Lessons Learned About Pyrotechnic Delays

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“For Want of a Nail…the Kingdom was Lost”

Leaders in the chemistry, physics, and ballistics of energetic devices.
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AVIATION WEEK

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Inside

In Brief

Rocket Fairing Failure Dooms NASA Carbon Monitoring Mission

NASA’s first mission to monitor the effects of humanity’s input of greenhouse gas-causing carbon dioxide was lost Feb. 24 when the payload fairing on its Taurus XL 3110 launcher apparently failed to open about 2 minutes an... seconds into the mission.

The Orbital Carbo... (OCO) and four-sta... solid rocket... ences ... ...ally ...equence ...ftoff from Van... ...ase, Calif.

...age, which Orbital calls the ...,” burned for a nominal 84 sec... ...nds after liftoff, as did the second stage (Orbital’s “first stage”), and separation occurred at 2 minutes and 43 seconds, Launch Director Chuck Dovale said.

A 5-second coast was followed by a successful third stage ignition. The fairing is supposed to separate about 7 seconds after that ignition, but apparently didn’t.

“For th... ...mmunity, it’s a huge ... ...rus Program ... said.

...ol got confirma... ...trical impulses – two ... two redundant – were cor... sequenced to initiate the separa... ...ion and that there were “good power” readings.

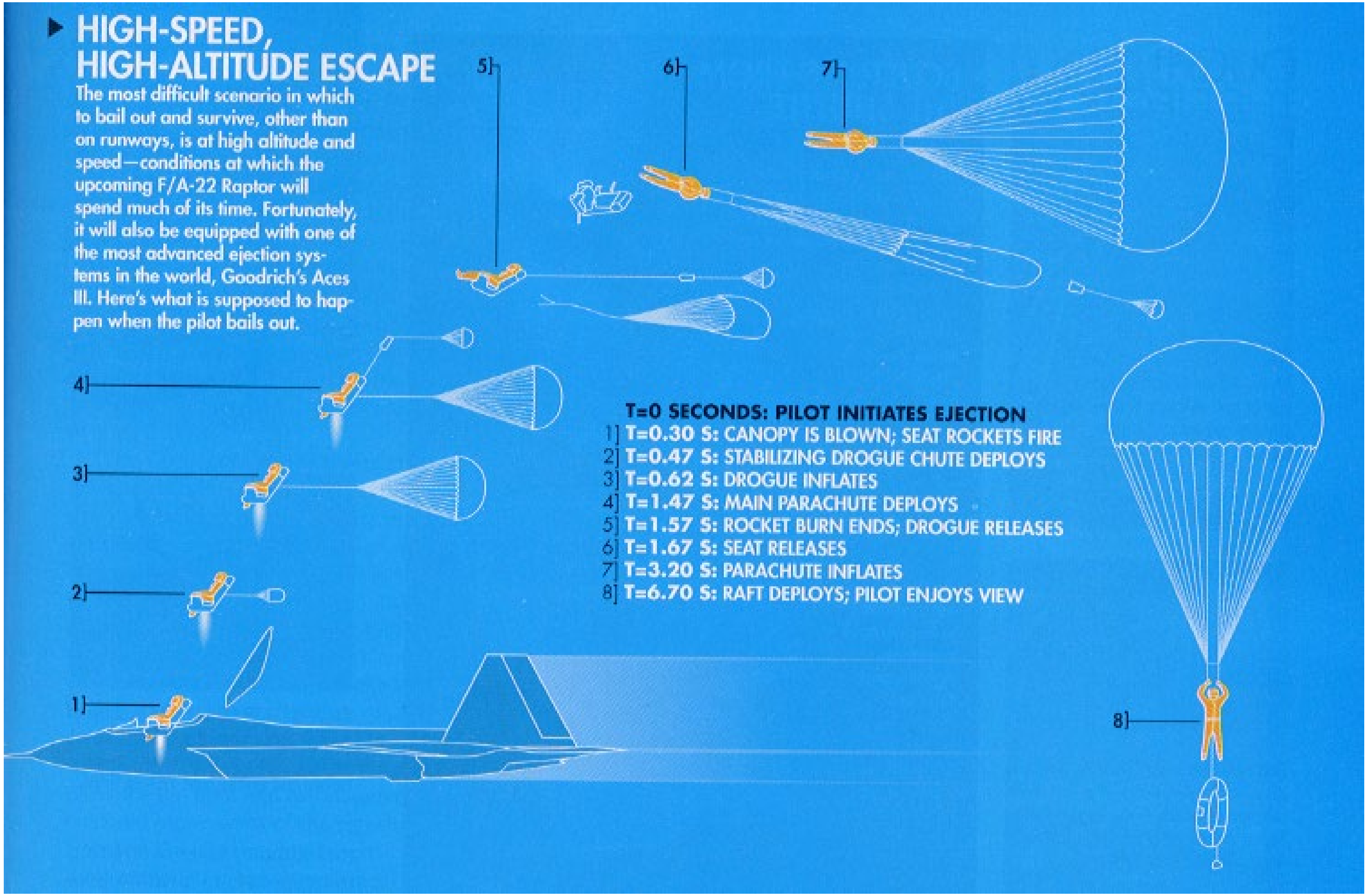
But three minutes into the flight, telemetry gave two indications there was no separation: temperature readings were off and wires that should have broken with the separation didn’t. The failure was confirmed when flight control did not notice a jump in acceleration in the third stage, which would have occurred had the heavy fairing properly separated, Brunschwyler said.

“The initial indication is that [the fair-

Rocket Failure, Page 2

Cost of Failure: $273.4M

CADs: At the Heart of Today's Aircrew Escape Systems



Popular Science
Oct 2003

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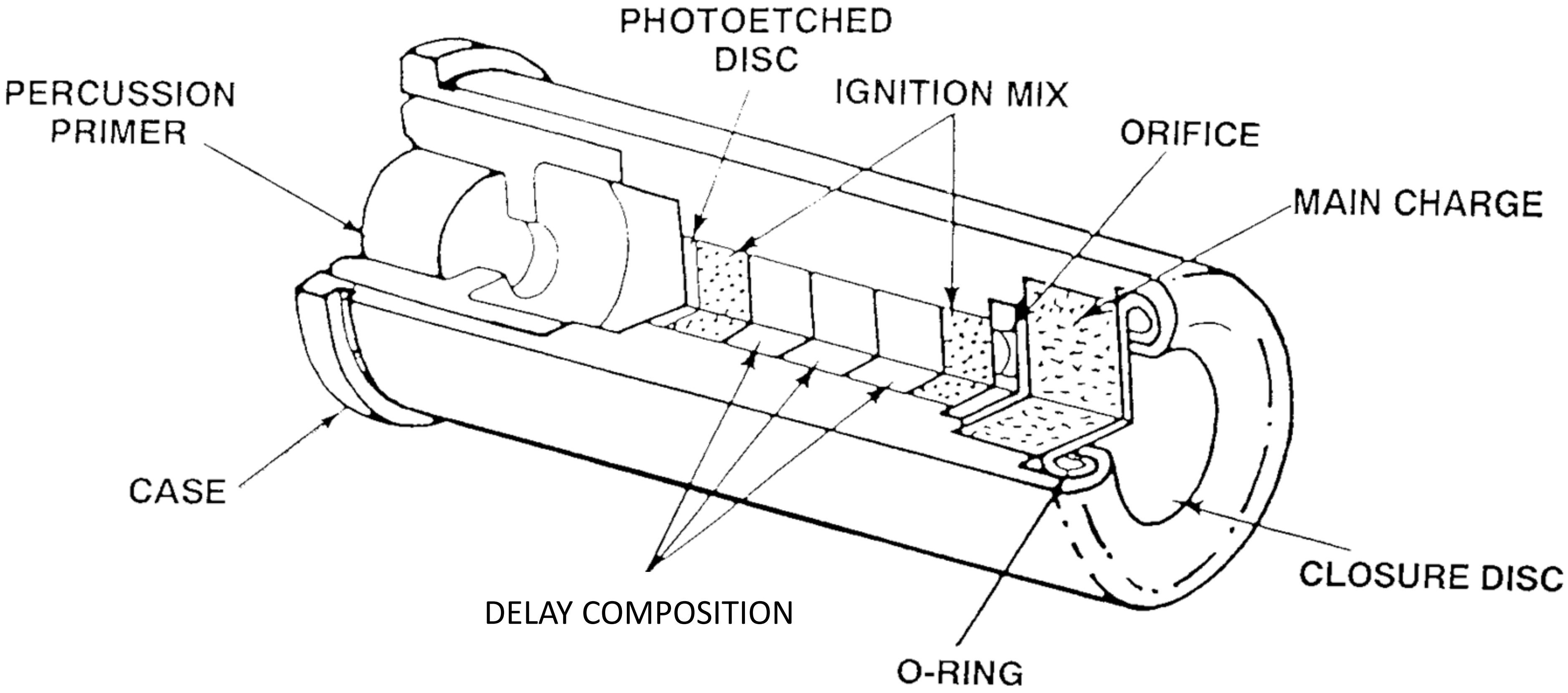
Typical Design of a Pyro Delay Cartridge



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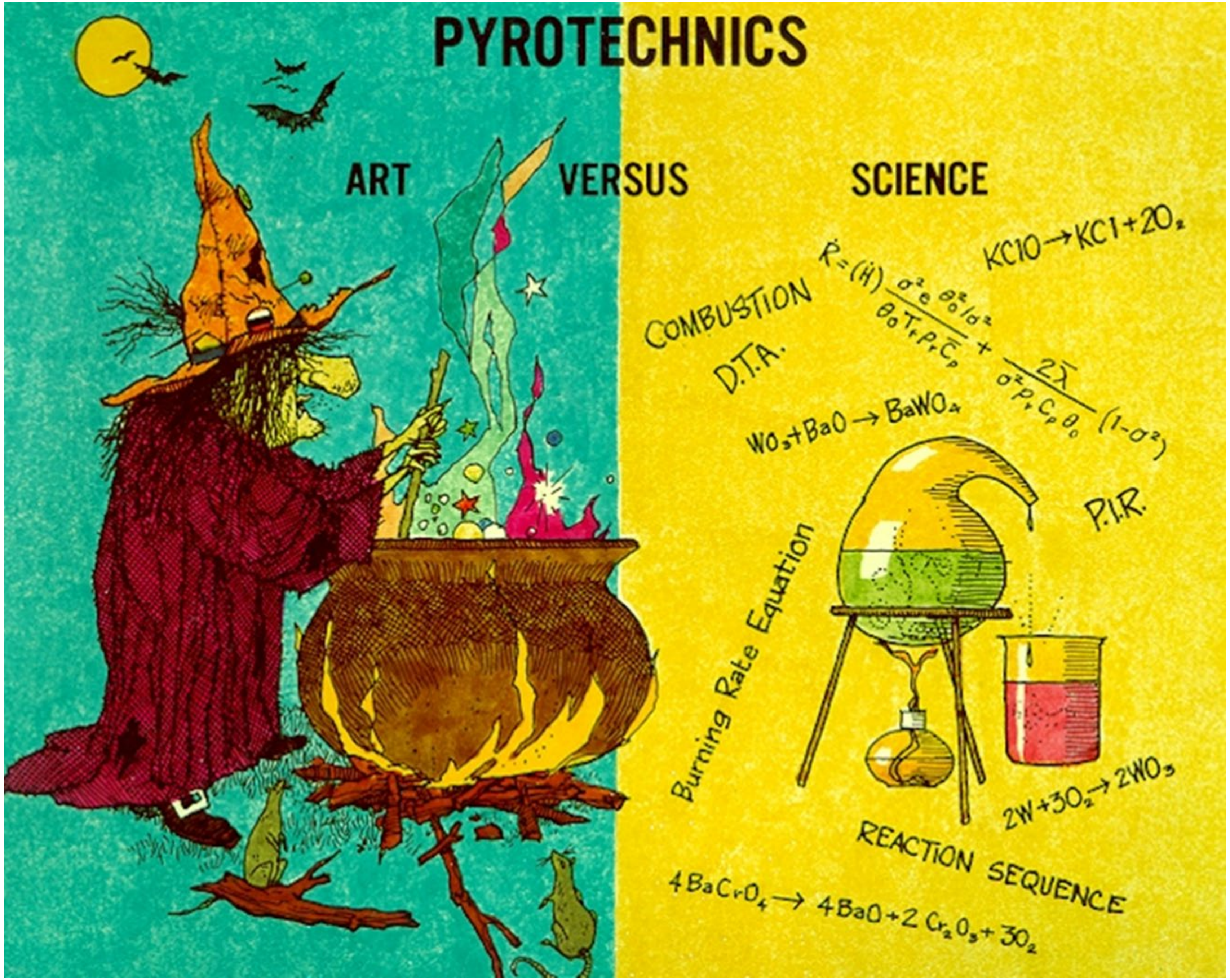


Commonly Used Navy Pyro Delay Systems

Tungsten Delay Compositions, MIL-T-23132

- W, $BaCrO_4$, $KClO_4$, SiO_2

Manganese Delay (D-16) Compositions, MIL-M-21388

- Mn, $BaCrO_4$, PbO_4

Boron Delay (T-10) Compositions, MIL-D-85306

- B, $BaCrO_4$

Zr-Ni Alloy Delay Compositions, MIL-D-85866

- Zr-Ni (I), Zr-Ni (II), $BaCrO_4$, $KClO_4$

Observed Delay Related Problems

- Delay time variability, high Coefficient of Variation
- Occasional out of population short delay times
- Occasional out of population long delay times
- Inter-incremental separation, quenching, propagation failures
- Wrong selection of target mean delay time (and unexpected shifts)
- Workmanship/Quality/Lack of Process Control
- Poor delay column or increment strength, consolidation characteristics
- Contamination of hardware, from loading tooling, or in delay composition
- Loading of delay or ignition increments out of proper sequence
- Change in delay time over short time periods
- Poor long term delay time stability (aging)
- Lot to lot differences in ingredient performance
- Etc.

Tungsten Metal Powder

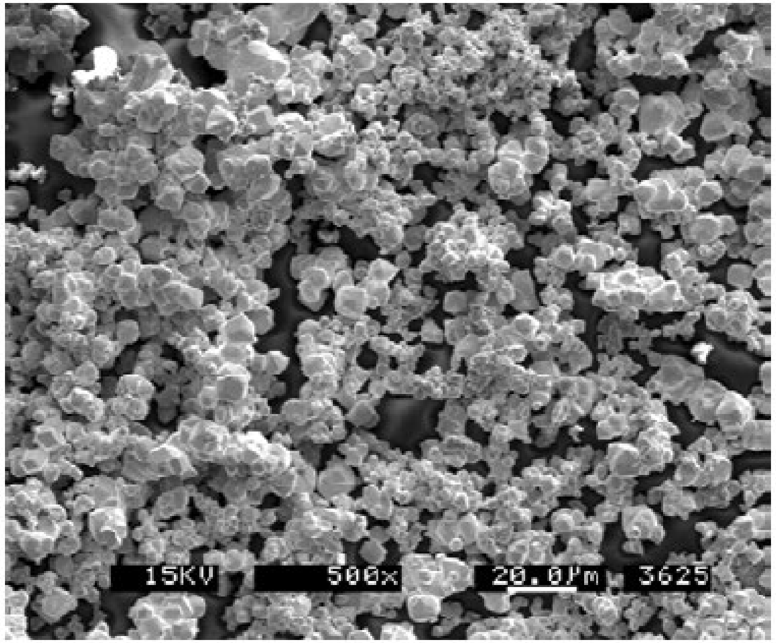


Figure 1(a) - Morphology of as-received tungsten powder observed by SEM, revealing the agglomerate structure.

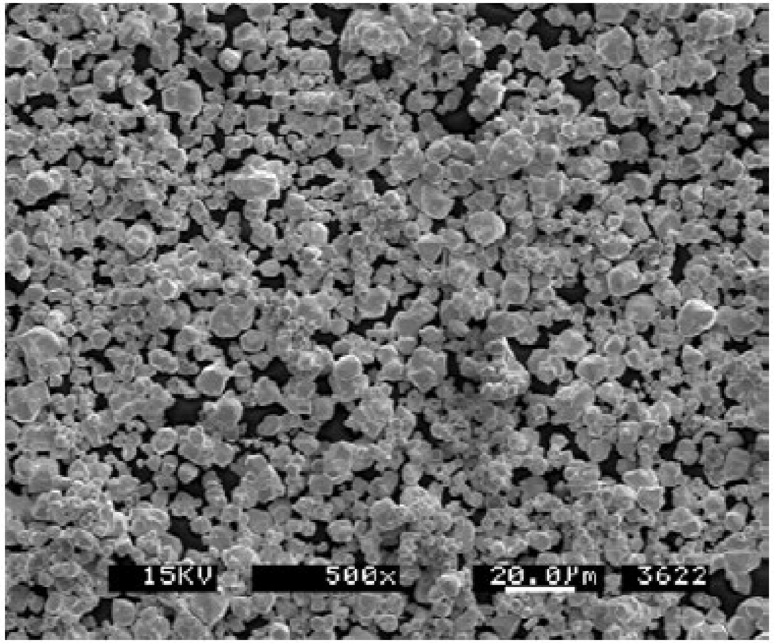
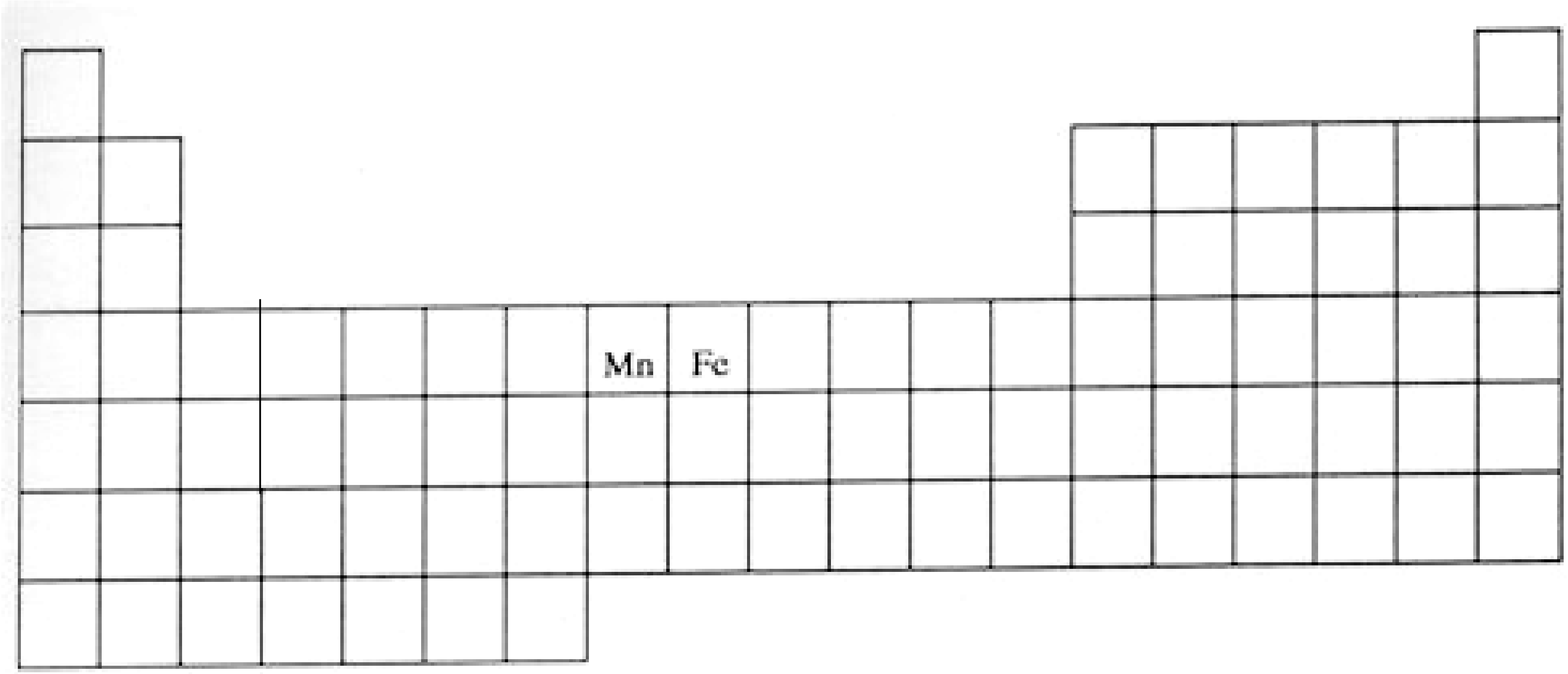


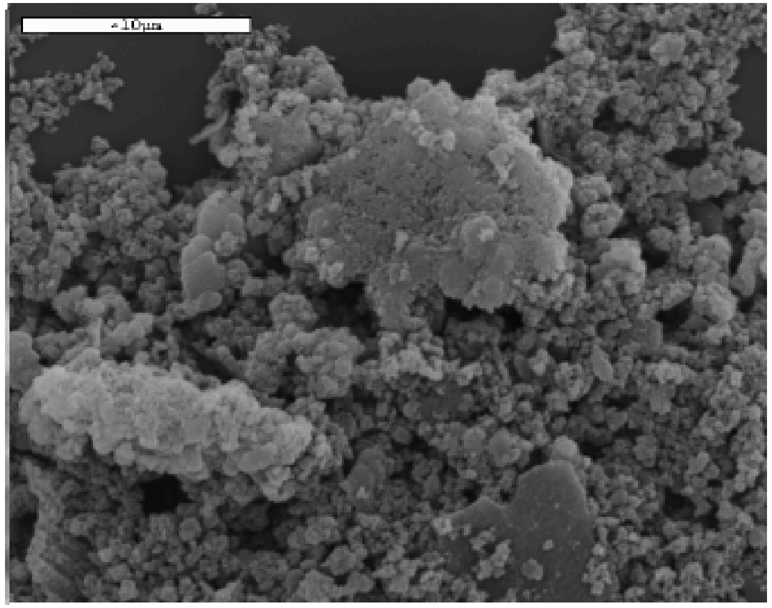
Figure 1(b) - Morphology of rod-milled tungsten powder observed by SEM, revealing the presence of a deagglomerated powder.

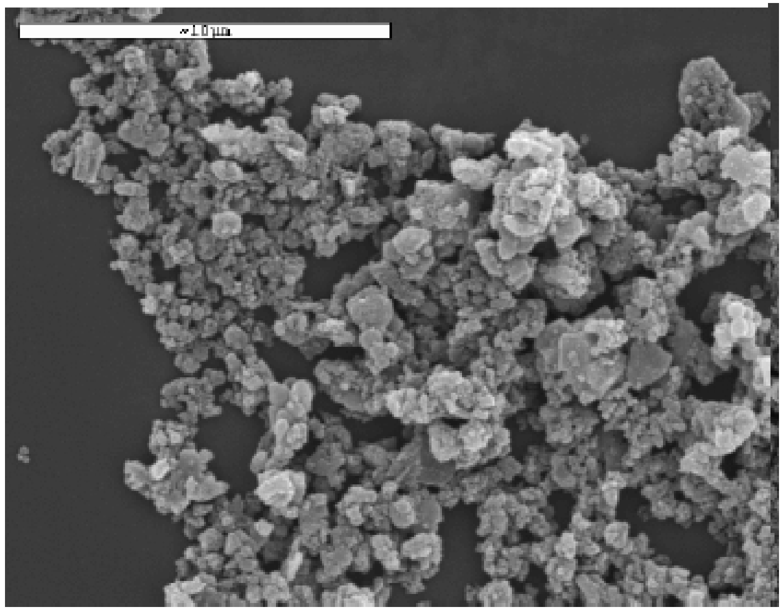
Chemical Properties of Manganese Metal



Manganese tends to easily oxidize, like Iron, and requires surface protection to remain chemically stable

Washing the Boron





Oxygen analyses indicates clearly the presence of oxygen containing compounds (HxByOz) on the surface of boron. Boron powder when exposed to moisture tends to hydrolyze forming boric acids and/or oxides. This oxygen containing compounds can be easily removed by dissolution in methanol.

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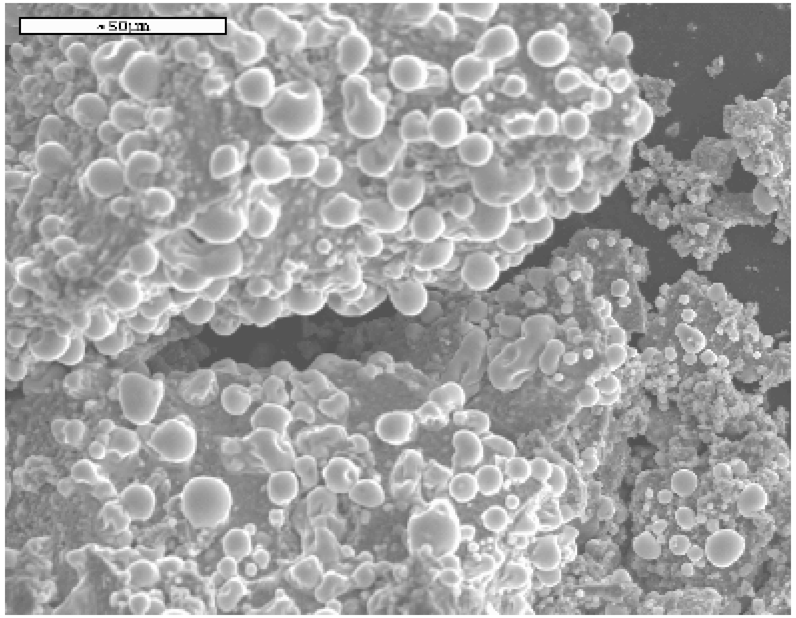
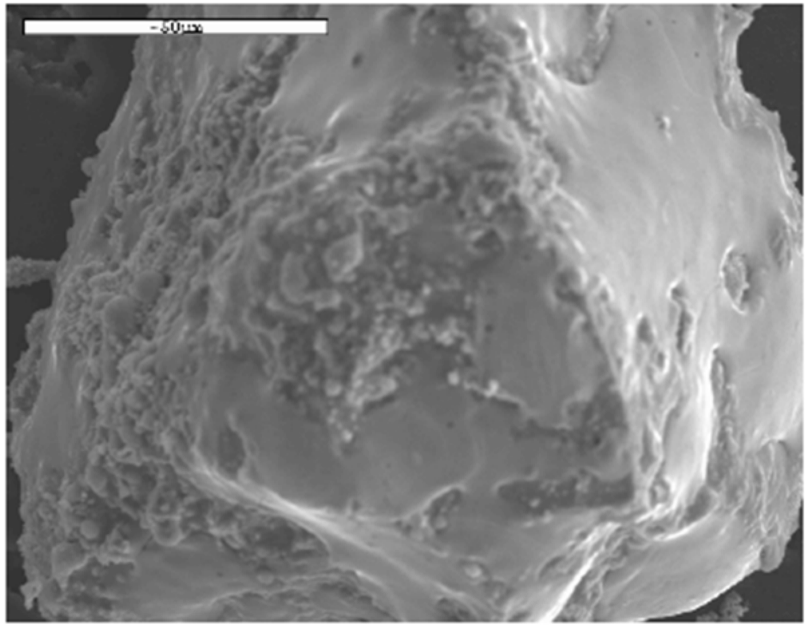
Barium Chromate



"Bad"



"Good"

BaCrO4 lots (used in a 4.5% boron mix). "Bad" barium chromate did not load well while the "good" barium chromate did. Both lots (from different suppliers) met the barium chromate spec.

Diatomaceous Earth

SEM image of selected
Diatomaceous earth aggregates

The Facts of Life About Ingredient Specs

- Most ingredient specs are based on “off the shelf” materials which were available 30-50 years ago
- Nearly all original suppliers are no longer providing those ingredients
- Environmental, safety and economic issues result in frequent changes in suppliers, sources, and production processes
- Some ingredient lots, although meeting spec, do not perform well in delay comps
- Performance (burn rate, heat output, long term stability, etc.) is often impacted by uncontrolled and/or unknown ingredient impurities

The Challenge: Identify ingredients which both meet the spec AND performs in the pyro mix.

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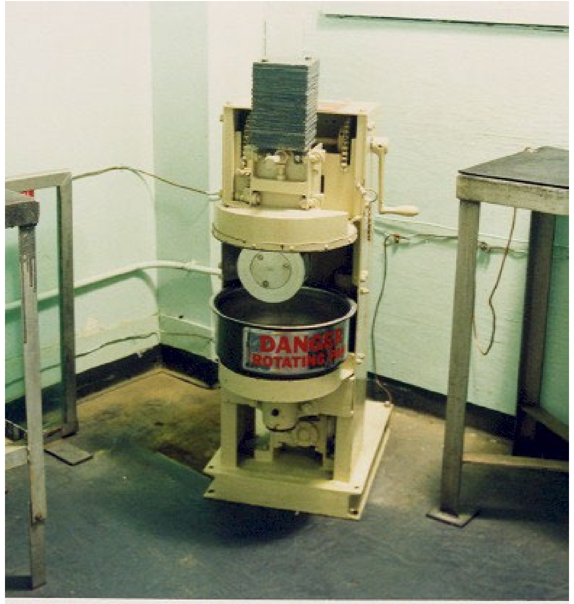
Many Ways to Mix Pyro Delays



- Each method can succeed
- Each method can fail
- Need to optimize/control parameters
- Often uses several processes together

Pyro Delays Are Not "Mixed Like a Cake…"

Tungsten Delay Composition:

- Density of tungsten is **19.25 g/cm^3**
- Density of diatomaceous earth (Superfloss, SiO_2) is **0.25 g/cm^3**

Settling/de-mixing can become a major problem when:

- Over mixing
- Re-blending
- Careless handling
- Shipping

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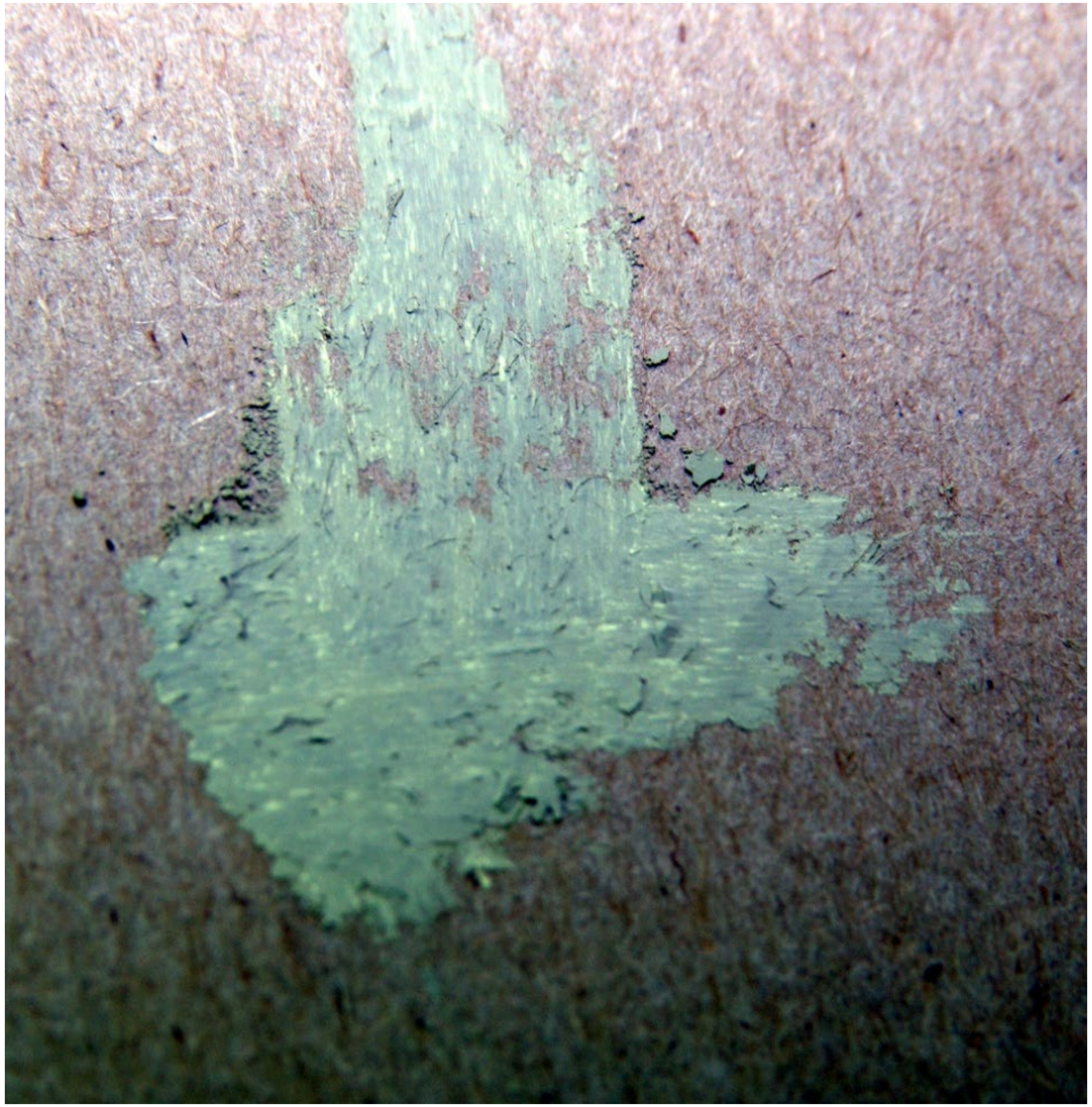
Potential for Settling Isn't Often Called Out In Specs

From the Tungsten Delay Composition Spec – MIL-T-23132:

4.3.2.5 Testing after shipment or prolonged storage. After tungsten delay composition has been properly mixed, it is possible for the fuel and oxidants to segregate under conditions of storage and transportation. Segregation appears to occur near the surface when a delay composition is subjected to prolonged agitation, particularly during shipment by rail.

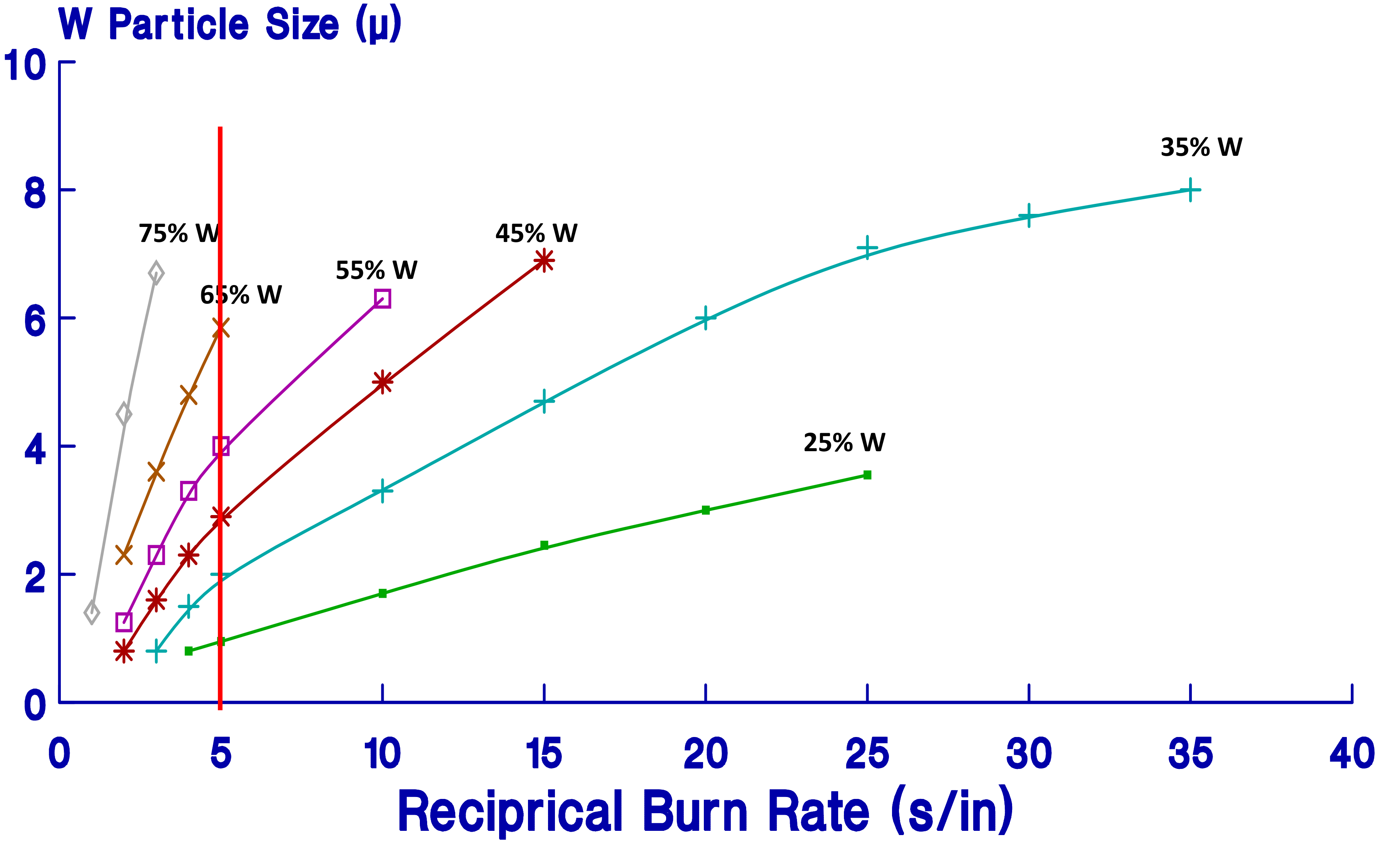
One Solution: Block the composition prior to shipping

Smear Test – For Mixing Evaluation

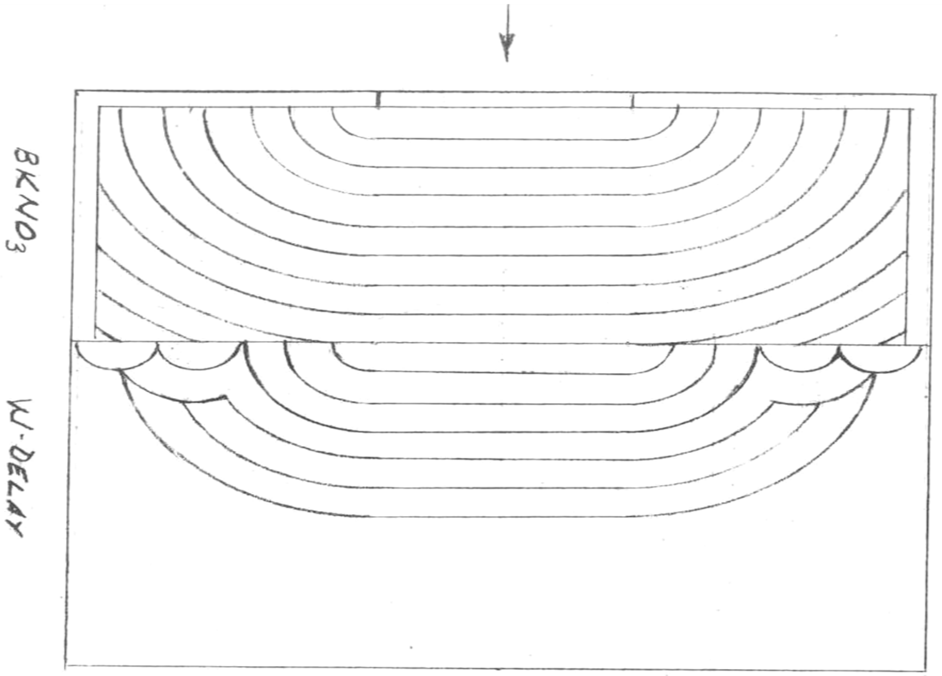


Shown is a B-$BaCrO_4$ delay composition mix (with 3.5% B). Yellow streaks show the presence of larger agglomerates of $BaCrO_4$

Tungsten Delay



Classic Thermal Quenching



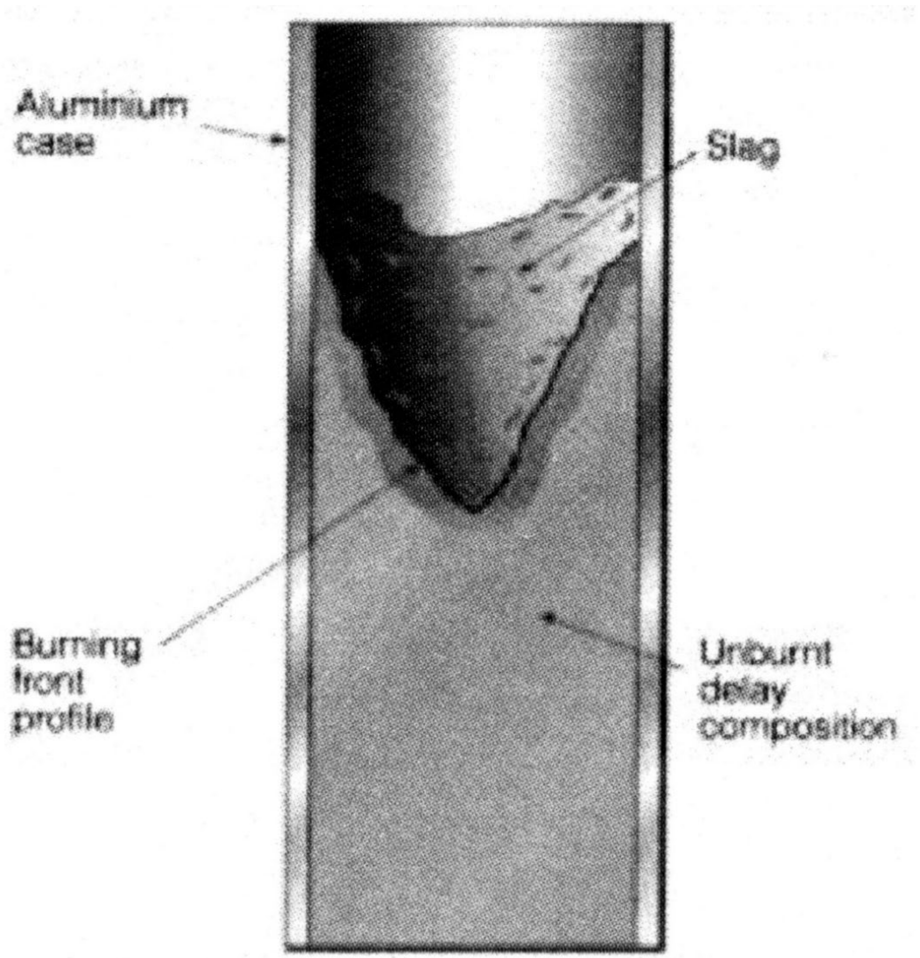
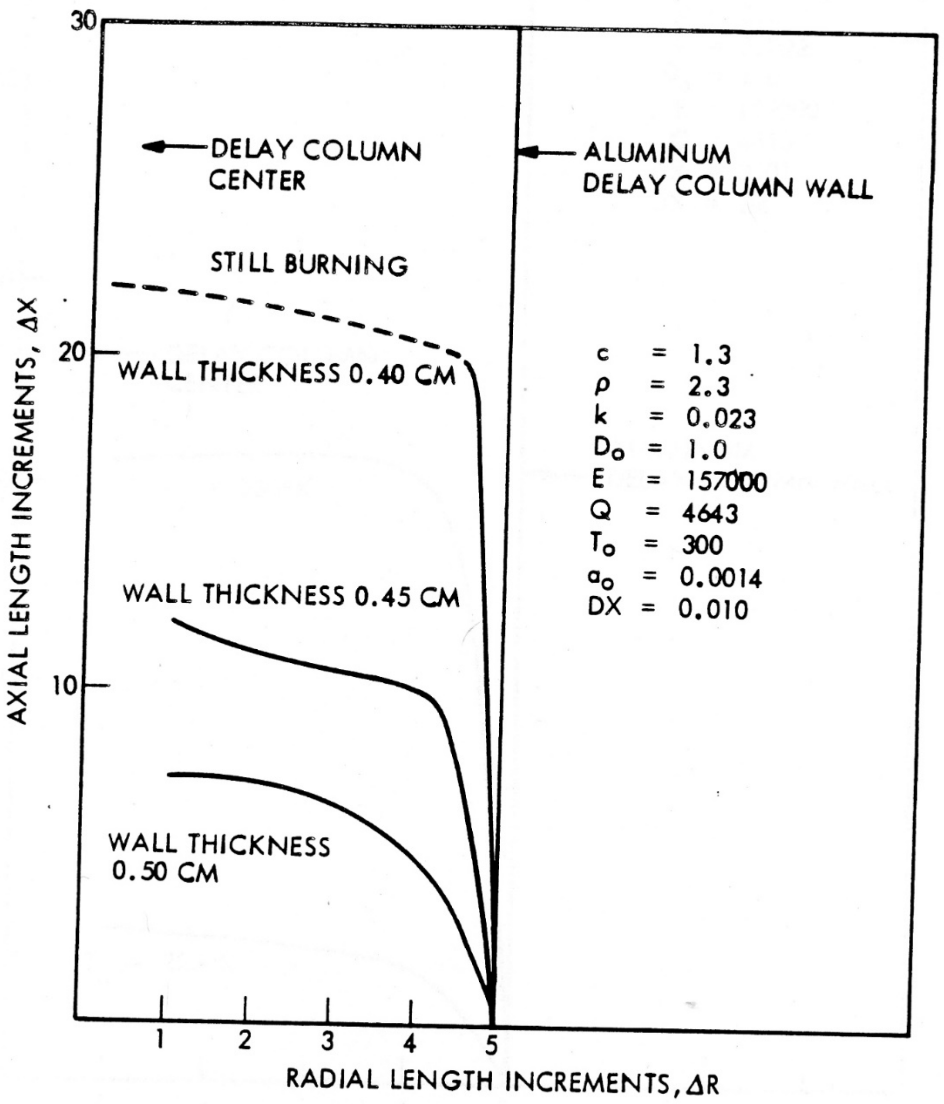


Figure 4. A delay column that has failed due to heat losses.

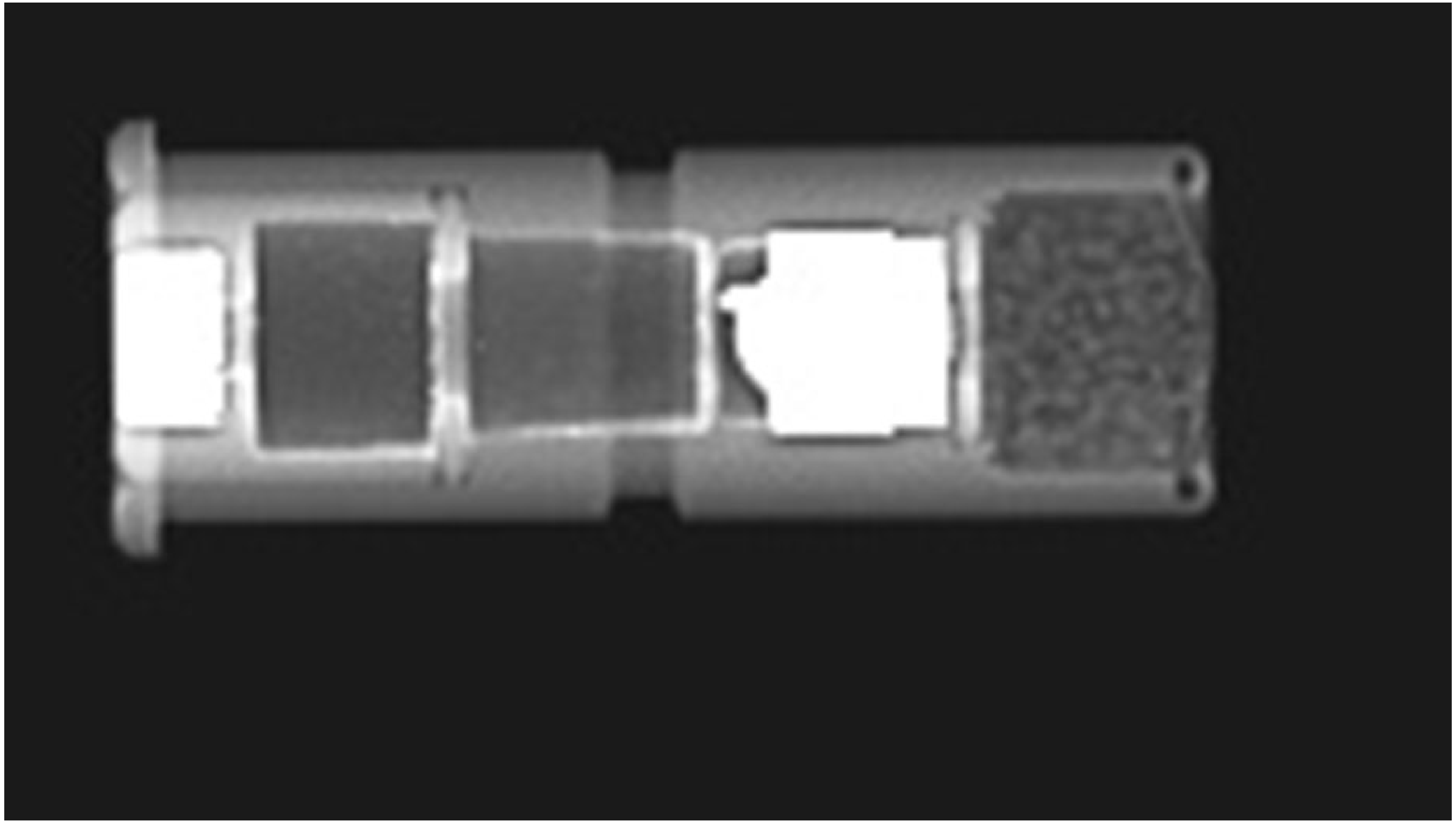
Extinction Distance for Flame Propagation



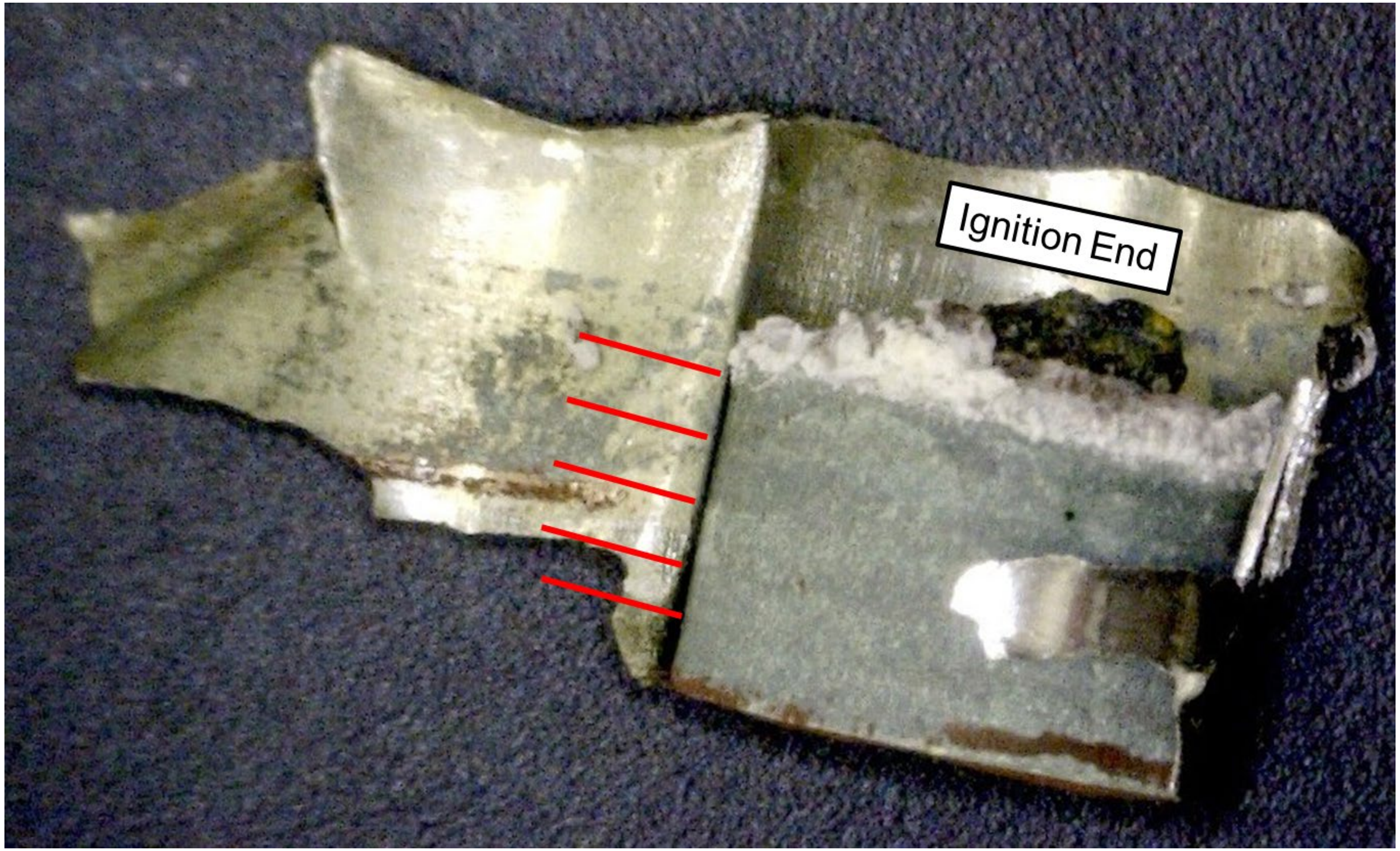
Effect of wall thickness

Hardt, Phung, Valenta – 5th IPS

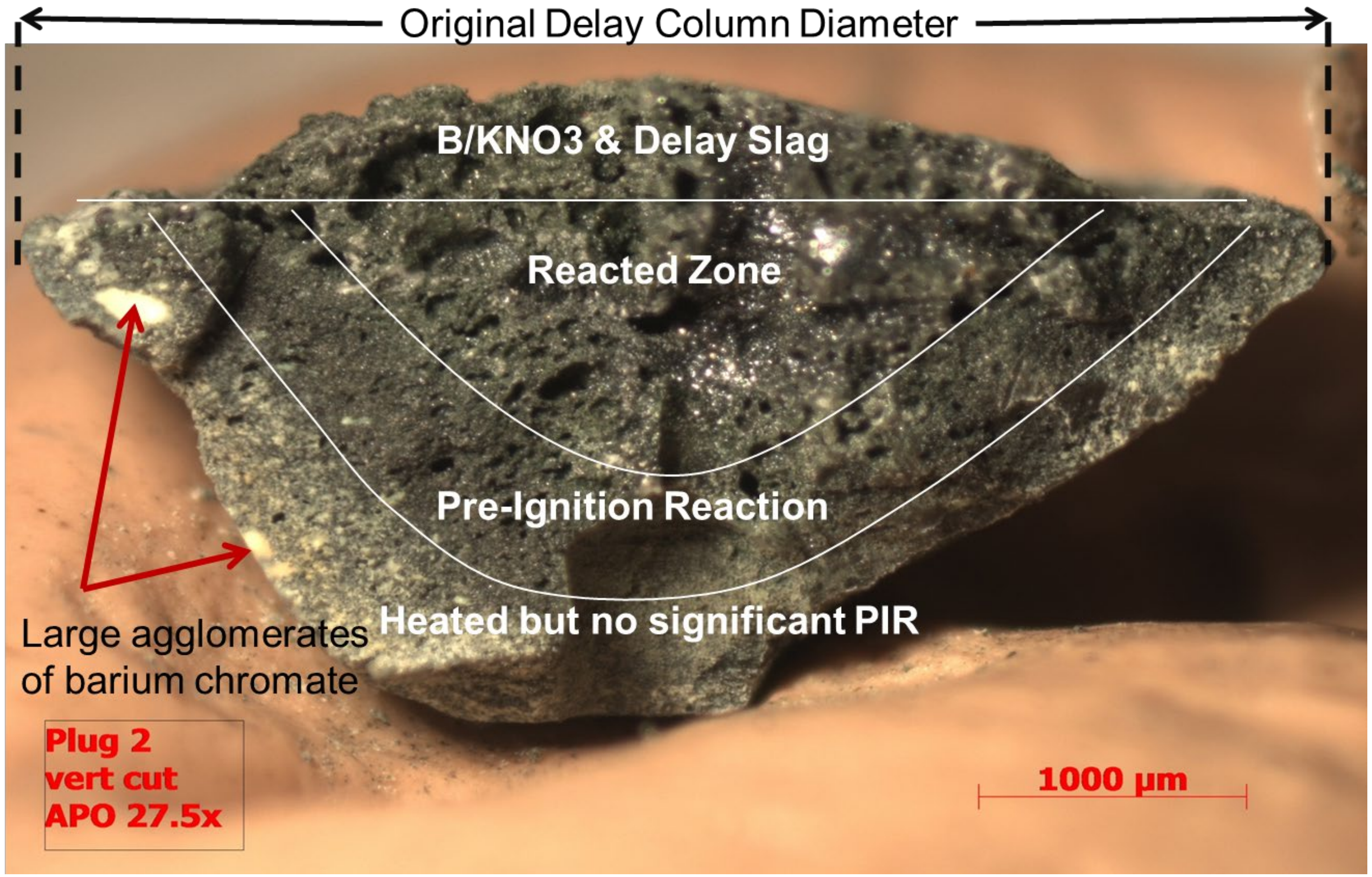
Delay Cartridge: Failure to Function



Disassembly



Sectioning and Analysis of the “Slug”



Reaction Chemistry of W Delay

$KClO_4$ decomposition at 580-600C
$KClO_4 \rightarrow KCl + 2O_2$

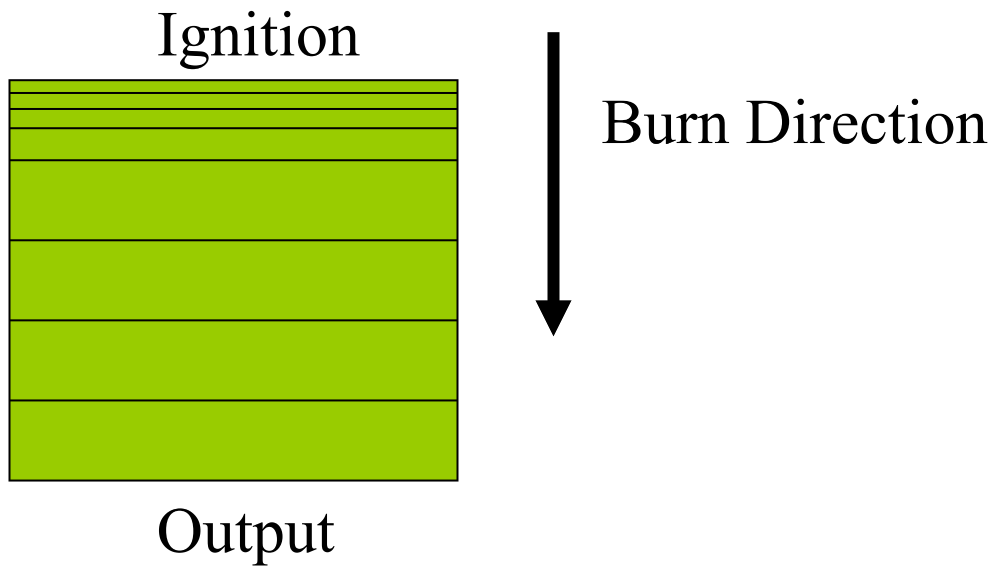
To sustain the reaction, $BaCrO_4$ decomposes at approx. 1400C
$BaCrO_4 \rightarrow 4BaO + 2Cr_2O_3 + 3O_2$

Tungsten reacts with the oxygen to form tungsten trioxide
$2W + 3O_2 \rightarrow 2WO_3$

If over-oxidized, rate controlling step is diffusion of oxygen through the oxide layer on the surface of the tungsten particle

If under-oxidized, burning rate is primarily controlled by heat conductivity of the metal fuel

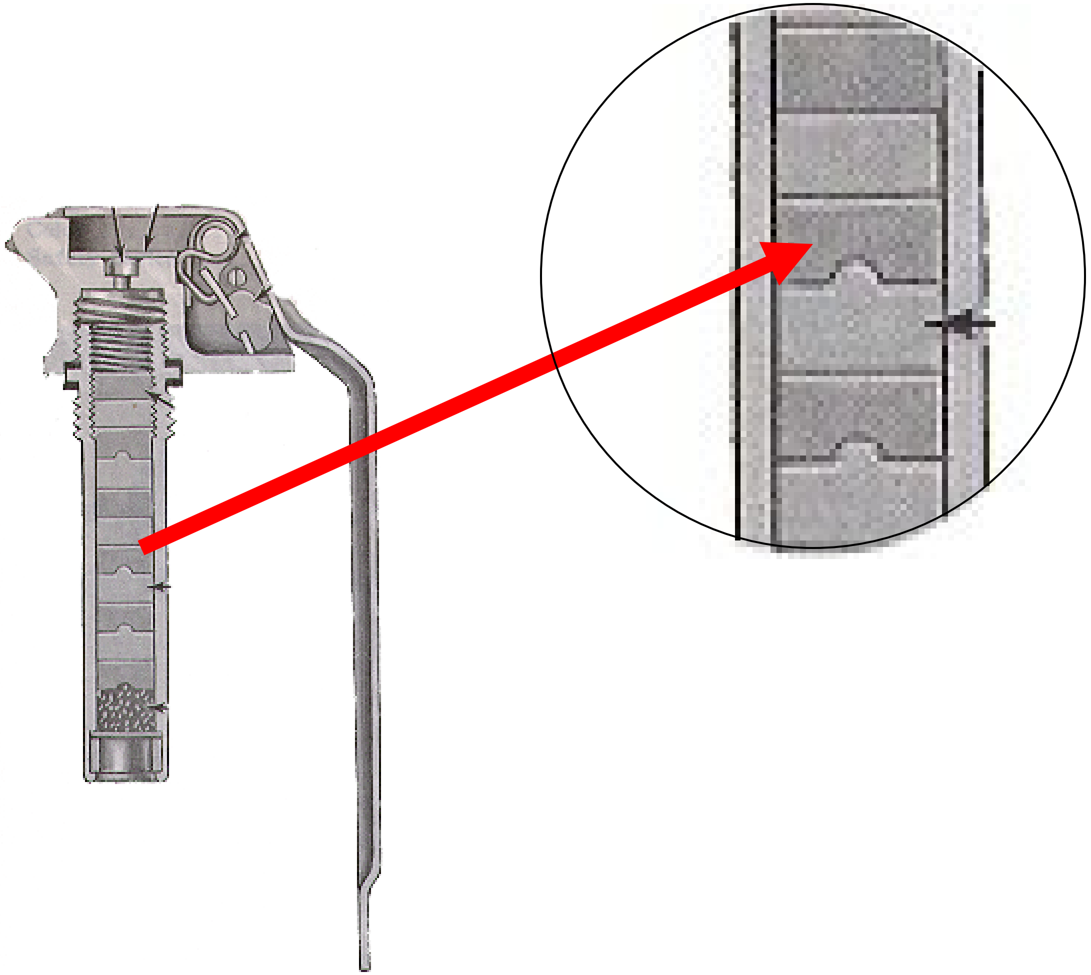
Delay Increment Loading Issue



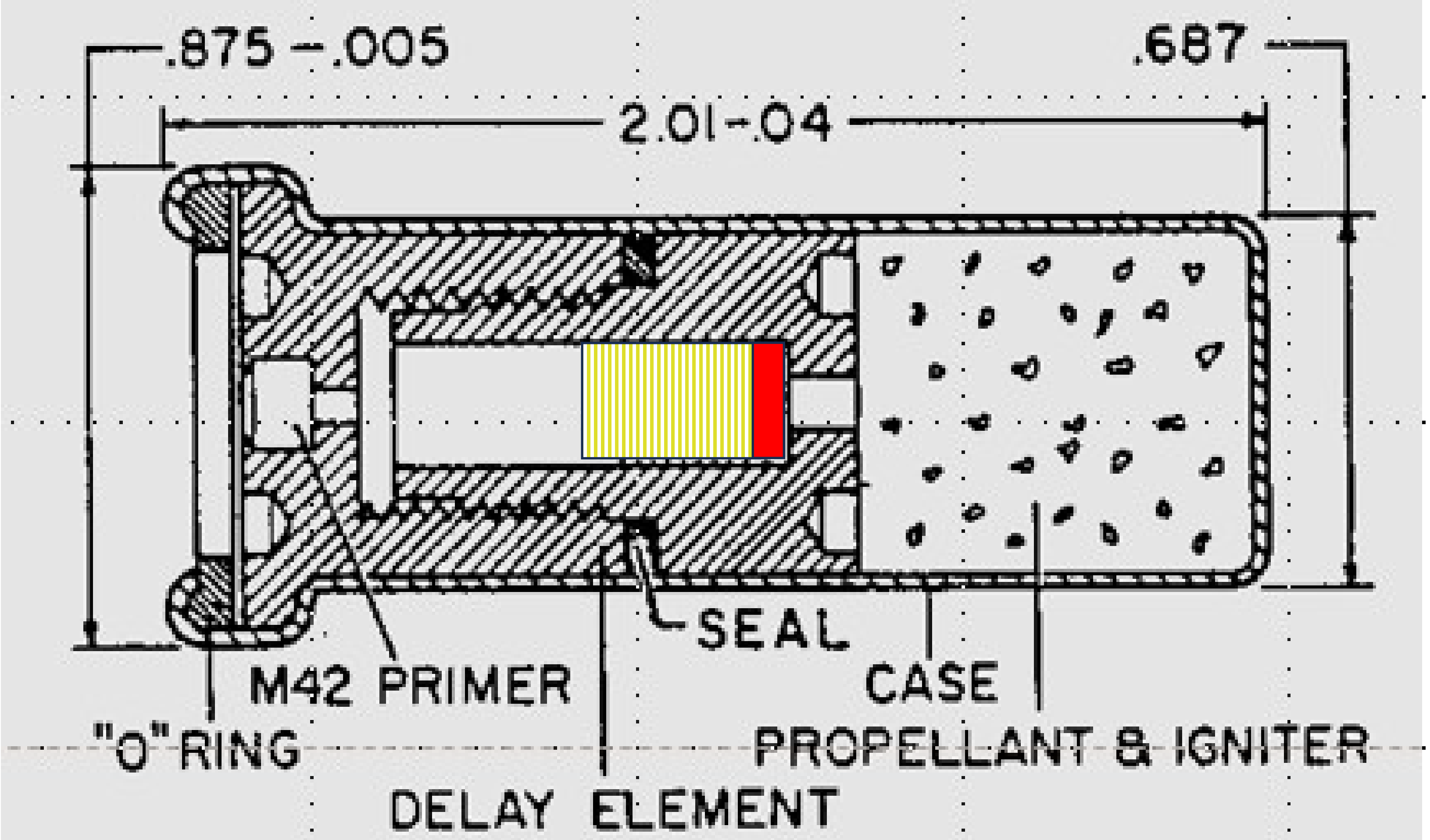
Loading:
- Flat Ram
- 44 ksi
- Scoop
- Load to exact length (± 0.001”)
- Use small final increments, if needed

Assigned Cause: Thin initial thin increment likely broke up and did not maintain sufficient contact with next increment to assure propagation.

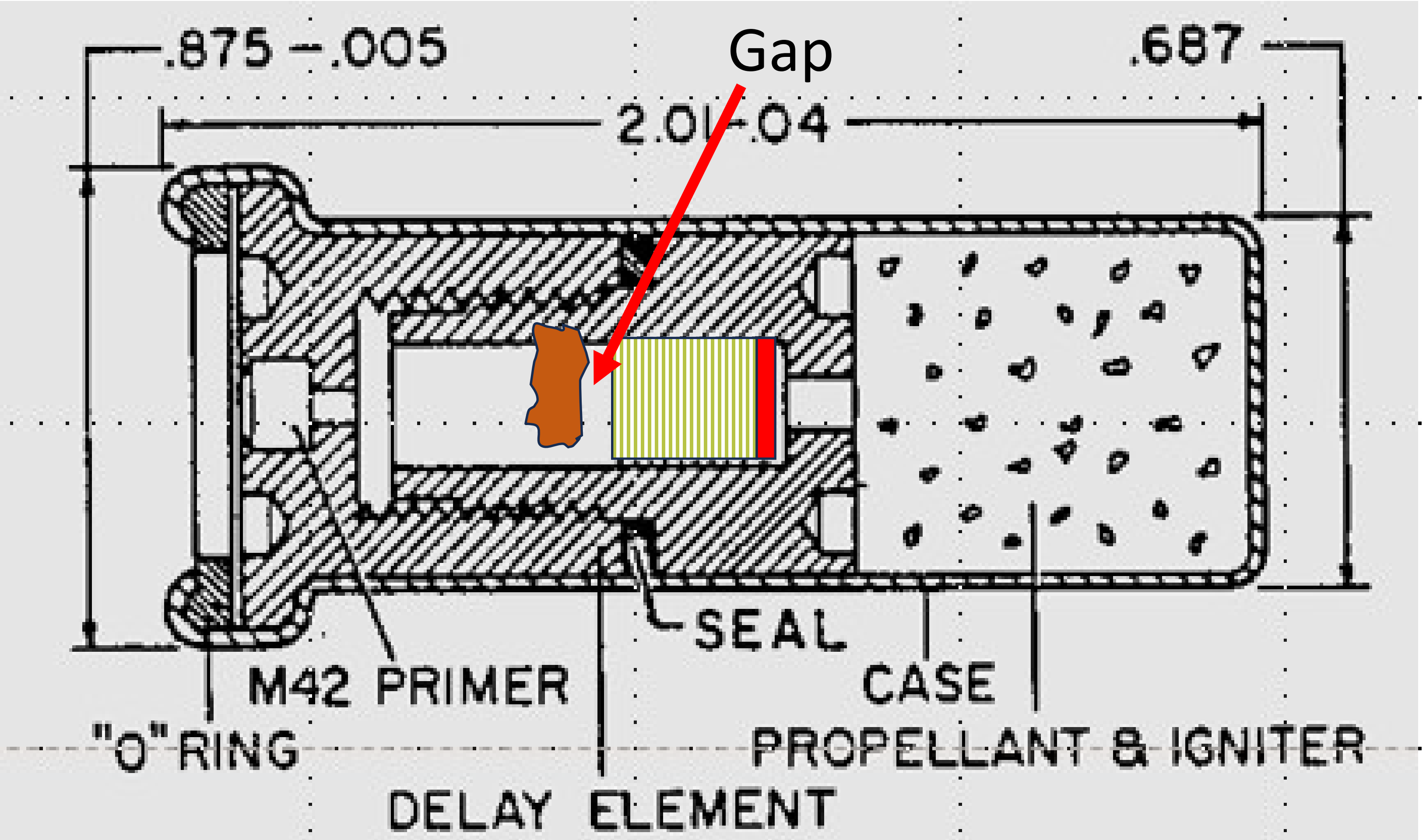
Nested Delay Increments Using a Step Ram



Zr-Ni Comp Delay Failure (Dud)



Post Firing

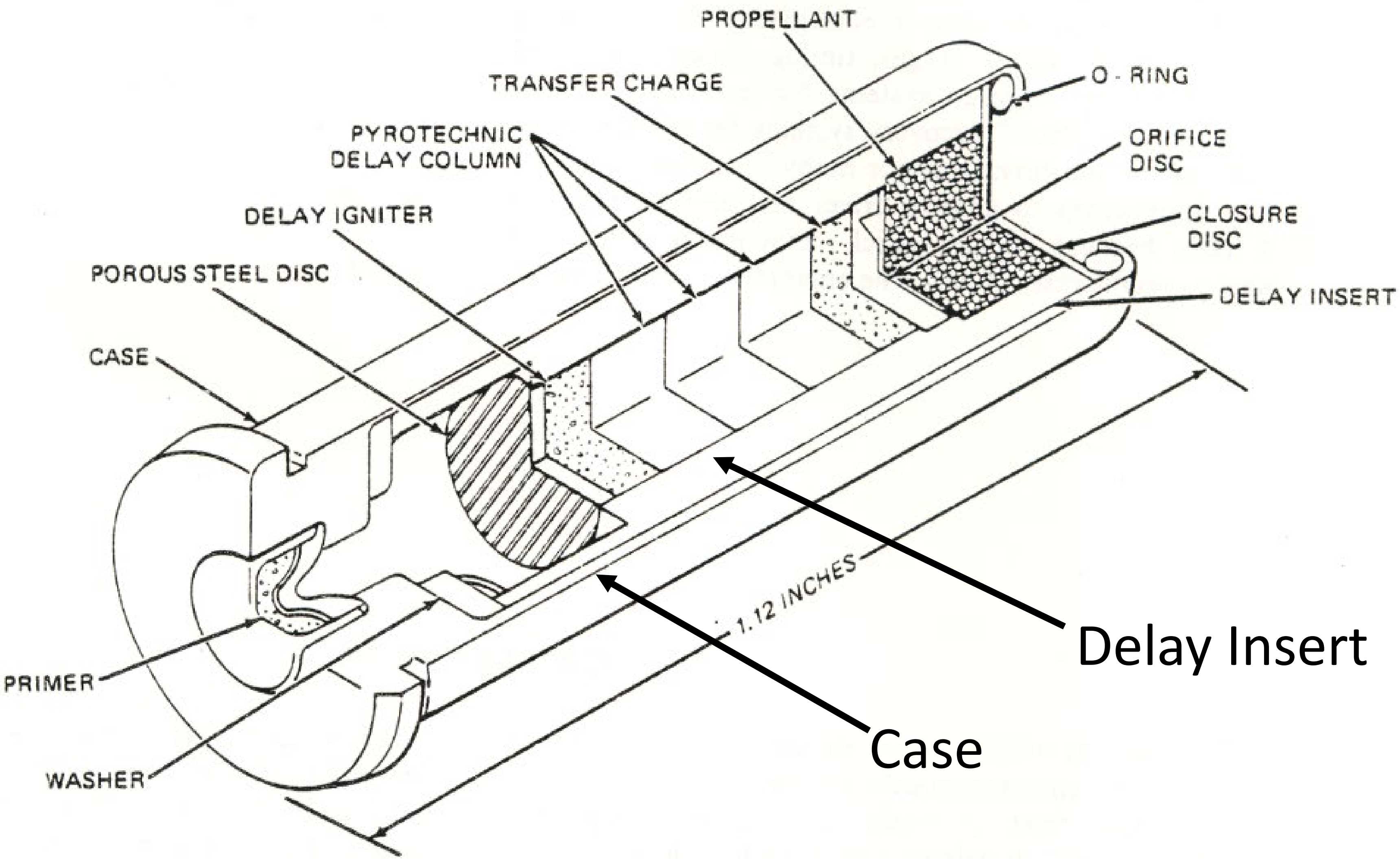


.875 -.005
Gap
.687
2.01-.04
SEAL
M42 PRIMER
CASE
"O" RING
PROPELLANT & IGNITER
DELAY ELEMENT

Possible Causes

- Insufficient thermal output, of primer or delay increment
- Too high density at increment interface, affecting ignitibility and gas flow
- Contamination of sidewall with output charge during loading
- Expansion/contraction causing movement of displaced increment during burn
- Too high loading pressure (glazed increment) – too hard to ignite
- Too low loading pressure (reacted increment) – too soft to retain position
- List could go on and on…

Design Problem



Concluding Remarks

- Pyro delays, because of their low cost, simplicity, and high reliability, will continue to be a critical part of many military systems for the foreseeable future. They will continue to be a critical “nail” in many systems.
- The CAD/PAD community needs to maintain technical competence in this area.
- Unlike propellants and explosives, the knowledge base for pyro delay has not expanded much since the 1960’s. What we learn today generally comes out of trying to understand what went wrong.
- Pyro delays will likely continue to present challenges – ingredients and processes will change, safety and environmental regulations will increase, memories will fade and expertise will be lost.