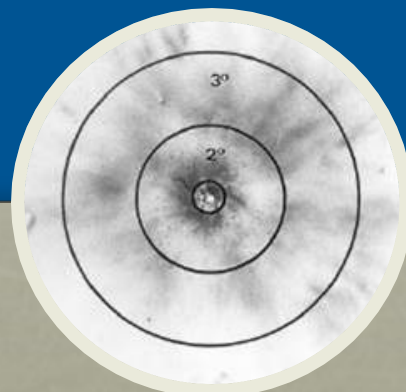
Lead Density on a Target, A Significant Indicator of Firing Distance, but is it Reliable?



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Purpose

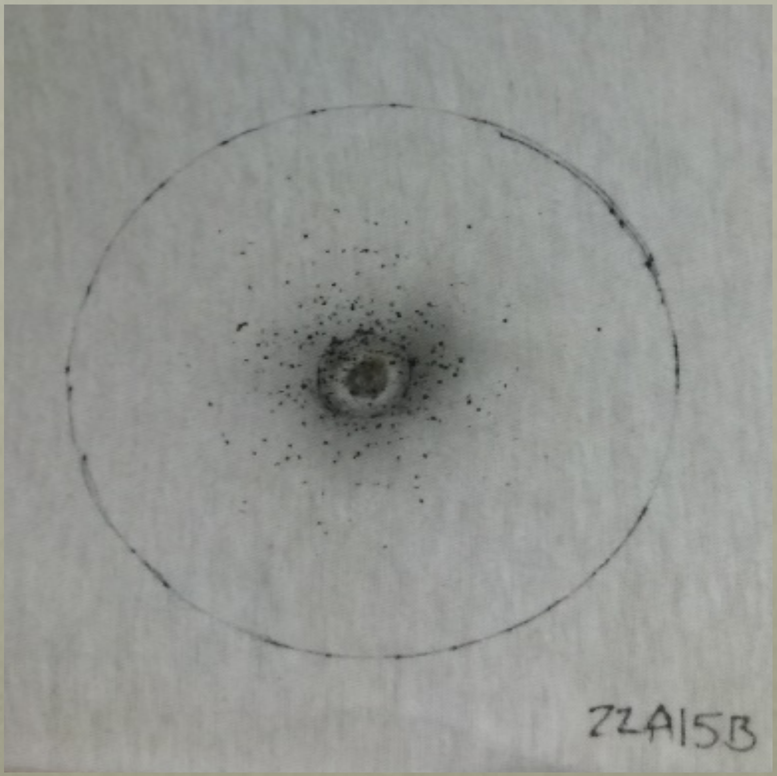
- In 2008, Gagliano-Candela *et al.*
  - Atomic absorption spectroscopy
  - Plotted the natural log of the lead density (ln *d*Pb) versus firing distance
    - Correlation coefficient, r = 0.97,
    - Coefficient of determination, R^2 = 0.94
    - Standard error = 0.19 cm
- Objectives of this study
  - Replicate with different firearm/ammunition systems
  - Asses validity of the calibration curves with test fires from known and unknown distances

Outline

- Colorimetic methods
- Previous studies of quantitative methods
- Experimental methods
- Results
- Discussion
- Conclusions

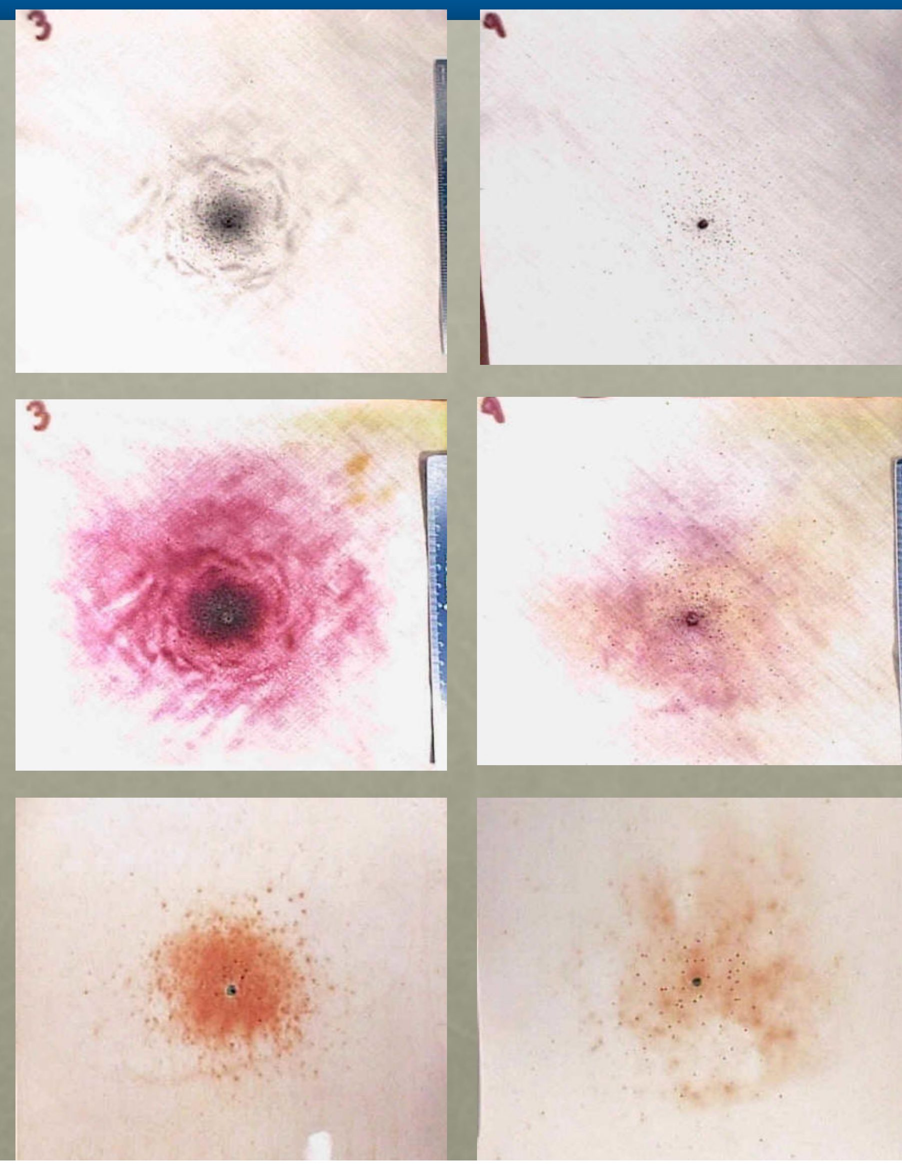
Gun Powder Patterns

- Circular pattern of GSR deposited around the bullet hole
- Diameter ∝ firing distance
- Amount 1/∝ distance
- Specific to each type of firearm and ammunition



Traditional Determination

3”　　9”



Row 1 - Untreated

Row 2 - Na Rhodizionate for lead

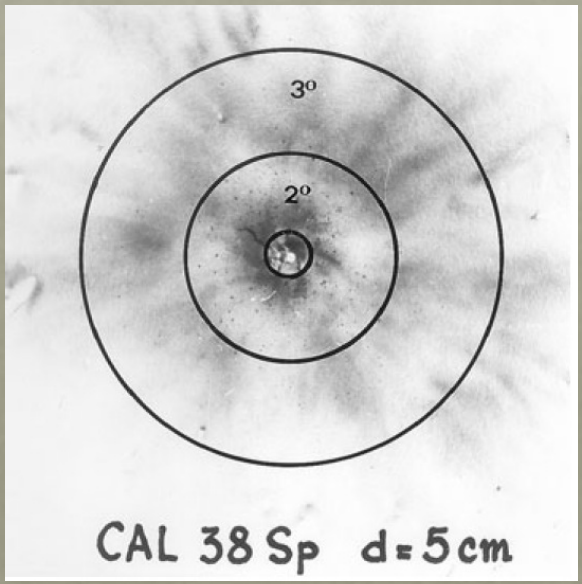
Row 3 - Griess for nitrites

http://www.firearmsid.com/A_distanceExams.htm

Quantitative Methods

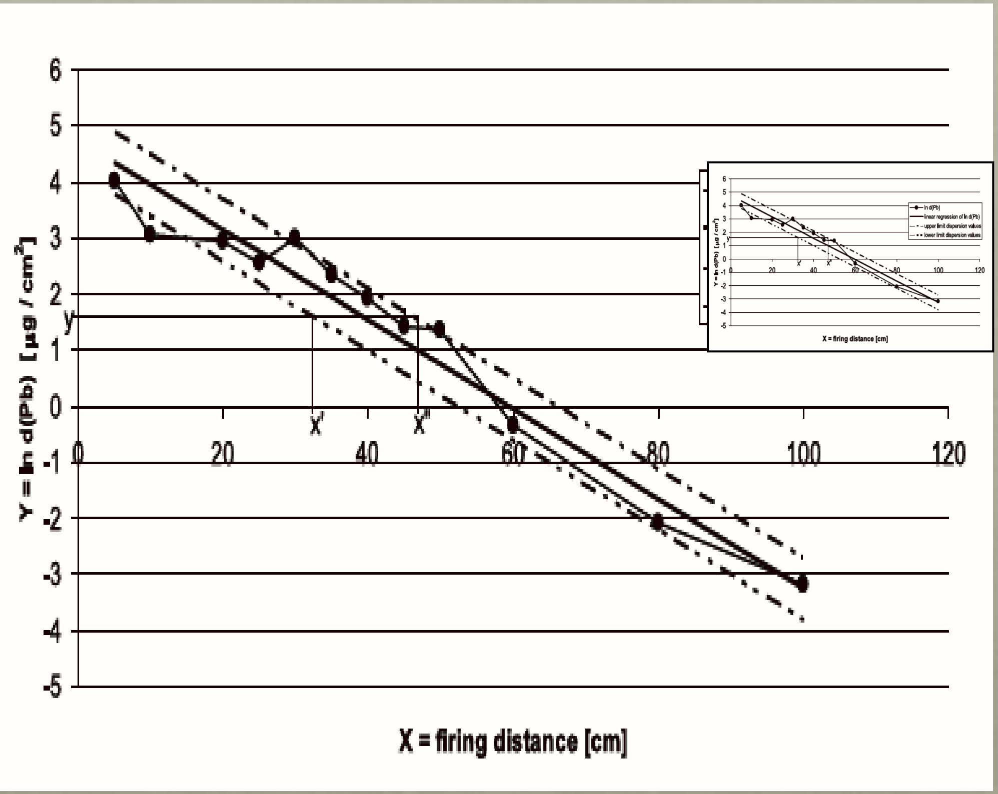
- Neutron Activation
- Image analysis
- Digital IR Photography
- SEMS/EDS
- Computed Tomography
- Atomic Absorption Spectroscopy
  - Krishnan, S.S., JoFS 1974
  - Gagliano-Candela, JoFS 2008

- Two test fires each from 5, 10, 20, 25, 30, 35, 40, 45, 50, 60, 80, and100 cm
- Extracted lead from 3 rings
  - 1.4, 5, and 10 cm diameter



Results of Gagliano Study

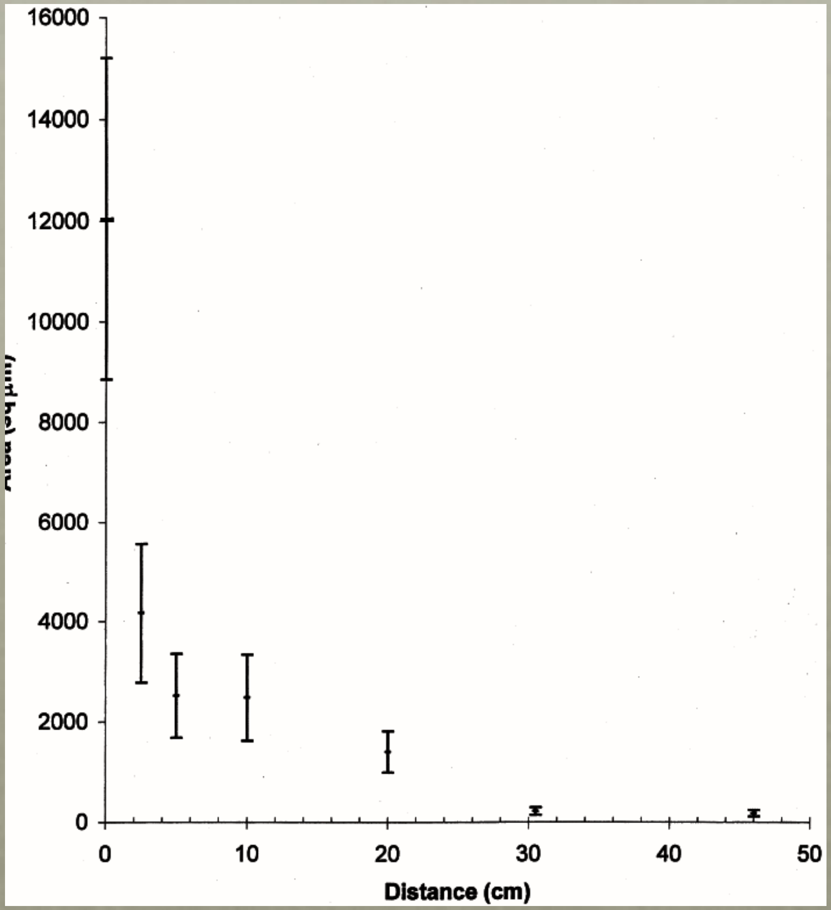
- Plotted ln Pb density (ln *d*Pb) for each ring and all combinations of rings
- Inner ring was most accurate for 5-35 cm
- Middle ring for 25-50 cm
- Outer ring for 40-100 cm
- Best calibration curve was constructed using the two outermost rings combined



Gagliano-Candela, R., Colucci, A. P., Salvatore, N., Journal of Forensic Sciences, 2008,

Brown et al. FS Int., 1999

- Image analysis
  - Combined light microscopy and automated image analysis
- Area of the pattern
- Can only distinguish
  - Contact from all others
  - Less than 20 cm from greater than 20 cm



Method: Test Fires

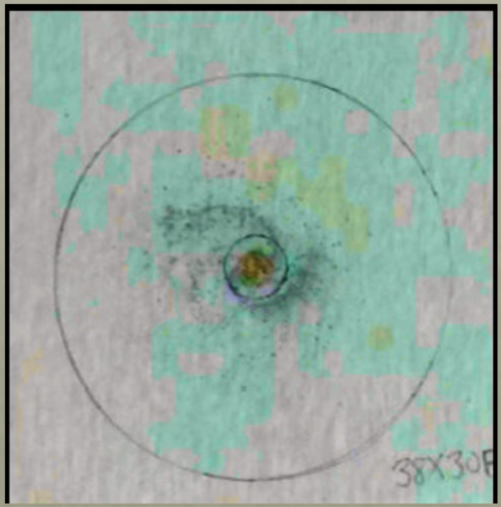
- Hi Standard .22 Double-Nine
  - 22A Aguila SuperExtra .22 LR High Velocity, copper plated, 40 gr
  - 22R Remington Thunderbolt .22 LR High Velocity, round nose, 40 gr
- .38 Smith & Wesson model 65
  - 38W Winchester Train & Defend 38 SPL, FMJ, 130 gr
  - 38F Freedom Munitions 38 SPL, 158 gr, RNFP

- Security Engineers, Inc. indoor range, B'Ham, AL
- Cotton cloth target with cardboard backing
- Three test fires at each distance of 15, 30, 45, 60, and 75 cm
- Three test fires at known distances of 35 and 55 cm
- Nine test fires at distances unknown to researcher

Lead Extraction

- Place ring in beaker
- Add 5.0 mL 1.0 M HNO_3
- Digest 5 minutes
- Dilute with DI water
  - 15 cm: 130 mL
  - 30 cm: 90 mL
  - 45 cm: 25 mL
  - 60 cm: 10 mL
  - 75 cm: 10 mL
- Incubate 30 minutes on orbital shaker

- Ring dimensions
  - Internal diameter: 1.4 cm
  - External diameter: 10.2 cm



38W at 30 cm

Plot of ln *d*Pb

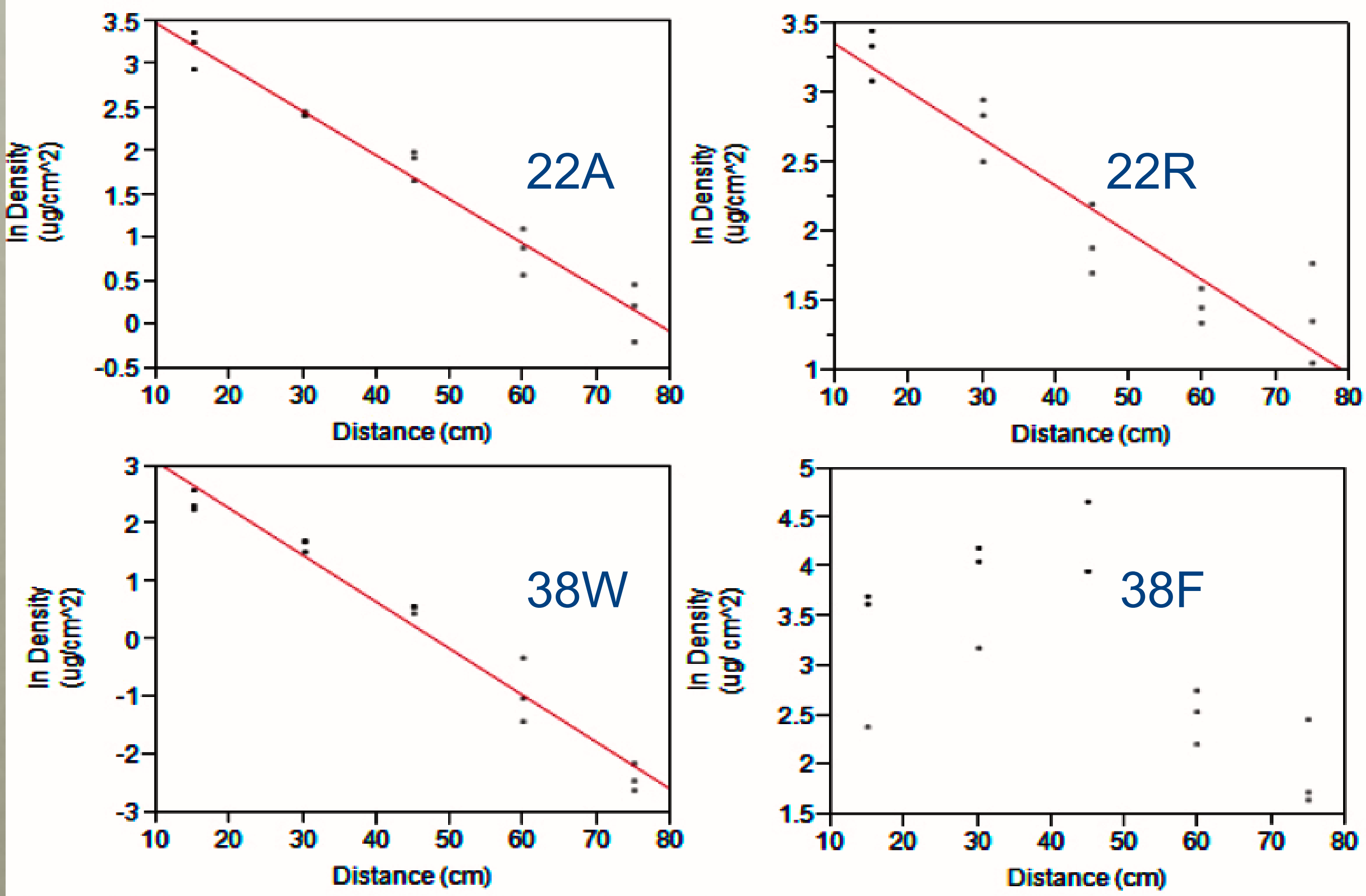


Figure 1. Linear regression models for sample sets shot with various ammunitions. The ammunition brands are, from left to right, Aguila, Remington, Winchester, and Freedom Munitions.

Comparison of linear regression

Ammunition	Slope	Intercept	r	r^2	s_{yx}
22A	-0.05	3.98	0.98	0.96	0.22
22R	-0.03	3.69	0.93	0.86	0.29
38W	-0.08	3.87	0.98	0.96	0.35
Gagliano-Candela	-0.08	4.76	0.97	0.94	0.19

$Y = a + bx$,

for 22A, $y = 3.98$ cm – $0.05x$ cm

Confidence Interval for Test Fires

$$s_x = \frac{s_y}{|a|}\sqrt{\frac{1}{m}+\frac{1}{n}+\frac{(y_0 - y)^2}{a^2 \sum (x - x)^2}}$$

Formula for uncertainty of one measured value

The 95% confidence interval or 'range' was calculated from s_x using the equation

$$95\%\ CI = t s_x$$

Further from centroid → greater error → values above and below expected values

Test Fires from Known Distances – Too Many Rejected Results

System	Distance	Calc	Min/Max Distance at 95% CI	
22A	35	29.5	23.3	35.7
	35	31.6	25.5	37.7
	35	37.3	31.3	43.3
	55	43.7	37.8	49.6
	55	52	46	58
	55	51.3	45.3	57.3
22R	35	24.2	11.5	36.9
	35	28	15.6	40.4
	35	34.6	22.6	46.6
	55	57.3	45.2	69.4
	55	39.3	27.5	51.1
	55	88.4	73.1	103.7
38W	35	34.9	28.8	41
	35	35.2	29.1	41.3
	35	36.7	30.7	42.7
	55	44.8	38.8	50.8
	55	51.2	45.2	57.2
	55	46.7	40.7	52.7

Is the Linear Model Appropriate?

- Used SPSS to evaluate the slope and intercept
  - Passed test
- Other factors
  - Recoil
  - Clean firearm between fires
  - Variation in mass of powder
  - Variation in mass of projectile
  - .....

Cleaned and Clamped

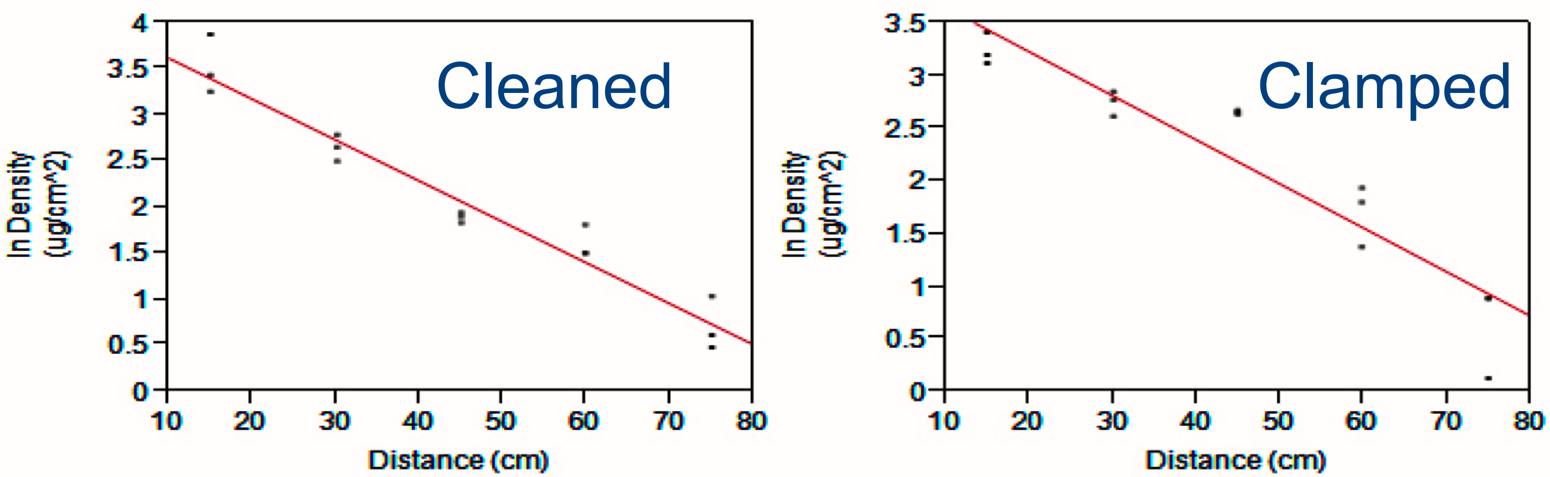


Figure 2. Linear regression models for sample sets shot with bore cleaning between each shot and with the revolver held stationary

Ammunition	Slope	Intercept	r	r^2	s_{yx}
22A	-0.05	3.98	0.98	0.96	0.22
22A cleaned	-0.04	4.05	0.97	0.94	0.24
22A clamped	-0.04	4.06	0.93	0.86	0.37
22R	-0.03	3.69	0.93	0.86	0.29
38W	-0.08	3.87	0.98	0.96	0.35
Gagliano-Candela	-0.08	4.76	0.97	0.94	0.19

Test Fires from Know Distances

Sample Set	Distance	Calc	Min./Max 95% CI	
Cleaned	35	26.7	18.8	34.6
	35	31.5	23.8	39.2
	35	39.7	32.2	47.2
	55	52.8	45.3	60.3
	55	54.5	46.9	62.1
	55	59.5	51.8	67.2
Stationary	35	34.6	22.3	46.9
	35	20.1	6.8	33.4
	35	40.8	28.7	52.9
	55	45.5	33.5	57.5
	55	54.9	42.7	67.1
	55	50.6	38.5	62.7

R^2 Is Not Enough![1]

- The coefficient of determination is a measure of how well the regression line represents the data

However, the model must be validated

- Numerical and graphical methods

- Most often recommended: graphical residual analysis

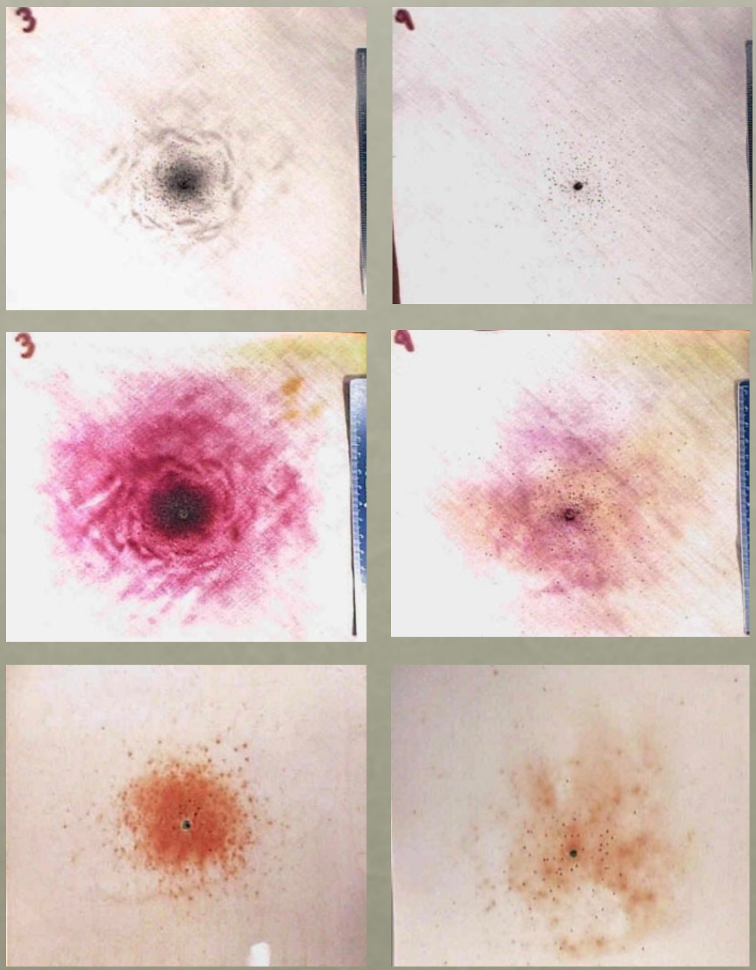
Residual = Observed value - Predicted value

$$e = y - \hat{y}$$

[1]http://www.itl.nist.gov/div898/handbook/pmd/section4/pmd44.htm

To Improve the Model

- Colorimetric tests produce the entire pattern
- When only one component is measured
  - May require more replicates
- Is the lead completely extracted
- Identification of factors affecting lead deposition



Conclusions

- Possible to generate calibration curve for 38W
  - Lead free primer and full metal jacket (not TMJ)
- All residue may not be deposited on target surface
  - At distances < 45 cm
- Distance for test fires should extend to *d*Pb = 0
- The error rate was higher than should occur at the 95% confidence level
  - Barrel fouling and recoil were eliminated as the cause of the errors
  - Analysis of the intercept and the slope verified that the statistical analysis was valid
- A high r or r^2 values are not a sufficient measure of the reliability of a calibration curve
  - Plotting residuals
  - Test calibration with known test fires

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Test Fires from Unknown Distances – 22A

System	Distance	Calc	Min.Max 95% CI Distance	
Aguila	20	21.4	14.9	27.9
	65	62.8	56.5	69.1
	36	39.9	33.9	45.9
	27	36.1	30.1	42.1
	45	45.8	39.9	51.7
	15	21.4	14.9	27.9
	75	66.5	60.1	72.9
	65	61.2	55	67.4
	40	45.6	39.7	51.5

Test Fires from Unknown Distances – 22R

Remington	15	24.2	11.5	36.9
	17	72.1	58.8	85.4
	65	67	54.2	79.8
	40	44.8	33	56.6
	45	45.1	33.3	56.9
	20	11.9	-2	25.8
	66	88.3	73	103.6
	57	64.7	52.1	77.3
	33	27.8	15.2	40.4

Test Fires from Unknown Distances – 38W

Winchester	30	28.8	22.4	35.2
	70	70.7	64.3	77.1
	51	60.4	54.2	66.6
	24	32.5	26.4	38.6
	20	25.8	19.4	32.2
	65	65.3	58.9	71.7
	36	37.1	31.1	43.1
	27	30.4	24.2	36.6

Least Squares Regression Line
$y = a + Bx$

$$b = \frac{\sum (x_i - \overline{x})(y_i - \overline{y})}{\sum (x_i - \overline{x})^2} = \frac{S_{xy}}{S_{xx}},$$

$$a = \overline{y} - b\overline{x}$$

b = The slope of the regression line
a = The intercept
x = Mean of x values
y = Mean of y values
SD_x = Standard Deviation of x
SD_y = Standard Deviation of y
r = (NΣxy - ΣxΣy) / sqrt ((NΣx^2 - $(\Sigma x)^2$) x $(N\Sigma y)^2$ - $(\Sigma y)^2$) =

r and r^2

- The **coefficient of determination** (denoted by R^2) is a key output of regression analysis. It is interpreted as the proportion of the variance in the dependent variable that is predictable from the independent variable.
- Correlation coefficient, r

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}}$$

Standard Error of x

Interpolating a Single Value:

If only one measured value is available, the uncertainty in the corresponding concentration will be higher than if replicate measurements had been performed. The standard error (or standard deviation) of the interpolated value s_{xo} is given by:

$$s_x = \frac{s_y}{|a|}\sqrt{\frac{1}{m} + \frac{1}{n} + \frac{(y_0 - \bar{y})^2}{a^2 \sum (x - \bar{x})^2}} \qquad (2)$$

where s_y is the standard error of the y-values in the calibration curve, a is the slope of the regression line, m is the number of replicate measurements of each sample (m = 3 in this case), n is the total number of reference data points in the calibration curve (n = 15), $y_0 - \bar{y}$ is the difference in ln *d*Pb in the experimental test fire and the mean value of ln *d*Pb for all reference test fires in the calibration curve, and $(x - \bar{x})$ is the difference in each firing distance in the calibration curve and the mean value of all firing distances in the calibration curve.

Further from centroid →greater error → values above and below expected values.

Harris, D., Quantitative Chemical Analysis, W. H. Freeman and Company, New York, 1999

http://www.chem.utoronto.ca/coursenotes/analsci/stats/ConcCalib.html

The 95% confidence interval was calculated from s_x using the equation (3),

$$95\%\ CI = ts_x \qquad (3)$$