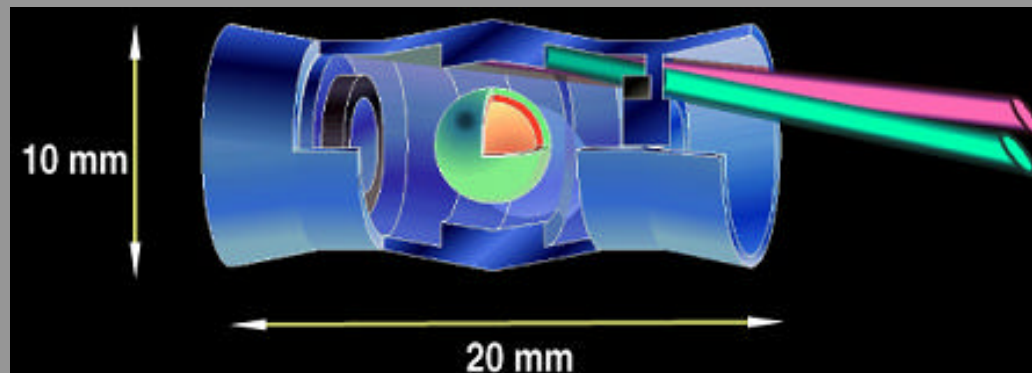


***Fabrication of Functionally-Graded Inertial
Fusion Energy (IFE) Targets***



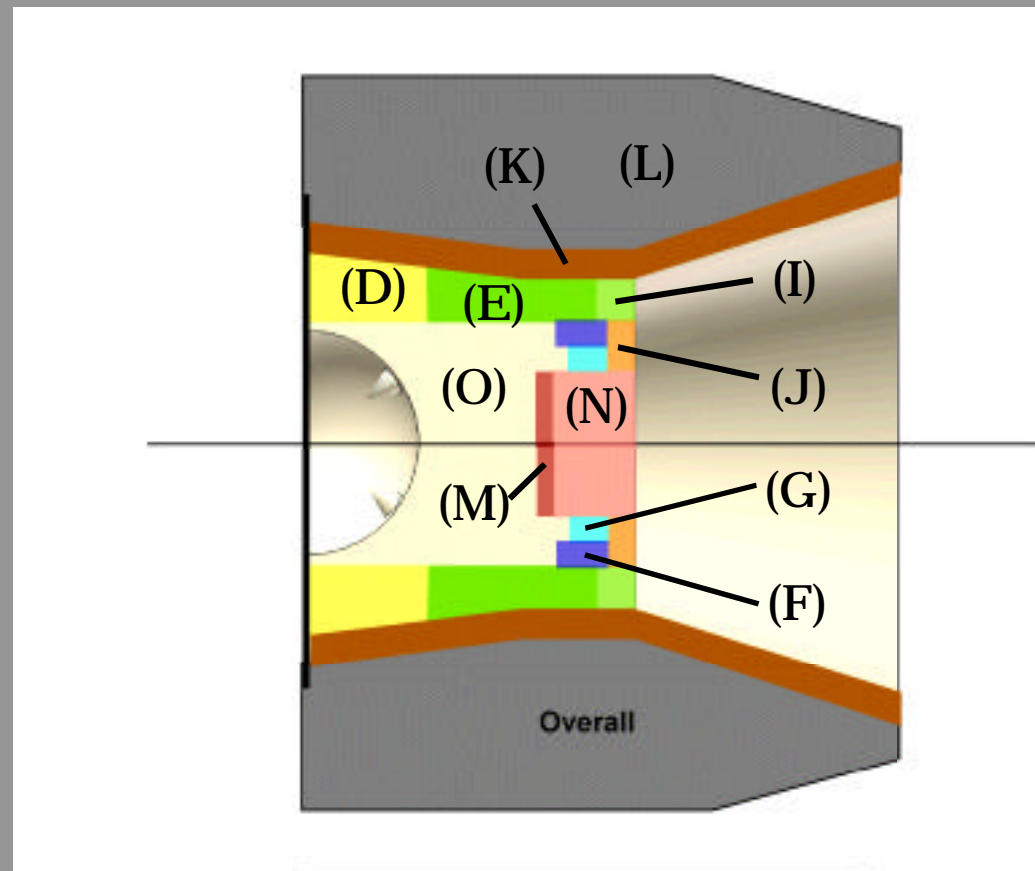
Target Fabrication Facility, Materials Science & Technology
Division Los Alamos National Lab, jmaxwell@lanl.gov, ph: 505-665-4289

General Atomics, San Diego, CA

Unclassified

HIF Distributed Radiator Target (Densities in g/cm^3)

- (D) Au (.032)
- (E) $\text{CD}_2\text{Au}0.03$ (0.011)
- (F) Fe (0.064)
- (G) Fe (0.083)
- (I) AuGd (0.10)
- (J) AuGD (0.26)
- (K) AuGd (0.099)
- (L) AuGd (13.5)
- (M) Al (0.055)
- (N) AuGd (0.099, 1.0, 0.5)
- (O) D_2 (0.001)



● Callahan & Tabak, Nuc. Fus. V.39 (884)

Unclassified

Material Substitutions

— AuGd →

- Alloys A-B

— High-Z (A) →

- La, Ta, Hf, W

— High-Z (B) →

- Hg, Pb, Bi, I

Periodic Table of the Elements

1999 IUPAC Values (limited to 0.001 atomic mass units)
Complete values with errors available at
www.chem.qmw.ac.uk/iupac/AtWt/

Hydrogen 1.0079 H 1																	Helium 4.003 He 2																	
Lithium 6.941 Li 3	Beryllium 9.012 Be 4											Boron 10.811 B 5	Carbon 12.011 C 6	Nitrogen 14.007 N 7	Oxygen 15.999 O 8	Fluorine 18.998 F 9	Neon 20.180 Ne 10																	
Sodium 22.990 Na 11	Magnesium 24.305 Mg 12											Aluminum 26.982 Al 13	Silicon 28.086 Si 14	Phosphorus 30.974 P 15	Sulfur 32.065 S 16	Chlorine 35.453 Cl 17	Argon 39.948 Ar 18																	
Potassium 39.098 K 19	Calcium 40.078 Ca 20	Scandium 44.956 Sc 21	Titanium 47.867 Ti 22	Vanadium 50.942 V 23	Chromium 51.996 Cr 24	Manganese 54.938 Mn 25	Iron 55.845 Fe 26	Cobalt 58.933 Co 27	Nickel 58.693 Ni 28	Copper 63.546 Cu 29	Zinc 65.39 Zn 30	Gallium 69.723 Ga 31	Germanium 72.64 Ge 32	Arsenic 74.922 As 33	Selenium 78.96 Se 34	Bromine 79.904 Br 35	Krypton 83.80 Kr 36																	
Rubidium 85.468 Rb 37	Sr 87.62 Sr 38	Yttrium 88.906 Y 39	Zirconium 91.224 Zr 40	Niobium 92.906 Nb 41	Molybdenum 95.94 Mo 42	Technetium {98} Tc 43	Ruthenium 101.07 Ru 44	Rhodium 102.906 Rh 45	Palladium 106.42 Pd 46	Silver 107.868 Ag 47	Cadmium 112.411 Cd 48	Indium 114.818 In 49	Tin 118.710 Sn 50	Antimony 121.760 Sb 51	Tellurium 127.60 Te 52	Iodine 126.904 I 53	Xenon 131.293 Xe 54																	
Cesium 132.905 Cs 55	Barium 137.327 Ba 56	Lanthanum 174.967 La 57	Hafnium 178.49 Hf 72	Tantalum 180.948 Ta 73	Tungsten 183.84 W 74	Rhenium 186.207 Re 75	Osmium 190.23 Os 76	Iridium 192.217 Ir 77	Platinum 195.078 Pt 78	Gold 196.967 Au 79	Mercury 200.59 Hg 80	Thallium 204.383 Tl 81	Lead 207.2 Pb 82	Bismuth 208.980 Bi 83	Polonium {209} Po 84	Astatine {210} At 85	Radon {222} Rn 86																	
Francium {223} Fr 87	Radium {226} Ra 88	Lanthanum {262} La 103	Rutherfordium {261} Rf 104	Dubnium {262} Db 105	Seaborgium {266} Sg 106	Berkelium {264} Bk 107	Hassium {277} Hs 108	Mt {268} Mt 109	Bohrium {277} Bh 110	Hassium {277} Hs 111	Mt {268} Mt 112	Bohrium {277} Bh 113	Hassium {277} Hs 114	Mt {268} Mt 115	Bohrium {277} Bh 116	Hassium {277} Hs 117	Mt {268} Mt 118																	
																	Roentgenium 1110 Rg 111	Uubium 1111 Uub 112	Uutium 1112 Uut 113	Uuqium 1113 Uuq 114	Uuqium 1114 Uuq 115	Uuqium 1115 Uuq 116	Uuqium 1116 Uuq 117	Uuqium 1117 Uuq 118										
																	Meitnerium 1120 Mt 119	Darmstadtium 1121 Ds 120	Roentgenium 1122 Rg 121	Uubium 1123 Uub 122	Uuqium 1124 Uuq 123	Uuqium 1125 Uuq 124	Uuqium 1126 Uuq 125	Uuqium 1127 Uuq 126	Uuqium 1128 Uuq 127	Uuqium 1129 Uuq 128	Uuqium 1130 Uuq 129	Uuqium 1131 Uuq 130	Uuqium 1132 Uuq 131	Uuqium 1133 Uuq 132	Uuqium 1134 Uuq 133	Uuqium 1135 Uuq 134	Uuqium 1136 Uuq 135	
																	Uuqium 1137 Uuq 136	Uuqium 1138 Uuq 137	Uuqium 1139 Uuq 138	Uuqium 1140 Uuq 139	Uuqium 1141 Uuq 140	Uuqium 1142 Uuq 141	Uuqium 1143 Uuq 142	Uuqium 1144 Uuq 143	Uuqium 1145 Uuq 144	Uuqium 1146 Uuq 145	Uuqium 1147 Uuq 146	Uuqium 1148 Uuq 147	Uuqium 1149 Uuq 148	Uuqium 1150 Uuq 149	Uuqium 1151 Uuq 150	Uuqium 1152 Uuq 151	Uuqium 1153 Uuq 152	
																	Uuqium 1154 Uuq 153	Uuqium 1155 Uuq 154	Uuqium 1156 Uuq 155	Uuqium 1157 Uuq 156	Uuqium 1158 Uuq 157	Uuqium 1159 Uuq 158	Uuqium 1160 Uuq 159	Uuqium 1161 Uuq 160	Uuqium 1162 Uuq 161	Uuqium 1163 Uuq 162	Uuqium 1164 Uuq 163	Uuqium 1165 Uuq 164	Uuqium 1166 Uuq 165	Uuqium 1167 Uuq 166	Uuqium 1168 Uuq 167	Uuqium 1169 Uuq 168	Uuqium 1170 Uuq 169	Uuqium 1171 Uuq 170
																	Uuqium 1172 Uuq 171	Uuqium 1173 Uuq 172	Uuqium 1174 Uuq 173	Uuqium 1175 Uuq 174	Uuqium 1176 Uuq 175	Uuqium 1177 Uuq 176	Uuqium 1178 Uuq 177	Uuqium 1179 Uuq 178	Uuqium 1180 Uuq 179	Uuqium 1181 Uuq 180	Uuqium 1182 Uuq 181	Uuqium 1183 Uuq 182	Uuqium 1184 Uuq 183	Uuqium 1185 Uuq 184	Uuqium 1186 Uuq 185	Uuqium 1187 Uuq 186	Uuqium 1188 Uuq 187	Uuqium 1189 Uuq 188
																	Uuqium 1190 Uuq 189	Uuqium 1191 Uuq 190	Uuqium 1192 Uuq 191	Uuqium 1193 Uuq 192	Uuqium 1194 Uuq 193	Uuqium 1195 Uuq 194	Uuqium 1196 Uuq 195	Uuqium 1197 Uuq 196	Uuqium 1198 Uuq 197	Uuqium 1199 Uuq 198	Uuqium 1200 Uuq 199	Uuqium 1201 Uuq 200	Uuqium 1202 Uuq 201	Uuqium 1203 Uuq 202	Uuqium 1204 Uuq 203	Uuqium 1205 Uuq 204	Uuqium 1206 Uuq 205	Uuqium 1207 Uuq 206

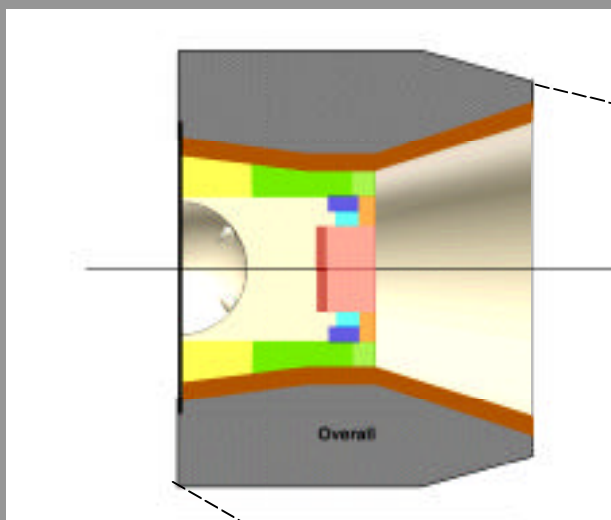
Revised
8-13-01
© Harcourt
& Murrice
Co.

**Solids
Liquids
Gases**

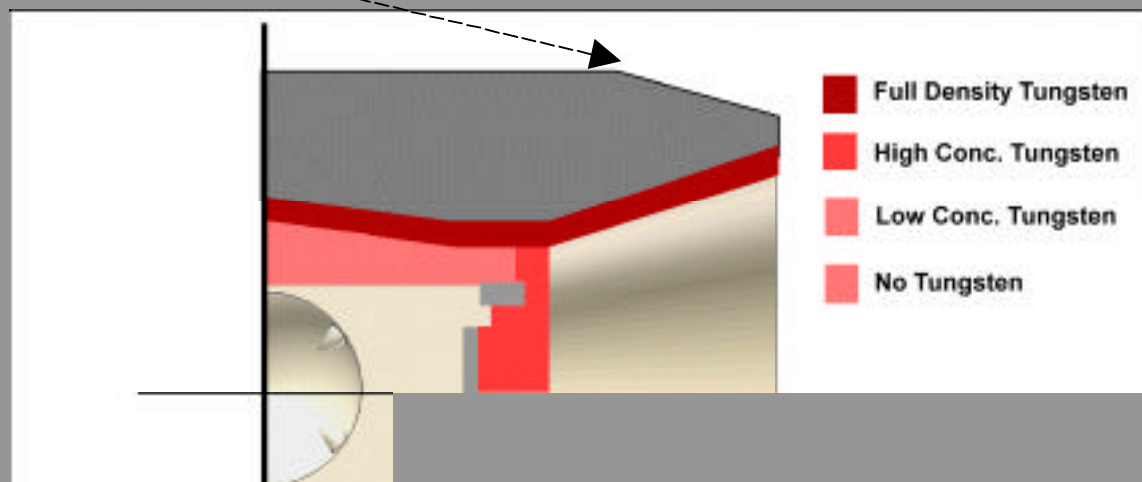
Additional Substitutions

- CD2Au Foam→
 - High-Z metals in B lattice
- Al →Boron Lattice
- Fe →High-Z metals in B or Si lattice
- CD2 →Boron Lattice

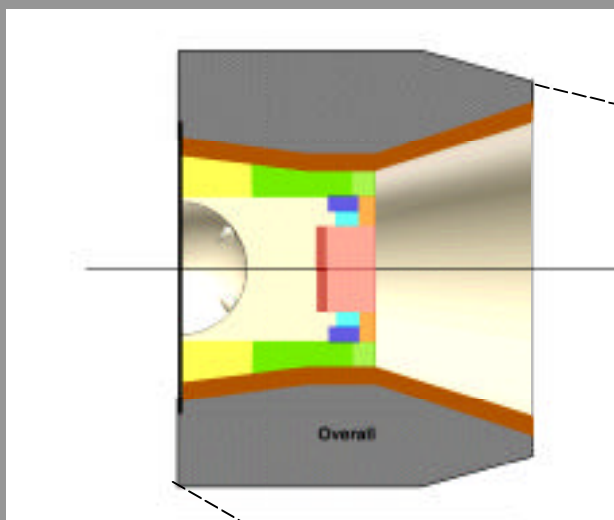
Simplifies to Three Elements



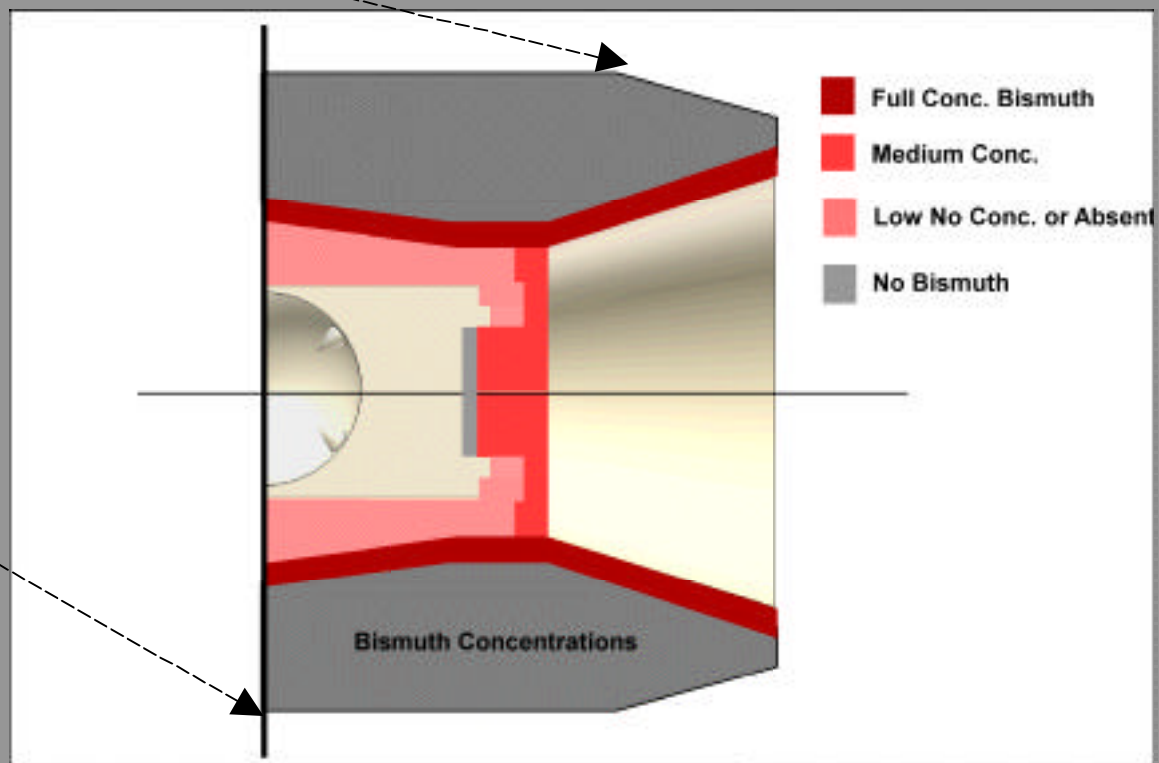
- **Relative Tungsten Concentration vs. Location within Hohlraum**



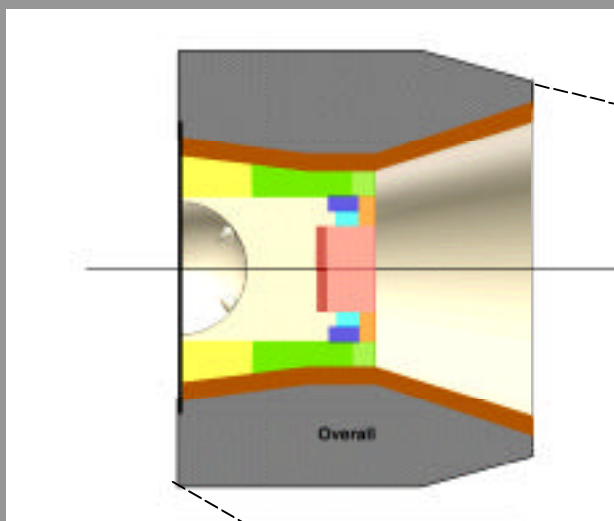
- **Callahan & Tabak,
HIF Distributed
Radiator Target
Nuc. Fus. V.39 (884)**



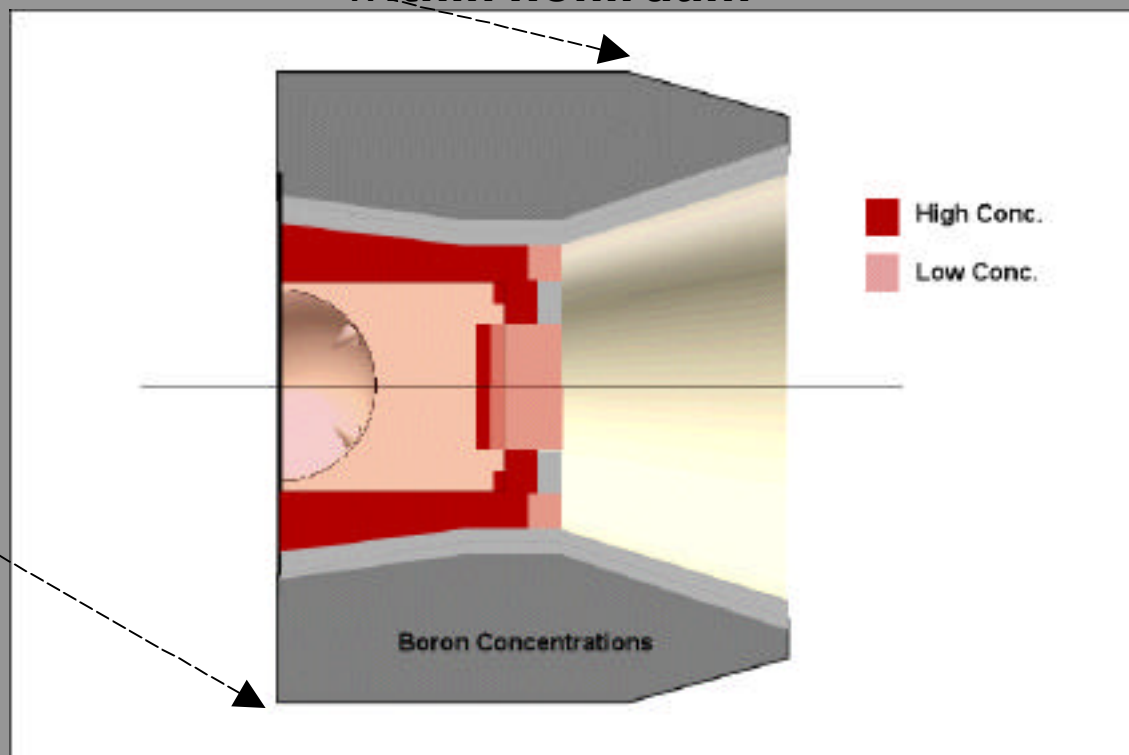
- **Relative Bismuth Concentration vs. Location within Hohlräum**



- **Callahan & Tabak,
HIF Distributed
Radiator Target
Nuc. Fus. V.39 (884)**

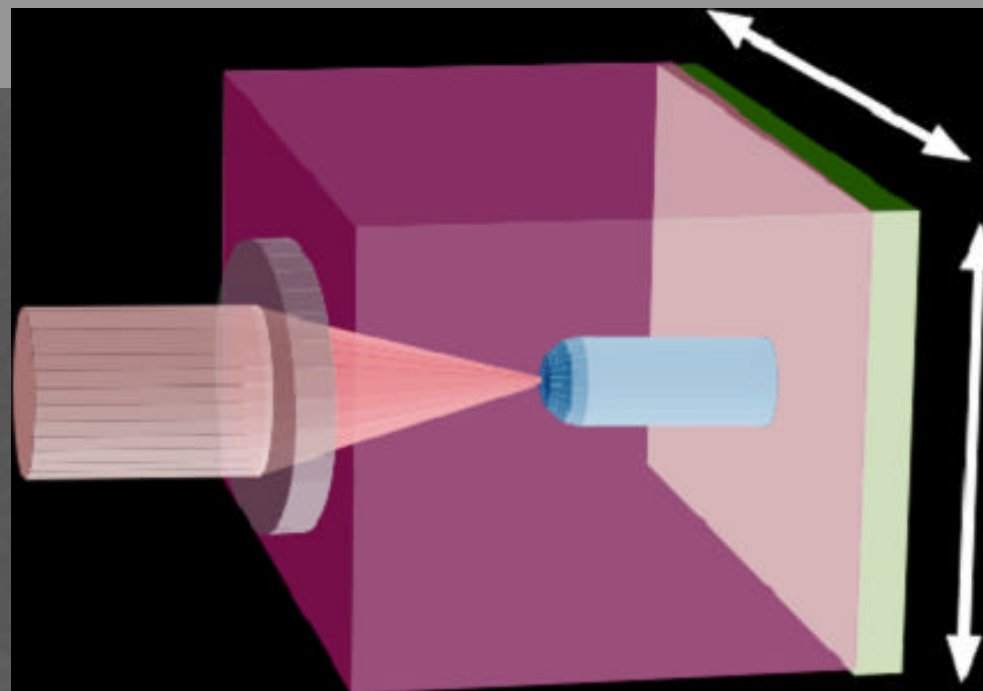
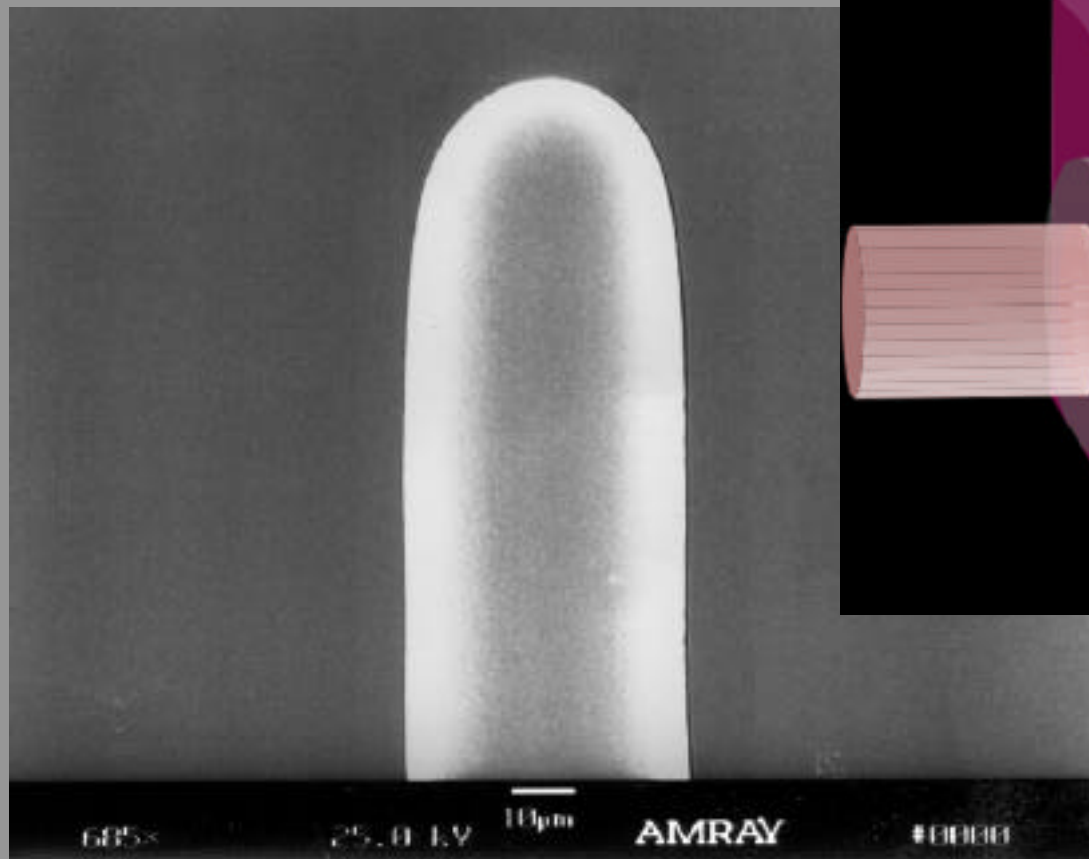


- **Relative Boron Concentration vs. Location within Hohlraum**

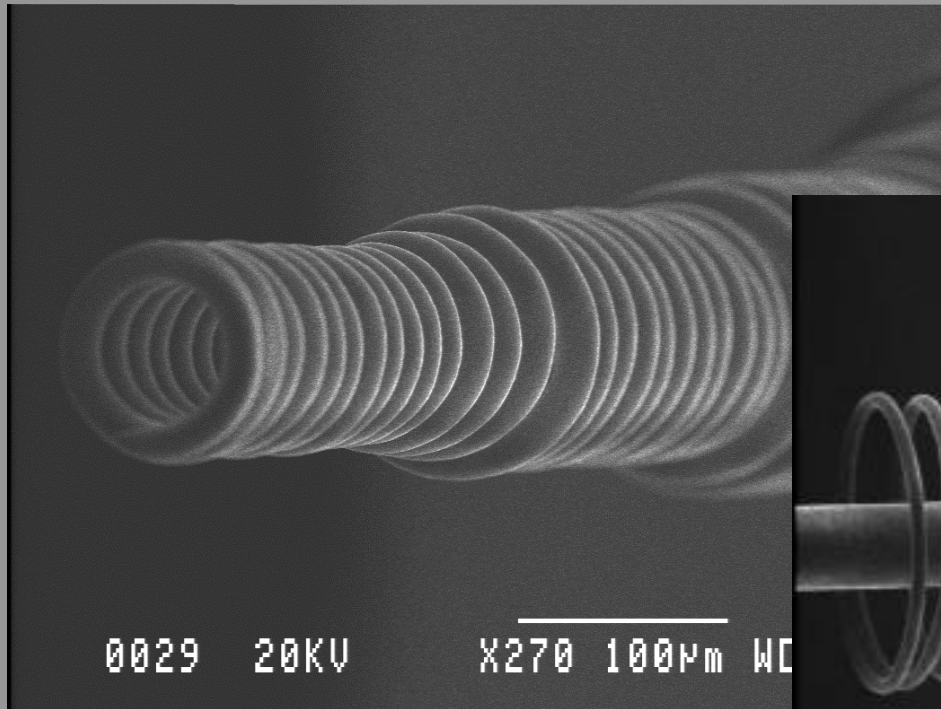


- **Callahan & Tabak,
HIF Distributed
Radiator Target
Nuc. Fus. V.39 (884)**

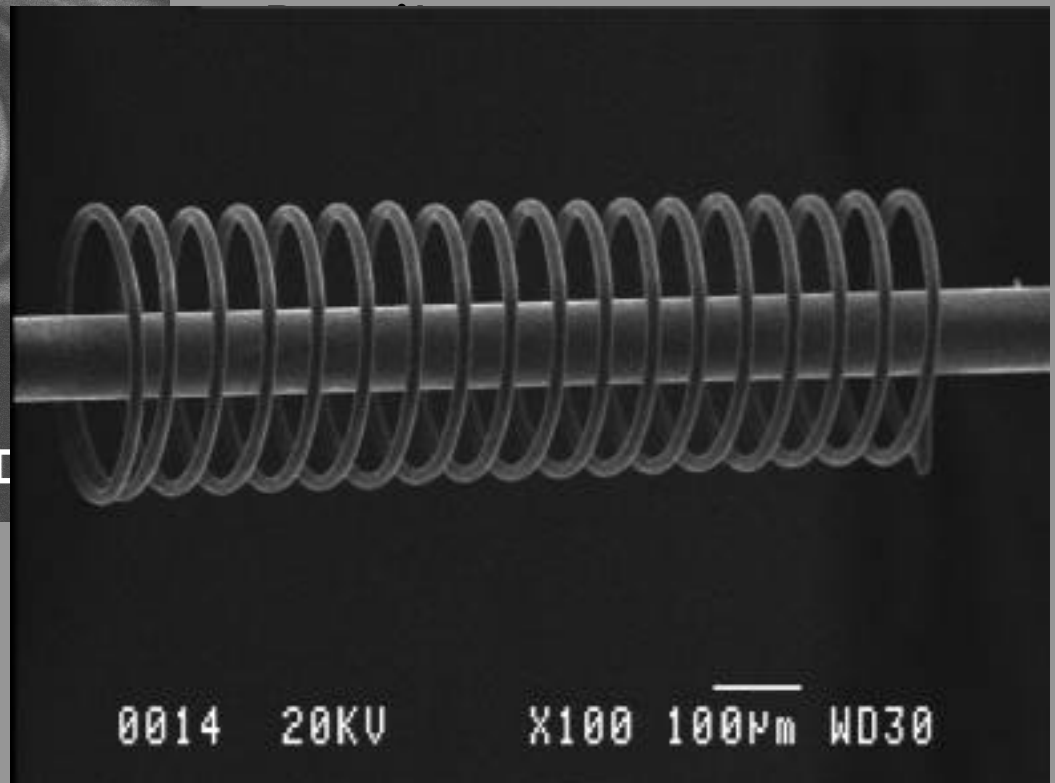
What is LCVD?



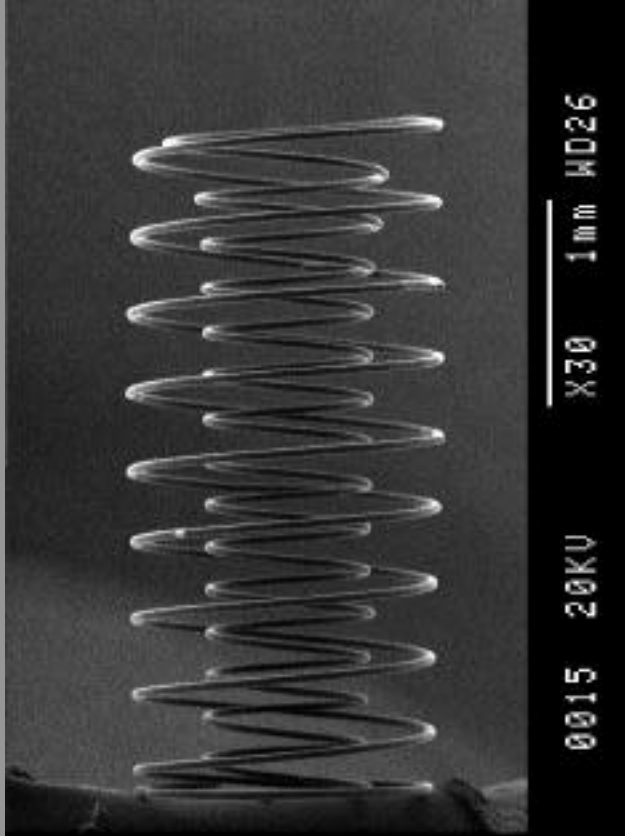
Unclassified



- **Variable Spacing, Variable Fiber Diameter → Variable**

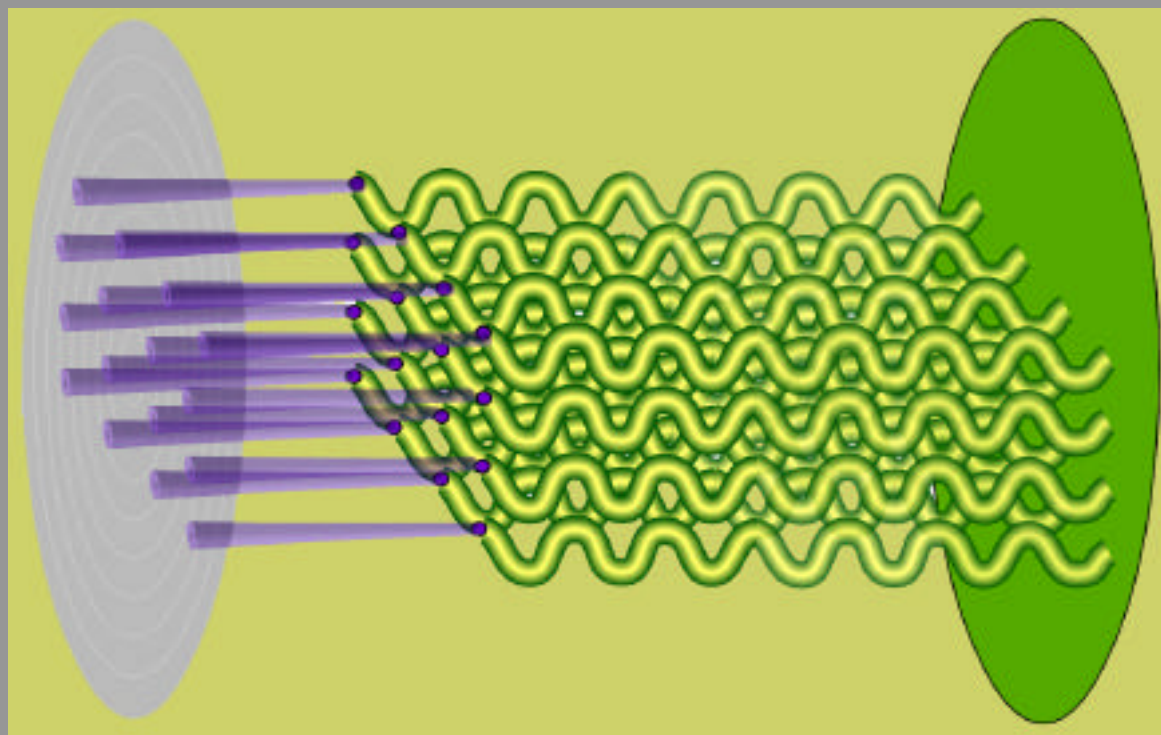
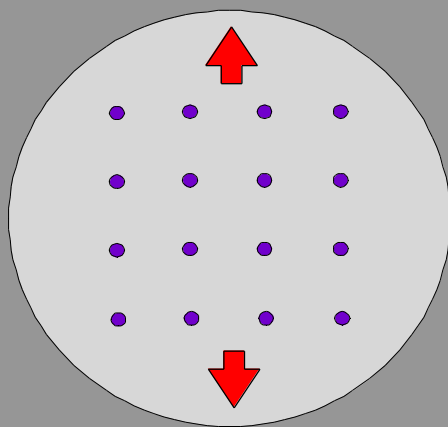


Truly Freeform Fabrication



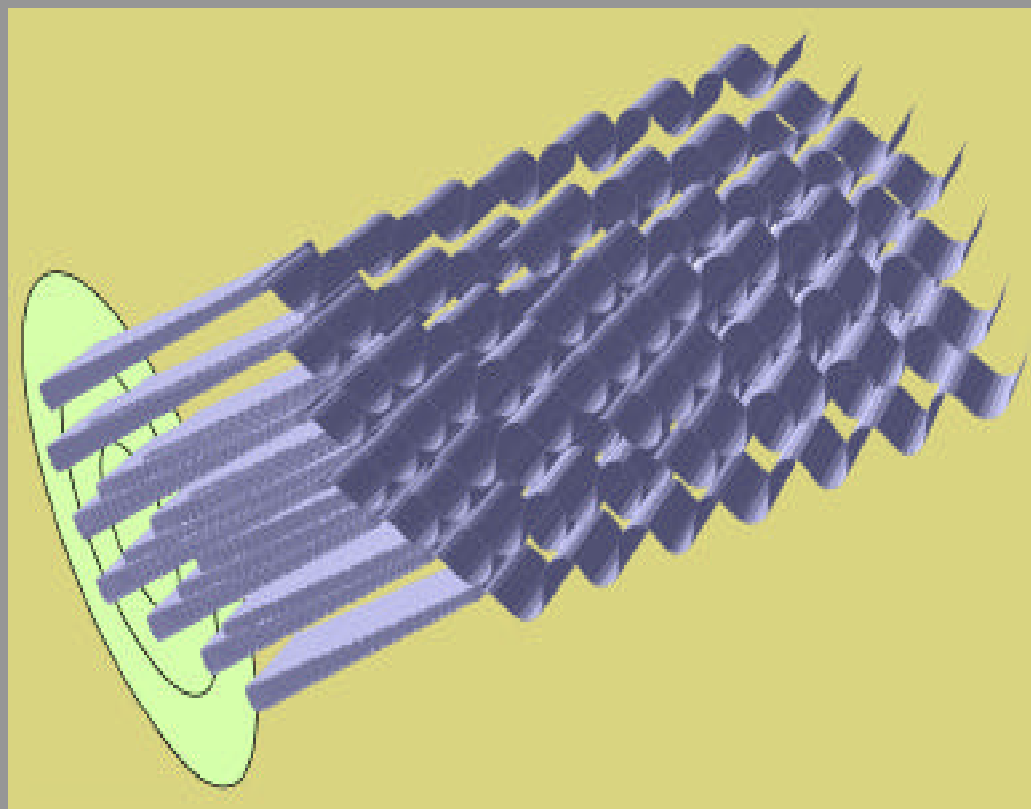
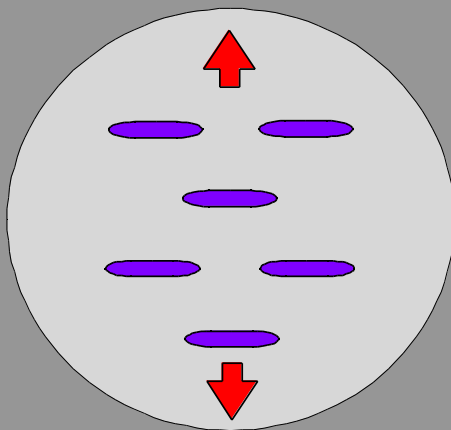
Unclassified

- **Diffraction Optic Spot Array**
 - 2-D Grid of Gaussian Spots
 - Source Oscillated During Growth to Form “Snake-like” Fibers



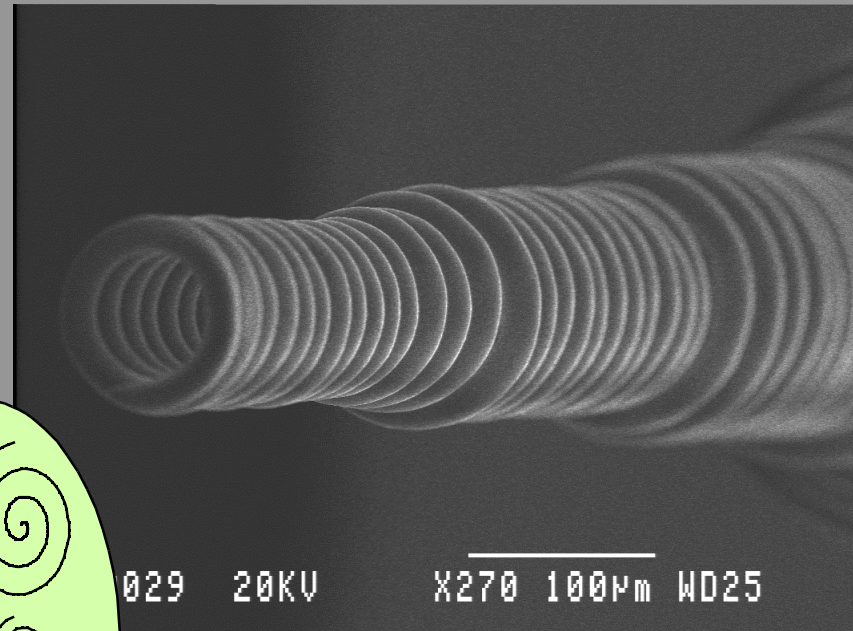
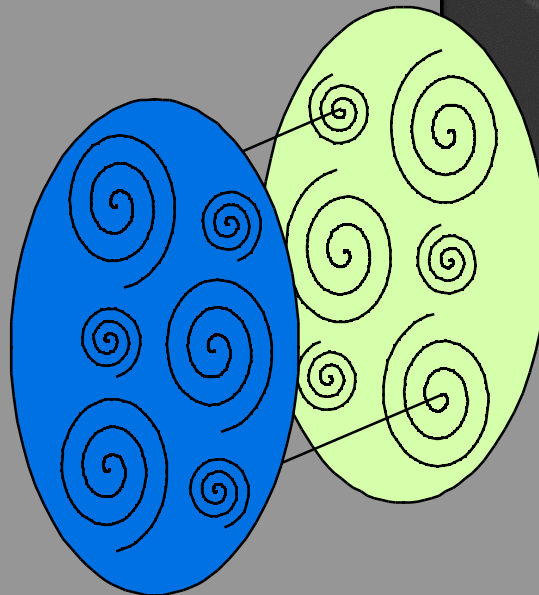
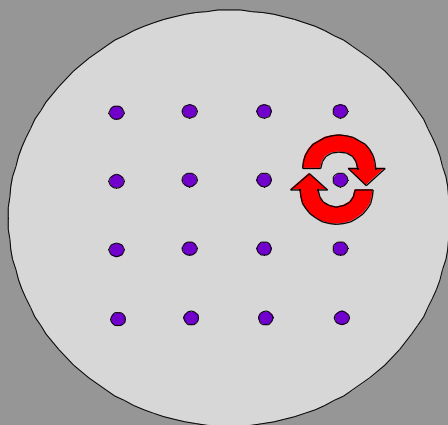
- **Line-Source
Diffractive Patterns**

- 2-D grid of lines
- Source Oscillated
During Growth to
Form Ribbon-like
Structures



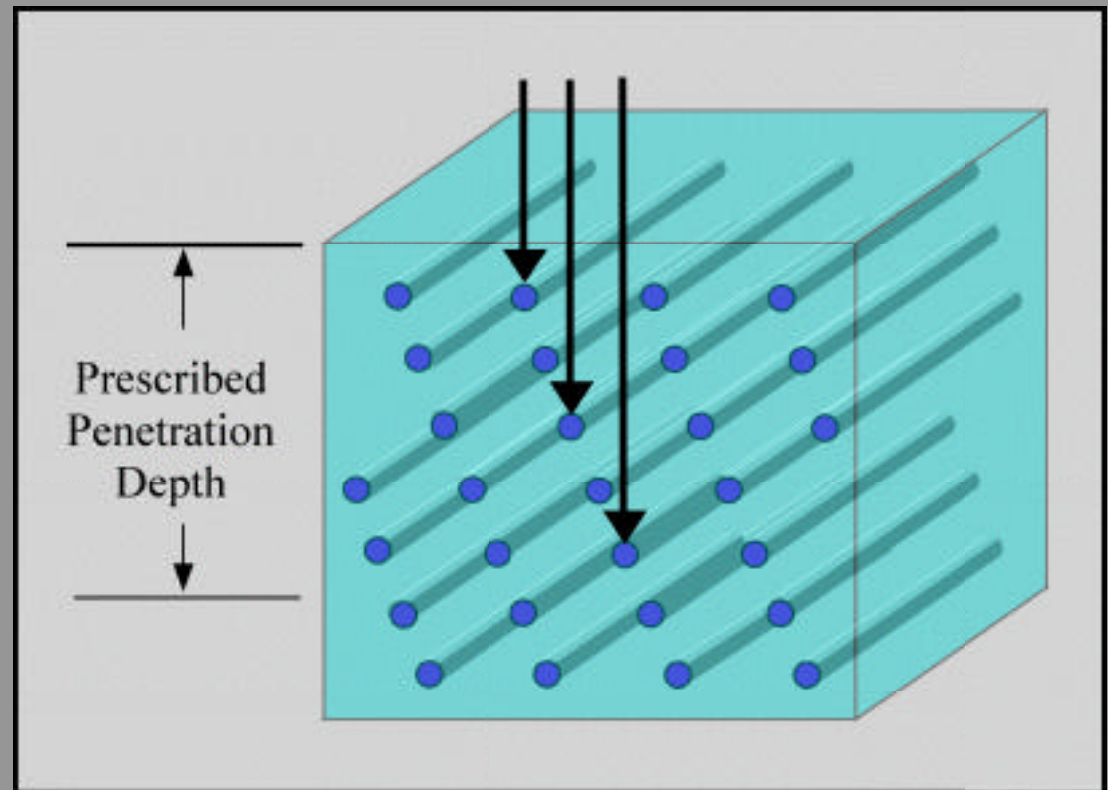
- **Spiroidal Lattices**

- 2-D array of Dots
- Pattern Oscillates Rapidly in 2-D
- Amplitude (Radius) of Oscillation also varies Sinusoidally at Lower Frequency



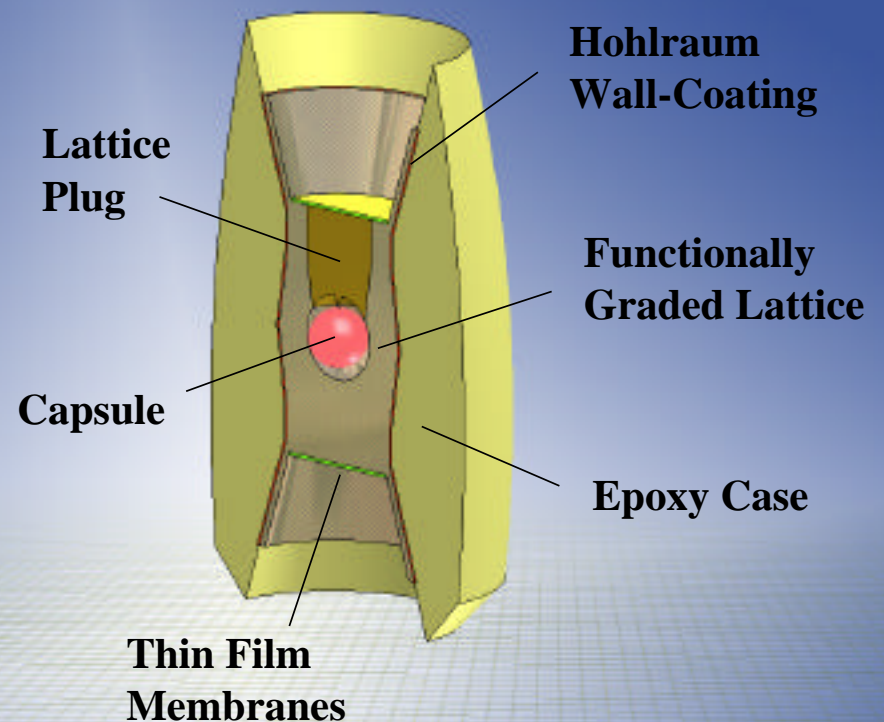
Unclassified

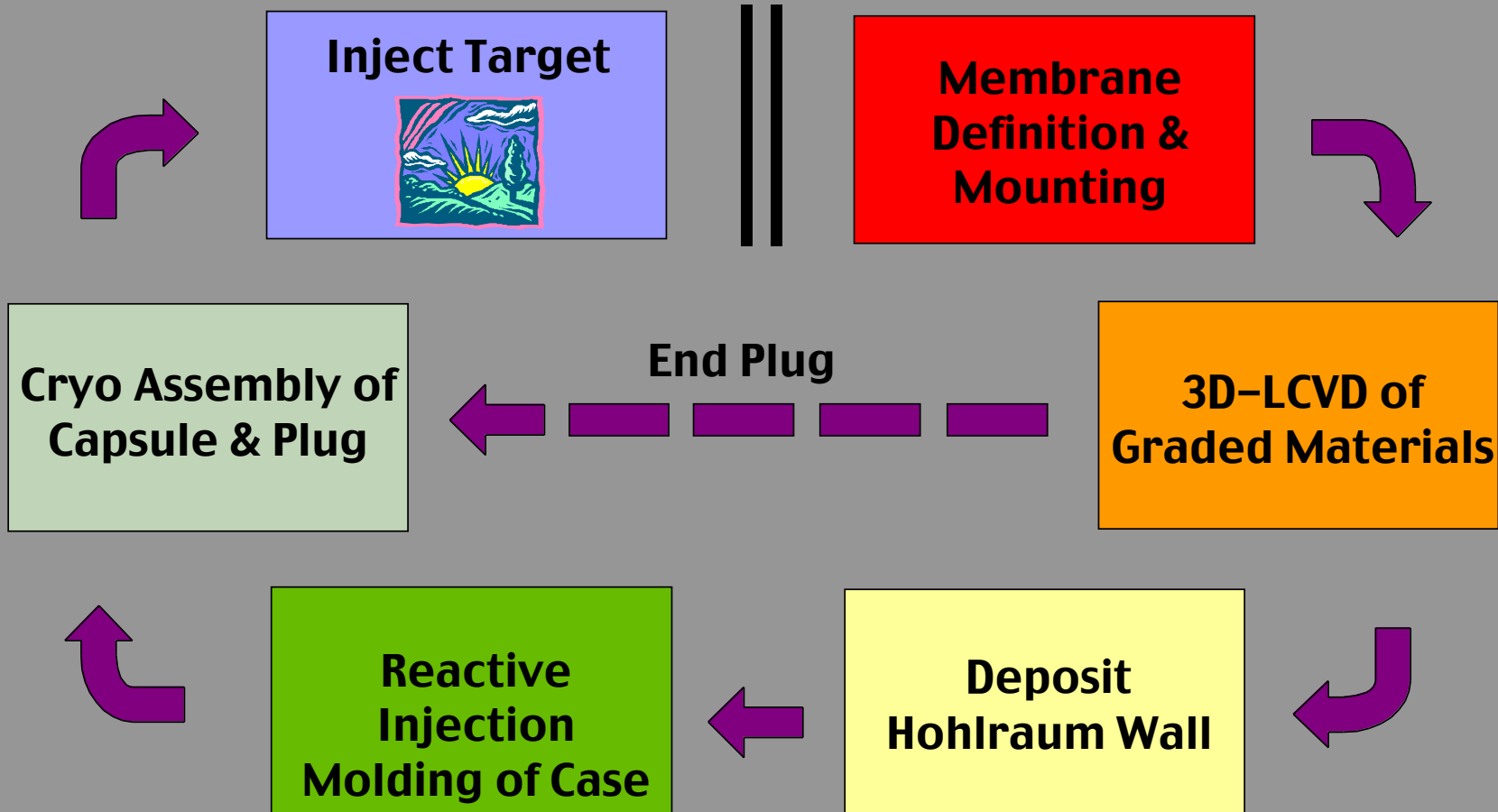
- Hohlraum Low-Density “Foams”
- Create Materials that Exhibit:
 - Variable Ion Penetration Depth
 - Variable (Low) Density
 - Variable, High-Z Doping
 - Variable X-ray Absorption
 - Handling-Shock Resistant, Mechanically Elastic Materials
 - Variable Geometries



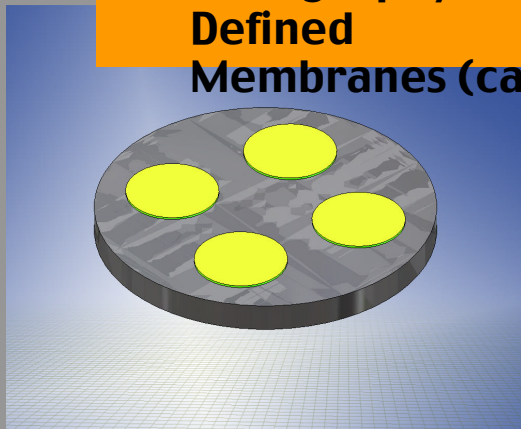
Unclassified

- **Final Assembly**
 - Uses Functionally-graded Engineered Foams to Simplify Fabrication
- **Design for Manufacture:**
 - Builds from Inside Out
 - Avoids Precision Machining Steps
 - Avoids Assembly Steps
 - Avoids “Split” Hohlräum Assemblies
 - Auto-aligned Final Assembly Step for Capsule Insertion
 - Fewest Process Steps
 - Uses Low-cost Materials & Processes

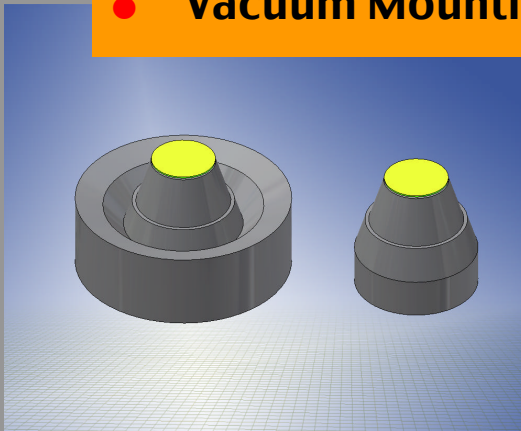




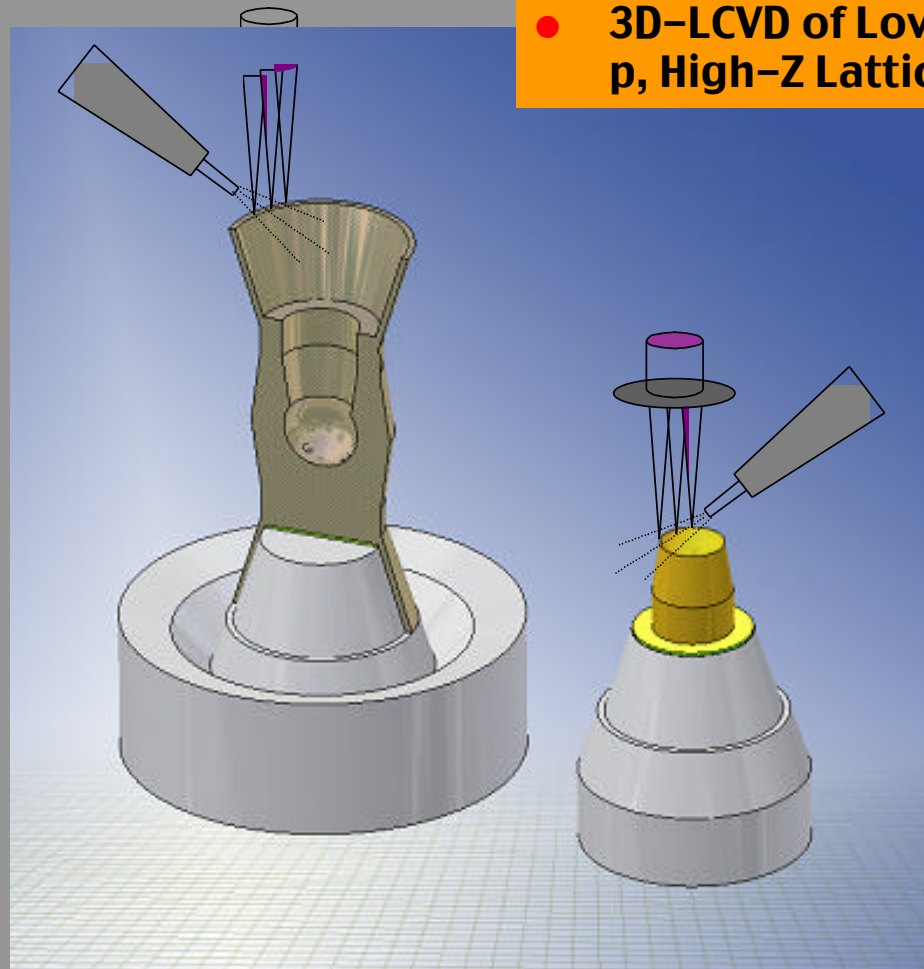
- **Lithography-Defined Membranes (caps)**

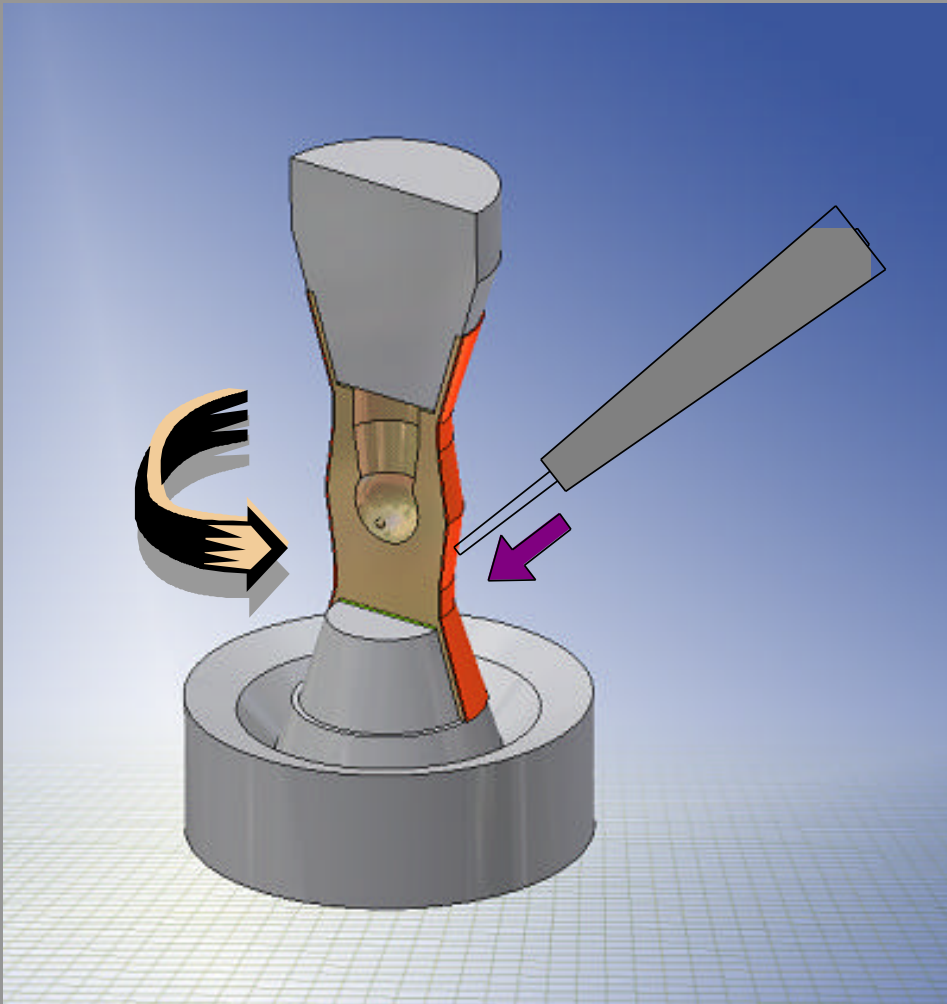


- **Vacuum Mounting**



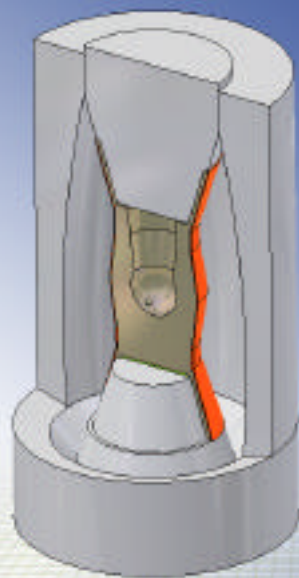
- **3D-LCVD of Low-p, High-Z Lattices**



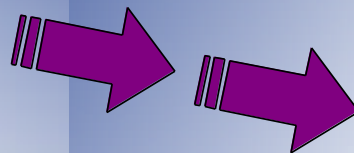


- **Coat Hohlräum Wall**
 - Closes Exterior of Lattice
 - Builds thick Overlayer for Support & Containment
- **Relevant Processes**
 - Plasma Spray
 - Flame Spray
 - DW LCVD

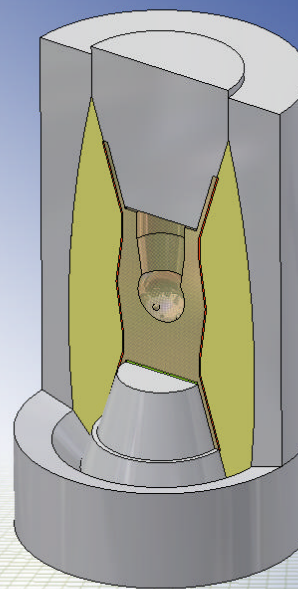
Fabrication Sequence



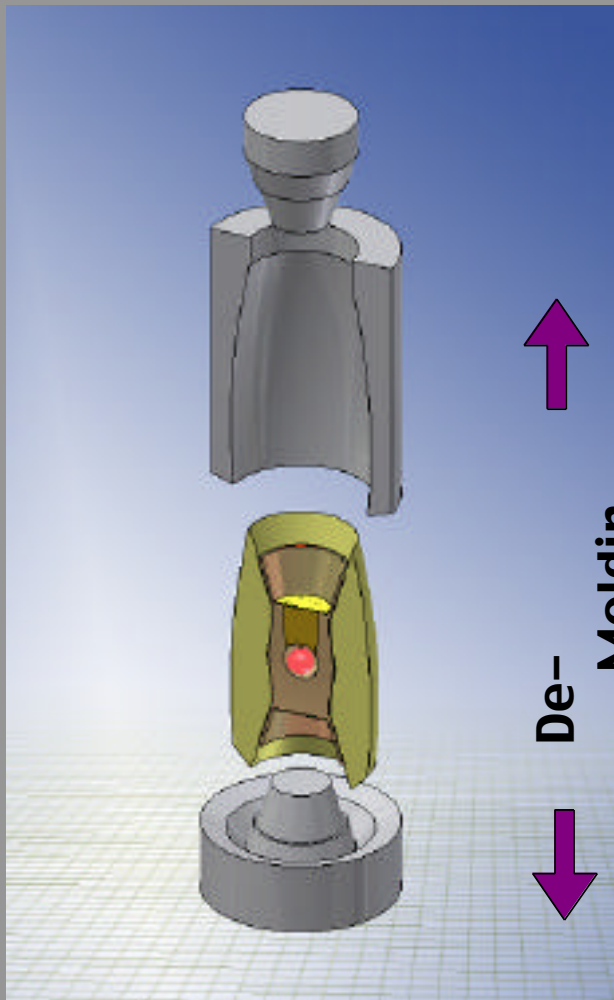
- **Insertion into Casing Injection Mold Cap**



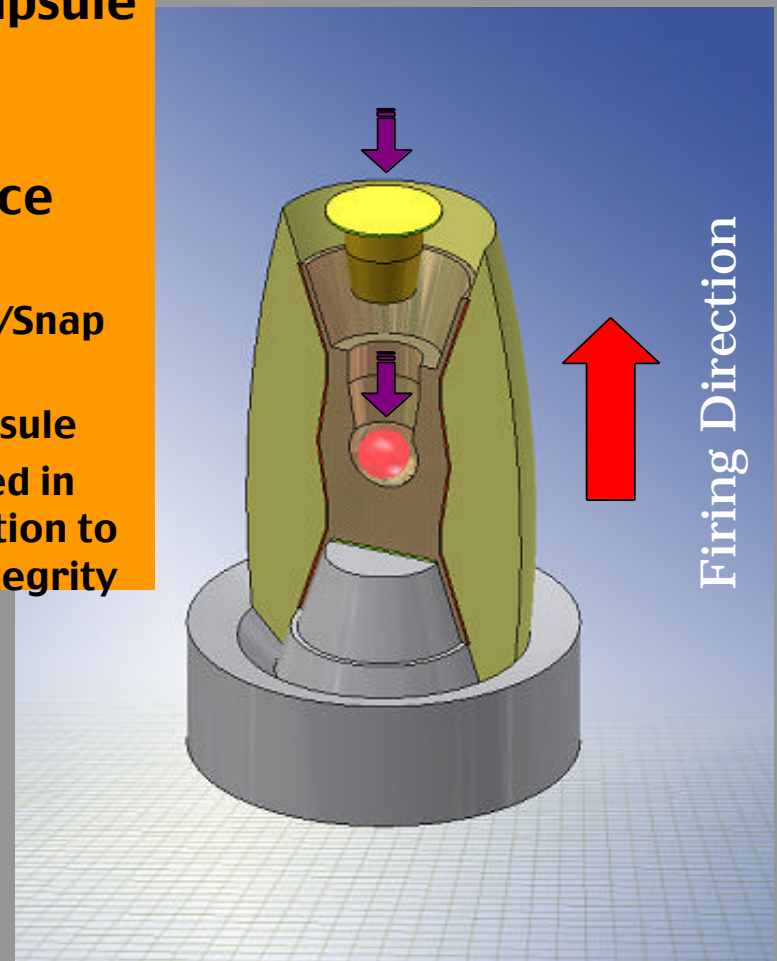
- **Reactive Injection of Polymeric Case**



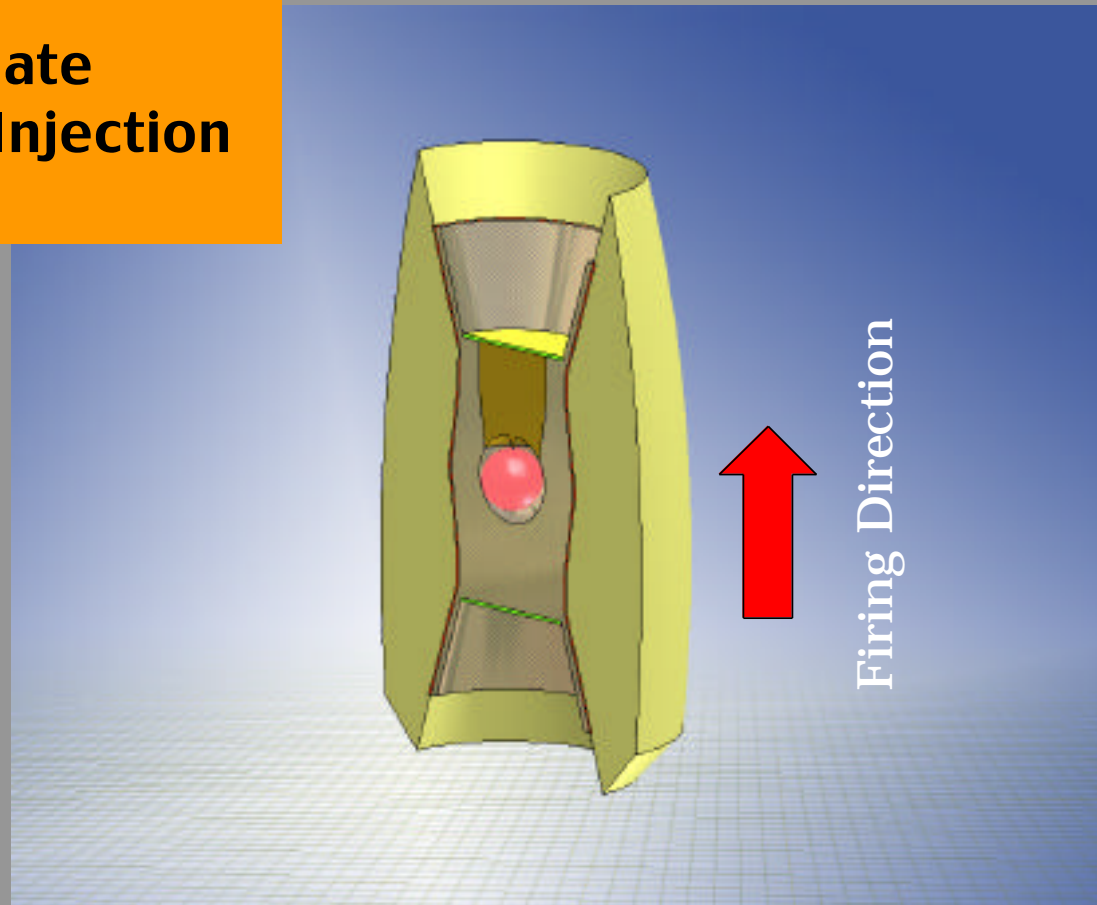
Unclassified



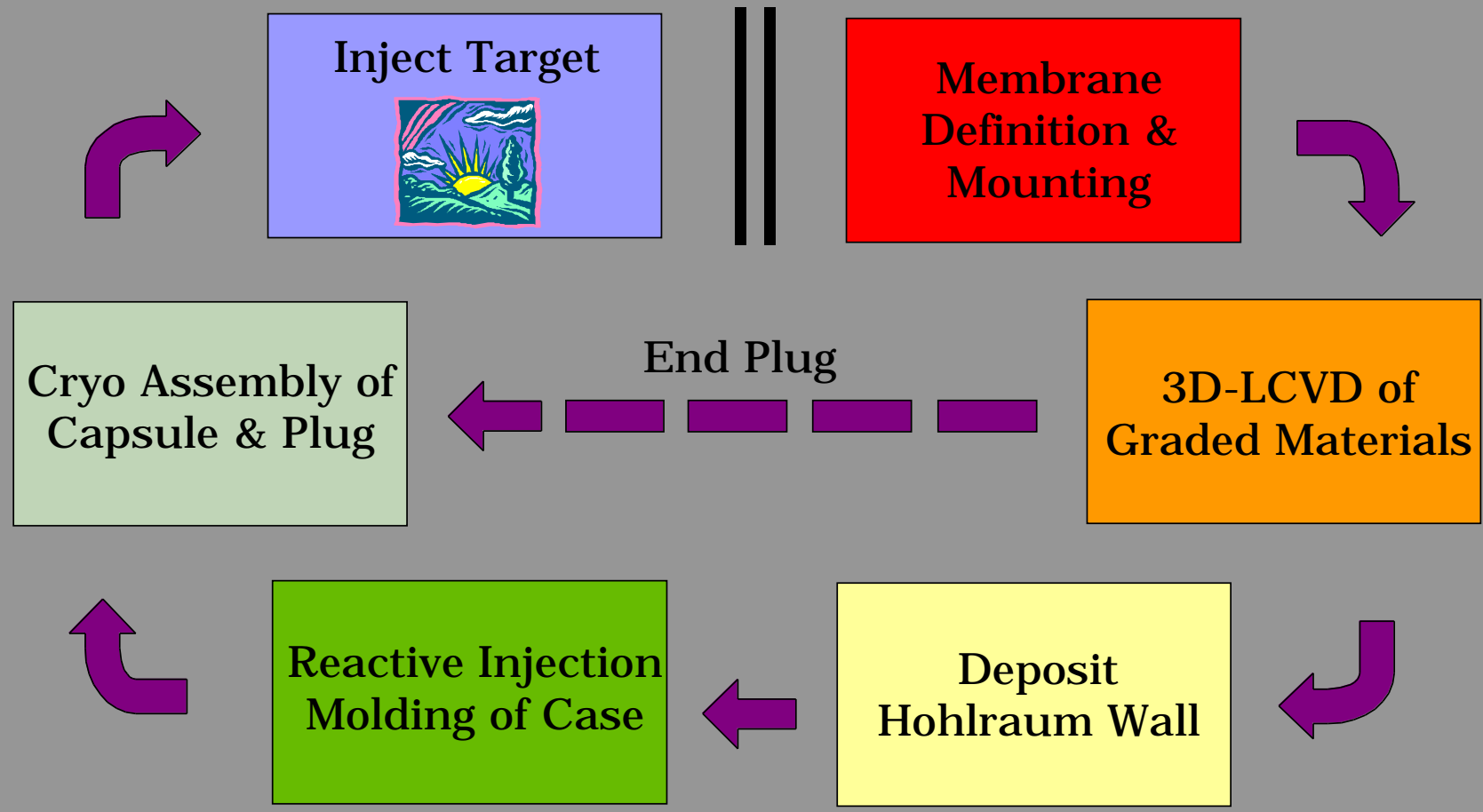
- **Cryogenic Capsule Placement**
- **Insertion of “Foam” Lattice Cap**
 - Auto-aligns/Snap Fit
 - Secures Capsule
 - Plug Oriented in Firing Direction to Maintain Integrity

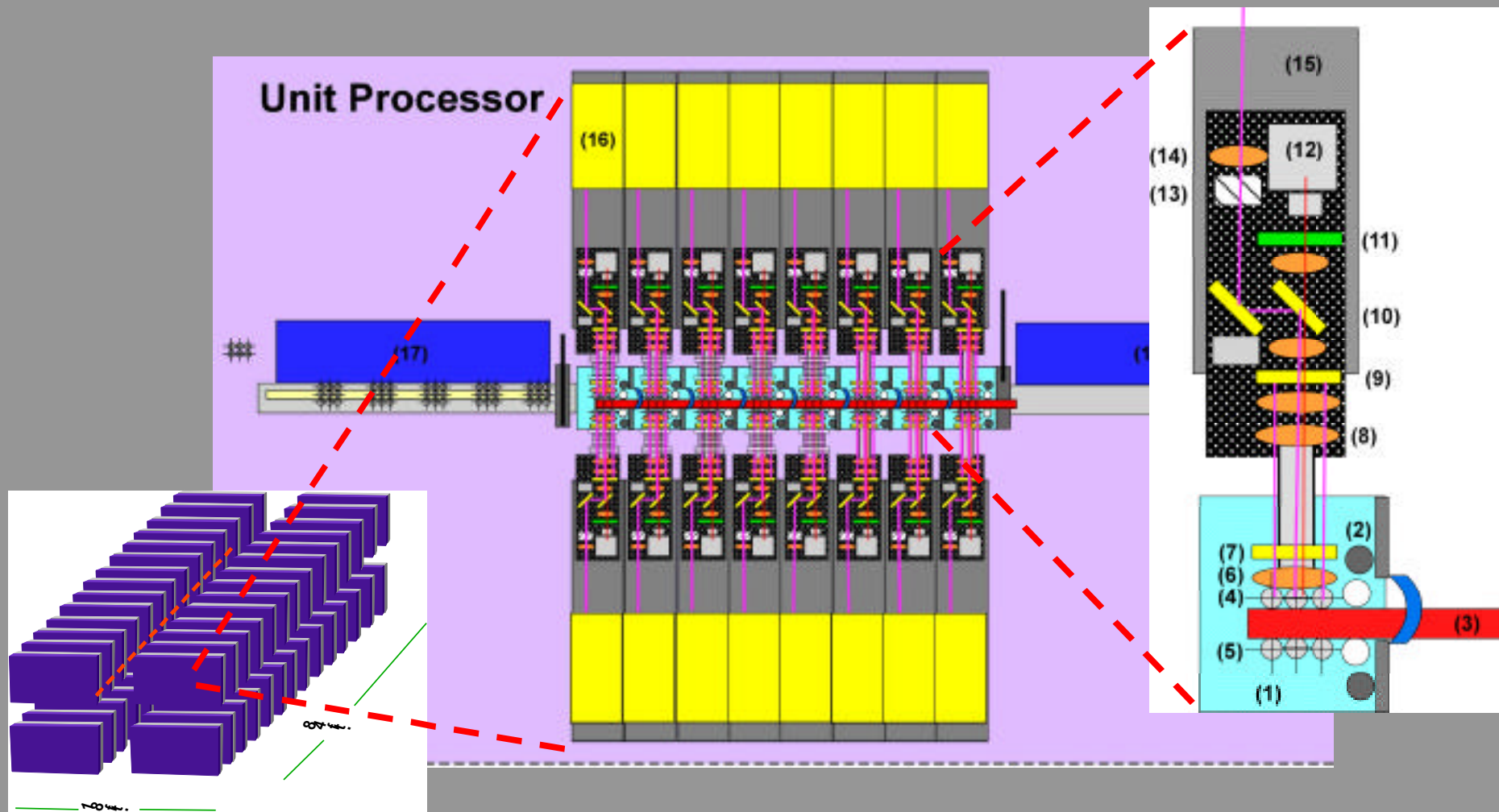


- **Immediate Target Injection**

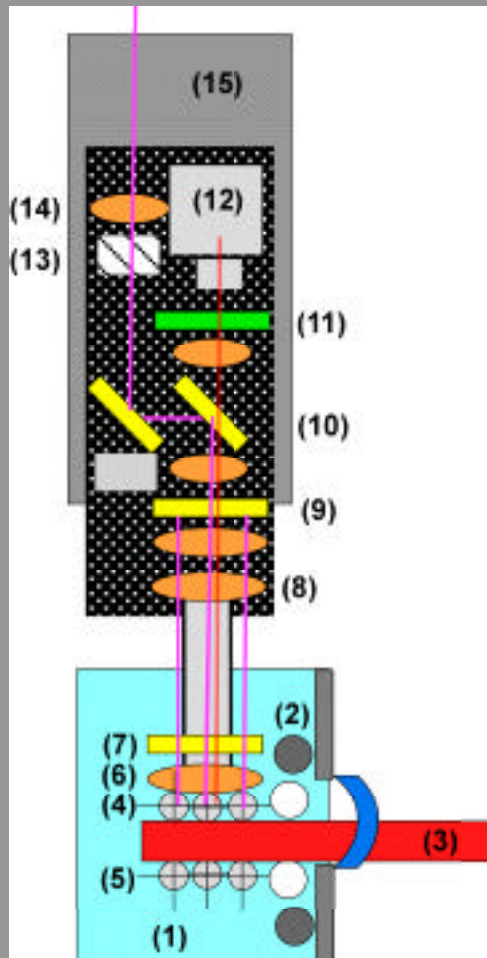


Unclassified

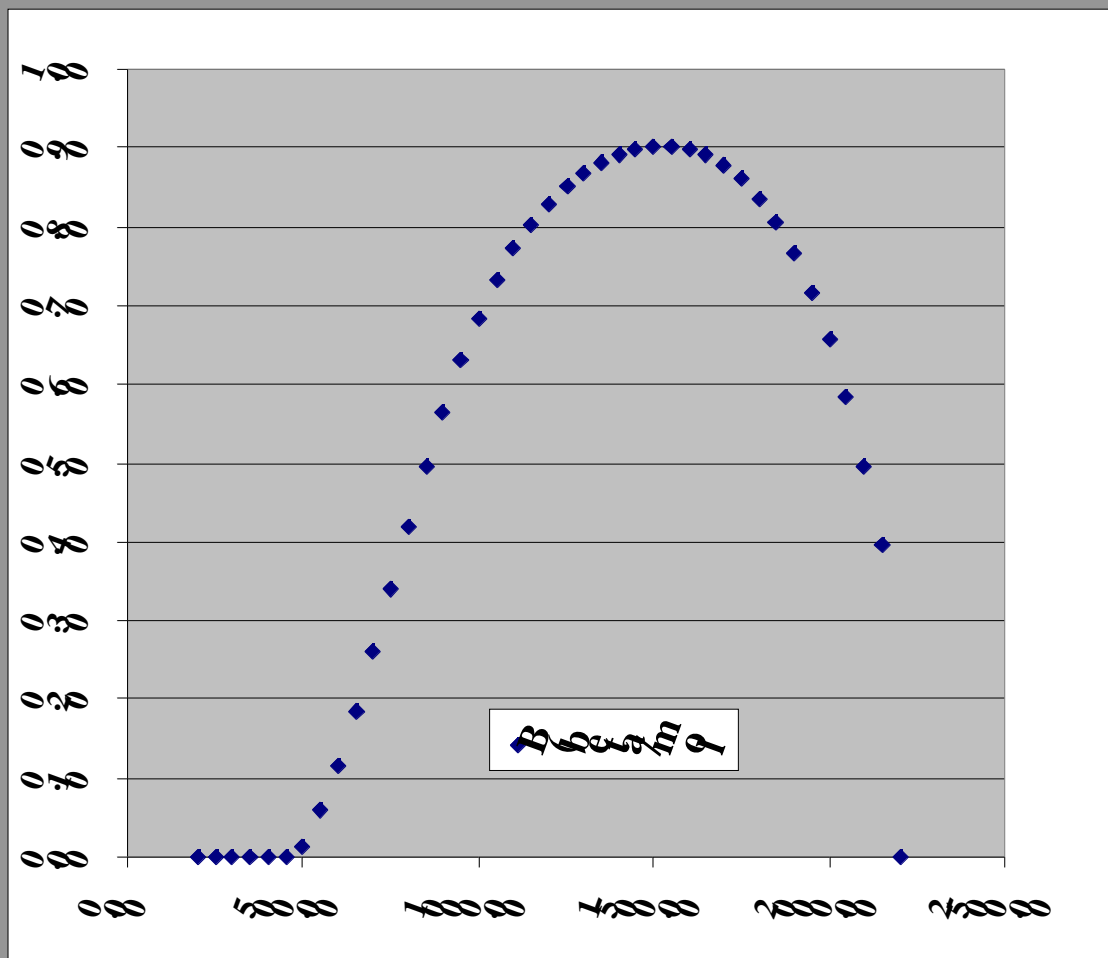




Unclassified



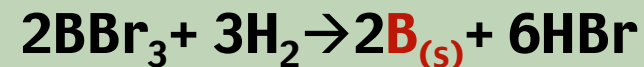
- **Important System Components**
 - Pressure Vessel Compartment
 - Gas Inlet/Outlet
 - Sample Mandrel
 - Samples (3 in Parallel)
 - Archived Samples (9 on mandrel)
 - Focusing Optics
 - Diffractive Optic
 - Beam Expander
 - Beam Splitter
 - Steering Optics
 - Narrow-band Filters
 - Power Meter
 - Pockels Cell
 - Beam Polarizer
 - Precision Stages
 - Gaussian Beam Output 3kW
 - Load Lock and Transfer Systems



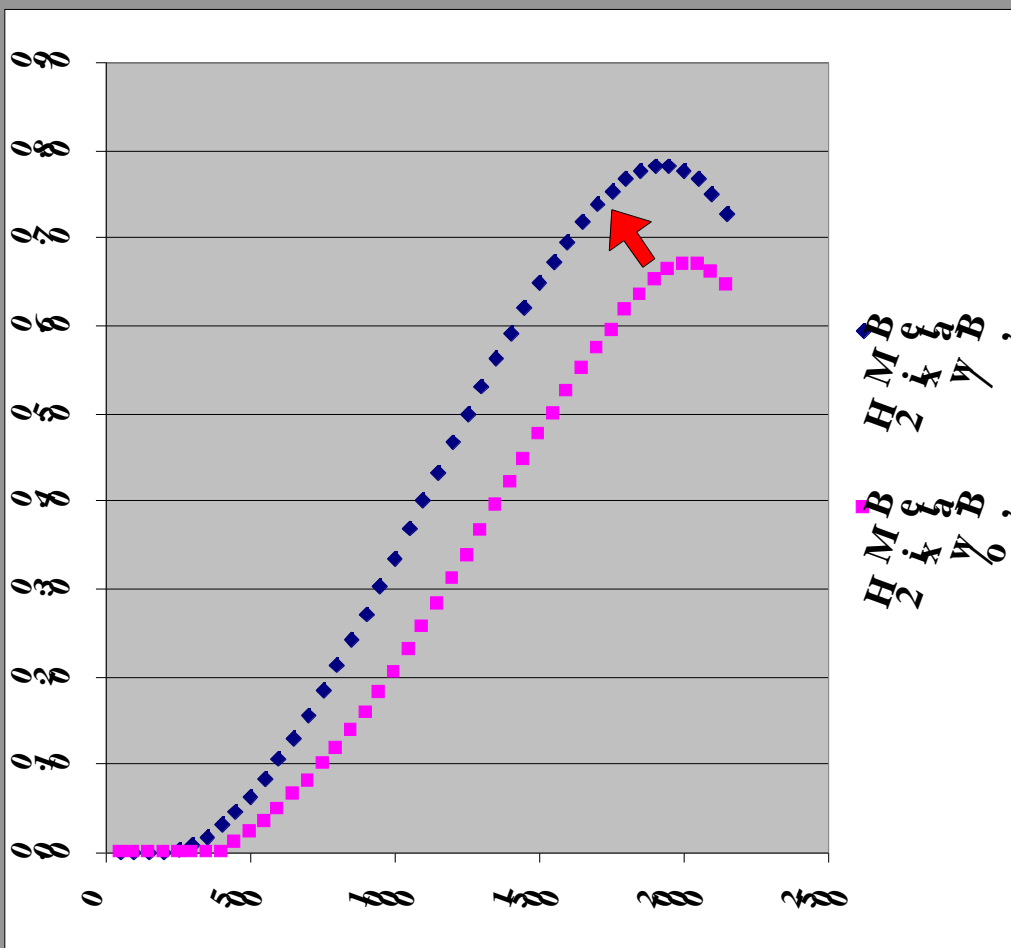
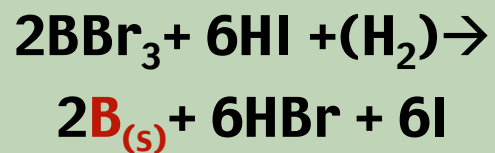
Candidate Precursors

● Boron Deposition

- Halides: BCl₃, BBr₃, BI₃
- Hydrides: B₂H₆, etc.

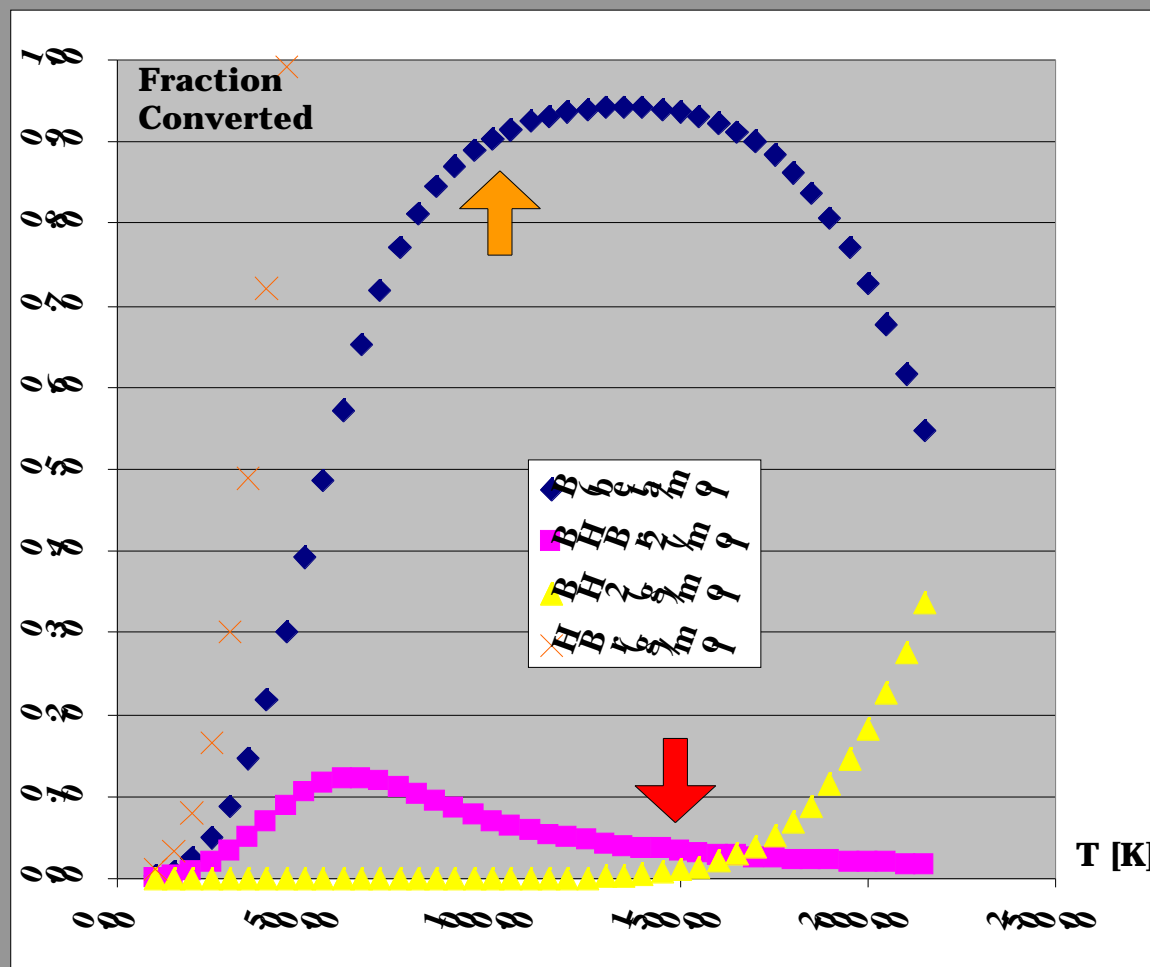
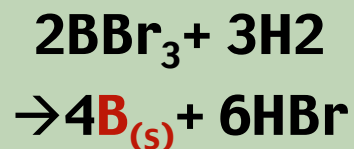


- Simultaneous Use:
 - Boron Tribromide
 - Hydrogen Iodide
 - Optional Hydrogen
- 1 Atm Pressure



Unclassified

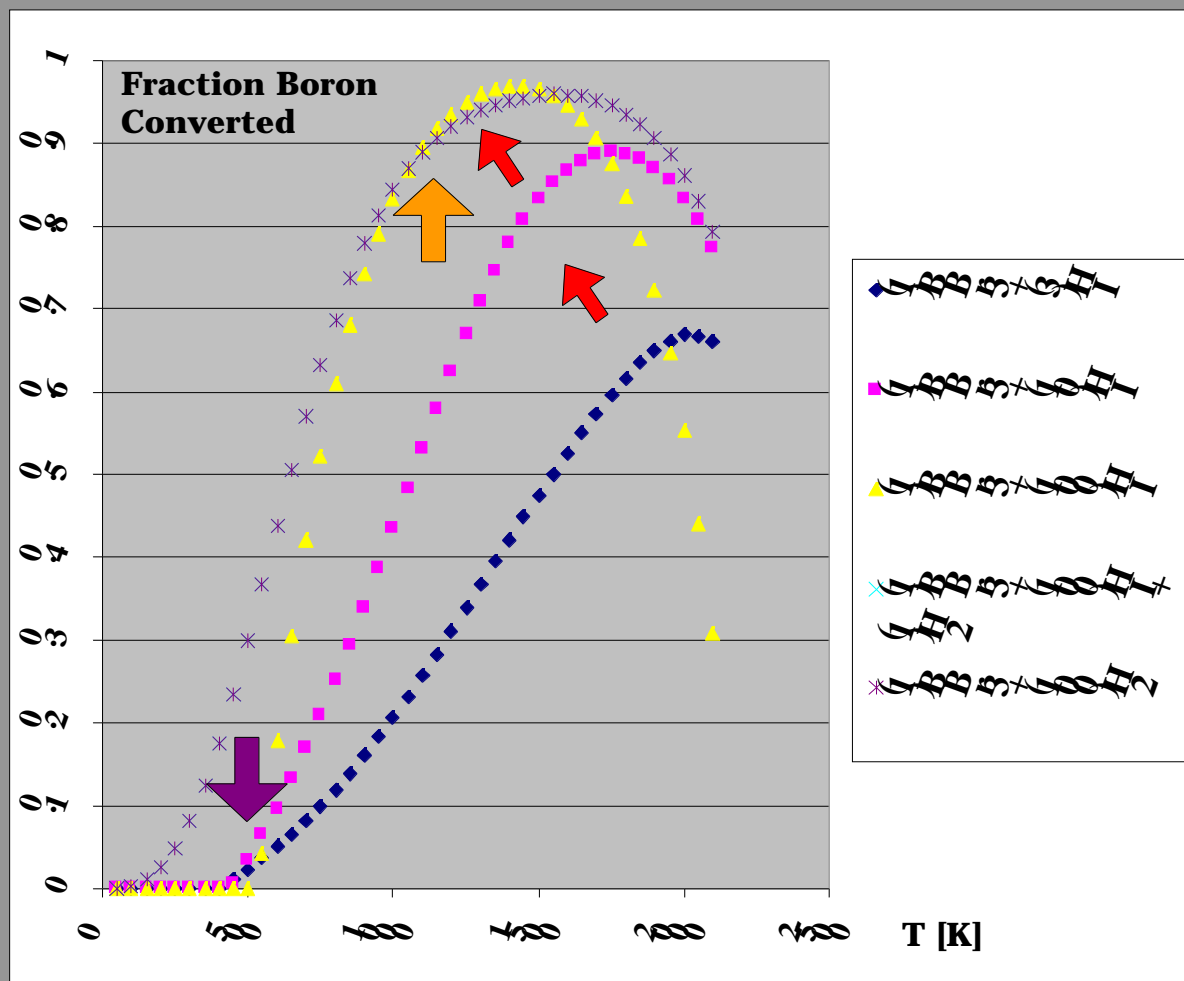
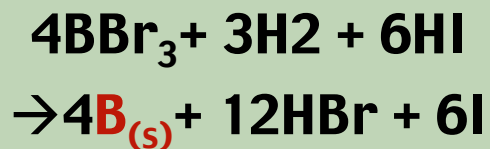
- By-Products from:
 - Boron TriBromide
 - Hydrogen
- 10 Atm Pressure



Unclassified

● Simultaneous Use:

- Boron Tribromide
- Hydrogen
- Hydrogen Iodide



- **Boron Deposition**

- Halides: BCl₃, BBr₃, BI₃
- Hydrides: B

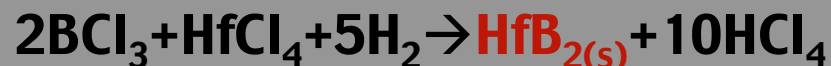
- **HfB₂ Doping**

- Halides: HfCl₄, HfBr₄, HfI₄
- Temp. >300 C
- Hydrides: non-volatile
- Organometallics: tetrakis-Diethylamido Hafnium:
Hf[N(CH₂CH₃)₂]₄

- **Combination Precursors**

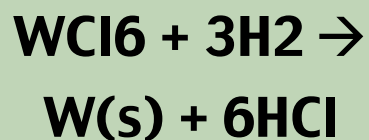
- Hf(BH₄)₄ (Boron-rich Deposits)...New

Copyright 2008

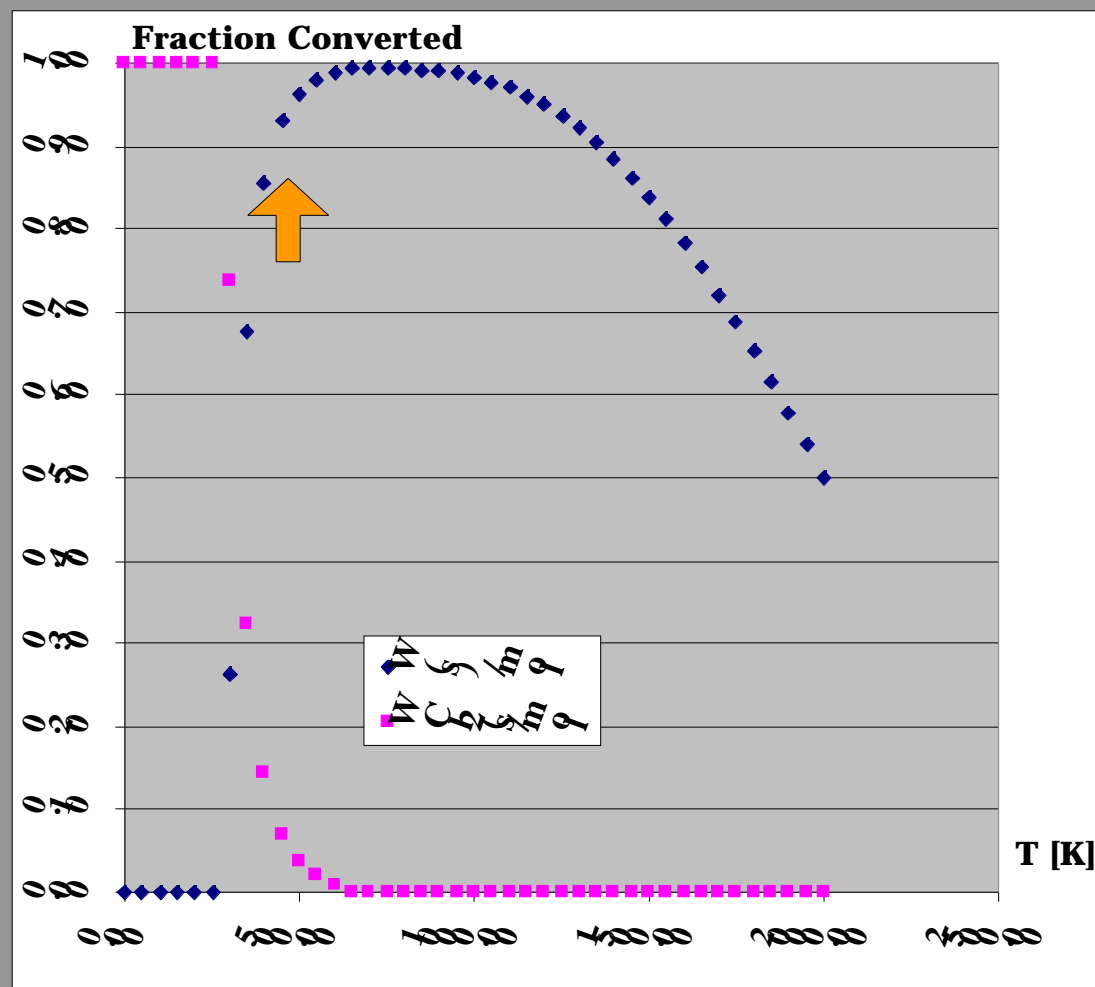


- Simultaneous Use:

- Tungsten Hexachloride
- Hydrogen



- Tungsten Hexafluoride begins decomposing at about 200–250C



Unclassified

- **Assembled LCVD System**
- **Performed Thermodynamic Calculations, selecting Optimal Precursors for High-Z Alloys**
- **Worked with Target Designers to Simplify Hohlraum Materials → Alloys/Intermetallics of 3 Elements**
- **Developed Alternate Fabrication Processes**
- **Narrowed Options to a Simple Process**

Current

- **Kinetic Experiments with High-Z Precursors**
- **Pulsed Deposition**
- **High-Temperature Chamber(s)**
- **Parallel Growth**

Future