

VACUUM FURNACE  
REFERENCE SERIES

number 1

# Critical Melting Points and Reference Data for Vacuum Heat Treating



# Critical Melting Points and Reference Data for Vacuum Heat Treating

---

Edited by: Virginia Osterman, Ph.D.  
Harry Antes Jr., Ph.D.  
Technical Consultants  
September 2010



## **Acknowledgments**

This work is an update of the original reference compilation by Charles F. Burns, Jr., Copyright 1997. The current booklet contains revisions to the original work as well as numerous additions. This booklet should serve as a handy reference for people that work in the metals industry.

Contributors to this body of work include:

William R Jones, CEO

Don Jordan, Vice President -Technology/Corporate Metallurgist

Robert Hill Jr., President - Western PA

Trevor Jones, Engineer -Technology

## **Limitations**

This data is for reference only. Solar Atmospheres Inc. will not assume liability for accuracy.

## TABLE OF CONTENTS

|                                                                                          |        |
|------------------------------------------------------------------------------------------|--------|
| Definitions                                                                              | 4      |
| Melting Points of:                                                                       |        |
| Elements                                                                                 | 5      |
| Stainless Steels                                                                         | 7      |
| Corrosion-resistant Steel Castings                                                       | 8      |
| Heat-resistant Alloy Castings                                                            | 8, 9   |
| Aluminum Alloys                                                                          | 9, 10  |
| Aluminum Casting Alloys                                                                  | 10, 11 |
| Copper Alloys                                                                            | 12, 13 |
| Copper Casting Alloys                                                                    | 13, 14 |
| Magnesium Alloys/ Casting Alloys                                                         | 14     |
| Magnesium Alloys/Wrought Alloys                                                          | 15     |
| Nickel Alloys                                                                            | 15     |
| Super Alloys                                                                             | 16-18  |
| Tin Alloys                                                                               | 18     |
| Zinc Alloys                                                                              | 19     |
| Precious Metal Alloys                                                                    | 19     |
| Ni-Cr-Mo alloys                                                                          | 19     |
| Electrical Resistance Alloys                                                             | 20     |
| Titanium Alloys                                                                          | 20     |
| Eutectics                                                                                | 21, 22 |
| Onset Temperature of Adverse Reactions Between Oxides or Graphite with Furnace Materials | 23     |
| Melting Point of Certain Simple and Complex Metal Oxides                                 | 24     |
| Black Body Radiation Graph                                                               | 25     |
| Emissivity of Common Materials                                                           | 26     |
| Emissivity of Select Metals                                                              | 26, 27 |
| Vapor Pressure of the Elements                                                           | 28, 29 |
| Vapor Pressure of Certain Metal Oxides                                                   | 30     |
| Richardson-Ellingham Diagram                                                             | 31     |
| Gas Purge Chart and Dew Point vs. PPM Charts                                             | 32     |
| Vacuum Furnace Blank Off Pressure vs. Leak Rate                                          | 33     |
| Common English to Metric Conversion                                                      | 34     |
| Common Pressure Conversion Factors                                                       | 35     |
| Equivalence Table for Pressure Between PSI Gauge and Absolute Pressure                   | 36     |
| Equivalence Table for Pressure/Vacuum Measurements                                       | 37     |
| Temperature Conversion Table                                                             | 38     |
| Powder Metals: U.S. Mesh Conversion to Microns                                           | 39     |
| References                                                                               | 40     |

## DEFINITIONS

### ALLOY

[MET] Any of a large number of substances having metallic properties consisting of two or more elements; at least one component must be a metal.

### EUTECTIC ALLOY

[Met] A material, predominantly one of a specific microstructure, made up of two or more phases formed simultaneously during solidification of two or more elements. A eutectic alloy melts to become a free running liquid at a single temperature, which is lower than the melting point of any of its components.

### EMISSION

The ratio defined by the radiation emitted by a surface to the radiation emitted by a blackbody at the same temperature.

### MELTING OF PURE SUBSTANCES

[Chem] The temperature, at given pressure, upon which a chemically pure substance changes from a solid state to a liquid state.

### MELTING POINT OF MIXTURES OR ALLOYS

[MET] Unlike pure metals, many alloys do not have a single melting point. Instead, they have a melting range in which the material is a mixture of solid and liquid phases during the melting process. The temperature at which melting begins is called the solidus, and that at which melting is complete is called the liquidus. Special alloys can be designed with a single melting point, however, and these are called eutectic mixtures.

### VAPOR PRESSURE

The vapor pressure of a substance (liquid or solid) is the equilibrium pressure of a vapor above the substance; in other words the vapor (formed from evaporation or sublimation) above the substance when in a closed container.

*When working in vacuum one must recognize that even if the work is not at the boiling point for the substance there is always vapor forming above the surface and excessive heating of a substance under vacuum has the possibility of evaporating the substance. For example at 760 Torr and 50 °C, if water is heated for an extended period in an open container the water will eventually evaporate. Therefore care must be used when heating under vacuum at high temperatures if one is at or near the known vapor pressure of a substance.*

### SUBLIMATION

A phase change process in which a material passes from a solid state to a gaseous state without becoming a liquid.

| <b>MELTING POINTS OF THE ELEMENTS</b><br>(atmospheric pressure), (s) = sublimes |        |                    |                    |
|---------------------------------------------------------------------------------|--------|--------------------|--------------------|
| Element                                                                         | Symbol | Melting Point (°F) | Melting Point (°C) |
| Aluminum                                                                        | Al     | 1220               | 660                |
| Antimony                                                                        | Sb     | 1168               | 631                |
| Arsenic                                                                         | As     | 1135 (s)           | 613 (s)            |
| Barium                                                                          | Ba     | 1341               | 727                |
| Beryllium                                                                       | Be     | 2348.6             | 1287               |
| Bismuth                                                                         | Bi     | 520                | 271.3              |
| Boron                                                                           | B      | 3767               | 2075               |
| Cadmium                                                                         | Cd     | 610                | 321                |
| Calcium                                                                         | Ca     | 1544               | 840                |
| Carbon                                                                          | C      | 6588 (s)           | 3642 (s)           |
| Cerium                                                                          | Ce     | 1468               | 798                |
| Cesium                                                                          | Cs     | 83.4               | 28.4               |
| Chromium                                                                        | Cr     | 3465               | 1907               |
| Cobalt                                                                          | Co     | 2723               | 1495               |
| Copper                                                                          | Cu     | 1981               | 1083               |
| Columbium (Niobium)                                                             | Cb     | 4491               | 2477               |
| Dysprosium                                                                      | Dy     | 2574               | 1412               |
| Erbium                                                                          | Er     | 2784               | 1529               |
| Europium                                                                        | Eu     | 1512               | 822                |
| Gallium                                                                         | Ga     | 86                 | 30                 |
| Germanium                                                                       | Ge     | 1719               | 937                |
| Gold                                                                            | Au     | 1947               | 1064               |
| Hafnium                                                                         | Hf     | 4051               | 2233               |
| Indium                                                                          | In     | 314                | 157                |
| Iodine                                                                          | I      | 237                | 114                |
| Iridium                                                                         | Ir     | 4435               | 2446               |
| Iron                                                                            | Fe     | 2795               | 1535               |
| Lanthanum                                                                       | La     | 1684               | 918                |
| Lead                                                                            | Pb     | 622                | 328                |
| Lithium                                                                         | Li     | 358                | 181                |
| Magnesium                                                                       | Mg     | 1202               | 650                |
| Manganese                                                                       | Mn     | 2275               | 1246               |
| Mercury                                                                         | Hg     | -37.97             | -38.87             |

| <b>MELTING POINTS OF THE ELEMENTS</b><br>(atmospheric pressure), (s) = sublimes |        |                       |                       |
|---------------------------------------------------------------------------------|--------|-----------------------|-----------------------|
| Molybdenum                                                                      | Mo     | 4748                  | 2620                  |
| Element                                                                         | Symbol | Melting Point<br>(°F) | Melting Point<br>(°C) |
| Neodymium                                                                       | Nd     | 1870                  | 1021                  |
| Nickel                                                                          | Ni     | 2647                  | 1453                  |
| Niobium (Columbium)                                                             | Nb     | 4491                  | 2477                  |
| Osmium                                                                          | Os     | 5491                  | 3033                  |
| Palladium                                                                       | Pd     | 2826                  | 1552                  |
| Phosphorus                                                                      | P      | 111                   | 44                    |
| Platinum                                                                        | Pt     | 3214                  | 1768                  |
| Potassium                                                                       | K      | 147                   | 64                    |
| Praseodymium                                                                    | Pr     | 1708                  | 931                   |
| Rhenium                                                                         | Re     | 5756                  | 3180                  |
| Rhodium                                                                         | Rh     | 3567                  | 1964                  |
| Rubidium                                                                        | Rb     | 102                   | 39                    |
| Ruthenium                                                                       | Ru     | 4233                  | 2334                  |
| Scandium                                                                        | Sc     | 2802                  | 1539                  |
| Selenium                                                                        | Se     | 422                   | 217                   |
| Silicon                                                                         | Si     | 2570                  | 1410                  |
| Silver                                                                          | Ag     | 1764                  | 962                   |
| Sodium                                                                          | Na     | 208                   | 98                    |
| Strontium                                                                       | Sr     | 1431                  | 777                   |
| Sulfur                                                                          | S      | 239                   | 115                   |
| Tantalum                                                                        | Ta     | 5425                  | 2996                  |
| Tellurium                                                                       | Te     | 842                   | 450                   |
| Thallium                                                                        | Tl     | 579                   | 304                   |
| Thorium                                                                         | Th     | 3182                  | 1750                  |
| Tin                                                                             | Sn     | 450                   | 232                   |
| Titanium                                                                        | Ti     | 3034                  | 1668                  |
| Tungsten                                                                        | W      | 6192                  | 3422                  |
| Uranium                                                                         | U      | 2070                  | 1132                  |
| Vanadium                                                                        | V      | 3434                  | 1890                  |
| Yttrium                                                                         | Y      | 2773                  | 1523                  |
| Zinc                                                                            | Zn     | 788                   | 420                   |
| Zirconium                                                                       | Zr     | 3366                  | 1852                  |

| <b>MELTING POINTS</b>   |                             |                            |
|-------------------------|-----------------------------|----------------------------|
| <b>Stainless Steels</b> |                             |                            |
| <b>Alloy</b>            | <b>MELTING RANGE<br/>°F</b> | <b>MELTINGRANGE<br/>°C</b> |
| 301 S/S                 | 2550-2590                   | 1400-1420                  |
| 302 S/S                 | 2550-2590                   | 1400-1420                  |
| 302B S/S                | 2500-2550                   | 1370-1400                  |
| 303 S/S                 | 2550-2590                   | 1400-1420                  |
| 304 S/S                 | 2550-2650                   | 1400-1455                  |
| 305 S/S                 | 2550-2650                   | 1400-1455                  |
| 308 S/S                 | 2550-2650                   | 1400-1455                  |
| 309 S/S                 | 2550-2650                   | 1400-1455                  |
| 310 S/S                 | 2550-2650                   | 1400-1455                  |
| 314 S/S                 | 2412-2530                   | 1322-1388                  |
| 316 S/S                 | 2500-2550                   | 1370-1400                  |
| 317 S/S                 | 2500-2550                   | 1370-1400                  |
| 321 S/S                 | 2550-2600                   | 1400-1425                  |
| 330 S/S                 | 2550-2600                   | 1400-1425                  |
| 347 S/S                 | 2550-2600                   | 1400-1425                  |
| 384 S/S                 | 2550-2650                   | 1400-1455                  |
| 403 S/S                 | 2700-2790                   | 1480-1530                  |
| 405 S/S                 | 2700-2790                   | 1480-1530                  |
| 409 S/S                 | 2600-2750                   | 1425-1510                  |
| 410 S/S                 | 2700-2790                   | 1480-1530                  |
| 416 S/S                 | 2700-2790                   | 1480-1530                  |
| 420 S/S                 | 2650-2750                   | 1455-1510                  |
| 430 S/S                 | 2650-2750                   | 1455-1510                  |
| 430F S/S                | 2550-2650                   | 1400-1455                  |
| 431 S/S                 | 2600-2700                   | 1476-1482                  |
| 440A S/S                | 2500-2750                   | 1370-1510                  |
| 440B S/S                | 2500-2750                   | 1370-1510                  |
| 440C S/S                | 2500-2750                   | 1370-1510                  |
| 442,443,446 S/S         | 2600-2750                   | 1425-1510                  |
| 501 S/S                 | 2700-2800                   | 1480-1540                  |
| 502 S/S                 | 2700-2800                   | 1480-1540                  |

| <b>MELTING POINTS</b><br><b>Corrosion-resistant Steel Castings</b> |                             |                             |
|--------------------------------------------------------------------|-----------------------------|-----------------------------|
| <b>Alloy</b>                                                       | <b>MELTING POINT<br/>°F</b> | <b>MELTING POINT<br/>°C</b> |
| CA-15                                                              | 2750                        | 1510                        |
| CA-40                                                              | 2750                        | 1510                        |
| CB-30                                                              | 2725                        | 1496                        |
| CC-50                                                              | 2725                        | 1496                        |
| CE-30                                                              | 2650                        | 1454                        |
| CF-8                                                               | 2600                        | 1427                        |
| CF-20                                                              | 2575                        | 1413                        |
| CF-8M                                                              | 2550                        | 1399                        |
| CF-12M                                                             | 2550                        | 1399                        |
| CF-8C                                                              | 2600                        | 1427                        |
| CF-16F                                                             | 2550                        | 1399                        |
| CH-20                                                              | 2600                        | 1427                        |
| CK-20                                                              | 2600                        | 1427                        |
| CN-7M                                                              | 2650                        | 1454                        |

| <b>MELTING POINTS</b><br><b>Heat-resistant Alloy Castings</b> |                             |                             |
|---------------------------------------------------------------|-----------------------------|-----------------------------|
| <b>ALLOY</b>                                                  | <b>MELTING POINT<br/>°F</b> | <b>MELTING POINT<br/>°C</b> |
| HA                                                            | 2750                        | 1510                        |
| HC                                                            | 2725                        | 1496                        |
| HD                                                            | 2700                        | 1482                        |
| HE                                                            | 2650                        | 1454                        |
| HF                                                            | 2550                        | 1399                        |
| HH                                                            | 2500                        | 1371                        |
| HI                                                            | 2550                        | 1399                        |
| HK                                                            | 2550                        | 1399                        |
| HL                                                            | 2600                        | 1427                        |
| HN                                                            | 2500                        | 1371                        |
| HP                                                            | 2450                        | 1343                        |
| HT                                                            | 2450                        | 1343                        |

| <b>MELTING POINTS</b><br><b>Heat-resistant Alloy Castings</b> |                             |                             |
|---------------------------------------------------------------|-----------------------------|-----------------------------|
| <b>ALLOY</b>                                                  | <b>MELTING POINT<br/>°F</b> | <b>MELTING POINT<br/>°C</b> |
| HA                                                            | 2750                        | 1510                        |
| HC                                                            | 2725                        | 1496                        |
| HD                                                            | 2700                        | 1482                        |
| HE                                                            | 2650                        | 1454                        |
| HF                                                            | 2550                        | 1399                        |
| HH                                                            | 2500                        | 1371                        |
| HI                                                            | 2550                        | 1399                        |
| HK                                                            | 2550                        | 1399                        |
| HL                                                            | 2600                        | 1427                        |
| HN                                                            | 2500                        | 1371                        |
| HU                                                            | 2450                        | 1343                        |
| HW                                                            | 2350                        | 1288                        |
| HX                                                            | 2350                        | 1288                        |

| <b>MELTING POINTS</b><br><b>Aluminum Alloys</b> |                                   |                                   |
|-------------------------------------------------|-----------------------------------|-----------------------------------|
| <b>ALLOY</b>                                    | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| EC                                              | 1215                              | 657                               |
| 1060                                            | 1195-1215                         | 646-657                           |
| 1100                                            | 1190-1215                         | 643-657                           |
| 2011                                            | 1005-1190                         | 541-643                           |
| 2014                                            | 945-1180                          | 507-637                           |
| 2024                                            | 935-1180                          | 507-638                           |
| 2218                                            | 940-1175                          | 504-635                           |
| 3003                                            | 1190-1210                         | 643-654                           |
| 4032                                            | 990-1060                          | 532-571                           |
| 5005                                            | 1170-1210                         | 632-654                           |
| 5050                                            | 1155-1205                         | 624-652                           |
| 5052                                            | 1125-1200                         | 607-649                           |
| 5056                                            | 1055-1180                         | 568-638                           |
| 5083                                            | 1095-1180                         | 591-638                           |
| 5086                                            | 1085-1185                         | 585-641                           |

| <b>MELTING POINTS</b><br><b>Aluminum Alloys</b> |                             |                             |
|-------------------------------------------------|-----------------------------|-----------------------------|
| 5154                                            | 1100-1190                   | 545-643                     |
| <b>ALLOY</b>                                    | <b>MELTING RANGE<br/>°F</b> | <b>MELTING RANGE<br/>°C</b> |
| 5357                                            | 1210                        | 654                         |
| 5456                                            | 1055-1180                   | 568-638                     |
| 6061                                            | 1080-1205                   | 582-652                     |
| 6063                                            | 1140-1210                   | 616-654                     |
| 6101                                            | 1150-1210                   | 621-654                     |
| 6151                                            | 1090-1200                   | 588-649                     |
| 7075                                            | 890-1175                    | 477-635                     |
| 7079                                            | 1180                        | 637                         |
| 7178                                            | 890-1165                    | 477-629                     |

| <b>MELTING POINTS</b><br><b>Aluminum Casting Alloys</b> |                             |                             |
|---------------------------------------------------------|-----------------------------|-----------------------------|
| <b>ALLOY</b>                                            | <b>MELTING RANGE<br/>°F</b> | <b>MELTING RANGE<br/>°C</b> |
| 201.0                                                   | 1060-1200                   | 570-650                     |
| 206.0                                                   | 1060-1200                   | 570-650                     |
| A206.0                                                  | 1060-1200                   | 570-650                     |
| 208.0                                                   | 970-1170                    | 520-630                     |
| 222.0                                                   | 970-1160                    | 520-625                     |
| 224.0                                                   | 1020-1190                   | 550-645                     |
| 238.0                                                   | 950-1110                    | 510-600                     |
| 240.0                                                   | 960-1120                    | 515-605                     |
| 242.0                                                   | 990-1180                    | 530-635                     |
| 295.0                                                   | 970-1190                    | 520-645                     |
| 296.0                                                   | 970-1170                    | 520-630                     |
| 308.0                                                   | 970-1140                    | 520-615                     |
| 319.0                                                   | 970-1120                    | 520-605                     |
| 324.0                                                   | 1010-1120                   | 545-605                     |
| 332.0                                                   | 970-1080                    | 520-580                     |
| 333.0                                                   | 970-1090                    | 520-585                     |
| 336.0                                                   | 1000-1060                   | 540-570                     |
| 354.0                                                   | 1000-1110                   | 540-600                     |
| 355.0                                                   | 1020-1150                   | 550-620                     |
| C355.0                                                  | 1020-1150                   | 550-620                     |

| <b>MELTING POINTS</b><br><b>Aluminum Casting Alloys</b> |                     |                     |
|---------------------------------------------------------|---------------------|---------------------|
| 356.0                                                   | 1040-1140           | 560-615             |
| ALLOY                                                   | MELTING RANGE<br>°F | MELTING RANGE<br>°C |
| A356.0                                                  | 1040-1130           | 560-610             |
| 357.0                                                   | 1040-1140           | 560-615             |
| A357.0                                                  | 1030-1130           | 555-610             |
| 358.0                                                   | 1040-1110           | 560-600             |
| 359.0                                                   | 1050-1110           | 565-600             |
| 360.0                                                   | 1060-1090           | 570-590             |
| A360.0                                                  | 1060-1090           | 570-590             |
| 364.0                                                   | 1040-1110           | 560-600             |
| 380.0                                                   | 970-1090            | 520-590             |
| A380.0                                                  | 970-1090            | 520-590             |
| 384.0                                                   | 900-1080            | 480-580             |
| 390.0                                                   | 950-1200            | 510-650             |
| 392.0                                                   | 1020-1240           | 550-670             |
| 413.0                                                   | 1070-1090           | 575-585             |
| A413.0                                                  | 1070-1090           | 575-585             |
| 443.0                                                   | 1070-1170           | 575-630             |
| A444.0                                                  | 1070-1170           | 575-630             |
| 511.0                                                   | 1090-1180           | 590-640             |
| 512.0                                                   | 1090-1170           | 590-630             |
| 513.0                                                   | 1080-1180           | 580-640             |
| 514.0                                                   | 1110-1180           | 600-640             |
| 518.0                                                   | 1000-1150           | 540-620             |
| 520.0                                                   | 840-1110            | 450-600             |
| 535.0                                                   | 1020-1170           | 550-630             |
| A535.0                                                  | 1020-1150           | 550-620             |
| B535.0                                                  | 1020-1170           | 550-630             |
| 705.0                                                   | 1110-1180           | 600-640             |
| 707.0                                                   | 1090-1170           | 585-630             |
| 710.0                                                   | 1110-1200           | 600-650             |
| 711.0                                                   | 1110-1190           | 600-645             |
| 712.0                                                   | 1110-1180           | 600-640             |
| 713.0                                                   | 1100-1170           | 595-630             |
| 850.0                                                   | 440-1200            | 225-650             |
| 851.0                                                   | 450-1170            | 230-630             |
| 852.0                                                   | 410-1180            | 210-635             |

| <b>MELTING POINTS/RANGES</b>               |                                   |                                   |
|--------------------------------------------|-----------------------------------|-----------------------------------|
| <b>Copper Alloys</b>                       |                                   |                                   |
| <b>ALLOY</b>                               | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| C10200 (Oxygen Free)                       | <b>1950-1980</b>                  | 1065-1083                         |
| C11000 (Copper ETP)                        | <b>1950-1980</b>                  | 1065-1083                         |
| C12000 (Copper DLP)                        | <b>1981</b>                       | 1083                              |
| C12200 (Copper DHP)                        | <b>1981</b>                       | 1083                              |
| C14500 (Free Machining [Te])               | <b>1924-1967</b>                  | 1051-1075                         |
| C17000 (Beryllium Copper)                  | <b>1590-1800</b>                  | 805-980                           |
| C21000 (Gilding)                           | <b>1920-1950</b>                  | 1050-1066                         |
| C22000 (Commercial Bronze [90% Cu])        | <b>1870-1910</b>                  | 1020-1043                         |
| C22600 (Jewelry Bronze [87.5% Cu])         | <b>1840-1890</b>                  | 1005-1035                         |
| C23000 (Red Brass [85% Cu])                | <b>1810-1880</b>                  | 990-1027                          |
| C24000 (Low Brass [80% Cu])                | <b>1770-1830</b>                  | 965-1000                          |
| C26000 (Cartridge Brass [70% Cu])          | <b>1680-1750</b>                  | 915-954                           |
| C27000 (Yellow Brass [65% Cu])             | <b>1660-1710</b>                  | 905-932                           |
| C280000 (Muntz Metal [60% Cu])             | <b>1650-1660</b>                  | 900-904                           |
| C31400 (Leaded Commercial Bronze)          | <b>1850-1900</b>                  | 1010-1038                         |
| C33000 Low Leaded Brass [0.5% Pb])         | <b>1660-1720</b>                  | 905-938                           |
| C34000 (Medium Leaded Brass [1% Pb])       | <b>1630-1700</b>                  | 885-927                           |
| C35300 (High Leaded Brass [1.6% Pb])       | <b>1650-1710</b>                  | 900-932                           |
| C34200 (High Leaded Brass [2% Pb])         | <b>1630-1670</b>                  | 885-910                           |
| C35600 (Extra High Leaded Brass [2.5% Pb]) | <b>1630-1660</b>                  | 885-904                           |
| C36000 (Free Cutting Brass)                | <b>1630-1650</b>                  | 885-900                           |
| C36500 (Leaded Muntz Metal)                | <b>1630-1650</b>                  | 885-900                           |
| C37700 (Forging Brass)                     | <b>1620-1640</b>                  | 880-893                           |
| C38500 (Architectural Bronze)              | <b>1610-1630</b>                  | 875-888                           |
| C44400 (Inhibited Admiralty)               | <b>1650-1720</b>                  | 900-938                           |
| C46400 (Naval Brass)                       | <b>1630-1650</b>                  | 885-900                           |
| C50500 (Phosphor Bronze [1.25% Sn])        | <b>1890-1970</b>                  | 1035-1077                         |
| C51000 (Phosphor Bronze [5% Sn])           | <b>1790-1940</b>                  | 975-1060                          |
| C52100 (Phosphor Bronze [8% Sn])           | <b>1620-1880</b>                  | 880-1027                          |
| C52400 (Phosphor Bronze [10% Sn])          | <b>1550-1830</b>                  | 845-1000                          |
| C54400 (Free Cutting Phosphor Bronze)      | <b>1710-1830</b>                  | 930-1000                          |
| C60600 (Aluminum Bronze [5% Al])           | <b>1920-1950</b>                  | 1050-1065                         |

| <b>MELTING POINTS/RANGES</b>            |                                   |                                   |
|-----------------------------------------|-----------------------------------|-----------------------------------|
| <b>Copper Alloys</b>                    |                                   |                                   |
| <b>ALLOY</b>                            | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| C61000 (Aluminum Bronze [7% Al])        | <b>1900-1910</b>                  | 1040-1045                         |
| C62300 (Aluminum Bronze [11% Al])       | <b>1880-1900</b>                  | 1025-1040                         |
| C63200 (Aluminum Bronze [9% Al])        | <b>1900-1910</b>                  | 1040-1045                         |
| C64200 (Aluminum Silicon Bronze)        | <b>1800-1840</b>                  | 985-1004                          |
| C65500 (High Silicon Bronze [3% Si])    | <b>1780-1880</b>                  | 970-1027                          |
| Low Silicon Bronze (1.5% Si)            | <b>1890-1940</b>                  | 1030-1060                         |
| C67500 (Manganese Bronze)               | <b>1630-1690</b>                  | 888-920                           |
| C70600 (Cupro-Nickel [10% Ni])          | <b>2010-2100</b>                  | 1100-1149                         |
| C71500 (Cupro-Nickel [30% Ni])          | <b>2140-2260</b>                  | 1170-1238                         |
| C75200 (Nickel-Silver [65% Cu])         | <b>2030</b>                       | 1110                              |
| C75700 (Nickel-Silver [65% Cu- 12% Ni]) | <b>1900</b>                       | 1038                              |
| C77000 (Nickel-Silver [55% Cu])         | <b>1930</b>                       | 1054                              |

| <b>MELTING POINTS</b>            |                                   |                                   |
|----------------------------------|-----------------------------------|-----------------------------------|
| <b>Copper Casting Alloys</b>     |                                   |                                   |
| <b>ALLOY</b>                     | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Chrome Copper (1% Cr)            | <b>1970-1990</b>                  | 1075-1085                         |
| Tin Bronze, Alloy 1A             | <b>1570-1830</b>                  | 834-1000                          |
| Tin Bronze, Alloy 1B             | <b>1570-1830</b>                  | 834-1000                          |
| Tin Bronze, Alloy SAE 65         | <b>1832</b>                       | 1000                              |
| Navy M Bronze, Alloy 2A          | <b>1520-1810</b>                  | 825-990                           |
| Leaded Tin Bronze, Alloy 2B      | <b>1570-1830</b>                  | 854-1000                          |
| Leaded Tin Bronze, Alloy 2C      | <b>1550-1800</b>                  | 845-980                           |
| High Leaded Tin Bronze, Alloy 3A | <b>1400-1710</b>                  | 762-930                           |
| High Leaded Tin Bronze, Alloy 3B | <b>1570-1790</b>                  | 855-975                           |
| High Leaded Tin Bronze, Alloy 3C | <b>1570-1830</b>                  | 855-1000                          |
| High Leaded Tin Bronze, Alloy 3D | <b>1570-1730</b>                  | 855-945                           |
| High Leaded Tin Bronze, Alloy 3E | <b>1650-1700</b>                  | 900-925                           |
| Leaded Red Brass, Alloy 4A       | <b>1570-1850</b>                  | 855-1010                          |
| Leaded Red Brass, Alloy 4B       | <b>1550-1840</b>                  | 845-1005                          |
| Leaded Semi Red Brass, Alloy 5A  | <b>1540-1840</b>                  | 840-1005                          |
| Leaded Semi Red Brass, Alloy 5B  | <b>1530-1750</b>                  | 832-955                           |
| Leaded Yellow Brass, Alloy 6A    | <b>1700-1720</b>                  | 925-940                           |

| <b>MELTING POINTS</b><br><b>Copper Casting Alloys</b> |                                   |                                   |
|-------------------------------------------------------|-----------------------------------|-----------------------------------|
| <b>ALLOY</b>                                          | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Leaded Yellow Brass, Alloy 6B                         | <b>1700-1720</b>                  | 925-940                           |
| Manganese Bronze (59% Cu)                             | <b>1675</b>                       | 913                               |
| Manganese Bronze (57.5% Cu)                           | <b>1616</b>                       | 880                               |
| Manganese Bronze (64% Cu)                             | <b>1700</b>                       | 937                               |
| Manganese Bronze (110,000 psi)                        | <b>1693</b>                       | 923                               |
| Aluminum Bronze, Alloy 9A                             | <b>1900-1910</b>                  | 1040-1045                         |
| Aluminum Bronze, Alloy 9B                             | <b>1900-1910</b>                  | 1040-1045                         |
| Aluminum Bronze, Alloy 9C                             | <b>1880-1900</b>                  | 1027-1040                         |
| Aluminum Bronze, Alloy 9D                             | <b>1900-1930</b>                  | 1038-1055                         |
| Nickel Silver (12% Ni)                                | <b>Max: 1900</b>                  | Max: 1040                         |
| Nickel Silver (15% Ni)                                | <b>1850-1970</b>                  | 1010-1075                         |
| Nickel Silver (18% Ni)                                | <b>Max: 1930</b>                  | Max: 1055                         |
| Nickel Silver (25% Ni)                                | <b>2300</b>                       | 1260                              |
| Low-Silicon Bronze (1% Si)                            | <b>1890-1940</b>                  | 1030-1060                         |
| High-Silicon Bronze (3% Si)                           | <b>1780-1880</b>                  | 700-875                           |
| Silicon Brass                                         | <b>1510-1680</b>                  | 821-917                           |

| <b>MELTING POINTS</b><br><b>Magnesium Alloys/Casting Alloys</b> |                                   |                                   |
|-----------------------------------------------------------------|-----------------------------------|-----------------------------------|
| <b>ALLOY</b>                                                    | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| AM100A                                                          | <b>1101</b>                       | 594                               |
| AZ63A                                                           | <b>1130</b>                       | 610                               |
| AZ81A                                                           | <b>1132</b>                       | 611                               |
| AZ91A, B & C Alloys                                             | <b>1105</b>                       | 596                               |
| AZ92A                                                           | <b>1100</b>                       | 593                               |
| HK31A                                                           | <b>1090-1200</b>                  | 590-650                           |
| HZ32A                                                           | <b>1020-1200</b>                  | 550-650                           |
| ZH42                                                            | <b>1180</b>                       | 638                               |
| ZH62A                                                           | <b>968-1170</b>                   | 520-630                           |
| ZK51A                                                           | <b>1020-1180</b>                  | 550-640                           |
| ZE41A                                                           | <b>977-1190</b>                   | 525-645                           |
| EZ33A                                                           | <b>1010-1190</b>                  | 545-645                           |
| EZ30A                                                           | <b>1184</b>                       | 640                               |
| EZ41A                                                           | <b>1193</b>                       | 645                               |

| <b>MELTING POINTS</b><br><b>Magnesium Alloys/Wrought Alloys</b> |                                   |                                   |
|-----------------------------------------------------------------|-----------------------------------|-----------------------------------|
| <b>ALLOY</b>                                                    | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| MIA                                                             | 1200                              | 649                               |
| AZ31B                                                           | 1120-1170                         | 605-632                           |
| PE                                                              | 990-1170                          | 532-632                           |
| AZ61A                                                           | 785-1150                          | 418-620                           |
| AZ80A                                                           | 801-1130                          | 421-610                           |
| ZK60A                                                           | 964-1170                          | 518-635                           |
| ZE10A                                                           | 1195                              | 646                               |
| HM21A                                                           | 1120-1200                         | 605-650                           |
| HM31A                                                           | 900-1200                          | 482-650                           |

| <b>MELTING POINTS</b><br><b>Nickel Alloys</b> |                                   |                                   |
|-----------------------------------------------|-----------------------------------|-----------------------------------|
| <b>ALLOY</b>                                  | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| "A" Nickel                                    | 2642                              | 1450                              |
| "D" Nickel                                    | 2600                              | 1427                              |
| Duranickel                                    | 2550-2620                         | 1400-1440                         |
| Cast Nickel                                   | 2450                              | 1343                              |
| Monel                                         | 2370                              | 1299                              |
| "K" Monel                                     | 2400-2460                         | 1315-1349                         |
| Monel (Cast)                                  | 2450                              | 1343                              |
| "H" Monel (Cast)                              | 2315                              | 1268                              |
| "S" Monel (Cast)                              | 2300                              | 1260                              |
| Inconel                                       | 2470-2580                         | 1354-1413                         |
| Inconel (Cast)                                | 2500                              | 1371                              |
| Ni-O-Nel                                      | 1340-1390                         | 727-754                           |
| Hastelloy Alloy "B"                           | 2375-2495                         | 1302-1368                         |
| Hastelloy Alloy "C"                           | 2417-2498                         | 1325-1370                         |
| Hastelloy Alloy "D"                           | 2050                              | 1121                              |
| Hastelloy Alloy "F"                           | 2350                              | 1288                              |
| Hastelloy Alloy "N"                           | 2370-2550                         | 1300-1400                         |
| Hastelloy Alloy "W"                           | 2400                              | 1316                              |
| Hastelloy Alloy "X"                           | 2300-2470                         | 1260-1355                         |

| <b>MELTING POINTS/RANGES</b> |                                   |                                   |
|------------------------------|-----------------------------------|-----------------------------------|
| <b>Superalloys</b>           |                                   |                                   |
| <b>ALLOY</b>                 | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Inconel alloy 600            | 2470-2575                         | 1354-1413                         |
| Inconel alloy 601            | 2480-2571                         | 1360-1411                         |
| Inconel alloy 601GC          | 2374-2494                         | 1301-1368                         |
| Inconel alloy 603XL          | 2516-2552                         | 1380-1400                         |
| Inconel alloy 617            | 2430-2510                         | 1332-1380                         |
| Inconel alloy 625            | 2350-2460                         | 1290-1350                         |
| Inconel alloy 625LCF         | 2350-2460                         | 1290-1350                         |
| Inconel alloy 686            | 2440-2516                         | 1338-1380                         |
| Inconel alloy 690            | 2450-2510                         | 1343-1377                         |
| Inconel alloy 693            | 2403-2493                         | 1317-1367                         |
| Inconel alloy 706            | 2434-2499                         | 1334-1371                         |
| Inconel alloy 718            | 2300-2437                         | 1260-1336                         |
| Inconel alloy 718SPF         | 2300-2437                         | 1260-1336                         |
| Inconel alloy 725            | 2320-2449                         | 1271-1343                         |
| Inconel alloy 740            | 2350-2484                         | 1288-1362                         |
| Inconel alloy X-750          | 2540-2600                         | 1393-1427                         |
| Inconel alloy 751            | 2540-2600                         | 1393-1427                         |
| Inconel alloy MA754          | 2550                              | 1400                              |
| Inconel alloy MA758          | 2507                              | 1375                              |
| Inconel alloy 783            | 2437-2565                         | 1336-1407                         |
| Inconel alloy 230            | 2480-2570                         | 1360-1410                         |
| Inconel alloy C-276          | 2415-2500                         | 1325-1370                         |
| Inconel alloy G-3            | 2300-2450                         | 1260-1343                         |
| Inconel alloy HX             | 2300-2470                         | 1260-1355                         |
| Inconel alloy 22             | 2464-2529                         | 1351-1387                         |
| Incoloy alloy 800            | 2475-2525                         | 1357-1385                         |
| Incoloy alloy 800H/800HT     | 2475-2525                         | 1357-1385                         |
| Incoloy alloy 803            | 2490-2555                         | 1365-1400                         |
| Incoloy alloy 825            | 2500-2550                         | 1370-1400                         |
| Incoloy alloy 864            | 2467-2539                         | 1353-1393                         |

| <b>MELTING POINTS/RANGES</b> |                                   |                                   |
|------------------------------|-----------------------------------|-----------------------------------|
| <b>Superalloys</b>           |                                   |                                   |
| <b>ALLOY</b>                 | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Incoloy alloy 890            | <b>2388-2522</b>                  | 1309-1383                         |
| Incoloy alloy 903            | <b>2405-2539</b>                  | 1318-1393                         |
| Incoloy alloy 907            | <b>2440-2550</b>                  | 1335-1400                         |
| Incoloy alloy 908            | <b>2482-2571</b>                  | 1361-1410                         |
| Incoloy alloy 925            | <b>2392-2490</b>                  | 1311-1366                         |
| Incoloy alloy MA956          | <b>2700</b>                       | 1482                              |
| Incoloy alloy DS             | <b>2426-2552</b>                  | 1330-1400                         |
| Incoloy alloy 330            | <b>2520-2590</b>                  | 1380-1420                         |
| Incoloy alloy 25-6MO         | <b>2410-2550</b>                  | 1320-1400                         |
| Incoloy alloy A-286          | <b>2500-2600</b>                  | 1370-1430                         |
| Brightray alloy B            | <b>2550-2590</b>                  | 1400-1420                         |
| Brightray alloy C            | <b>2520-2550</b>                  | 1380-1400                         |
| Brightray alloy F            | <b>2430-2550</b>                  | 1330-1400                         |
| Brightray alloy S            | <b>2550-2590</b>                  | 1400-1420                         |
| Brightray alloy 35           | <b>2440-2520</b>                  | 1340-1380                         |
| Nimonic alloy 75             | <b>2450-2520</b>                  | 1340-1380                         |
| Nimonic alloy 80A            | <b>2410-2490</b>                  | 1320-1365                         |
| Nimonic alloy 81             | <b>2381-2507</b>                  | 1305-1375                         |
| Nimonic alloy 90             | <b>2390-2500</b>                  | 1310-1370                         |
| Nimonic alloy 91             | <b>2372-2462</b>                  | 1300-1350                         |
| Nimonic alloy 105            | <b>2354-2453</b>                  | 1290-1345                         |
| Nimonic alloy 115            | <b>2300-2399</b>                  | 1260-1315                         |
| Nimonic alloy 263            | <b>2372-2471</b>                  | 1300-1355                         |
| Nimonic alloy 901            | <b>2336-2453</b>                  | 1280-1345                         |
| Nimonic alloy PE11           | <b>2340-2460</b>                  | 1280-1350                         |
| Nimonic alloy PE16           | <b>2390-2471</b>                  | 1310-1355                         |
| Nimonic alloy PK33           | <b>2372-2453</b>                  | 1300-1345                         |
| Udimet alloy 188             | <b>2375-2425</b>                  | 1300-1330                         |
| Udimet alloy L-605           | <b>2426-2570</b>                  | 1330-1410                         |

| <b>MELTING POINTS/RANGES</b> |                                   |                                   |
|------------------------------|-----------------------------------|-----------------------------------|
| <b>Superalloys</b>           |                                   |                                   |
| <b>ALLOY</b>                 | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Udimet alloy 520             | <b>2300-2560</b>                  | 1260-1405                         |
| Udimet alloy 720             | <b>2180-2440</b>                  | 1194-1338                         |
| Udimet alloy D-979           | <b>2225-2530</b>                  | 1220-1390                         |
| Udimet alloy R41             | <b>2250-2535</b>                  | 1232-1391                         |
| Udimet alloy 250             | <b>2600-2650</b>                  | 1427-1454                         |
| Udimet alloy 300             | <b>2600-2650</b>                  | 1427-1454                         |
| Nilo alloy 36                | <b>2605</b>                       | 1430                              |
| Nilo alloy 42                | <b>2615</b>                       | 1435                              |
| Nilo alloy 48                | <b>2640</b>                       | 1450                              |
| Nilo alloy K                 | <b>2640</b>                       | 1450                              |

| <b>MELTING POINTS</b> |                                   |                                   |
|-----------------------|-----------------------------------|-----------------------------------|
| <b>Tin Alloys</b>     |                                   |                                   |
| <b>ALLOY</b>          | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Hard Tin (pure tin)   | <b>450</b>                        | 232                               |
| Antimonial Tin Solder | <b>453-464</b>                    | 234-240                           |
| Tin-Silver Solder     | <b>430-473</b>                    | 221-245                           |
| Soft Solder (70% Sn)  | <b>361-378</b>                    | 183-192                           |
| Soft Solder (63% Sn)  | <b>361</b>                        | 183                               |
| Soft Solder (50% Sn)  | <b>361-421</b>                    | 183-216                           |
| Tin Babbitt Alloy 1   | <b>433-700</b>                    | 223-371                           |
| Tin Babbitt Alloy 2   | <b>466-669</b>                    | 241-354                           |
| Tin Babbitt Alloy 3   | <b>464-792</b>                    | 240-422                           |
| Tin Babbitt Alloy 4   | <b>363-583</b>                    | 184-306                           |
| Tin Babbitt Alloy 5   | <b>358-565</b>                    | 181-296                           |
| Tin Die Casting Alloy | <b>700</b>                        | 371                               |
| White Metal           | <b>475</b>                        | 246                               |
| Pewter                | <b>471-563</b>                    | 244-295                           |

| <b>MELTING POINTS</b>                    |                                   |                                   |
|------------------------------------------|-----------------------------------|-----------------------------------|
| <b>Zinc Alloys</b>                       |                                   |                                   |
| <b>ALLOY</b>                             | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Pure Zinc                                | <b>787</b>                        | 419.6                             |
| AG40A                                    | <b>718-729</b>                    | 381-387                           |
| AC41A                                    | <b>716-727</b>                    | 380-386                           |
| Zinc-Base Slush-Casting Alloy (4.75% Al) | <b>716-734</b>                    | 380-390                           |
| Zinc-Base Slush-Casting Alloy (5.5% Al)  | <b>716-743</b>                    | 380-395                           |
| Commercial Rolled Zinc (0.08% Pb)        | <b>786</b>                        | 419                               |
| Commercial Rolled Zinc (0.06% Pb)        | <b>786</b>                        | 419                               |
| Commercial Rolled Zinc (0.3% Pb)         | <b>786</b>                        | 419                               |
| Copper Hardened Rolled Zinc              | <b>786-792</b>                    | 419-422                           |
| Rolled Zinc Alloy (1% Cu)                | <b>786-792</b>                    | 419-422                           |
| Zn-Cu-Ti                                 | <b>786-792</b>                    | 419-422                           |

| <b>MELTING POINTS</b>        |                                   |                                   |
|------------------------------|-----------------------------------|-----------------------------------|
| <b>Precious Metal Alloys</b> |                                   |                                   |
| <b>ALLOY</b>                 | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Silver                       | <b>1760</b>                       | 962                               |
| 70% Gold – 30% Platinum      | <b>2240-2640</b>                  | 1228-1450                         |
| 60% Pd – 40% Cu              | <b>2180-2240</b>                  | 1196-1224                         |

| <b>MELTING POINTS</b>     |                                   |                                   |
|---------------------------|-----------------------------------|-----------------------------------|
| <b>Ni-Cr-Mo-Cu Alloys</b> |                                   |                                   |
| <b>ALLOY</b>              | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| Illium “B”                | -----                             |                                   |
| Illium “G”                | <b>2300-2440</b>                  | 1260-1338                         |
| Illium “R”                | <b>2500</b>                       | 1371                              |

| <b>MELTING POINTS</b><br><b>Electrical Resistance Alloys</b> |                             |                             |
|--------------------------------------------------------------|-----------------------------|-----------------------------|
| <b>ALLOY</b>                                                 | <b>MELTING POINT<br/>°F</b> | <b>MELTING POINT<br/>°C</b> |
| 80 Ni -20 Cr                                                 | 2550                        | 1400                        |
| 60 Ni -24 Fe-16 Cr                                           | 2530                        | 1390                        |
| 35 Ni-45 Fe-20 Cr                                            | 2530                        | 1390                        |
| Constantan                                                   | 2230                        | 1220                        |

| <b>MELTING POINTS</b><br><b>Titanium Alloys</b> |                                   |                                   |
|-------------------------------------------------|-----------------------------------|-----------------------------------|
| <b>ALLOY</b>                                    | <b>MELTING POINT/RANGE<br/>°F</b> | <b>MELTING POINT/RANGE<br/>°C</b> |
| 99.2%                                           | 3135                              | 1724                              |
| 99.0%                                           | 3020                              | 1660                              |
| Ti- 6 Al - 4V                                   | 2920-3020                         | 1604-1660                         |
| Ti – 5 Al - 2.5 Sn                              | Max: 2890                         | Max: 1590                         |
| Ti – 2 Fe – 2 Cr - 2Mo                          | 3010                              | 1654                              |
| Ti – 8 Mn                                       | 2370-2970                         | 1300-1635                         |
| Ti – 4 Al -4 Mn                                 | 2820                              | 1549                              |

| <b>MELTING POINTS</b>         |                             |                             |
|-------------------------------|-----------------------------|-----------------------------|
| <b>Eutectics</b>              |                             |                             |
| <b>ALLOY (Element-Wt. %)</b>  | <b>MELTING POINT<br/>°F</b> | <b>MELTING POINT<br/>°C</b> |
| Aluminum-Gold (Au-96)         | 968                         | 520                         |
| Aluminum-Beryllium (Be-0.8)   | 1191                        | 644                         |
| Aluminum-Copper (Cu-33)       | 1019                        | 548                         |
| Aluminum-Iron ( Fe-98)        | 1211                        | 655                         |
| Aluminum-Lithium (Li-93)      | 351                         | 177                         |
| Aluminum-Magnesium (Mg-66)    | 819                         | 437                         |
| Aluminum-Nickel (Ni-5.7)      | 1182                        | 639                         |
| Aluminum-Silicon (Si-12.6)    | 1071                        | 577                         |
| Aluminum-Zinc (Zn-94)         | 718                         | 381                         |
| Aluminum-Zirconium (Zr-57)    | 2732                        | 1500                        |
| Beryllium-Chromium (Cr-13)    | 2232                        | 122                         |
| Beryllium-Copper (Cu-94.7)    | 1576                        | 858                         |
| Beryllium (Fe-22.6)           | 2219                        | 1215                        |
| Beryllium-Nickel (Ni-95)      | 2102                        | 1150                        |
| Beryllium-Silicon (Si-64)     | 1994                        | 1090                        |
| Carbon-Iron (Fe-22.6)         | 2107                        | 1153                        |
| Carbon-Molybdenum             | 4001                        | 2205                        |
| Carbon-Nickel (C-2.5)         | 2421                        | 1327                        |
| Chromium-Carbon (C-3.6)       | 2793                        | 1534                        |
| Chromium-Cobalt (Co-59)       | 2489                        | 1365                        |
| Chromium- Molybdenum, (Mo-21) | 3308                        | 1820                        |
| Chromium-Nickel (Ni-46)       | 2453                        | 1345                        |
| Chromium-Tantalum (Ta-34)     | 3200                        | 1760                        |
| Chromium-Titanium (Ti-53)     | 2570                        | 1410                        |
| Chromium-Zirconium (Zr-86)    | 2430                        | 1332                        |
| Cobalt-Carbon (C-2.6)         | 2498                        | 1320                        |
| Cobalt-Molybdenum (Mo-39)     | 2435                        | 1335                        |
| Cobalt-Tantalum (Ta-21)       | 2336                        | 1280                        |
| Cobalt-Tin (Sn-34)            | 2034                        | 1112                        |
| Cobalt-Titanium (Ti-73)       | 1868                        | 1020                        |
| Cobalt-Vanadium (V-38)        | 2278                        | 1248                        |
| Cobalt-Tungsten (W-45)        | 2680                        | 1471                        |
| Copper-Magnesium(Mg-66)       | 909                         | 487                         |

| <b>MELTING POINTS</b>        |                             |                             |
|------------------------------|-----------------------------|-----------------------------|
| <b>Eutectics</b>             |                             |                             |
| <b>ALLOY (Element-Wt. %)</b> | <b>MELTING POINT<br/>°F</b> | <b>MELTING POINT<br/>°C</b> |
| Copper-Silicon               | 1476                        | 802                         |
| Copper-Titanium (Ti-12)      | 1607                        | 875                         |
| Iron-Carbon (C-4.2)          | 2107                        | 1153                        |
| Iron-Molybdenum (Mo-37)      | 2640                        | 1449                        |
| Iron-Niobium (Nb-19)         | 2503                        | 1373                        |
| Iron-Silicon (Si-20 & Si-53) | 2197                        | 1203                        |
| Iron-Tin (Sn-49)             | 2066                        | 1130                        |
| Iron-Tantalum (Ta-20))       | 2606                        | 1430                        |
| Iron-Titanium (Ti-67)        | 1985                        | 1085                        |
| Magnesium-Nickel (Mg-24)     | 946                         | 508                         |
| Magnesium-Silicon (Si-1.34)  | 1180                        | 638                         |
| Magnesium-Tin (Sn-98)        | 399                         | 204                         |
| Magnesium-Zinc (Zn-53)       | 644                         | 340                         |
| Manganese-Titanium (Ti-59)   | 2156                        | 1180                        |
| Molybdenum-Nickel (56-Mo)    | 2388                        | 1309                        |
| Molybdenum-Silicon (Si-94)   | 2577                        | 1414                        |
| Nickel-Carbon (C-0.6)        | 2421                        | 1327                        |
| Nickel-Niobium (Nb-23)       | 2347                        | 1286                        |
| Nickel-Silicon (Si-29)       | 1767                        | 964                         |
| Nickel-Tantalum (Ta-63)      | 2462                        | 1350                        |
| Nickel-Tin (Sn-33)           | 2066                        | 1130                        |
| Nickel-Titanium ((Ti-73)     | 1728                        | 942                         |
| Nickel-Vanadium (V-47)       | 2196                        | 1202                        |
| Silicon-Tantalum (Ta-5)      | 2543                        | 1395                        |
| Silicon-Zinc (Zn-99.98)      | 787                         | 419                         |
| Silver-Aluminum (Al-26.5)    | 1053                        | 567                         |
| Silver-Beryllium (Be-0.03)   | 1616                        | 880                         |
| Silver-Calcium (Ca-60)       | 878                         | 470                         |
| Silver-Copper (Cu-28)        | 1434                        | 779                         |
| Silver-Magnesium (Mg-51.4)   | 882                         | 472                         |
| Silver-Tin (Sn-96.5)         | 430                         | 221                         |
| Tantalum-Carbon (C-2)        | 5149                        | 2843                        |
| Tungsten-Carbon (W-1.3)      | 4919                        | 2715                        |

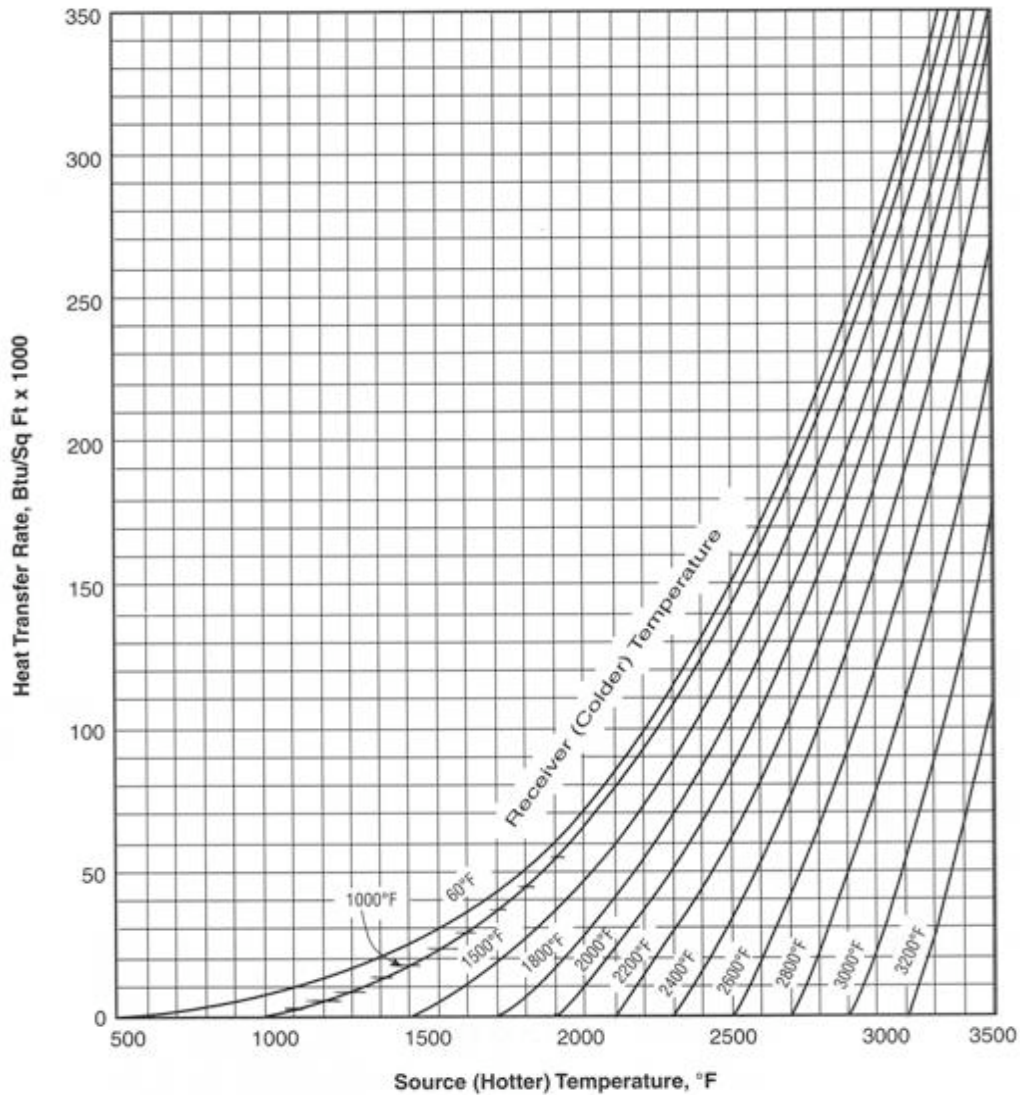
| <b>ONSET TEMPERATURE FOR ADVERSE REACTIONS BETWEEN<br/>GRAPHITE OR OXIDES AND FURNACE COMPONENTS</b> |                           |                           |
|------------------------------------------------------------------------------------------------------|---------------------------|---------------------------|
| <b>Surface to Surface Contact</b>                                                                    | <b>Temperature<br/>°F</b> | <b>Temperature<br/>°C</b> |
| <b>Al<sub>2</sub>O<sub>3</sub>-C</b>                                                                 | <b>&lt;2912</b>           | <b>&lt;1600</b>           |
| <b>Al<sub>2</sub>O<sub>3</sub>-Mo</b>                                                                | <b>3452</b>               | <b>1900</b>               |
| <b>Al<sub>2</sub>O<sub>3</sub>-Ta</b>                                                                | <b>3452</b>               | <b>1900</b>               |
| <b>Al<sub>2</sub>O<sub>3</sub>-W</b>                                                                 | <b>3452</b>               | <b>1900</b>               |
| <b>BeO-C</b>                                                                                         | <b>4172</b>               | <b>2300</b>               |
| <b>BeO-Mo</b>                                                                                        | <b>3452</b>               | <b>1900</b>               |
| <b>BeO-MgO</b>                                                                                       | <b>3272</b>               | <b>1800</b>               |
| <b>BeO-W</b>                                                                                         | <b>3632</b>               | <b>2000</b>               |
| <b>C-Mo</b>                                                                                          | <b>2192</b>               | <b>1200*</b>              |
| <b>C-Ta</b>                                                                                          | <b>1832</b>               | <b>1000*</b>              |
| <b>C-W</b>                                                                                           | <b>2730</b>               | <b>1499*</b>              |
| <b>BeO-ZrO<sub>2</sub></b>                                                                           | <b>3452</b>               | <b>1900</b>               |
| <b>MgO-C</b>                                                                                         | <b>3272</b>               | <b>1800</b>               |
| <b>MgO-Mo</b>                                                                                        | <b>2912</b>               | <b>1600</b>               |
| <b>MgO-Ta</b>                                                                                        | <b>3272</b>               | <b>1800</b>               |
| <b>MgO-W</b>                                                                                         | <b>3632</b>               | <b>2000**</b>             |
| <b>MgO-ZrO<sub>2</sub></b>                                                                           | <b>3632</b>               | <b>2000</b>               |
| <b>ZrO<sub>2</sub>-C</b>                                                                             | <b>2912</b>               | <b>1600</b>               |
| <b>ZrO<sub>2</sub>-Mo</b>                                                                            | <b>3992</b>               | <b>2200</b>               |
| <b>ZrO<sub>2</sub>-W</b>                                                                             | <b>2912</b>               | <b>1600</b>               |

- \*Strong Carbide Formation at higher temperatures.
  - \*\* Strong Magnesia evaporation

| <b>MELTING POINTS OF CERTAIN SIMPLE AND COMPLEX REFRACTORY OXIDES</b> |                                                    |                      |           |
|-----------------------------------------------------------------------|----------------------------------------------------|----------------------|-----------|
| <b>Compound</b>                                                       | <b>Chemical Formula</b>                            | <b>Melting Point</b> |           |
|                                                                       |                                                    | <b>°F</b>            | <b>°C</b> |
| Alumina                                                               | Al <sub>2</sub> O <sub>3</sub>                     | <b>3762</b>          | 2072      |
| Aluminum Silicate (mullite)                                           | 3Al <sub>2</sub> O <sub>3</sub> ·2SiO <sub>2</sub> | <b>3326</b>          | 1830*     |
| Aluminum Titanate                                                     | Al <sub>2</sub> O <sub>3</sub> ·TiO <sub>2</sub>   | <b>3371</b>          | 1855      |
| Aluminum Titanate                                                     | Al <sub>2</sub> O <sub>3</sub> ·2TiO <sub>2</sub>  | <b>3443</b>          | 1895      |
| Barium Aluminate                                                      | BaO·Al <sub>2</sub> O <sub>3</sub>                 | <b>3632</b>          | 2000      |
| Barium Aluminate                                                      | BaO 6Al <sub>2</sub> O <sub>3</sub>                | <b>3380</b>          | 1860      |
| Barium Orthosilicate                                                  | BaO·SiO <sub>2</sub>                               | <b>3191</b>          | 1755      |
| Barium Zirconate                                                      | BaO·ZrO <sub>2</sub>                               | <b>4892</b>          | 2700      |
| Beryllium Oxide                                                       | BeO                                                | <b>4649</b>          | 2565      |
| Chromic Oxide                                                         | Cr <sub>2</sub> O <sub>3</sub>                     | <b>4109</b>          | 2265      |
| Iron (II) Oxide                                                       | FeO                                                | <b>2510</b>          | 1377      |
| Iron (III) Oxide                                                      | Fe <sub>2</sub> O <sub>3</sub>                     | <b>2851</b>          | 1566      |
| Iron (IV) Oxide                                                       | Fe <sub>3</sub> O <sub>4</sub>                     | <b>2901</b>          | 1594      |
| Magnesium Aluminate                                                   | MgO·Al <sub>2</sub> O <sub>3</sub>                 | <b>3875</b>          | 2135      |
| Magnesium Ferrite                                                     | MgO·Fe <sub>2</sub> O <sub>3</sub>                 | <b>3200</b>          | 1760      |
| Magnesium Oxide                                                       | MgO                                                | <b>5156</b>          | 2852      |
| Manganese Oxide                                                       | Mn <sub>3</sub> O <sub>4</sub>                     | <b>2849</b>          | 1565      |
| Niobium Pentoxide                                                     | Nb <sub>2</sub> O <sub>5</sub>                     | <b>2716</b>          | 1491      |
| Nickel Oxide                                                          | NiO                                                | <b>3603</b>          | 1984      |
| Silicon Dioxide                                                       | SiO <sub>2</sub>                                   | <b>3133</b>          | 1723      |
| Tantalum Pentoxide                                                    | Ta <sub>2</sub> O <sub>5</sub>                     | <b>3402</b>          | 1872      |
| Titanium Dioxide                                                      | TiO <sub>2</sub>                                   | <b>3344</b>          | 1840      |
| Vanadium Oxide                                                        | V <sub>2</sub> O <sub>3</sub>                      | <b>3578</b>          | 1970      |
| Zinc Aluminate                                                        | ZnO·Al <sub>2</sub> O <sub>3</sub>                 | <b>3542</b>          | 1950      |
| Zinc Oxide                                                            | ZnO                                                | <b>3576</b>          | 1969      |
| Zirconium Oxide                                                       | ZrO <sub>2</sub>                                   | <b>4825</b>          | 2663      |
| Zirconium Oxide (stabilized)                                          | ZrO <sub>2</sub> (stabilized)                      | <b>4500</b>          | 2482      |
| Zinc Zirconium Silicate                                               | ZnO·ZrO <sub>2</sub> ·SiO <sub>2</sub>             | <b>3772</b>          | 2078      |
| Tungsten Oxide                                                        | WO <sub>3</sub>                                    | <b>2683</b>          | 1473      |

# BLACK BODY RADIATION

(Reprinted with permission from "Combustion Engineering Guide," published by Eclipse, Inc., Rockford, IL, 1986).



These curves are plotted from the relationship

$$Q = \frac{AK(T_1^4 - T_2^4)}{\frac{1}{P_1} + \frac{1}{P_2} - 1}$$

where  $P_1$  &  $P_2$  equal 1, that is, the heat source and receiver both have emissivities of 1.0, and they are arranged so there is no barrier to heat transfer between them.

| <b>EMISSIVITY OF COMMON MATERIALS</b>         |                           |                           |                          |
|-----------------------------------------------|---------------------------|---------------------------|--------------------------|
| <b>MATERIAL</b>                               | <b>TEMPERATURE<br/>°F</b> | <b>TEMPERATURE<br/>°C</b> | <b>EMISSIVITY NUMBER</b> |
| Blackbody                                     | <b>75</b>                 | 24                        | 1.0                      |
| Black Paint, CuO                              | <b>75</b>                 | 24                        | 0.96                     |
| Carbon, Lamp Black                            | <b>75</b>                 | 24                        | 0.96                     |
| Soot , acetylene                              | <b>75</b>                 | 24                        | 0.97                     |
| Cement                                        | <b>32-392</b>             | 0-200                     | 0.96                     |
| White ceramic, Al <sub>2</sub> O <sub>3</sub> | <b>75</b>                 | 24                        | 0.90                     |
| Carbon, unoxidized                            | <b>75</b>                 | 24                        | 0.81                     |
| Water                                         | <b>100</b>                | 38                        | 0.67                     |

| <b>EMMISSIVITY OF SELECT METALS</b> |                           |                           |                          |
|-------------------------------------|---------------------------|---------------------------|--------------------------|
| <b>MATERIAL</b>                     | <b>TEMPERATURE<br/>°F</b> | <b>TEMPERATURE<br/>°C</b> | <b>EMISSIVITY NUMBER</b> |
| Aluminum unoxidized                 | <b>75</b>                 | 24                        | 0.02                     |
| Aluminum oxidized                   | <b>390</b>                | 199                       | 0.11                     |
| Aluminum heavily oxidized           | <b>200</b>                | 93                        | 0.20                     |
| Brass unoxidized                    | <b>77</b>                 | 25                        | 0.035                    |
| Brass oxidized                      | <b>392</b>                | 200                       | 0.61                     |
| Bronze polished                     | <b>122</b>                | 50                        | 0.10                     |
| Chromium unoxidized                 | <b>212</b>                | 100                       | 0.08                     |
| Chromium oxidized                   | <b>600</b>                | 316                       | 0.08                     |
| Copper cuprous oxide                | <b>100</b>                | 38                        | 0.87                     |
| Copper heavily oxidized, black      | <b>100</b>                | 38                        | 0.78                     |
| Copper polished                     | <b>100</b>                | 38                        | 0.03                     |
| Copper Dow Metal                    | <b>100</b>                | 38                        | 0.15                     |
| GOLD polished or unoxidized         | <b>212</b>                | 100                       | 0.02                     |
| Iconel X                            | <b>75</b>                 | 24                        | 0.19                     |
| Iconel B                            | <b>75</b>                 | 24                        | 0.21                     |
| Iron cast unoxidized                | <b>392</b>                | 200                       | 0.21                     |
| <b>Iron</b> cast oxidized           | <b>392</b>                | 200                       | 0.64                     |
| Iron cast heavily oxidized          | <b>100</b>                | 38                        | 0.95                     |
| Iron unoxidized                     | <b>212</b>                | 100                       | 0.05                     |
| Iron oxidized                       | <b>212</b>                | 100                       | 0.74                     |
| Iron heavily oxidized (rust)        | <b>77</b>                 | 25                        | 0.65                     |
| Iron (Wrought)                      | <b>77</b>                 | 25                        | 0.94                     |
| Lead oxidized                       | <b>100</b>                | 38                        | 0.43                     |
| Magnesium                           | <b>100</b>                | 38                        | 0.07                     |

## EMMISSIVITY OF SELECT METALS

| MATERIAL                 | TEMPERATURE<br>°F | TEMPERATURE<br>°C | EMISSIVITY NUMBER |
|--------------------------|-------------------|-------------------|-------------------|
| Mercury                  | 77                | 25                | 0.10              |
| Molybdenum               | 100               | 38                | 0.06              |
| Molybdenum               | 2000              | 1093              | 0.18              |
| Monel Ni-Cu              | 392               | 200               | 0.41              |
| Monel Ni-Cu, oxidized    | 77                | 25                | 0.43              |
| Nickel unoxidized        | 77                | 25                | 0.05              |
| Nickel oxidized          | 100               | 38                | 0.31              |
| Niobium unoxidized       | 1500- 2000        | 816-1093          | 0.19-0.24         |
| Niobium oxidized         | 1500              | 816               | 0.73              |
| Nichrome wire unoxidized | 122               | 50                | 0.65              |
| Nichrome wire oxidized   | 122               | 50                | 0.95              |
| Nickel unoxidized        | 77 -932           | 25-500            | 0.045-0.0.12)     |
| Nickel oxidized          | 392               | 200               | 0.37              |
| Platinum                 | 100               | 38                | 0.05              |
| Platinum Black           | 100               | 38                | 0.93              |
| Silver polished          | 100               | 38                | 0.01              |
| Steel unoxidized         | 212               | 100               | 0.08              |
| Steel oxidized           | 77                | 25                | 0.80              |
| Steel type 301 polished  | 75                | 24                | 0.27              |
| Steel type 303 oxidized  | 600               | 316               | 0.74              |
| Steel type 316           | 75                | 24                | 0.28              |
| Tantalum unoxidized      | 2732              | 1500              | 0.21              |
| Tin unoxidized           | 77                | 25                | 0.04              |
| Titanium C110M           | 300               | 149               | 0.08              |
| Tungsten unoxidized      | 77                | 25                | 0.02              |
| Zinc Bright galvanized   | 100               | 38                | 0.23              |
| Zinc unoxidized          | 500               | 260               | 0.05              |
| Zinc oxidized            | 500               | 260               | 0.11              |

# VAPOR PRESSURE OF THE ELEMENTS (s-sublime)

| <i>Element</i> | <i>10<sup>-4</sup> Torr</i> |             | <i>10<sup>-3</sup> Torr</i> |             | <i>10<sup>-2</sup> Torr</i> |             | <i>10<sup>-1</sup> Torr</i> |             |
|----------------|-----------------------------|-------------|-----------------------------|-------------|-----------------------------|-------------|-----------------------------|-------------|
|                | °C                          | °F          | °C                          | °F          | °C                          | °F          | °C                          | °F          |
| Aluminum       | 808,                        | <b>1486</b> | 889                         | <b>1632</b> | 996,                        | <b>1825</b> | 1123                        | <b>2053</b> |
| Beryllium      | 1029                        | <b>1884</b> | 1130                        | <b>2066</b> | 1246                        | <b>2275</b> | 1395                        | <b>2543</b> |
| Boron          | 1140                        | <b>2084</b> | 1239                        | <b>2262</b> | 1355                        | <b>2471</b> | 1489                        | <b>2712</b> |
| Cadmium        | 180                         | <b>356</b>  | 220                         | <b>428</b>  | 264,                        | <b>507</b>  | 321                         | <b>610</b>  |
| Calcium        | 463                         | <b>865</b>  | 528,                        | <b>982</b>  | 605,                        | <b>1121</b> | 700                         | <b>1292</b> |
| Carbon         | 2290                        | <b>4150</b> | 2471                        | <b>4480</b> | 2681                        | <b>4858</b> | 2926                        | <b>5299</b> |
| Cerium         | 1091                        | <b>1996</b> | 1190                        | <b>2174</b> | 1305                        | <b>2381</b> | 1439                        | <b>2622</b> |
| Cesium         | 74                          | <b>165</b>  | 110                         | <b>230</b>  | 153,                        | <b>307</b>  | 207                         | <b>405</b>  |
| Chromium       | 992,                        | <b>1818</b> | 1090                        | <b>1994</b> | 1205                        | <b>2201</b> | 1342                        | <b>2448</b> |
| Cobalt         | 1362                        | <b>2484</b> | 1494                        | <b>2721</b> | 1649                        | <b>3000</b> | 1833                        | <b>3331</b> |
| Copper         | 1035                        | <b>1895</b> | 1141                        | <b>2086</b> | 1273                        | <b>2323</b> | 1432                        | <b>2610</b> |
| Gallium        | 859                         | <b>1578</b> | 965,                        | <b>1769</b> | 1093                        | <b>1999</b> | 1248                        | <b>2278</b> |
| Germanium      | 996                         | <b>1825</b> | 1112                        | <b>2034</b> | 1251                        | <b>2284</b> | 1421                        | <b>2590</b> |
| Gold           | 1190                        | <b>2174</b> | 1316                        | <b>2401</b> | 1465                        | <b>2669</b> | 1646                        | <b>2995</b> |
| Iron           | 1195                        | <b>2183</b> | 1310                        | <b>2390</b> | 1447                        | <b>2637</b> | 1602                        | <b>2916</b> |
| Lead           | 548,                        | <b>1018</b> | 620                         | <b>1148</b> | 718                         | <b>1324</b> | 832                         | <b>1508</b> |
| Magnesium      | 331,                        | <b>628</b>  | 380                         | <b>716</b>  | 443                         | <b>829</b>  | 515                         | <b>959</b>  |
| Manganese      | 791                         | <b>1456</b> | 878,                        | <b>1612</b> | 980                         | <b>1796</b> | 1020                        | <b>1868</b> |
| Mercury        |                             |             | 18                          | <b>64</b>   | 48                          | <b>118</b>  | 82                          | <b>180</b>  |
| Molybdenum     | 2098                        | <b>3809</b> | 2295                        | <b>4163</b> | 2533                        | <b>4591</b> | 2880                        | <b>5216</b> |
| Neodymium      |                             |             | 1192                        | <b>2177</b> | 1342                        | <b>2448</b> | 1537                        | <b>2799</b> |
| Nickel         | 1257                        | <b>2295</b> | 1371                        | <b>2500</b> | 1510                        | <b>2750</b> | 1679                        | <b>3054</b> |
| Niobium        | 2355                        | <b>4271</b> | 2539                        | <b>4602</b> |                             |             |                             |             |
| Palladium      | 1271                        | <b>2320</b> | 1405                        | <b>2561</b> | 1566                        | <b>2851</b> | 1759                        | <b>3198</b> |
| Phosphorus     |                             |             | 160                         | <b>320</b>  | 190                         | <b>374</b>  | 225                         | <b>437</b>  |
| Platinum       | 1744                        | <b>3171</b> | 1904                        | <b>3459</b> | 2090                        | <b>3794</b> | 2293                        | <b>4150</b> |
| Potassium      | 123                         | <b>253</b>  | 161                         | <b>322</b>  | 207                         | <b>405</b>  | 265                         | <b>509</b>  |
| Rhenium        |                             |             | 2790                        | <b>5054</b> | 3060                        | <b>5540</b> | 3400                        | <b>6152</b> |
| Rhodium        | 1815                        | <b>3299</b> | 1971                        | <b>3580</b> | 2149                        | <b>3900</b> | 2358                        | <b>4274</b> |
| Selenium       |                             |             | 200                         | <b>392</b>  | 235                         | <b>455</b>  | 280                         | <b>536</b>  |
| Silicon        | 1116                        | <b>2041</b> | 1223                        | <b>2233</b> | 1343                        | <b>2449</b> | 1485                        | <b>2705</b> |
| Silver         | 848                         | <b>1558</b> | 920                         | <b>1688</b> | 1047                        | <b>1917</b> | 1184                        | <b>2163</b> |
| Sodium         | 195                         | <b>383</b>  | 238                         | <b>460</b>  | 291                         | <b>556</b>  | 356                         | <b>673</b>  |
| Sulfur         |                             |             | 66                          | <b>151</b>  | 97                          | <b>207</b>  | 135                         | <b>275</b>  |
| Tantalum       | 2599                        | <b>4710</b> | 2820                        | <b>5108</b> | 3074                        | <b>5565</b> | 3370                        | <b>6098</b> |
| Tin            | 922                         | <b>1692</b> | 1042                        |             | 1189                        |             | 1373                        |             |
| Titanium       | 1250                        |             | 1384                        | <b>2523</b> | 1546                        | <b>2815</b> | 1742                        | <b>3168</b> |
| Tungsten       | 2767                        |             | 3016                        | <b>5461</b> | 3309                        | <b>5988</b> |                             |             |
| Uranium        | 1585                        |             | 1730                        | <b>3146</b> | 1898                        | <b>3448</b> | 2098                        | <b>3808</b> |
| Vanadium       | 1586                        |             | 1725                        | <b>3137</b> | 1888                        | <b>3430</b> | 2079                        | <b>3774</b> |
| Yttrium        | 1362                        | <b>2484</b> | 1494                        | <b>2721</b> | 1650                        | <b>3000</b> | 1833                        | <b>3331</b> |
| Zinc           | 248,                        | <b>478</b>  | 292                         | <b>558</b>  | 343                         | <b>649</b>  | 405                         | <b>761</b>  |
| Zirconium      | 1660                        | <b>3020</b> | 1816                        | <b>3301</b> | 2001                        | <b>3634</b> | 2212                        | <b>4014</b> |

## VAPOR PRESSURE OF THE ELEMENTS (s-sublimes)

| <i>Element</i> | <i>1.0 Torr</i> |           | <i>10<sup>-1</sup> Torr</i> |           | <i>10<sup>-2</sup> Torr</i> |           | <i>760 Torr</i> |           |
|----------------|-----------------|-----------|-----------------------------|-----------|-----------------------------|-----------|-----------------|-----------|
|                | <i>°C</i>       | <i>°F</i> | <i>°C</i>                   | <i>°F</i> | <i>°C</i>                   | <i>°F</i> | <i>°C</i>       | <i>°F</i> |
| Aluminum       | 1279            | 2334      | 1487                        | 2709      | 1749                        | 3180      | 2467            | 4473      |
| Beryllium      | 1567            | 2853      | 1787                        | 3249      | 2097                        | 3087      | 2507            | 4545      |
| Boron          | 1648            | 2998      | 3030                        | 5486      | 3460                        | 6260      | 2527(s)         | 4581(s)   |
| Cadmium        | 394             | 741       | 484                         | 903       | 611,                        | 1132      | 765,            | 1409      |
| Calcium        | 817             | 1503      | 983,                        | 1801      | 1207                        | 2205      | 1487            | 2709      |
| Carbon         | 3214            | 5817      | 3946                        | 7135      | 4373                        | 7903      | 4827            | 8721      |
| Cerium         |                 |           |                             |           |                             |           | 3426            | 6199      |
| Cesium         |                 |           | 373                         | 703       | 513                         | 955       | 690             | 1274      |
| Chromium       | 1504            | 2739      |                             |           |                             |           | 2222            | 4031      |
| Cobalt         | 2056            | 3732      | 2380                        | 4316      | 2720                        | 4928      | 3097            | 5607      |
| Copper         | 1628            | 2962      | 1879                        | 3414      | 2207                        | 4005      | 2595            | 4703      |
| Gallium        | 1443            | 2629      | 1541                        | 2806      | 1784                        | 3243      | 2427            | 4400      |
| Germanium      | 1635            | 2975      | 1880                        | 3416      | 2210                        | 4010      | 2707            | 4905      |
| Gold           | 1867            | 3393      | 2154                        | 3909      | 2521                        | 4570      | 2966            | 5371      |
| Iron           | 1783            | 3241      | 2039                        | 3702      | 2360                        | 4280      | 2727            | 4941      |
| Lead           | 975             | 1787      | 1167                        | 2133      | 1417                        | 2583      | 1737            | 3159      |
| Magnesium      | 605             | 1121      | 702                         | 1296      | 909                         | 1668      | 1126            | 2059      |
| Manganese      | 1251            | 2284      | 1505                        | 2741      | 1792                        | 3257      | 2097            | 3807      |
| Mercury        | 126             | 259       | 184                         | 363       | 216                         | 421       | 361             | 682       |
| Molybdenum     | 3102            | 5616      | 3535                        | 6395      | 4109                        | 7428      | 4804            | 8679      |
| Neodymium      | 1775            | 3227      | 2095                        | 3803      | 2530                        | 4586      | 3090            | 5594      |
| Nickel         | 1884            | 3423      | 2007                        | 3645      | 2364                        | 4287      | 2837            | 5139      |
| Niobium        |                 |           |                             |           |                             |           | 4742            | 8568      |
| Palladium      | 2000            | 3632      | 2280                        | 4136      | 2780                        | 5036      | 3167            | 5732      |
| Phosphorus     | 265             | 509       | 310                         | 590       | 370                         | 698       | 431,            | 808       |
| Platinum       | 2582            | 4680      | 3146                        | 5695      | 3714                        | 6717      | 3827            | 6921      |
| Potassium      | 338             | 640       | 443                         | 829       | 581                         | 1078      | 779             | 1434      |
| Rhenium        | 3810            | 6890      |                             |           |                             |           | 5630            | 10166     |
| Rhodium        | 2607            | 4725      | 2880                        | 5216      | 3392                        | 6138      | 3877            | 7011      |
| Selenium       | 350             | 662       | 430                         | 806       | 550                         | 1022      | 685             | 1265      |
| Silicon        | 1670            | 3038      | 1888                        | 3430      | 2083                        | 3781      | 2477            | 4491      |
| Silver         | 1353            | 2467      | 1575                        | 2867      | 1865                        | 3389      | 2212            | 4013      |
| Sodium         | 437             | 819       | 548                         | 1018      | 696                         | 1285      | 914             | 1677      |
| Sulfur         | 183             | 361       | 246                         | 475       | 333                         | 631       | 444             | 831       |
| Tantalum       | 3740            | 6764      |                             |           |                             |           | 6027            | 10881     |
| Tin            | 1609            |           | 1703                        |           | 1968                        |           | 2727            |           |
| Titanium       | 1965            | 3569      | 2180                        | 3956      | 2480                        | 4496      | 3127            | 5661      |
| Tungsten       |                 |           |                             |           |                             |           | 5927            | 10701     |
| Uranium        | 2338            | 4240      |                             |           |                             |           | 3527            | 6381      |
| Vanadium       | 2207            | 4005      | 2570                        | 4665      | 2950                        | 5342      | 3380            | 6116      |
| Yttrium        |                 |           |                             |           |                             |           | 3338            | 6040      |
| Zinc           | 487             | 907       | 593                         | 1099      | 736                         | 1357      | 907             | 1665      |
| Zirconium      | 2459            | 4458      |                             |           |                             |           | 3577            | 6471      |

## Vapor Pressures of Certain Metal Oxides

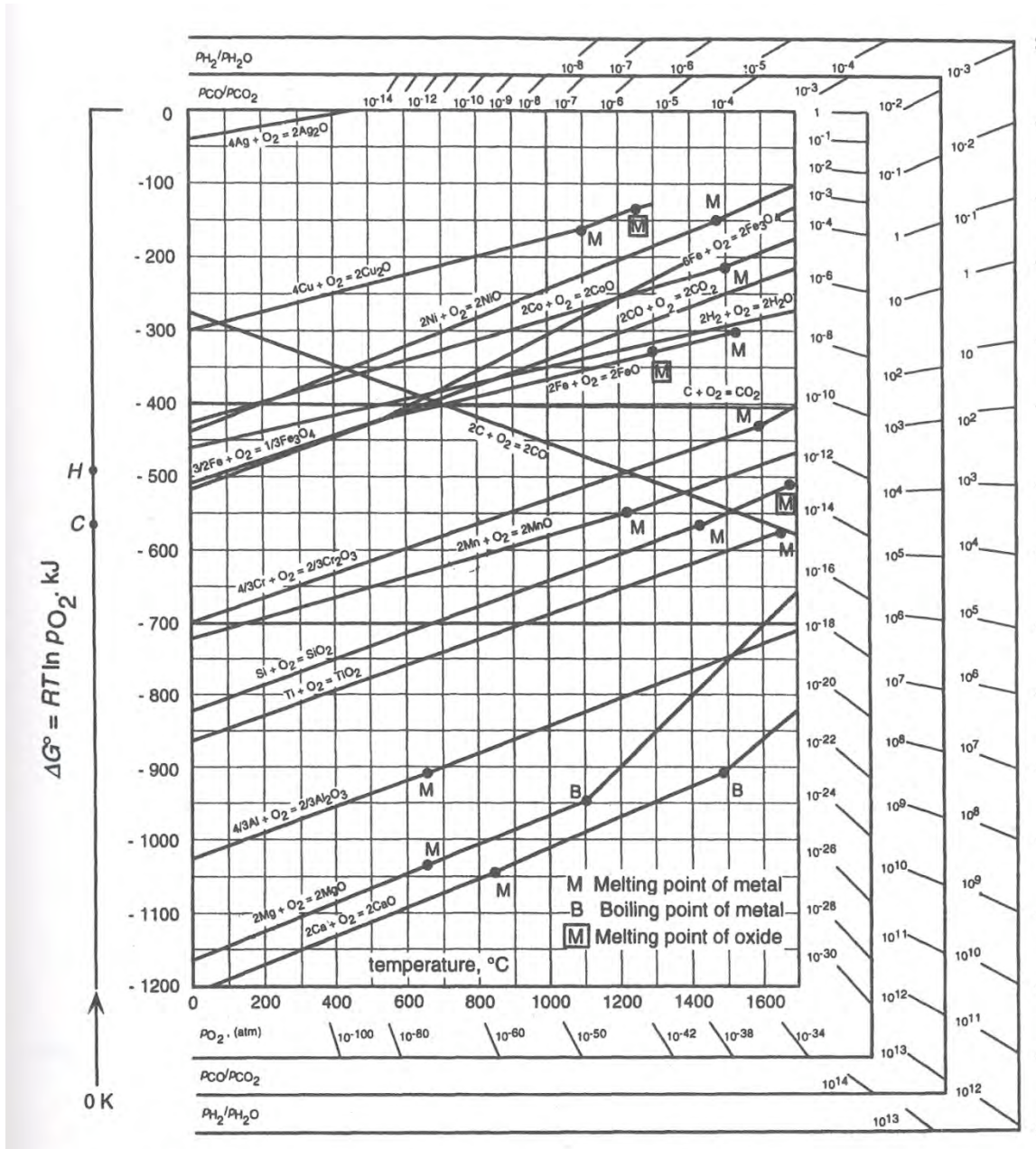
| Compound            | Formula                        | 10 <sup>-5</sup> Torr<br>(0.01 micron) |             | 10 <sup>-4</sup> Torr<br>(0.1 microns) |             | 10 <sup>-3</sup> Torr<br>(1.0 micron) |             | 10 <sup>-2</sup> Torr<br>(10 microns) |             | 10 <sup>-1</sup> Torr<br>(100 microns) |             | 760 Torr<br>760,000 microns |             |
|---------------------|--------------------------------|----------------------------------------|-------------|----------------------------------------|-------------|---------------------------------------|-------------|---------------------------------------|-------------|----------------------------------------|-------------|-----------------------------|-------------|
|                     |                                | °C                                     | °F          | °C                                     | °F          | °C                                    | °F          | °C                                    | °F          | °C                                     | °F          | °C                          | °F          |
| Aluminum Oxide      | Al <sub>2</sub> O <sub>3</sub> |                                        |             | 1880                                   | <b>3390</b> | 1980                                  | <b>3570</b> | 2105                                  | <b>3790</b> | 2265                                   | <b>4080</b> | 3545                        | <b>6330</b> |
| Barium Oxide        | BaO                            |                                        |             | 1266                                   | <b>2310</b> | 1382                                  | <b>2520</b> | 1516                                  | <b>2760</b> |                                        |             | 1999                        | <b>3630</b> |
| Beryllium Oxide     | BeO                            | 1754                                   | <b>3190</b> | 1893                                   | <b>3440</b> | 2049                                  | <b>3720</b> | 2227                                  | <b>4040</b> | 2421                                   | <b>4390</b> | 4132                        | <b>7470</b> |
| Calcium Oxide       | CaO                            | 1543                                   | <b>2810</b> | 1666                                   | <b>3030</b> | 1810                                  | <b>3290</b> | 1982                                  | <b>3600</b> | 2182                                   | <b>3960</b> | 2849                        | <b>5160</b> |
| Chromic Oxide       | Cr <sub>2</sub> O <sub>3</sub> | 1320                                   | <b>2410</b> | 1425                                   | <b>2600</b> | 1555                                  | <b>2830</b> | 1695                                  | <b>3080</b> | 1875                                   | <b>3380</b> | 3030                        | <b>5440</b> |
| Iron (III) Oxide    | Fe <sub>2</sub> O <sub>3</sub> |                                        |             |                                        |             |                                       |             |                                       | <b>1880</b> |                                        |             |                             |             |
| Magnesium Oxide     | MgO                            | 1388                                   | <b>2530</b> | 1510                                   | <b>2750</b> | 1632                                  | <b>2970</b> | 1788                                  | <b>3250</b> | 1954                                   | <b>3550</b> | 3599                        | <b>6510</b> |
| Molybdenum Trioxide | MoO <sub>3</sub>               |                                        |             |                                        |             | 593                                   | <b>1100</b> | 627                                   | <b>1160</b> | 699                                    | <b>1290</b> | 793                         | <b>1460</b> |
| Potassium Oxide     | K <sub>2</sub> O               | 438                                    | <b>820</b>  | 499                                    | <b>930</b>  | 577                                   | <b>1070</b> | 643                                   | <b>1190</b> | 743                                    | <b>1370</b> | 1466                        | <b>2670</b> |
| Silicon Dioxide     | SiO <sub>2</sub>               | 1366                                   | <b>2490</b> | 1482                                   | <b>2700</b> | 1604                                  | <b>2920</b> | 1738                                  | <b>3160</b> | 1893                                   | <b>3440</b> | 2232                        | <b>4050</b> |
| Sodium Oxide        | Na <sub>2</sub> O              | 554                                    | <b>1031</b> | 627                                    | <b>1160</b> | 704                                   | <b>1300</b> | 799                                   | <b>1470</b> | 916                                    | <b>1680</b> | 1277                        | <b>2330</b> |
| Titanium Oxide      | TiO <sub>2</sub>               | 1577                                   | <b>2870</b> | 1704                                   | <b>3100</b> |                                       |             |                                       |             |                                        |             |                             |             |
| Zirconium Oxide     | ZrO <sub>2</sub>               | 1877                                   | <b>3410</b> | 2049                                   | <b>3720</b> | 2177                                  | <b>3950</b> | 2399                                  | <b>4350</b> | 2577                                   | <b>4670</b> | 4299                        | <b>7770</b> |

# Richardson-Ellingham Diagram

The Richardson-Ellingham Diagram is a graphical representation of the standard Gibbs free energy changes for chemical reactions. It can be used to determine necessary furnace conditions for prevention of unwanted oxidation of metals or the reduction of metal oxides.

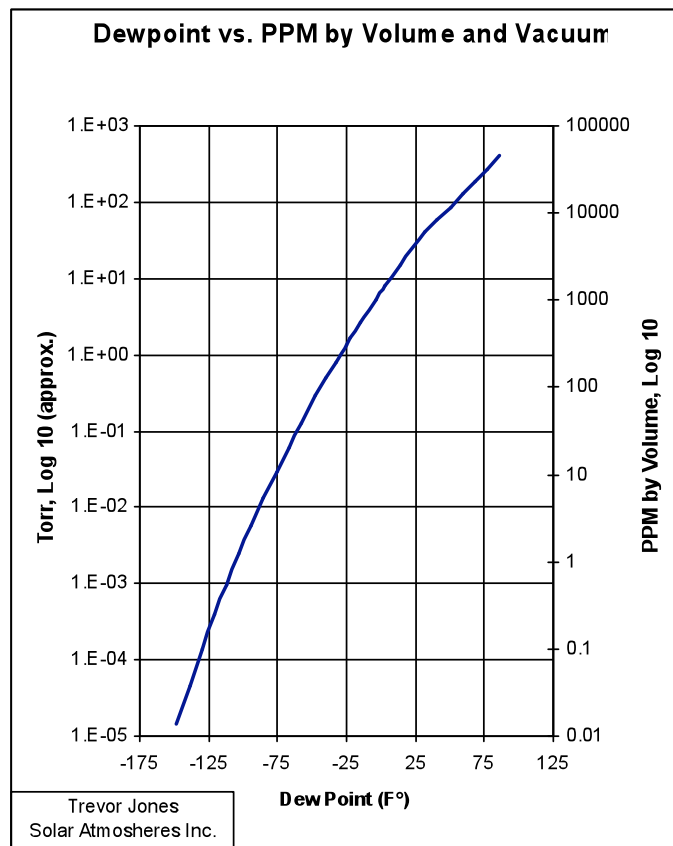
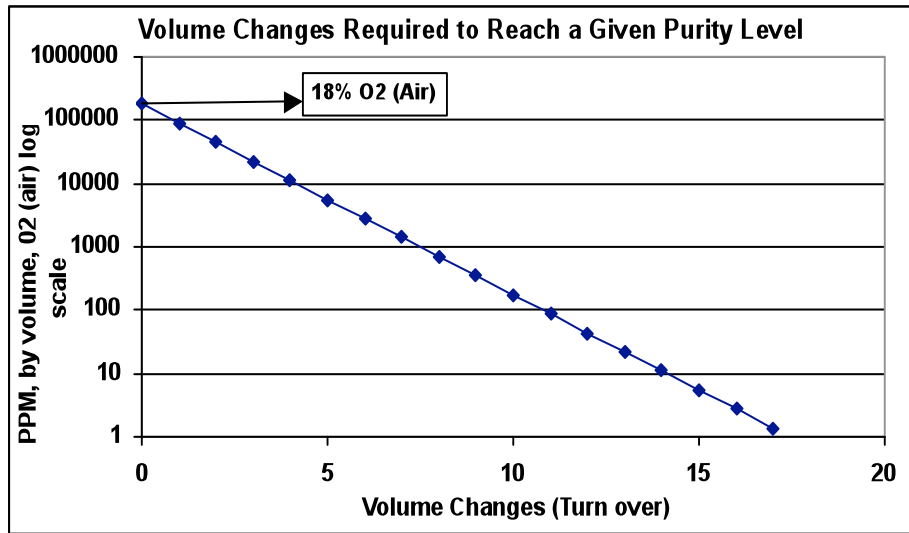
The main uses of this diagram are:

1. Determine the partial pressure of oxygen that is in equilibrium with the metal oxide for a given temperature;
2. Calculate the CO/CO<sub>2</sub> ratio required to reduce an oxide at a given temperature.
3. Determine the ease of oxidation for a given temperature and dew point.
4. Predict the temperatures at which a metal is stable and the temperature that it will readily oxidize.

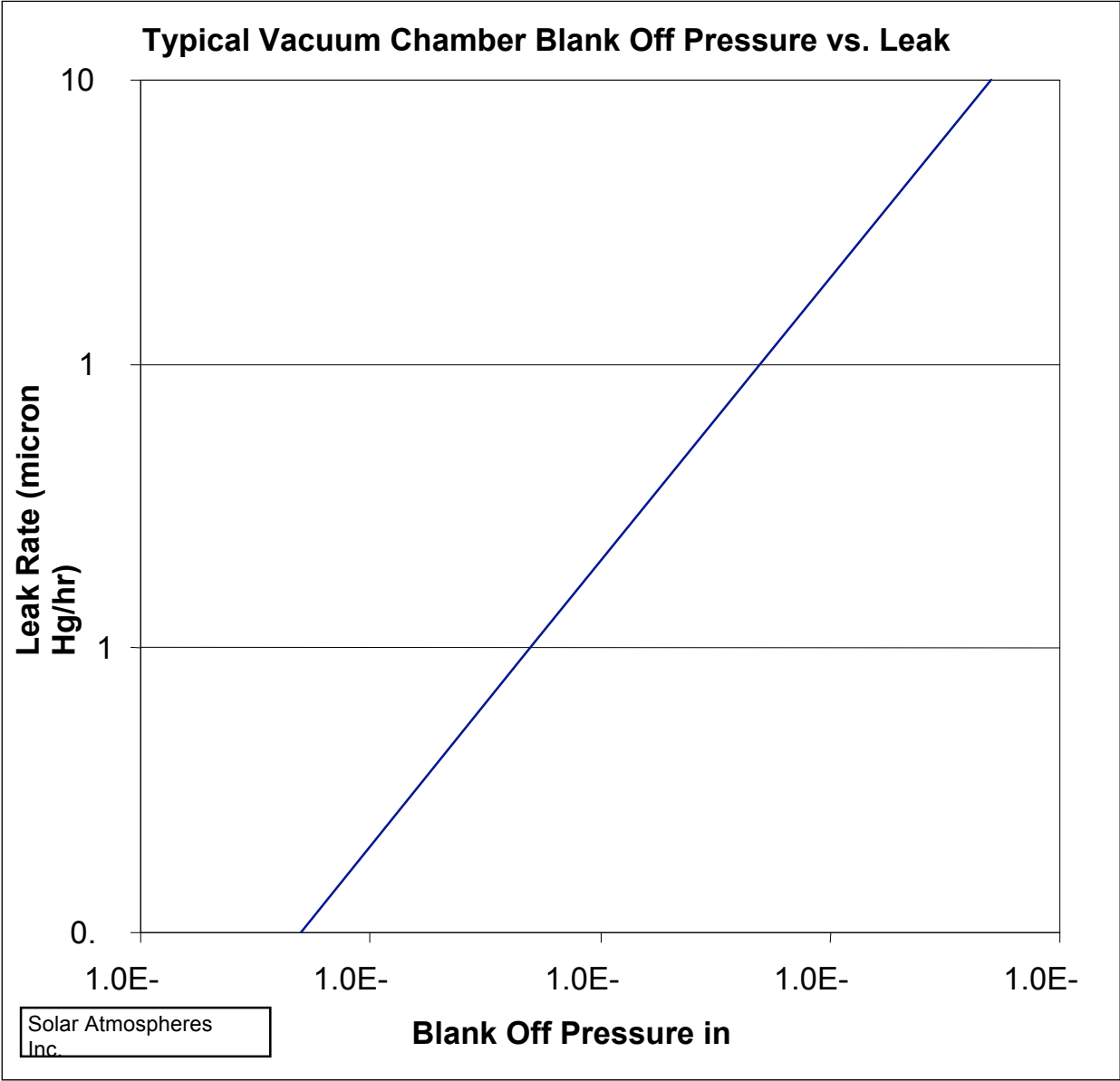


Gaskell, David R. *Introduction of the Thermodynamics of Materials*, 4<sup>th</sup> Edition. New York: Taylor & Francis, 2003

# Gas Purge Chart



# Vacuum Furnace Blank Off Pressure vs. Leak Rate



## **Common English to Metric Conversions**

### **Conversion Factors for Common Units of Length**

1 inch = 2.54 centimeters (cm) = 25.4 millimeters (mm)

1 foot = 0.305 meters

1 centimeter = 0.394 inches

1 meter = 39.37 inches = 3.28 feet = 1.094 yards

### **Conversion Factors for Common Units of Area**

1 square inch = 6.45 square centimeters

1 square foot = 0.093 square meter = 930 square centimeters

1 square centimeter = 0.155 square inches

1 square meter = 10.764 square feet = 1550 square inches

### **Common Conversion Factors for Units of Volume (Solid and Liquid)**

1 cubic inch = 16.4 cubic centimeters (cc)

1 cubic inches = 16.4 milliliters (ml)

1 cubic foot = 0.0283 cubic meters

1 cubic foot = 7.48 U.S. gallons

1 U.S. gallon = 3.78 liters

1 cubic foot = 28.3 liters (L)

1 cubic centimeter (cc) = 0.061 cubic inches

1 milliliters (ml) = 0.061 cubic inches

1 cubic meter = 35.314 cubic feet

1 liter = 35.314 cubic feet

### **Common Conversion Factors for Units of Mass (Weight)**

1 pound (avoirdupois) lb. = 453.6 gram

1 ounce = 0.0625 lb. = 28.35 grams

1 gram = 0.0022 pounds = 0.0353 ounces

## Common Pressure Conversion Factors

| Multiply by ↓<br>to calculate→ | Atmosphere<br>(Atm)      | Torr                    | Pascal                  | Bar                     | Micron                 | Psia<br>(lb/in <sup>2</sup> ) |
|--------------------------------|--------------------------|-------------------------|-------------------------|-------------------------|------------------------|-------------------------------|
| Atm                            | 1                        | 760                     | 1.01325X10 <sup>5</sup> | 1.01325                 | 7.6X10 <sup>5</sup>    | 14.696                        |
| Torr                           | 1.316X10 <sup>-3</sup>   | 1                       | 133.322                 | 1.3332X10 <sup>-3</sup> | 1000                   | 1.9337X10 <sup>-2</sup>       |
| Pascal                         | 9.8692X10 <sup>-6</sup>  | 7.5006X10 <sup>-3</sup> | 1                       | 1X10 <sup>-5</sup>      | 7.5006                 | 1.4504X10 <sup>-4</sup>       |
| Bar                            | 9.8692X10 <sup>-1</sup>  | 750.06                  | 1X10 <sup>5</sup>       | 1                       | 7.5006X10 <sup>5</sup> | 14.504                        |
| Microns                        | 1.31579X10 <sup>-6</sup> | 1X10 <sup>-3</sup>      | 1.3332X10 <sup>-1</sup> | 1.3332X10 <sup>-6</sup> | 1                      | 1.9337X10 <sup>-5</sup>       |
| Psia<br>Lb/In <sup>2</sup>     | 6.8046X10 <sup>-2</sup>  | 51.7151                 | 6894.757                | 6.8946X10 <sup>-2</sup> | 51715.1                | 1                             |

*To convert from one pressure unit to another use the left column to locate the old unit and multiply by the conversion factor to obtain the value in the new pressure unit.*

**Example:**

***To convert Atmospheres to Bar***

$$1 \text{ Atm} = 1.01325 \text{ Bar}$$

$$1 \text{ Pascal} = 9.8692 \times 10^{-6} \text{ Atm}$$

## Equivalence Table for Pressure/Vacuum Measurements

(Relating Furnace Vacuum Gauge Readings (Inches Hg) to Absolute Pressure Values)

| Micron Hg | Millibar<br>(mbar) | Torr<br>(mmHg) | <i><b>Inches<br/>Hg*<br/>Vacuum<br/>Gauge</b></i> | Inches Hg<br>Absolute | Psia<br>(lb/in. <sup>2</sup><br>absolute) | Atm       |
|-----------|--------------------|----------------|---------------------------------------------------|-----------------------|-------------------------------------------|-----------|
| 760,000   | 1013               | 760            | <b>0.0</b>                                        | 29.92                 | 14.7                                      | 1.000     |
| 750,000   | 1000               | 750            | <b>0.42</b>                                       | 29.5                  | 14.5                                      | 0.987     |
| 735,000   | 981                | 735.6          | <b>1.02</b>                                       | 28.9                  | 14.2                                      | 0.968     |
| 700,000   | 934                | 700            | <b>2.32</b>                                       | 27.6                  | 13.5                                      | 0.921     |
| 600,000   | 800                | 600            | <b>6.32</b>                                       | 23.6                  | 11.6                                      | 0.789     |
| 500,000   | 667                | 500            | <b>10.22</b>                                      | 19.7                  | 9.7                                       | 0.658     |
| 400,000   | 533                | 400            | <b>14.22</b>                                      | 15.7                  | 7.7                                       | 0.526     |
| 380,000   | 507                | 380            | <b>14.92</b>                                      | 15.0                  | 7.3                                       | 0.500     |
| 300,000   | 400                | 300            | <b>18.12</b>                                      | 11.8                  | 5.8                                       | 0.395     |
| 200,000   | 267                | 200            | <b>22.07</b>                                      | 7.85                  | 3.9                                       | 0.264     |
| 100,000   | 133.3              | 100            | <b>25.98</b>                                      | 3.94                  | 1.93                                      | 0.132     |
| 90,000    | 120                | 90             | <b>26.38</b>                                      | 3.54                  | 1.74                                      | 0.118     |
| 80,000    | 106.8              | 80             | <b>26.77</b>                                      | 3.15                  | 1.55                                      | 0.105     |
| 70,000    | 93.4               | 70             | <b>27.16</b>                                      | 2.76                  | 1.35                                      | 0.0921    |
| 60,000    | 80                 | 60             | <b>27.56</b>                                      | 2.36                  | 1.16                                      | 0.0789    |
| 51,700    | 68.8               | 51.7           | <b>27.89</b>                                      | 2.03                  | 1.00                                      | 0.068     |
| 50,000    | 66.7               | 50             | <b>27.95</b>                                      | 1.97                  | 0.97                                      | 0.0658    |
| 40,000    | 53.3               | 40             | <b>28.35</b>                                      | 1.57                  | 0.77                                      | 0.0526    |
| 30,000    | 40.0               | 30             | <b>28.74</b>                                      | 1.18                  | 0.58                                      | 0.0395    |
| 25,400    | 33.8               | 25.4           | <b>28.92</b>                                      | 1.00                  | 0.4912                                    | 0.034     |
| 20,000    | 26.7               | 20             | <b>29.14</b>                                      | 0.785                 | 0.39                                      | 0.0264    |
| 10,000    | 13.33              | 10             | <b>29.53</b>                                      | 0.394                 | 0.193                                     | 0.0132    |
| 7,600     | 10.13              | 7.6            | <b>29.62</b>                                      | 0.299                 | 0.147                                     | 0.01      |
| 1,000     | 1.33               | 1              | <b>29.88</b>                                      | 0.03937               | 0.01934                                   | 0.00132   |
| 750       | 1.00               | 0.75           | <b>29.89</b>                                      | 0.0295                | 0.0145                                    | 0.000987  |
| 100       | 0.133              | 0.1            | <b>29.916</b>                                     | 0.00394               | 0.00193                                   | 0.000132  |
| 10        | 0.0133             | 0.01           | <b>29.9196</b>                                    | 0.000394              | 0.000193                                  | 0.0000132 |
| 1         | 0.00133            | 0.001          | <b>29.91996</b>                                   | 0.0000394             | 0.0000193                                 | 0.0000013 |
| 0.1       | 0.000133           | 0.0001         | <b>29.919996</b>                                  | 0.0000039             | 0.0000019                                 | 0.0000001 |

**EQUIVALENCE TABLE**  
**FURNACE VACUUM GAUGE READINGS (PSIG OR PSI)**  
**TO ABSOLUTE PRESSURE VALUES**

| <b>Bar</b> | <b>Torr</b> | <b>Psig<br/>(Furnace gauge)</b> | <b>Psia<br/>(lb/in<sup>2</sup>)</b> | <b>Atm</b> |
|------------|-------------|---------------------------------|-------------------------------------|------------|
| 1.01325    | 760.0       | <b>0</b>                        | 14.7                                | 1.00       |
| 1.082515   | 811.8       | <b>1</b>                        | 15.7                                | 1.0682     |
| 1.358315   | 1018.7      | <b>5</b>                        | 19.7                                | 1.3404     |
| 1.703065   | 1277.4      | <b>10</b>                       | 24.7                                | 1.6806     |
| 2.047815   | 1535.8      | <b>15</b>                       | 29.7                                | 2.0208     |
| 2.392565   | 1794.3      | <b>20</b>                       | 34.7                                | 2.36098    |
| 3.082065   | 2311.4      | <b>30</b>                       | 44.7                                | 3.04139    |
| 3.771565   | 2828.5      | <b>40</b>                       | 54.7                                | 3.72179    |
| 4.461065   | 3345.6      | <b>50</b>                       | 64.7                                | 4.40219    |
| 5.150565   | 3862.7      | <b>60</b>                       | 74.7                                | 5.08259    |
| 5.840065   | 4379.8      | <b>70</b>                       | 84.7                                | 5.76299    |
| 6.529565   | 4896.9      | <b>80</b>                       | 94.7                                | 6.44339    |
| 7.219065   | 5414.0      | <b>90</b>                       | 104.7                               | 7.12379    |
| 7.908565   | 5931.1      | <b>100</b>                      | 114.7                               | 7.80419    |
| 14.80357   | 11102.1     | <b>200</b>                      | 214.7                               | 14.6082    |
| 18.25207   | 13690.2     | <b>250</b>                      | 264.7                               | 18.0102    |
| 21.69857   | 16273.1     | <b>300</b>                      | 314.7                               | 21.4122    |
| 28.59357   | 21444.1     | <b>400</b>                      | 414.7                               | 28.2162    |
| 35.48857   | 26615.1     | <b>500</b>                      | 514.7                               | 35.0202    |
| 42.38357   | 31786.1     | <b>600</b>                      | 614.7                               | 41.8242    |
| 49.27857   | 36957.1     | <b>700</b>                      | 714.7                               | 48.6282    |
| 56.17357   | 42128.1     | <b>800</b>                      | 814.7                               | 55.4322    |
| 63.06857   | 47299.1     | <b>900</b>                      | 914.7                               | 62.2362    |
| 69.96357   | 52470.1     | <b>1000</b>                     | 1014.7                              | 69.0402    |
| 104.4386   | 78325.1     | <b>1500</b>                     | 1514.7                              | 103.0602   |
| 173.3886   | 130052.9    | <b>2500</b>                     | 2514.7                              | 171.1206   |
| 207.8636   | 155910.2    | <b>3000</b>                     | 3014.7                              | 205.1447   |
| 242.3386   | 181769.9    | <b>3500</b>                     | 3514.7                              | 239.1688   |

# **TEMPERATURE CONVERSION** **FAHRENHEIT TO CELSIUS OR KELVIN**

| °F  | °C    | K     | °F   | °C    | K      | °F   | °C     | K      |
|-----|-------|-------|------|-------|--------|------|--------|--------|
| -40 | -40   | 233.2 | 550  | 287.8 | 560.9  | 1700 | 926.7  | 1199.8 |
| -32 | -35.6 | 237.6 | 600  | 315.6 | 588.7  | 1750 | 954.4  | 1227.6 |
| -20 | -28.9 | 244.3 | 650  | 343.3 | 616.5  | 1800 | 982.2  | 1255.4 |
| -10 | -23.3 | 249.8 | 700  | 371.1 | 644.3  | 1850 | 1010.0 | 1283.2 |
| 0   | -17.8 | 255.4 | 750  | 398.9 | 672.0  | 1900 | 1037.8 | 1310.9 |
| 5   | -15   | 258.2 | 800  | 426.7 | 699.8  | 1950 | 1065.6 | 1338.7 |
| 10  | -12.2 | 260.9 | 850  | 454.4 | 727.6  | 2000 | 1093.3 | 1366.5 |
| 20  | -6.7  | 266.5 | 900  | 482.2 | 755.4  | 2050 | 1121.1 | 1394.3 |
| 32  | 0     | 273.2 | 950  | 510.0 | 783.2  | 2100 | 1148.9 | 1422.0 |
| 40  | 4.4   | 277.6 | 1000 | 537.8 | 810.9  | 2150 | 1176.7 | 1449.8 |
| 50  | 10    | 283.2 | 1050 | 565.6 | 838.7  | 2200 | 1204.4 | 1477.6 |
| 70  | 21.1  | 294.3 | 1100 | 593.3 | 866.5  | 2250 | 1232.2 | 1505.4 |
| 90  | 32.2  | 305.4 | 1150 | 621.1 | 894.3  | 2300 | 1260.0 | 1533.2 |
| 100 | 37.8  | 310.9 | 1200 | 648.9 | 922.0  | 2350 | 1287.8 | 1560.9 |
| 120 | 48.9  | 322.0 | 1250 | 676.7 | 949.8  | 2400 | 1315.6 | 1588.7 |
| 150 | 65.6  | 338.7 | 1300 | 704.4 | 977.6  | 2450 | 1343.3 | 1616.5 |
| 212 | 100   | 373.2 | 1350 | 732.2 | 1005.4 | 2500 | 1371.1 | 1644.3 |
| 250 | 121.1 | 394.3 | 1400 | 760.0 | 1033.2 | 2550 | 1398.9 | 1672.0 |
| 300 | 148.9 | 422.0 | 1450 | 787.8 | 1060.9 | 2600 | 1426.7 | 1699.8 |
| 350 | 176.7 | 449.8 | 1500 | 815.6 | 1088.7 | 2650 | 1454.4 | 1727.6 |
| 400 | 204.4 | 477.6 | 1550 | 843.3 | 1116.5 | 2700 | 1482.2 | 1755.4 |
| 450 | 232.2 | 505.4 | 1600 | 871.1 | 1144.3 | 2750 | 1510.0 | 1783.2 |
| 500 | 260   | 533.2 | 1650 | 898.9 | 1172.0 | 2800 | 1537.8 | 1810.9 |

Formulas:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32)/1.8$$

$$\text{K} = (^{\circ}\text{F} + 459.67)/1.8$$

$$^{\circ}\text{F} = (1.8 * \text{K}) - 459.67$$

$$^{\circ}\text{F} = (1.8 * ^{\circ}\text{C}) + 32$$

$$^{\circ}\text{C} = \text{K} - 273$$

$$\text{K} = ^{\circ}\text{C} + 273$$

| <b>POWDERED METALS</b><br><b>U.S. MESH TO MICRON CONVERSION CHART</b> |         |             |        |              |
|-----------------------------------------------------------------------|---------|-------------|--------|--------------|
| U.S. Mesh                                                             | Microns | Millimeters | Inches | Appearance   |
| 5                                                                     | 400     | 4.0         | 0.1570 |              |
| 10                                                                    | 2000    | 2.0         | 0.0787 |              |
| 20                                                                    | 841     | 0.841       | 0.0331 |              |
| 28                                                                    | 700     | 0.700       | 0.028  | Beach Sand   |
| 35                                                                    | 500     | 0.500       | 0.0197 |              |
| 40                                                                    | 400     | 0.400       | 0.0165 |              |
| 50                                                                    | 297     | 0.297       | 0.0117 |              |
| 60                                                                    | 250     | 0.250       | 0.0098 | Fine Sand    |
| 70                                                                    | 210     | 0.210       | 0.0083 |              |
| 80                                                                    | 177     | 0.177       | 0.0070 |              |
| 100                                                                   | 149     | 0.149       | 0.0059 |              |
| 120                                                                   | 125     | 0.125       | 0.0049 |              |
| 140                                                                   | 105     | 0.105       | 0.0041 |              |
| 200                                                                   | 74      | 0.074       | 0.0029 | Cement       |
| 325                                                                   | 44      | 0.044       | 0.0017 | Silt         |
| 400                                                                   | 37      | 0.037       | 0.0015 | Plant pollen |

## **References**

- ASM Handbook, 8<sup>th</sup> ed. Materials Park, OH: ASM International, 1970.
- ASM Handbook, 9<sup>th</sup> ed. Materials Park, OH: ASM International, 1989.
- ASM Handbook, 10<sup>th</sup> ed., vol.1. Materials Park, OH: ASM International, 1990.
- ASM Handbook, 10<sup>th</sup> ed., vol. 2. Materials Park, OH: ASM International, 1990.
- Baker, Hugh, managing ed. Metals Handbook, 9<sup>th</sup> ed, vol. 2. Metals Park, OH: American Society for Metals, 1989.
- Bauccio, Michael, ed. ASM Metals Reference Book, 3<sup>rd</sup> ed. Materials Park, OH: ASM International, 1993.
- Burns, Jr., Charles F., ed. Critical Melting Points for Metals and Alloys. Souderton, PA: Solar Atmospheres, Inc. 1997.
- “Emissivity of Common Materials.” 2003. Omega Engineering, Inc. 3 June 2005. [www.omega.com/literature/transactions/volume1/emissivityb.html](http://www.omega.com/literature/transactions/volume1/emissivityb.html).
- “Emissivity Table.” Calnex Electronics Limited, 9 June 2005. [www.elit.se/pdf/calex](http://www.elit.se/pdf/calex).
- Gaskell, David R. Introduction to the Thermodynamics of Materials, 4<sup>th</sup> ed. New York: Taylor & Francis Group, 2003.
- Hansen, Max, and Kurt Anderko. Constitution of Binary Alloys. New York: McGraw-Hill Book Company, Inc, 1958.
- Harvey, Philip D., ed. Engineering Properties of Steel. Metals Park, OH: American Society for Metals, 1982.
- Hatch, John E., ed. Aluminum: Properties and Physical Metallurgy. Metals Park, OH: American Society for Metals, 1984.
- “High Performance Alloys.” 2003. Special Metals: The Alloy Experts. 10, 13 June 2005. [www.specialmetals.com/products](http://www.specialmetals.com/products).
- Hunt, Margaret W., ed. “Guide to Engineered Materials.” *Advanced Materials & Processes* December 1999
- Kohl, Walter H., Handbook of Materials and Techniques for Vacuum Devices. American Institute of Physics, 1995
- Lide, David R., Editor in chief. Handbook of Chemistry and Physics. 85<sup>th</sup> Edition, Boca Raton, FL. CRC Press 2004-2005
- “Matweb: Material Property Data.” 1996-2005. Automation Creations, Inc. 23 & 24 May 2005. [www.matweb.com](http://www.matweb.com).
- Okamoto, Hiroaki. Desk Handbook: Phase Diagrams for Binary Alloys. Materials Park, OH: ASM International, 2000.
- Standards Handbook Part 2—Alloy Data. Greenwich, CT: Copper Development Association, Inc, 1985.
- Standards Handbook Part 7—Alloy Data. New York: Copper Development Association, Inc, 1978.
- “Steel Castings Handbook, Supplement 8: High Alloy Data Sheets, Corrosion Series.” 2004. Steel Founders Society of America. 23 May 2005. [www.sfsa.org/sfsa/pubs/hbk/s8.pdf](http://www.sfsa.org/sfsa/pubs/hbk/s8.pdf).
- “Steel Castings Handbook, Supplement 9: High Alloy Data Sheets, Heat Series.” 2004. Steel Founders Society of America. 23 May 2005. [www.sfsa.org/sfsa/pubs/hbk/s9.pdf](http://www.sfsa.org/sfsa/pubs/hbk/s9.pdf).
- “Total of Emissivity of Various Surfaces.” Mikron Infrared, June 3 2005. [www.contika.dk/Download/content-filer/emissionsfaktor.pdf](http://www.contika.dk/Download/content-filer/emissionsfaktor.pdf).



**Solar Atmospheres Eastern PA Plant A**

1969 Clearview Road, Souderton, PA 18964  
p. 800.347.3236

**Solar Atmospheres Eastern PA Plant B**

255 Township Line Road, Hatfield, PA 19440  
p. 800.347.3236

**Solar Atmospheres Western PA**

30 Industrial Road, Hermitage, PA 16148  
p. 866.982.0660

**Solar Atmospheres CA**

8606 Live Oak Avenue, Fontana, CA 92335  
p. 866.559.5994

[www.solaratm.com](http://www.solaratm.com)



1983 Clearview Road, Souderton, PA 18964  
p. 267.384.5040

[www.solararmfg.com](http://www.solararmfg.com)