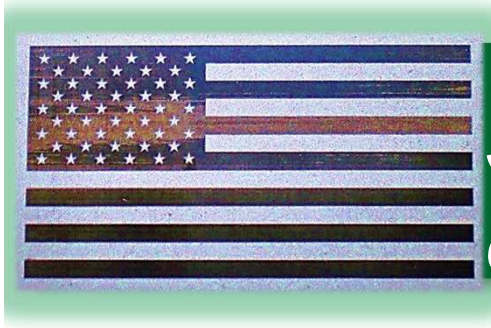

Jacques Matteau

Global Sales Manager

NanoFoil – Novel use for Exploration of Mars

jmatteau@indium.com

indium.us/F014

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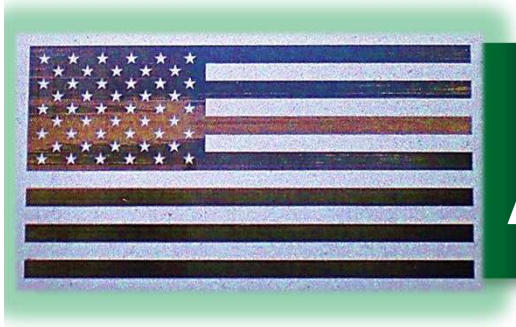
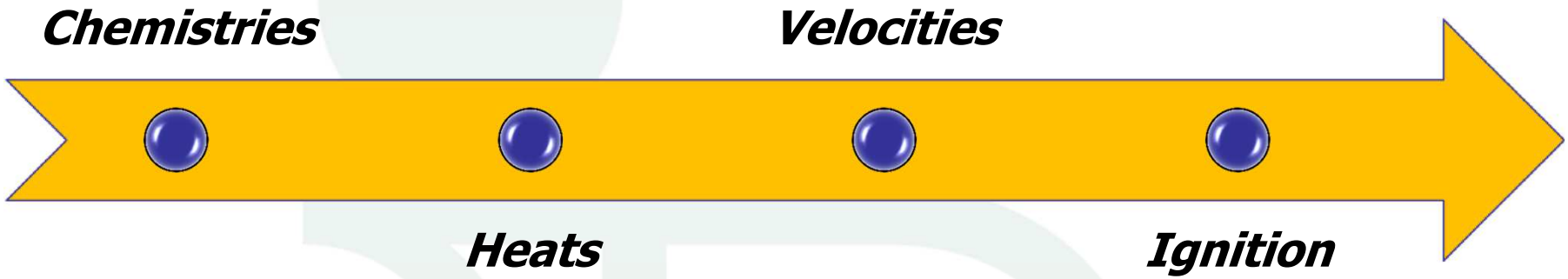
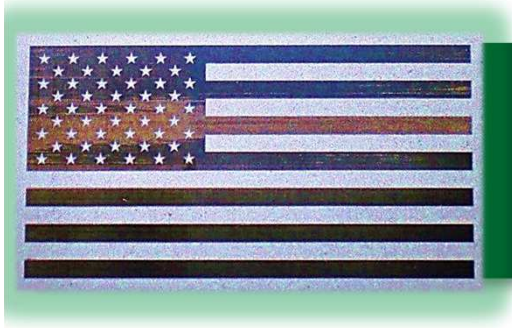


NanoFoil
A Reactive Multilayer Foil





Reactive Materials

Reaction Product	Heat of Reaction (kJ/mol)	Adiabatic Temperature (°C)	Phase of Product
TiB_2	-108	2920	solid & liquid
ZrB_2	-108	3000	solid & liquid
HfB_2	-110	3370	solid & liquid
TiC	-93	3067	solid & liquid
ZrC	-104	3417	solid & liquid
HfC	-105	3830	solid & liquid
Ti_5Si_3	-72	2120	solid & liquid
Zr_5Si_3	-72	2250	solid & liquid
Nb_5Si_3	-57	2060	solid
NiAl	-59	1639	solid & liquid
ZrAl	-45	1480	solid & liquid
PdAl	-92	2380	liquid

Heats of Reaction and Maximum Reaction Temperatures

SHS

Self Propagating High Temperature Synthesis Reactions

- Formation reactions: **Ni/Al**, Ti/C, Zr/Si, etc.
  - ΔH_{rxn}= 30 to 100 kJ/mol-atom
  - T_{max} = 1000^{0}C to 3000^{0}C
- Thermite Reactions: Al/CuOx, Al/FeOx, etc.
  - ΔH_{rxn} = 100 to 150 kJ/mole-atom
  - T_{max} = 2000^{0}C to 4000^{0}C

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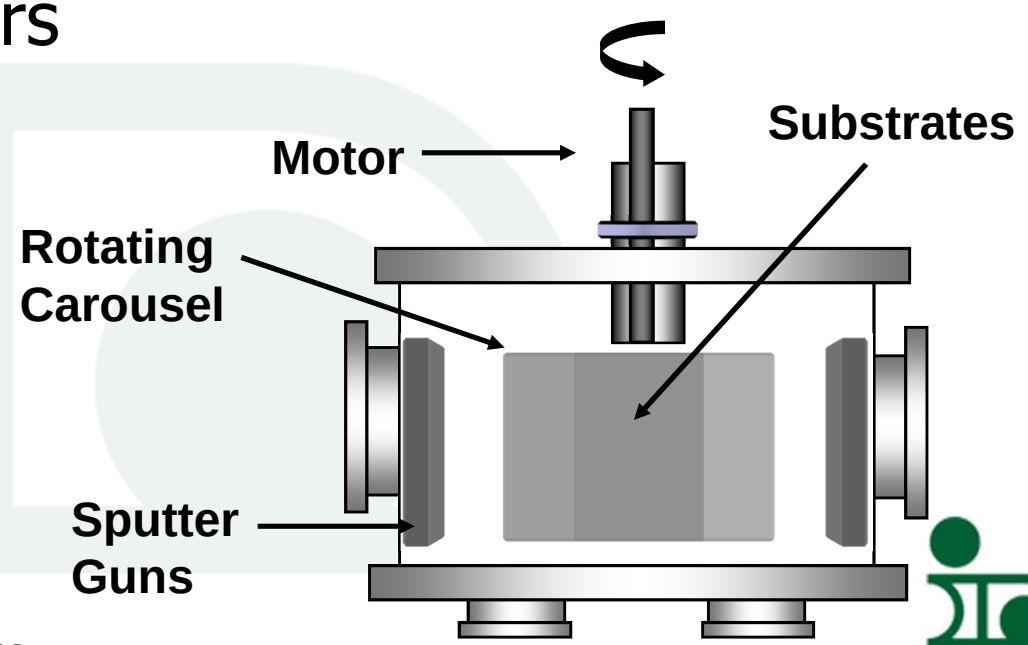
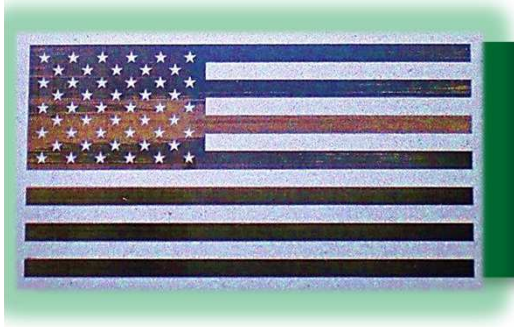
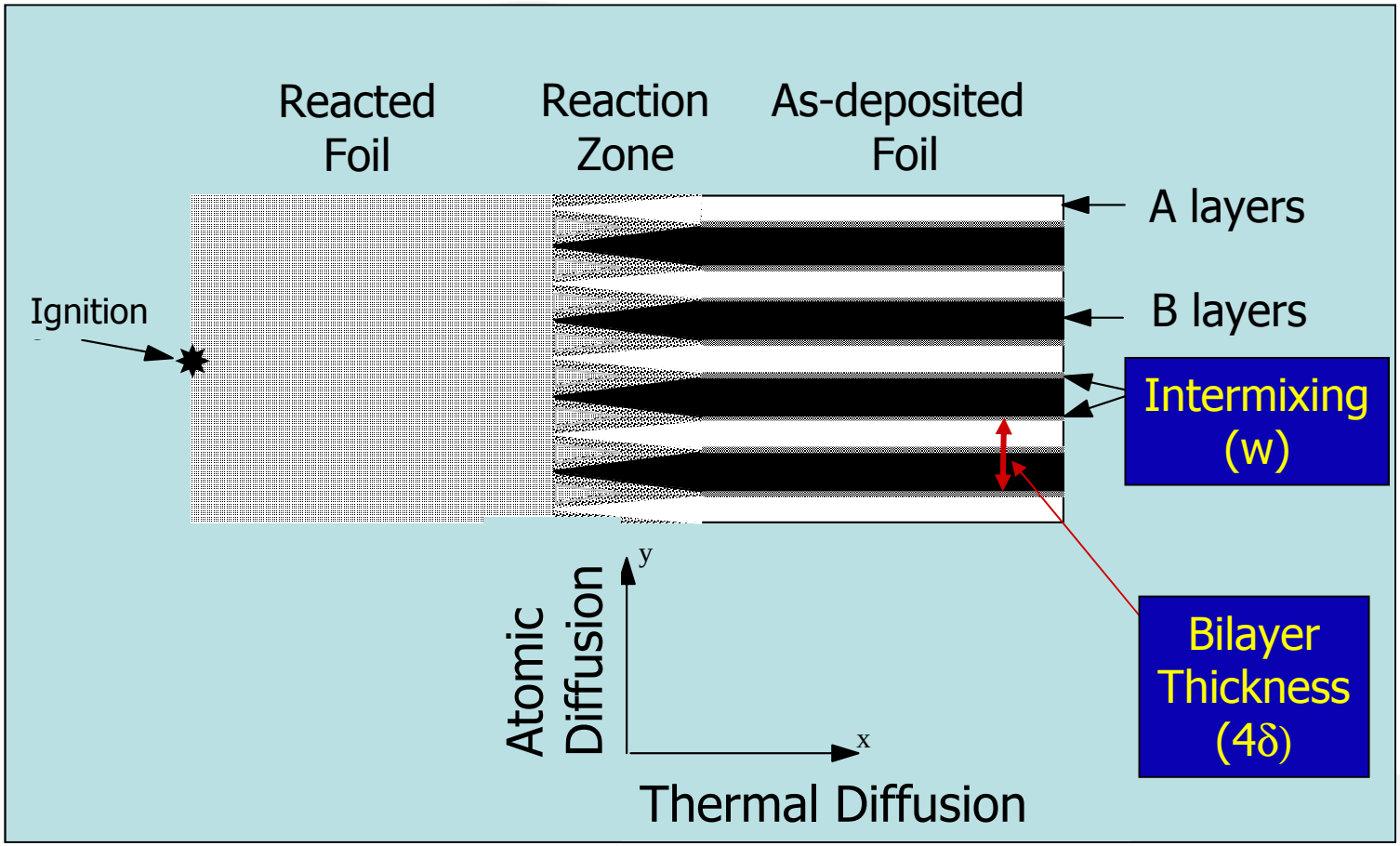
NanoFoil Fabrication

- Magnetron Sputter Deposited
- Free-standing Foils (10-200μm thick)
- Bilayer Thicknesses - 10 to 500nm
- Use Ni and Al layers
- Several 1000 layers





Modeling Reaction Self-Propagation and Ignition



Input
$w, 4\delta, \Delta H_{rx}$

↓

Model Reaction

↓

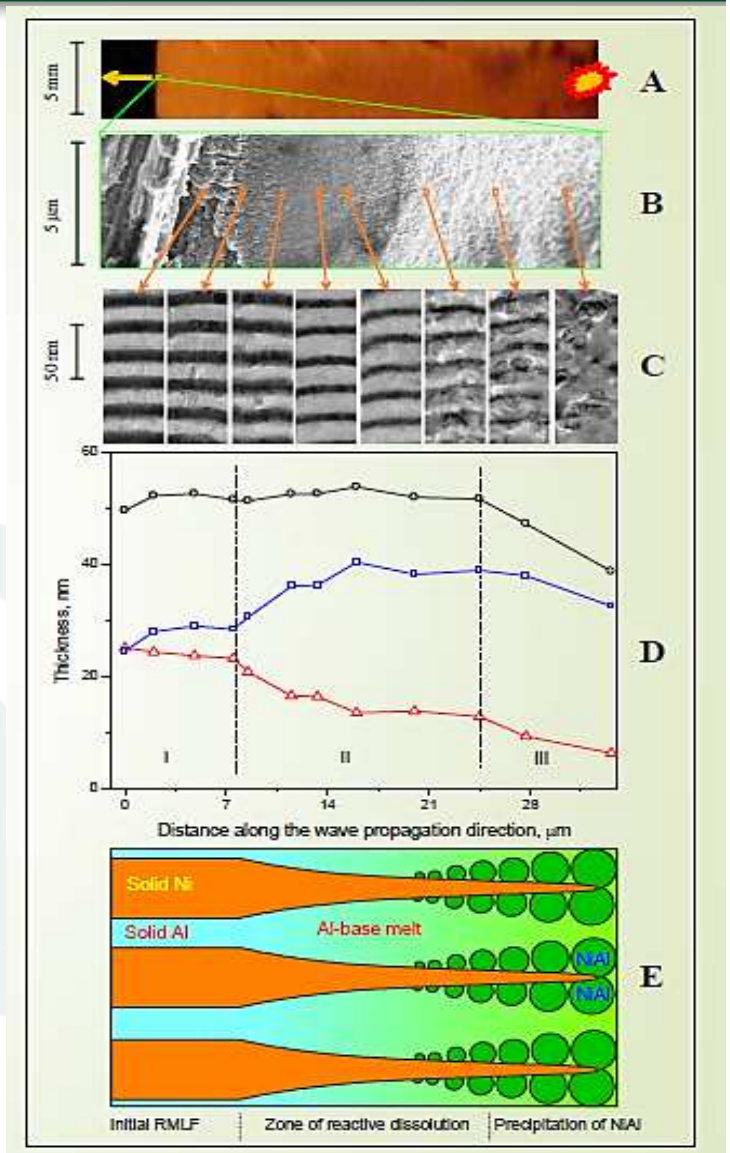
Predict Properties

NanoFoil General Reaction Scheme

(A) Photo of the exothermic wave (A);
(B) SEM picture of the quenched reaction front;
(C) TEM pictures of the reaction zone;
(D) dynamics of the thickness of:

- Ni layer (Δ), Al-rich layer (□), and bilayer period (○),
- I-initial structure, II – Ni dissolution, III – NiAl precipitation;

(E) schematic draw of the wave structure.

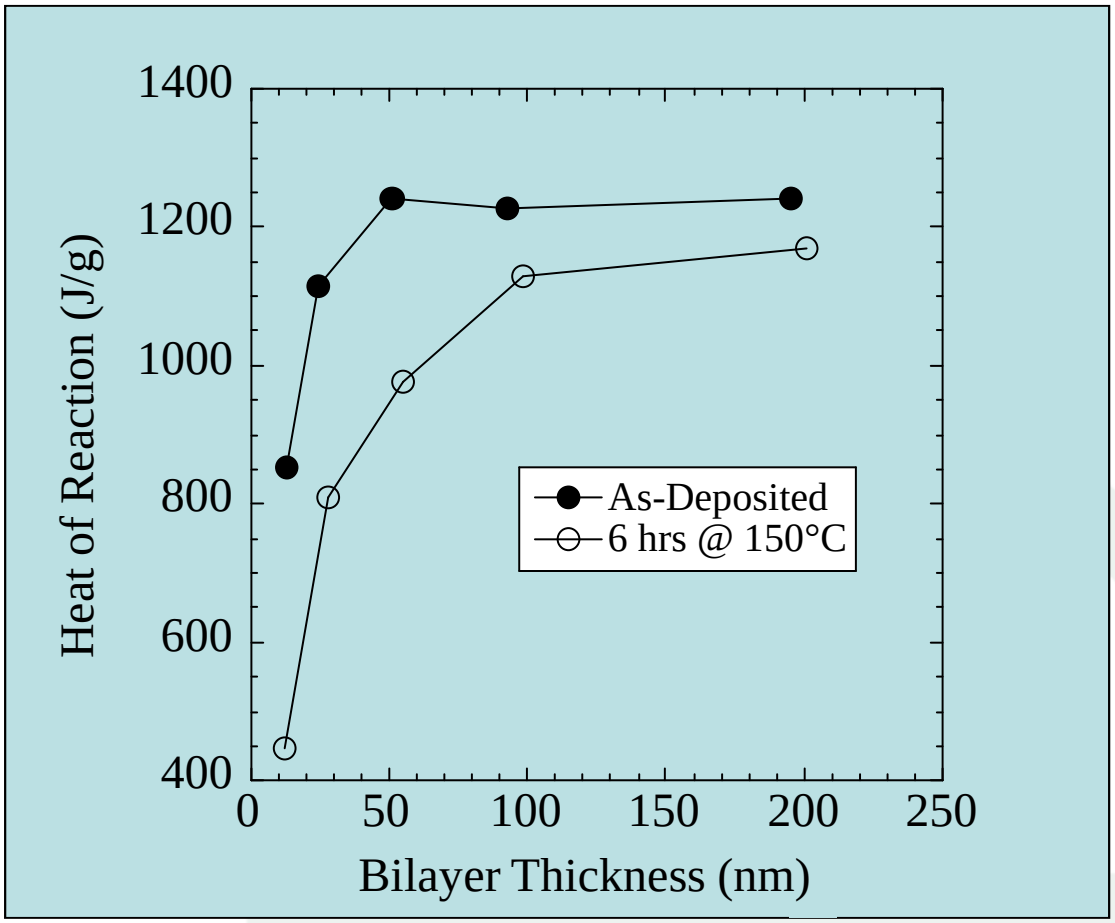


The sequence of the process stages can be represented as follows:

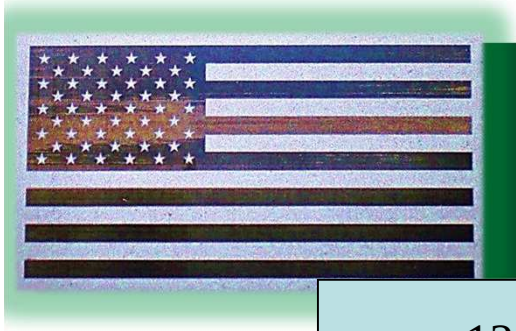
Ni(s) + Al(s) ® Ni(s) + Al(m);
Ni(s) + Al(m) ® Ni(s) + AlNix(m);
Ni(s) + AlNix(m) ® AlNi(s),

At the first stage, the aluminum melts just above the reaction front due to heat flow from the reaction zone.
Melting of Al initiates partial dissolution of the
Ni layers (stage 2) into Al melt until the saturation concentration (x ~ 0,25 - 0,3) is reached.
At the third stage, solid grains of the NiAl B2-phase nucleate and grow.
The characteristic feature of the process is that the grains have different crystallographic orientations and are separated by liquid/amorphous interlayers.
The existence of the liquid between the solid grains allows Ni to dissolve into the melt by means of liquid-state diffusion, which is much faster than solid state diffusion across the intermetallic solid compound.

Measured Heats of Reaction

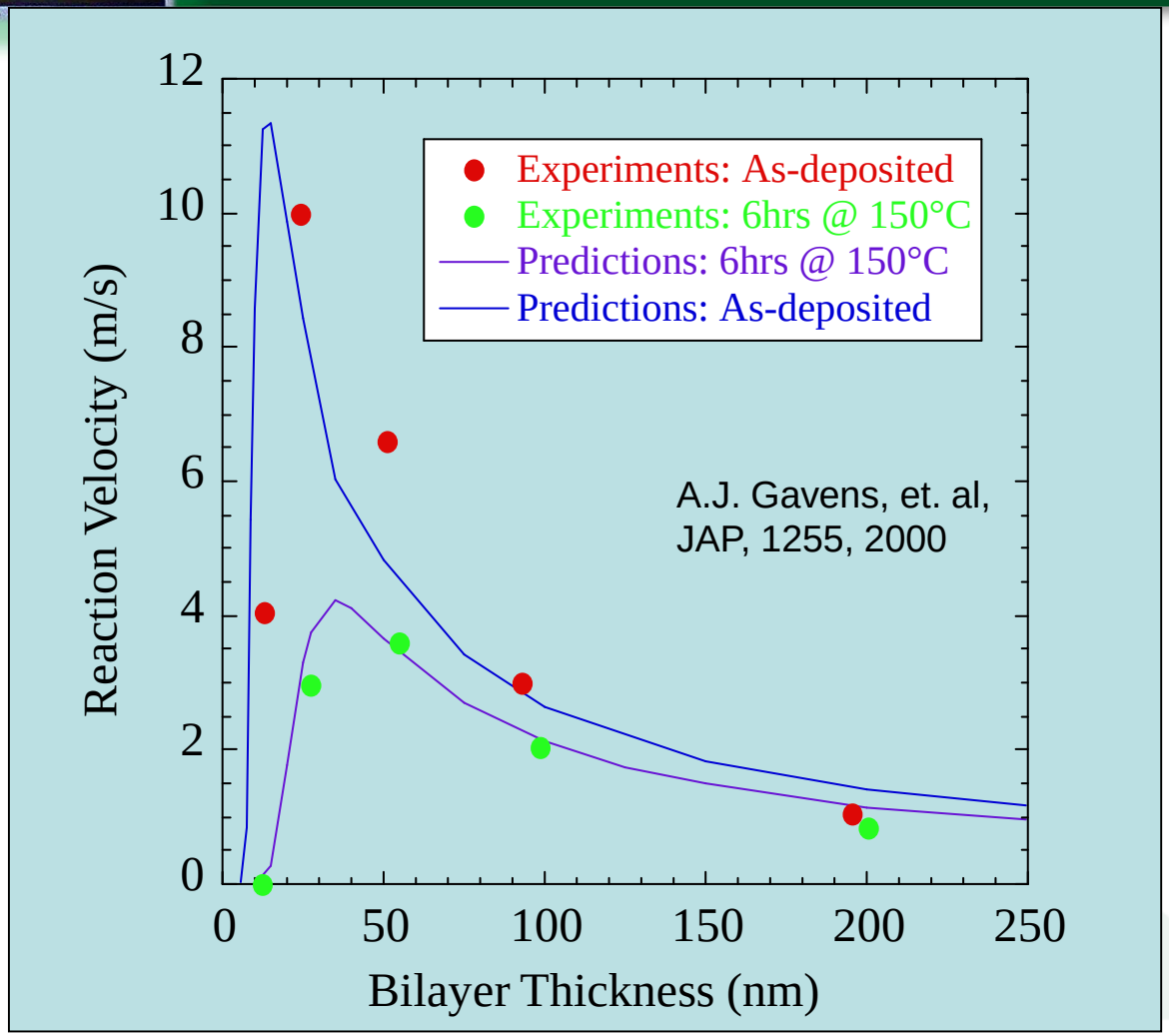


<u>As-deposited</u>
w = 1.2nm
<u>Annealed</u>
w = 3.1nm



Reaction Velocities can be Controlled/Predicted

Al/Ni Vapor Deposited NanoFoil®



As-deposited
w = 1.2nm

↓

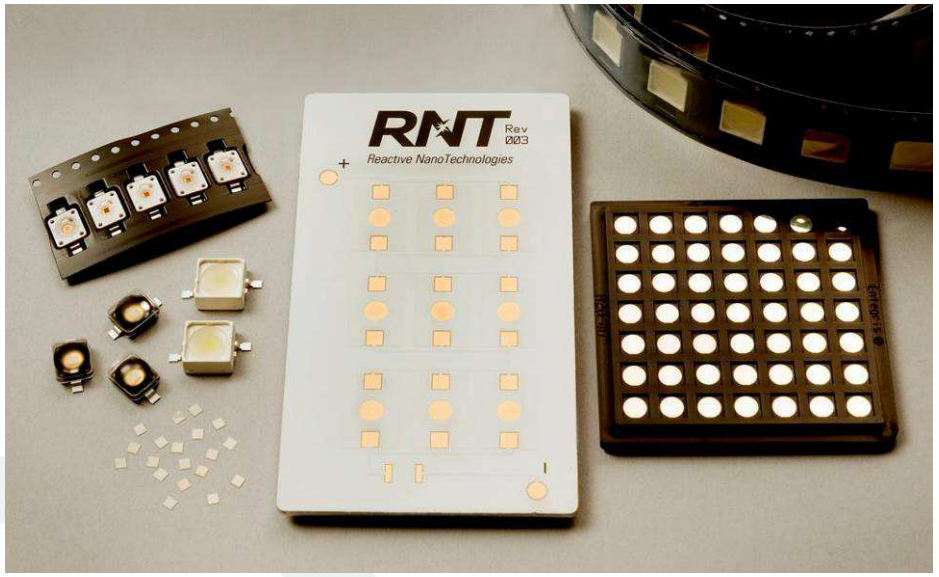
Annealed
w = 3.1nm

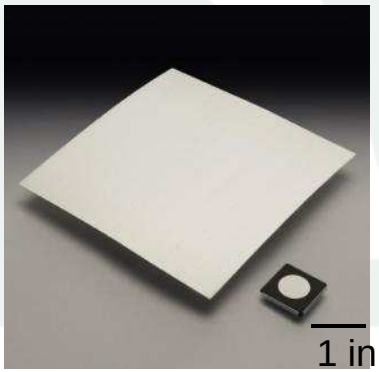
Annealing increases intermixing and slows the reaction

NanoFoil® Forms

- Largest Manufactured Piece: **43.5” x 9”**
- Smallest Produced Size: **.010”x .010”***
- Cutting Methods
  - Laser
  - Chemical Milling
  - Stamping
  - Hand Cutting
- Packaging
  - Tape and Reel
  - Waffle Pack
  - Freestanding

** Can be cut smaller,*





Above: NanoFoil® with LED board and components
Left: Freestanding NanoFoil®

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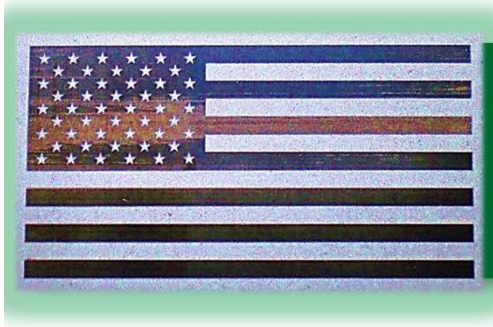
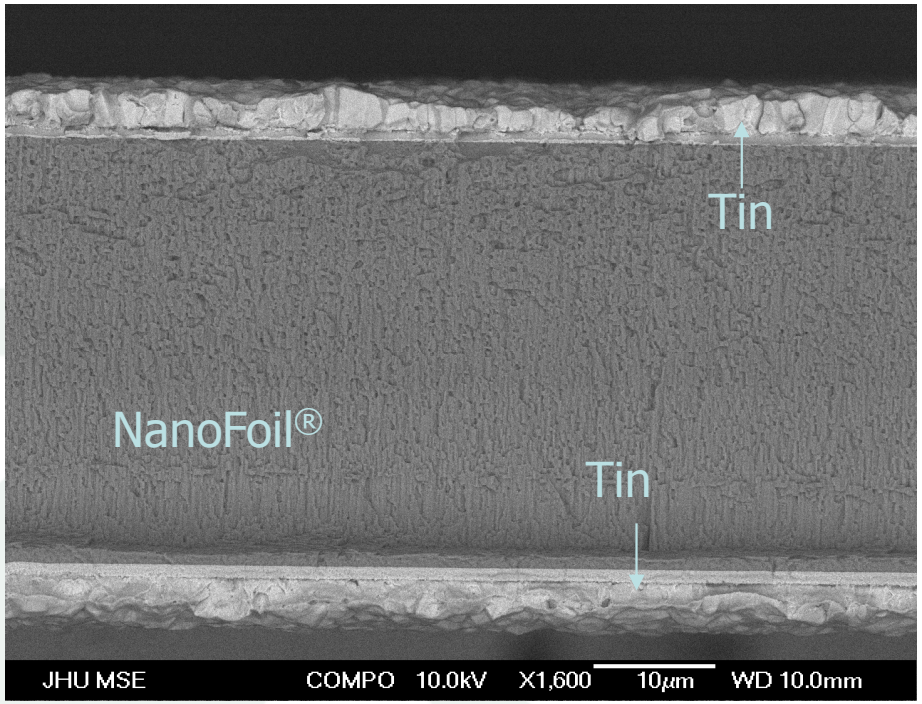


Tin Plated NanoFoil®

- **Tin acts as solder**
  - no solder preforms or prewet needed
- **Works with standard board finishes**
  - Immersion tin
  - ENIG
  - Immersion silver
- **Lead-free and lead-tin compatible**
- **Thickness 5µm (0.0002”) to 0.0012” (30µm) per side**

SEM image: 40µm NanoFoil + 4µm tin each side



Ignition Methods

- Several techniques are available, depending on joint geometry
- Ignition methods should be optimized for each customer/application:
  - **Electrical heating:** good for automated assembly
  - **Laser:** suitable for automated assembly
  - **Spark**: good for manual assembly
  - **Flame/torch:** avoids electric charge
  - **Induction**: NanoFoil® need not be exposed
  - **Mechanical**: Special applications

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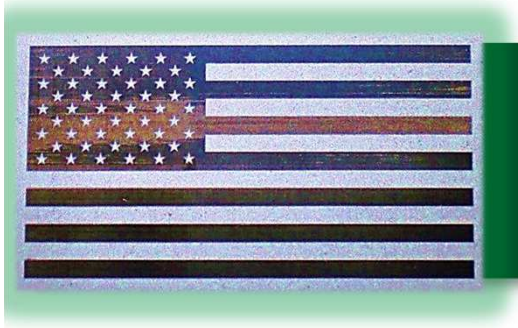
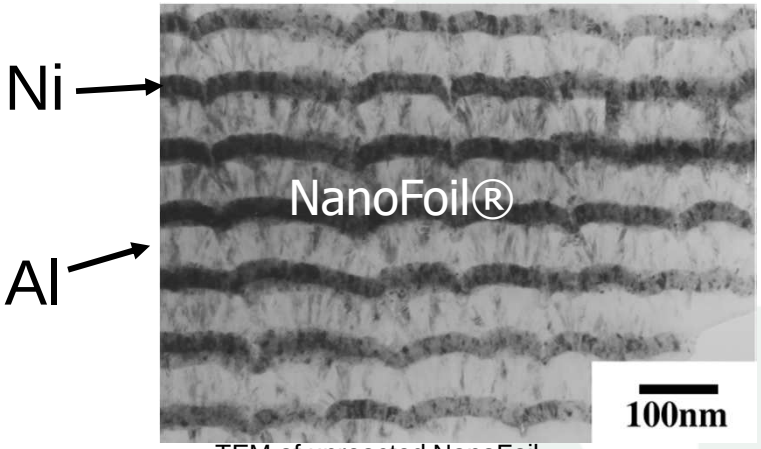


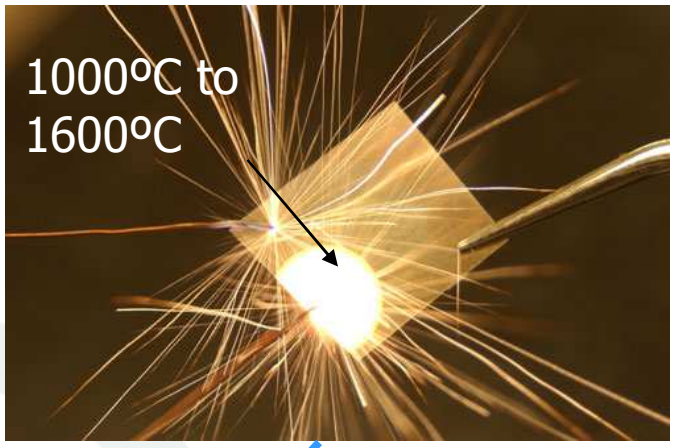
NanoFoil® Reaction

Before reaction



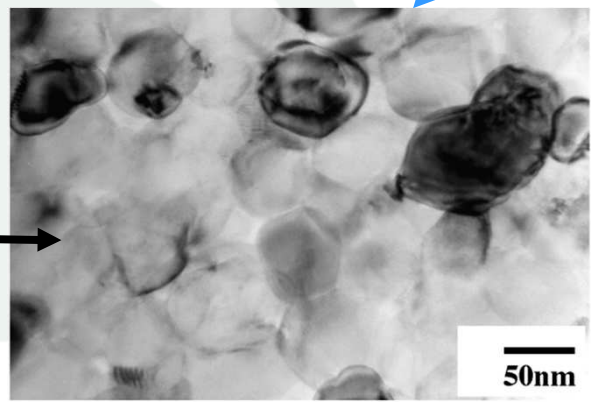
TEM of unreacted NanoFoil

During reaction



Final Product:

Al-Ni Intermetallic



TEM of reacted NanoFoil

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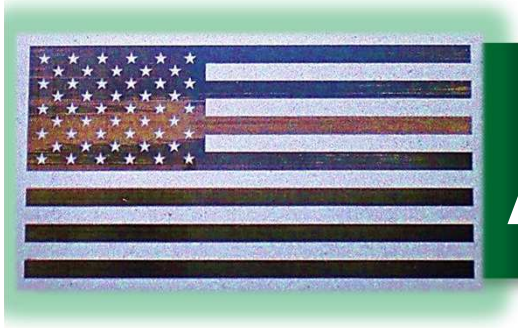


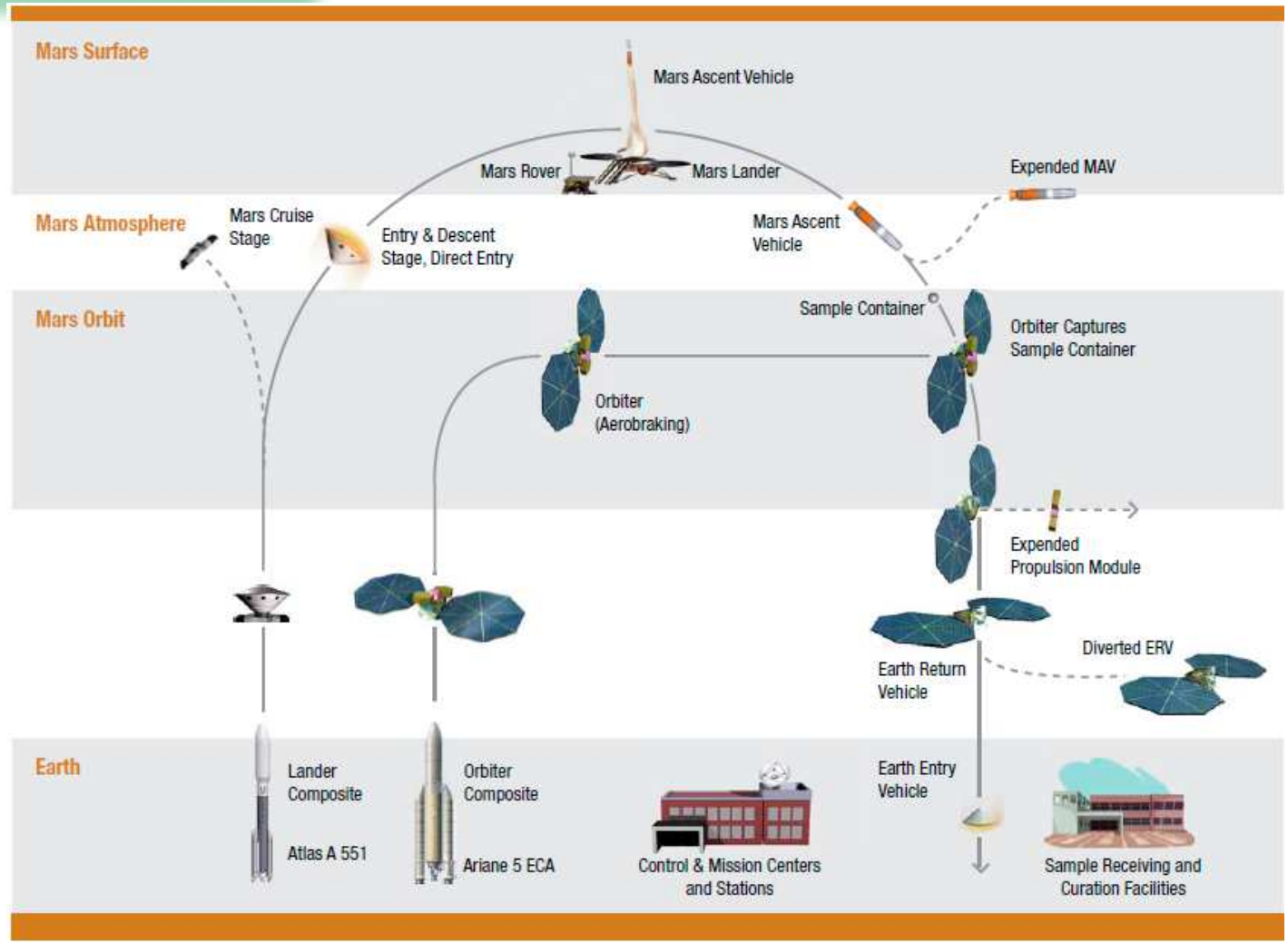
NanoFoil
A Reactive Multilayer Foil

Process and Use

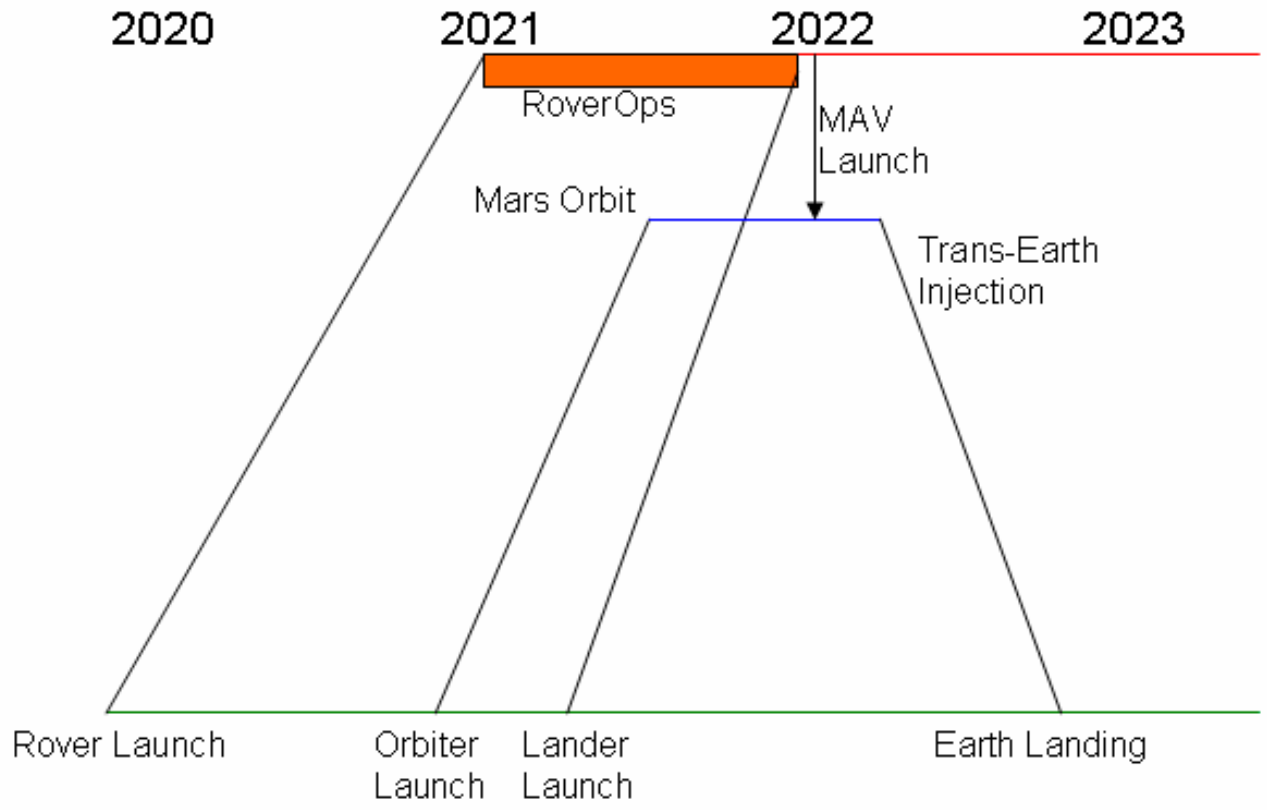
Space –

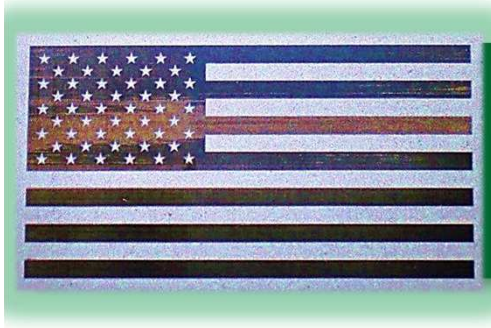
The Final Frontier

Mars 2020 Current Plan

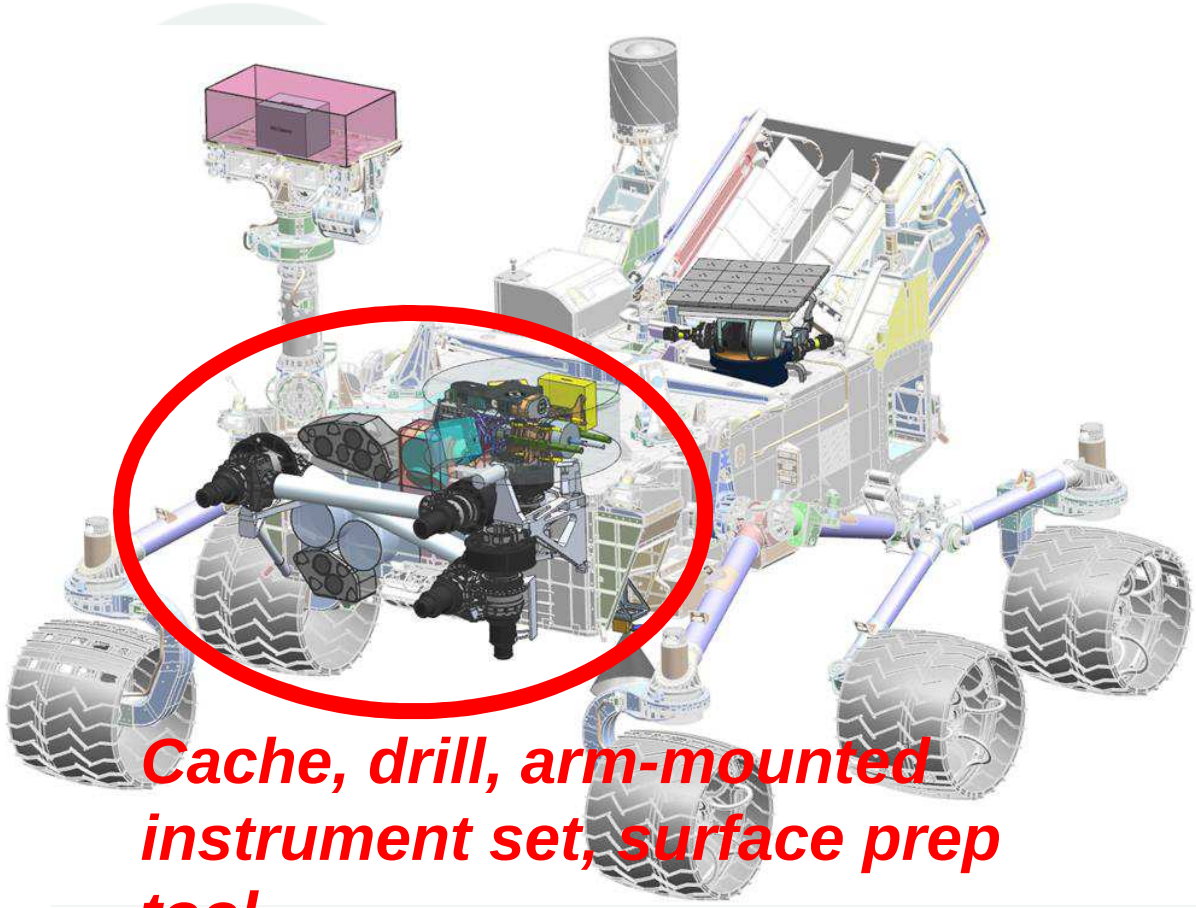


Timeline for Mission 2020

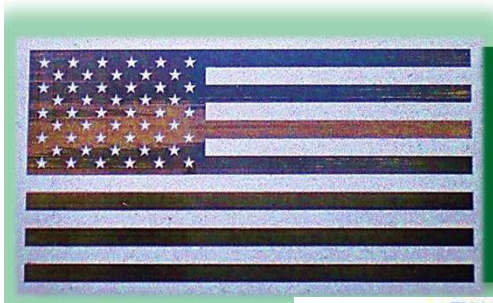




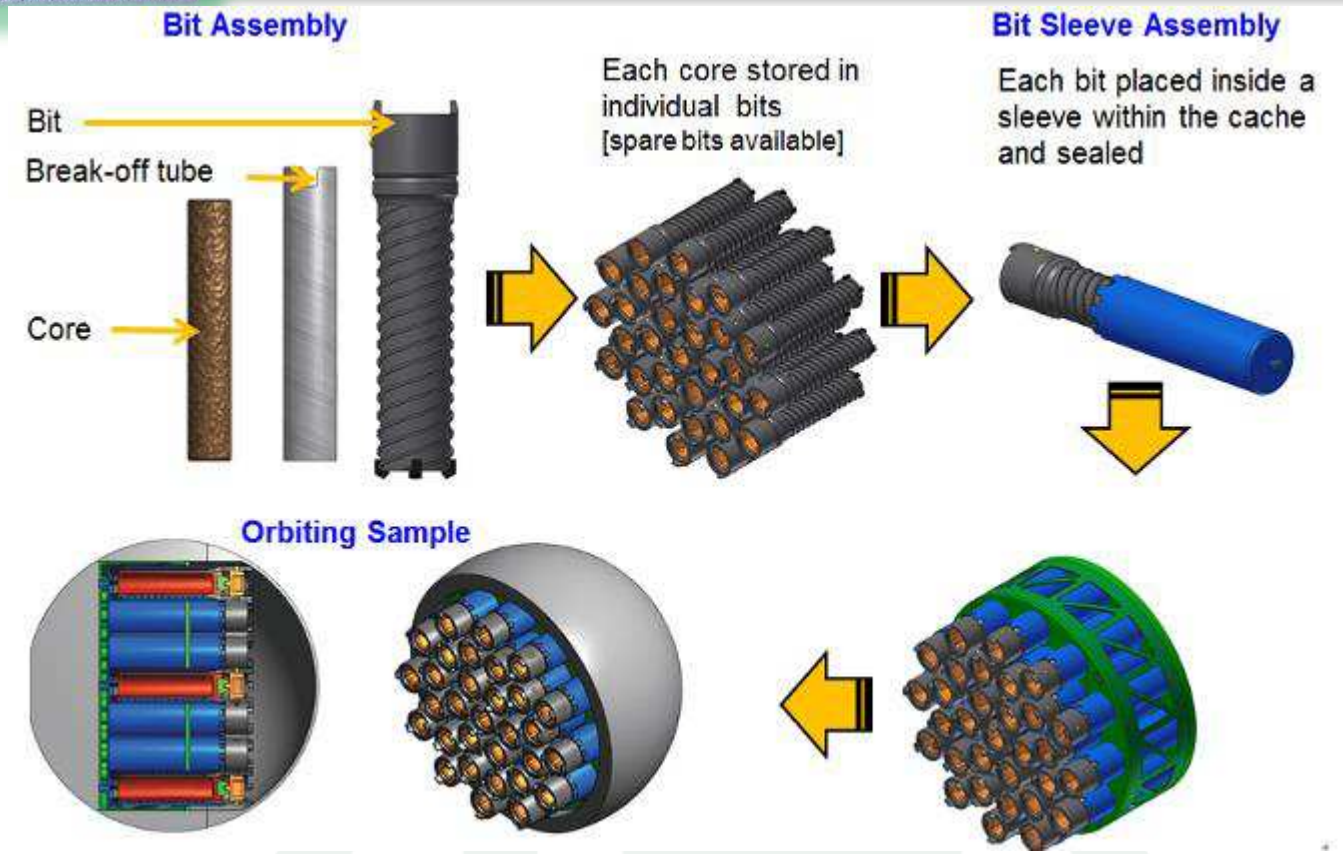
Land the Rover



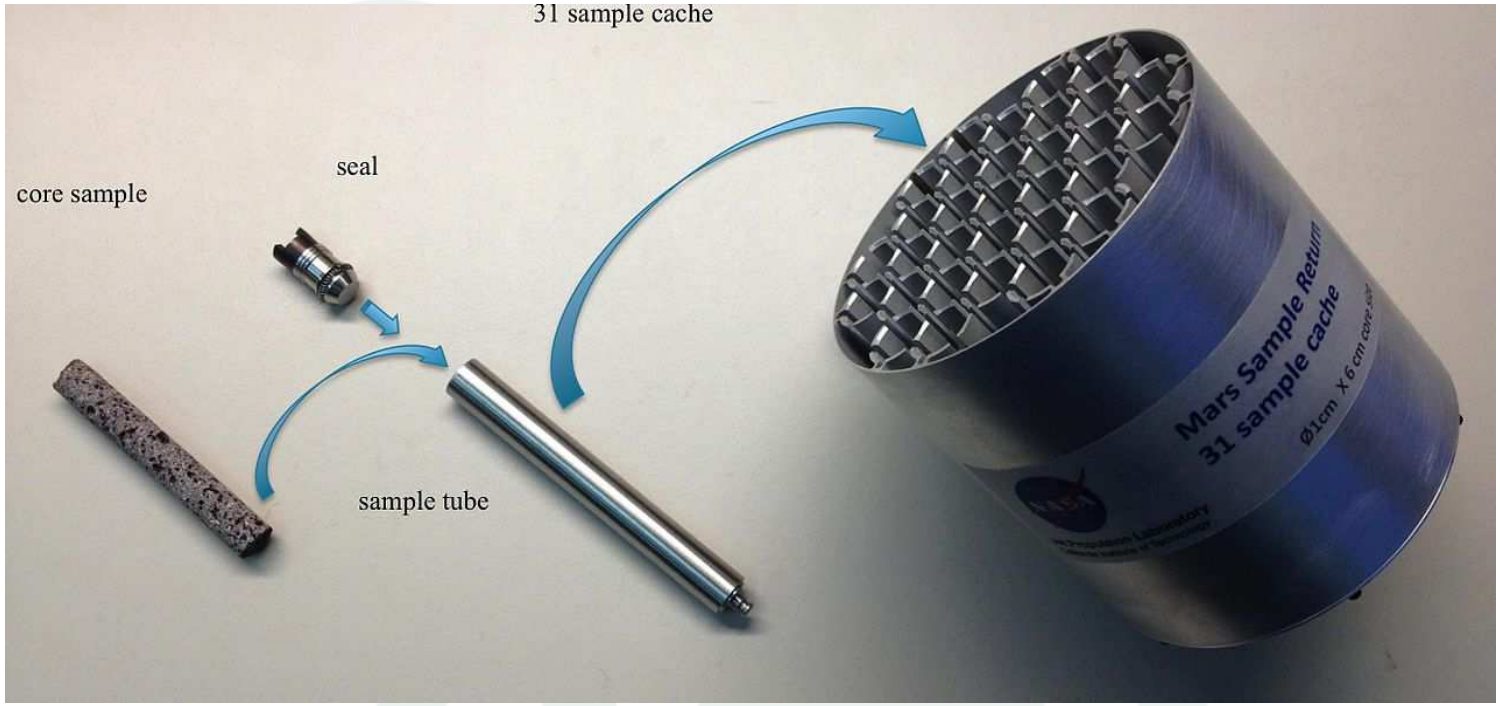
Cache, drill, arm-mounted instrument set, surface prep tool



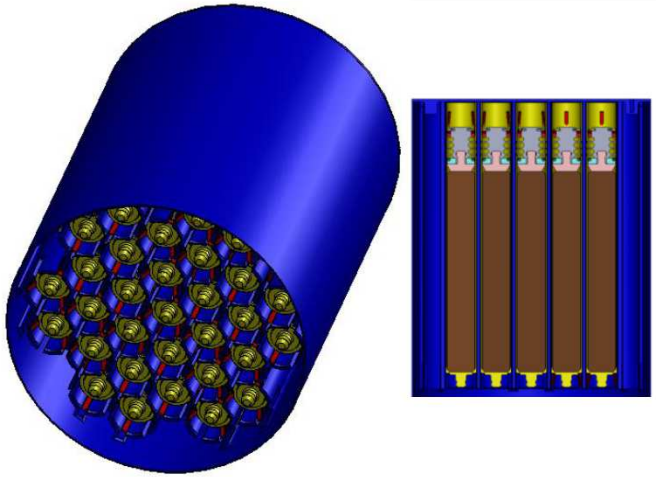
Sample Mars

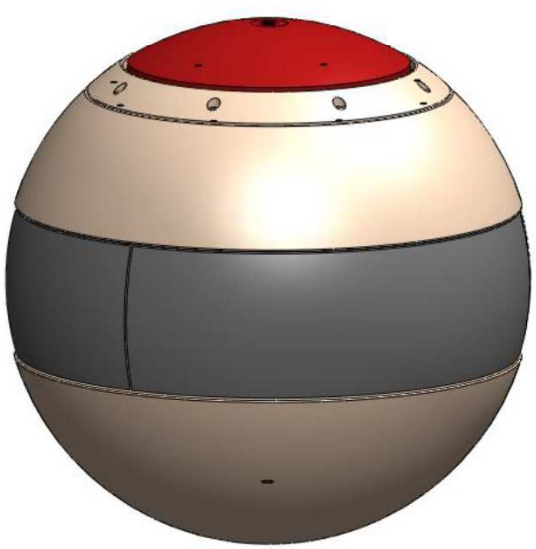

Bit Assembly
Bit
Break-off tube
Core
Each core stored in individual bits [spare bits available]
Bit Sleeve Assembly
Each bit placed inside a sleeve within the cache and sealed
Orbiting Sample

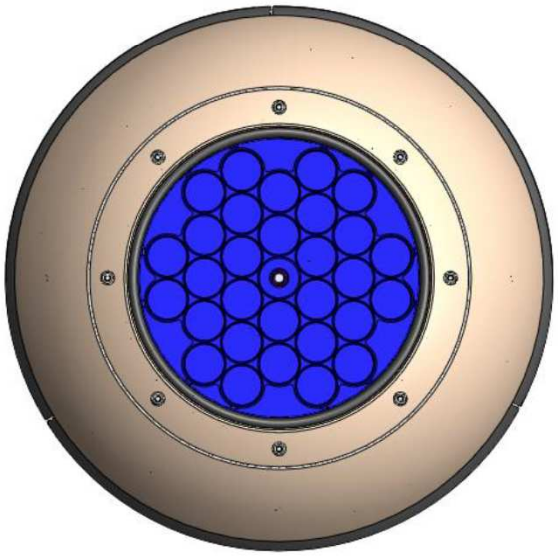
Cache

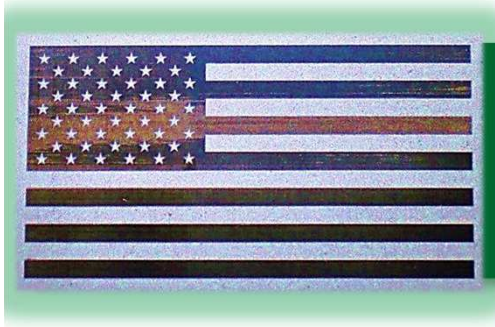

31 sample cache
core sample
seal
sample tube
Mars Sample Return
31 sample cache
Ø1cm X 6 cm core

Orbital Sample

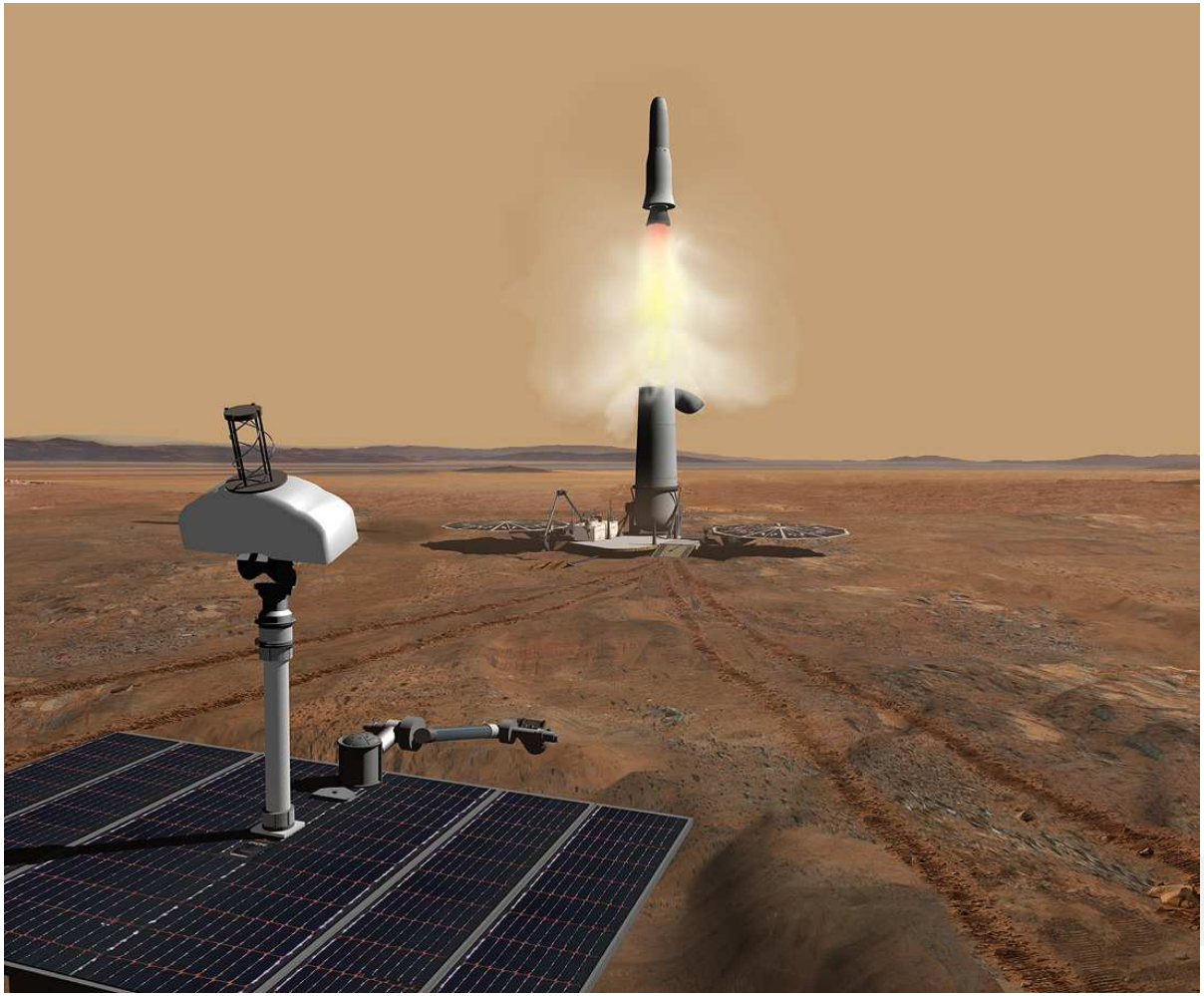








Back To Earth



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Summary

- External Orbital Sample sterilization
  - Coating sphere with NanoFoil
  - Igniting Nanofoil after retrieval from Mars
  - Key to mission
    - No terrestrial contaminants
    - No Martian contaminants
    - NanoFoil sterilization
  - Work in progress

Maximize possibility of identification of Martian Biosignature(s) in samples

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