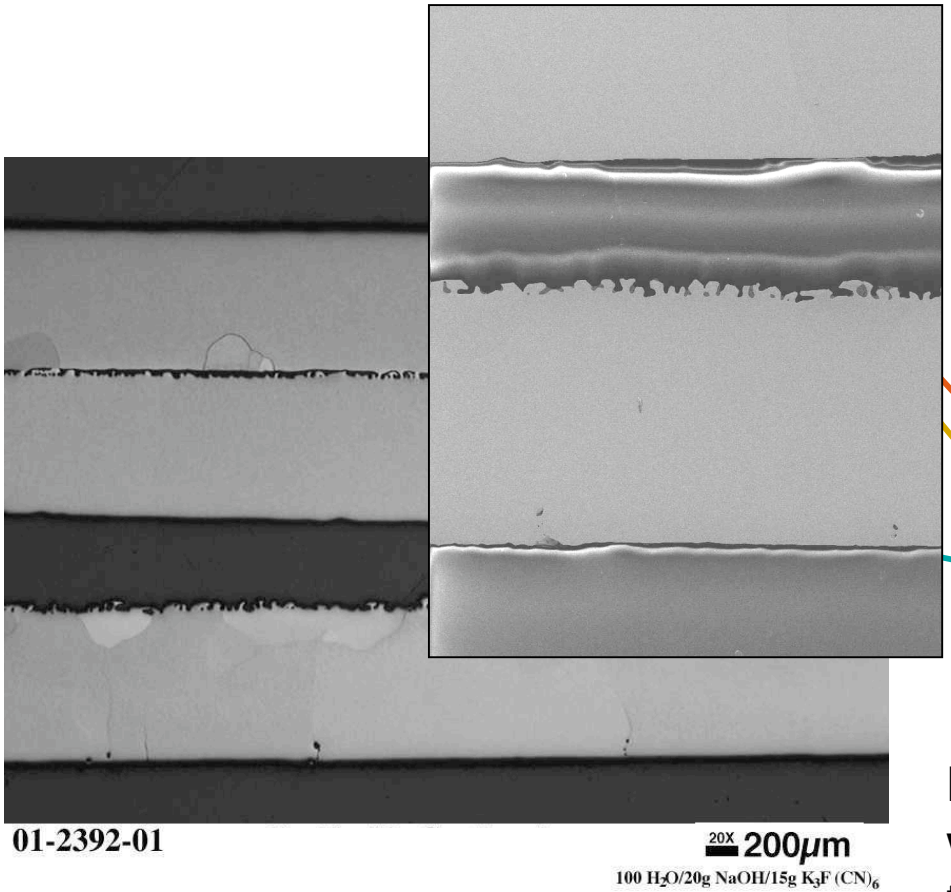
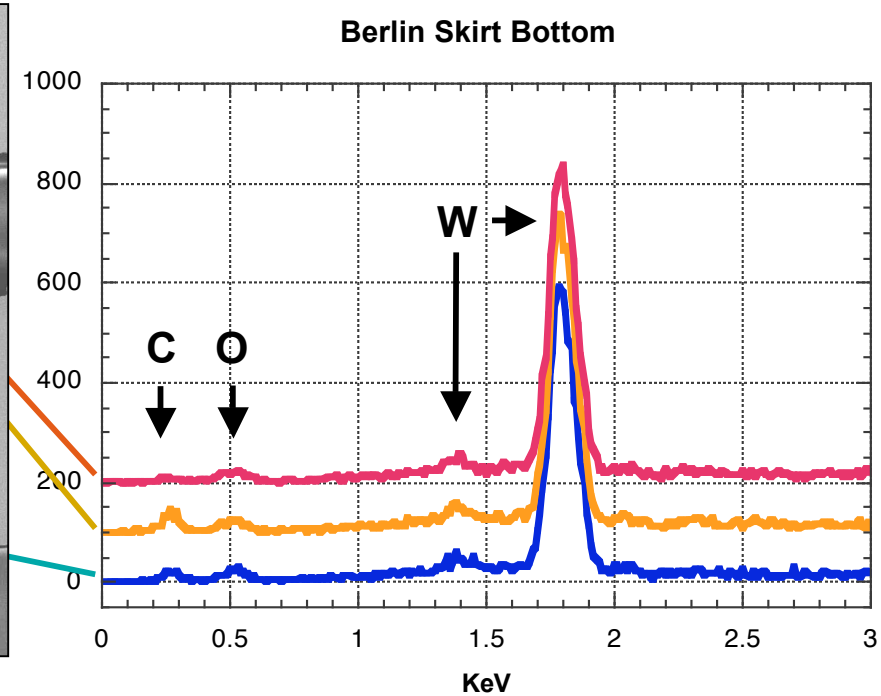
Only W Crystals Form Between the Sheets at the Bottom of Type 2 Skirt

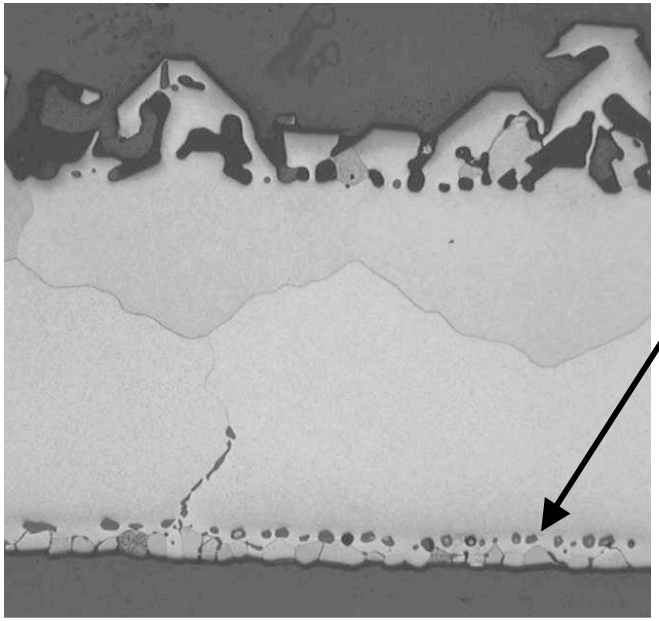




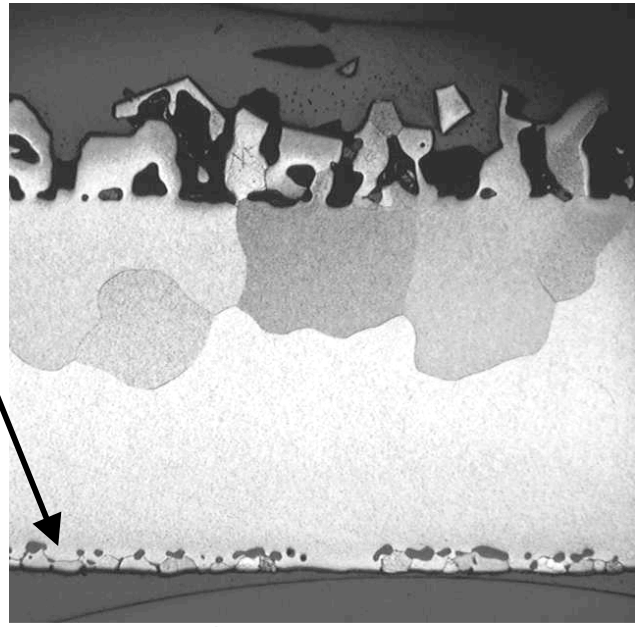
Neither crystals nor molybdenum was observed on the inside of the tungsten skirt away from the orifice.

Crystals Form on Both Sides of the Inner W Sheet at Top of Type 2 Skirt

Oriented crystals grow on the outer surface of the tungsten sheet.

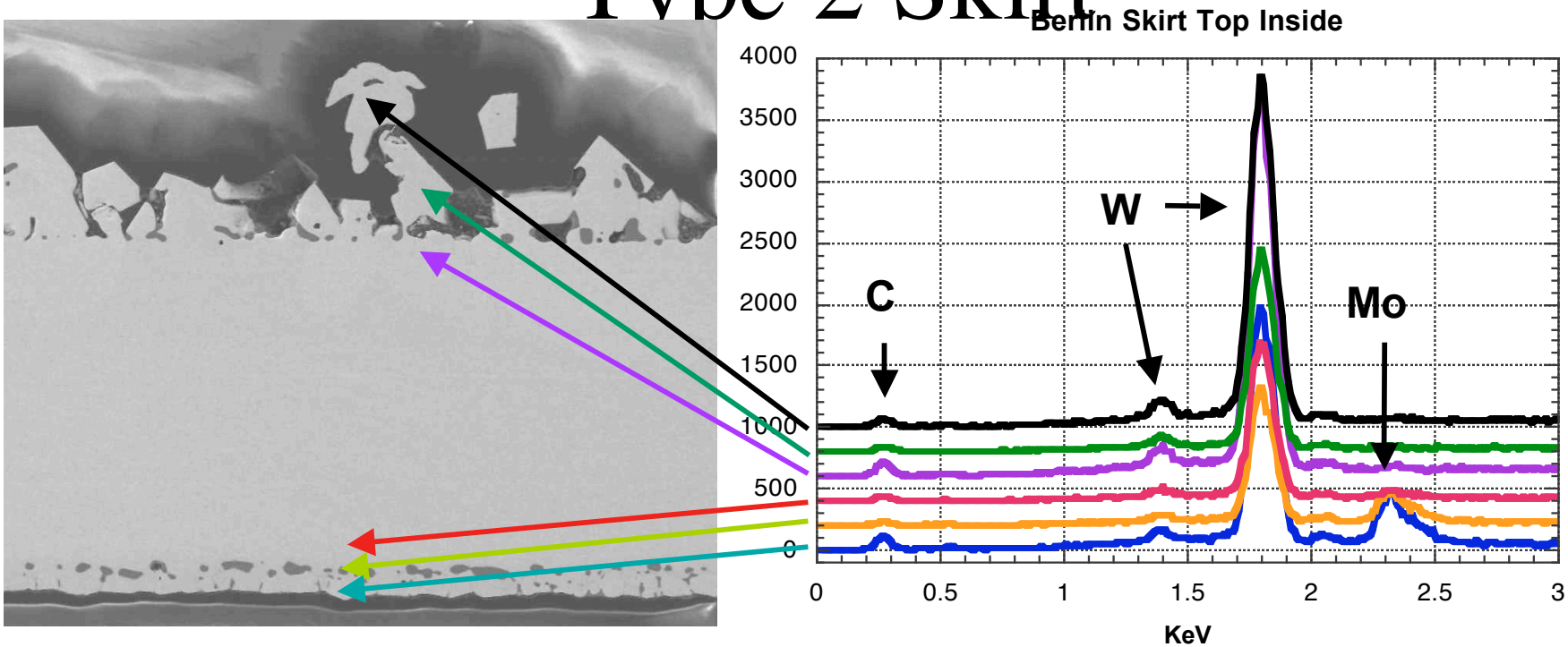


Holes are present between the base metal and the very small crystals on the inner surface



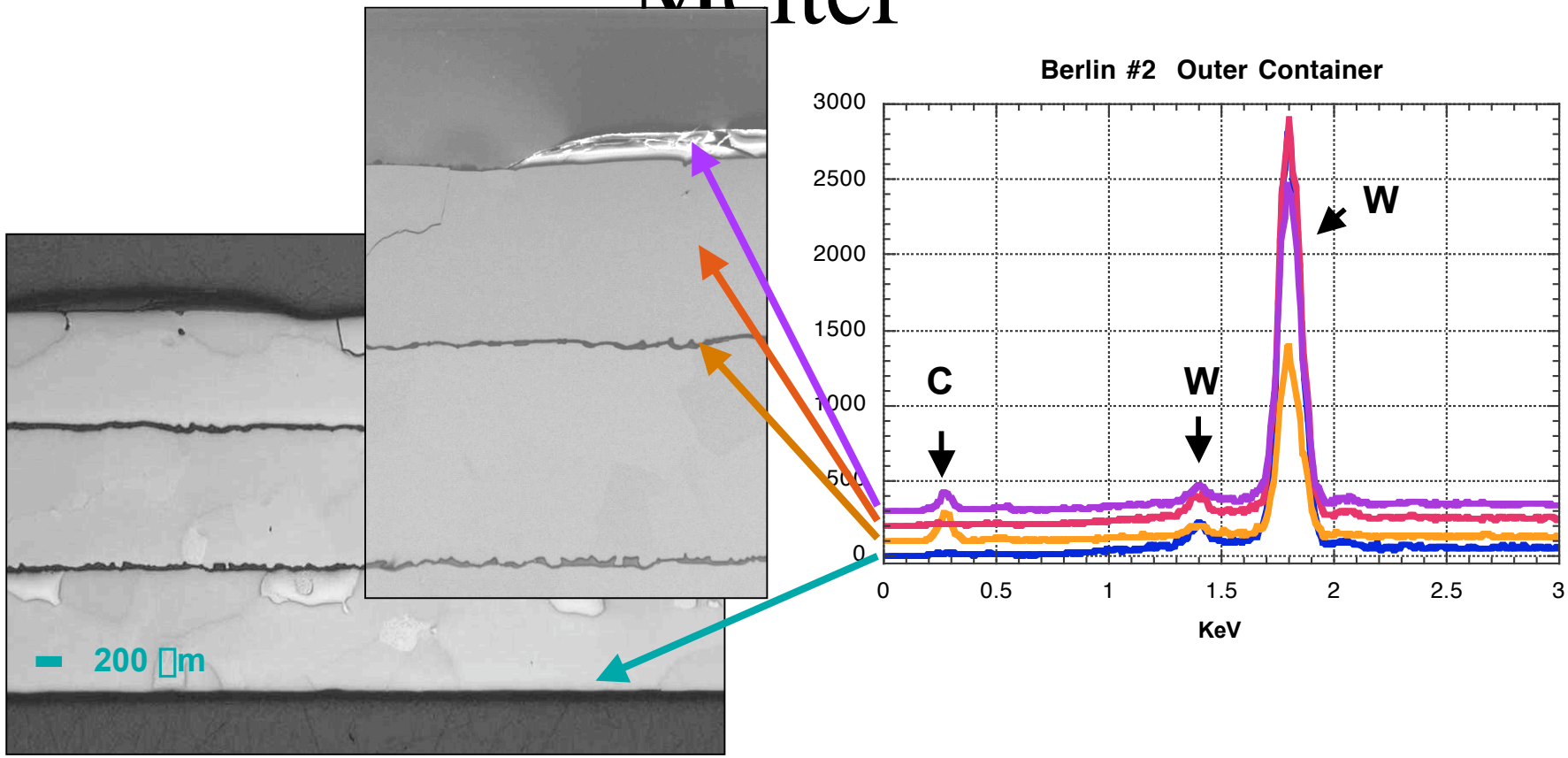
Very small crystals grow in random directions on the inner surface of the tungsten sheet.

W or W/Mo Crystals Grow on Opposite Surfaces at the Top of the Type 2 Skirt

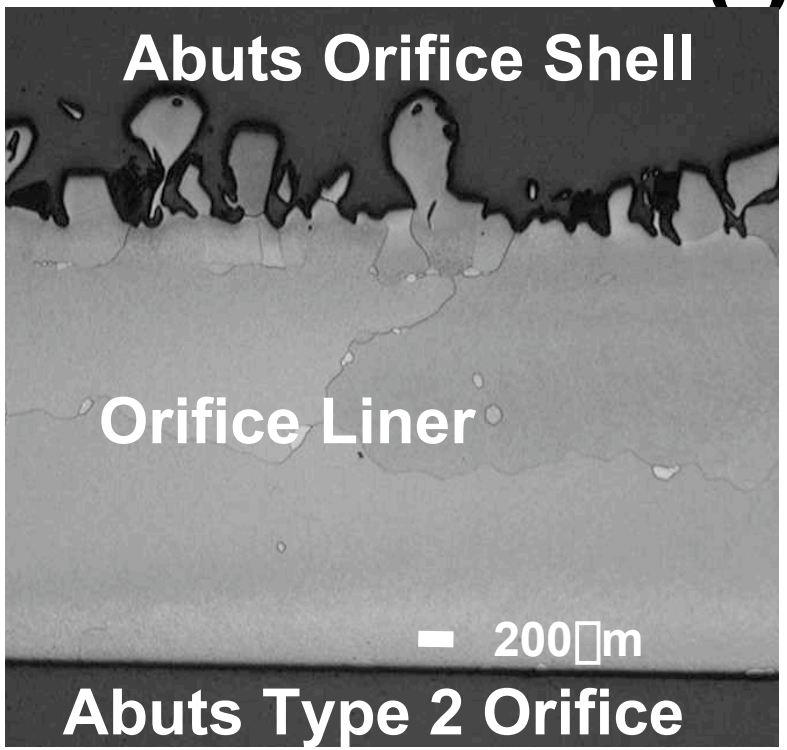


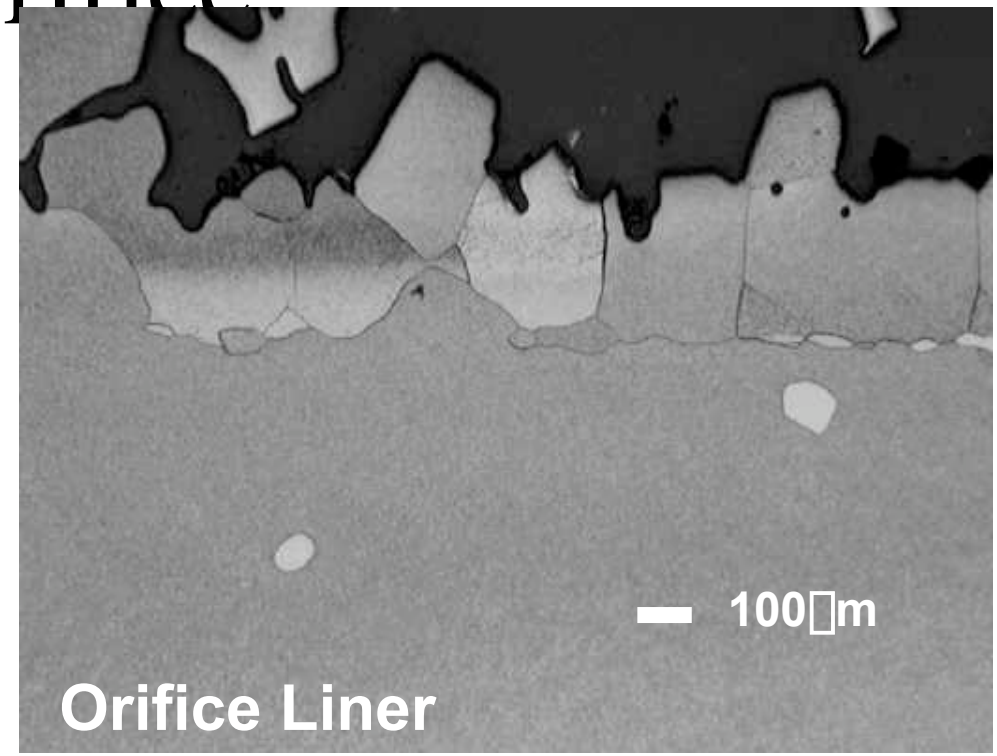
SEM shows crystals growing on opposite sides of the W sheet are either W for the outer surface or W /Mo for the top inner surface of the Berlin skirt.

Three Tungsten Sheets Form the Orifice Shell of the Type 2 Melter



Crystals Grow at the Interface of the Shell & Liner Abutting Type 2 #2 Orifice

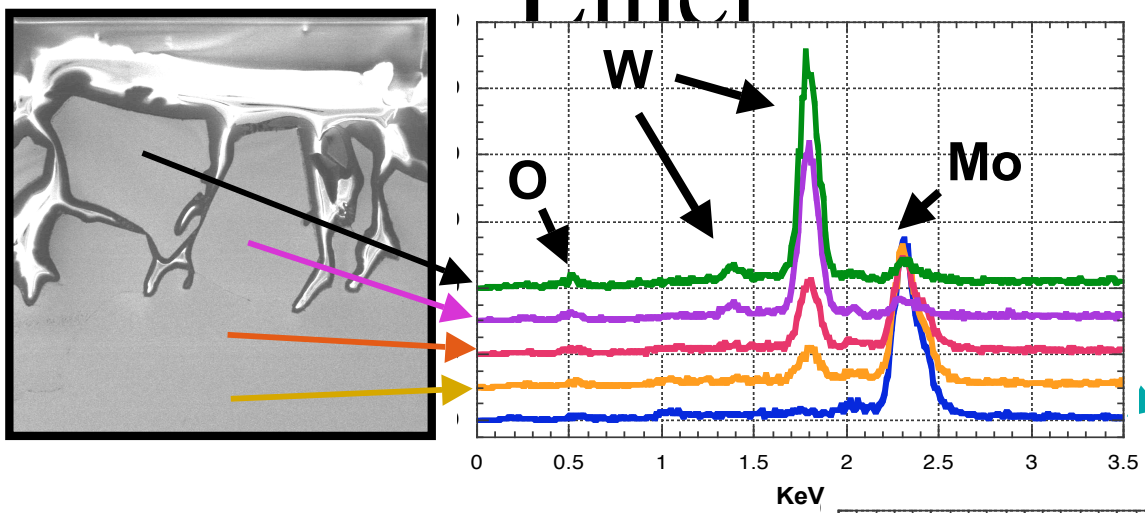




Crystals with random orientations grow as small grains on the surface of larger grains. This differs from crystal growth on orifice.

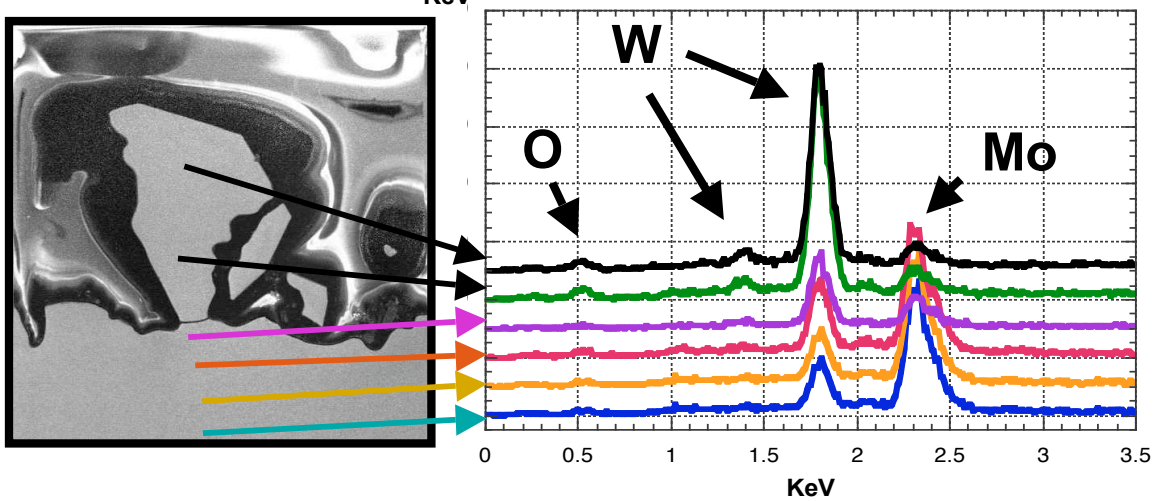
Tungsten Diffuses Into Molybdenum of Type 2's Orifice Liner

W / Mo crystals form between shell & liner.

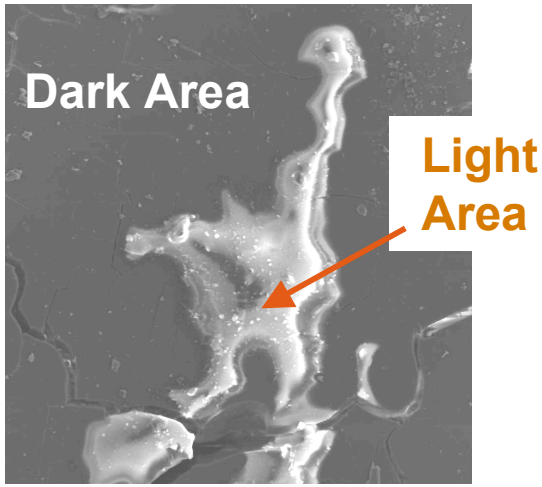


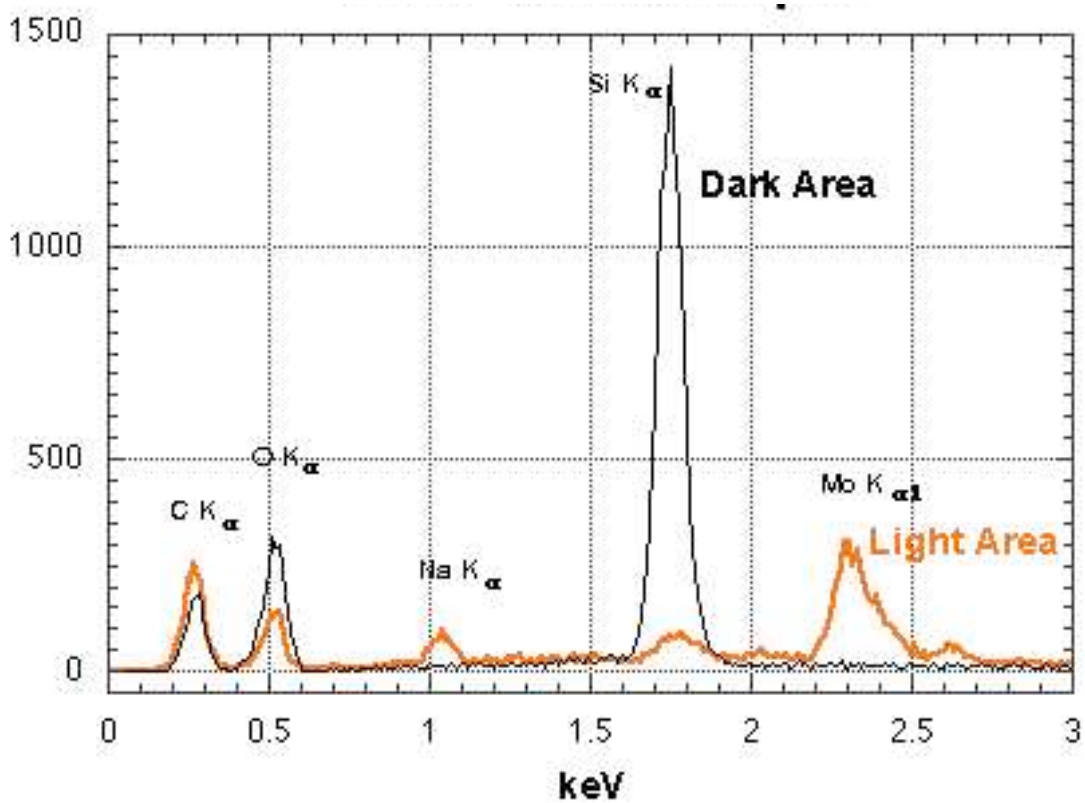
Molybdenum Interior

Tungsten content decreases with depth as it diffuses into the orifice liner.

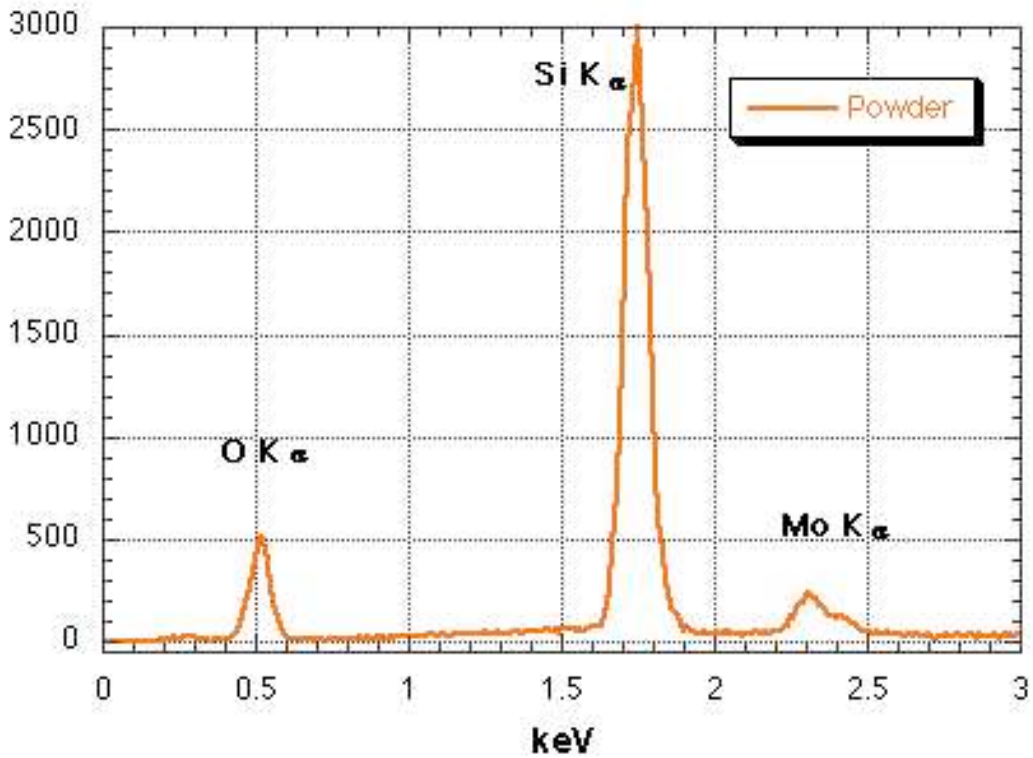


Light Areas in Glass on Inside of the Type 2 #2 Orifice Contain Molybdenum





Powder From Inside the Extruded Glass Tube Contains Si, O and Mo



Depositions on inside of quartz tube, supports the hypothesis of Mo-O_X or Mo-Si-O_X vapor.

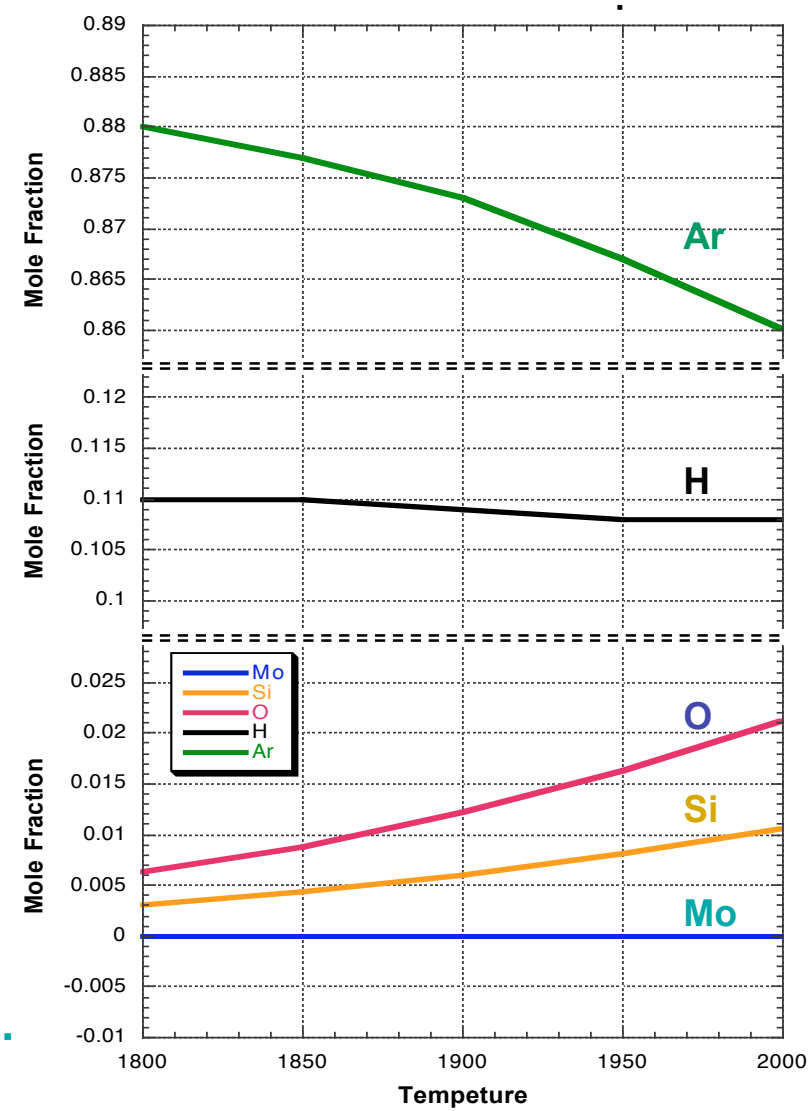
Elemental Mole Fraction Calculated Using Chem Sage

Starting Conditions

Stream Constituents	Amount/mol
Mo	1.00E+02
H2/Gas	6.00E+00
O2/Gas	1.00E-03
Ar/Gas	9.60E+01
SiO2 (Quartz)	1.00E+02

Oxygen mole fraction increases with temperature not with initial concentration.

Elemental Mole Fraction of Gas Phase Components



Thermodynamic Modeling Shows Mo Oxides Can Originate Inside Melter

- Oxygen available from SiO_2 reduced by Ar/H2
- Mo reacts with oxygen to form Mo-oxides
- MoO_X migrate through orifice & begins to cool
- Mo oxides reduce in Ar/H_2 on cooling
- Reduced molybdenum condenses out forming crystals on bottom of orifice and skirt

At 1800 °C, ~ 13 lbs of molybdenum can be transported in a year.

Use of Tungsten in Type 2 Quartz Melter Alters Crystal Formations

- Differences
  - W container limits Molybdenum available for deposition
  - Tungsten skirt alters crystal formation
    - Surface at top of skirt has an outer Mo/W layer
    - Crystals in Mo/W layer have different orientations than that of the base metal

- Similarities
  - No tungsten crystals form under current operating temperature & P_{O_2}

Experimental Results Indicate Vapor Deposition of Mo crystals

- Nucleation of crystals by single grains
  - Similar to coatings grown on single crystal substrates
- Clustering of crystals at vents
  - Mixing point of Mo rich and poor gases
  - Potential temperature variation in gases
- Growth of crystals on the (111) plane
  - Preferred growth plane in BCC metals

Thermodynamic Modeling shows Mo Most Likely from Inside the Melter

- Gas from outside melter would not pick up MoO_X at 2000 °C even with minor impurities of O_2 (1000 ppm)
- Addition of SiO_2 into calculations forms SiO which releases O to form MoO_X at equilibrium at 2000 °C
- As the saturated gas cools to 1800 °C, then Mo is deposited out of the reducing gas phase

Conclusions

- Vapor deposition of molybdenum occurs upon reducing gas phase Mo oxides on bottom of orifice and skirt
- Source of Mo oxides is most likely from transported through the orifice by the molten quartz or as a gas stream
- Below the orifice the MoO_X phases is releaxed from the molten quartz and reduced in the Ar/H_2 environment
- Molybdenum crystals nucleate at single grains and grow in a preferred direction

Recommendations Are to Either Eliminate or Direct Crystal Growth

- Eliminate Crystal Growth
  - All tungsten components
  - Tungsten lining on the inside of the melter
  - Mo sequestering agent in Ar/H_2 gas below orifice
- Direct Crystal Growth
  - Attach seed crystals on skirt vents and orifice
  - Attach a textured Mo surface on bottom of orifice and skirt
  - Develop a coating to inhibit crystal growth