EPNM-2008, Lisse Holland

Defence Research and Explosive Processing of Materials

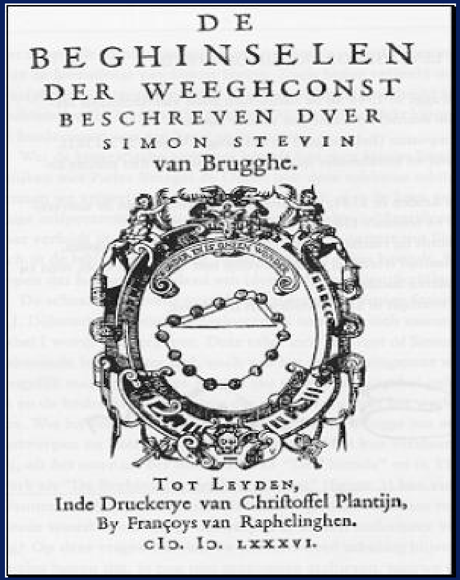
TNO Defence, Safety and Security

Lay-out

- History
- Spin-off & spin-in examples

History

- Simon Stevin Dutch scientist (1548)
- Prins Maurits used his skills for warfare (>1590)



DE
BEGHINSELEN
DER WEEGHCONST
BESCHREVEN DVER
SIMON STEVIN
van Brugghe.

TOT LEYDEN,
Inde Druckerye van Chriſtoffel Plantijn,
By Françoys van Raphelinghen.
cIↄ. Iↄ. LXXXVI.

History

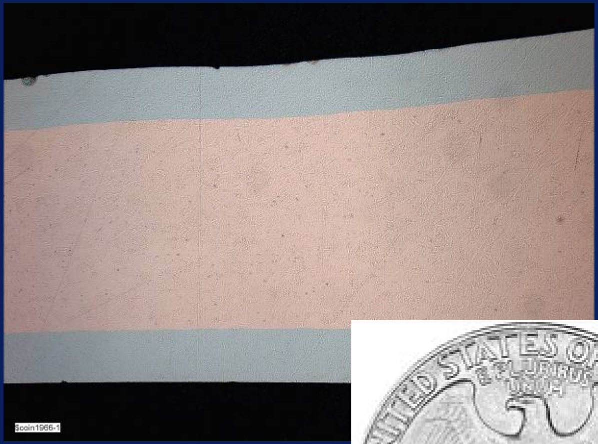
- **Alfred Nobel**
  - Made explosive safe and useful tool
  - Around 1860 in St. Petersburg explosions on the Neva river; photo
  - Patented Dynamite in 1867
  - Used metal plates to show the power of his explosives!

History

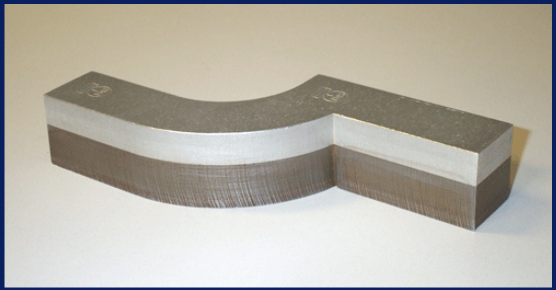
- **Mr. R. W. Gurney chemical scientist (sept. 1943 BRL)**
  - Model to calculate the (final) velocity of bomb shells (fragments)
  - For each explosive type a specific (kinetic) energy $\sqrt{(2E_g)}$ is released
  - Final velocity of metal (M) depends on E/M-ratio and configuration

- **$Vf = \sqrt{(2E_g)}\ [(M/C) + 1/2]^{-1/2}$ *Cylinder (expanding)***
- $Vf = \sqrt{(2E_g)}\ [(M/C) + 1/3]^{-1/2}$ ***Symmetric Sandwich***
- $V_{p,\,final} = \sqrt{2E}\left(\frac{3}{1+5(M/C)+4(M/C)^2}\right)^{\frac{1}{2}}$ ***Explosive layer on plate***

History Explosive welding/cladding



- **Research started around 1950**
  - USA/Russia
- **Patented by DuPont (1960-)**
  - Coins (1/4 $, due to high sliver price)
- **Several production companies world-wide**
  - Reliable bimetal half-products for several markets like:
  - Ship building, Chemical plants, Smelters



History

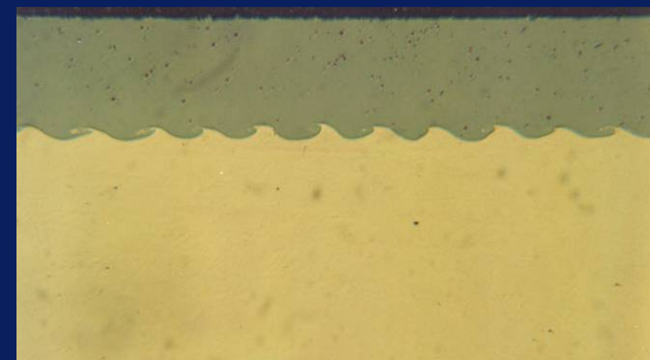
- **TNO was founded in 1933 by law**

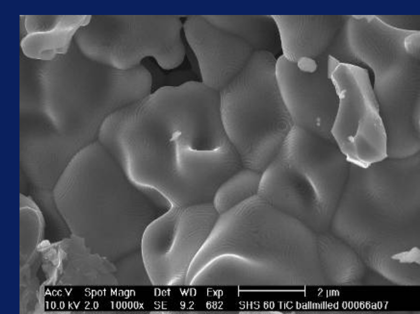
- **Work on EPM since 1960**
  - TNO Metal Institute (van Wely, Verbraak, Boes, Remmerswaal)
  - TNO Defence, Safety and Security

- **TNO Defence, Safety and Security**
  - Part of this used to be called the Prins Maurits Laboratory
  - Cooperation with Delft University of Technology
  - Since 1986 Ph-D students working on explosive compaction of powders

Nowadays wide range of processes

- **Metal processing technologies**
  - Forming
  - Cladding/Welding
  - Cutting/Perforation
  - Hardening
  - Engraving
  - Stress release (welds)
- **Material processing**
  - Shock treatment of wood
  - Cleansing
  - Tenderization of meat
- **Material synthesis**
  - Powder compaction
  - Self-sustained High-temperature Synthesis (SHS)





Explosive Compaction of Powders

Room temperature consolidation of powders

Powder in tube: composition is free

(metals, polymers, ceramics and mixtures of those)

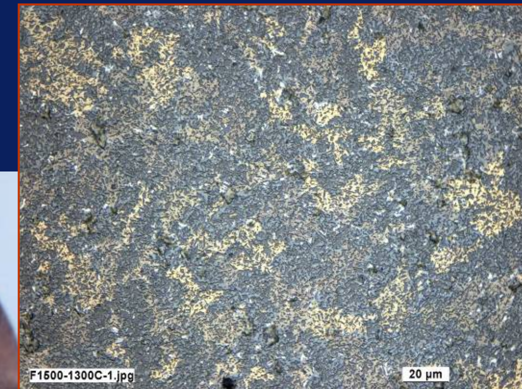
Ceramics show (at RT) residual porosity: subsequent metal infiltration

B_4C (82%) + Al (18%) = BORCAL

TiB_2 (85%) + Al (15%) = TIBAL

X-ray flash image of the explosive compaction process

Explosive compaction

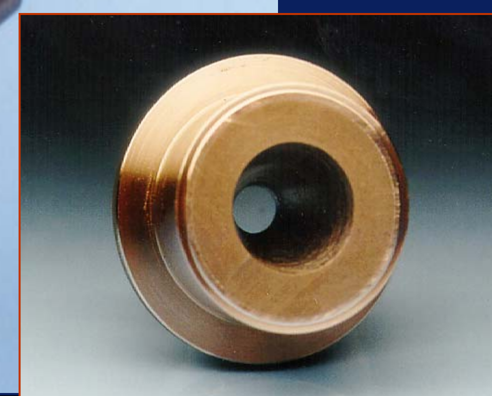


Control of bulk material properties

- Microstructure (amorphous, nano)
- Hardness
- Strength
- Density

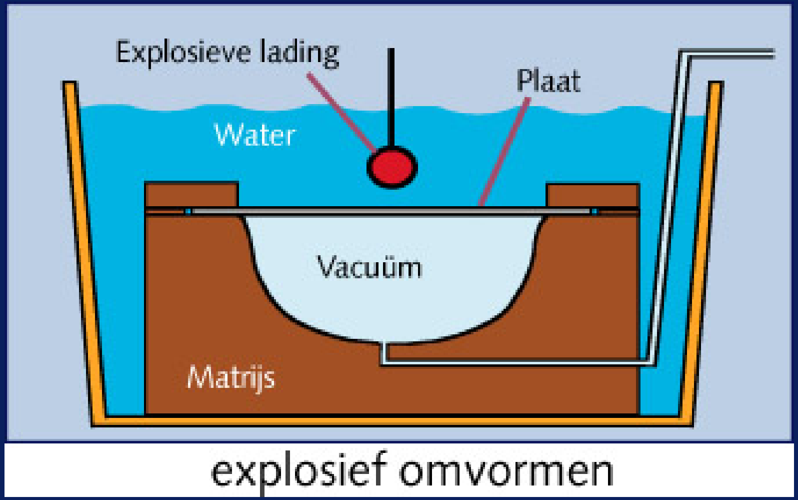
Examples

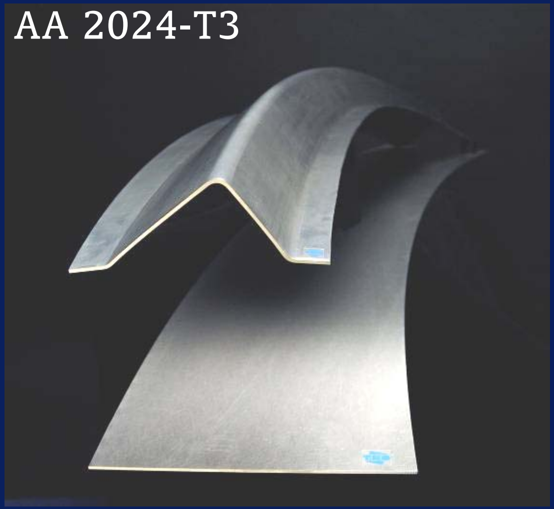
- Metal-Ceramics matrix for e.g. tooling
- Light weight armor material
- Nozzles

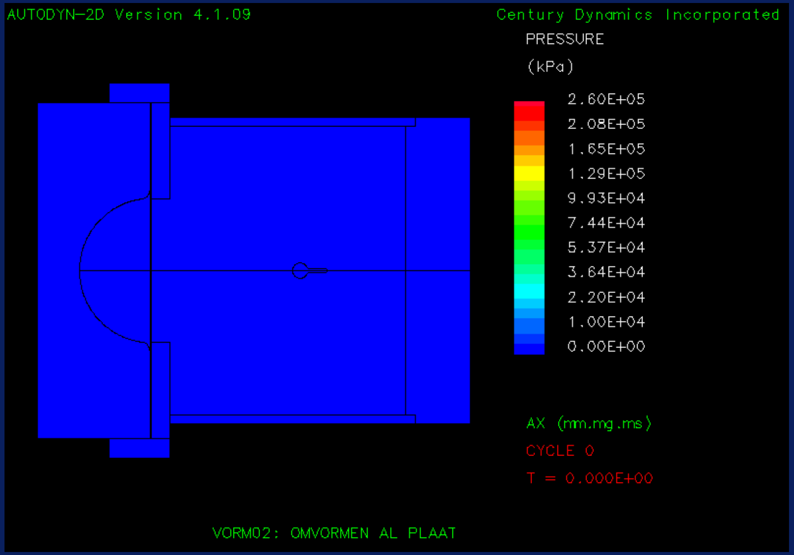


Explosive forming of metals

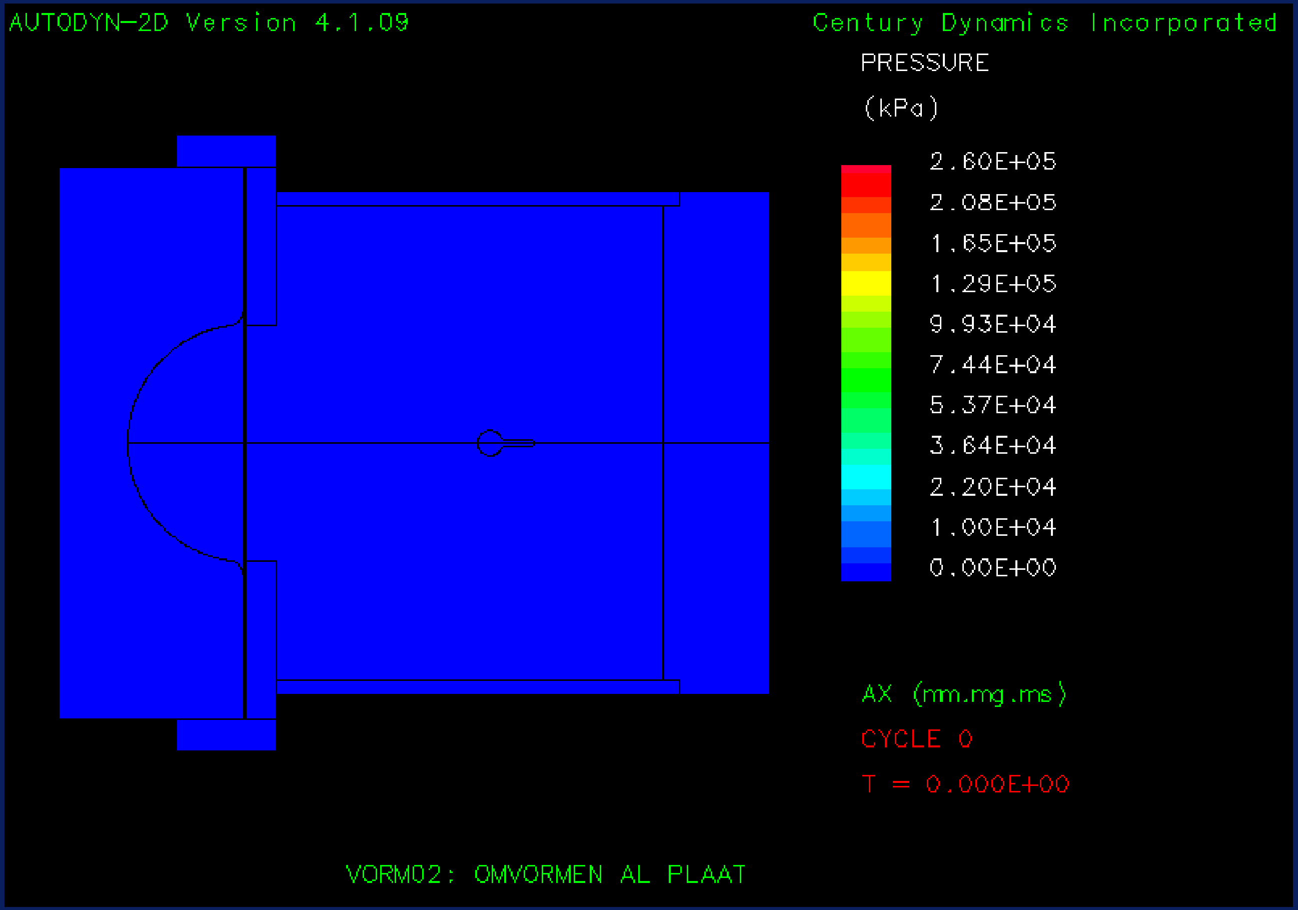
- Metal sheets and tubes
- Explosive charge as energy source
- Small charges in water
- Single sided tooling (die)



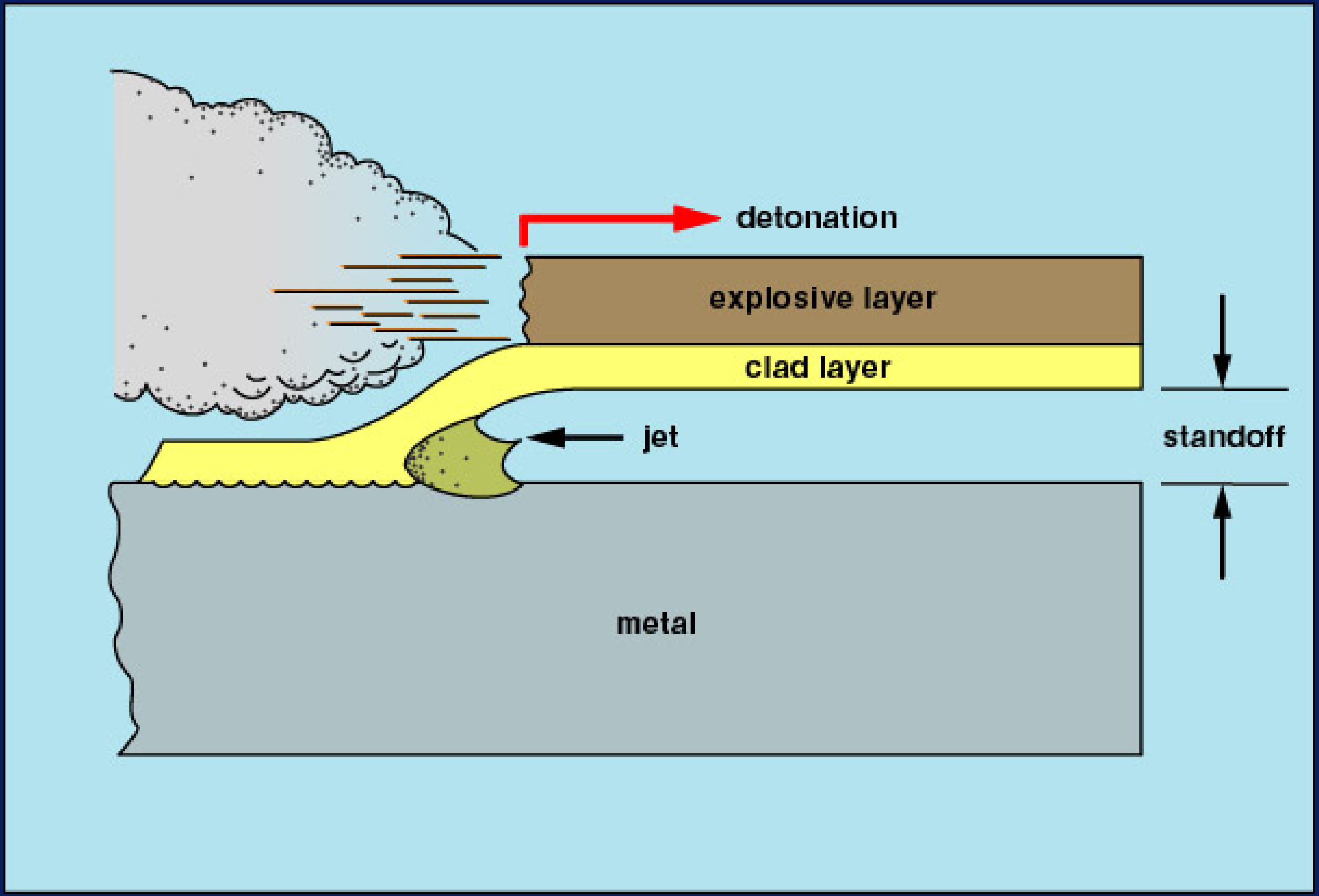




Computer simulation of explosive forming



Explosive Welding and Cladding

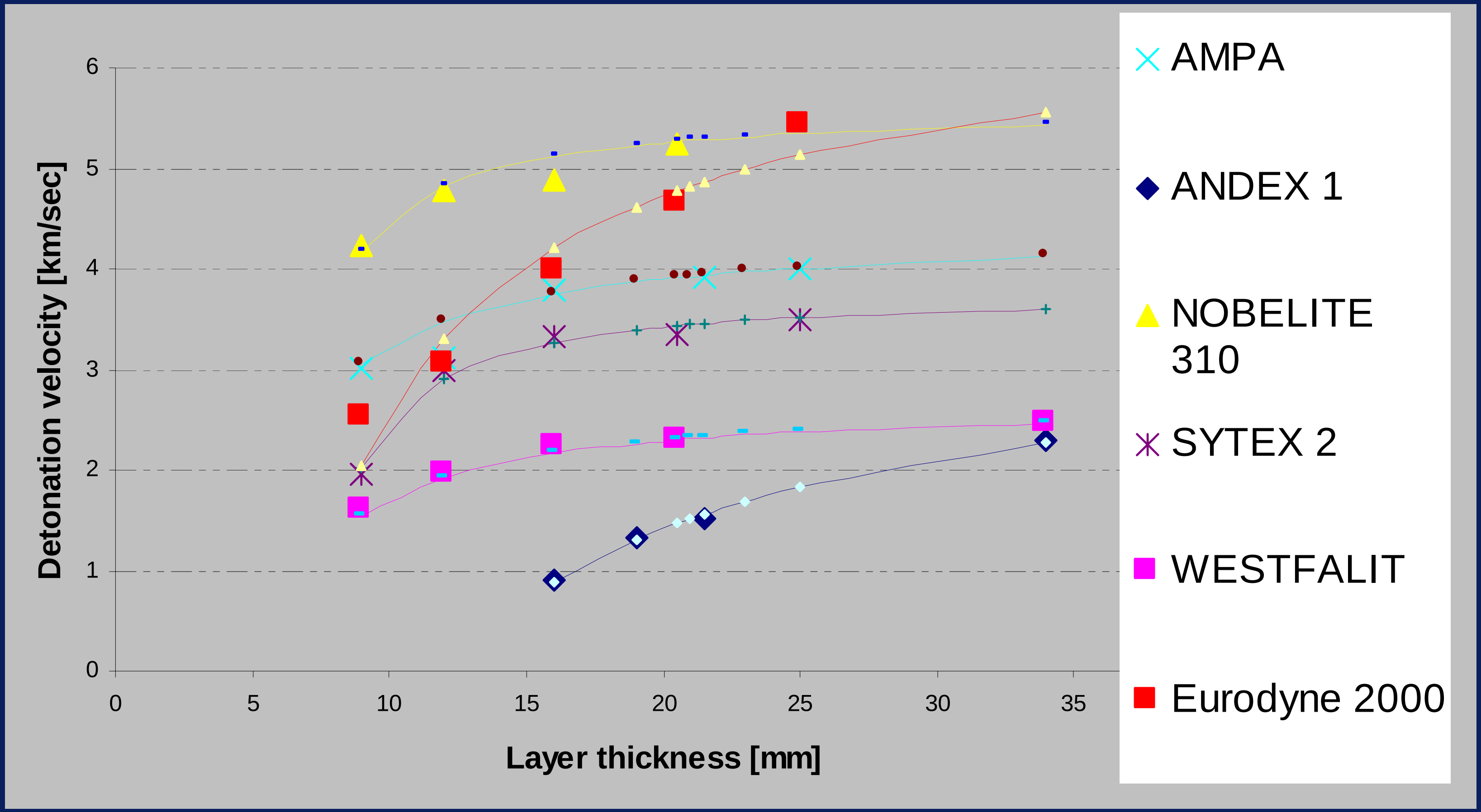


Explosive cladding process (I)
THEORY

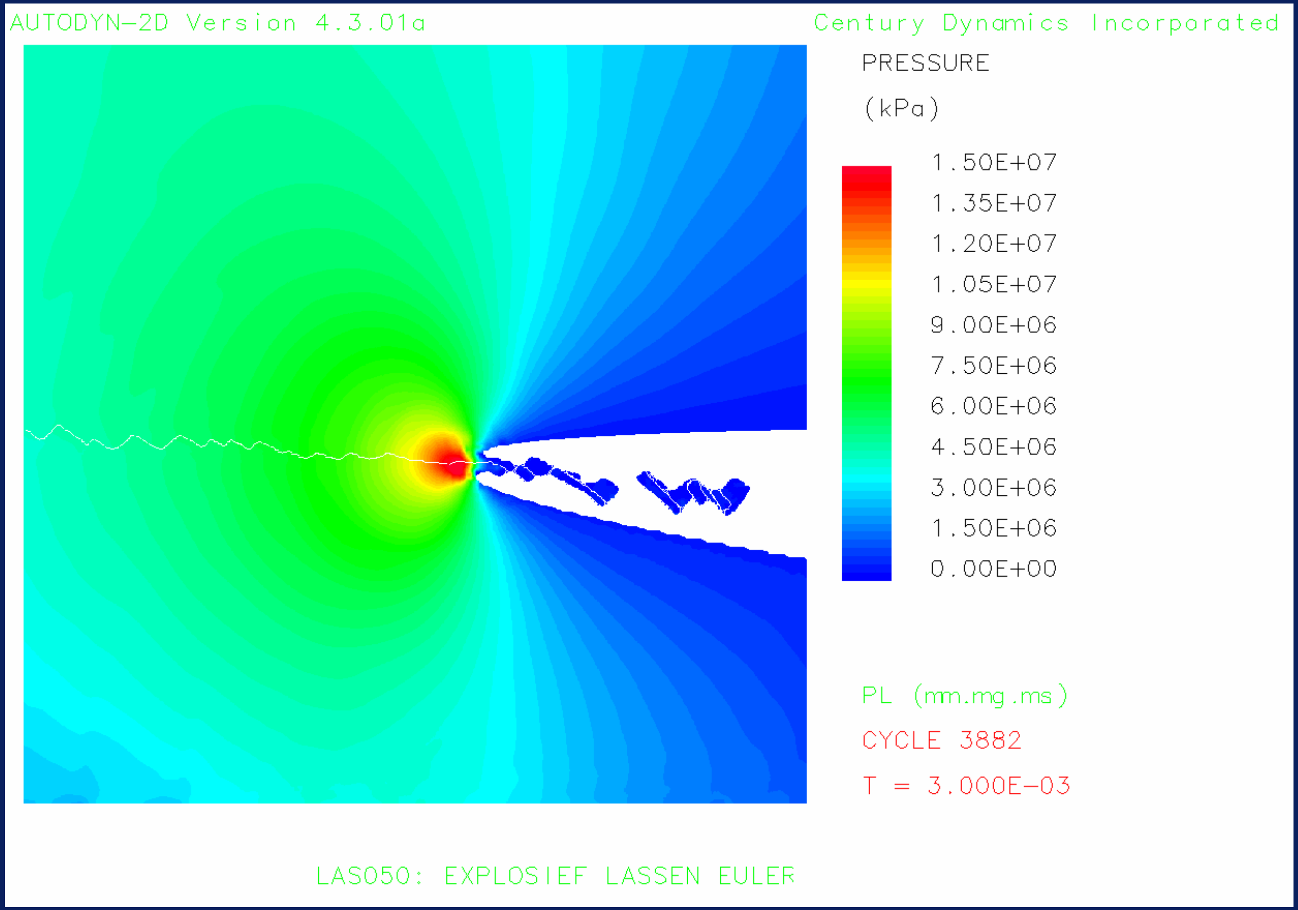
- **Non-ideal detonation of explosives**
  - Influence of layer thickness and confinement on detonation
- **Explosive plate acceleration**
  - Gurney relations
  - Computer simulations
- **Impact phenomena**
  - Hydrodynamics, shape charges, jetting and shock loading
- **Wave formation mechanisms**
  - Influence of plate thickness, dynamic impact angle (β)
- **Intermetallic reactions**
  - Miedema model, Phase diagrams

Non-ideal detonation Model:

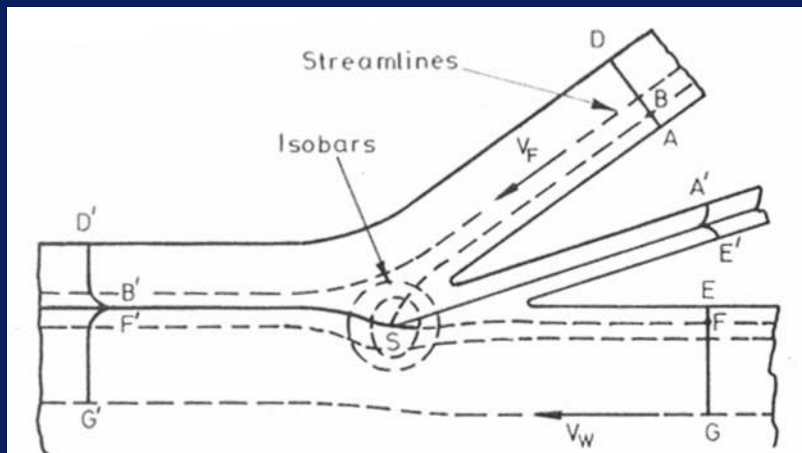
$$D(L) = D_i \bullet \left(1 - \frac{c}{L - d}\right)$$

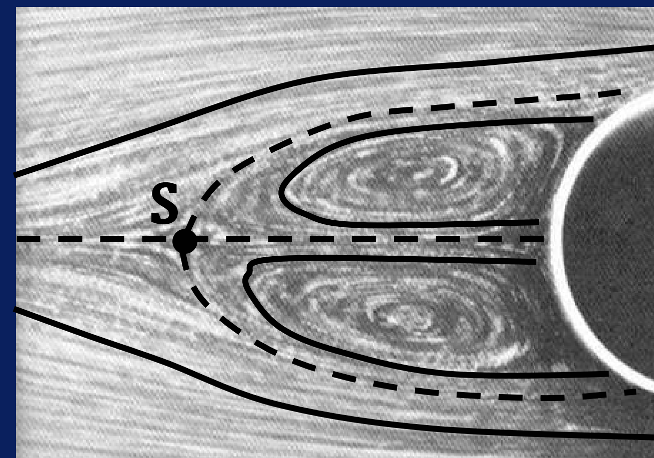


Simulation of explosive cladding: jetting



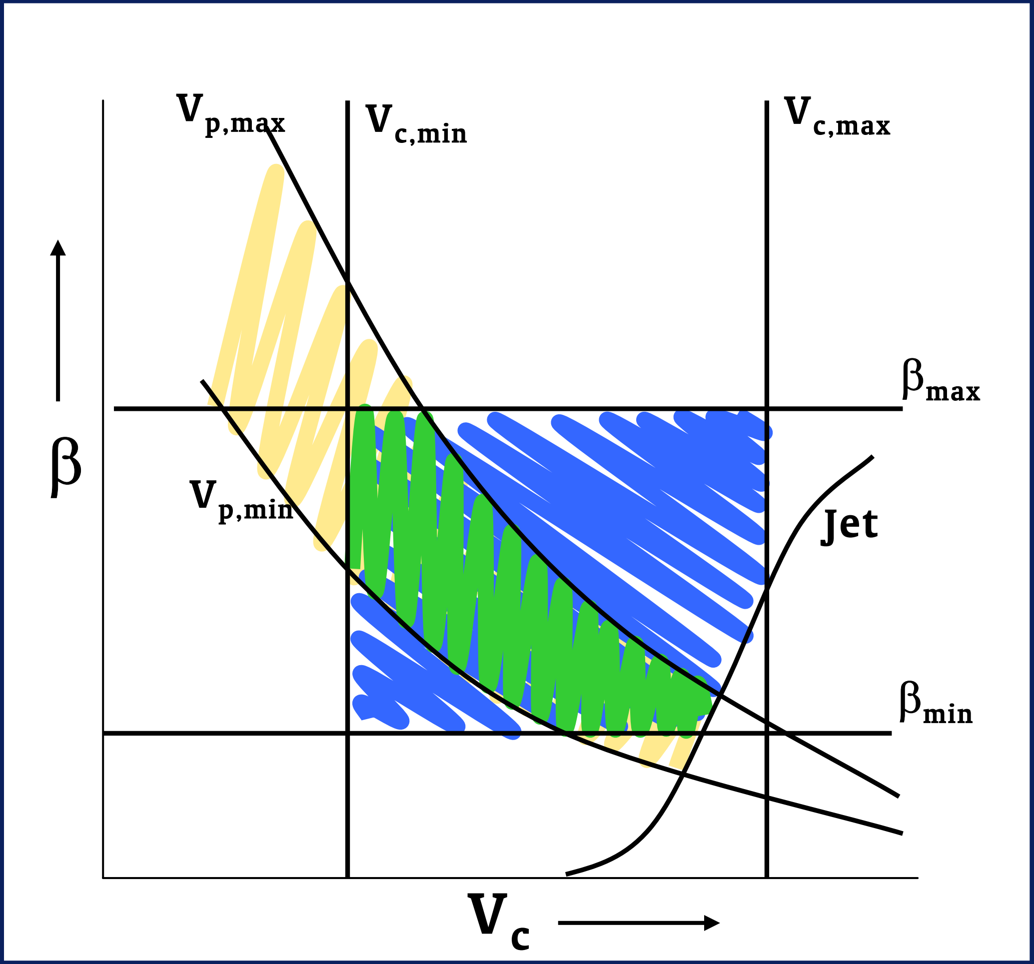
Link between jet and wave formation





Cu-jet from interrupted cladding

Welding Window

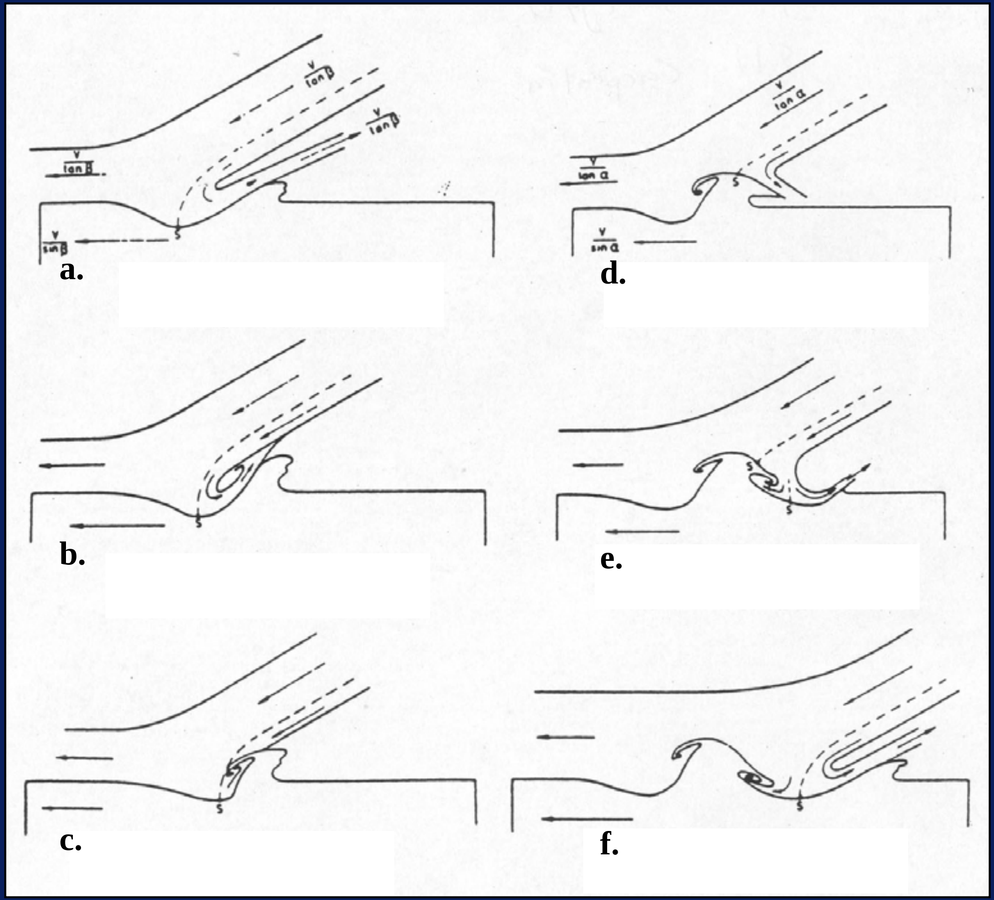


Jet: prerequisite for welding

$V_{p,min}$:hydrodynamic behavior

$V_{p,max}$: no excessive melting

Wave forming mechanisms



Jet indentation

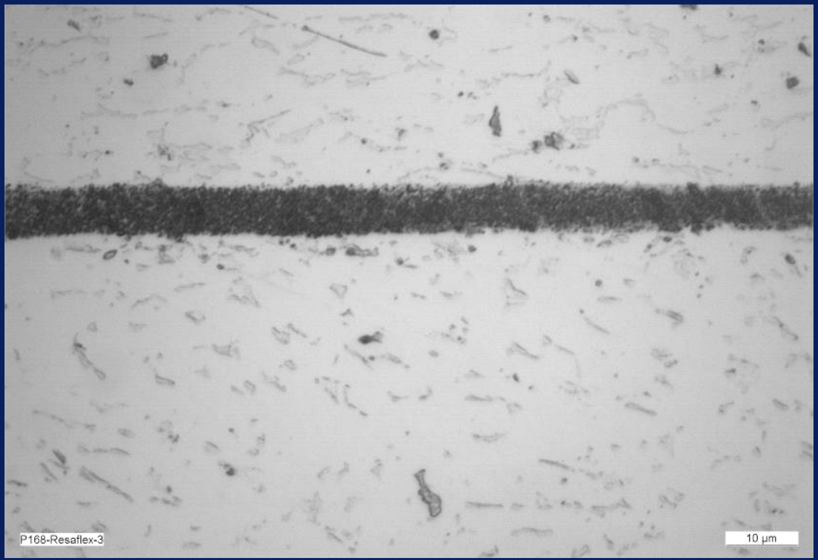
Others:

Von Karman array

Helmholtz instabilities

Explosive cladding process (II)

- **In process measurements**
  - Detonation velocity (electrical, fiber optic probe)
  - Plate velocity (electrical, optical)
  - Ultra-fast photography (Imacon)
  - X-ray flash photography
- **Interface analysis**
  - Ultrasonic scans
  - Light microscopy
  - SEM
  - X-ray Diffraction
  - Micro-Vickers hardness

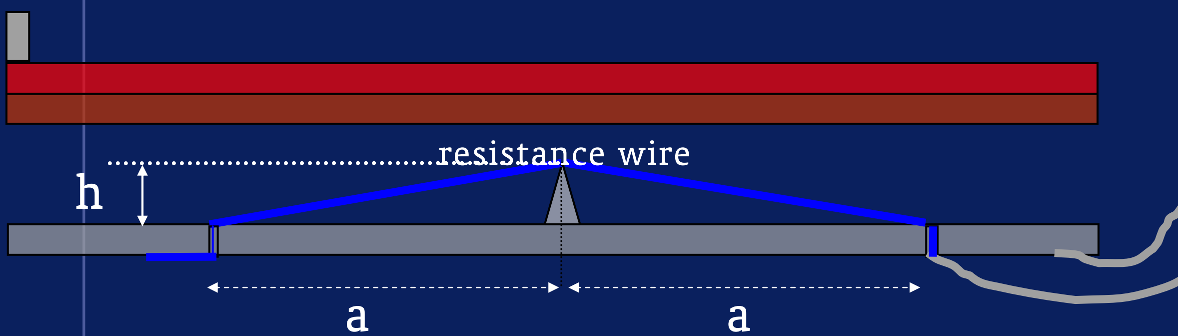


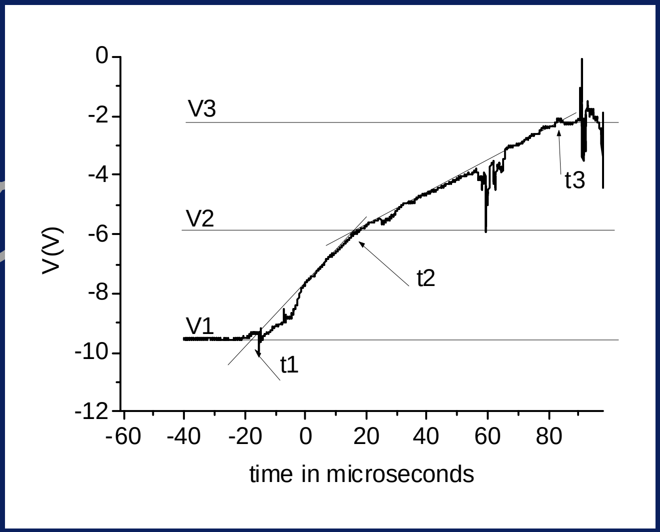
Ti6,4 cladding using D= 7.2 km/s

Collision point and plate velocity measurement

Double slanted wire method (Prummer)

- Simultaneous measurement of collision and detonation velocities
- One current supply and one oscilloscope needed



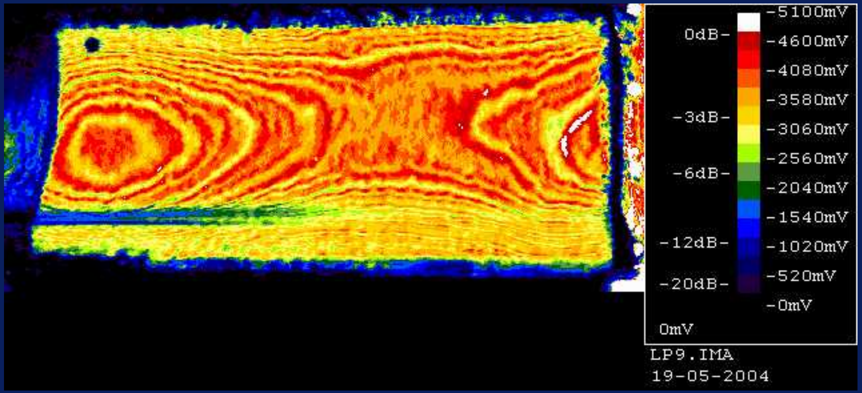


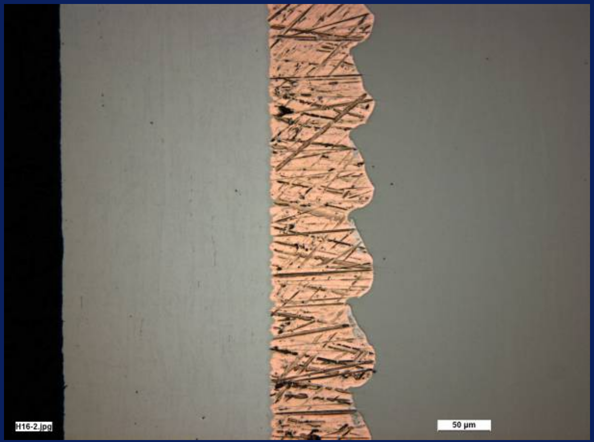
High-speed camera recordings

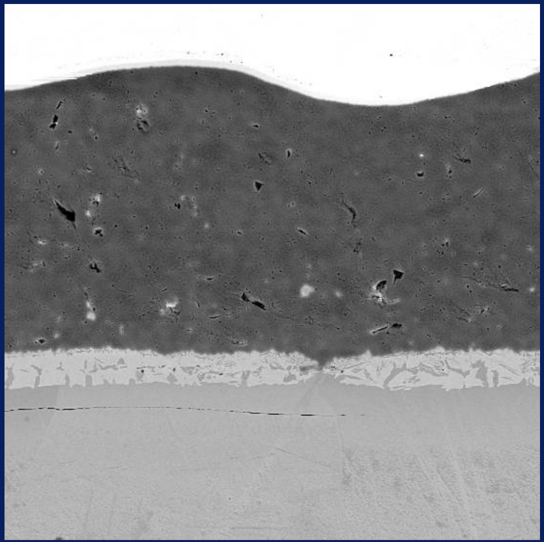
High-speed camera recordings

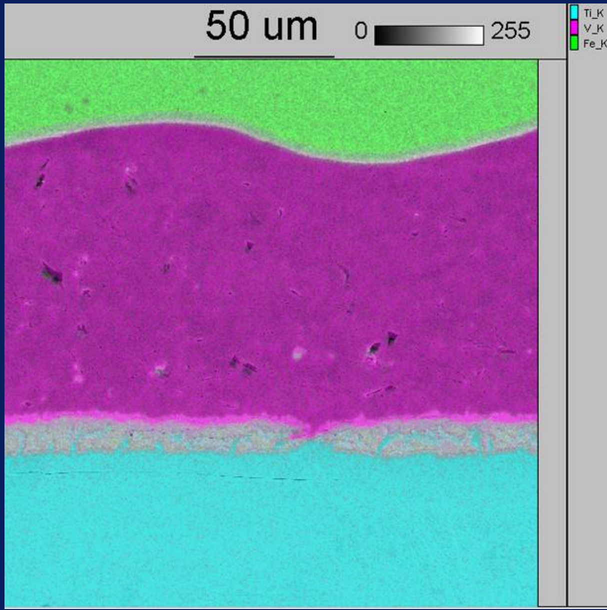
Explosive cladding process (III)

- **Interface analysis**
  - Ultrasonic scans
  - Light-microscopy
  - SEM
  - X-ray Diffraction
  - Micro-Vickers hardness









Explosive welding development at TNO

- **Spin-off**

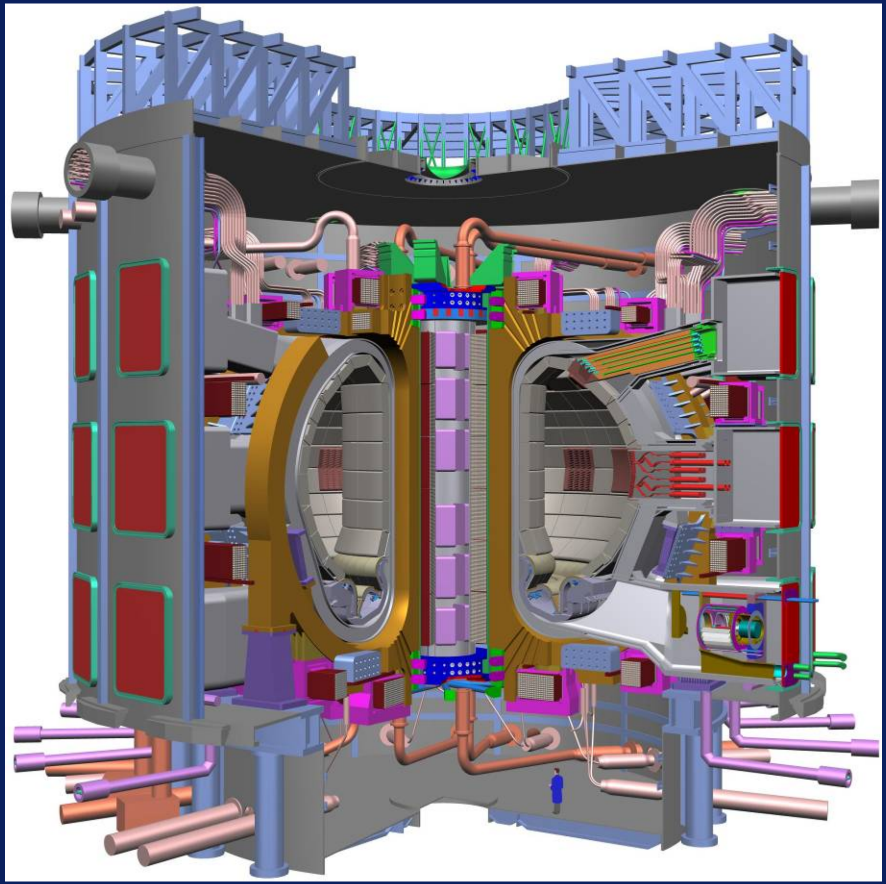
  ITER component development (presentation by M. Stuivinga)
  - W-CuCrZr (hot cladding)
  - Triangular support (cladding around obstacles)

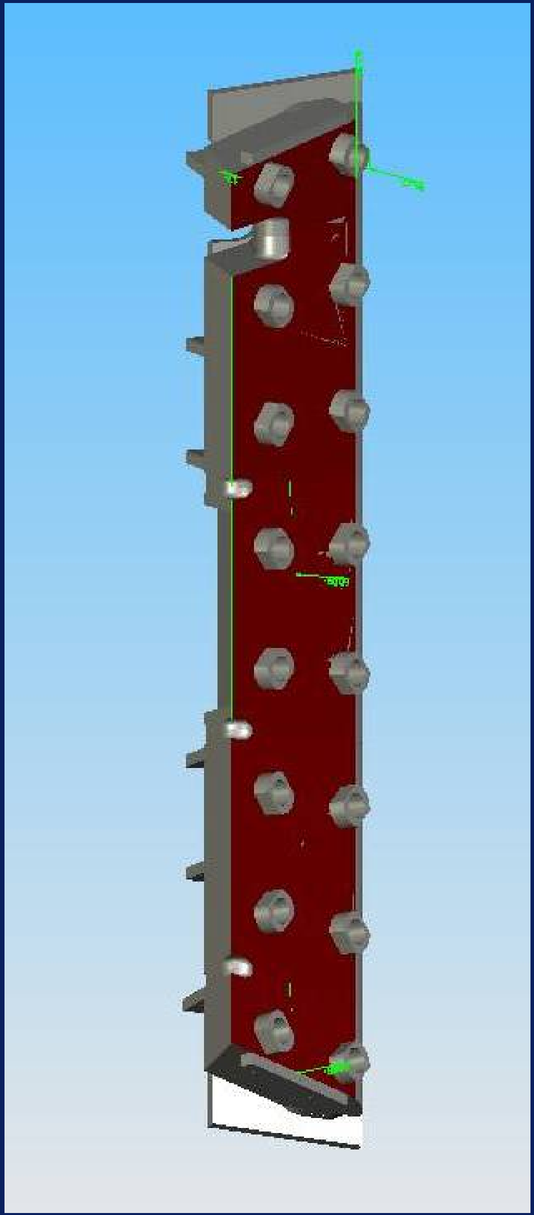
  Mars sample return mission (Poster presentation)
  - Biosealing of container parts by:
    - Explosive welding
    - Foil brazing using SHS heating

- **Spin-in**
  - Anti-spall liner on Ti6,4
  - Gun barrel liner
  - Dual hardness armor (Explosia-presentation EPNM-2006)

Spin-off: ITER components

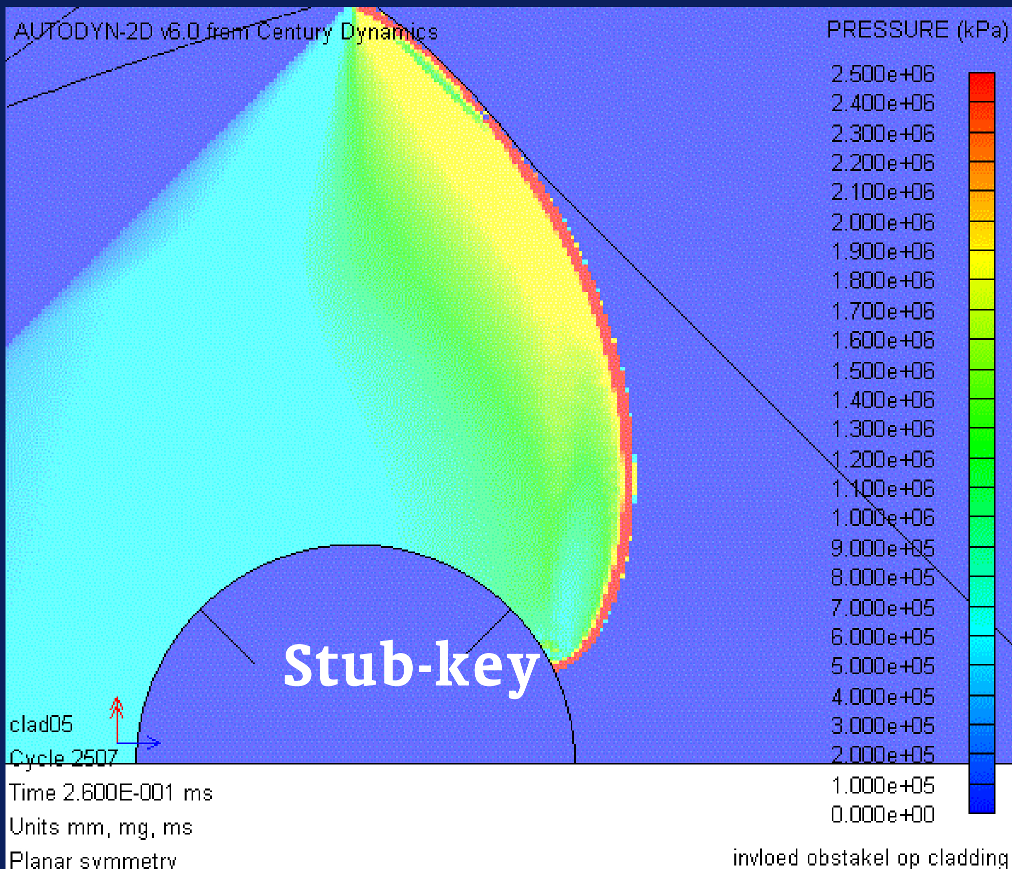
- **Triangular support (16 stub-keys)**
  - Cu (1.5 mm) clad on 60 mm SS316L (IG)

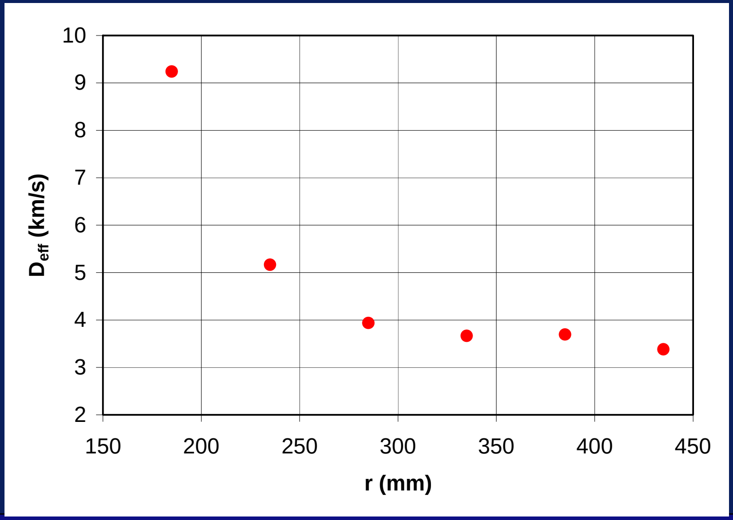




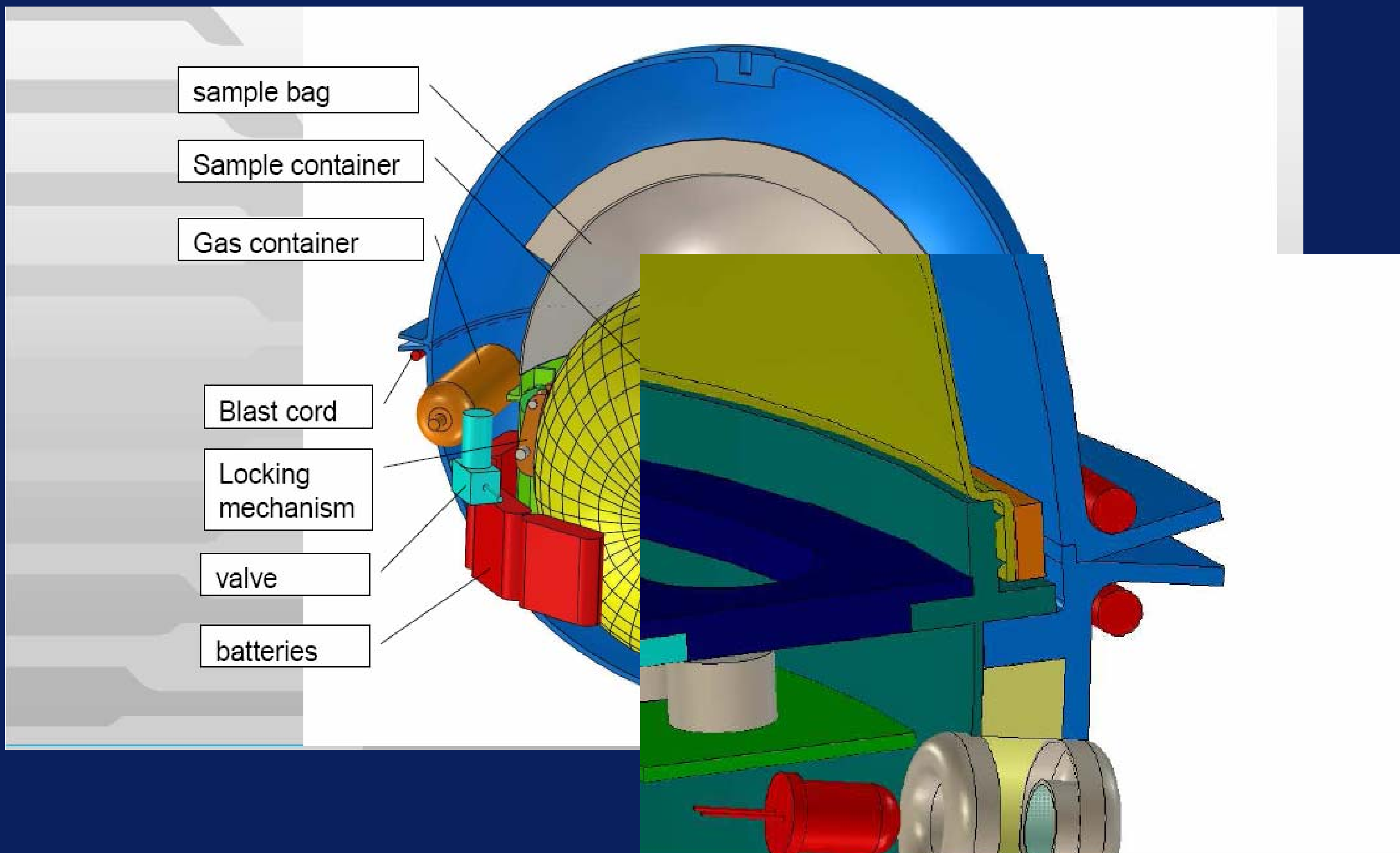
Computer simulation of detonation

Detonation around a stub-key





Spin-off:
Bio-sealing a Mars-sample container



Spin-in:
Anti-spall liner for Ti6,4 armour plates

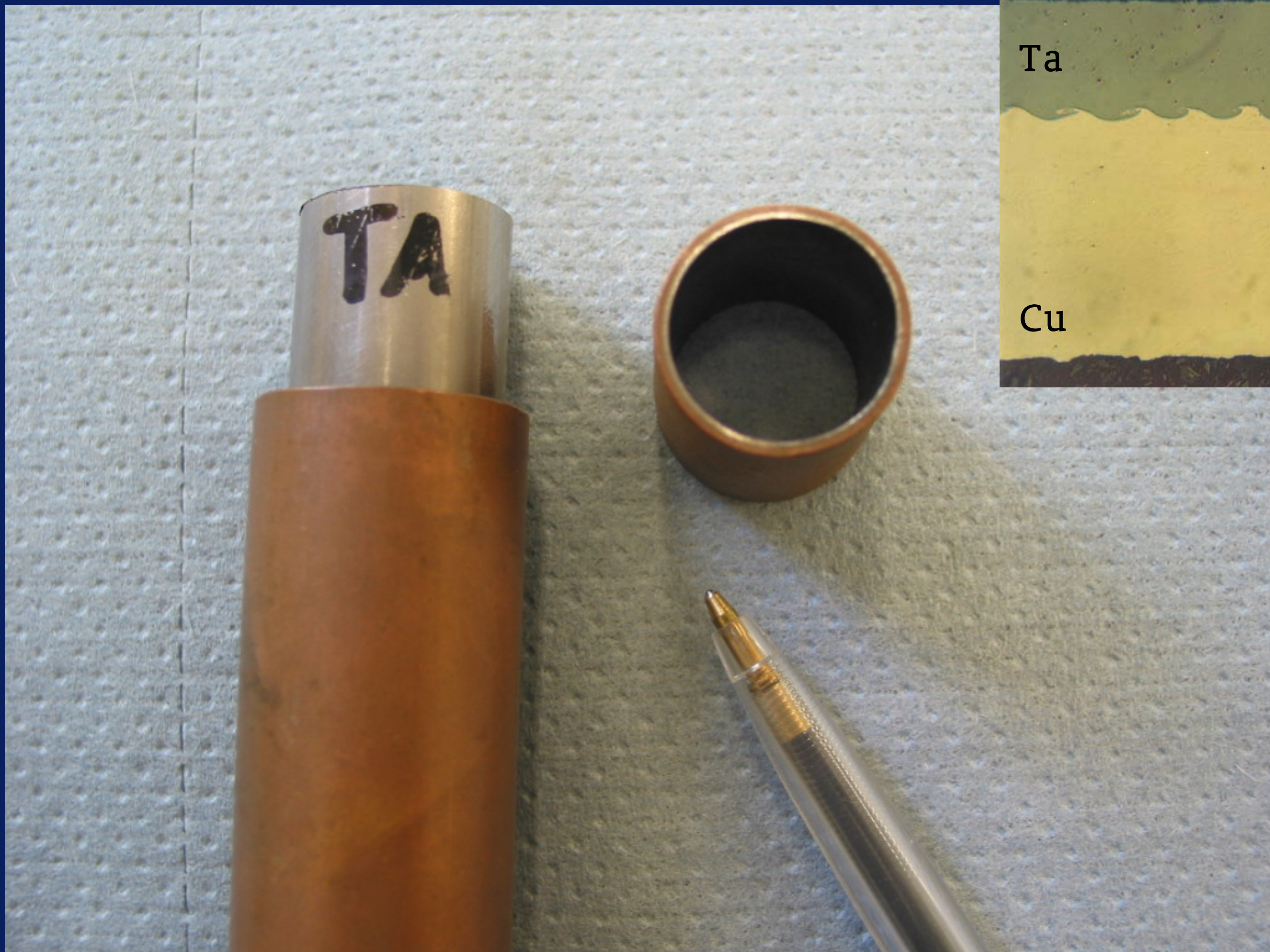
Spin-in:
Anti-erosion liners in gun barrels

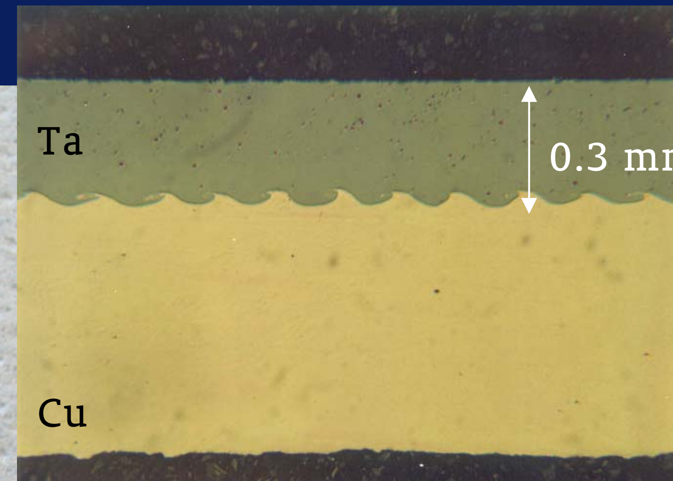
Standard Bushmaster barrel
375 shots

Ta-clad Bushmaster barrel after
600 shots (still serviceable)

Internal or external cladding of tubes

Cu-Ta (0.3 mm)

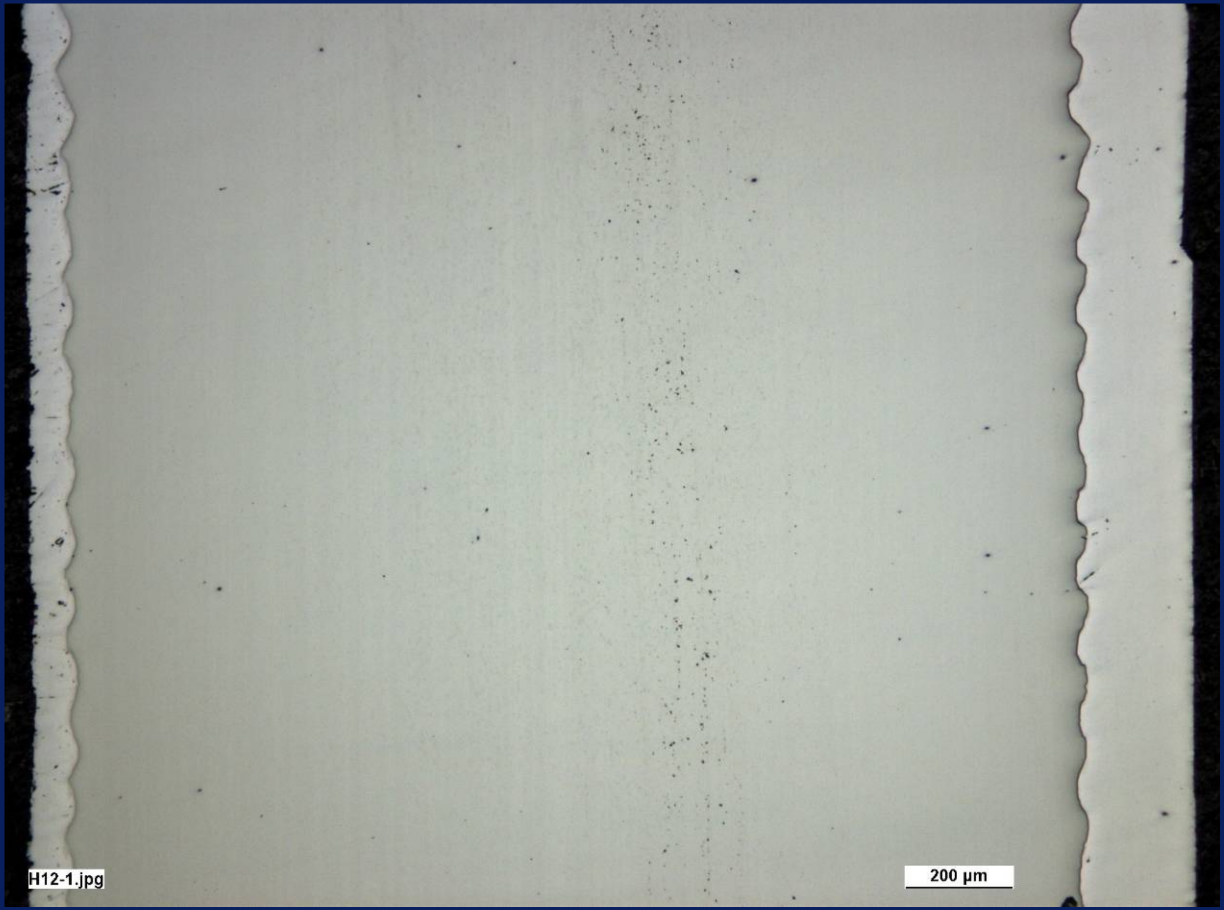




Foil cladding; coating technology

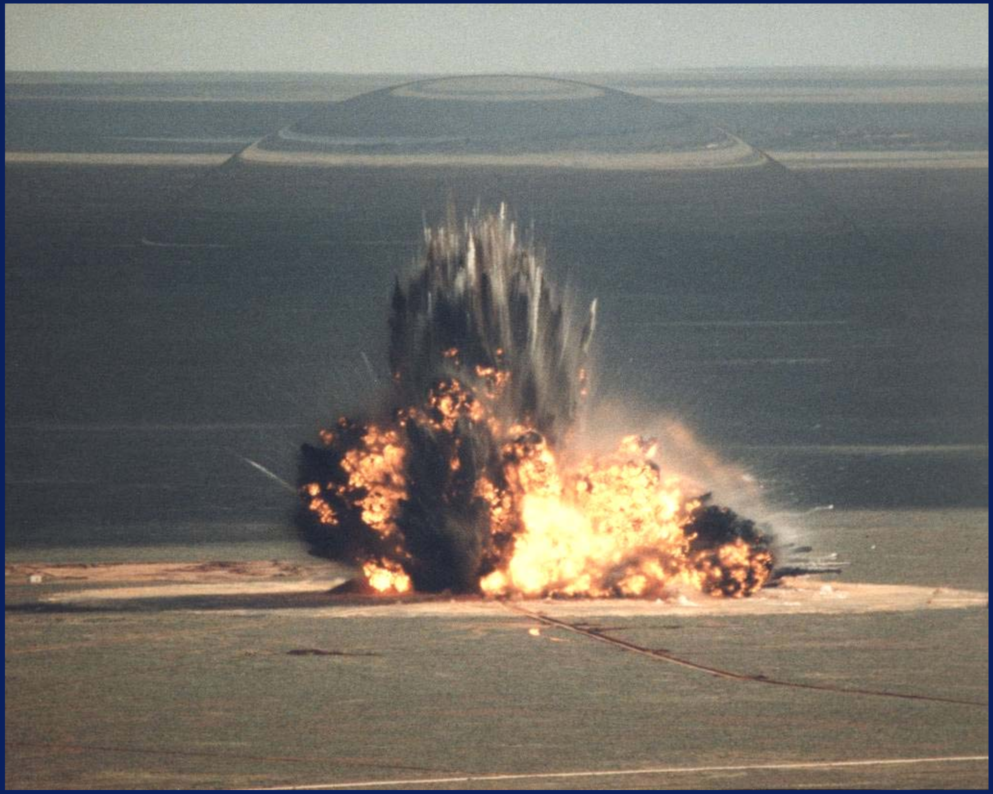
- Foil attached to buffer plate
- Same process as cladding thicker plates
- Buffer does not bond (no inclined impact)

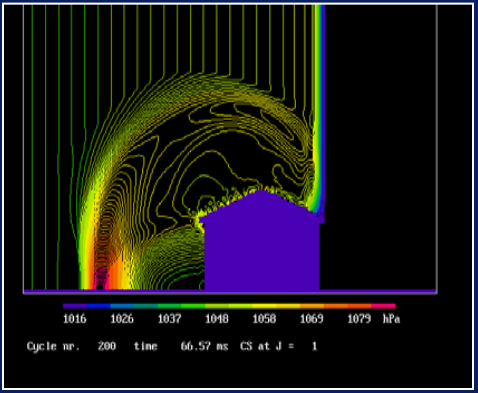
Two-sided Stainless Steel 316 cladding of a Ti6,4 sheet (2 mm plate thickness)



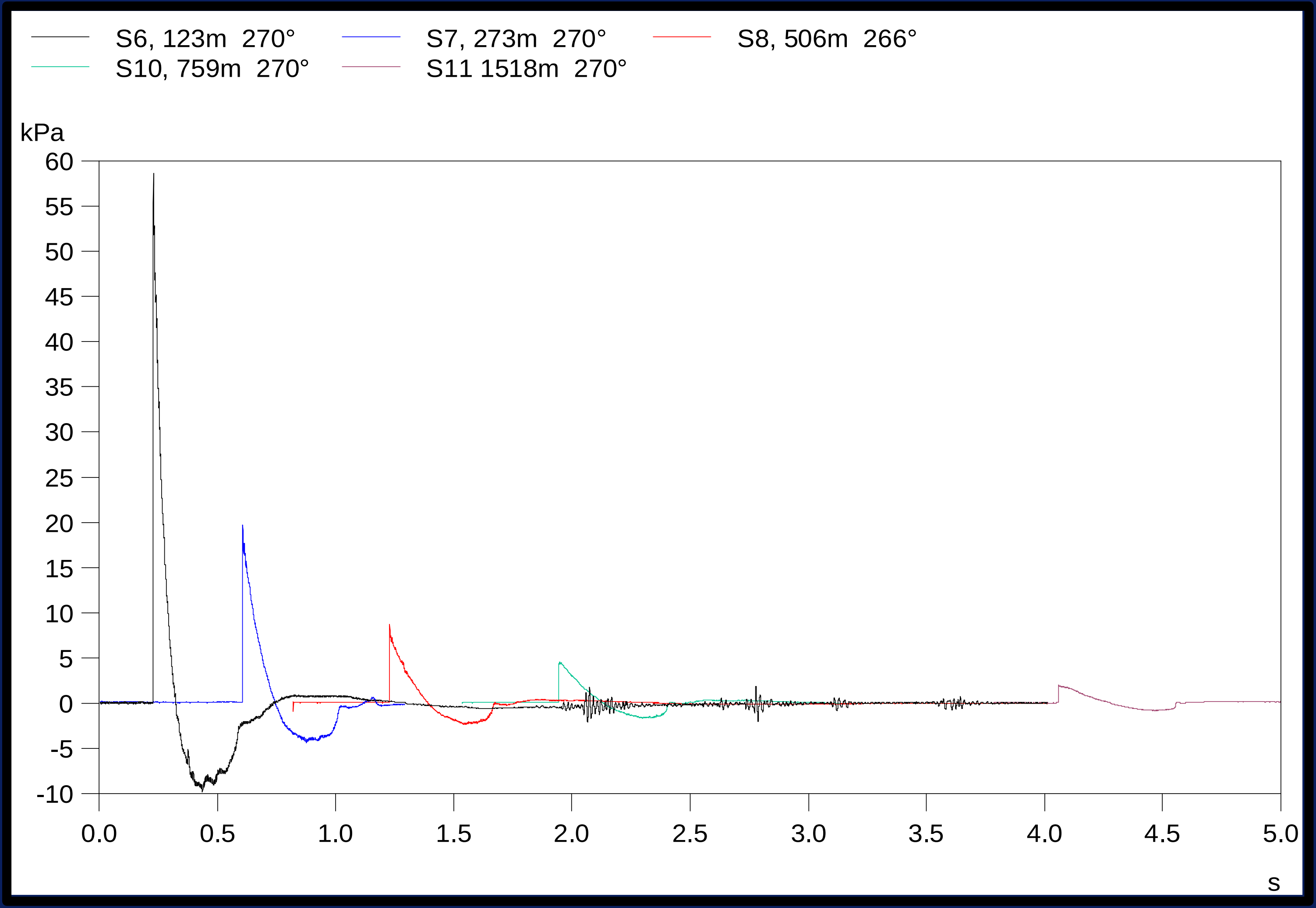
Blast measurements

- **Blast team (TNO Defense, Safety and Security)**
  - Mobile equipment for strain, shock and blast measurements
  - High speed imaging



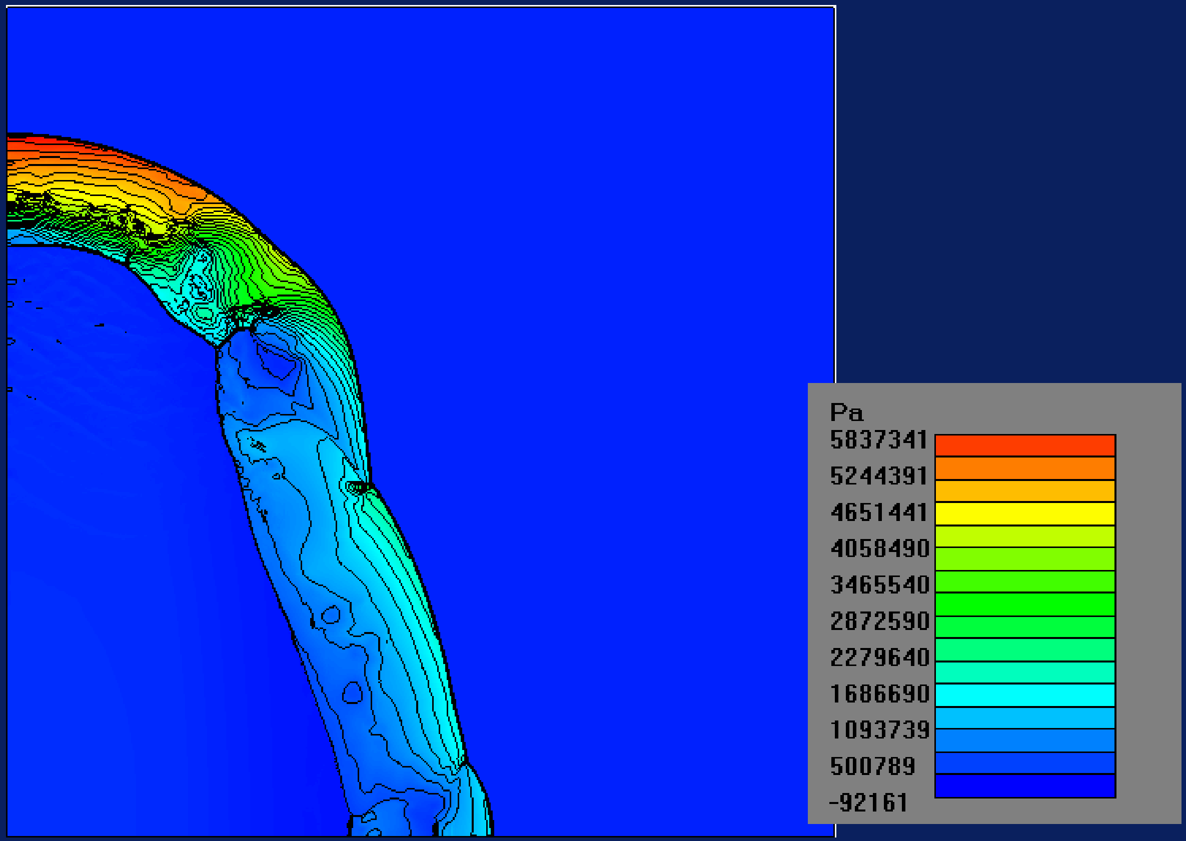


Example of a blast measurement



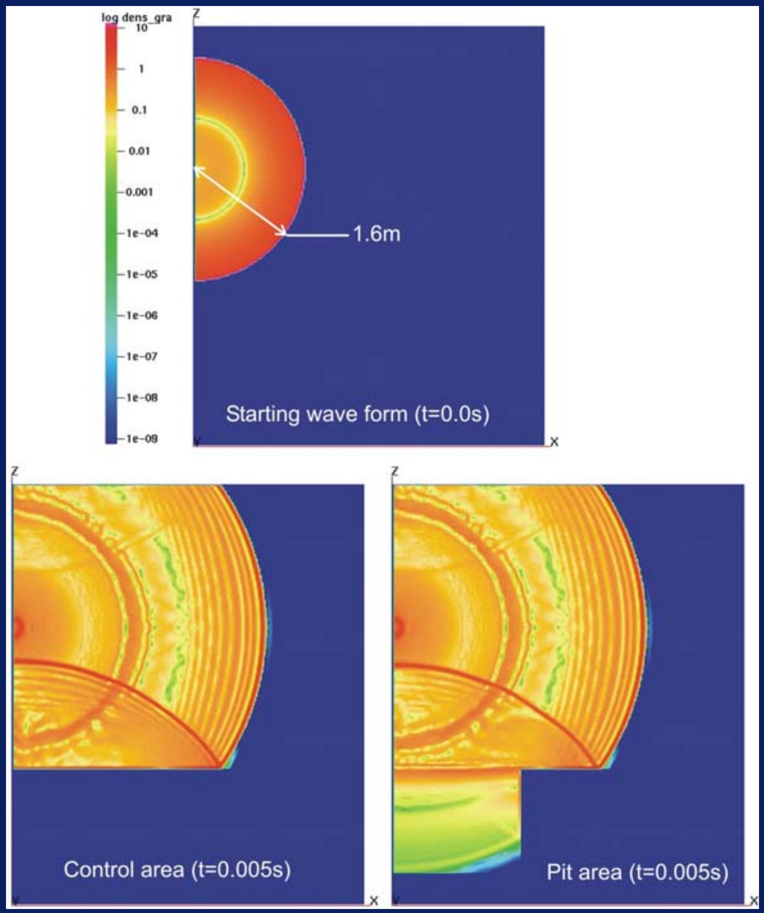
Shape effect of explosive on blast

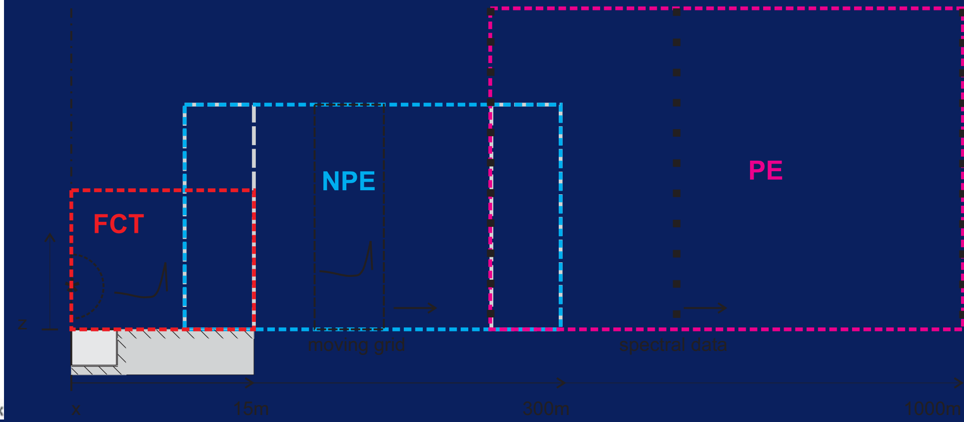
- Simulation of the blast wave form a Ø 2 m plate of detonating TNT (0.1 m thick)



Acoustic measurements

TNO Science and Industry





Blast mitigation

- **Relation between blast and noise intensity:**
- **Sound pressure level (SPL)**
  - **20 log (Y Pa/20 µPa)**
  - **If Y = 200 Pa for a blast wave SPL = 140 dB**

- **Blast mitigation could be used for noise reduction!**
  - Kill the monster while it is "small"
- **TNO Defense, Safety and security core-business!**
  - Protection of ships (internal explosion)
  - Safety of munition storage
  - Large blast measuring experience (Australia, Canada, Sweden)
- **Mitigation knowledge and techniques developed could be used for noise-reduction of open air explosions**

Blast mitigation calculations

- **Calculation of energy distribution of a TNT sphere (55 kg) in air (left) and TNT for 50% surrounded by 114 kg water at 300 mm from charge (right)**

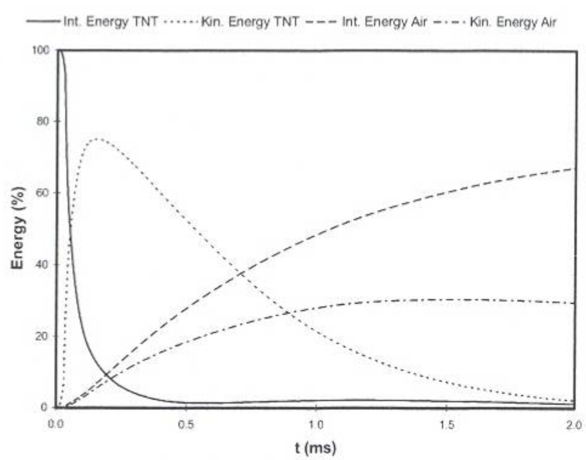


Figure 7 Energy distribution as a function of time for an unobstructed blast wave

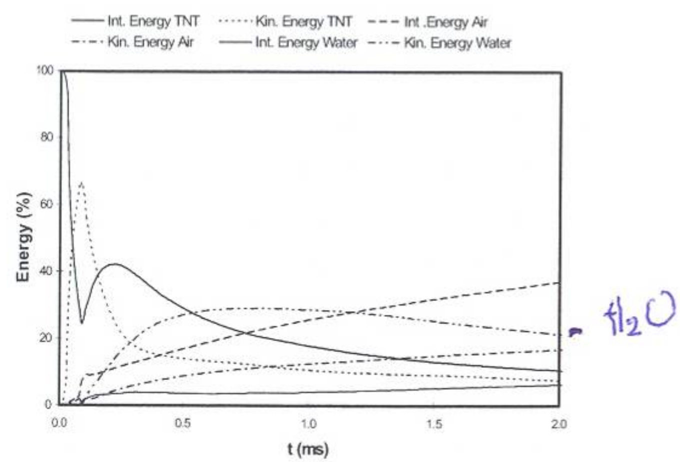


Figure 8 Energy distribution as function of time with water blocks

Conclusion

- There is an overlap between defence research issues and explosive processing of materials
- Unique expertise and equipment is available for EPM research
- There are both examples of spin-in as well as spin-off from defence research

- Both worlds can learn from each other!