# APPENDIX 1

Properties of sintered carbides
Brookes 1979

# APPENDIX 1

Properties of sintered carbides
(Brookes, 1979)

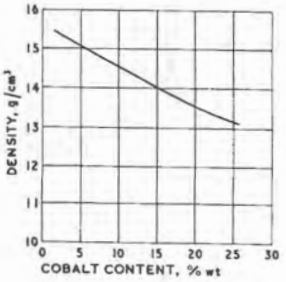
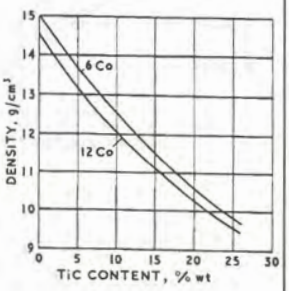



Figure 4.1. (left) Density of typical WC/Co grades; variation with cobalt content.

Figure 4.2. (right) Density of WC/TiC/Co and WC/TiC/Ta(Nb)C/Co grades; variation with TiC content (calculated figures, assuming zero porosity). Practical values are typically 0.1 to 0.2 g/cm³ lower.



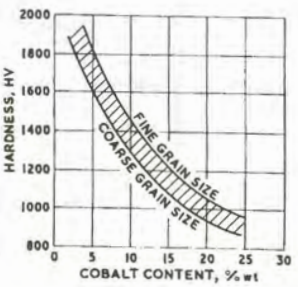
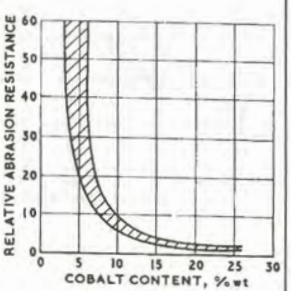




Figure 4.3. (left) Hardness of typical WC/Co grades; variation with cobalt content and grain size. Higher values relate to finer grain size.

Figure 4.4. (right) Relative abrasion resistance (reciprocal wear rate under standard conditions) of typical WC/Co grades. Highest values relate to finest grain size.



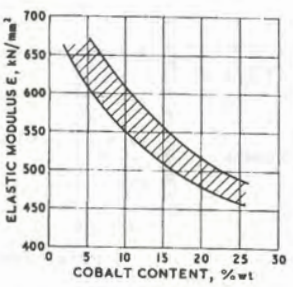
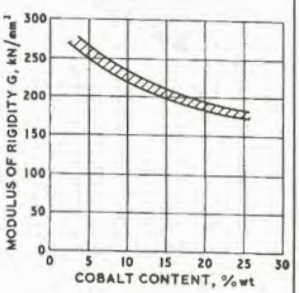




Figure 4.5. (left) Elastic modulus E of typical WC/Co grades; variation with cobalt content.

Figure 4.6. (right) Modulus of rigidity G of typical WC/Co grades; variation with cobalt content.



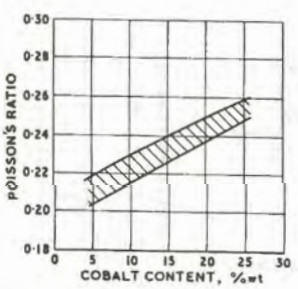
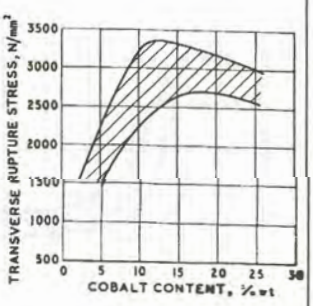




Figure 4.7. (left) Poisson's ratio of typical WC/Co grades; variation with cobalt content.

Figure 4.8. (right) Transverse rupture stress of typical WC/Co grades; variation with cobalt content.



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Properties of sintered carbides
(Brookes, 1979)

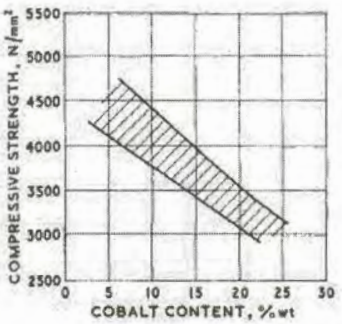
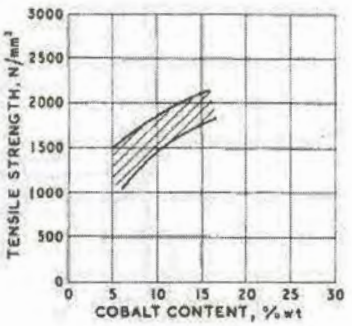



Figure 4.9. (left) Compressive strength of typical WC/Co grades; variation with cobalt content.

Figure 4.10. (right) Tensile strengths of typical WC/Co grades.



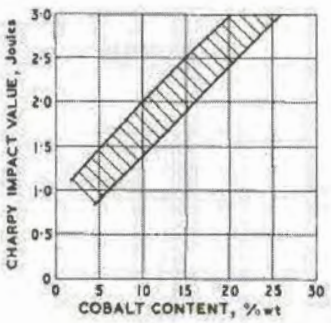
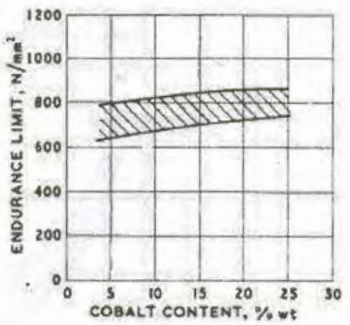




Figure 4.11 (left) Charpy impact values of typical WC/Co grades; variation with cobalt content.

Figure 4.12. (right) Fatigue strength endurance limit ($10^8$ stress cycles) of typical WC/Co grades.



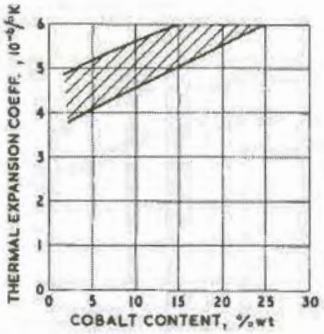
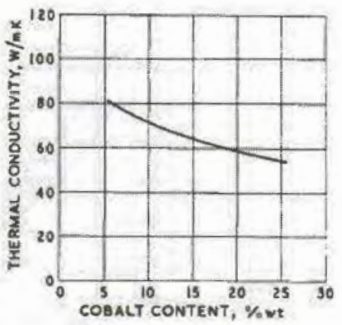




Figure 4.13. (left) Thermal expansion coefficient of typical WC/Co grades.

Figure 4.14. (right) Thermal conductivity of typical WC/Co grades; variation with cobalt content.



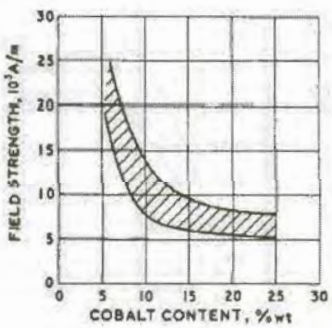
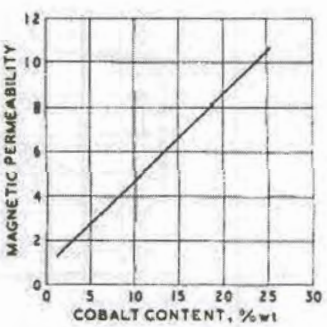




Figure 4.15 (left) Magnetisation coercive field strength (coercive force) of typical WC/Co grades; variation with cobalt content. Lower values tend to be associated with coarser grain sizes.

Figure 4.16. (right) Magnetic permeability of typical WC/Co grades.



# APPENDIX 2

Tables of typical carbide grades for machining and
tables of historical developments of sintered carbides
Brookes 1979

# APPENDIX 2

Tables of typical carbide grades for machining and tables of historical development of sintered carbides (Brookes, 1979)

| Designations | | | Compositions | | | | | | Properties | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ISO Application Code | U.S. Industry Code | BHMA Properties Code | WC | TiC | Ta(Nb)C | Co | Ni | Mo | Density g/cm³ | Hardness HV | Transverse Rupture Stress N/mm² |
| P01 | C8 | 919 | - | 80 | - | - | 10 | 10 | 5.8 | 1900 | 850 |
| P01 | C8 | 919 | 50 | 35 | 7 | 6 | | | 8.5 | 1900 | 1100 |
| P05 | C7 | 926 | 78 | 16 | - | 6 | | | 11.4 | 1820 | 1300 |
| P10 | C7 | 727 | 69 | 15 | 8 | 8 | | | 11.5 | 1740 | 1400 |
| P15 | C6 | 635 | 78 | 12 | 3 | 7 | | | 11.7 | 1660 | 1500 |
| P20 | C6 | 444 | 79 | 8 | 5 | 8 | | | 12.1 | 1580 | 1600 |
| P25 | C6 | 344 | 82 | 6 | 4 | 8 | | | 12.9 | 1530 | 1700 |
| P30 | C5 | 353 | 84 | 5 | 2 | 9 | | | 13.3 | 1490 | 1850 |
| P40 | C5 | 263 | 85 | 5 | - | 10 | | | 13.4 | 1420 | 1950 |
| P50 | - | 182 | 78 | 3 | 3 | 16 | | | 13.1 | 1250 | 2300 |
| M10 | - | 453 | 85 | 5 | 4 | 6 | | | 13.4 | 1590 | 1800 |
| M20 | - | 363 | 82 | 5 | 5 | 8 | | | 13.3 | 1540 | 1900 |
| M30 | - | 263 | 86 | 4 | - | 10 | | | 13.6 | 1440 | 2000 |
| M40 | - | 273 | 84 | 4 | 2 | 10 | | | 14.0 | 1380 | 2100 |
| K01 | C4 | 930 | 97 | - | - | 3 | | | 15.2 | 1850 | 1450 |
| K05 | C4 | 830 | 95 | - | 1 | 4 | | | 15.0 | 1780 | 1550 |
| K10 | C3 | 741 | 92 | - | 2 | 6 | | | 14.9 | 1730 | 1700 |
| K20 | C2 | 560 | 94 | - | - | 6 | | | 14.8 | 1650 | 1950 |
| K30 | C1 | 280 | 91 | - | - | 9 | | | 14.4 | 1400 | 2250 |
| K40 | C1 | 290 | 89 | - | - | 11 | | | 14.1 | 1320 | 2500 |

* Very considerable variation between manufacturers is possible.

**Table 1.2 Historical Development**
*WC-base sintered carbides*

| | |
|---|---|
| 1923-25 | WC-Co |
| 1929-31 | WC-TiC-Co |
| 1930-31 | WC-TaC(VC, NbC)-Co |
| 1932 | WC-TiC-TaC(NbC)-Co |
| 1938 | WC-$Cr_3C_2$-Co |
| 1956 | WC-TiC-Ta(Nb)C-$Cr_3C_2$-Co |
| 1959 | WC-TiC-HfC-Co |
| 1968-69 | WC-TiC-TaC(NbC)-HfC-Co |
| 1968-69 | WC-TiC-NbC(TaC)-HfC-Co |
| 1965-78 | TiC, TiN, Ti(C,N), HfC, HfN and $Al_2O_3$ coatings on WC-base alloys |
| 1967-70 | Sub-micron WC/Co |
| 1965-75 | Hot isostatic pressing |
| 1969-71 | Thermochemical surface hardening |
| 1974-77 | Polycrystalline diamond layers on WC-base hardmetal |
| 1973-78 | Multi-carbide, carbonitride/nitride and multiple carbide/carbonitride/nitride/oxide coatings |
| 1976-79 | Complex hardmetals with Ru additions |

**Table 1.3 Historical Development**
*WC-free sintered carbides*

| | |
|---|---|
| 1929-31 | TiC-$Mo_2C$-Ni, Cr, Mo |
| 1930-31 | TaC-Ni |
| 1931 | TiC-TaC-Co |
| 1931 | TiC-Cr, Mo, W, Ni, Co |
| 1938 | TiC-VC-Ni, Fe |
| 1944 | TiC-NbC-Ni, Co |
| 1949 | TiC-VC-NbC-$Mo_2C$-Ni |
| 1950 | TiC($Mo_2C$, TaC)-Ni, Co-Cr |
| 1952-66 | TiC - heat-treatable steels and alloys |
| 1957 | TiC-$TiB_2$ |
| 1965-70 | TiC-$Mo_2C$(mixtures)-Ni, Mo |
| 1968-70 | (Ti, Mo)C(solid solution)-Ni, Mo, Cr |
| 1969-70 | TiC-TiN-Ni |
| 1968-73 | TiC-$Al_2O_3$ |
| 1972-75 | TiC-TaN-Ni |

# APPENDIX 3

Certificate of analysis for NIST
standard reference material 889: cemented carbide

# National Institute of Standards & Technology

# Certificate of Analysis

## Standard Reference Material 889

### Cemented Carbide

### (W-75,Co-9,Ta-5,Ti-4)

(In Cooperation with the American Society for Testing and Materials)

This Standard Reference Material (SRM) is a sintered tungsten carbide base material in the form of a fine powder (150 μm) intended for use in checking chemical and instrumental methods of analysis. SRM 889 was developed under the cooperative program for certification with the National Institute of Standards and Technology (NIST) and the American Society for Testing and Materials (ASTM).

| | Certified Value[a] | Estimated Uncertainty[b] |
|---|---|---|
| | Percent by Weight | |
| Cobalt | 9.50 | 0.15 |
| Tantalum | 4.60 | .15 |
| Titanium | 4.03 | .10 |

[a] The certified value is the present best estimate of the "true" value based on the NIST/ASTM cooperative program for certification.

b The estimated uncertainty is based on judgment and represents an evaluation of the combined effects of method imprecision, possible systematic errors among methods, and material variability. No attempt was made to derive exact statistical measures of imprecision because several methods were involved in the determination of the certified constituent.

The overall coordination of the technical measurements leading to certification was performed under the direction of J.I. Shultz, Research Associate, ASTM-NIST Research Associate Program.

The technical and support aspects involved in the preparation, certification, and issuance of this Standard Reference Material were coordinated through the Office of Standard Reference Materials by W.P. Reed.

PLANNING, PREPARATION, TESTING, AND ANALYSIS:

The material for this SRM was provided by GTE Products Corp., Towanda, Pennsylvania through the courtesy of R. Dyck.

The preparation of the material was under the direction of M.E. Shaffer of the Hard Materials Section, GTE Products Corp., Towanda, Pennsylvania.

Homogeneity testing was performed at GTE Products Corp. by J.S. Mras and at NIST by G.A. Sleater.

Cooperative analyses for certification were performed in the following laboratories:

- GTE Products Corp., Towanda, Pennsylvania, J. Mras, J.R. Barton, L.J. Kring and M. Fedorchak.
- Ledoux & Company, Teaneck, N.J., S. Kallmann and C.L. Maul.

September 5, 1988
Gaithersburg, MD 20899

Stanley D. Rasberry, Chief
Office of Standard Reference Materials

Metallurgical Industries, Inc., Tinton Falls, N.J., R. Liu.
- National Institute of Standards and Technology, Gas and Particulate Science Division, Gaithersburg, MD, Z. Wang and P.A. Pella.
- Timken Company, Canton, Ohio, N.J. Stecyk.
- Valeron Corporation, Troy, Michigan, R. Fike.

Elements other than those certified may be present in this material as indicated below. These are not certified, but are given as additional information on the composition.

| Element | Concentration, % by Weight |
|---|---|
| Molybdenum | (<.05) |
| Nickel | (<.05) |
| Iron | (<.05) |
| Niobium | (<.05) |
| Carbon | (6.0) |

# APPENDIX 4

Calibration data

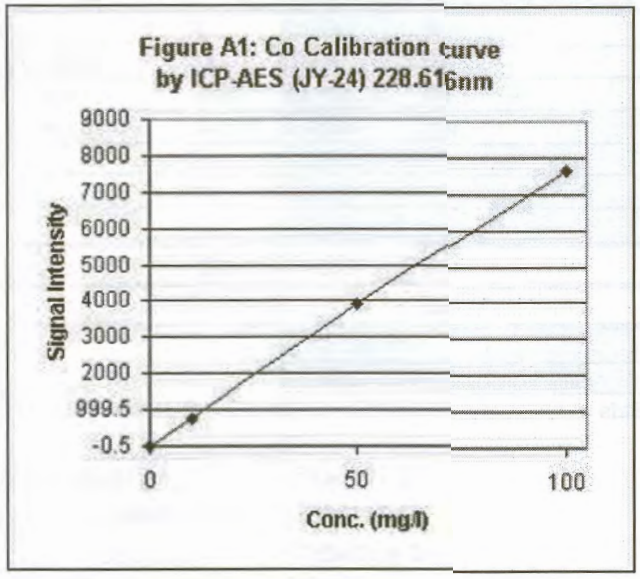
## APPENDIX 4: FIGURE A1

**Co** **228.616nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\|yi - \ddot{y}i\|$ | $(yi - \ddot{y}i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | 0.29306 | 0 | 19.5251 | -19.232 | 369.8714804 | 1600 |
| 10 | 766.25 | 100 | 783.3215 | -17.0715 | 291.4367455 | 900 |
| 50 | 3907.7 | 2500 | 3838.507 | 69.19282 | 4787.646273 | 100 |
| 100 | 7624.6 | 10000 | 7657.489 | -32.8893 | 1081.703285 | 3600 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 160 | 3074.71 | 12600 | | | 6530.657784 | 6200 |
| 40 | | | | | | |

| | |
|---|---|
| a | 19.52510306 |
| b | 76.37964155 |

| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 57.14305638 |
| $s_a$ | 40.73079601 |
| $s_b$ | 0.725717542 |
| Lowest signal detectable | 190.954 |
| **Lowest conc. Detectable** | **2.244ppm** |
| Lowest quantitation signal | 590.956 |
| **Lowest conc.quantifiable** | **7.481ppm** |




SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.99991 |
| R Square | 0.999819 |
| Adjusted R Square | 0.999729 |
| Standard Error | 57.14306 |
| Observations | 4 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 36169867.79 | 36169868 | 11076.9448 | 9.0265E-05 |
| Residual | 2 | 6530.657784 | 3265.329 | | |
| Total | 3 | 36176398.44 | | | |

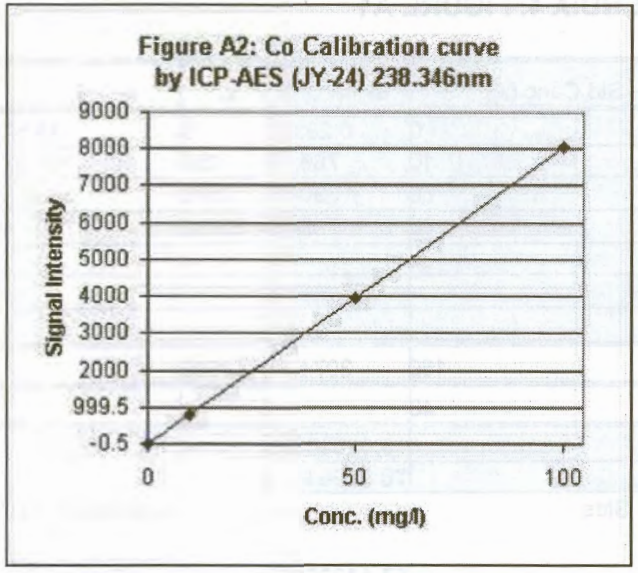
| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 19.5251 | 40.73079601 | 0.47937 | 0.67897567 | -155.72549 | 194.7757 | -155.725 | 194.7757 |
| X Variable 1 | 76.37964 | 0.725717542 | 105.2471 | 9.0265E-05 | 73.2571288 | 79.50215 | 73.25713 | 79.50215 |

## APPENDIX 4: FIGURE A2

**Co** **238.346nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\lvert yi - \ddot{y}i \rvert$ | $(yi - \ddot{y}i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | 0.312 | 0 | -17.0536 | 17.36558 | 301.5633911 | 1600 |
| 10 | 790.1 | 100 | 788.0731 | 2.026935 | 4.108467456 | 900 |
| 50 | 3970.2 | 2500 | 4008.58 | -38.3796 | 1472.997163 | 100 |
| 100 | 8053.2 | 10000 | 8034.213 | 18.98713 | 360.5110689 | 3600 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 160 | 3203.45 | 12600 | | | 2139.18009 | 6200 |
| 40 | | | | | | |

| | |
|---|---|
| a | -17.0535806 |
| b | 80.51266452 |




| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 32.70458752 |
| $s_a$ | 23.31138668 |
| $s_b$ | 0.415348677 |
| Lowest signal detectable | 81.060 |
| **Lowest conc. Detectable** | **1.219ppm** |
| Lowest quantitation signal | 309.992 |
| **Lowest conc.quantifiable** | **4.062ppm** |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.999973 |
| R Square | 0.999947 |
| Adjusted R Square | 0.99992 |
| Standard Error | 32.70459 |
| Observations | 4 |

ANOVA

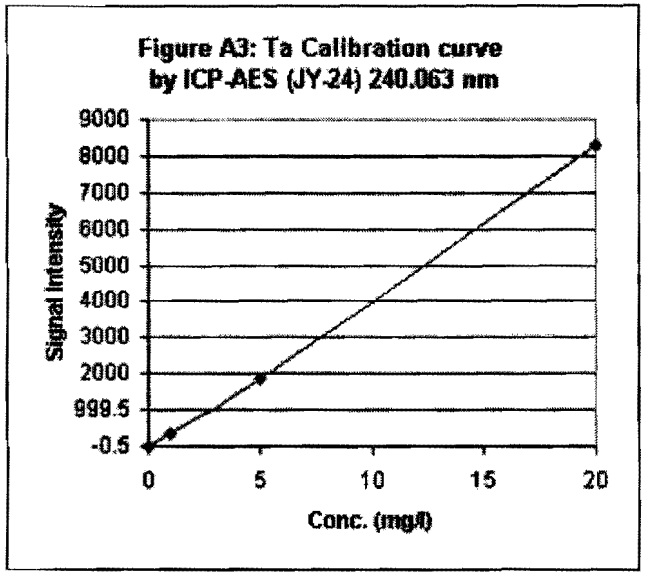
| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 40190192.71 | 40190193 | 37575.3242 | 2.6612E-05 |
| Residual | 2 | 2139.18009 | 1069.59 | | |
| Total | 3 | 40192331.89 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -17.0536 | 23.31138668 | -0.73156 | 0.54054436 | -117.354452 | 83.24729 | -117.354 | 83.24729 |
| X Variable 1 | 80.51266 | 0.415348677 | 193.8436 | 2.6612E-05 | 78.7255622 | 82.29977 | 78.72556 | 82.29977 |

## APPENDIX 4: FIGURE A3

**Ta** **240.063nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\|yi - \ddot{y}i\|$ | $(yi - \ddot{y}i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | -3.403 | 0 | -96.832 | 93.42902 | 8728.98204 | 42.25 |
| 1 | 343.68 | 1 | 321.9051 | 21.7749 | 474.1463886 | 30.25 |
| 5 | 1844.7 | 25 | 1996.854 | -152.154 | 23150.70947 | 2.25 |
| 20 | 8314.86 | 400 | 8277.91 | 36.94965 | 1365.276477 | 182.25 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 26 | 2624.96 | 426 | | | 33719.11437 | 257 |
| 6.5 | | | | | | |
| a | -96.8320214 | | | | | |
| b | 418.7371187 | | | | | |




| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 129.8443575 |
| $s_a$ | 83.58557302 |
| $s_b$ | 8.099468491 |
| Lowest signal detectable | 292.701 |
| **Lowest conc. Detectable** | **0.930ppm** |
| Lowest quantitation signal | 1201.612 |
| **Lowest conc.quantifiable** | **3.101ppm** |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.999626 |
| R Square | 0.999252 |
| Adjusted R Square | 0.998878 |
| Standard Error | 129.8444 |
| Observations | 4 |

ANOVA

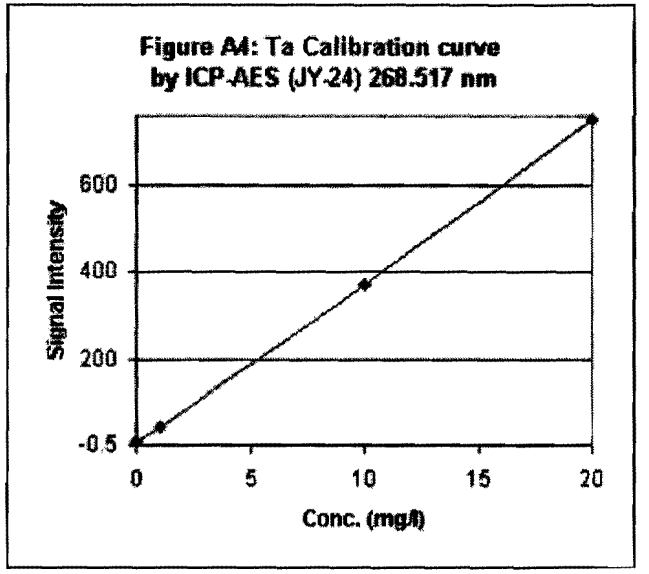
| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 45062579.06 | 45062579 | 2672.82103 | 0.00037393 |
| Residual | 2 | 33719.11437 | 16859.56 | | |
| Total | 3 | 45096298.18 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -96.832 | 83.58557302 | -1.15848 | 0.3663056 | -456.471966 | 262.8079 | -456.472 | 262.8079 |
| X Variable 1 | 418.7371 | 8.099468491 | 51.69933 | 0.00037393 | 383.887894 | 453.5863 | 383.8879 | 453.5863 |

## APPENDIX 4: FIGURE A4

**Ta** **268.517nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\|yi - \ddot{y}i\|$ | $(yi - \ddot{y}i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | 9.6677 | 0 | 6.06506 | 3.60264 | 12.97901414 | 60.0625 |
| 1 | 42.087 | 1 | 43.25682 | -1.16982 | 1.36847152 | 45.5625 |
| 10 | 373 | 100 | 377.9826 | -4.98263 | 24.82657888 | 5.0625 |
| 20 | 752.45 | 400 | 749.9002 | 2.549805 | 6.501503998 | 150.0625 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 31 | 294.30 | 501 | | | 45.67556854 | 260.75 |
| 7.75 | | | | | | |
| a | 6.065060115 | | | | | |
| b | 37.19175676 | | | | | |




| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 4.778889439 |
| $s_a$ | 3.312101915 |
| $s_b$ | 0.295947601 |
| Lowest signal detectable | 20.402 |
| **Lowest conc. Detectable** | **0.385ppm** |
| Lowest quantitation signal | 53.854 |
| **Lowest conc.quantifiable** | **1.285ppm** |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.999937 |
| R Square | 0.999873 |
| Adjusted R Square | 0.99981 |
| Standard Error | 4.778889 |
| Observations | 4 |

ANOVA

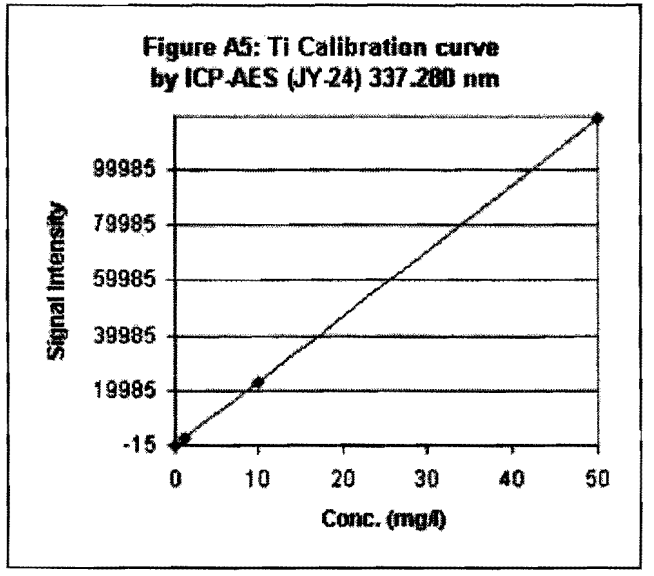
| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 360676.3805 | 360676.4 | 15792.9673 | 6.3313E-05 |
| Residual | 2 | 45.67556854 | 22.83778 | | |
| Total | 3 | 360722.0561 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 6.06506 | 3.312101915 | 1.831182 | 0.20854974 | -8.18577415 | 20.31589 | -8.18577 | 20.31589 |
| X Variable 1 | 37.19176 | 0.295947601 | 125.6701 | 6.3313E-05 | 35.9183961 | 38.46512 | 35.9184 | 38.46512 |

## APPENDIX 4: FIGURE A5

**Ti** **337.280nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\lvert yi - \ddot{y}i \rvert$ | $(yi - \ddot{y}i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | -14.319 | 0 | -126.538 | 112.2193 | 12593.18003 | 232.5625 |
| 1 | 2351.4 | 1 | 2237.318 | 114.082 | 13014.7114 | 203.0625 |
| 10 | 23232 | 100 | 23512.02 | -280.025 | 78413.81593 | 27.5625 |
| 50 | 118120 | 2500 | 118066.3 | 53.72329 | 2886.192241 | 1207.563 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 61 | 35922.27 | 2601 | | | 106907.8996 | 1670.75 |
| 15.25 | | | | | | |
| a | -126.538339 | | | | | |
| b | 2363.856301 | | | | | |




| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 231.2011025 |
| $s_a$ | 144.2362246 |
| $s_b$ | 5.656322535 |
| Lowest signal detectable | 567.065 |
| **Lowest conc. Detectable** | **0.293ppm** |
| Lowest quantitation signal | 2185.473 |
| **Lowest conc.quantifiable** | **0.978ppm** |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.999994 |
| R Square | 0.999989 |
| Adjusted R Square | 0.999983 |
| Standard Error | 231.2011 |
| Observations | 4 |

ANOVA

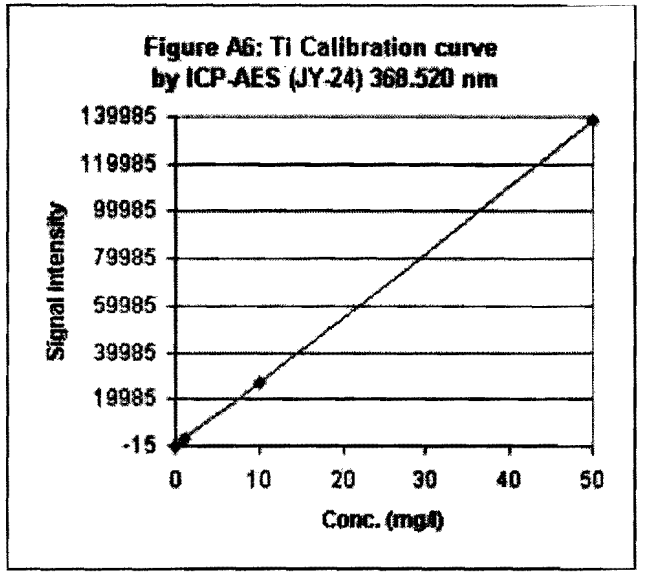
| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 9335844603 | 9.34E+09 | 174652.1 | 5.7256E-06 |
| Residual | 2 | 106907.8996 | 53453.95 | | |
| Total | 3 | 9335951511 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -126.538 | 144.2362246 | -0.8773 | 0.47284902 | -747.137157 | 494.0605 | -747.137 | 494.0605 |
| X Variable 1 | 2363.856 | 5.656322535 | 417.914 | 5.7256E-06 | 2339.51909 | 2388.194 | 2339.519 | 2388.194 |

## APPENDIX 4: FIGURE A6

**Ti** **368.520nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\lvert y_i - \ddot{y}_i \rvert$ | $(y_i - \ddot{y}_i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | -1.9728 | 0 | -84.1301 | 82.15727 | 6749.816891 | 232.5625 |
| 1 | 2796.3 | 1 | 2681.425 | 114.8752 | 13196.30987 | 203.0625 |
| 10 | 27328 | 100 | 27571.42 | -243.419 | 59252.66228 | 27.5625 |
| 50 | 138240 | 2500 | 138193.6 | 46.38624 | 2151.682857 | 1207.563 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 61 | 42090.58 | 2601 | | | 81350.4719 | 1670.75 |
| 15.25 | | | | | | |
| a | -84.1300693 | | | | | |
| b | 2765.554877 | | | | | |




| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 201.6810253 |
| $s_a$ | 125.8199435 |
| $s_b$ | 4.934115433 |
| Lowest signal detectable | 520.913 |
| **Lowest conc. Detectable** | **0.219ppm** |
| Lowest quantitation signal | 1932.680 |
| **Lowest conc.quantifiable** | **0.729ppm** |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.999997 |
| R Square | 0.999994 |
| Adjusted R Square | 0.99999 |
| Standard Error | 201.681 |
| Observations | 4 |

ANOVA

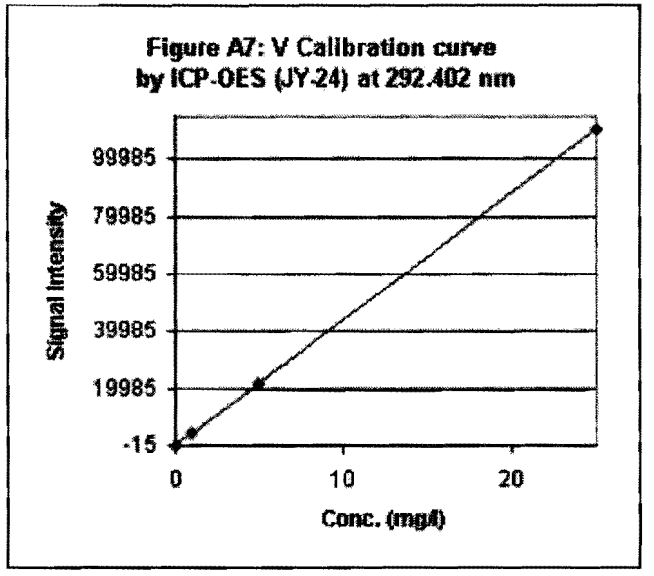
| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 12778386826 | 1.28E+10 | 314156.428 | 3.1831E-06 |
| Residual | 2 | 81350.4719 | 40675.24 | | |
| Total | 3 | 12778468177 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -84.1301 | 125.8199435 | -0.66865 | 0.57255917 | -625.48997 | 457.2298 | -625.49 | 457.2298 |
| X Variable 1 | 2765.555 | 4.934115433 | 560.4966 | 3.1831E-06 | 2744.32508 | 2786.785 | 2744.325 | 2786.785 |

## APPENDIX 4: FIGURE A7

**V** **292.402nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\lvert y_i - \ddot{y}_i \rvert$ | $(y_i - \ddot{y}_i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | 13.472 | 0 | -28.9639 | 42.43592 | 1800.807691 | 60.0625 |
| 1 | 4384.7 | 1 | 4384.166 | 0.533999 | 0.2851547 | 45.5625 |
| 5 | 21983 | 25 | 22036.69 | -53.6857 | 2882.154835 | 7.5625 |
| 25 | 110310 | 625 | 110299.3 | 10.71578 | 114.8279601 | 297.5625 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 31 | 34172.79 | 651 | | | 4798.075641 | 410.75 |
| 7.75 | | | | | | |
| a | -28.9639245 | | | | | |
| b | 4413.129926 | | | | | |




| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 48.97997367 |
| $s_a$ | 30.83118803 |
| $s_b$ | 2.41673906 |
| Lowest signal detectable | 117.976 |
| **Lowest conc. Detectable** | **0.033ppm** |
| Lowest quantitation signal | 460.836 |
| **Lowest conc.quantifiable** | **0.111ppm** |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 1 |
| R Square | 0.999999 |
| Adjusted R Square | 0.999999 |
| Standard Error | 48.97997 |
| Observations | 4 |

ANOVA

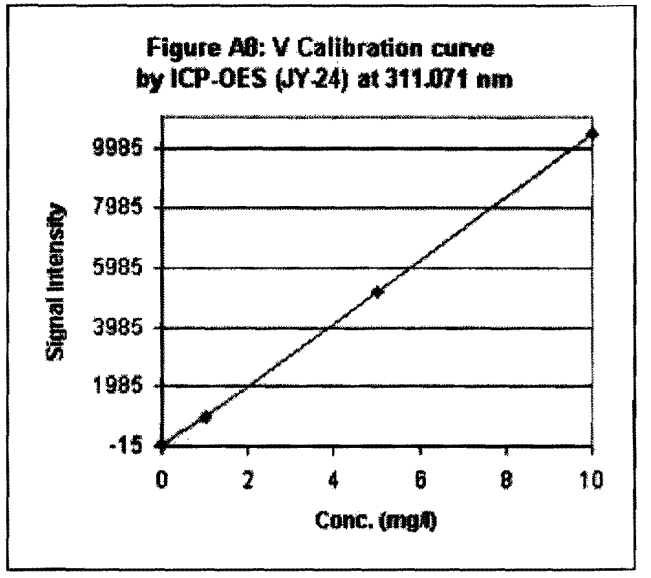
| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 7999650241 | 8E+09 | 3334524.44 | 2.9989E-07 |
| Residual | 2 | 4798.075641 | 2399.038 | | |
| Total | 3 | 7999655039 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -28.9639 | 30.83118803 | -0.93944 | 0.44667602 | -161.619912 | 103.6921 | -161.62 | 103.6921 |
| X Variable 1 | 4413.13 | 2.41673906 | 1826.068 | 2.9989E-07 | 4402.73153 | 4423.528 | 4402.732 | 4423.528 |

## APPENDIX 4: FIGURE A8

**V** **311.071nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\lvert yi - \ddot{y}i \rvert$ | $(yi - \ddot{y}i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | 19 | 0 | -27.4153 | 46.41532 | 2154.38217 | 16 |
| 1 | 973.58 | 1 | 1021.737 | -48.1573 | 2319.121504 | 9 |
| 5 | 5212.2 | 25 | 5218.348 | -6.14758 | 37.79274779 | 1 |
| 10 | 10472 | 100 | 10464.11 | 7.889516 | 62.24446475 | 36 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 16 | 4169.195 | 126 | | | 4573.540887 | 62 |
| 4 | | | | | | |
| a | -27.4153226 | | | | | |
| b | 1049.152581 | | | | | |




| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 47.82018866 |
| $s_a$ | 34.08558227 |
| $s_b$ | 6.073170033 |
| Lowest signal detectable | 116.045 |
| **Lowest conc. Detectable** | **0.137ppm** |
| Lowest quantitation signal | 450.787 |
| **Lowest conc.quantifiable** | **0.456ppm** |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.999966 |
| R Square | 0.999933 |
| Adjusted R Square | 0.999899 |
| Standard Error | 47.82019 |
| Observations | 4 |

ANOVA

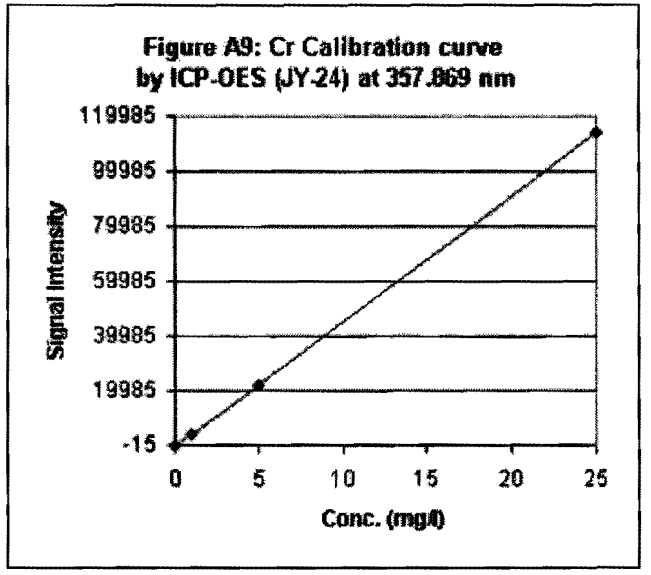
| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 68244710.52 | 68244711 | 29843.2712 | 3.3507E-05 |
| Residual | 2 | 4573.540887 | 2286.77 | | |
| Total | 3 | 68249284.06 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -27.4153 | 34.08558227 | -0.80431 | 0.50562912 | -174.073848 | 119.2432 | -174.074 | 119.2432 |
| X Variable 1 | 1049.153 | 6.073170033 | 172.7521 | 3.3507E-05 | 1023.02182 | 1075.283 | 1023.022 | 1075.283 |

## APPENDIX 4: FIGURE A9

**Cr** **357.869nm**

| Std Conc ($x_i$) | Signal ($y_i$) | $x_i^2$ | $\ddot{y}_i$ | $\lvert yi - \ddot{y}i \rvert$ | $(yi - \ddot{y}i)^2$ | $(x_i - x_m)^2$ |
|---|---|---|---|---|---|---|
| 0 | 8.5556 | 0 | -256.874 | 265.4298 | 70452.97672 | 60.0625 |
| 1 | 4285.9 | 1 | 4308.124 | -22.2243 | 493.9180794 | 45.5625 |
| 5 | 22263 | 25 | 22568.12 | -305.118 | 93097.06954 | 7.5625 |
| 25 | 113930 | 625 | 113868.1 | 61.9126 | 3833.169481 | 297.5625 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 31 | 35121.8639 | 651 | | | 167877.1338 | 410.75 |
| 7.75 | | | | | | |
| a | -256.874196 | | | | | |
| b | 4564.998464 | | | | | |




| | |
|---|---|
| No. of Stds | 4 |
| DF | 2 |
| sy/x | 289.7215334 |
| $s_a$ | 182.3696177 |
| $s_b$ | 14.29525771 |
| Lowest signal detectable | 612.290 |
| **Lowest conc. Detectable** | **0.190ppm** |
| Lowest quantitation signal | 2640.341 |
| **Lowest conc.quantifiable** | **0.635ppm** |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.99999 |
| R Square | 0.99998 |
| Adjusted R Square | 0.999971 |
| Standard Error | 289.7215 |
| Observations | 4 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 8559705909 | 8.56E+09 | 101975.84 | 9.8061E-06 |
| Residual | 2 | 167877.1338 | 83938.57 | | |
| Total | 3 | 8559873786 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -256.874 | 182.3696177 | -1.40854 | 0.29431686 | -1041.54788 | 527.7995 | -1041.55 | 527.7995 |
| X Variable 1 | 4564.998 | 14.29525771 | 319.3366 | 9.8061E-06 | 4503.49089 | 4626.506 | 4503.491 | 4626.506 |