Studies on Composition and Manufacturing Process for 5.56mm Tracer Ammunition

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Overview

- Determine levels for a factor study for ternary tracer composition changes
- Technical Challenges:
  - Weak Test
  - Unknown reaction stability outside “production limits”
  - Must keep cost of experimentation to minimum (repeat experiments not allowed)
  - Minimize production interruption for experiments
  - Difficult to control production process variables simultaneously (as in a lab)
- Approach:
  - Software tools to screen before empirical high-cost work
  - After screening, increase chances to yield high quality datasets the first time through DOE execution:
    - Materials Preparations
    - Manufacturing Samples
    - Testing
    - Analysis
- Application to Product Performance

Background

- Study planned that would vary composition of a ternary tracer mixture
- Desire to understand fundamental material performance differences with changes in chemical composition

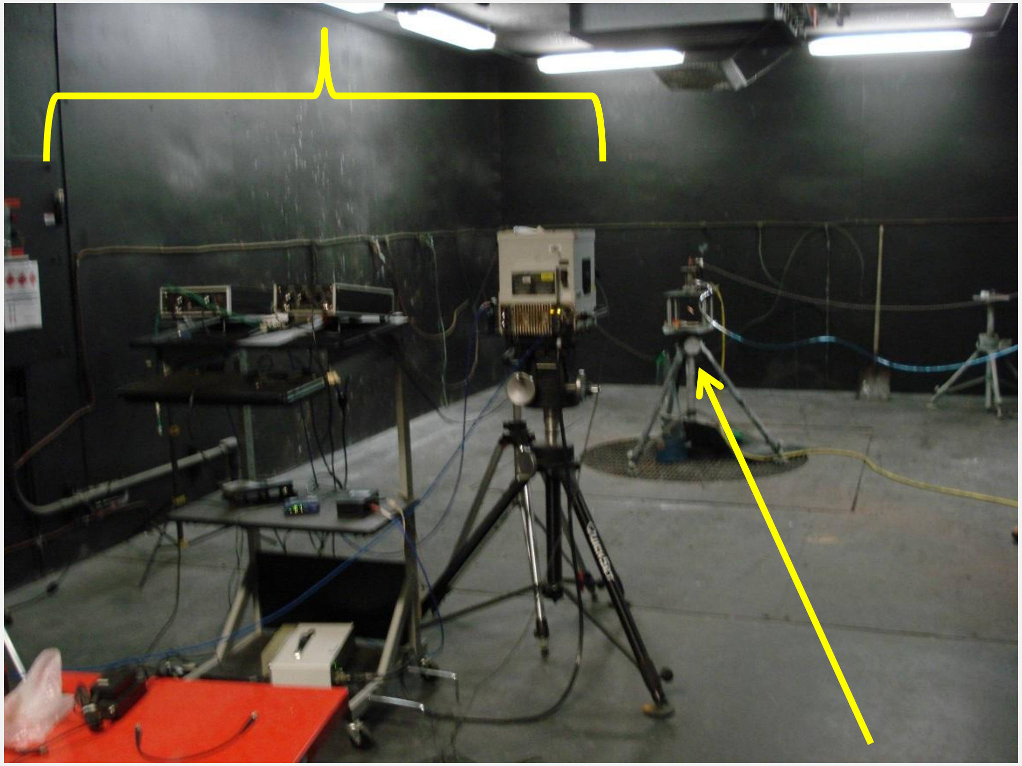
Composition Feature / function	Ammunition Performance Observed	Objective measurement approach
Color	Visual observation at times red-orange-white	Photopic and scotopic for wavelength
Intensity / output	Visual observation at times may be "blinker" "dim" or "none"	Integral intensity
Burn Time	Visual observation variable/dependent with distance traveled	Burn Time and rate by instruments at fixed distance

Production Environment

Static Lab Environment

High instrumentation for experiments in lab environment

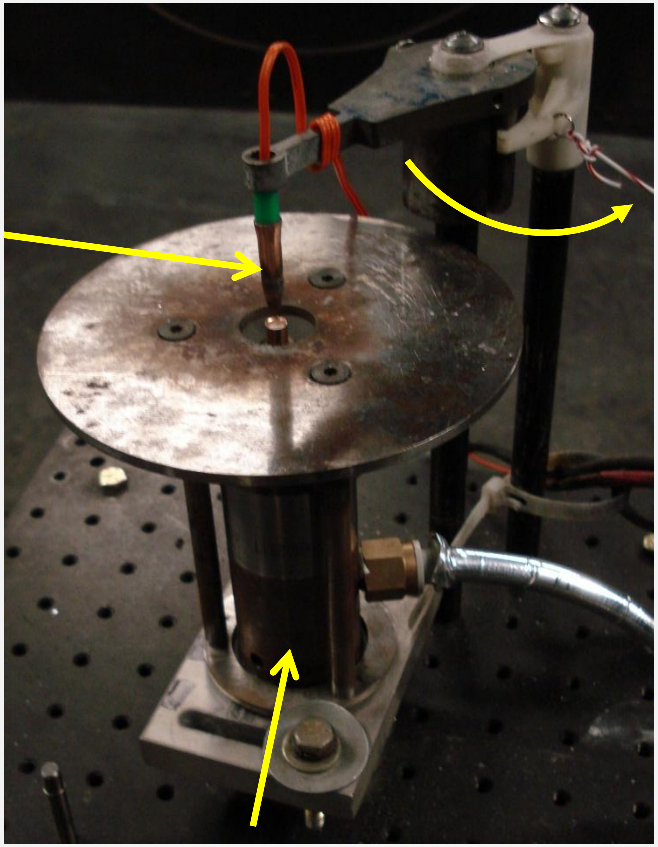
Instrumentation
and sensor cluster



Sample holder / bullet spinner

Bullet Spinner Apparatus

Ignition by electronically fired match with a special orifice to direct the effluent



Igniter arm swings out of the way after triggering ignition

Air motor spins bullet

Design of Experiments Test Plan Details

Sr Nitrate	Mg	PVC
0	0	0
+	-	0
-	+	0
+	0	-
-	0	+
0	+	-
0	-	+

- **What level to set the factors?**
  - Show a detectable difference (level high)
  - In practice, the burn needs to be stable (not too high)
- Knowing / hypothesizing:
  - Magnesium content affects temperature
  - Temperature affects product species
  - Product species affects color and intensity
  - Temperature affects burn rate / total time
  - Projectile spin and temperature affects product species, mass transport and heat conduction rates
  - Among others… complicated system

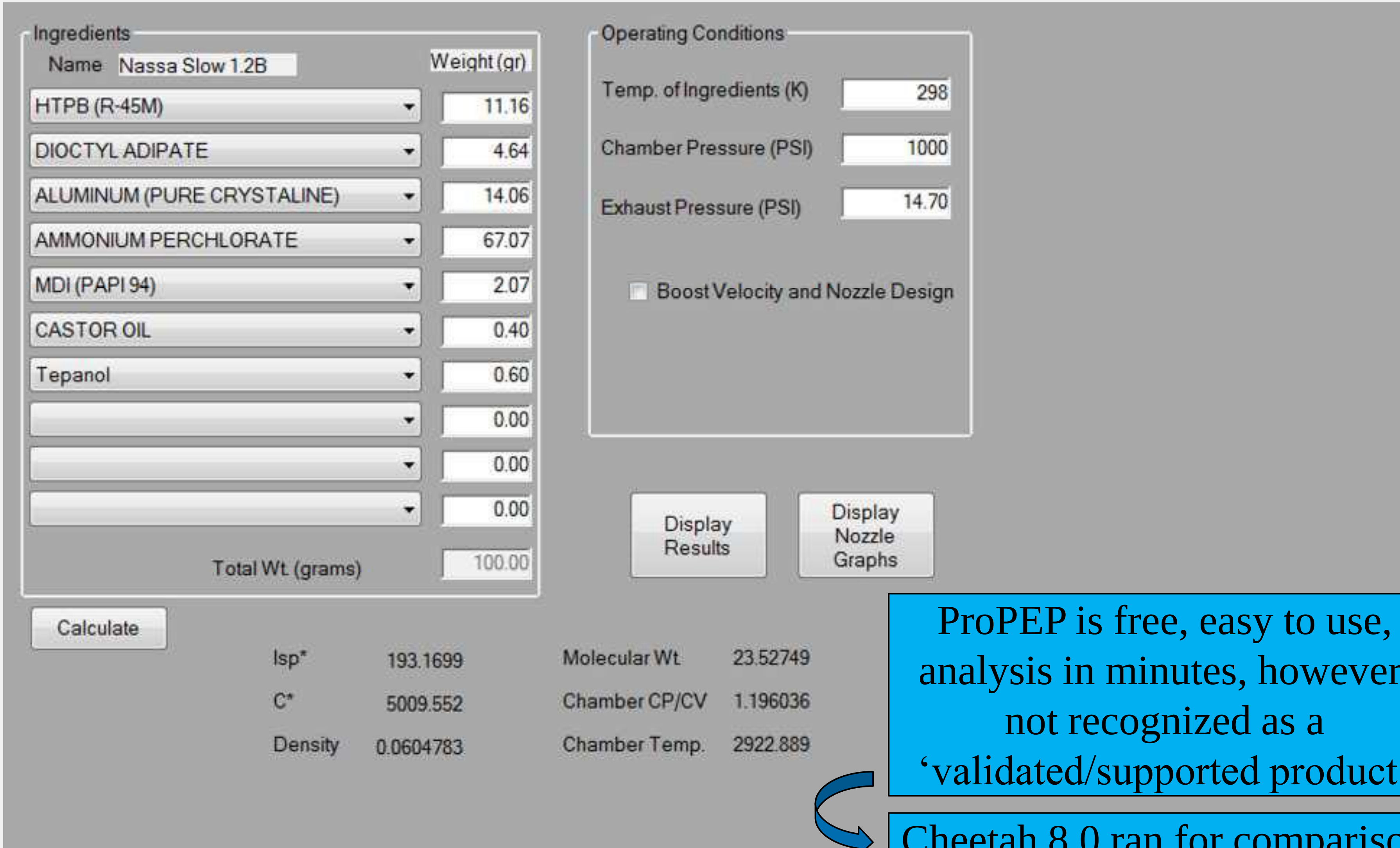
Problem Statement

- High purity RED color comes from SrCl• formation (630nm, Kosanke)
- Assumed that $SrCl_2$ was also SrCl• during reaction event
- Red-orange color is partially due to SrOH formation (610nm, Kosanke)
- Other negative species include Sr(s), SrO(s), among others, result in color shift and broad spectral emissions, depending on type
- White (multispectral) color is due to both magnesium reaction products and high temperature that drives unfavorable reactions

So we can make use of the chemical equilibrium simulation to estimate the quantity and quality of RED by tracking:

1) Predicted flame temperature
2) Predicted preferred photon species (SrCl• + $SrCl_2$)
3) Predicted negative photon species (SrOH, and assuming Mg is equally detrimental chemically, and its contributions are effectively included in temperature)

ProPEP 3.0 useful for solid→gas phase thermochemical equilibrium



ProPEP is free, easy to use, analysis in minutes, however, not recognized as a 'validated/supported product'

Cheetah 8.0 ran for comparison

ProPEP DOE Runs and Outputs Using +/-1%, +/- 3%, +/- 5% Composition Levels

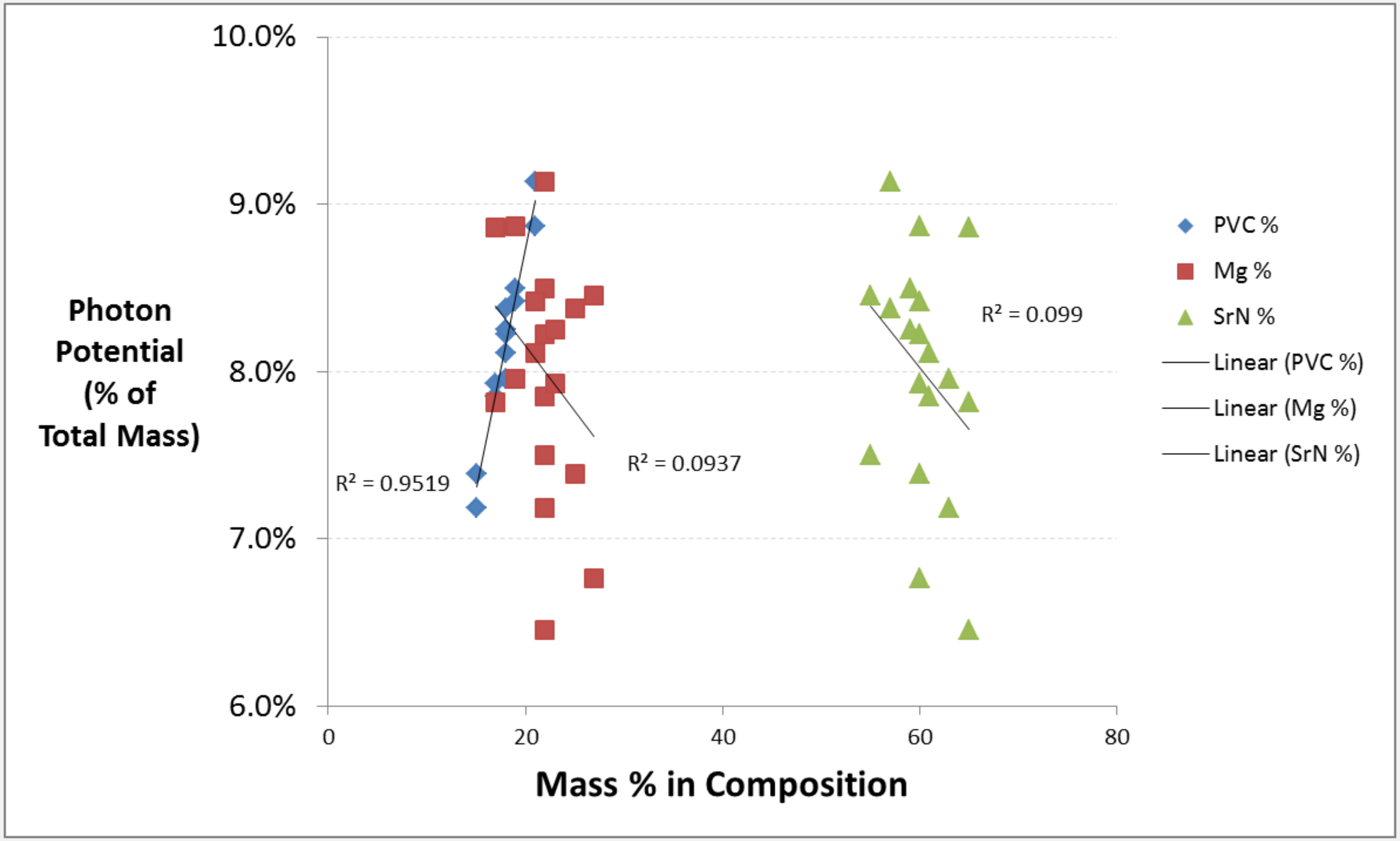
Inputs			Responses				
SrN %	Mg %	PVC %	Temp (F)	SrCl•	SrCl2	SrOH•	SrCl• + SrCl2
60	22	18	5535	1.4%	6.9%	0.8%	8.2%
59	23	18	5497	1.5%	6.7%	0.7%	8.3%
61	21	18	5559	1.2%	6.9%	0.7%	8.1%
61	22	17	5655	1.3%	6.5%	0.8%	7.9%
59	22	19	5408	1.4%	7.1%	0.7%	8.5%
60	21	19	5442	1.3%	7.2%	0.7%	8.4%
60	23	17	5627	1.5%	6.5%	0.8%	7.9%
57	25	18	5371	1.8%	6.6%	0.7%	8.4%
63	19	18	5568	0.9%	7.0%	0.7%	8.0%
63	22	15	5863	1.2%	6.0%	0.9%	7.2%
57	22	21	5137	1.5%	7.6%	0.5%	9.1%
60	19	21	5245	1.1%	7.8%	0.5%	8.9%
60	25	15	5804	1.6%	5.8%	1.0%	7.4%
55	27	18	5166	2.0%	6.4%	0.5%	8.5%
65	17	18	5528	0.7%	7.1%	0.5%	7.8%
65	22	13	6009	1.0%	5.5%	0.9%	6.5%
55	22	23	5122	0.2%	7.3%	0.5%	7.5%
65	17	23	5138	0.7%	8.2%	0.4%	8.9%
60	27	13	5975	1.7%	5.0%	1.1%	6.8%

+/-1% level

+/-3% level

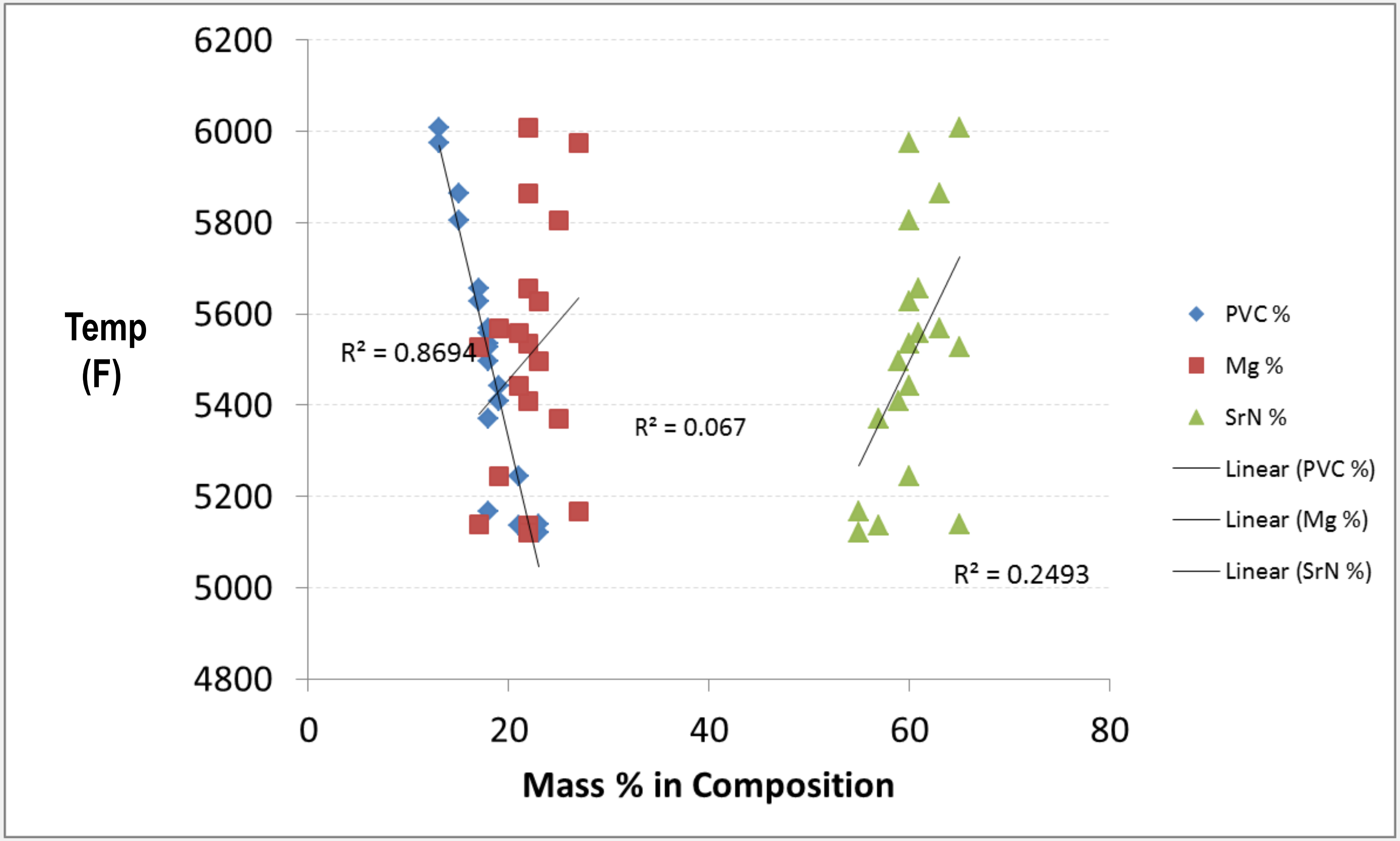
+/-5% level

Trends in Preferred Red Species via Simulation



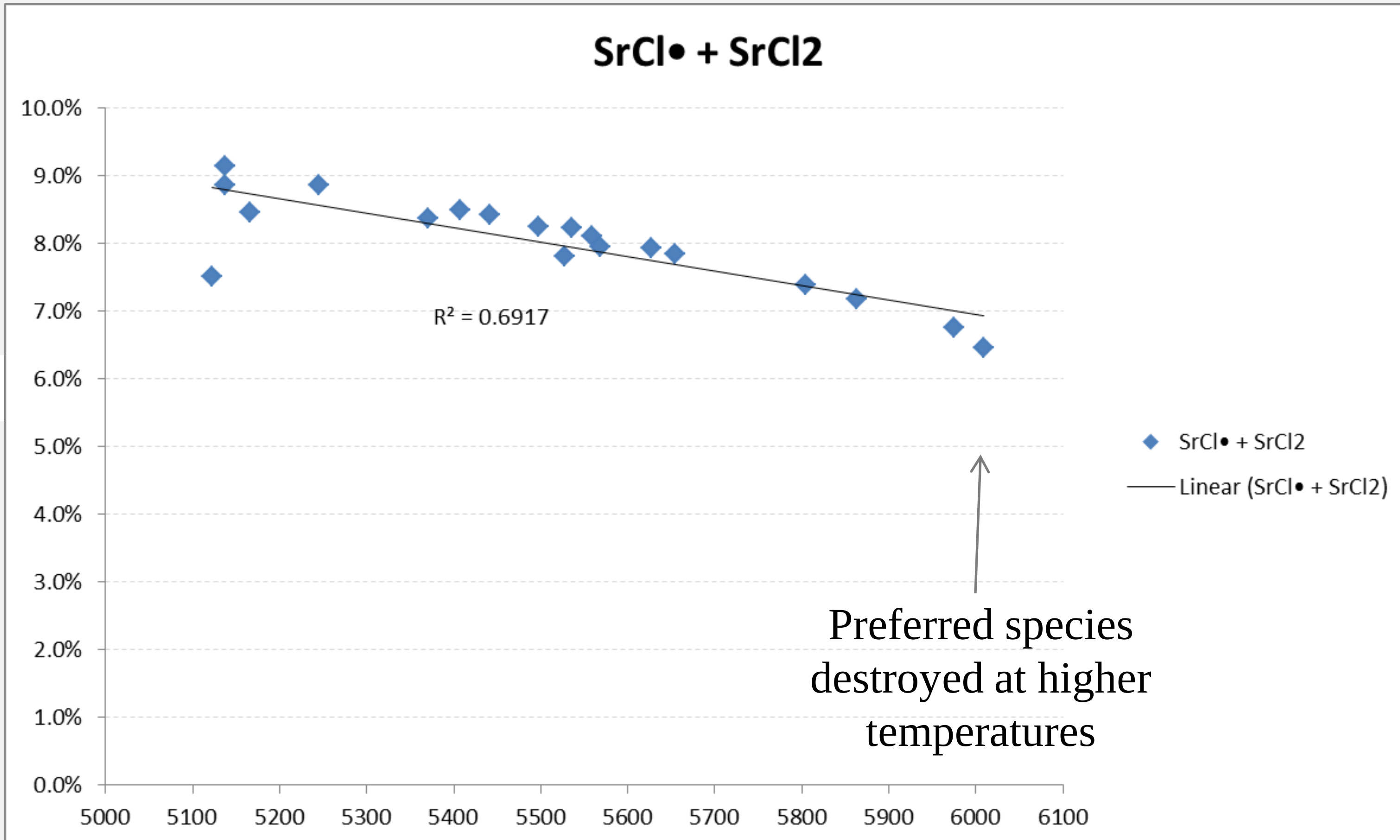
Increased chlorine (PVC) correlates to increased favorable species generated, makes sense as PVC is a limiting reactant

Trends in Temperature via Simulation



PVC % composition extreme from 13% to 23% composition swings temperature nearly 1000F

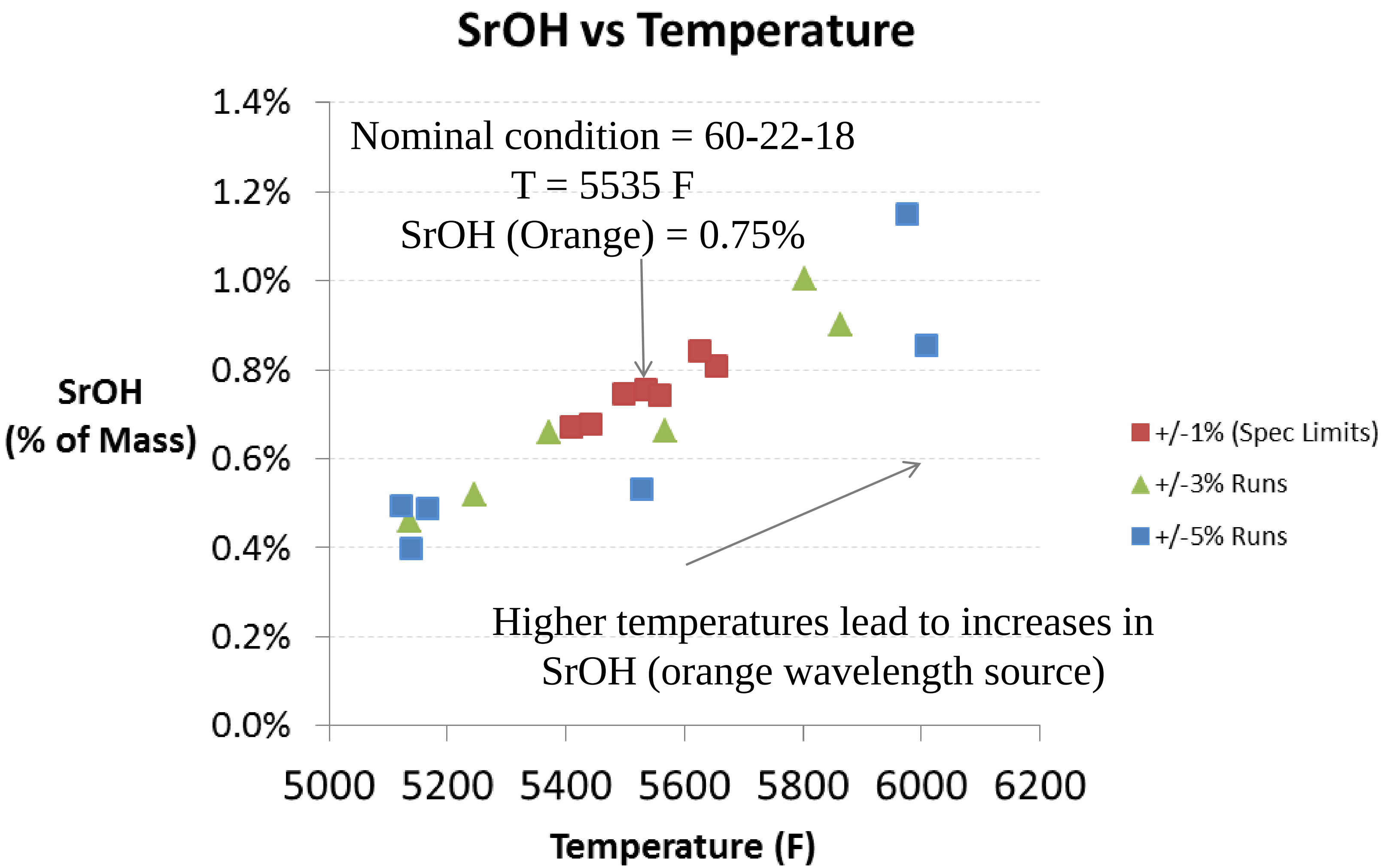
Trends in Favorable Species via Simulation



Trend within the factor levels is lower temperature = more preferred species

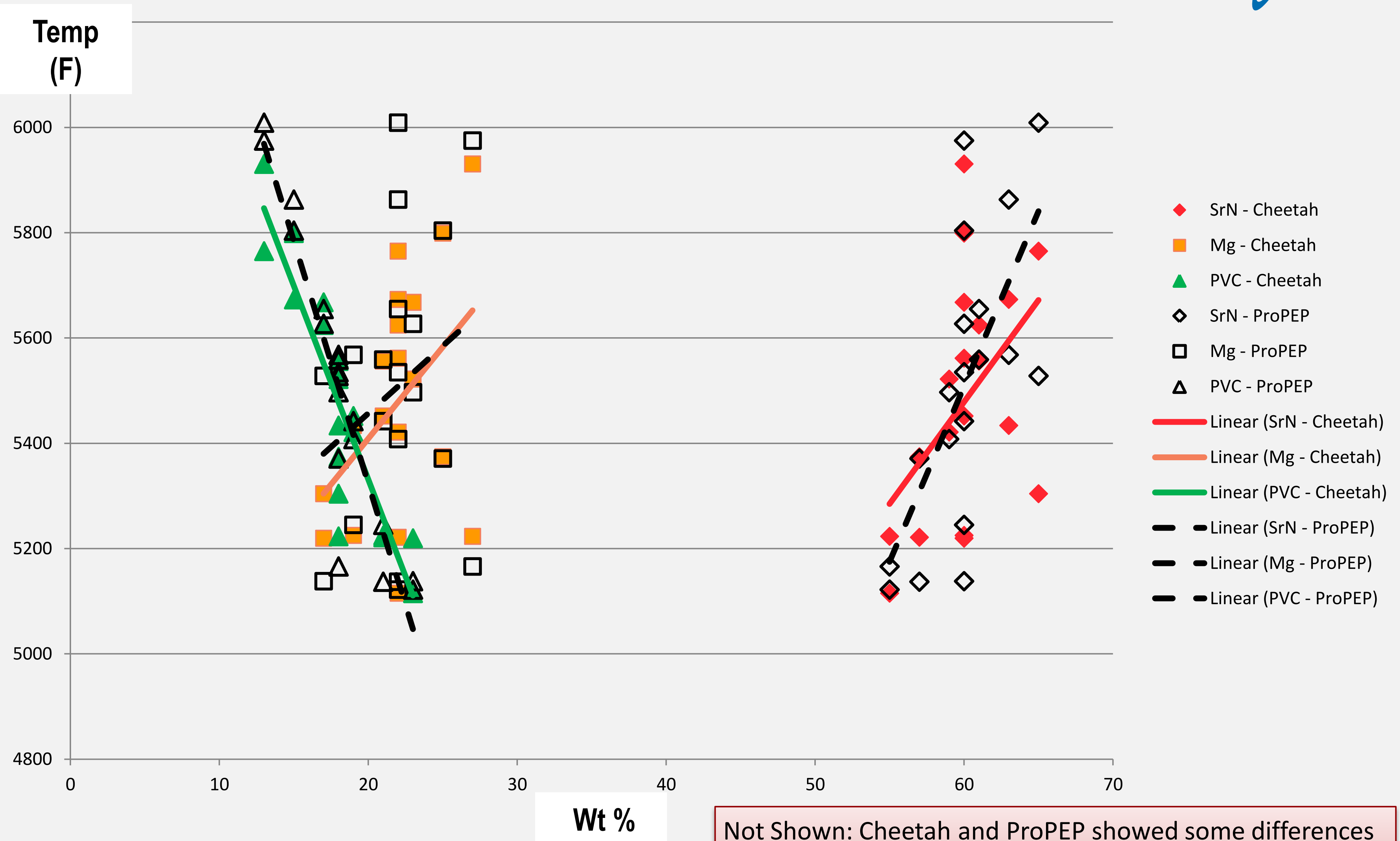
However, more instability in the predictions due to extreme chemistry in fuel:ox and temperature resulting from less magnesium in the system when Cl donor is increased

Trends in Negative Species via Simulation



Lower temperature favorable to minimize SrOH

Cheetah – ProPEP Comparison for Temperatures



Not Shown: Cheetah and ProPEP showed some differences in composition, although trends the same

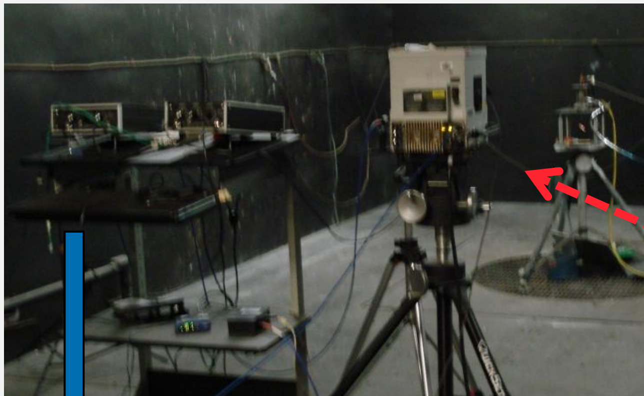
Conclusions

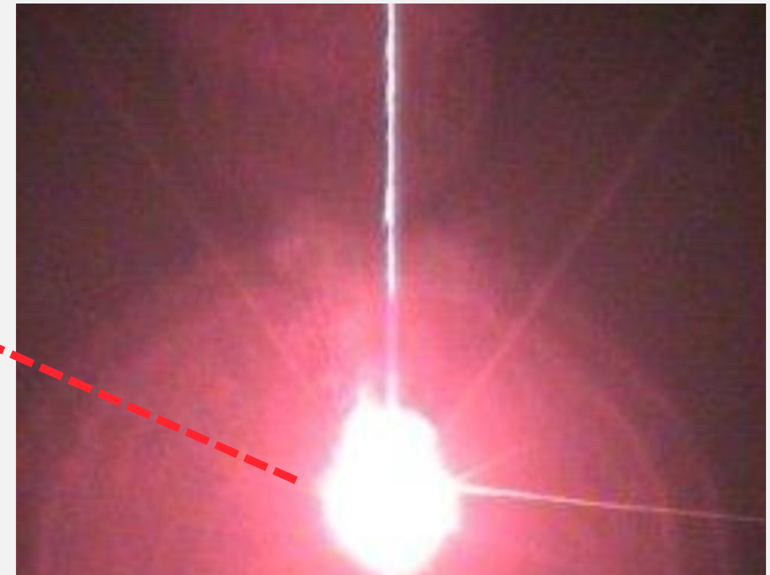
- Chlorine is a limiting reactant (Sr in excess)
- More chlorine = more photon potential (i.e. light output)
- Mg and SrN % do not correlate with photon potential
- Reaction temperature plays a role in photon potential (cooler may be better direction)
- PVC % drives reaction temperature proportionally similar to Mg % (common thought is that the temperature was driven mostly from the Mg!)
- More chlorine = more photon potential competes with temperature management
- Empirical validation is needed, this simulation helps guide experimental factors and levels and type of response collection tools needed
- +/-5% appears to push burn stability limits predicted from thermochemistry equilibrium alone
- Approximately 1000F differences between extremes is predicted (which seems excessive)

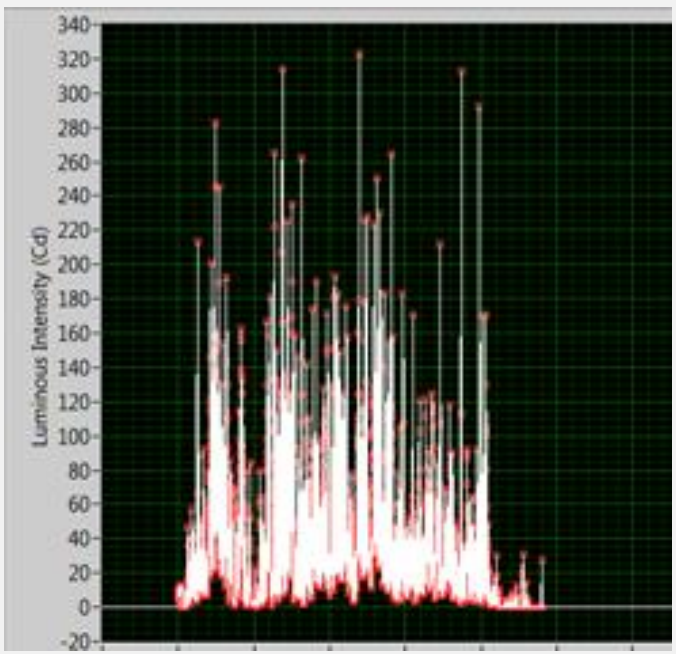
Recommendations to the Empirical Test Team

- Use +/-3% factor levels
  - Covers about a 650 F range from min-max (provoking intensity and spectral species changes)
  - Produces approximately a 20% shift in preferred species (expected correlation to wavelength dominance)
  - Produces at least a factor of 2X shift in negative species wavelengths dominance
- Based on experience, +/-3% level adjustments should yield mostly stable burns and drive the responses to a sufficient level of detection and discrimination
- Do not recommend any higher than 3%, as the extreme conditions showed signs of instability and is sufficiently far from production range of operation, risky to complete build-test

Example Raw Data Output From Lab Experimental Efforts







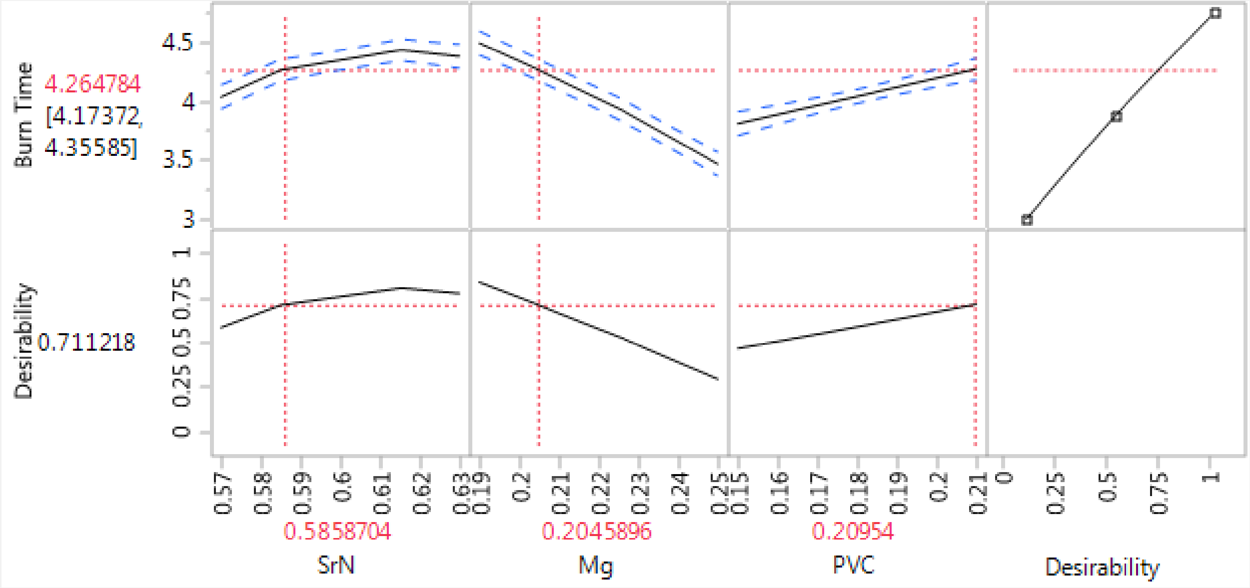
Design of Experiments Results

Chemistry Table with responses, average of 7 or more shots:

- Burn time
- Intensity
- Spectral purity
- Dominant Wavelength

Sr Nitrate	Mg	PVC	Burn Time (s)	Integral Intensity (cd*s)	Spectral Purity (%)	Dom. WaveLength (nm)
60	22	18	3.92	132.3	83.6	626.2
63	19	18	4.38	83.6	82.6	627.6
57	25	18	3.62	208.9	85.1	624.6
60	25	15	3.37	210.1	80.8	623.7
60	19	21	4.59	88.66	80.9	622.3
63	22	15	3.91	151.5	80.2	626.2
57	22	21	4.07	138.6	84.7	622.4

Design Optimization – Burn Time

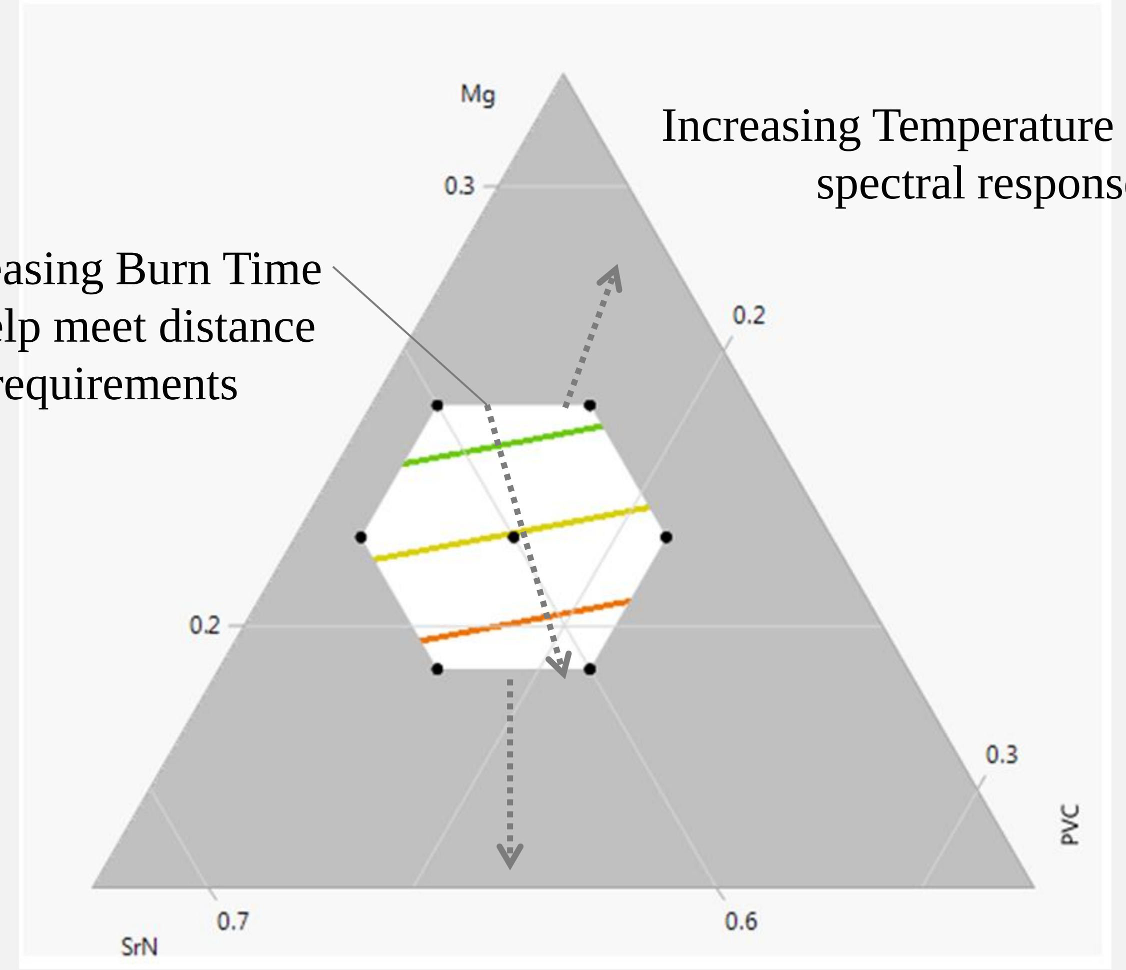


- PVC directly correlates to burn time but with less effect than magnesium
- Strontium Nitrate reacts with both PVC and Mg
- Any deviation in composition must take into account many competing responses (changing burn time through composition has other effects)

Ternary Plot for Burn Time Visualization of Competing Performance Parameters

Increasing Temperature (Negative spectral response)

Increasing Burn Time to help meet distance requirements



Improving Red Spectral Response

Translation from Laboratory to Production

- 5.56mm tracer ammunition historically has had marginal performance
  - Blinds
  - Inconsistent tracer burn
  - Washed out color
  - Erratic flights
  - Increased dispersion mean radius partially to drag offset variation

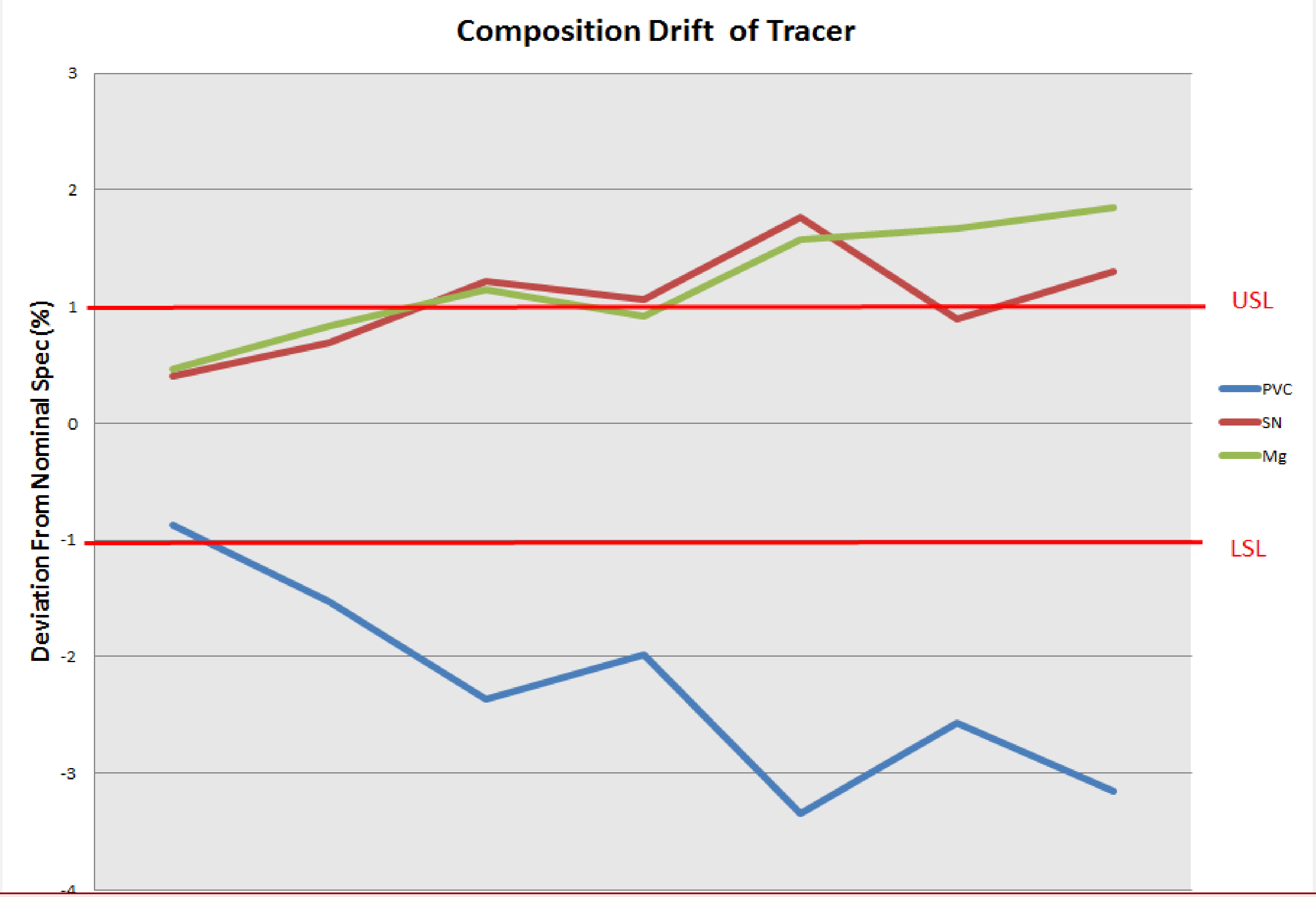
Project was initiated to determine how composition influences tracer performance

Tracer Charging Process

- **Dry-blending pyro mixture constituents**
  - PVC blended with SrNO3 in large batches (premix)
  - Premix & magnesium precisely weighed and mixed in sealed tubes
  - Delivered to bullet charging process in sealed tubes

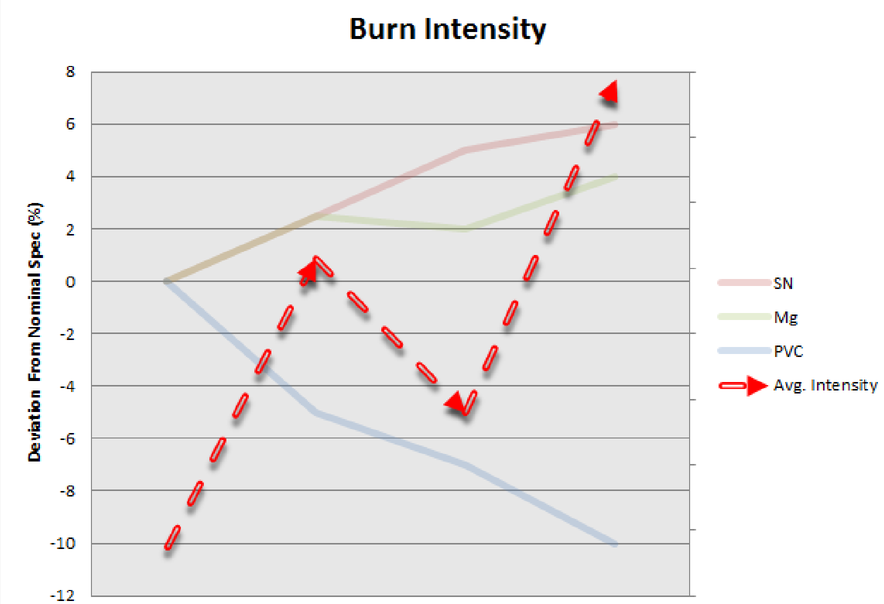
- **Open system charging process**
  - Mix poured from tubes into bullet charging machines dispense system
  - Charging dispense system is open oscillating bag
  - Charge is dispensed with spoon / funnel system

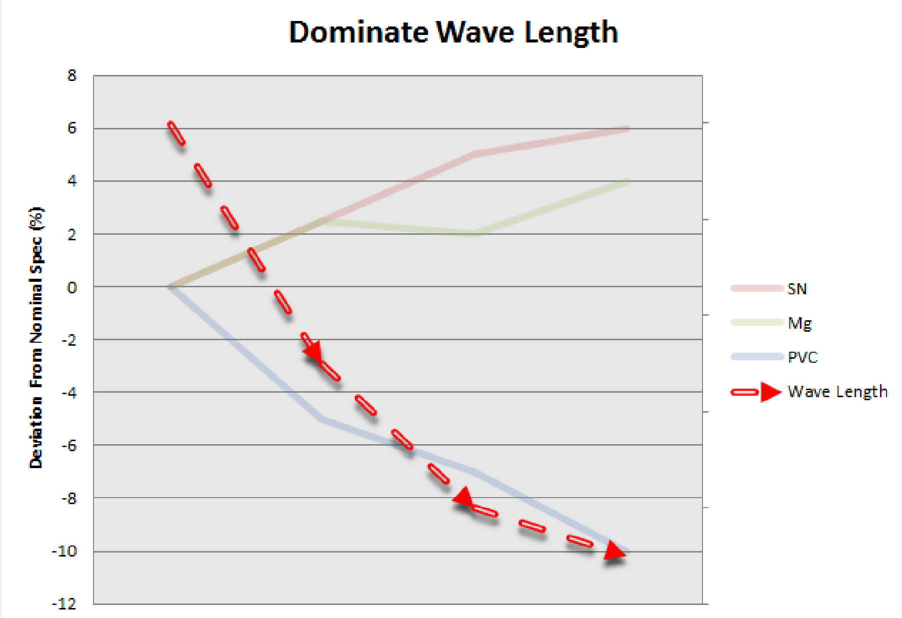
Composition Drift Seen in Tracer Process

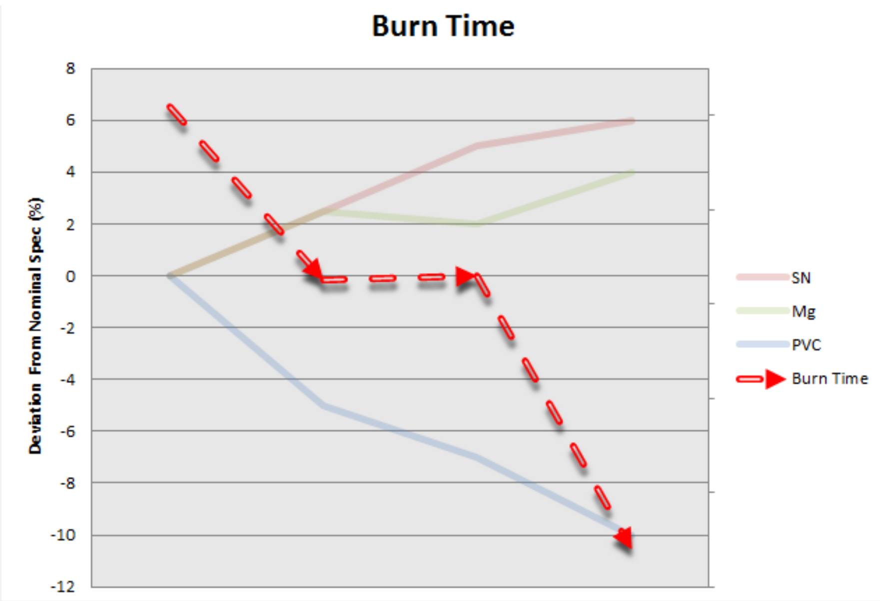


In a controlled experiment, PVC floats out of mixture during charging process, increasing ratio of Mg & Sn

Lab Test Results: Current Process





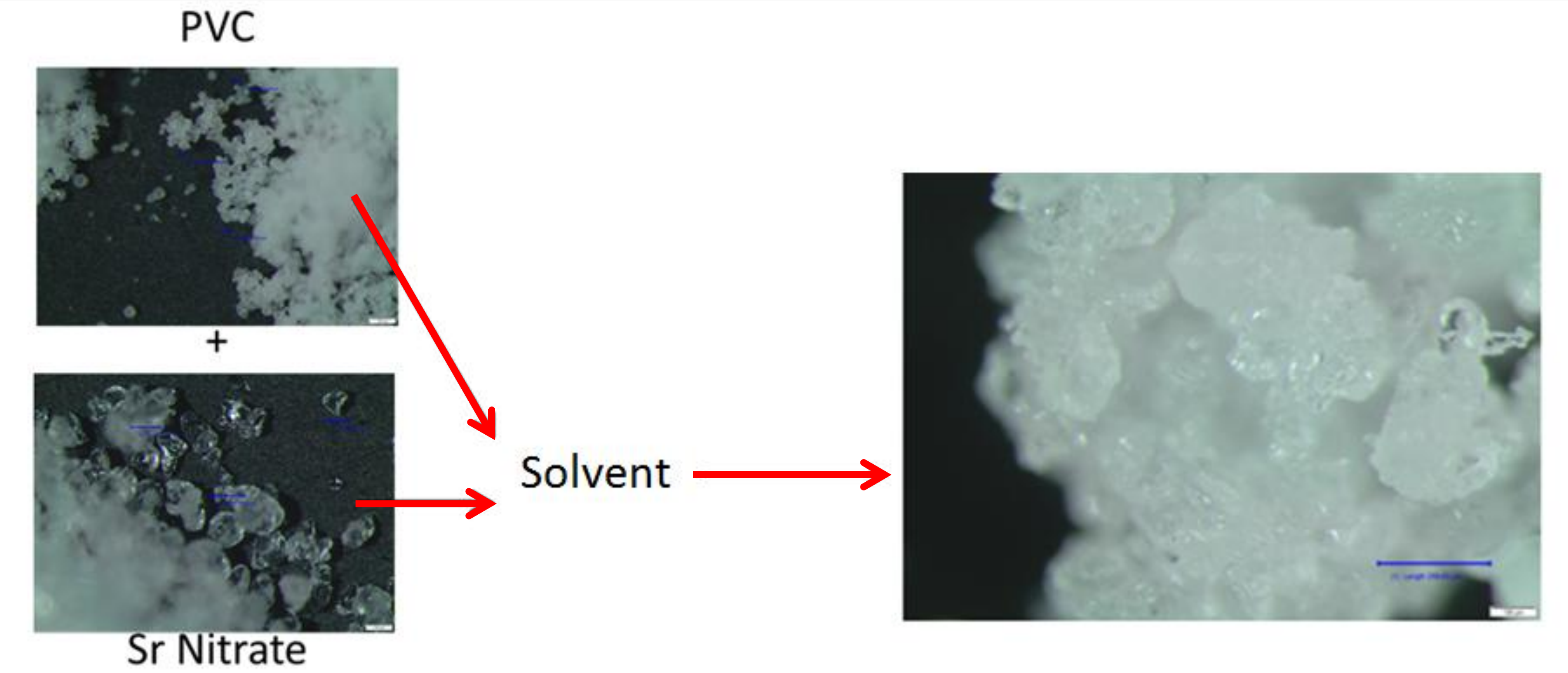


- As PVC drifts out of mixture
  - ➢ Burn Intensity Increases
  - ➢ Burn time decreases
  - ➢ Red Hue becomes washed out

Drifts in tracer mix composition induce color and burn time variation seen in completed bullets

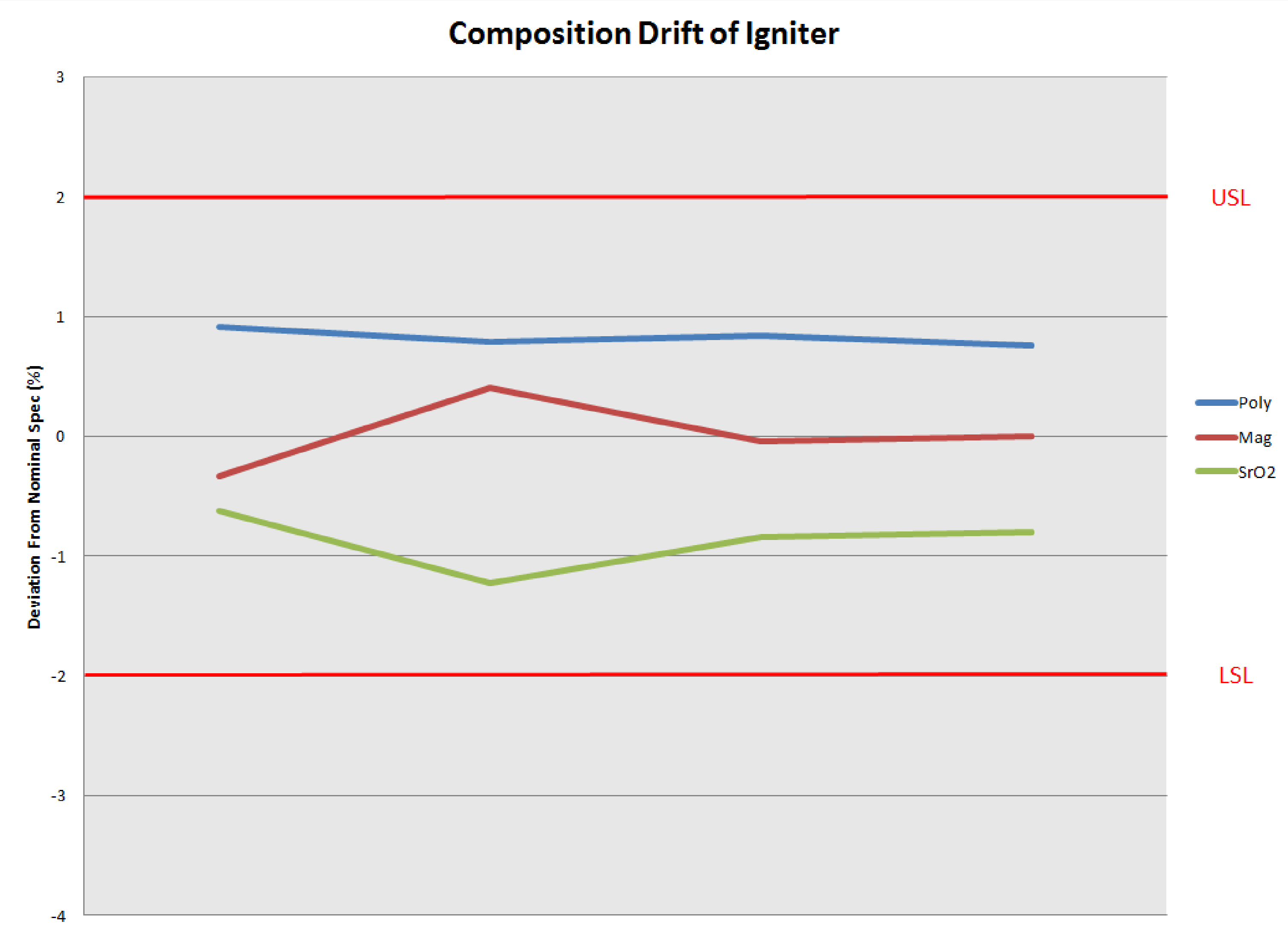
Potential Solution

- Keep PVC bound to other particles
  - Dry mix binder and oxidizer
  - Add solvent to dissolve binder and coat oxidizer
  - Dry off solvent



Use of solvent binds PVC to Sn & eliminates segregation of two ingredients

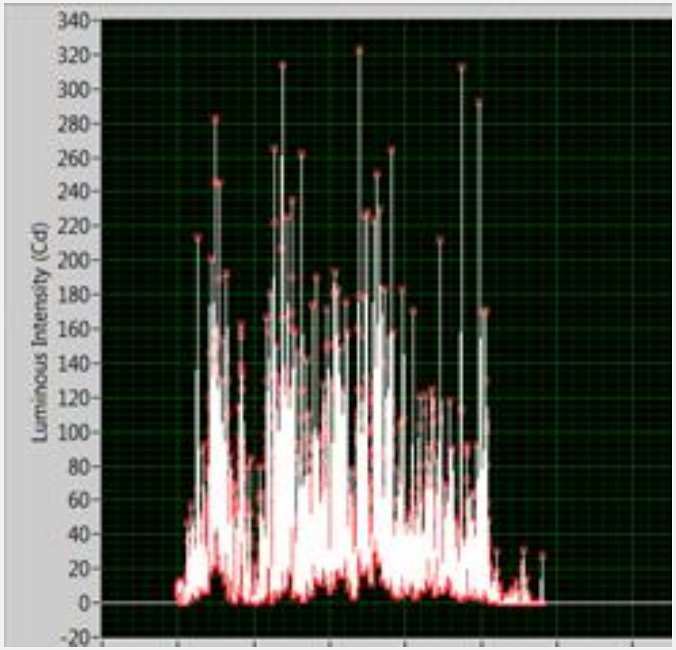
Observations: Potential Solution in Process



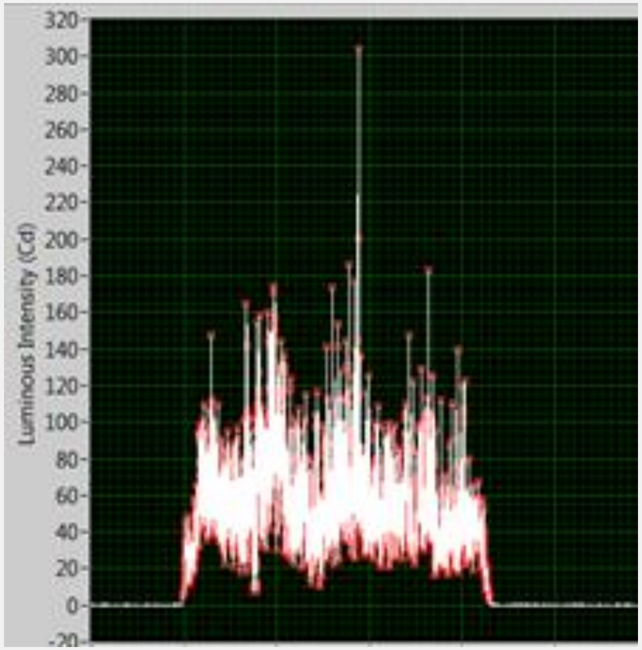
Binder remains in the mix of fuel and oxidizer over the course of entire shift

Lab test results: Current Process vs. Possible Solution

Current Process



Possible Solution

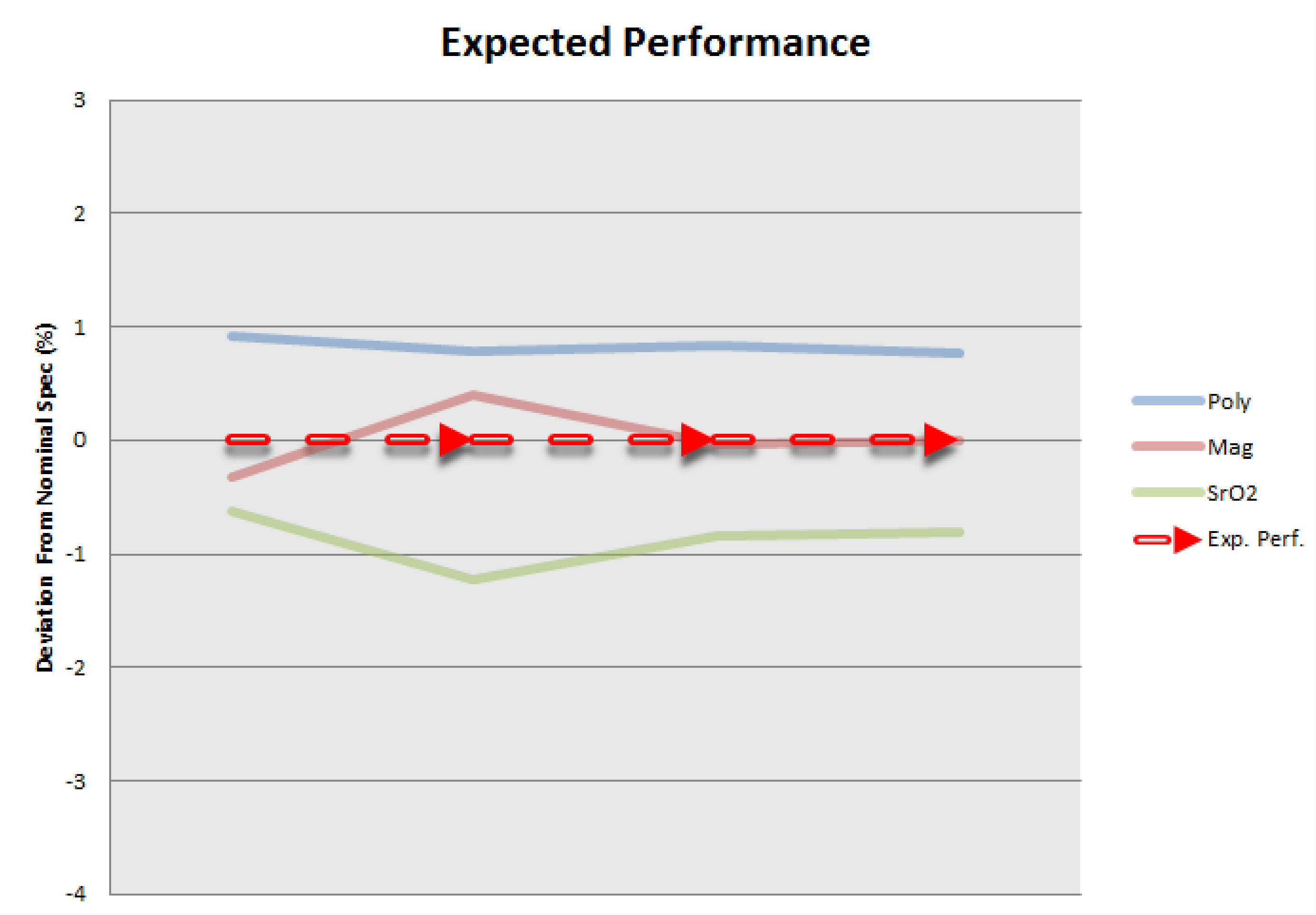


- Very erratic oscillations in luminous output
- Low average intensity
- Red hue washed out

- More consistent luminous output
- Higher average intensity
- Deeper red hue

Reduction in composition variability expected to improve flame color and burn consistency

Possible Solution Expected Performance



Adhering the binder to oxidizer drastically reduces shifts in tracer composition during bullet charging operations

Conclusions

- One cause of 5.56 tracer defects and burn inconsistency has been determined to be from drifts in composition created during the bullet charging process
- One possible solution is to control the chemistry by adhering the binder to the oxidizer
- Controlling the chemistry has shown to improve tracer reliability:
  - Increase intensity shot to shot
  - Improve burn time consistency
  - Improved wavelength consistency