CESIUM-DIODE PERFORMANCES
FROM THE 1963-TO-1971
THERMIonic CONVERSION
SPECIALIST CONFERENCES

by James F. Morris
Lewis Research Center
Cleveland, Ohio 44135
This report indexes and summarizes papers containing cesium-diode results from the proceedings of the 1963-to-1971 Thermionic Conversion Specialist Conferences. Lists of converter materials, geometries, conditions, outputs, and lifetimes accompany the references. Simple chemical designations for emitters, collectors, and additives direct the reader to appropriate selections.
CESIUM-DIODE PERFORMANCES FROM THE 1963-TO-1971 THERMIonic CONVERSION SPECIALIST CONFERENCES

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SUMMARY

This report indexes and summarizes papers containing cesium-diode results from the proceedings of the 1963-to-1971 Thermionic Conversion Specialist Conferences. Lists of converter materials, geometries, conditions, outputs, and lifetimes accompany the references. Simple chemical designations for emitters, collectors, and additives direct the reader to appropriate selections.

INTRODUCTION

Most cesium-diode performance studies reach the Thermionic Conversion Specialist Conferences eventually. If the work fails to appear in the proceedings originally, it often enters in subsequent comparisons. And the accompanying references generally include expansive current, voltage data in agency, contractor, or company publications. So the Thermionic Conversion Specialist Conferences provide extensive cesium-diode output information. To increase the accessibility of this technology the present report indexes and summarizes such contributions for the past decade.

Beginning with the 1963 conference an annotated, chronological tabulation indicates 129 papers containing thermionic-converter results. Lists of diode materials, geometries, conditions, outputs, and lifetimes, if they were found, accompany the references. A simple chemical index for emitters, collectors, and additives directs the reader to appropriate selections. Because these chemical labels are guides not analyses, they lack the complexity of additive product permutations; they are easily recognized elemental or molecular forms. But they adequately identify the materials involved.

With a set of the proceedings for the Thermionic Conversion Specialist Conferences and the present report, comprehensive literature surveys on cesium-diode performances are readily available.
# Simple Chemical Index for Diode Materials

<table>
<thead>
<tr>
<th>Emitter</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity</td>
<td>53</td>
</tr>
<tr>
<td>Iridium (Ir)</td>
<td>10, 17, 18</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>5, 6, 7, 9, 10, 12, 14, 20, 21, 34, 38, 39, 47, 82, 84, 89, 92, 98, 100 (single-crystal 110 (1-xtal 110)), 120, 127, 10, 17, 18</td>
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<tr>
<td>Molybdenum-based alloy</td>
<td>98</td>
</tr>
<tr>
<td>Rhenium (Re)</td>
<td>3, 4, 12, 14, 15, 16, 19, 21, 22, 23, 27, 31 (electroetched), 40, 41, 42, 44, 56 (etched), 57 (etched), 58 (electroetched), 59, 64, 65, 66, 67, 68, 69, 73, 74, 76, 79 (1-xtal 0001), 82, 87, 91, 95, 101, 103, 107 (etched), 114 (etched or 1-xtal 0001), 115 (chemically vapor-deposited (CVD)), 122 (etched), 125 (etched), 126</td>
</tr>
<tr>
<td>Ruthenium (Ru)</td>
<td>11, 45</td>
</tr>
<tr>
<td>Tantalum (Ta)</td>
<td>4, 5, 42, 46, 53, 66, 82</td>
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<tr>
<td>Tungsten (W)</td>
<td>2, 4, 8, 13, 14, 21, 22, 24, 25, 26, 28, 29, 30 (Cl−CVD, 110), 33, 37, 43 (Cl−CVD), 48 (F−CVD (100) etched to 110), 49 (Cl−CVD), 50 (Cl−CVD, F−CVD), 55 (VD), 60, 61, 62 (1-xtal 110), 63, 70 (Cl−CVD, F−CVD), 71 (Cl−CVD), 72 (F−CVD, four surface preparations), 80 (F−CVD etched to 110), 81 (1-xtal 110), 82 (several orientations and surface preparations), 83 (1-xtal 110), 84 (F−CVD), 85 (F−CVD), 86 (Cl−CVD), 88 (F−CVD), 90 (F−CVD), 90 (F−CVD, four surface preparations), 93 (SIMCON), 94 (Cl−CVD), 96 (CVD), 97 (physically vapor-deposited (PVD)), 102 (1-xtal 110, Cl−CVD, F−CVD), 104 (1-xtal 110, Cl−CVD, F−CVD), 105 (1-xtal 110, Cl−CVD, F−CVD), 106 (F−CVD etched to 110, Cl−CVD, F−CVD), 108 (Cl−CVD), 109 (Cl−CVD, F−CVD), 110, 111, 112, 113 (F−CVD), 116 (CVD), 117 (Cl−CVD), 118 (F−CVD), 121 (Cl− vapor deposited by thermal decomposition (TVD)), 122 (PVD, Cl−CVD), 123 (Cl−CVD), 124 (PVD, Cl−CVD, F−CVD), 126, 128 (CVD), 129 (Cl−CVD, SIMCON)</td>
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<tr>
<td>Emitter</td>
<td>Reference</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>-----------</td>
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<tr>
<td>Tungsten-based mixture</td>
<td>98 (&quot;tungsten-based alloy,&quot; &quot;tungsten, rhenium&quot;), 32 (W, 20 percent Re), 78 (W, 25 percent Re), 82 (W, 25 percent Re), 1 (with a small amount of Th), 119 (W, 2 percent ThO₂)</td>
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</table>

<table>
<thead>
<tr>
<th>Collector</th>
<th>Reference</th>
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<tr>
<td>Grooved</td>
<td>36</td>
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<tr>
<td>Inconel</td>
<td>8</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>3, 4, 5, 11, 12, 13, 15, 19, 22, 24, 27, 30, 31, 33, 34, 36 (with and without grooves), 38, 39, 40, 41, 42, 44, 45, 49, 50, 51, 53, 56, 57 (VD), 59, 62, 63, 64, 69, 71, 74, 76, 82, 84, 89, 91, 92, 93 (SIMCON), 94, 95, 96, 99, 100 (1-xtal 110), 104, 105 (polycrystal (polyxtal) or PVD (110)), 108 (PVD), 110, 113, 114, 116, 118, 120, 122, 123 (PVD), 124 (PVD), 125 (PVD), 128</td>
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<tr>
<td>Nickel (Ni)</td>
<td>2, 7, 9, 10, 14, 16, 20, 21, 25, 28, 29, 33, 37, 43, 46, 51, 60, 82, 121</td>
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<tr>
<td>Niobium (Nb)</td>
<td>6, 21, 29, 45, 47, 48, 50, 56, 58, 66, 67, 68, 69, 70, 72, 79, 80, 81, 82, 85, 86, 90, 97, 98, 99, 101, 102, 103, 104, 105, 106, 107, 109, 112, 117, 121, 122, 123, 126, 129</td>
</tr>
<tr>
<td>Niobium-based mixtures</td>
<td>45 (Nb, 0), 55 (Nb, 1 percent Zr), 84 (Nb, 1 percent Zr), 88 (Nb, 1 percent Zr), 115 (Nb, 1 percent Zr), 127 (Nb, 1 percent Zr)</td>
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<tr>
<td>Palladium (Pd)</td>
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<tr>
<td>Rhenium (Re)</td>
<td>40, 45, 58, 65, 82, 87 (Cl⁻CVD), 91</td>
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<tr>
<td>Ruthenium (Ru)</td>
<td>11, 45</td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td>23</td>
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<tr>
<td>Stainless steel</td>
<td>1, 17, 18 (304)</td>
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<tr>
<td>Tantalum (Ta)</td>
<td>4, 5, 26, 111</td>
</tr>
<tr>
<td>Tungsten (W)</td>
<td>25 (from emitter on Ni collector), 61, 83 (1-xtal 110), 121, 123 (1-xtal 110, polycrystalline)</td>
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<tr>
<td>Tungsten-based mixtures</td>
<td>78 (W, 25 percent Re), 82 (W + WO₂ on Nb collector)</td>
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<tr>
<td>Additive</td>
<td>Reference</td>
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<td>Argon (Ar)</td>
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<tr>
<td>Barium (Ba)</td>
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<tr>
<td>Carbon (C) (possible diffusion into diode from UC)</td>
<td>3, 6, 117</td>
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<tr>
<td>Cesium fluoride (CsF)</td>
<td>12, 24, 34</td>
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<tr>
<td>Cesium oxide (Cs₂O)</td>
<td>44, 52</td>
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<tr>
<td>Fluorine (F or F₂)</td>
<td>12, 24, 34</td>
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<tr>
<td>Hydrogen (H or H₂)</td>
<td>2, 14</td>
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<tr>
<td>Iodine (I or I₂)</td>
<td>46</td>
</tr>
<tr>
<td>Krypton (Kr)</td>
<td>46, 54</td>
</tr>
<tr>
<td>Nitrogen (N or N₂) (possible diffusion into diode from UN)</td>
<td>126</td>
</tr>
<tr>
<td>Oxygen (O or O₂)</td>
<td>7 (possible diffusion into diode from UO₂), 8 (UO₂), 9 (UO₂), 23, 28 (UO₂), 44, 45 (in Nb), 47 (UO₂), 52, 55 (UO₂), 88 (UO₂), 89 (UO₂), 104, 105, 112 (UO₂), 114, 117 (UO₂), 119 (from ThO₂ in emitter), 124, 125 (UO₂)</td>
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<tr>
<td>Thorium (Th) (from the emitter composition)</td>
<td>1 (in W), 119 (W, 2 percent ThO₂)</td>
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<tr>
<td>Uranium (U) (possible diffusion into diodes from fuel)</td>
<td>3, 6, 7, 8, 9, 28, 47, 55, 88, 89, 112, 117, 125, 126</td>
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<tr>
<td>Xenon (Xe)</td>
<td>17, 18, 46, 54, 75</td>
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<tr>
<td>Emitter (E), Collector (C), Combination</td>
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<tr>
<td>Iridium (E)</td>
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<tr>
<td>Stainless steel (C)</td>
<td>17, 18</td>
</tr>
<tr>
<td>Molybdenum (E)</td>
<td></td>
</tr>
<tr>
<td>Molybdenum (C)</td>
<td>5, 12, 34, 38, 39, 82, 89, 92, 100, 120</td>
</tr>
<tr>
<td>Niobium, 1 percent zirconium (C)</td>
<td>127</td>
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<tr>
<td>Niobium (C)</td>
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<tr>
<td>Nickel (C)</td>
<td>7, 9, 10, 14, 20</td>
</tr>
<tr>
<td>Emitter (E), Collector (C), Combination</td>
<td>Reference</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-----------</td>
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<tr>
<td>Molybdenum-based alloy (E)</td>
<td>98</td>
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<tr>
<td>Niobium (C)</td>
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</tr>
<tr>
<td>Rhenium (E)</td>
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<tr>
<td>Molybdenum (C)</td>
<td>3, 4, 12, 15, 19, 22, 27, 31, 40, 41, 42, 44, 46, 56, 57, 59, 64, 69, 74, 76, 82, 91, 95, 114, 122, 125</td>
</tr>
<tr>
<td>Nickel (C)</td>
<td>14, 16, 82</td>
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<tr>
<td>Niobium (C)</td>
<td>21, 56, 58, 66, 67, 68, 69, 79, 82, 101, 103, 107, 122, 126</td>
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<tr>
<td>Niobium, 1 percent zirconium</td>
<td>115</td>
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<tr>
<td>Palladium (C)</td>
<td>58</td>
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<tr>
<td>Rhenium (C)</td>
<td>40, 58, 65, 82, 87, 91</td>
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<tr>
<td>Silver (C)</td>
<td>23</td>
</tr>
<tr>
<td>Tantalum (C)</td>
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<tr>
<td>Ruthenium (E)</td>
<td></td>
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<tr>
<td>Molybdenum (C)</td>
<td>11, 45</td>
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<tr>
<td>Niobium (C)</td>
<td>45</td>
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<tr>
<td>Niobium with oxygen (C)</td>
<td>45</td>
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<tr>
<td>Rhenium (C)</td>
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<tr>
<td>Ruthenium (C)</td>
<td>11, 45</td>
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<tr>
<td>Tantalum (E)</td>
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<tr>
<td>Molybdenum (C)</td>
<td>4, 5, 42</td>
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<tr>
<td>Nickel (C)</td>
<td>46</td>
</tr>
<tr>
<td>Niobium (C)</td>
<td>66, 82</td>
</tr>
<tr>
<td>Tantalum (C)</td>
<td>4, 5</td>
</tr>
<tr>
<td>Tungsten (E)</td>
<td>8</td>
</tr>
<tr>
<td>Inconel (C)</td>
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</tr>
<tr>
<td>Molybdenum (C)</td>
<td>13, 22, 24, 30, 33, 49, 50, 62, 63, 71, 82, 84, 93, 94, 96, 104, 105, 108, 110, 113, 116, 118, 123, 124, 128</td>
</tr>
<tr>
<td>Nickel (C)</td>
<td>2, 14, 21, 25, 28, 29, 33, 37, 43, 60, 82, 121</td>
</tr>
<tr>
<td>Niobium (C)</td>
<td>21, 29, 48, 50, 70, 72, 80, 81, 82, 85, 86, 90, 97, 102, 104, 105, 106, 109, 112, 117, 121, 122, 123, 126, 129</td>
</tr>
<tr>
<td>Niobium, 1 percent zirconium (C)</td>
<td>55, 84, 88</td>
</tr>
<tr>
<td>Tantalum (C)</td>
<td>4, 26, 111</td>
</tr>
</tbody>
</table>
Emitter (E), Collector (C), Reference

<table>
<thead>
<tr>
<th>Combination</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten (C)</td>
<td>25, 61, 83, 121, 123</td>
</tr>
<tr>
<td>Tungsten and tungsten oxide on a niobium collector (C)</td>
<td>82</td>
</tr>
<tr>
<td>&quot;Tungsten-based alloy&quot; (E)</td>
<td></td>
</tr>
<tr>
<td>Niobium (C)</td>
<td>98</td>
</tr>
<tr>
<td>Tungsten, rhenium alloys (E)</td>
<td></td>
</tr>
<tr>
<td>Nickel (C)</td>
<td>82</td>
</tr>
<tr>
<td>Niobium (C)</td>
<td>98</td>
</tr>
<tr>
<td>Tungsten, 25 percent rhenium (C)</td>
<td>78</td>
</tr>
<tr>
<td>Tungsten with a small amount of thorium (E)</td>
<td></td>
</tr>
<tr>
<td>Stainless steel (C)</td>
<td>1</td>
</tr>
</tbody>
</table>

CHRONOLOGICALLY ORDERED, ANNOTATED REFERENCES ON CESIUM-DIODE PERFORMANCES FROM THE 1963-TO-1971 PROCEEDINGS OF THE THERMIONIC SPECIALIST CONFERENCES


Emitter: W with a small amount of Th; \( T_E = 1900 \) to 2200 K
Collector: stainless steel; \( T_C = 583 \) to 783 K and optimum
Cesium gap: 1 mm; \( T_R = 424 \) to 573 K
Additive: Th
Geometry: cylindric, 1.52-cm diameter, 13.3 cm²
Output: 0.4 to 0.8 W/cm² with 1.2 to 2.4 percent efficiency at 1900 K; 6 to 9 W/cm² with 8.8 to 12 percent efficiency at 2200 K

Emitter: W; $T_E = 1000$ to $2300$ K
Collector: Ni; $T_C = 400$ to $1000$ K and optimum
Cesium gap: $T_R = 100^\circ$ and $200^\circ$ C
Additive: $H_2$
Geometry: filamentary
Output: power for Cs alone above that for Cs + $H_2$ with $T_R = 100^\circ$ C; for $T_R = 200^\circ$ C power for Cs + $H_2$ above that for Cs alone at $T_E < 1900$ K; for $T_R = 200^\circ$ C power for Cs + $H_2$ at 1500 K equal to that for Cs alone at 2100 K; power range $10^{-6}$ to $10^{-1}$ W/cm$^2$


Emitter: Re (UC backed); $T_E = 1550^\circ$ C (129 hr), $1600^\circ$ C (72 hr)
Collector: Mo; $T_C = 603^\circ$ to $617^\circ$ C
Additive: U and C possible
Geometry: plane
Output: 5 W/cm$^2$ (0.5 V, $1550^\circ$ C), more than 8 W/cm$^2$ (0.5 V, $1600^\circ$ C), no degradation of performance
Lifetime: 201 hr; thermal bond separation in fuel, emitter sandwich


Emitter: Re, Ta, or W; $T_E = 1980$ to $2050$ K
Collector: Mo or Ta; radiation cooled
Cesium gap: 0.051 to 0.064 mm; $T_R$ optimized
Geometry: plane solar diodes
Output: as shown in the following table (from ref. 4):
### SOLAR HARDWARE CONVERTERS (1962-1963)

<table>
<thead>
<tr>
<th>Type</th>
<th>Date</th>
<th>Emitter</th>
<th>Collector</th>
<th>Emitter area, cm²</th>
<th>Spacing, mm</th>
<th>Volts</th>
<th>Amp-</th>
<th>Watts</th>
<th>Emitter temperature, K</th>
<th>Geometry</th>
<th>Number built</th>
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</thead>
<tbody>
<tr>
<td>Series VI</td>
<td>1962-1963</td>
<td>Ta</td>
<td>Ta</td>
<td>2</td>
<td>0.064</td>
<td>0.8</td>
<td>1.0</td>
<td>28.0</td>
<td>18.7</td>
<td>Flat</td>
<td>21</td>
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<tr>
<td>VI -S -15</td>
<td>1962</td>
<td>Ta</td>
<td>Ta</td>
<td>2</td>
<td>0.064</td>
<td>0.6</td>
<td>71.0</td>
<td>42.6</td>
<td>2050</td>
<td>Flat</td>
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<tr>
<td>EX-1, -7</td>
<td>1962</td>
<td>Re</td>
<td>Mo</td>
<td>2</td>
<td>0.058</td>
<td>0.7</td>
<td>1.0</td>
<td>50.0</td>
<td>13.2</td>
<td>Flat</td>
<td>2</td>
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<tr>
<td>EX-2, -3</td>
<td>1962</td>
<td>Re</td>
<td>Ta</td>
<td>2</td>
<td>0.058</td>
<td>0.7</td>
<td>30.0</td>
<td>21.0</td>
<td>1990</td>
<td>Flat</td>
<td>2</td>
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<tr>
<td>EX-4, -5, -6</td>
<td>1962</td>
<td>W</td>
<td>Ta</td>
<td>2</td>
<td>0.058</td>
<td>0.5</td>
<td>1.0</td>
<td>27.0</td>
<td>6.8</td>
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<tr>
<td>EX-8</td>
<td>1962</td>
<td>Ta</td>
<td>Mo</td>
<td>2</td>
<td>0.064</td>
<td>0.7</td>
<td>1.0</td>
<td>25.5</td>
<td>11.0</td>
<td>Flat</td>
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<tr>
<td>EX-9</td>
<td>1962</td>
<td>Ta</td>
<td>Ta</td>
<td>2</td>
<td>0.064</td>
<td>0.6</td>
<td>1.0</td>
<td>40.0</td>
<td>12.0</td>
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<tr>
<td>Series VII</td>
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<td>Ta</td>
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<td>0.051</td>
<td>0.5</td>
<td>1.0</td>
<td>40.0</td>
<td>12.0</td>
<td>Flat</td>
<td>9</td>
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<tr>
<td>Series 2</td>
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<td>Ta</td>
<td>Mo</td>
<td>3</td>
<td>0.051</td>
<td>1.0</td>
<td></td>
<td>20.0</td>
<td>20.0</td>
<td>Flat</td>
<td>11</td>
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<tr>
<td>Series 300</td>
<td>1963</td>
<td>Ta</td>
<td>Mo</td>
<td>3</td>
<td>0.051</td>
<td>0.5</td>
<td></td>
<td>58.0</td>
<td>29.0</td>
<td>Flat</td>
<td>5</td>
</tr>
</tbody>
</table>

#### Lifetime

- over 2000 hr

5. Rouklove, P.: Results of Laboratory Tests of Set Thermionic Converters and Generators, pp. 305-313.

- Emitter: Mo (C), Ta (A, B, D); $T_E = 1677^\circ C$ (D) and $1700^\circ C$ (A, B, C)
- Collector: Mo (B, C, D), Ta (A); radiation cooled
- Cesium gap: 0.051 mm (A), 0.025 to 0.203 mm (B), 0.127 mm (B); $T_R$ optimized
- Geometry: plane solar diodes
- Output: 11 to 18 W/cm² to 0.6 V with 8.5 to 9 percent efficiency (A), 5 to 8.5 W/cm² maximums for 0.076 to 0.025 mm at 0.6 V with 5.4 percent efficiency (B), 9.3 W/cm² maximum with 7.4 percent efficiency (B), 7.0 to 8.5 W/cm² (C), 10 to 13 W/cm² (D)

#### Lifetime

- some in excess of 2000 hr

- Emitter: Mo ((UZr)C backed)
- Collector: Nb
- Cesium gap: 0.5 mm
- Additive: U and C (through the emitter and through a hole in the emitter)
- Geometry: cylindric with emitter cavity, diode gap, and Cs reservoir interconnected
- Output: 0.22 W/cm² at 1 MW reactor power \( (T_R = 177^\circ C) \)
- Lifetime: cesium heater failed in initial checkouts and allowed no high-power runs in the reactor


- Emitter: Mo (UO₂ backed); \( T_E = 1200^\circ \text{C} \) to \( 1700^\circ \text{C} \) with \( 1350^\circ \text{C} \) design optimum
- Collector: Ni; \( T_C \) optimums 525°C to 825°C (for \( 1200^\circ \text{C} \) to \( 1700^\circ \text{C} \)); \( 570^\circ \text{C} \) for \( T_E = 1350^\circ \text{C} \)
- Cesium gap: 0.838 to 0.076 mm optimums (for \( 1200^\circ \text{C} \) to \( 1700^\circ \text{C} \)), 0.279 mm for \( T_E = 1350^\circ \text{C} \); \( T_R \) optimums 270°C to 380°C (for \( 1200^\circ \text{C} \) to \( 1700^\circ \text{C} \)), \( 310^\circ \text{C} \) for \( T_E = 1350^\circ \text{C} \)
- Additive: U and O possible
- Geometry: cylindric; 60 cm²
- Output: 1.3 to 15 W/cm² (for \( 1200^\circ \text{C} \) to \( 1700^\circ \text{C} \)), 3.2 W/cm² at \( T_E = 1350^\circ \text{C} \); 11 percent "typical efficiency"; in-pile 2.25 W/cm² at 9 percent efficiency (see ref. 9)
- Lifetime: 2600 hr for one and 1400 hr at 3 W/cm² for another out of pile, both continuing; in-pile performance plummeted after 300 hr


- Emitter: W (UO₂ backed); \( T_E = 1700^\circ \text{C}, 1720^\circ \text{C}, 1800^\circ \text{C} \)
- Collector: Inconel; \( T_C = 650^\circ \text{C} \) to \( 700^\circ \text{C} \)
- Cesium gap: 0.254 mm; \( T_R = 335^\circ \text{C} \) to 345°C for power maximums
- Additive: U and O possible
- Geometry: cylindric; 1.17-cm diameter, 8.6 cm²
- Output: 4 W/cm² at 0.6 V and \( 1700^\circ \text{C} \), 5 W/cm² at 0.64 V and \( 1720^\circ \text{C} \), 6 W/cm² at 0.78 V and \( 1800^\circ \text{C} \); 10.5 percent efficiency at peak
- Lifetime: 224 hr in testing reactor before Cu pinchoff failed

Emitter Mo (UO$_2$ back); $T_E = 1300^\circ$ to $1500^\circ$ C
Collector Ni; $T_C$ optimized
Cesium gap optimized widths and $T_R$'s
Geometry cylindric, $60 \text{ cm}^2$
Output 1 to 4 W/cm$^2$ at 8 to 12 percent efficiencies (see ref. 7); complete performance map


Emitter Ir at $1430^\circ$ C, Mo at $1400^\circ$ C
Collector Ni
Cesium gap 0.762 mm with $T_R = 252^\circ$ C for Ir, 0.208 mm with $T_R = 315^\circ$ C for Mo
Geometry plane; 2.54-cm diameter
Output projected from RCA tube 1195A data, 5.5 W/cm$^2$ for Ir, 4.25 W/cm$^2$ for Mo


Emitter two of hot-pressed Ru, one of plasma-sprayed Ru; $T_E = 1500$ to $1900$ K
Collector one of arc-cast Mo, two of plasma-sprayed Ru; $T_C = 698$ to $1031$ K
Cesium gap 0.102 to 0.762 mm; $T_R = 535$ to $589$ K
Geometry plane
Output 8 W/cm$^2$ for 0.254 mm and $T_E = 1800$ K; Ru gives higher power densities than Re and Ir produce for gaps wider than 0.254 mm


Emitter (1) Mo or (2) Re; $T_E = 1800$ K (A), 1900 K (B), 2000 K (C)
Collector Mo; $T_C = 750$ or $800$ K or optimum
Cesium gap 0.05 to 0.4 mm; $T_R = 531$ to $609$ K or optimum
Additive CsF at $T_{CsF} = 800$ K
Geometry plane
Output for Cs with CsF: emitter (1A) 12 W/cm² at 0.35 V; (1B) 20 W/cm² at 0.5 V; (1C) 24 W/cm² at 0.6 V; (2A) 16 W/cm² at 0.4 V; (2B) 20 W/cm² at 0.65 V; (2C) 28 W/cm² at 0.7 V; at identical voltages Cs with CsF gave more power, allowed lower Cs pressure, or permitted greater gap widths; good performance maps.


Emitter: W; Tₑ = 1700, 1800, 1900, or 2000 K
Collector: Mo; Tᶜ's within 25°C above Tᶜ
Cesium gap: 0.025 to 1.016 mm; Tᵣ = 425 to 647 K
Additive: Ba; Tₜ = 1000 to 1200 K
Geometry: plane
Output: 8.5 W/cm² at Tₑ = 2000 K, Tᶜ = 1100 K, Tᵣ = 1080 K, Tᶜ ≈ 470 K with a "fundamental conversion efficiency" of 27 percent; output dropped from 8.5 to 8.2 W/cm² as the gap widened from 0.051 to 1.016 mm.


Emitter: Mo, Re, or "special" W; Tₑ = 1250°C to 1550°C
Collector: Ni; optimum Tᶜ's
Cesium gap: optimum width; optimum Tᵣ's
Additive: H₂
Geometry: plane; 11.7 cm²
Output: at 1550°C, 9.5 W/cm² (Mo), 12 W/cm² (Re), 17 W/cm² (W); H₂ from 10⁻⁶ to 10⁻³ torr did not affect W or Re; it dropped Mo performance 15 percent and lowered the output of a contaminated W emitter over 40 percent.


Emitter: Re; Tₑ = 1520 to 1900 K
Collector: Mo
Cesium map: 0.008 to 0.254 mm; Tᵣ = 480 to 539 K
Geometry: plane, guarded
Output: very low (uniganted mode)

Emitter  Re; $T_E = 1700$ to $2123$ K
Collector Ni; $T_C = 873$ K
Cesium gap 0.051 mm; $T_R = 593$ to $643$ K
Output  38 W/cm$^2$ at 0.5 V and 2000 K


Emitter  Ir; $T_E = 1370^\circ$ C
Collector stainless steel; $T_C = 290^\circ$ to $760^\circ$ C
Cesium gap 0.310 mm; $T_R = 290^\circ$ C
Additive Xe; 60 torr
Geometry plane
Output  postulate of higher performance with Xe because of increased Cs$_2^+$ decay times


Emitter  Ir; $T_E = 1260^\circ$ to $1370^\circ$ C
Collector 304 stainless steel; $T_C = 607^\circ$ to $682^\circ$ C and 1.62 $T_R$
Cesium gap 0.178 to 0.762 mm; $T_R = 270^\circ$ to $310^\circ$ C
Additive Xe; 60 torr
Geometry plane
Output  8.3 W/cm$^2$ maximum for Cs + Xe with $T_E = 1370^\circ$ C; Xe increased output 15 to 80 percent; Ne decreased output; performance curves


Emitter  Re pyrolytic or pressure-bonded, $T_E = 2000^\circ$ C
Collector Mo, $T_C = 529^\circ$ to $821^\circ$ C
Cesium gap 0.051 mm, $T_R = 336^\circ$ to $398^\circ$ C
Geometry plane solar diode, 2.0 cm$^2$
Output  as shown in the following table (from ref. 19):
Performance of Series VIII Prototypes at 2000 K

<table>
<thead>
<tr>
<th>Diode</th>
<th>I, A</th>
<th>J, A/cm²</th>
<th>V, volts</th>
<th>Output power, W</th>
<th>T_R, °C</th>
<th>T_C, °C</th>
<th>Input power, W</th>
<th>Efficiency, η</th>
<th>Diode weight, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIII-P-1</td>
<td>15.4</td>
<td>7.7</td>
<td>1.0</td>
<td>15.4</td>
<td>362</td>
<td>652</td>
<td>---</td>
<td>------</td>
<td>230</td>
</tr>
<tr>
<td>good quality</td>
<td>30.0</td>
<td>15.0</td>
<td>.85</td>
<td>25.5</td>
<td>369</td>
<td>652</td>
<td>---</td>
<td>------</td>
<td>---</td>
</tr>
<tr>
<td>pyrolytic</td>
<td>39.0</td>
<td>19.5</td>
<td>.8</td>
<td>31.2</td>
<td>388</td>
<td>652</td>
<td>---</td>
<td>------</td>
<td>---</td>
</tr>
<tr>
<td>rhenium</td>
<td>60.0</td>
<td>30.0</td>
<td>.688</td>
<td>41.4</td>
<td>384</td>
<td>652</td>
<td>---</td>
<td>------</td>
<td>---</td>
</tr>
<tr>
<td>emitter</td>
<td>80.7</td>
<td>40.35</td>
<td>.6</td>
<td>49.4</td>
<td>398</td>
<td>652</td>
<td>---</td>
<td>------</td>
<td>---</td>
</tr>
<tr>
<td>VIII-P-2a</td>
<td>24.0</td>
<td>12.0</td>
<td>1.0</td>
<td>24.0</td>
<td>349</td>
<td>529</td>
<td>300</td>
<td>0.08</td>
<td>494</td>
</tr>
<tr>
<td>pressure-bonded</td>
<td>34.0</td>
<td>17.0</td>
<td>.9</td>
<td>30.6</td>
<td>347</td>
<td>561</td>
<td>325</td>
<td>0.0942</td>
<td>---</td>
</tr>
<tr>
<td>rhenium</td>
<td>47.5</td>
<td>23.75</td>
<td>.8</td>
<td>38.0</td>
<td>357</td>
<td>616</td>
<td>358</td>
<td>0.106</td>
<td>---</td>
</tr>
<tr>
<td>emitter</td>
<td>61.0</td>
<td>30.5</td>
<td>.7</td>
<td>42.7</td>
<td>372</td>
<td>666</td>
<td>388</td>
<td>0.110</td>
<td>---</td>
</tr>
<tr>
<td>VIII-P-2b</td>
<td>12.6</td>
<td>6.3</td>
<td>1.0</td>
<td>12.6</td>
<td>336</td>
<td>543</td>
<td>263</td>
<td>0.0479</td>
<td>494</td>
</tr>
<tr>
<td>pyrolytic</td>
<td>16.0</td>
<td>8.0</td>
<td>.9</td>
<td>14.4</td>
<td>338</td>
<td>554</td>
<td>270</td>
<td>0.0534</td>
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</tr>
<tr>
<td>rhenium</td>
<td>24.0</td>
<td>12.0</td>
<td>.8</td>
<td>19.2</td>
<td>348</td>
<td>584</td>
<td>292</td>
<td>0.0658</td>
<td>---</td>
</tr>
<tr>
<td>emitter with impurities</td>
<td>32.0</td>
<td>16.0</td>
<td>.7</td>
<td>22.4</td>
<td>355</td>
<td>623</td>
<td>310</td>
<td>0.0724</td>
<td>---</td>
</tr>
<tr>
<td>VIII-P-3</td>
<td>29.0</td>
<td>14.5</td>
<td>1.0</td>
<td>29.0</td>
<td>353</td>
<td>661</td>
<td>310</td>
<td>0.0936</td>
<td>255</td>
</tr>
<tr>
<td>pressure-bonded</td>
<td>39.0</td>
<td>19.5</td>
<td>.9</td>
<td>35.1</td>
<td>360</td>
<td>698</td>
<td>335</td>
<td>0.1048</td>
<td>---</td>
</tr>
<tr>
<td>rhenium</td>
<td>49.0</td>
<td>24.5</td>
<td>.8</td>
<td>39.2</td>
<td>366</td>
<td>751</td>
<td>365</td>
<td>0.1073</td>
<td>---</td>
</tr>
<tr>
<td>emitter</td>
<td>58.0</td>
<td>29.0</td>
<td>.7</td>
<td>40.6</td>
<td>380</td>
<td>793</td>
<td>385</td>
<td>0.1053</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>65.0</td>
<td>32.5</td>
<td>.6</td>
<td>39.0</td>
<td>387</td>
<td>821</td>
<td>400</td>
<td>0.0975</td>
<td>---</td>
</tr>
</tbody>
</table>


Emitter Mo apparently; T_E = 1450° to 1800° C
Collector Ni apparently; T_C = 610° to 740° C
Cesium gap T_R = 335° to 345° C
Geometry cylindric; 40 cm²
Output up to 13.75 W/cm²; efficiencies as high as 19.8 percent; good performance maps
Lifetime 2600 hr average for 12 diodes
Comment according to RCA, A-1272 is a high-performance version of A-1197A (Mo, Ni)


Emitter

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>W, Mo, W, Re, W; ( T_E = 2263 \text{ K} )</td>
</tr>
<tr>
<td>2</td>
<td>Mo, 1973 K</td>
</tr>
<tr>
<td>3</td>
<td>1900 and 2000 K</td>
</tr>
<tr>
<td>4</td>
<td>1900 K</td>
</tr>
<tr>
<td>5</td>
<td>2100 K</td>
</tr>
</tbody>
</table>

Collector

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ni, unknown, Nb, Nb, Nb; ( T_C = 898 ) to ( 1053 \text{ K} ) for</td>
</tr>
<tr>
<td>2</td>
<td>(1)</td>
</tr>
</tbody>
</table>

Cesium gap

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.051, 0.3, 0.16, 0.25, 0.25 mm; ( T_R = 593 ) to</td>
</tr>
<tr>
<td>2</td>
<td>693 K for</td>
</tr>
</tbody>
</table>

Geometry

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>(1)</td>
<td>plane, the rest cylindric</td>
</tr>
</tbody>
</table>

Output

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>over 75 W/cm(^2), 4.2 W/cm(^2), 5 to 8.4 W/cm(^2), 3.75 W/cm(^2), 10 W/cm(^2); efficiency of (2) 8 percent, (3) 11 percent; performance map for</td>
</tr>
</tbody>
</table>


Emitter

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Re (four surface preparations), W; ( T_E = 1605 ) to 1975 K for Re, 1630 to 1950 for W</td>
<td></td>
</tr>
</tbody>
</table>

Collector

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Mo; ( T_C = ) optimum</td>
<td></td>
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</table>

Cesium gap

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>optimum; ( T_R = ) optimum</td>
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</table>

Geometry

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<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>plane; 3-cm(^2) emitter, 2-cm(^2) collector, guard</td>
<td></td>
</tr>
</tbody>
</table>

Output

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>22 W/cm(^2) for Re and 14 for W at ( T_E = 1850 \text{ K} ); 40 W/cm(^2) for Re at 1975 K; fully optimized performance plots</td>
<td></td>
</tr>
</tbody>
</table>


Emitter

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<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Re; ( T_E = 1350^\circ \text{ C} )</td>
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</tbody>
</table>

Collector

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<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Ag; ( T_C = 350^\circ ) to ( 550^\circ \text{ C} )</td>
<td></td>
</tr>
</tbody>
</table>

Cesium gap

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.356 mm; ( T_R = 285^\circ ) and ( 290^\circ \text{ C} )</td>
<td></td>
</tr>
</tbody>
</table>

Additive

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>( O_2 ) introduced through Ag membrane on collector</td>
<td></td>
</tr>
</tbody>
</table>

Geometry

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>plane</td>
<td></td>
</tr>
</tbody>
</table>

Output

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.6 W/cm(^2) with 11.6 percent efficiency at 0.2 V, ( T_C = 400^\circ \text{ C} ), and ( T_R = 285^\circ \text{ C} ); performance plots</td>
<td></td>
</tr>
</tbody>
</table>


Emitter

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>W; ( T_E = 1630 ) to 1950 K</td>
<td></td>
</tr>
</tbody>
</table>
Collector Mo; $T_C = 813$ to 943 K
Cesium gap 0.025 to 0.762 mm; $T_R = 480$ to 645 K
Additive CsF; $T_{CSF} = 378$ to 770 K
Geometry plane, guarded
Output 40 W/cm$^2$ at 0.58 V for Cs + CsF, $T_E = 1870$ K, $T_C = 893$ to 943 K, $T_{CSF} = 623$ K, $T_R = 538$ to 609 K, $d = 0.127$ mm; 9 W/cm$^2$ at 0.58 V for Cs alone, $T_E = 1850$ K, $T_C = 862$ K, $T_R = 562$ to 635 K, $d = 0.153$ mm; good performance plots

Emitter W; $T_E = 1633$ to 2183 K
Collector Ni or W (from emitter) on Ni; $T_C = 863$ to 973 K
Cesium gap 0.051 mm; $T_R = 553$ to 663 K
Geometry plane, guarded
Output at 100 A/cm$^2$, 78 W/cm$^2$ (2183 K), 65 W/cm$^2$ (2074 K), 47 W/cm$^2$ (1963 K), and 35 W/cm$^2$ (1855 K) for Ni and 20 W/cm$^2$ (1855 K) for W on Ni; subsequent contamination nearly regenerated the initial performance; good I, V curves

Emitter W; $T_E = 2150$ or 2225 K
Collector Ta; $T_C = 1355$ to 1675 K
Cesium gap 0.051 to 0.432 mm; $T_R = 633$ to 693 K and optimum
Geometry plane, guarded
Output at $T_E = 2225$ K, $T_C = 1500$ K, $T_{CS} = 673$ K, $d = 0.135$ mm, 27.5 W/cm$^2$ maximum for 0.45 V and 9 percent efficiency and 10.5 percent maximum efficiency; extensive performance plots show effects of high collector temperatures

Emitter Re; $T_E = 1680$ to 2000 K
Collector Mo; $T_C = 873$ to 1073 K
Cesium gap 0.013 to 0.508 mm; $T_R = 543$ to 630 K
Geometry plane, guarded
Output  5.3 W/cm$^2$ at 0.38 V, $T_E = 1740$ K, $T_C = 1053$ K, $T_R = 588$ K, $d = 0.102$ mm; I, V plots; an attempt to correlate optimum collector temperatures

Conference Record of the Thermionic Conversion Specialist Conference.  IEEE, 1966.


   Emitter    W (UO$_2$ backed); $T_E = 1500^\circ$ to 1830$^\circ$ C
   Collector  Ni; $T_C = 700^\circ$ C
   Cesium gap 0.127 mm; $T_R = 330^\circ$ to 370$^\circ$ C
   Additive  U and O possible
   Geometry  cylindric; 1-cm diameter, 8.6 cm$^2$
   Output  18.8 W/cm$^2$ maximum measured for $T_E = 1830^\circ$ C; 10.2 W/cm$^2$ and 15.8 percent efficiency during life test at $T_E = 1730^\circ$ C, $T_C = 700^\circ$ C, and $T_R = 345^\circ$ C
   Lifetime  9227 hr before shorting out


   Emitter    W; $T_E = 1673$ to 2153 K
   Collector  Nb or Ni; $T_C = 873$ to 1173 K
   Cesium gap 0.025 to 0.508 mm; $T_R = 583$ to 683 K
   Geometry  plane
   Output  voltage is 0.1 to 0.16 V higher with Ni rather than Nb; good performance curves


   Emitter  Cl$^-$CVD (~110) W; $T_E = 1900$ to 2000 K
   Collector  Mo; $T_C = 833$ to 1033 K
   Cesium gap 0.203 mm; $T_R = 563$ to 588 K
   Geometry  plane
   Output  11 W/cm$^2$ with 0.5 V at $T_E = 2000$ K; 9 W/cm$^2$ with 0.45 V at $T_E = 1900$ K


   Emitter  Electroetched Re; $T_E = 1555$ to 1960 K
Collector Mo; $T_C = 843$ to $943 K$ and optimum
Cesium gap 0.013 to 1.016 mm and optimum; $T_R = 514$ and 616 K and optimum
Geometry plane, guarded
Output fully optimized, $3 \text{ W/cm}^2$ with 0.2 V at $T_E = 1560 K$, $7.5 \text{ W/cm}^2$ with 0.3 V at $T_E = 1650 K$, $13 \text{ W/cm}^2$ with 0.5 V at $T_E = 1740 K$, $18 \text{ W/cm}^2$ with 0.7 V at $T_E = 1860 K$, and $40 \text{ W/cm}^2$ with 0.8 V at $T_E = 1960 K$; electroetched Re is considerably more effective than electropolished Re

Emitter W, 20 percent Re; $T_E = 1500^O$ to $1800^O$ C
Geometry cylindric
Output little information to define performance given in this dynamics study; influences of $T_C$ and $T_R$ considered negligible

Emitter W; $T_E = 2100 K$ maximum
Collector Mo or Ni; $T_C = 1000 K$
Cesium gap 0.127 or 0.178 mm; $T_R = 598$ or 643 K
Geometry cylindric; 1.2-cm diameter, variable length (for the analysis)
Output previous data used as bases for numerical optimizations with respect to emitter length and support and output voltage

Emitter Mo; $T_E = 1450^O$ and $1700^O$ C
Collector Mo; $T_C$ optimum
Cesium gap 0.25 mm; $T_R$ optimum
Additive CsF; $T_{CsF} = 325^O$ to $550^O$ C
Output at 2 W/cm$^2$ 6.7 percent efficiency for Cs and 8 percent for Cs + CsF; at 4 W/cm$^2$ 9.7 percent efficiency for Cs and 10 percent for Cs + CsF; at 6 W/cm$^2$ 11.7 percent efficiency for Cs and 10.9 percent for Cs + CsF

Emitter $T_E = 1863, 1740, 1645 K$
Collector \( T_C = 873 \text{ K} \)

Cesium gap \( 0.051, 0.254, 0.508 \text{ mm}; \ T_R = 558 \text{ to} 638 \text{ K} \)

Additive 0 to 100 torr

Geometry plane, guarded

Output increasing Ar pressure decreases diode output; 10 torr of Ar attenuates electron current 5 to 15 percent


Emitter \( T_E = 1625, 1645 \text{ K} \)

Collector Mo with and without grooves; \( T_C = 773, 873 \text{ K} \)

Cesium gap \( 0.025 \text{ to} 0.635 \text{ mm}; \ T_R = 553 \text{ K}, 593 \text{ K}, \text{ and variable} \)

Geometry plane, guarded

Output small increase in output for grooved collector over flat one even without optimization


Emitter \( W; \ T_E = 1400^\circ \text{ C} \)

Collector Ni

Cesium gap 0.254 mm

Geometry \( 20 \text{ cm}^2 \)

Output 5 W/cm\(^2\) at 0.55 V and 10 percent efficiency


Emitter Mo; \( T_E = 1300^\circ \text{ to} 1500^\circ \text{ C} \)

Collector Mo; \( T_C = 625^\circ \text{ to} 675^\circ \text{ C} \)

Cesium gap \( T_R = 285^\circ \text{ to} 325^\circ \text{ C} \)

Geometry cylindric, \( 40 \text{ cm}^2 \)

Output 2.05 W/cm\(^2\) (0.25 V), 2.8 W/cm\(^2\) (0.28 V), 4.0 W/cm\(^2\) (0.32 V), 5.0 W/cm\(^2\) (0.38 V), 6.9 W/cm\(^2\) (0.45 V)


Emitter Mo; \( T_E = 1450^\circ \text{ to} 1530^\circ \text{ C} \)

Collector Mo; \( T_C = 475^\circ \text{ to} 710^\circ \text{ C} \)

Cesium gap \( T_R = 95^\circ \text{ to} 321^\circ \text{ C} \)

Geometry cylindric; \( 50 \text{ cm}^2 \)

Output 3.2 W/cm\(^2\) at 0.6 V, \( T_E = 1510^\circ \text{ C}, T_C = 710^\circ \text{ C}, T_R = 318^\circ \text{ C} \)

Emitter Re; $T_E = 1735^\circ$ C
Collector Re or Mo; $T_C = 507^\circ$ to $790^\circ$ C
Cesium gap 0.089 mm (Re, Re), 0.0051 mm (Re, Re), 0.089 mm (Re, Mo)
Geometry plane; 2.0 cm$^2$ faces, 0.4 cm$^2$ sidewalls
Output 20 W/cm$^2$ at 0.8 V for Re, Re diode with 0.051-mm gap; 15.2 W/cm$^2$
        at 0.8 V, 21.0 W/cm$^2$ at 0.7 V, 26.4 W/cm$^2$ at 0.6 V for Re,
        Re diode with 0.089-mm gap; Re collector gave average of 0.08 V
        more than its Mo counterpart


Emitter Re; $T_E = 1600^\circ$, 1700$^\circ$, 1800$^\circ$ C
Collector Mo; radiation cooled ($T_C$ near optimum)
Cesium gap 0.038 mm; $T_R$ optimum
Geometry plane SET diodes; 2.5 cm$^2$
Output 25 W/cm$^2$ (0.6 V), 21 W/cm$^2$ (0.7 V), 15.7 W/cm$^2$ (0.8 V) with ef-
        ficiencies near 12.5 percent


Emitter Re or Ta; $T_E = 2000$ K
Collector Mo; radiation cooled ($T_C$ near optimum)
Cesium gap $T_R$ optimum
Geometry solar energy thermionics (SET) (plane); as described in the following
        table (from ref. 42):
## DESCRIPTION OF PROTOTYPE DIFFERENCE

<table>
<thead>
<tr>
<th>Prototype</th>
<th>100</th>
<th>101</th>
<th>102</th>
<th>103</th>
<th>104</th>
<th>201</th>
<th>202</th>
<th>203</th>
<th>204</th>
<th>205</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitter material</td>
<td>Ta</td>
<td>Ta</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
</tr>
<tr>
<td>Emitter fabrication</td>
<td>M</td>
<td>M</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>M</td>
<td>M</td>
<td>E</td>
</tr>
<tr>
<td>Emitter preparation</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>PE</td>
<td>PE</td>
<td>PE</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Emitter support material</td>
<td>Ta</td>
<td>Ta</td>
<td>Ta</td>
<td>Ta</td>
<td>Ta</td>
<td>Ta</td>
<td>Ta</td>
<td>Ta</td>
<td>Re</td>
<td>Re</td>
</tr>
<tr>
<td>Collector material</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
</tr>
<tr>
<td>Collector preparation</td>
<td>G</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Collector lateral area(a), cm(^2)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>1.3</td>
<td>0.5</td>
<td>2.0</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Nominal spacing, mm</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
<td>0.025</td>
<td>0.045</td>
<td>0.107</td>
</tr>
<tr>
<td>Measured spacing, mm</td>
<td>0.035</td>
<td>-----</td>
<td>0.025</td>
<td>-----</td>
<td>0.025</td>
<td>0.035</td>
<td>0.041</td>
<td>0.033</td>
<td>0.045</td>
<td>0.107</td>
</tr>
<tr>
<td>Lateral spacing, mm</td>
<td>0.152</td>
<td>0.152</td>
<td>0.152</td>
<td>0.152</td>
<td>0.152</td>
<td>0.152</td>
<td>0.152</td>
<td>0.152</td>
<td>0.152</td>
<td>0.102</td>
</tr>
<tr>
<td>Internal radiation shield</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Compression jig</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Amperes at 0.8 V, 2000 K</td>
<td>26.5</td>
<td>24</td>
<td>42</td>
<td>42.5</td>
<td>34</td>
<td>27.8</td>
<td>44.5</td>
<td>40</td>
<td>46.5</td>
<td>41.5</td>
</tr>
<tr>
<td>Amperes at 1.0 V, 2000 K</td>
<td>18.5</td>
<td>16.8</td>
<td>32</td>
<td>31</td>
<td>27</td>
<td>20.5</td>
<td>14</td>
<td>23</td>
<td>26</td>
<td>22</td>
</tr>
</tbody>
</table>

\(a\) Collector plane area, 2.5 cm\(^2\).


   Emitter \(\text{Cl}^+\text{CVD W (110)}; \ T_E = 1755, 1825, 2000 \text{ K}\)
   Collector \(\text{Ni}; \ T_C = 843 \text{ to } 1183 \text{ K}\)
   Cesium gap 0.10 mm; Cs, graphite reservoir at collector temperatures
   Geometry plane, ceramic guarded
   Output \(4.2 \text{ W/cm}^2\) at 0.5 V, \(T_E = 2000 \text{ K}, T_C = 1183 \text{ K}\)


   Emitter \(\text{Re}; \ T_E = 1650 \text{ to } 1850 \text{ K}\)
   Collector \(\text{Mo}; \ T_C = 573 \text{ to } 773 \text{ K}\)
   Cesium gap 0.127, 0.254, 0.508 mm; \(T_R = 481 \text{ to } 538 \text{ K}\)
   Additive \(\text{Cs}_2\text{O}, \text{O}_2\); collector acted as \(\text{Cs}_2\text{O}\) reservoir
   Geometry plane, guarded
   Output \(6.8 \text{ W/cm}^2\) for Cs + \(\text{Cs}_2\text{O}\), \(4.4 \text{ W/cm}^2\) for Cs only at 0.4 V,
   \(T_E = 1750 \text{ K with } 0.254\text{-mm gap}; \text{ for Cs + }\text{Cs}_2\text{O} I, V \text{ curves for}
   0.127 \text{ and } 0.508 \text{ mm are nearly identical at } T_E = 1750 \text{ K}\)


   Emitter \(\text{Ru}; \ T_E = 1425^\circ \text{ to } 1627^\circ \text{ C}\)
   Collector \(\text{Mo}; \text{Nb; Nb (O) (oxygenated Nb)}; \text{Re; Ru}; \ T_C = 390^\circ \text{ to } 570^\circ \text{ C}\)
Cesium gap 0.127, 0.152 mm; $T_R = 175^\circ$ to $345^\circ$ C

Additive Ba (Cs diode containing Ba shorted internally without yielding data)

Geometry plane, unguarded; 1.18 cm$^2$

Output as shown in the following table for $T_E = 1627^\circ$ C, $T_R$ optimum, $d = 0.152$ mm:

<table>
<thead>
<tr>
<th>Collector</th>
<th>Nb</th>
<th>Ru</th>
<th>Nb(O)</th>
<th>Re</th>
<th>Mo</th>
<th>Ru</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_C$, $^\circ$C</td>
<td>570</td>
<td>570</td>
<td>570</td>
<td>517</td>
<td>517</td>
<td>517</td>
</tr>
<tr>
<td>W/cm$^2$</td>
<td>11</td>
<td>10</td>
<td>10</td>
<td>8.5</td>
<td>6.5</td>
<td></td>
</tr>
</tbody>
</table>


Emitter Ta; $T_E = 1850$ K
Collection Ni; $T_C = 725$ K

Cesium gap 0.762 mm; $T_R$ optimum

Additive Ar, Kr, Xe, I

Geometry plane; 2.38-cm diameter

Output for Cs alone, 1.4 W/cm$^2$ maximum; output dropped steadily with increasing inert-gas pressure and produced at 30 torr and 0.6 V decreases of 46 percent for Ar, 76 percent for Kr, 83 percent for Xe; with I output at 0.6 V increased by 110 percent at 36 torr, then diminished to the initial (Cs only) value at 120 torr


Emitter Mo; $T_E = 1460$ to $2010$ K
Collection Nb; $T_C = 923$ to $953$ K

Cesium gap 0.204 mm; $T_R$ optimum

Geometry cylindric; 1.6-cm diameter, 20 cm$^2$

Output 9 W/cm$^2$ with 11 percent efficiency at $T_E = 2000$ K, $T_R = 360^\circ$ C (optimum); in-core performance plots

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1967.

48. Wilson, V. C.; and Lawrence, Jackson: Characteristics of a Thermionic Converter with a Fluoride Vapor Deposited Tungsten Emitter Etched to Preferentially Expose the 110 Crystal Planes, pp. 1-9.
Emitter: F^−CVD W (100) etched to expose 110 W faces and 40 percent more area; T_E = 1650 to 2150 K

Collector: Nb; T_C optimum

Cesium gap: 0.025 to 0.508 mm; T_R optimum

Geometry: plane, guarded

Output: 42 W/cm^2 with 50 A/cm^2, 20 percent efficiency and 30 W/cm^2 with 30 A/cm^2, 23 percent efficiency for d = 0.051 mm, T_E = 2155 K, T_C = 973 K; unusually high outputs at low Cs pressures and large spacings; greatest outputs came with gaps of 0.254 mm or more; good performance maps

Lifetime: performance decayed because of thermal reforming at 2155 K


Emitter: Cl^+CVD W (110); T_E = 1700, 1735, 1850 K

Collector: Mo; T_C = 470° to 660° C

Cesium gap: 0.127 mm

Geometry: plane, unguarded

Output: 16 W/cm^2 at 0.5 V, T_E = 1850 K; 9.8 W/cm^2 at 0.39 V, T_E = 1700 K


Emitter: F^−CVD W (100); Cl^+CVD W (110); T_E = 1600° to 1800° C

Collector: Mo; Nb; T_C optimum

Cesium gap: 0.229 mm; T_R optimum

Geometry: cylindric thermionic fuel (nuclear) elements (TFE's)

Output: Cl^+CVD W emitter gave 25 percent more power than F^−CVD W; Mo collector, 40 percent more than Nb at optimum current densities

Lifetime: over 3600 hr for F^−CVD-W, Nb diode; over 6000 hr for Cl^+CVD-W, Nb diode


Emitter: None

Collector: Comparison of Ni and Mo; T_C = 400° to 730° C

Cesium gap: 0.210 mm cold, 0.15 mm at 700° C; T_R < 485 K

Geometry: plane double-collector isothermal diode; 4 cm^2

Output: Mo collector was superior to Ni, giving 0.05 to 0.14 V lower cesiated surface potentials

Emitter \( T_E = 1500 \) to \( 1900 \) K
Cesium gap \( T_R = 433 \) to \( 638 \) K
Additive CsO\(_2\), O
Geometry plane, fixed-gap
Output CsO\(_2\) increased Cs diode performance considerably; diode was run with Cs only, then with Cs + Cs\(_2\)O, and finally with Cs alone; Cs\(_2\)O improved performance, reduced Cs pressure, decreased electron scattering in gap, and allowed operation with higher diode-component temperatures; performance curves


Emitter Ta with cavities; \( T_E = 1200 \) to \( 2100 \) K
Collector Mo; \( T_C = 400^\circ\) C
Cesium gap 0.051 mm; 0.324 to cavity bottoms
Geometry plane, unguarded; 2 cm\(^2\)
Output work functions from saturation currents and \( J, V \) curve knees were 0.4 eV lower than predicted by Rasor, Warner theory


Emitter \( T_E = 1800 \) K
Collector \( T_C \) optimum
Cesium gap 0.254, 1.016 mm; \( T_R \) optimum
Additive Xe, Kr, 0 to 213 torr
Output both Kr and Xe decreased diode performance with increasing pressure; at \( T_E = 1800 \) K, \( d = 0.254 \) mm a 20 percent current drop resulted for 60 torr Xe or for 100 torr Kr; previous reports of output gains with inert gas additions probably resulted from oxygen contamination


Emitter CVD W; \( T_E = 1350^\circ\) to \( 1700^\circ\) C
Collector Nb, 1 percent Zr; \( T_C = 741^\circ\) to \( 814^\circ\) C
Cesium gap 0.16 mm; \( T_R = 693^\circ\) to over \( 860^\circ\) C
Additive emitter backed by 20 percent enriched \( \text{UO}_2 \)
Geometry cylindric; 4 cm long, 20 cm\(^2\)
Output 4.25 W/cm$^2$ with 10.6 percent efficiency at 0.78 V, $T_E = 1695^\circ$ C, $T_C = 763^\circ$ C, $T_R = 810^\circ$ C

Lifetime 1650 hr without degradation


Emitter etched Re
Collector Nb; PVD Mo
Geometry cylindric; 3.81 cm long, 15 cm$^2$
Output as shown in the following table (from ref. 56):

<table>
<thead>
<tr>
<th>Diode data</th>
<th>Serial number</th>
<th>2</th>
<th>4</th>
<th>12</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>AEC</td>
<td>AEC</td>
<td>JPL</td>
<td>MEL</td>
<td>MEL</td>
<td>MEL</td>
<td>MEL</td>
<td>MEL</td>
<td>MEL</td>
<td>MEL</td>
</tr>
<tr>
<td>Emitter</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
</tr>
<tr>
<td>Collector</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Nb</td>
<td>Nb</td>
<td>Nb</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
</tr>
<tr>
<td>Spacing, mm</td>
<td>0.254</td>
<td>0.254</td>
<td>0.203</td>
<td>0.127</td>
<td>0.127</td>
<td>0.127</td>
<td>0.127</td>
<td>0.127</td>
<td>0.127</td>
<td>0.127</td>
</tr>
</tbody>
</table>

600 Watt input
Maximum device efficiency, percent 10.1 9.8 9.2 9.4 9.0 9.2 9.0 9.4 9.2
Maximum output, W/cm$^2$ 4.0 3.9 3.7 3.8 3.6 3.7 3.6 3.8 3.7

750 Watt input
Maximum device efficiency, percent 12.7 11.3 12.4 12.6 --- 10.8 11.2 13.2 11.7
Maximum output, W/cm$^2$ 6.4 5.7 6.2 6.3 --- 5.4 5.6 6.6 5.9

900 Watt input
Maximum device efficiency, percent 13.8 13.5 13.8 13.3 13.2 12.5 13.3 14.5 11.5
Maximum output, W/cm$^2$ 8.3 8.1 8.3 8.0 7.9 7.5 8.0 8.7 6.9

Life test
Hours attained 1221 100 0 146 211 148 650 1272 1001
Stopped by Open circuit Program ---- Program Water failure Program Program Program


Emitter etched Re; $T_E = 1860$ K
Collector VD Mo; $T_C = 973$ K
Cesium gap 0.114 mm; $T_R = 289^\circ$ to $373^\circ$ C
Geometry plane; 1.77 cm$^2$
Output as shown in the following table (from ref. 57):
DATA SUMMARY

<table>
<thead>
<tr>
<th>Output voltage, volts</th>
<th>Input power density, W/cm(^2)</th>
<th>Output power density, W/cm(^2)</th>
<th>Device efficiency, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Calculated</td>
<td>Measured</td>
</tr>
<tr>
<td>0.40</td>
<td>104</td>
<td>112</td>
<td>12.8</td>
</tr>
<tr>
<td>.40</td>
<td>101</td>
<td>101</td>
<td>13.7</td>
</tr>
<tr>
<td>.60</td>
<td>94</td>
<td>86</td>
<td>12.9</td>
</tr>
<tr>
<td>.65</td>
<td>58</td>
<td>66</td>
<td>9.0</td>
</tr>
<tr>
<td>.70</td>
<td>48</td>
<td>55</td>
<td>6.8</td>
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<tr>
<td>.75</td>
<td>42</td>
<td>49</td>
<td>5.5</td>
</tr>
<tr>
<td>.80</td>
<td>35</td>
<td>43</td>
<td>4.0</td>
</tr>
</tbody>
</table>


Emitter etched Re; \(T_E = 1800, 1900, 2000\) K
Collector Nb; Pd; Re
Cesium gap 0.051 mm; \(T_R\) optimum
Geometry plane; 2.5 cm\(^2\)
Output diode voltages decreased by averages of 0.037 V for Pd and 0.074 V for Nb relative to those for Re collector


Emitter Re; \(T_E = 1600^\circ\) to 1800\(^\circ\) C
Collector Mo; \(T_C\) optimum
Cesium gap \(T_R\) optimum
Geometry plane SET diodes
Output as shown in the following tables (from ref. 59):

Table 1. - Performance of SET-type converters

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power output, W</td>
<td>12</td>
<td>25</td>
<td>36</td>
<td>44</td>
<td>50</td>
<td>45</td>
<td>3.75</td>
</tr>
<tr>
<td>Power density, W/cm(^2)</td>
<td>6</td>
<td>12</td>
<td>18</td>
<td>22</td>
<td>20</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Efficiency, percent</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>12.5</td>
<td>10</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Maximum life, hr</td>
<td>119</td>
<td>1500</td>
<td>3200+</td>
<td>13 150+</td>
<td>15 210</td>
<td>N.A.</td>
<td>128</td>
</tr>
<tr>
<td>Vibration, 20 g at 0 to 2000 cps</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>Passed</td>
<td>Passed</td>
<td>N.A.</td>
<td>------</td>
</tr>
<tr>
<td>Shock, 100 g, 0.5 msec</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>Passed</td>
<td>Passed</td>
<td>N.A.</td>
<td>------</td>
</tr>
<tr>
<td>Power to weight ratio, W/kg</td>
<td>4.30</td>
<td>9.04</td>
<td>14.8</td>
<td>15.9</td>
<td>18.5</td>
<td>574</td>
<td>133</td>
</tr>
<tr>
<td>Weight/kg, kg/kW</td>
<td>23.2</td>
<td>11.1</td>
<td>8.66</td>
<td>7.08</td>
<td>7.68</td>
<td>1.74</td>
<td>15.1</td>
</tr>
</tbody>
</table>

25
### Table 2. - Converter characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VIII-15</th>
<th></th>
<th>VIII-17</th>
<th></th>
<th>VIII-25</th>
<th></th>
<th>VIII-26</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_e = 1700^\circ C$</td>
<td>$T_e = 1800^\circ C$</td>
<td>$T_e = 1700^\circ C$</td>
<td>$T_e = 1800^\circ C$</td>
<td>$T_e = 1700^\circ C$</td>
<td>$T_e = 1800^\circ C$</td>
<td>$T_e = 1700^\circ C$</td>
<td>$T_e = 1800^\circ C$</td>
</tr>
<tr>
<td>$E_b', v$</td>
<td>0.8</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>$T_b', A$</td>
<td>42.5</td>
<td>75.3</td>
<td>63.5</td>
<td>85.5</td>
<td>42.5</td>
<td>70.0</td>
<td>54.5</td>
<td>84.0</td>
</tr>
<tr>
<td>$w, w$</td>
<td>34</td>
<td>45</td>
<td>51</td>
<td>51</td>
<td>34</td>
<td>42</td>
<td>48</td>
<td>50</td>
</tr>
<tr>
<td>$F_{oc}, v$</td>
<td>2.1</td>
<td>1.7</td>
<td>1.8</td>
<td>1.6</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>$w_{in}, w$</td>
<td>344</td>
<td>445</td>
<td>469</td>
<td>532</td>
<td>330</td>
<td>409</td>
<td>434</td>
<td>518</td>
</tr>
<tr>
<td>Efficiency, percent</td>
<td>9.9</td>
<td>10.2</td>
<td>10.8</td>
<td>9.7</td>
<td>10.3</td>
<td>10.3</td>
<td>11.0</td>
<td>9.7</td>
</tr>
<tr>
<td>$T_{cs}, ^\circ C$</td>
<td>321</td>
<td>353</td>
<td>344</td>
<td>352</td>
<td>330</td>
<td>346</td>
<td>348</td>
<td>353</td>
</tr>
<tr>
<td>$T_{seal}, ^\circ C$</td>
<td>586</td>
<td>657</td>
<td>658</td>
<td>705</td>
<td>602</td>
<td>667</td>
<td>672</td>
<td>730</td>
</tr>
<tr>
<td>$T_{col}, ^\circ C$</td>
<td>624</td>
<td>764</td>
<td>724</td>
<td>850</td>
<td>577</td>
<td>683</td>
<td>668</td>
<td>720</td>
</tr>
<tr>
<td>$T_{rad}, ^\circ C$</td>
<td>540</td>
<td>625</td>
<td>622</td>
<td>680</td>
<td>533</td>
<td>605</td>
<td>612</td>
<td>657</td>
</tr>
</tbody>
</table>

Emitter W; $T_E = 1380^\circ, 1425^\circ, 1450^\circ C$
Collector Ni; $T_C = 580^\circ C$
Cesium gap 0.254 mm
Geometry 29 cm$^2$
Output 2.9 W/cm$^2$ at 8.6 percent efficiency, $T_E = 1380^\circ C$


Emitter W; $T_E = 1640$ to $1930$ K
Collector W; $T_C$ optimum
Cesium gap 0.5 mm; $T_R \approx T_C$ for Cs, C compound reservoir
Geometry plane
Output 1.8 W/cm$^2$ ($T_E = 1640$ K) to 4.1 W/cm$^2$ ($1930$ K)


Emitter single crystal 110 W; $T_E = 1800$ K
Collector Mo; $T_C = 981$ K
Cesium gap 0.2 mm; $T_R = 603$ K
Geometry plane; 4 cm$^2$
Output 5.3 W/cm$^2$ at 0.53 V

63. Gronroos, Henrik G.; Davis, Jerry P.; Weaver, Lynn E.; and Guppy, James G.: A Control System Study for an In-Core Thermionic Reactor, pp. 130-137.

Emitter W; $T_E = 1500$ to $2000$ K
Collector Mo; $T_C$ optimum
Cesium gap 0.254 mm; $T_R$ optimum
Output SIMCON performance plots; as shown in the following table:

<table>
<thead>
<tr>
<th>Emitter temperature, K</th>
<th>1500</th>
<th>1600</th>
<th>1700</th>
<th>1800</th>
<th>1900</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power maximum, W/cm$^2$</td>
<td>1.5</td>
<td>2.3</td>
<td>3.5</td>
<td>5.2</td>
<td>7.3</td>
<td>9.7</td>
</tr>
<tr>
<td>Efficiency maximums, percent</td>
<td>7.3</td>
<td>9.3</td>
<td>10.2</td>
<td>12.3</td>
<td>13.8</td>
<td>15.2</td>
</tr>
</tbody>
</table>

- Emitter: Re; $T_E = 1975, 2000$ K
- Collector: Mo; $T_C = 773$ to $1093$ K
- Cesium gap: 0.051 mm; $T_R = 583$ to $633$ K
- Geometry: plane; $2$ cm$^2$
- Output: average of 12 diodes $18.8$ W/cm$^2$ (17.5 to 20.3) at 0.7 V,
  $T_E = 2000$ K, $T_{C,ave} = 1045$ K, $T_{R,ave} = 630$ K

65. Merrill, O. S.: Correlation of Fixed-Spacing Thermionic Converter Performance with Variable-Spacing Test Vehicle Data, pp. 103-112.

- Emitter: Re (polycrystal or vapor-deposited); $T_E = 1600$ to $2100$ K
- Collector: Re (polycrystal or vapor-deposited); $T_C = 983$ to $993$ K and optimum
- Cesium gap: 0.080 to 0.305 mm; $T_R = 562$ to $604$ and optimum
- Geometry: seven plane diodes, $2$ cm$^2$; one cylindrical, $2$ cm$^2$
- Output: for 0.127 mm, maximums are $24$ W/cm$^2$ (0.69 V, $T_E = 2100$ K),
  $20$ W/cm$^2$ (0.60 V, $T_E = 2000$ K),
  $17$ W/cm$^2$ (0.52 V, $T_E = 1900$ K),
  $11.4$ W/cm$^2$ with 8.9 percent efficiency (0.41 V, $T_E = 1800$ K),
  $7$ W/cm$^2$ (0.28 V, $T_E = 1700$ K); good performance curves
- Lifetime: 11 600 hr for one diode at $27$ W/cm$^2$, 0.77 V, $2000$ K

66. Speidel, T. O.; and Williams, R. M.: Fixed-Space Planar Thermionic Diode with Collector Guard Ring, pp. 113-117.

- Emitter: Re; Ta; $T_E = 1505^0$ to $1680^0$ C
- Collector: Nb
- Cesium gap: 0.254 mm; $T_R$ optimum
- Geometry: plane, guarded; $1.82$ cm$^2$
- Output: not maximums but highest tested for each: $14.4$ W/cm$^2$ (Re, $1660^0$ C, 0.4 V), $4.2$ W/cm$^2$ (Ta, $1680^0$ C, 0.3 V)


- Emitter: $F^{-CVD}$ Re mechanically polished or etched; $T_E = 1875$ to $2075$ K
- Collector: Nb; $T_C = 973$ K for $T_E = 1900$ K and optimum
- Cesium gap: 0.254 mm; $T_R$ optimum
- Geometry: cylindric; 1.28-cm diameter, $15.2$ cm$^2$
for maximum electrode efficiencies from 1875 to 2075 K, 6.8 to 9.2 W/cm² with 12.6 to 14.6 percent efficiency for mechanically polished Re, 5.5 to 8.3 W/cm² with 11.4 to 13.6 percent efficiency for electroetched Re


Emitter vapor-deposited, electroetched Re; Tₑ = 1600 to 2050 K
Collector Nb; Tᶜ = 873 to 1173 K
Cesium gap 0.254 mm; Tᵣ optimum
Geometry cylindric; 1.27-cm diameter, 15.2 cm²
Output for maximum efficiency, 1.2 to 8.1 W/cm² with 5.2 to 13.4 percent efficiency; for maximum power, 1.4 to 8.8 W/cm² with 4.9 to 12.8 percent efficiency


Emitter etched Re; Tₑ = 1600⁰ and 1770⁰ C
Collector Mo (Mo, Nb data in comparison); Tᶜ optimum
Cesium gap 0.254 mm; Tᵣ optimum
Geometry cylindric; 1.905-cm diameter, 30 cm²
Output maximum power 3.8 to 9.8 W/cm², maximum efficiency 9.4 to 13.2 percent; results comparable with averages for six Re, Mo and three Re, Nb diodes having 0.178-mm gaps and 15-cm² emitters


Emitter Cl⁻CVD W (110); F⁻CVD W (100); etched F⁻CVD W (110);
Collector Nb; Tᶜ optimum
Cesium gap 0.203 mm; Tᵣ optimum
Geometry six plane diodes
Output as shown in the following table for polycrystalline 110 types at 10 A/cm²:

<table>
<thead>
<tr>
<th>Tₑ, K</th>
<th>W/cm²</th>
<th>1600</th>
<th>1700</th>
<th>1800</th>
<th>1900</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1.8 to 2.7</td>
<td>3.0 to 4.4</td>
<td>4.8 to 5.5</td>
<td>5.8 to 7.0</td>
<td>7.4 to 8.6</td>
</tr>
</tbody>
</table>
above 1800 K Cl\textsuperscript{−}CVD W gave 50 percent higher power densities than F\textsuperscript{−}CVD W; below 1700 K Cl\textsuperscript{−}CVD W performed better only at low output voltages; etching raised F\textsuperscript{−}CVD W outputs to those of Cl\textsuperscript{−}CVD W; good performance maps


| Emitter | Duplex W (Cl\textsuperscript{−}CVD on F\textsuperscript{−}CVD); T_E = 1600 to 1915 K |
| Collector | Mo; T_C = 900 and 950 K |
| Cesium gap | 0.013 to 1.016 mm; T_R's giving 0.5 to 11 torr |
| Geometry | plane, guarded |
| Output | excellent performance maps; for optimum spacings and cesium pressures at 10 A/cm\textsuperscript{2} output was as follows: |

| T_E, K | 1600 | 1700 | 1800 | 1900 |
| T_C, K | 900 | 900 | 950 | 950 |
| W/cm\textsuperscript{2} | 2.8 | 3.8 | 5.6 | 7.2 |


<p>| Emitter | F\textsuperscript{−}CVD W (100): (1) as-deposited, (2) etched as-deposited, (3) as-ground, (4) etched as-ground; T_E = 1800\degree C or less |
| Collector | Nb; T_C optimum |
| Cesium gap | 0.254 mm; T_R optimum |
| Geometry | 1.27-cm diameter, 15 cm\textsuperscript{2} |
| Output | as shown in the following table: |</p>
<table>
<thead>
<tr>
<th>Diode, ( \varphi ), eV</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 W input</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum efficiency, percent</td>
<td>7.7</td>
<td>9.3</td>
<td>7.8</td>
<td>9.0</td>
</tr>
<tr>
<td>Maximum power, W/cm(^2)</td>
<td>3.1</td>
<td>3.8</td>
<td>3.1</td>
<td>3.6</td>
</tr>
<tr>
<td>750 W input</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum efficiency, percent</td>
<td>8.9</td>
<td>10.2</td>
<td>9.3</td>
<td>9.7</td>
</tr>
<tr>
<td>Maximum power, W/cm(^2)</td>
<td>4.5</td>
<td>5.1</td>
<td>4.6</td>
<td>4.9</td>
</tr>
<tr>
<td>900 W input</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum efficiency, percent</td>
<td>9.8</td>
<td>11.0</td>
<td>10.1</td>
<td>10.2</td>
</tr>
<tr>
<td>Maximum power, W/cm(^2)</td>
<td>5.8</td>
<td>6.6</td>
<td>6.1</td>
<td>6.2</td>
</tr>
</tbody>
</table>

73. Shimada, K.: Side-Wall Currents in Unignited Hardware-Type Thermionic Energy Converters, pp. 155-158.

Emitter Re; \( T_E = 1700 \) to 2016 K
Geometry SET plane diode
Output side-wall-current theory agrees with test results

74. Stapfer, G.; and Shimada, K.: Electrical Testing of a Six-Converter Generator, pp. 159-163.

Emitter Re; \( T_E = 1600^\circ \) and 1700\(^\circ\) C
Collector Mo; \( T_C \) near optimum (radiation cooling)
Cesium gap \( T_R \) optimum
Geometry six SET plane diodes in a generator, 2 cm\(^2\) each
Output for the generator, 140 W at 3.0 V (4.0 V without lead losses), 4.5 percent efficiency, \( T_E = 1700^\circ \) C; 96 W at 3.0 V (3.75 V without lead losses), 4.5 percent efficiency (at 3.5 V), \( T_E = 1600^\circ \) C; averages for the diodes, 11.7 W/cm\(^2\) at 0.67 V, \( T_E = 1700^\circ \) C; 8 W/cm\(^2\) at 0.62 V, \( T_E = 1600^\circ \) C


Emitter \( T_E = 1800 \) K
Collector \( T_C \) optimum
Cesium gap 0.254 mm; $T_R$ optimum
Additive Ar, Xe
Output additions of inert gases only degrade diode performance; at 10 A/cm$^2$
40 torr of Ar caused a drop from 3.4 W/cm$^2$ to 2.4 W/cm$^2$


Emitter Re; $T_E = 1850$ K
Collector Mo probably
Output 18 W/cm$^2$


Emitter $T_E = 1600$ to 2000 K
Cesium gap 0.127 to 0.305 mm; $T_R = 548$ to 635 K
Output $I, V$ curves for high- and low-performance diodes used to show that above-optimum $T_R$'s insure against in-core thermal runaway

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1969.


Emitter 75 percent W, 25 percent Re; $T_E = 1800$, 2000 K
Collector 75 percent W, 25 percent Re; $T_C = 927$ to 1000 K
Cesium gap 0.003 to 0.762 mm; 0.254-mm fixed gap; $T_R = 588$ to 650 K
Geometry variable-parameter, plane, guarded diode; fixed-gap plane diode; cylindric diode; each 2 cm$^2$
Output 16 W/cm$^2$ at 0.5 to 0.6 V, $T_E = 2000$ K for fixed-gap plane diode;
18 W/cm$^2$ at 0.4 to 0.5 V, $T_E = 2000$ K for cylindric diode


Emitter 1-xtal 0001 Re; $T_E = 1600$ to 2000 K
Collector Nb; $T_C = 933$ K
Cesium gap 0.254 mm; $T_R = 507$ to 611 K
Geometry plane, guarded; 0.621 cm$^2$
Output maximum electrode power densities, 5.1 W/cm$^2$ at $T_E = 1600$ K to 15.4 W/cm$^2$ at $T_E = 2000$ K; at 10 A/cm, $T_C = 933$ K, $T_R$ optimum, power density was as follows:

<table>
<thead>
<tr>
<th>$T_E$, K</th>
<th>1600</th>
<th>1700</th>
<th>1800</th>
<th>1900</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/cm$^2$</td>
<td>3.6</td>
<td>5.2</td>
<td>6.7</td>
<td>7.8</td>
<td>9.3</td>
</tr>
</tbody>
</table>


Emitter F$^-$CVD W (100) etched to 110 faces (compared with polycrystalline W, 100 W, and 112 to 114 W); $T_E = 1650$ to 2150 K

Collector Nb; $T_C$ optimum

Cesium gap spacing optimum; $T_R$ optimum

Geometry plane, guarded

Output 4.2 W/cm$^2$ at 10 A/cm$^2$ and $T_E = 1650$ K to 13.9 W/cm$^2$ at 10 A/cm$^2$ and $T_E = 2150$ K

Lifetime 150 hr with no effect at 1980 K; surface changed after 22 hr at 2130 K


Emitter 110 W (several crystals with 110 faces within 4$^\circ$ of emitter surface); $T_E = 1600$ to 2000 K

Collector Nb; $T_C = 700$ to 1025 K

Cesium gap 0.013 to 1.016 mm; $T_R = 528$ to 653 K

Geometry plane, guarded

Output performance is better than that for a high-output Cl$^-$CVD W diode below 0.47 V at $T_E = 1700$ K and below 0.8 V at $T_E = 1900$ K; excellent performance maps; fully optimized at 10 A/cm$^2$; power as shown in the following table:

<table>
<thead>
<tr>
<th>$T_E$, K</th>
<th>1600</th>
<th>1700</th>
<th>1800</th>
<th>1900</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/cm$^2$</td>
<td>3.1</td>
<td>4.7</td>
<td>6.2</td>
<td>7.8</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Emitter: several orientations and surface preparations for W and for Re; W, 25 percent Re; Mo; Ta; \( T_E = 1650 \) to \( 2150 \) K
Collector: \( W + WO_2 \) on Nb; Mo; Nb; Ni; Re; \( T_C \) optimum
Cesium gap: 0.051 to 0.508 mm and optimum; \( T_R = 513 \) to \( 633 \) K and optimum
Geometry: plane
Output: excellent condensation and comparison of output results mostly for high-performance diodes


Emitter: single-crystal 110 W; \( T_E = 1550 \) to \( 1950 \) K
Collector: single-crystal 110 W; \( T_R \) = four temperatures around peak-power point
Cesium gap: 0.025 to 0.305 mm; \( T_R = 520 \) to \( 600 \) K
Geometry: plane, guarded; 1.02-cm diameter
Output: for 0.203 mm and \( T_R = 600 \) K maximums were 3 W/cm\(^2\) at 0.4 V, \( T_E = 1750 \) K; 3.8 W/cm\(^2\) at 0.4 V, \( T_E = 1850 \) K


Emitter: F\(^-\)CVD W (100); \( T_E = 1300^0 \) to \( 1650^0 \) C
Collector: Mo or Nb, 1 percent Zr; \( T_C \) optimum
Cesium gap: 0.20 to 0.25 mm; \( T_R \) optimum
Geometry: cylindric, 20 cm\(^2\)
Output: as shown in the following table (from ref. 84):
<table>
<thead>
<tr>
<th>Serial number</th>
<th>COL 130</th>
<th>COL 135</th>
<th>COL 134</th>
<th>COP 140</th>
<th>312</th>
<th>314</th>
<th>308</th>
<th>310</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitter</td>
<td>Mo/W, 60 μ</td>
<td>Mo</td>
<td>Mo/W, 85 μ</td>
<td>Mo/W, 150 μ</td>
<td>Mo/W, &gt;200 μ</td>
<td>W, 2 mm</td>
<td>Mo/W, &gt;200 μ</td>
<td>Mo/W, &gt;200 μ</td>
</tr>
<tr>
<td>Collector</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Mo</td>
<td>Nb, 1% Zr</td>
<td>Nb, 1% Zr</td>
<td>Nb, 1% Zr</td>
<td>Nb, 1% Zr</td>
</tr>
<tr>
<td>Cold spacing, μ</td>
<td>230</td>
<td>250</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>$p_e = 40$ W/cm², $T_e = 1470^0$ C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum total efficiency, percent</td>
<td>11.3</td>
<td>8.7, 15</td>
<td>10</td>
<td>11.8</td>
<td>9.3</td>
<td>9.5</td>
<td>8.5</td>
<td>8.2</td>
</tr>
<tr>
<td>Maximum output, W/cm²</td>
<td>4.5</td>
<td>3.45, 6</td>
<td>4</td>
<td>4.7</td>
<td>3.7</td>
<td>3.84</td>
<td>3.4</td>
<td>3.3</td>
</tr>
<tr>
<td>$p_e = 50$ W/cm², $T_e = 1600^0$ C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum total efficiency, percent</td>
<td>11.8</td>
<td>9.4, 16</td>
<td>11</td>
<td>14</td>
<td>10</td>
<td>9.6</td>
<td>9.9</td>
<td>10.3</td>
</tr>
<tr>
<td>Maximum output, W/cm²</td>
<td>5.9</td>
<td>4.7, 8</td>
<td>5.5</td>
<td>7</td>
<td>5</td>
<td>4.8</td>
<td>4.9</td>
<td>5.15</td>
</tr>
<tr>
<td>Life tests, hr</td>
<td>4600</td>
<td>1125</td>
<td>5256</td>
<td>1860</td>
<td>2400</td>
<td>1100</td>
<td>8500</td>
<td>5000</td>
</tr>
<tr>
<td>Cause of failure</td>
<td>S.C., W emitter peeling off and blistering</td>
<td>S.C., W emitter transport</td>
<td>S.C., W emitter had localized blisters</td>
<td>S.C., W emitter had localized blisters</td>
<td>S.C.</td>
<td>Cs leak at the E, C insulator</td>
<td>Still running</td>
<td>Voluntarily stopped</td>
</tr>
<tr>
<td>Remarks</td>
<td>Bad CVD condition ($WCl_6$), first S.C. at 3300 hr</td>
<td>High performance followed by rapid degradation</td>
<td>W transport material (emitter to collector)</td>
<td>W transport material (emitter to collector)</td>
<td>Under post-test examination</td>
<td>Under post-test examination</td>
<td>Water leak in environment</td>
<td></td>
</tr>
</tbody>
</table>

Emitter: F⁺CVD W (100); Tₑ = 1600 to 2000 K
Collector: Nb; T_c optimum
Cesium gap: 0.254 mm; T_r = 330° to 400° C
Geometry: 12 cylindric diodes, each 20 cm²
Output: as shown in the following table (with a 3.7 percent standard deviation):

<table>
<thead>
<tr>
<th>Tₑ, K</th>
<th>1760</th>
<th>1860</th>
<th>1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_max W/cm²</td>
<td>3.0</td>
<td>4.6</td>
<td>5.9</td>
</tr>
<tr>
<td>η_max percent</td>
<td>7.5</td>
<td>9.2</td>
<td>9.9</td>
</tr>
</tbody>
</table>


Emitter: Cl⁺CVD W (110); Tₑ ≈ 1700° C
Collector: Nb; T_c ≈ 700° C
Cesium gap: 0.254 mm; T_r = 340° to 372° C
Geometry: cylindric; 1.42-cm diameter, 11.0 cm²
Output: 7.4 W/cm² maximum at Tₑ = 1700° C, T_c = 700° C, T_r = 360° C; 9.5 W/cm² maximum at Tₑ = 1710° C, T_c = 710° C, T_r = 354° C after 5000 hr
Lifetime: removed after 5000 hr for examination


Emitter: Cl⁺CVD Re; Tₑ = 1573, 1673, 1800 K
Collector: Cl⁺CVD Re; T_c = 875 to 976 K and optimum
Cesium gap: 0.152 mm (2 cm²), 0.203 mm (4 cm²); T_r = 582 to 612 K and optimum
Geometry: cylindric; two with 2-cm² emitters, three with 4-cm² emitter
Output: 10.3 W/cm² at Tₑ = 1800 K for 2 cm²; 4.25 W/cm² at 1673 K for 4 cm²


Emitter: F⁺CVD W (100) on Mo (backed by enriched UO₂); Tₑ = 1560° C (out of core), 1601° C (in core)
Collector Nb, 1 percent Zr; \( T_C = 632^\circ C \) (out of core)
Cesium gap 0.2 mm; \( T_R \) optimum for Cs, C compound reservoir
Geometry cylindric; 20 cm
Output out of core, 5 W/cm\(^2\) at 10 percent efficiency; in core, 4.6 W/cm\(^2\) at 8.5 percent efficiency
Lifetime 4740 hr in 6-MW reactor \( (2 \times 10^{12} \text{ N/cm}^2) \), 3800 hr with no degradation; test terminated by emitter shortout


Emitter Mo (with and without UO\(_2\) backing); \( T_E = 1400^\circ \) to 1700\(^\circ \) C
Collector \( T_C = 600^\circ \) to 700\(^\circ \) C
Cesium gap \( T_R = 350^\circ \) to 370\(^\circ \) C and optimum
Output and lifetime in-core test: UO\(_2\) fueled emitter at 1400\(^\circ \) to 1500\(^\circ \) C, collector at 600\(^\circ \) to 700\(^\circ \) C, and reservoir at 350\(^\circ \) C gave 3.5 to 5 W/cm\(^2\) at 0.5 to 0.6 V for 3750 hr; out-of-core tests: as shown in the following table (from ref. 89):

<table>
<thead>
<tr>
<th>Diode</th>
<th>Emmitter material</th>
<th>Emitter dimensions, mm</th>
<th>Collector material</th>
<th>Metal, ceramic seal</th>
<th>Life time, hr</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sintered Mo</td>
<td>16 40</td>
<td>Sintered Mo</td>
<td>E2: Mo, Mn</td>
<td>300</td>
<td>Ceramic destroyed by cesium attack; shrinking of emitter diameter 0.1 mm</td>
</tr>
<tr>
<td>2</td>
<td>Sintered Mo</td>
<td>16 40</td>
<td>Sintered Mo</td>
<td>E2: Mo, Mn</td>
<td>300</td>
<td>Operated as vacuum diode; shrinking of emitter diameter 0.1 mm</td>
</tr>
<tr>
<td>3</td>
<td>Arc cast Mo</td>
<td>16 40</td>
<td>Sintered Mo</td>
<td>E37: Mo, Mn</td>
<td>100</td>
<td>Leak in metal, ceramic seal</td>
</tr>
<tr>
<td>4</td>
<td>Arc cast Mo</td>
<td>16 40</td>
<td>Sintered Mo</td>
<td>E37: Mo, Mn</td>
<td>&gt;16 000</td>
<td>Still operating</td>
</tr>
<tr>
<td>5</td>
<td>Arc cast Mo</td>
<td>20 54</td>
<td>Sintered Mo</td>
<td>E37: tungsten metallizing</td>
<td>&gt;7 000</td>
<td>Still operating; dimensions of electrodes as proposed for ITR</td>
</tr>
<tr>
<td>6</td>
<td>Arc cast Mo</td>
<td>16 40</td>
<td>Sintered Mo</td>
<td>E37: tungsten metallizing</td>
<td>&gt;4 000</td>
<td>Still operating; emitter fueled with UO(_2) powder</td>
</tr>
<tr>
<td>7</td>
<td>Arc cast Mo</td>
<td>20 54</td>
<td>Sintered Mo</td>
<td>E37: tungsten metallizing</td>
<td>&gt;4 000</td>
<td>Still operating; dimensions of electrodes and metal ceramic seal for ITR</td>
</tr>
</tbody>
</table>

Diode 4 to 5 W/cm\(^2\) at \( T_E \)'s from 1650\(^\circ \) to 1700\(^\circ \) C and \( T_R \) optimums from 360\(^\circ \) to 370\(^\circ \) C - except six in which "electrical output was high and the optimum cesium temperature was low," "attributed to excess oxygen diffusing through the emitter ..."

Valid for electrodes and metal, ceramic seal; cesium reservoir replaced after 3000 hr because of a leak.
90. Ernst, D. M.: Life Test Results from Cylindrical Diodes with Tungsten Emitters, pp. 146-149.

Emitter: F'CVD W (100) (1) as-deposited, (2) etched as-deposited, (3) as-ground, (4) etched as-ground
Collector: Nb; $T_C$ optimum
Cesium gap: 0.254 mm; $T_R$ optimum
Geometry: cylindric, 1.27-cm diameter, 15 cm$^2$
Output: for 50 W/cm$^2$ input and 8 A/cm$^2$: (1) 4.7 W/cm$^2$, (2) 5.1 W/cm$^2$, (3) 4.4 W/cm$^2$, (4) 4.5 W/cm$^2$; see ref. 72
Lifetime: (1) 6550 hr, (2) 6200 hr, (3) 5850 hr, (4) 5250 hr

91. Stapfer, Gerhard: Thermionic Converter Life-Test Program, pp. 150-156.

Emitter: Re; $T_E$ = 1800, 1900, 2000 K
Collector: Mo, Re; $T_C$ near optimum (radiation cooled)
Cesium gap: $T_R$ optimum
Geometry: 10 plane SET diodes
Output: as shown in the following table (from ref. 91):

<table>
<thead>
<tr>
<th>Converter</th>
<th>Design, $T_E$, K</th>
<th>Operating, $T_E$, K</th>
<th>Electrode material</th>
<th>Collector area, cm$^2$</th>
<th>Average, $P_{OUT}$, W/cm$^2$</th>
<th>$E_{OUT}$, V</th>
<th>Efficiency, percent</th>
<th>Thermal cycles</th>
<th>Operating time, hr</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>SN-101</td>
<td>2000</td>
<td>2000</td>
<td>Re, Re</td>
<td>1.88</td>
<td>25.0</td>
<td>0.7</td>
<td>10.0</td>
<td>195</td>
<td>20 700</td>
<td>Operating</td>
</tr>
<tr>
<td>SN-103</td>
<td>2000</td>
<td>2000</td>
<td>Re, Mo</td>
<td>1.88</td>
<td>21.0/10.0</td>
<td>0.7/0.5</td>
<td>9.0/5.5</td>
<td>15</td>
<td>7 168</td>
<td>Open circuit</td>
</tr>
<tr>
<td>SN-108</td>
<td>1900</td>
<td>2000</td>
<td>Re, Re</td>
<td>1.88</td>
<td>18.0</td>
<td>.7</td>
<td>7.7</td>
<td>0</td>
<td>1 247</td>
<td>Open circuit</td>
</tr>
<tr>
<td>T-VII-7</td>
<td>2000</td>
<td>2000</td>
<td>Re, Mo</td>
<td>2.0</td>
<td>17.0</td>
<td>.7</td>
<td>7.5</td>
<td>10</td>
<td>8 326</td>
<td>Operating</td>
</tr>
<tr>
<td>T-VII-12</td>
<td>2000</td>
<td>2000</td>
<td>Re, Mo</td>
<td>2.0</td>
<td>17.0</td>
<td>.7</td>
<td>7.5</td>
<td>9</td>
<td>6 421</td>
<td>Operating</td>
</tr>
<tr>
<td>T-VII-16</td>
<td>2000</td>
<td>2000</td>
<td>Re, Mo</td>
<td>2.0</td>
<td>16.0</td>
<td>.7</td>
<td>7.0</td>
<td>14</td>
<td>8 100</td>
<td>Operating</td>
</tr>
<tr>
<td>TE-206</td>
<td>2000</td>
<td>2000</td>
<td>Re, Re</td>
<td>2.0</td>
<td>7.0</td>
<td>.7</td>
<td>4.0</td>
<td>7</td>
<td>11 470</td>
<td>Operating</td>
</tr>
<tr>
<td>VIII-S-23</td>
<td>2000</td>
<td>1800</td>
<td>Re, Mo</td>
<td>2.0</td>
<td>12.1</td>
<td>.7</td>
<td>6.9</td>
<td>2</td>
<td>740</td>
<td>Discontinued</td>
</tr>
<tr>
<td>VIII-S-20</td>
<td>2000</td>
<td>1800</td>
<td>Re, Mo</td>
<td>2.0</td>
<td>6.6</td>
<td>.7</td>
<td>5.0</td>
<td>2</td>
<td>2 944</td>
<td>Discontinued</td>
</tr>
<tr>
<td>VIII-S-9</td>
<td>2000</td>
<td>1900</td>
<td>Re, Mo</td>
<td>2.0</td>
<td>9.8</td>
<td>.7</td>
<td>5.5</td>
<td>8</td>
<td>1 200</td>
<td>Discontinued</td>
</tr>
</tbody>
</table>

Emitter Mo; $T_E = 1500$ to $1750$ K
Collector Mo; $T_C = 873$ to $1063$ K
Cesium gap 0.254 mm; $T_R = 515$ to $555$ K
Geometry cylindric; 1.27-mm diameter, $15.2 \text{ cm}^2$
Output as shown in the following table (from ref. 92):

**DIODE OUTPUT FOR MAXIMUM EFFICIENCY AND MAXIMUM POWER DENSITY CONDITIONS**

<table>
<thead>
<tr>
<th>Emitter temperature, K</th>
<th>At maximum efficiency</th>
<th>At maximum power density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electrode efficiency, percent</td>
<td>Electrode voltage, V</td>
</tr>
<tr>
<td>1500</td>
<td>2.1</td>
<td>0.12</td>
</tr>
<tr>
<td>1600</td>
<td>5.3</td>
<td>0.26</td>
</tr>
<tr>
<td>1750</td>
<td>8.4</td>
<td>0.46</td>
</tr>
</tbody>
</table>


Emitter polycrystalline W; $T_E = 1640$ to $1950$ K
Collector polycrystalline Mo; $T_C = 840$ to $910$ K
Cesium gap 0.152 to 0.508 mm; $T_R = 571$ to $635$ K
Geometry plane
Output SIMCON correlation and performance maps


Emitter Cl$^-$CVD W (110) (on F$^-$CVD W (100)); $T_E = 1800$, 1500, $\gg 1300$ K
Collector Mo; $T_C = 605$ to $1022$ K
Cesium gap 0.013 to 0.635 mm; $T_R = 461$ to $620$ K
Geometry plane, guarded
Output study of collector effects on diode voltage (work function) and current (back emission) indicates that present theories are not adequate

Emitter: Re; $T_E = 1850° C$ maximum, $1800° C$ average
Collector: Mo; $T_C = 700° C$
Geometry: four cylindric diodes, each $30 \text{ cm}^2$
Output: nominally $8.4 \text{ W/cm}^2$ at $0.6 \text{ V}$ and $12\%$ efficiency


Emitter: CVD W; $T_E = 1370°$ to $1790° C$
Collector: Mo; $T_C$ optimum
Cesium gap: $0.2 \text{ mm}$; $T_R$ from Cs, C reservoir coupled to collector ($T_C$ optimums occur within $50° C$ around $700° C$)
Geometry: cylindric
Output: over $10\%$ efficiency
Lifetime: $1000 \text{ hr}$ and continuing

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1970.


Emitter: PVD W (110) (on F$^-$CVD W (100)); $T_E = (1) 1700 \text{ K}$, (2) $1800 \text{ K}$, (3) $1900 \text{ K}$
Collector: Nb; $T_C$ optimum
Cesium gap: $0.254 \text{ mm}$; $T_R$ optimum
Geometry: plane
Output: at $10 \text{ A/cm}^2$ (1) $4.3 \text{ W/cm}^2$, (2) $5.7 \text{ W/cm}^2$, (3) $7.0 \text{ W/cm}^2$, which equal outputs for single-crystal 110 W


Emitter: Mo; "Mo-based alloy"; "W-based alloy"; "W, Re"; $T_E = 1300°$ to $1700° C$
Collector: Nb; $T_C = 600°$ to $700° C$
Cesium gap: $0.4$ to $0.5 \text{ mm}$; $2$ to $19 \text{ torr}$
Geometry: multielement assemblies; five or six axially alined diodes with cylindric emitters, each having a plane active end
Output and lifetime as shown in the following table (from ref. 98):
<table>
<thead>
<tr>
<th>Converter number</th>
<th>Number of elements</th>
<th>Cathode can material</th>
<th>Cathode temperature, °C</th>
<th>Electric power density, W/cm²</th>
<th>Time of in-pile experiment, hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIC-21</td>
<td>5</td>
<td>Molybdenum-based alloy</td>
<td>1600</td>
<td>a1.8 to 2.2</td>
<td>2750 b(2200)</td>
</tr>
<tr>
<td>TIC-28</td>
<td>5</td>
<td>Molybdenum monocrystal</td>
<td>1600</td>
<td>2.7</td>
<td>1400 b(1100)</td>
</tr>
<tr>
<td>TIC-20</td>
<td>5</td>
<td>Tungsten-based alloy</td>
<td>1850 to 1900</td>
<td>7.8</td>
<td>900 b(650)</td>
</tr>
<tr>
<td>ES-6-1</td>
<td>6</td>
<td>Tungsten, rhenium</td>
<td>1850</td>
<td>6 to 7</td>
<td>75</td>
</tr>
<tr>
<td>ES-6-2</td>
<td>6</td>
<td>Tungsten, rhenium</td>
<td>1950</td>
<td>10</td>
<td>220</td>
</tr>
</tbody>
</table>

*Efficiency, 9+ percent.

*Time of maximum electric-power operation.


Emitter  \( T_E = 575 \text{ to } 1800 \text{ K} \)

Collector  \( \text{Mo; Nb; } T_C = 670 \text{ to } 775 \text{ K, } T_C/T_R = 1.1 \text{ to } 2.5 \)

Cesium gap 0.013 to 1.016 mm; \( T_R = 428 \text{ to } 516 \text{ K, } T_R/T_C = 0.4 \text{ to } 0.91 \)

Output collector effects on diode performance (see ref. 94); present theories still fail to predict collector influences on outputs


Emitter single-crystal 110 Mo; \( T_E = 1600, 1682 \text{ K} \)

Collector single-crystal 110 Mo; \( T_C = 850 \text{ K} \)

Cesium gap 0.127 to 1.27 mm; \( T_R = 500 \text{ to } 580 \text{ K} \)

Geometry plane, guarded

Output 1.7 W/cm² at 0.65 V, \( T_E = 1682 \text{ K, } T_C = 850 \text{ K, } T_R = 548 \text{ K} \)


Emitter Re; \( T_E = 1573 \text{ to } 1773 \text{ K} \)

Collector Nb; \( T_C = 951 \text{ K for } 0.5 \text{ V} \)

Cesium gap 0.762 mm (hot); \( T_R = 594 \text{ to } 595 \text{ K for } 0.5 \text{ V} \)

Geometry cylindric; 4 cm²

Output at 1673 K design point 3.5 to 4.4 W/cm² at 0.5 V, 4.2 to 4.6 W/cm² at 0.4 V; at 10 A/cm² outputs were as follows:
<table>
<thead>
<tr>
<th>T_E, K</th>
<th>1573</th>
<th>1673</th>
<th>1713</th>
<th>1773</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/cm²</td>
<td>3.3</td>
<td>4.2</td>
<td>4.8</td>
<td>5.2</td>
</tr>
</tbody>
</table>


Emitter 110, Cl⁻CVD (110); F⁻CVD (100) W; T_E = 1600 to 1850 K
Collector Nb; T_C = 760 to 930 K
Cesium gap 0.054 to 0.508 mm; T_R = 530 to 660 K
Geometry plane, guarded; 2 cm²
Output apparent lower-mode saturation currents (at or near ignition); limited by electronic space charge and by collisions; used to determine emitter temperatures (for in-core diodes)


Emitter Re; T_E = 1300° to 1700° C
Collector Nb; T_R not optimum
Cesium gap 0.254 mm; T_R = 293° C (near optimum initially)
Geometry cylindric; 1.9-cm diameter, 5.08 cm long
Output 3.3 W/cm² at 0.5 V, T_E = 1700° C (not optimum, used for kinetics input to reactor simulator)


Emitter F⁻CVD W (100) (compared with Cl⁻CVD W (110), Mo; single-crystal 110 W, Nb; or single-crystal-110 W, Mo, O₂ diode); T_E = 1600 to 2000 K
Collector Nb (Mo or Nb); T_C = 670 to 1010 K
Cesium gap 0.013 to 1.03 mm; T_R = 480 to 655 K
Additive O₂ in the single-crystal 110 W, Mo diode
Geometry plane, guarded; 2 cm²
Output I, V performance maps for F⁻CVD-W, Nb diode; at T_E = 1800 K, 0.254 mm spacing, 10 A/cm² output was as follows:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>W/cm²</td>
<td>2.7</td>
<td>4.8</td>
<td>5.8</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Emitter: Cl²CVD W (110); F⁻CVD W (100); single-crystal 110 W;  
\[ T_E = 1600 \text{ to } 2000 \text{ K} \]
Collector: Mo (polycrystalline or PVD (110)) or Nb;  
\[ T_C = 970 \text{ to } 1023 \text{ K} \]
Cesium gap: 0.025 to 2.032 mm;  
\[ T_R = 539 \text{ to } 653 \text{ K} \]
Additive: \( O_2 \) in single-crystal 110 W, Mo diode
Output: good I, V curves for Cl²CVD W, Nb; from 1700 to 1900 K with  
0.254 mm spacing and 10 A/cm² output was as follows:

<table>
<thead>
<tr>
<th>Diode</th>
<th>1-xtal-110 W, Mo, ( O_2 )</th>
<th>1-xtal-110 W, Nb</th>
<th>Cl²CVD W, Mo</th>
<th>F⁻CVD W, Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/cm²</td>
<td>5.8 to 9.0</td>
<td>4.5 to 7.0</td>
<td>4.0 to 6.3</td>
<td>1.7 to 3.7</td>
</tr>
</tbody>
</table>


Emitter: Electroetched F⁻CVD W (110) (compared with both Cl²CVD (110) and F⁻CVD (100) W);  
\[ T_E = 1400^\circ, 1500^\circ, 1700^\circ \text{ C} \]
Collector: Nb;  
\[ T_C = 600^\circ, 800^\circ, 950^\circ, 1000^\circ \text{ C} \]
Cesium gap: 0.3 mm;  
\[ T_R = 320^\circ \text{ to } 377^\circ \text{ C} \]
Geometry: cylindric; 1.41-cm diameter, 11 cm²
Output: 3.2 to 7.6 W/cm² for 1400°C to 1700°C with  
\( T_R \) optimum and  
\( T_C \) near optimum at 10 A/cm²; performance curves and comparisons;  
electroetched F⁻CVD W (110) gave outputs comparable with those for Cl²CVD W (110)
Lifetime: output was stable for 5000 hr at 1700°C


Emitter: etched Re;  
\[ T_E = 1550 \text{ to } 2050 \text{ K} \]
Collector: Nb;  
\[ T_C = 750 \text{ to } 1180 \text{ K} \]
Cesium gap: 0.254 mm;  
\[ T_R = 525 \text{ to } 650 \text{ K} \]
Geometry: plane, guarded
Output: maximum efficiencies, 7.3 to 16 percent from 1600 to 2000 K; at  
10 A/cm² with  
\( T_C \) and  
\( T_R \) optimum output was as follows:
<table>
<thead>
<tr>
<th>$T_E$, K</th>
<th>1600</th>
<th>1700</th>
<th>1800</th>
<th>1900</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/cm²</td>
<td>2.1</td>
<td>4.1</td>
<td>5.7</td>
<td>7.8</td>
<td>9.1</td>
</tr>
</tbody>
</table>


Emitter Cl⁻CVD W (110); $T_E = 1600$ to 1900 K
Collector PVD Mo (110); $T_C = 292°$ to 640° C
Cesium gap 0.254 mm; $T_R = 245°$ to 305° C
Geometry five cylindric diodes, each 1.9-cm diameter and 20 cm²
Output at 10 A/cm² with $T_C$ and $T_R$ optimum output was as follows:

<table>
<thead>
<tr>
<th>$T_E$, K</th>
<th>1600</th>
<th>1700</th>
<th>1800</th>
<th>1900</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/cm²</td>
<td>3.2</td>
<td>5.3</td>
<td>7.4</td>
<td>9.2</td>
</tr>
</tbody>
</table>

this high performance was stable through 100 hr of initial testing


Emitter (1) Cl⁻CVD W (110) (standard Cs reservoir), (2) F⁻CVD W (100) (graphite, Cs reservoir); (1) $T_E = 1700°$ C, (2) $T_C = 1760°$ C
Collector Nb; (1) $T_C = 799°$ C, (2) 701° C
Cesium gap (1) 0.229 mm, (2) 0.203 mm; (1) $T_R = 352°$ C, (2) 814° C (C, Cs reservoir)
Geometry cylindric (1) 2.54 cm long, 16.1 cm²; (2) cylindric, 5.08 cm long, 26.7 cm²
Output (1) 8.0 W/cm² at 14 percent efficiency, (2) 6.8 W/cm² at 12 percent efficiency


Emitter W (apparently)
Collector Mo (apparently); $T_C ≈ 650$ K
Cesium gap 0.2 mm (apparently); $T_R$ near $T_C$ for Cs, C reservoir
Output maximum experimental value, 6.2 W/cm²

- **Emitter**: polycrystalline W; \( T_E = 1800, 1900, 1950 \) K
- **Collector**: Ta; \( T_C = 920 \) to 1120 K
- **Cesium gap**: 0.1 to 2.5 mm; \( T_R = 390 \) to 473 K, \( P_{Cs} = 0 \)
- **Additive**: Ba; \( T_{Ba} = 900 \) to 1100 K
- **Geometry**: plane
- **Output**: several I, V figures; at \( T_E = 1900 \) K, \( T_C = 1120 \) K, \( T_{Ba} = 1100 \) K, \( T_{Cs} = 473 \) K maximum outputs occurred at 0.1 mm spacing; for these conditions, \( 8.5 \) W/cm\(^2\) at 13 A/cm\(^2\) was approximate maximum


- **Emitter**: W (backed with enriched UO\(_2\)); \( T_E \approx 1900 \) to 2100 K
- **Collector**: Nb; \( T_C \) optimum
- **Cesium gap**: 0.254 mm; \( T_R \) optimum
- **Additive**: U and O possible
- **Geometry**: cylindric; 1.27-cm diameter, 20.32 cm long
- **Output**: 7.1 W/cm\(^2\) (9.8 A/cm\(^2\)) at 11.5 percent efficiency with \( T_E = 1940 \) K, \( T_R = 531 \) K


- **Emitter**: F\(^-\)CVD W (100); \( T_E = 1800 \) to 2070 K
- **Collector**: Mo; \( T_C = 675^0 \) to 845\(^0\) C
- **Cesium gap**: 0.254 mm; \( T_R = 290^0 \) to 333\(^0\) C
- **Geometry**: cylindric; 1.14-cm diameter, 84 cm\(^2\)
- **Output**: 4.1 to 6.2 W/cm\(^2\) at 6 A/cm\(^2\), \( T_E = 1900 \) to 2070 K

114. Teagan, W. Peter.: The Development of Thermionic Diodes for Isotope-Fueled Generators, pp. 539-545.

- **Emitter**: etched Re (compared with 0001 Re with and without O\(_2\)); \( T_E = 1600^0\) C
- **Collector**: Mo; \( T_C = 600^0\) C
- **Cesium gap**: 0.127 mm; \( T_R \) optimum
- **Additive**: O\(_2\) with 0001 Re
- **Geometry**: plane; 13.3 cm\(^2\)
Output

4.5 W/cm² (0.9 V) to 9.6 W/cm² (0.4 V); maximum electrode efficiency of 15 percent with 7.9 W/cm² at 0.7 V (0001 Re at 1900 K with T_R optimum and 0.254-mm spacing produced 11.9 W/cm² and with O₂ 17.5 W/cm² both at 0.7 V, 8.8 W/cm² and with O₂ 10.3 W/cm² both at 10 A/cm²)

Lifetime 3000 hr at maximum-electrode-efficiency point with no change


Emitter Cl^−CVD Re; T_E = 1600 to 1700 K
Collector Nb, 1 percent Zr
Cesium gap 0.229 mm
Geometry cylindric; 10.16 cm long, 73.7 cm²
Output better than that for a polycrystalline-Re, Nb diode


Emitter CVD W; T_E = 1820 K
Collector Mo; T_C = 840 K
Cesium gap 0.2 mm; T_R = 575 K
Geometry cylindric; 20 cm²
Output 7.5 W/cm² at 12.5 percent efficiency
Lifetime Emitter, collector short circuit after 9000 hr. "In any case, the failure was accelerated by material transport from the emitter to the molybdenum collector. This may be avoided by using converters with Nb, 1 percent Zr collectors gettering O₂ present in the interelectrode spacing."

Conference Record of the Thermionic Conversion Specialist Conference. IEEE. 1971.


Emitter Cl^−CVD W (110); T_E = 1500°, 1600° C
Collector Nb; T_C optimum
Cesium gap T_R optimum
Additive U and O or C possible
Geometry cylindric TFE's
Output as shown in the following table (from ref. 117):
## TFE TEST HISTORY

<table>
<thead>
<tr>
<th>Emitter</th>
<th>Collector</th>
<th>Fuel</th>
<th>Number of cells</th>
<th>Test duration, hr</th>
<th>Average electrode power density, W/cm²</th>
<th>Average emitter temperature, °C</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFE 2E1</td>
<td>W (110)</td>
<td>Nb</td>
<td>2</td>
<td>a9700</td>
<td>1600</td>
<td></td>
<td>(a)</td>
</tr>
<tr>
<td>TFE 2E2</td>
<td>W (110)</td>
<td>Nb</td>
<td>2</td>
<td>a200</td>
<td>1600</td>
<td></td>
<td>(a)</td>
</tr>
<tr>
<td>TFE 2E3</td>
<td>W (110)</td>
<td>Nb</td>
<td>2</td>
<td>3661</td>
<td>1500</td>
<td></td>
<td>(a)</td>
</tr>
<tr>
<td>TFE 6F1</td>
<td>W (110)</td>
<td>Nb</td>
<td>1</td>
<td>a1000</td>
<td>1500</td>
<td></td>
<td>(a)</td>
</tr>
<tr>
<td>TFE 1F1</td>
<td>W (110)</td>
<td>Nb</td>
<td>1</td>
<td>1200</td>
<td>1500</td>
<td></td>
<td>(a)</td>
</tr>
<tr>
<td>TFE 1F2</td>
<td>W (110)</td>
<td>Nb</td>
<td>1</td>
<td>1200</td>
<td>1500</td>
<td></td>
<td>(a)</td>
</tr>
</tbody>
</table>

Still in operation 9/71.


Emitter \( F^-CVD \) W (100); \( T_E = 1638 \) to 1942 K
Collector Mo; \( T_C = 885 \) to 945 K
Cesium gap \( T_R = 565 \) to 633 K
Geometry cylindric; 1.14-cm diameter, 91.2 cm²
Output 1.95 W/cm² with 5.5 percent efficiency at \( T_E = 1942 \) K, \( T_C = 900 \) K, \( T_R = 633 \) K


Emitter W, 2 percent ThO₂ (enriched UO₂ backed in core, not here); \( T_E = 1650^\circ \) to 1700°C
Collector \( T_C \) optimum
Cesium gap 0.254 mm; \( T_R = 380 \) to 540 K
Additive Th and O
Geometry cylindric; 20.3 cm long, 74.7 cm²
Output 7.1 W/cm² with 11.5 percent efficiency out of core at \( T_E = 1940 \) K, \( T_R = 531 \) K
Lifetime removed after 1100 hr


Emitter Mo; \( T_E = 1870 \) to 2000 K
Collector Mo; \( T_C = 950^\circ \) to 1150°C
Cesium gap 0.05 to 2.0 mm; \( T_R = 120^\circ \) to 300°C
Additive Ba; $T_Ba = 450$ to 950 K

Geometry plane, guarded

Output maximum indicated, 6 W/cm$^2$ at 1.0 V, 0.1 mm spacing,

$T_E = 2000$ K, $T_C = 1220$ K, $T_Ba = 950$ K, $T_R = 450$ K


Emitter Cl$^{-}$TVDW (110) (thermally vapor-deposited); $T_E = 1673, 1865, 2057$ K

Collector polycrystalline W; Nb; Ni; $T_C = 858$ to 1073 K and optimum

Cesium gap 0.051 to 0.508 mm; $T_R = 348$ to 453 K and optimum

Geometry plane, guarded

Output good performance comparison; at 10 A/cm$^2$, $T_C$ and $T_R$ optimum the output was as follows:

<table>
<thead>
<tr>
<th>Collector</th>
<th>$T_E$, K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1673</td>
</tr>
<tr>
<td></td>
<td>Volts</td>
</tr>
<tr>
<td>Nb</td>
<td>0.39</td>
</tr>
<tr>
<td>W</td>
<td>.45</td>
</tr>
<tr>
<td>Ni</td>
<td>.41</td>
</tr>
</tbody>
</table>


Emitter etched Re; Cl$^{-}$CVD W (110); PVD W; $T_E = 1500$ to 2000 K

Collector Mo; Nb; $T_C = 750$ to 1100 K

Cesium gap 0.254 mm; $T_R = 520$ to 650 K

Geometry plane, guarded

Output voltages at 10 A/cm$^2$ with $T_R$ and $T_C$ optimum were as follows:

<table>
<thead>
<tr>
<th>Diode</th>
<th>$T_E$, K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1700</td>
</tr>
<tr>
<td></td>
<td>Voltage, V</td>
</tr>
<tr>
<td>Re, Nb</td>
<td>0.43</td>
</tr>
<tr>
<td>CVD-W, Nb</td>
<td>.35</td>
</tr>
<tr>
<td>Re, Mo</td>
<td>.33</td>
</tr>
<tr>
<td>PVD-W, Nb</td>
<td>.30</td>
</tr>
</tbody>
</table>

Emitter: Cl^-CVD W (110); $T_E = 1600$ to $2000$ K
Collector: PVD Mo; Nb; W; single-crystal 110 W; $T_C = 620$ to $1020$ K
Cesium gap: 0.127 to 1.016 mm; $T_R = 517$ to $647$ K
Additive: special care to minimize $O_2$ effects
Geometry: plane, guarded
Output: 5.1 to 7.8 W/cm^2 with single-crystal-110-W collector and approximately 3.9 to 6.2 W/cm^2 with each of the other collectors, all for 0.254 mm spacing, 10 A/cm^2, $T_E = 1700$ to $1900$ K; excellent performance maps


Emitter: PVD W (compared with Cl^-CVD W and F^-CVD W); $T_E = 1600$ to 1900 K
Collector: PVD Mo (with MoO_2 and MoO_3)
Cesium gap: 0.508 mm; $T_R = 250^\circ$ to $300^\circ$ C
Additive: O with PVD-Mo collector
Geometry: cylindric, cup-shaped; 37 cm^2
Output: outputs limited to 7 A/cm^2 by test facility; at 6 A/cm^2, 0.508 mm spacing, $T_E = 1600$ to $1900$ K the output was as follows:

<table>
<thead>
<tr>
<th>Diode</th>
<th>W/cm^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVD-W, PVD-Mo</td>
<td>2.3 to 6.2</td>
</tr>
<tr>
<td>Cl^-CVD-W, Nb</td>
<td>2.1 to 3.8</td>
</tr>
<tr>
<td>F^-CVD-W, Nb</td>
<td>0.6 to 2.1</td>
</tr>
</tbody>
</table>


Emitter: etched Re (with and without UO_2 backing); $T_E = 1700$ to $2000$ K
Collector: PVD Mo; $T_C$ optimum (until heater failed)
Cesium gap: 0.203 mm; $T_R$ optimum
Additive: U and O (both definitely diffused through the emitter at 1900 to 2000 K)
Geometry cylindric, 1.27-cm diameter, 15.2 cm²
Output 6.5 W/cm² at 0.9 V with 11 percent efficiency for fueled diode, which was quite inferior to nonfueled one
Lifetime during 2400 hr at 2000 K fueled diode lost 15 percent in output current; nonfueled one showed no change after 4000 hr


Emitter Re; W (each UN backed); $T_E = 1660$ to 2000 K
Collector Nb; $T_C = 806, 840$ K, optimum
Cesium gap 0.25 mm; $T_R = 555$ to 622 K and optimum
Additive U and N possible
Geometry plane; 1.82 cm²
Output at 10 A/cm² the output was as follows:

<table>
<thead>
<tr>
<th>Emitter</th>
<th>$T_E$, K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re</td>
<td>1800</td>
</tr>
<tr>
<td>W</td>
<td>2000</td>
</tr>
<tr>
<td>W</td>
<td>$5.7$</td>
</tr>
<tr>
<td>W</td>
<td>8.0</td>
</tr>
<tr>
<td>W</td>
<td>1.2</td>
</tr>
<tr>
<td>W</td>
<td>3.2</td>
</tr>
</tbody>
</table>


Emitter Mo; $T_E = 1550$ to 2000 K
Collector Nb, 1 percent Zr; $T_C = 750$ to 1020 K
Cesium gap 0.16 mm; $T_R = 580$ to 670 K
Geometry cylindric; 2-cm diameter, 34 cm²
Output optimums from 1550 to 2000 K, 0.8 to 6.5 W/cm²; 3.4 to 12 percent efficiencies


Emitter CVD W; $T_E = 1890$ K
Collector Mo
Cesium gap 0.013 to 0.508 mm; 4 torr
Geometry plane
Output performance characteristics of an Ar diode (mixed-oxide emitter, Cu collector) contribute to understanding Cs counterparts

Emitter: Cl-CVD W (110); $T_E = 1600$ to 2200 K
Collector: Nb; $T_C = 800$ to 1200 K
Cesium gap: 0.254 to 0.381 mm; $T_R = 540$ to 653 K
Geometry: based on data from a plane, guarded diode
Output: SIMCON correlation of V. C. Wilson results; for 10 A/cm$^2$ and 0.254 mm spacing the output was as follows:

<table>
<thead>
<tr>
<th>$T_E$, K</th>
<th>1651</th>
<th>1843</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_C$, K</td>
<td>948</td>
<td>998</td>
<td>1073</td>
</tr>
<tr>
<td>$T_R$, K</td>
<td>573</td>
<td>600</td>
<td>625</td>
</tr>
<tr>
<td>W/cm$^2$</td>
<td>4.0</td>
<td>7.0</td>
<td>9.5</td>
</tr>
</tbody>
</table>

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 16, 1972,
503-25.
"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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