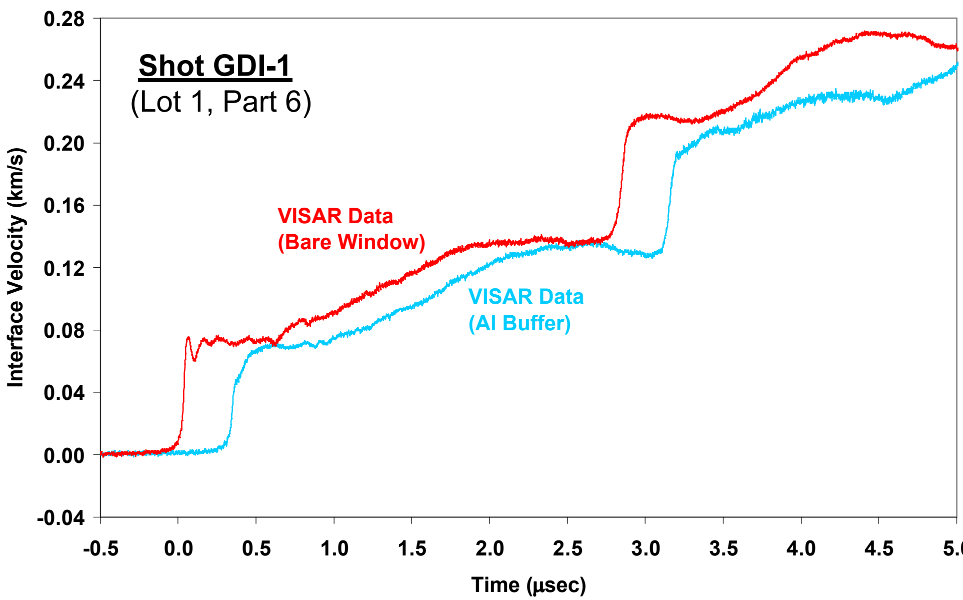


Control of plasma spray process parameters enabled "designer" flyer plates to be prepared.

Light Gas Gun Shot GDI-1



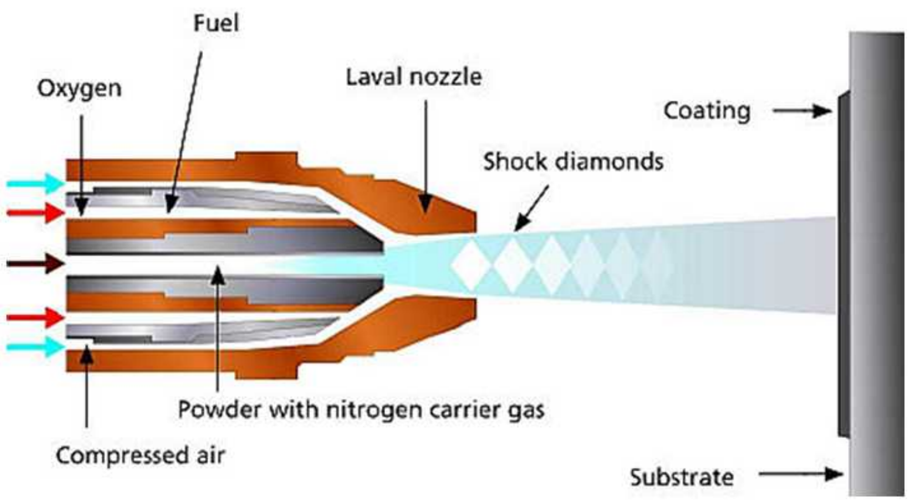


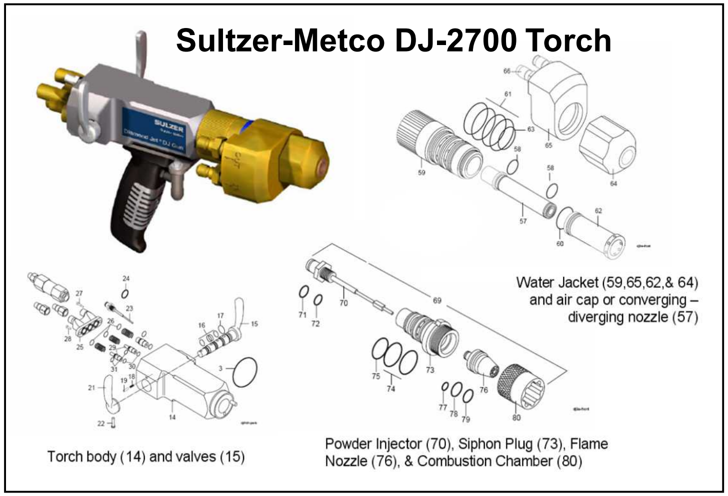


"Exceptional Service In the National Interest"

Sandia National Laboratories

Response Surface Measurement for the DJ-2700 HVOF Torch





SANDIA REPORT
SAND2007-0998
Unlimited Release
Printed March, 2007

Evaluation of the Sultzer-Metco Diamond Jet (DJ-2700) Hybrid High Velocity Oxy-Fuel (HVOF) Thermal Spray Torch

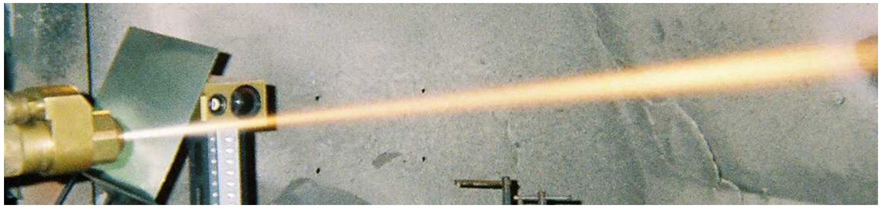
Dr. Aaron C. Hall, James F. Mccloskey, Dr. Nancy Yang

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

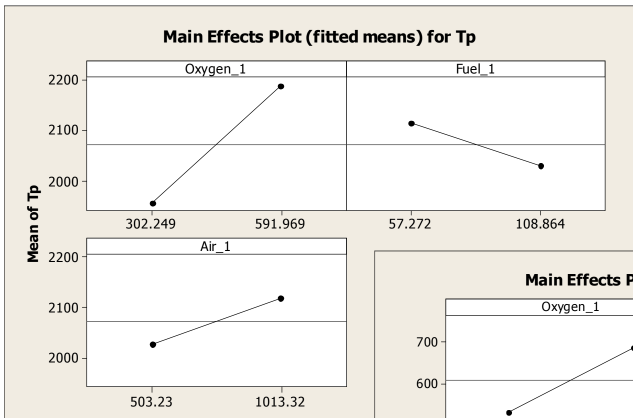
Approved for public release; further dissemination unlimited.

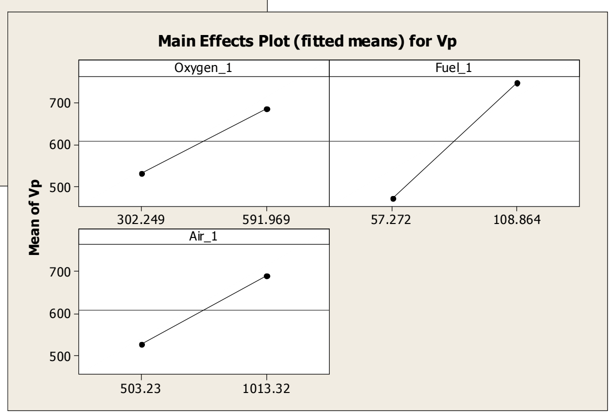
Sandia National Laboratories

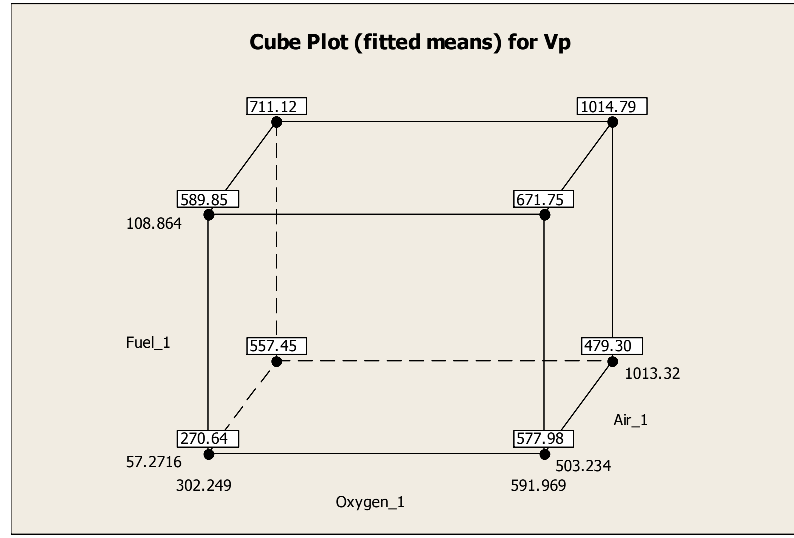


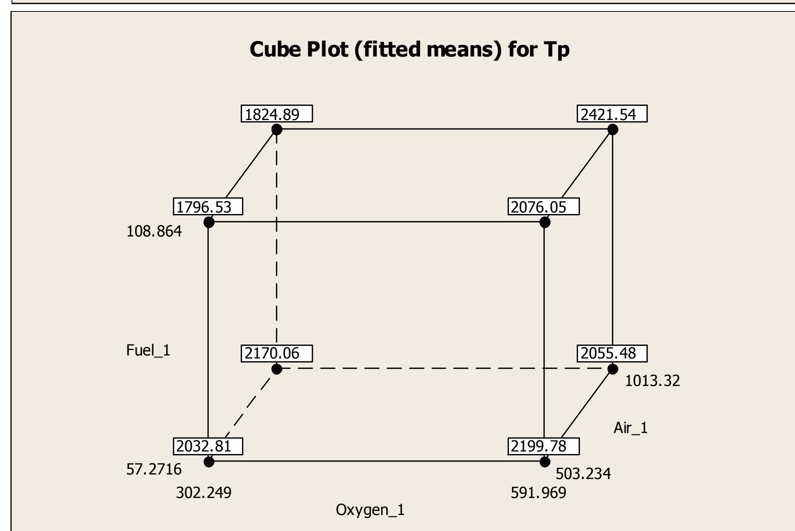
3^2 full factorial experiment to explore process space

Run #	Oxygen	Fuel	Air	Oxygen	Fuel	Air	Tp	Vp	Tp stdev	Vp stdev
	Actual (FMR)			Actual (SCFH)			1 Minute Average		1 Minute stdev	
1	40	30	30	591.969	108.8641	503.2343	2073.362	675.267	10.253	10.397
2	20	26	30	302.249	95.1061	503.2343	1854.024	511.954	50.677	69.168
3	20	22	60	302.249	81.3481	1013.324	2003.627	636.177	6.986	7.403
4	20	30	60	302.249	108.8641	1013.324	1821.676	715.329	4.945	2.124
5	34	22	30	505.053	81.3481	503.2343	2067.538	572.439	9.251	27.826
6	30	25	45	447.109	91.6666	758.2793	2075.078	646.126	6.423	6.948
7	40	19	59	591.969	71.0296	996.3213	2131.41	650.483	7.558	8.692
8	30	25	45	447.109	91.6666	758.2793	2061.952	685.123	7.21	7.624
9	30	25	45	447.109	91.6666	758.2793	2071.256	588.952	15.301	40.618
10	40	15	58	591.969	57.2716	979.3183	2078.864	467.838	13.584	38.497
11	20	30	30	302.249	108.8641	503.2343	1796.071	590.449	16.473	17.785



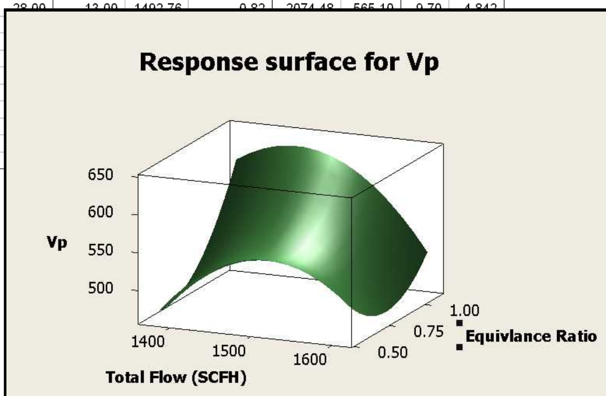


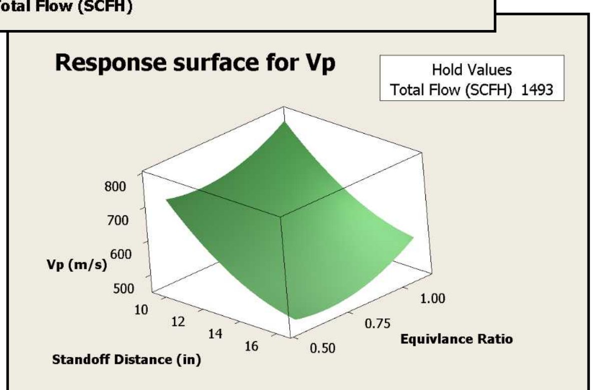


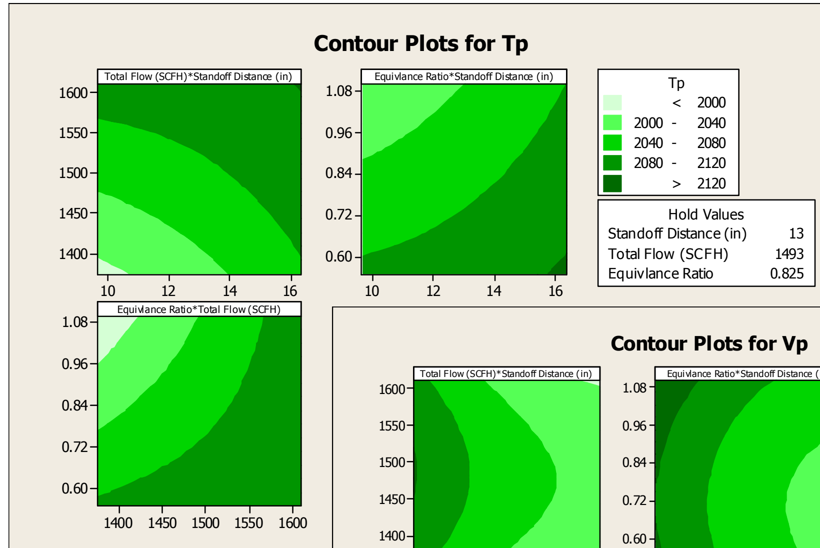


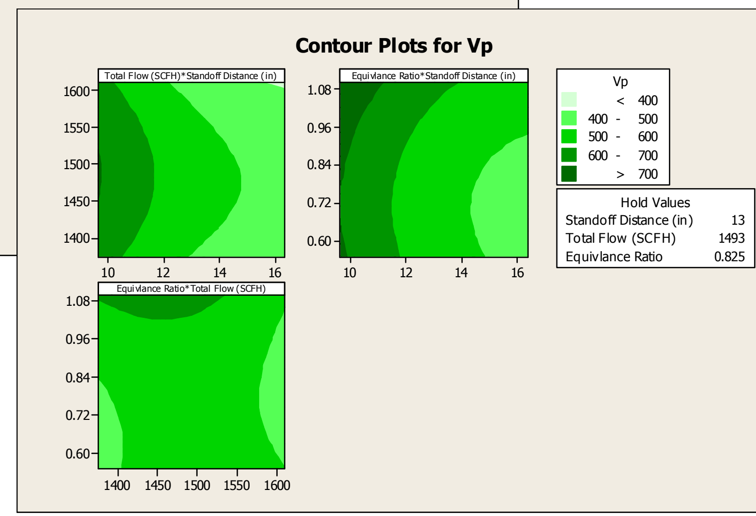
Additional experiments measure the response surface around a candidate operating condition

DOE Step #	Standard Order	Standoff Distance (in)	Total Flow (SCFH)	Equivalence Ratio	Tp (°C)	Vp (m/s)	Tp stdev	Vp stdev
1	13.00	9.64	1492.76	0.82	2047.96	705.99	5.74	2.457
2	16.00	9.64	1375.02	0.55	2060.35	632.20	6.52	2.034
3	22.00	9.64	1375.02	0.94	1969.74	661.28	6.22	1.74
4	25.00	9.64	1610.50	1.10	2102.92	688.04	6.48	3.182
5	26.00	9.64	1610.50	0.63	2099.70	652.50	7.44	4.448
6	5.00	11.00	1562.76	0.98	2071.99	610.33	8.67	3.302
7	17.00	11.00	1562.76	0.72	2089.40	616.87	10.52	28.691
8	18.00	11.00	1422.76	0.66	2067.65	566.60	7.88	24.821
9	23.00	11.00	1422.76	0.90	1962.31	650.59	22.00	17.473
10	1.00	13.00	1492.76	0.82	2073.15	588.01	6.44	4.176
11	2.00	13.00	1492.76	0.60	2095.00	537.04	7.57	5.462
12	4.00	13.00	1492.76	1.03	2045.51	594.91	5.22	3.829
13	6.00	13.00	1492.76	0.82	2079.68	560.04	7.54	6.553
14	8.00	13.00	1492.76	0.82	2059.60	501.74	15.79	36.872
15	11.00	13.00	1492.76	0.82	2081.44	539.74	8.47	10.74
16	14.00	13.00	1610.50	0.87	2086.86	438.71	17.15	65.196
17	19.00	13.00	1375.02	0.75	2055.92	513.47	9.40	4.865
18	24.00	13.00	1492.76	0.82	2073.34	511.31	8.93	15.892
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20								
21								
22								
23								
24								
25								
26								
27								
28								





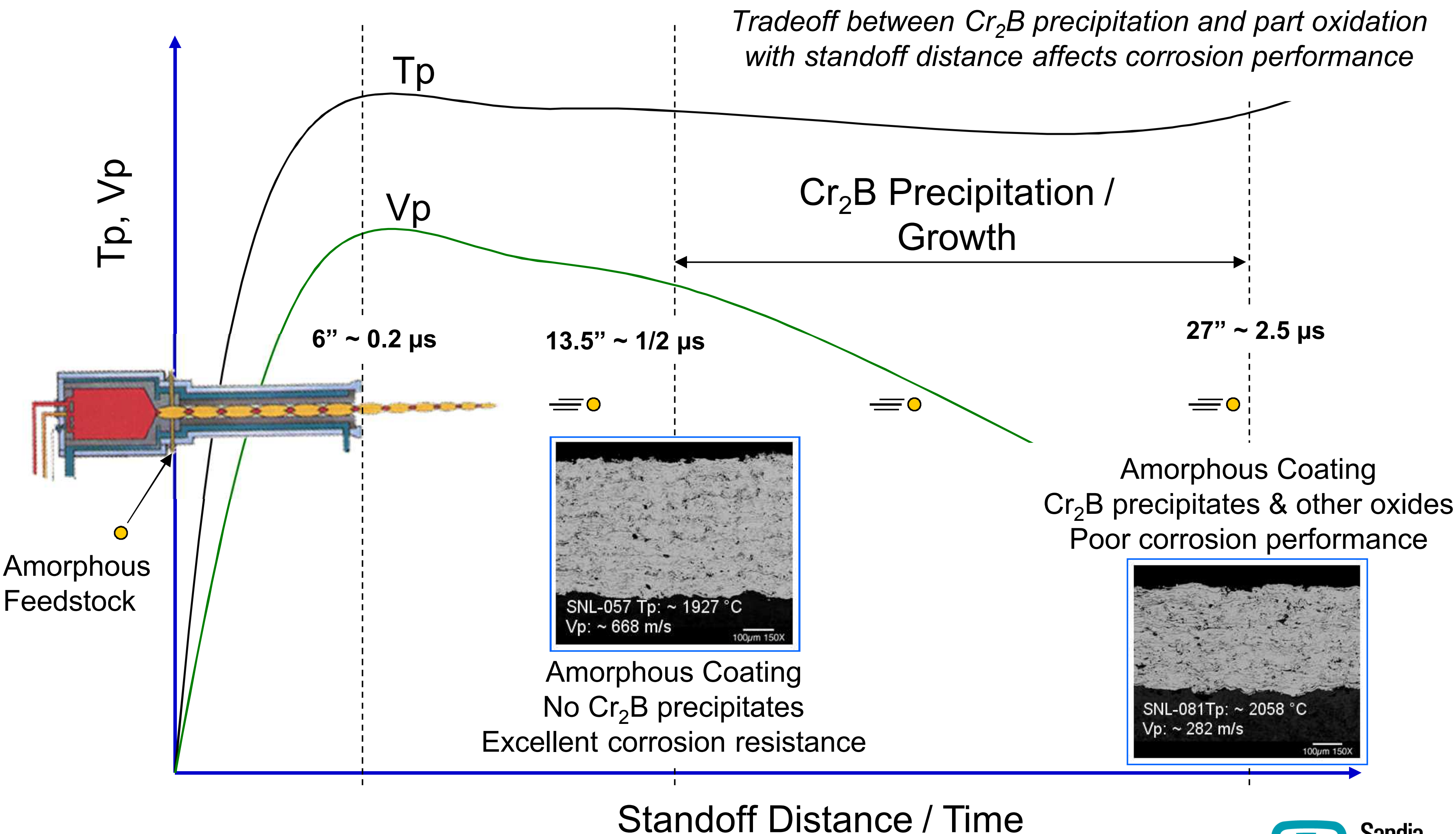




$$Tp = 48.30\,SD + 0.97\,TF - 1469.47\,\Phi + 0.40\,SD^2 + 12.08\,\Phi^2 - 0.04\,SD*TF + 9.19\,SD*\Phi + 0.82\,TF*\Phi + 1384.21$$

$$Vp = -108.9SD + 15.1TF + 686.4\Phi + 4.0SD^2 + 547.4\,\Phi^2 + 3.0\,SD*\Phi - TF*\Phi - 10005.6$$

Connecting Tp, Vp response surfaces, metallurgical analysis, and coating property measurement creates valuable process understanding.



Typical TSRL Project Deliverables

Science-based process definition

- Process maps and process variability
- Process-Microstructure-Property relationships

Selection, development, & pre-qualification of new feed stock

- Improved materials stability
- Reduced materials costs
- Improved materials availability

Recommendations for improved production equipment & quality controls

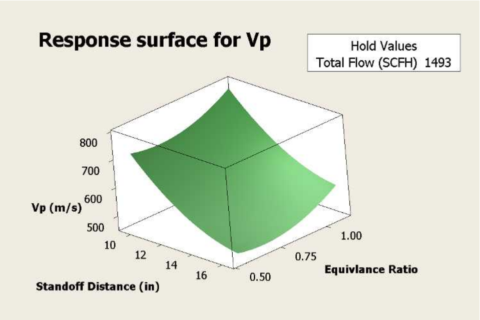
- Improved gas controllers & particle diagnostics
- Process monitoring procedures & control charting
- Robotics & safety equipment

Knowledge Based Process Specifications

- Feedstock requirements
- Process operating conditions and procedures
- Quality control requirements & inspection procedures

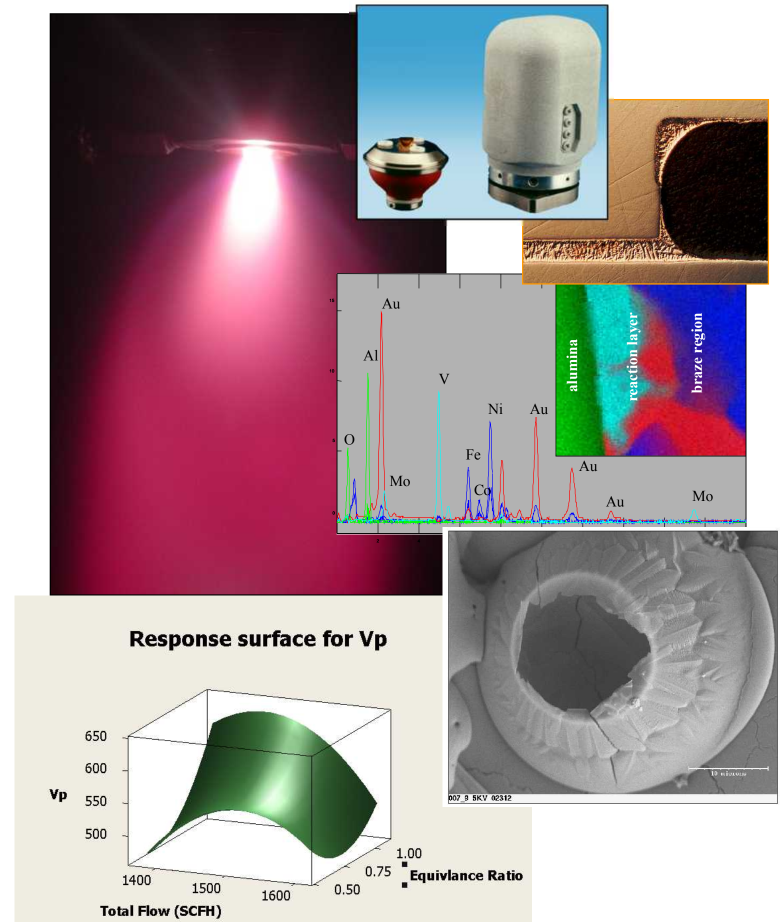
Support for transition to production

- Technical support of RFQ process for materials/process vendors
- Technical support for new materials suppliers & coating vendors



Why should I work with Sandia's Thermal Spray Research Laboratory?

- **I really like New Mexico and I just want to spend lots of money & time at Sandia!!!**
- **I need to work in a DOE / DoD secure environment.**
- **I want to leverage the expertise and analytic capability in Sandia's Materials Science and Engineering Center.**
- **I need access to the TSRL's unique facilities: LPPS® Thin Film, Cold Spray, Laser Velocimetry & Particle Diagnostics.**
- **I want a rigorous, science-based understanding of the process-microstructure-property relationships, interfaces, and metallurgy associated with my coating application.**
- **I want to take advantage of the non-competitive nature of a Federally Funded Research & Development Center (FFRDC).**
- **I want a team that will support my application across the entire technical readiness scale.**



Fundamental understanding of processes, interfacial reactions and microstructures related to properties and performance.

"Exceptional Service In the National Interest"

Sandia National Laboratories

Interdisciplinary Materials Science Approach to Obtain Engineering Solutions

- ✓ Assess Customer Needs
- Develop Joint Plan/SOW
- Materials/Process Selection
- Process Characterization
- Materials Characterization/Analysis
- Property Measurements (wear, strength, impact, corrosion/oxidation, etc. under baseline and service conditions)
- Prototyping & Analysis
- Technology Transfer/Vendor Qualification
- Documentation/Specifications

Summary

Sandia’s Thermal Spray Research Lab:

- Provides science-based process understanding
- Provides an unbiased technical resource for process development and specification writing
- Is experienced in fielding thermal spray processes to production in both the government & industrial sectors

Sandia National Laboratories

Extra Slides

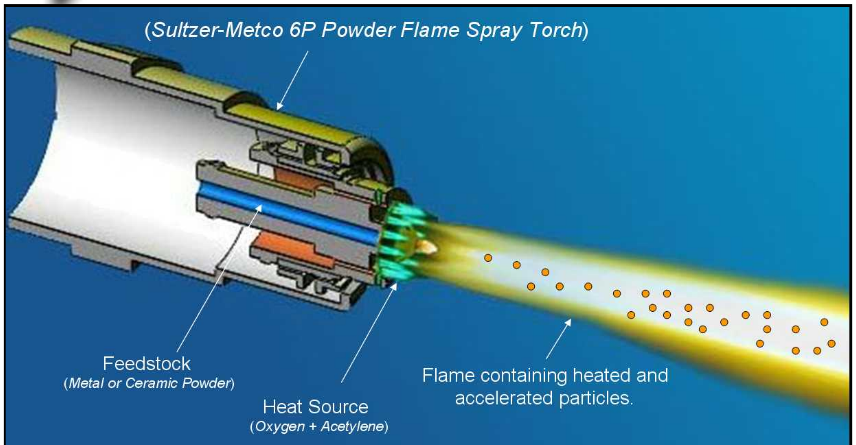
Powder & Wire Flame Spray

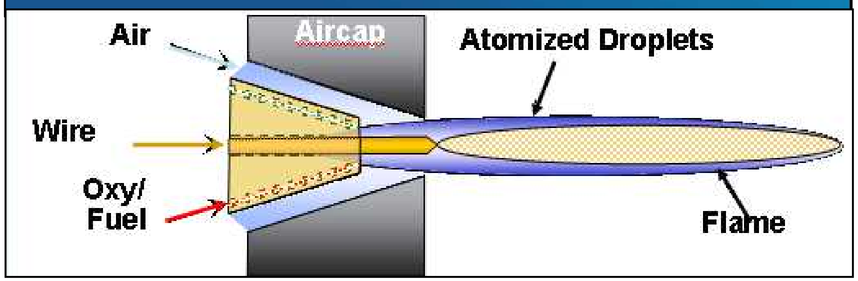
- Feedstock + Oxy-Fuel Flame
- Metals, ceramics, composites
- Lowest Tp, Vp regime
- Economic & Low noise

Process Control Vectors:

$$Tp \propto OFR \,\&\, AF$$

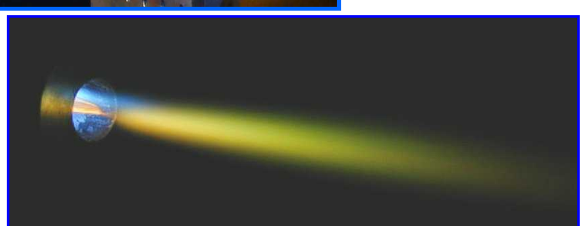
$$Vp \propto TF \,\&\, AF$$

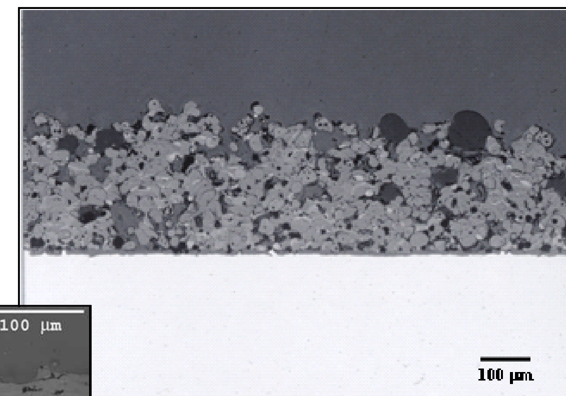


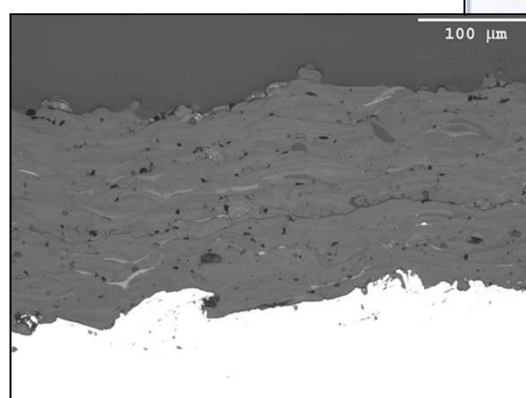


Powder Flame Spray

Wire Flame Spray







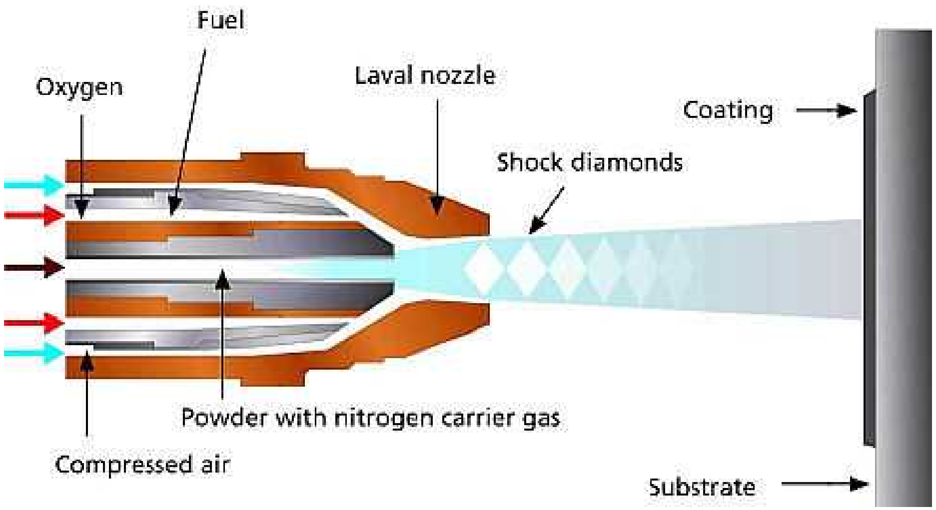
Low Tp & Vp

High Tp & Vp

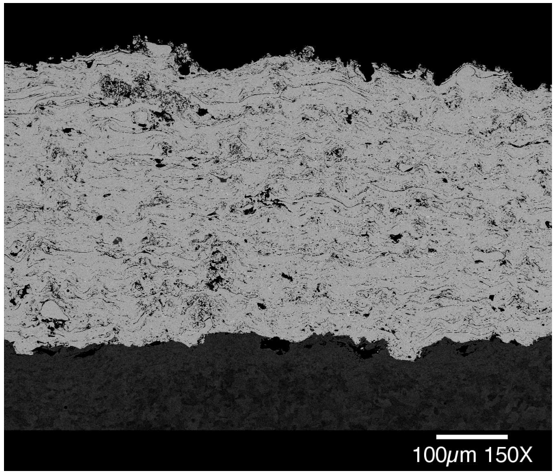
"Exceptional Service In the National Interest"

Sandia National Laboratories

High Velocity Oxy-Fuel (HVOF)



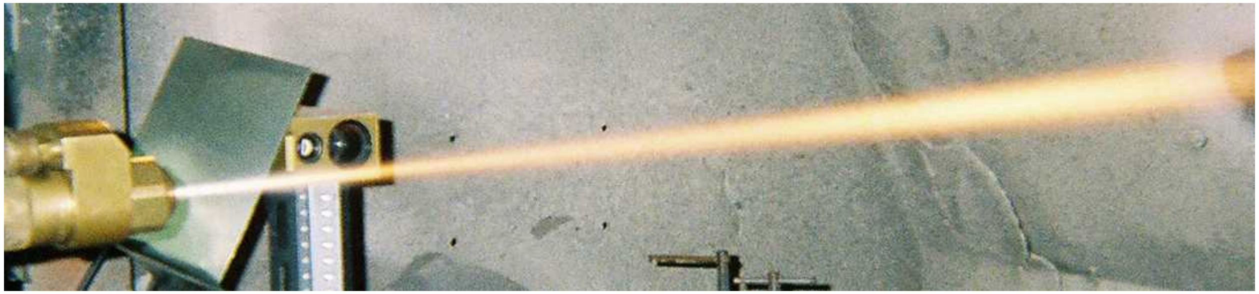
- Supersonic Flame Spray
- Dense metal & ceramic coatings
- Popular for Tungsten Carbide Cobalt
- Economic & Loud!

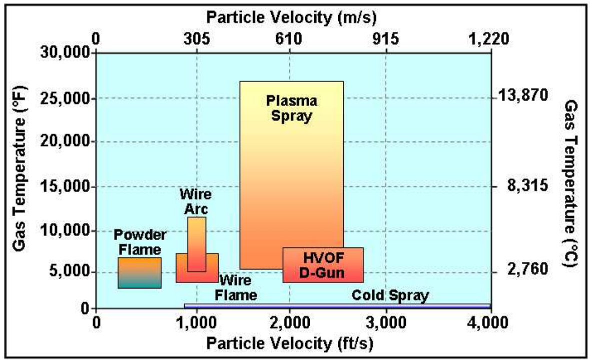


Process Control Vectors:

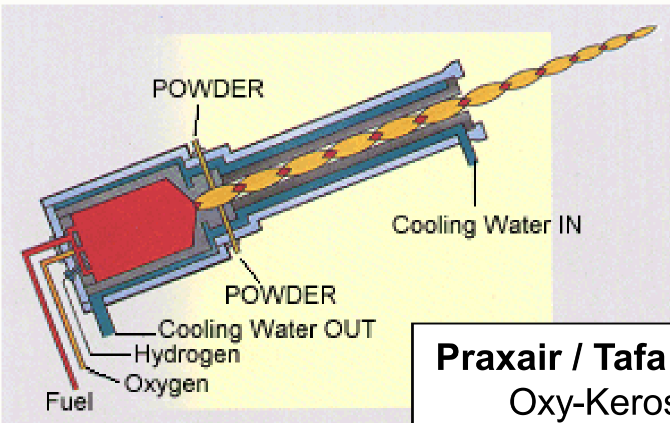
$$Tp \propto \phi$$

$$Vp \propto TF$$

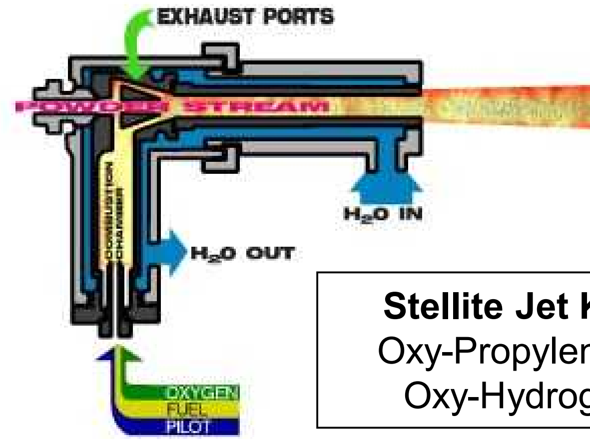




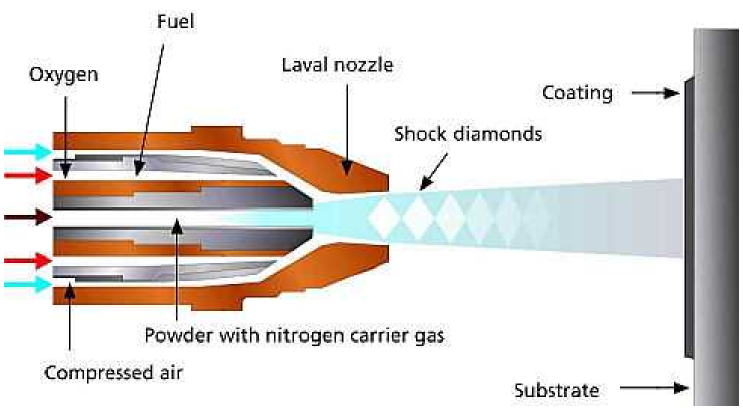
Many different HVOF torches are available today. Each torch has advantages and disadvantages.



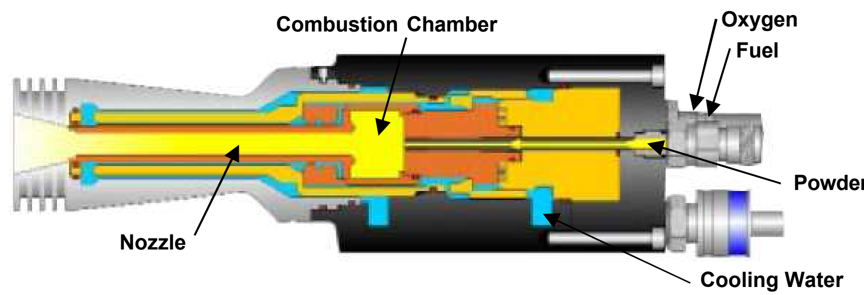
Praxair / Tafa JP-5000
Oxy-Kerosene



Stellite Jet Kote
Oxy-Propylene or
Oxy-Hydrogen

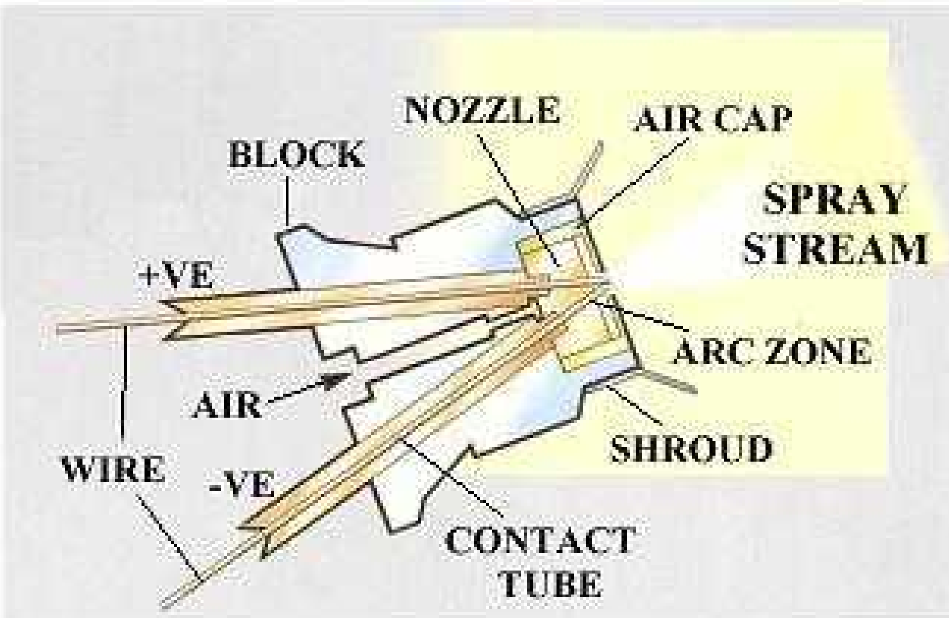


Sulzer-Metco Diamond Jet
Oxy-Propylene



Praxair / Miller Thermal HV-2000
Oxy-Hydrogen, Oxy-Propane, or
Oxy-Propylene

Twin Wire Arc Spray

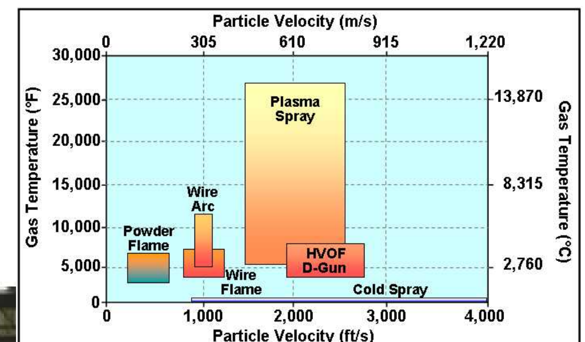


- Low thermal input
- Metal and metal composites
- Corrosion protection & EMI shielding
- Low cost & low noise

Process Control Vectors:

$$Tp \propto I$$

$$Vp \propto AF$$



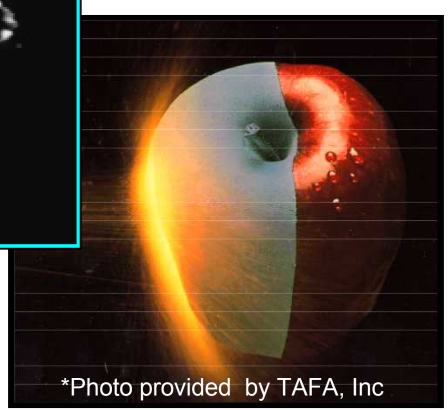
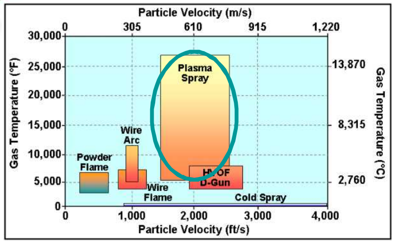
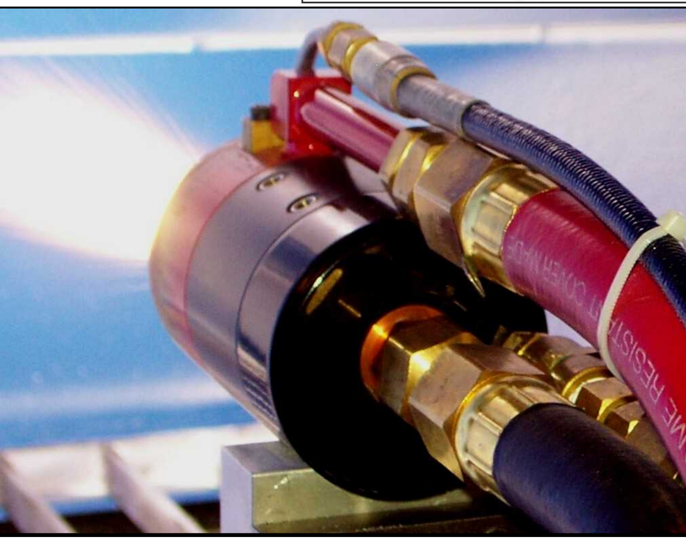


*Photo provided by TAFA, Inc

Plasma Spray



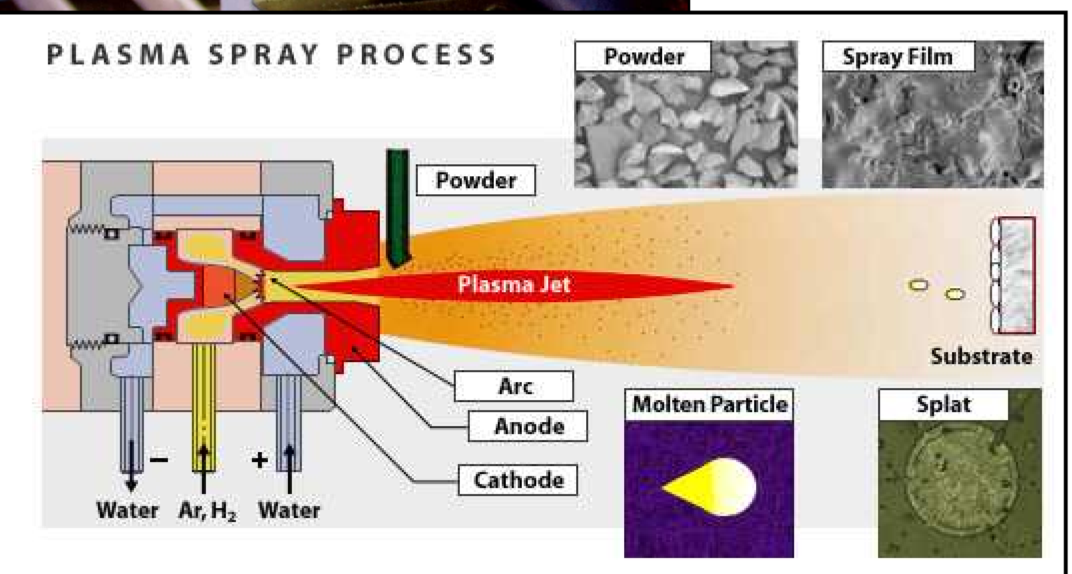


Air Plasma Spray

- DC Plasma heat source
- Metals, refractory metals, glasses, & ceramics
- Droplet deposition
- Most common plasma spray process
- I, V, & Gas Composition affect T_p & V_p

"Vacuum" Plasma Spray

- Plasma spray at ~ ½ atmosphere (380 torr)
- Thermal barrier coatings for gas turbine engines



Very Low Pressure Plasma Spray

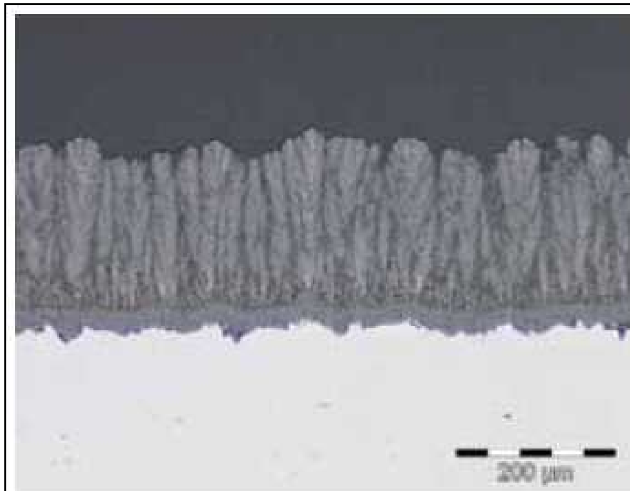
- Plasma spray at 1.0 Torr (0.001 atm)
- Emerging Technology
- ~ 12 VLPPS systems in the world
- SNL has only VLPPS system in U.S.
- ***Droplet Deposition***
- ***& Vapor Deposition!***
- ***High density, oxide free coatings***
- ***Thin coatings (< 50 microns)***

Sandia National Laboratories

LPPS® Thin Film Droplet & Vapor Deposition

- *"EB-PVD-like" Yitria-Stablized-Zirconia coatings were reported at the 2005 ITSC in Basel, Switzerland by a group working in Germany.*
- Columnar microstructures typical with vapor deposition mechanisms.
- Potential for new family of highly versatile deposited thin films, competitive with plating.

R&D Goal: Verify vapor deposition & characterize vapor deposited films.



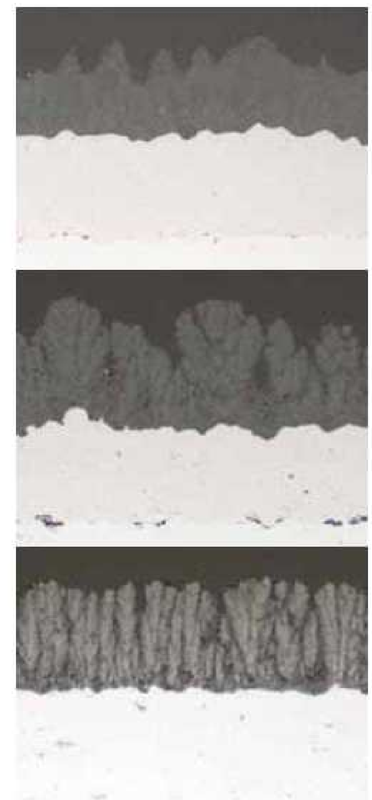


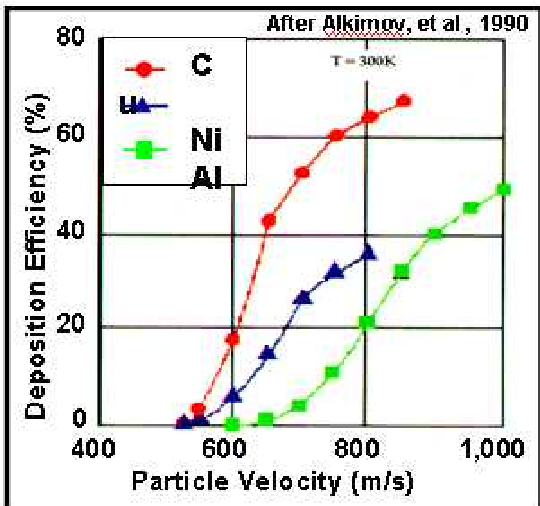
Fig. 5. LPPS-TF deposited TBC layers with increasing "degree of columnarity" and about 100 -150 µm thickness (low-, medium- and high columnarity).

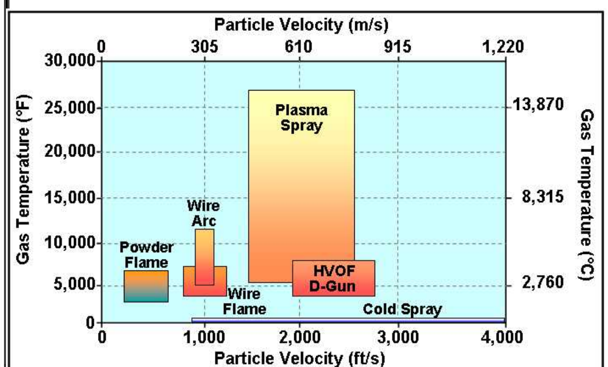
*** Figures from 2005 ITSC conference proceedings by: A. Refke, Wohlen/CH, D. Hawley, J. Doesburg and R.K. Schmid, Westbury/USA**

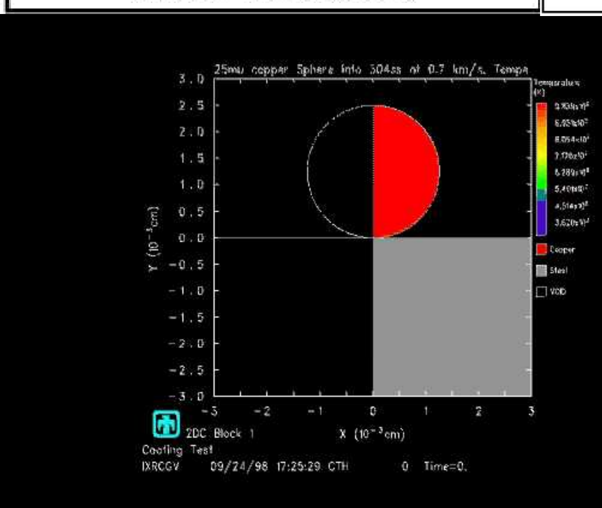
Cold Spray: A "Cold" Process from Siberia

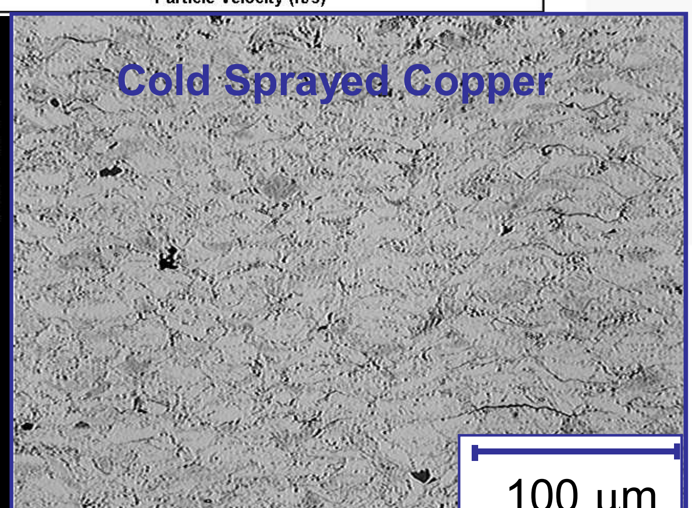
- Sold particle deposition
- High density metal coatings
- Low oxide content
- Compressive residual stress

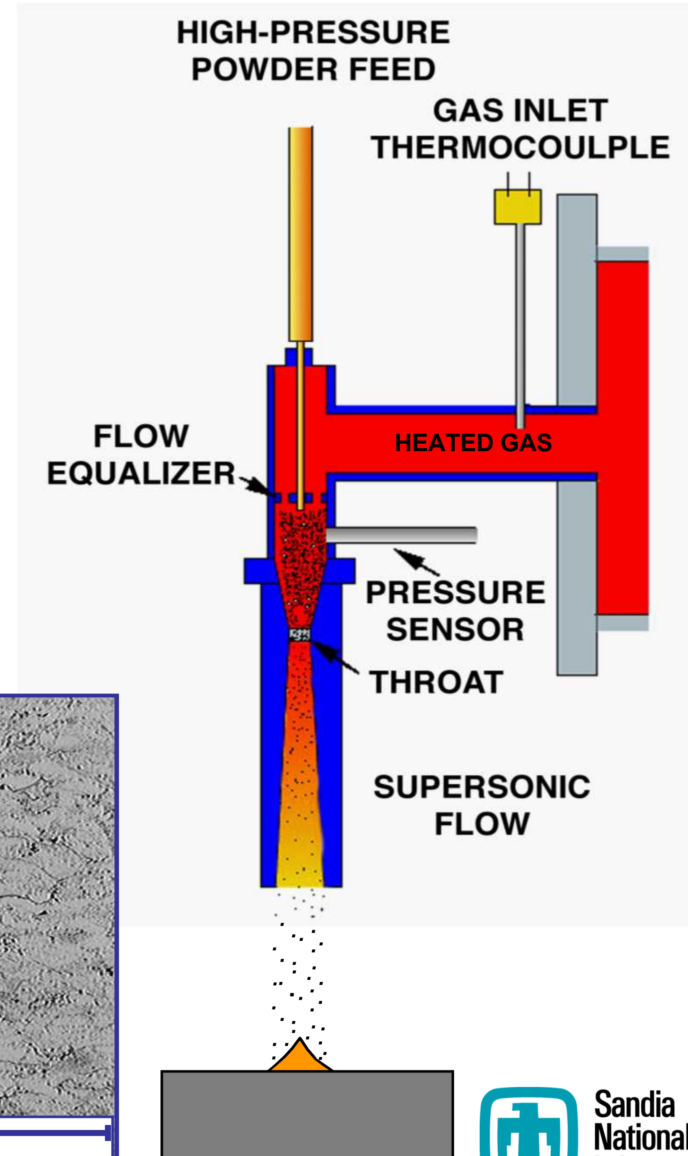
$$Vp \propto P + T$$











Sandia National Laboratories

Some Commercially Important Applications of Thermal Spray


SURFACE ENGINEERING SOLUTIONS FROM SULZER METCO

NUMBER 3

On Land, Sea and Air...

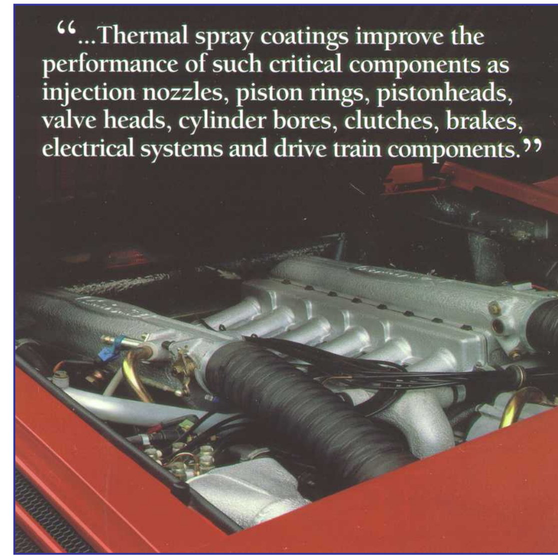
HVOF Thermal Spray Coating Replaces Hard Chrome Plating

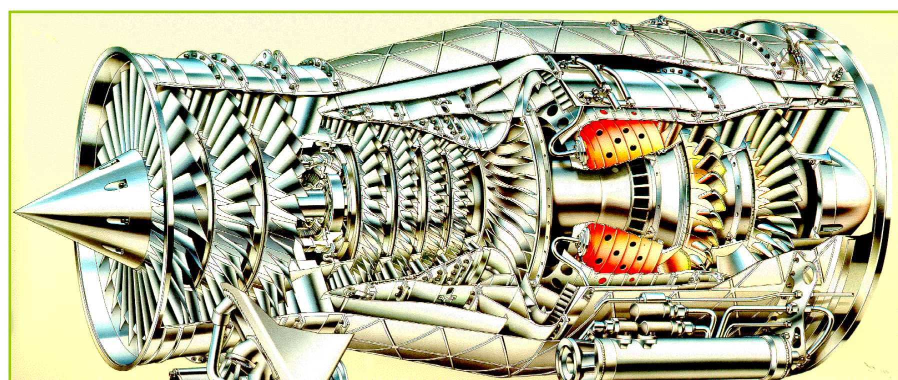
The successful application of Sulzer Metco High Velocity Oxygen Fuel (HVOF) thermal spray coatings on the *USS Saipan* several years ago has given the US Navy strong incentive to increase the number of ship parts that can be coated with HVOF technology. Following suit is The Boeing Company. Based on extensive, satisfactory testing, Boeing has recently substituted Sulzer Metco HVOF coatings for chrome on the landing gear of its new 767-400 airliner. Delta Airlines is also planning to use HVOF coatings on aircraft landing gear and, in fact, is participating in the Boeing trials. Similar thermal spray coatings from Sulzer Metco are also improving performance

(continued on page 4)

Carbon steel rams that control the rudder of the USS Saipan are 13 feet long and 18 inches in diameter. A plating facility would have to be enormous, so HVOF was the clear choice.

- **Aerospace**
- **Automotive**
- **Biomedical**
- **Computers**
- **Electronics**
- **Infrastructure**
- **Marine**
- **Paper Making**
- **Petrochemical**
- **Power Generation**
- **Printing**
- **Textiles**





"Exceptional Service In the National Interest"

Sandia National Laboratories