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ENERGY-CONVERSION RESEARCH AND DEVELOPMENT WITH DIMINIODES

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ABSTRACT

Diminiodes are variable-gap cesium diodes with plane miniature guarded electrodes. These converters allow thermionic evaluations of tiny pieces of rare solids. In addition to smallness, diminiode advantages comprise simplicity, precision, fabrication ease, parts interchangeability, cleanliness, full instrumentation, direct calibration, ruggedness, and economy. Diminiodes with computerized thermionic-performance mapping make electrode screening programs practical.

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SUMMARY

Diminiodes are variable-gap cesium diodes with plane emitters and guarded collectors a few millimeters in diameter. This miniaturization allows the electrodes to be made of little pieces of rare materials like single crystals of unusual metals or metallides. In addition to smallness, diminiode advantages include simplicity, precision, fabrication ease, parts interchangeability, cleanliness, full instrumentation, ruggedness, and economy. And processing of the assembled diminiode is efficient: The high-temperature bake-out, calibration, cesium filling, and brazed closure all occur in the same vacuum chamber with only one pumpdown. Calibrations of the emitter-surface temperature and the electrode spacing result from direct internal measurements made while heating the diminiode components over their operating thermal ranges. This procedure eliminates two major measurement doubts in thermionic diode testing. Furthermore, the temperatures are uniform over the guarded electrode surfaces to within pyrometric sensing limits.

The diminiode design also stresses effective, economical use with computers that control, collect, and correlate thermionic current, voltage data. Such diminiode tests completed recently for ultrapure metal electrodes produced relatively low, sharply defined ultimate power outputs. The results follow the often-predicted trends for greater precision, cleanliness, and definition in the active components of cesium diodes. These characteristics verify the value of the diminiode for screening and performance mapping high-efficiency, low-temperature thermionic energy converters.

TRENDS IN THERMIONIC RESEARCH AND DEVELOPMENT

Thermionic energy conversion must produce more intense power at less rigorous operating conditions. This means greater current densities at lower emitter temperatures and higher output voltages from better collectors and smaller plasma losses. Such improvements will allow more applications, wider design margins, and possible benefits for other technologies like MHD energy conversion (ref. 1). So a program to screen promising thermionic electrodes and to reduce plasma generation voltages in cesium diodes is necessary.

Traditional research methods militated against extensive thermionic-performance testing. But computer techniques now enable rapid, effective processing of cesium-diode data (refs. 2 to 13). A further facilitation of thermionic screening is the diminiode (fig. 1 and refs. 11 to 14). This converter basically comprises two (di) miniature (mini) electrodes (ode), each of which can come from considerably less than 0.1 cc of a rare material. Relative to conventional research diodes, the diminiode is small, simple, easy to machine and assemble, rugged, interchangeable, reusable, and economical. The design also stresses accurate instrumentation, direct calibration at operating conditions, and clean, efficient processing (refs. 13 to 15).

Used with a computer system for data acquisition, diminiodes increase the quantity, economy, and quality of thermionic performance maps.

THE DIMINIODE

The diminiode (fig. 1(a)) has a cylindric base composed of three concentric niobium, 1-percent-zirconium conductors bonded together with insulating annuli of sintered aluminum-oxide-coated niobium particles. This rugged lamination eliminates fragile metal-to-ceramic seals; provides low-resistance electrode leads; maintains collector, guard temperature uniformity; and serves as a precise, solid support for the diminiode.

A low-vapor-pressure brazing filler (refs. 13 and 16) holds the collector and guard on diminiode base. These two electrodes are one disc during the braze and intensive lapping procedures. After nearly complete polishing an electric-discharge cooky-cut separates the collector and guard with a circular gap approximately 0.07 millimeter wide. Then a final brief lapping produces surfaces smooth to 0.01 micron and flat except a 0.1-micron curvature at the collector edge (ref. 13). After thorough cleaning and bake-outs these electrodes faces with identical compositions, orientations, processing, and potentials act essentially as one: The 0.460-centimeter collector operates virtually without edge effects because of the guard ring, which has centimeter diameters of 0.475 inside and 0.635 outside.

The last dimension corresponds to the diameter of the emitter, which another low-vapor-pressure brazing filler (refs. 13 and 16) joins to the tantalum electron-bombardment target. This top piece in turn rests on a standard 1.905-centimeter tantalum tube attached to the base through electron-beam welds of precisely machined shoulders for alinement. On the side wall a standard 0.635-centimeter tantalum tube enables internal degassing and pyrometry until the cesium addition and brazed closure. Then it serves as a high-conductance cesium reservoir opening directly on interelectrode gap.

Thermal-control lines on the reservoir and base ground the electron-bombardment target and function as emitter leads. Electric taps for the collector and the guard are the center and seconds steps at the bottom of the diminiode base.

For electrode-spacing variation a simple diaphragm bellows, precision shims, and small clamps allow accurate gap settings. Indications of the effectiveness of these and the thermal measurements at operating conditions appear in the next section.

Diminiode pieces of any given type are interchangeable - except unusual electrodes, which require and receive special attention. Otherwise, the assembly of several parts (fig. 1(b) to (f)) produces another diminiode, like the rest, ready for the finishing operations.

DIMINIODE PROCESSING

In a multipurpose vacuum chamber (fig. 2) following just one pumpdown the diminiode undergoes final degassing, emitter-temperature and electrode-spacing calibrations, and a brazed closure after the cesium loading. The cesium addition results either from direct injection using a freeze, melt-valve dispensing system (fig. 3 and refs. 14 and 17) or from insertion of a capsule (fig. 4 and refs. 14 and 18). For the latter alternative the cesium comes off the shelf like the other diminiode components. Baked-out, brazed-shut, breakable molybdenum vials contain the cesium (fig. 5 and refs. 14 and 18) and allow vacuum-diode determinations before crushing the capsules in the sealed diminiode reservoirs. One of these cesium ampules, a degassed tantalum ball for the reservoir closure, and a diminiode go into the station (fig. 2). Then after general degassing at 450° C to below 10^{-8} torr the diminiode enters the critical stages of vacuprocessing.

Electron bombardment heats the emitter assembly while thermal control of the reservoir and base brings all diminiode temperatures to levels well above those for test operations. This bake-out continues until ion-gauge readings assure cleanliness. Then sighting the internal emitter hohlraum through the open reservoir allows calibrations of the complete automatic-pyrometry system for the tungsten-lined external black-body hole and of the high-temperature thermocouple. Because these temperature relations depend on heat-flow distributions the calibrations cover the various operational heating and cooling combinations.

Diminiode mock-up tests revealed that maximum temperature variations across the emitter face are less than the pyrometric resolution (ref. 15). And as two calibrated thermocouples in the diminiode base indicate, this comparatively massive, thermally conducting structure minimizes temperature differences in the collector, guard configuration. These thermal uniformities and the direct calibrations enable excellent electrode temperature determinations during diminiode testing.

In addition, cathetometry through the unblocked reservoir establishes the electrode-spacing relationship for all permutations of diminiode operating temperatures (ref. 13). For this gap calibration the demonstrated standard deviation is approximately 0.015 millimeter. So the two most questionable measurements in thermionic-diode evaluations, the electrode spacing and the emitter temperature, are well assured in diminiode testing.

Finally, after the previously discussed cesium addition, pulling a pin magnetically (fig. 2) releases the tantalum sphere, which lodges in the reservoir funnel lined at the top with degassed copper foil. Then electron bombardment circumferentially brazes the ball in place to complete the diminiode.

DIMINIODE TESTING

The vacuum-flange mounting for the diminiode bolts directly to its counterpart on the cooled metal bell jar of one of six complete facilitated test stations in the thermionic laboratory. Then connecting the thermal-control lines and instrumentation leads, evacuating the chamber, and slowly raising the temperatures to controlled operating levels prepare the diminiode for performance mapping.

A computer system (fig. 6 and ref. 2) controls, collects, and correlates diminiode output data. Typically an evaluation run involves thermally maintaining the collector and cesium reservoir while cooling the emitter through a series of six preset test temperatures in a fraction of a minute. At each selected emitter temperature the computer triggers a 0.01-second voltage pulse across the diminiode electrodes and during that span acquires 180 output measurements. For example, in less than a minute the system logs a curve comprising ninety current-density, voltage points for each of six emitter temperatures 50 degrees apart. Or with minor program changes, two sixty-point performance curves with different current-sensing amplifications result for each of the six emitter temperatures.

Figure 7 exemplifies the latter kind of data for an etched-rhenium, niobium diode with a 0.25-millimeter electrode gap (refs. 3 and 4): Individual performance maps for an 1800° K emitter, a 941° K collector, and a 650° K cesium reservoir appear in figure 7(a) and (b). Figure 7(c) implies the current-density, voltage envelope for an 1810° K emitter, a 945° K collector, and reservoir-temperature variation. Data for all collector and reservoir temperatures tested indicate the performance envelope for an 1810° K emitter in figure 7(d). And figure 7(e) presents such results for nine emitter temperatures.

Figure 7 represents actual computer-system outputs in ready-to-report forms. Within a few days, NASA Lewis facilities and procedures can produce several-hundred current-density, voltage and power-density, voltage curves like these - as well as the envelopes for the performance-mapped conditions.

RECENT DIMINIODE RESULTS

Data just published for a diminiode with a 99.999-percent 110-tungsten emitter and a 99.99-percent collector reveal lower ultimate power outputs at higher voltages with sharper performance maxima than for other similar cesium diodes (ref. 13).

Certain aspects of this current study deserve emphasis: First, the electrodes are very pure and well defined, and the diminiode is exceedingly clean. Second, the gap dimension, electrode parallelism, and emitter temperatures are highly reliable owing to careful assembly and to direct calibrations of the finished diminiode at operating conditions.

These points have a strong impact because small amounts of impurities and the electrode spacing and temperatures affect cesium-diode performance significantly. In particular, very low concentrations of oxygen increase thermionic-converter outputs considerably. Furthermore, impurities, electrode tilting, and emitter-temperature inhomogeneities smear out diode performance effects.

In contrast a chemically, thermally, and geometrically precise thermionic converter should produce relatively low power with more discrete output characteristics. Most cesium-diode experts concurred with this generalization long ago. And as converter production techniques grew more sophisticated, performances of standard metallic thermionic electrodes moved steadily downward. So in addition to the design, processing, and material improvements of this diminiode its sharply defined ultimate-power points at comparatively poor outputs support its effectiveness as a well-controlled tool for thermionic-conversion research and development.

DIMINIODE UTILITY

Computer systems brought obvious quantity, quality, and economy gains to performance mapping. With this data-processing capability the well-defined geometry of a plane, guarded, variable-gap thermionic diode makes it an excellent tool for certain kinds of research and development. This combination allows studies of relative emissive powers of promising new materials; of mechanisms of charged-particle emissions under various conditions; of the thermochemophysics of solid surfaces; of plasma effects; of high-temperature solid, gas interactions; and of voltages and current densities in thermionic half-cells. The results of such work apply to vacuum and gas-filled electron tubes; to high-temperature instrumentation; to high-temperature material problems; to energy conversion involving cesium diodes, MHD devices, or charged-particle beams; and in a broad sense, to the better understanding of all technologies involving electrodes in fluids (ref. 19).

But the preceding attributes are characteristic of computerized data acquisition with plane, guarded, variable-gap thermionic diodes in general. To these the diminiode adds its specific advantages: Miniature electrodes allow the screening of rare materials available only in small sizes, the economy of small diameter single crystals, and the very slight spacing aberration for a given misalinement angle between two small surfaces. The simple, rugged diminiode design makes possible the precision, ease, and economy of predominantly lathe machining and alining; the maintenance of detailed diode geometry through thermal and mechanical stresses; and the economy of interchangeable parts and repetitive production. Effective, low-cost high-temperature vacuprocessing enables bake-outs, direct calibration of internal-variable sensors at operating temperatures, cesium addition, and brazed closure - all with only one setup and pumpdown phase. All diminiode materials and constructions permit long bake-outs at temperatures considerably above maximum operation levels to produce extreme cleanliness and to assure no thermal relaxations of dimensions after the direct internal calibrations. And the measurement accuracy for emitter temperatures and electrode spacings of diminiodes further insure high-quality thermionic-performance mapping.

For these reasons diminiodes with computerized data processing can be very useful in energy-conversion research and development.

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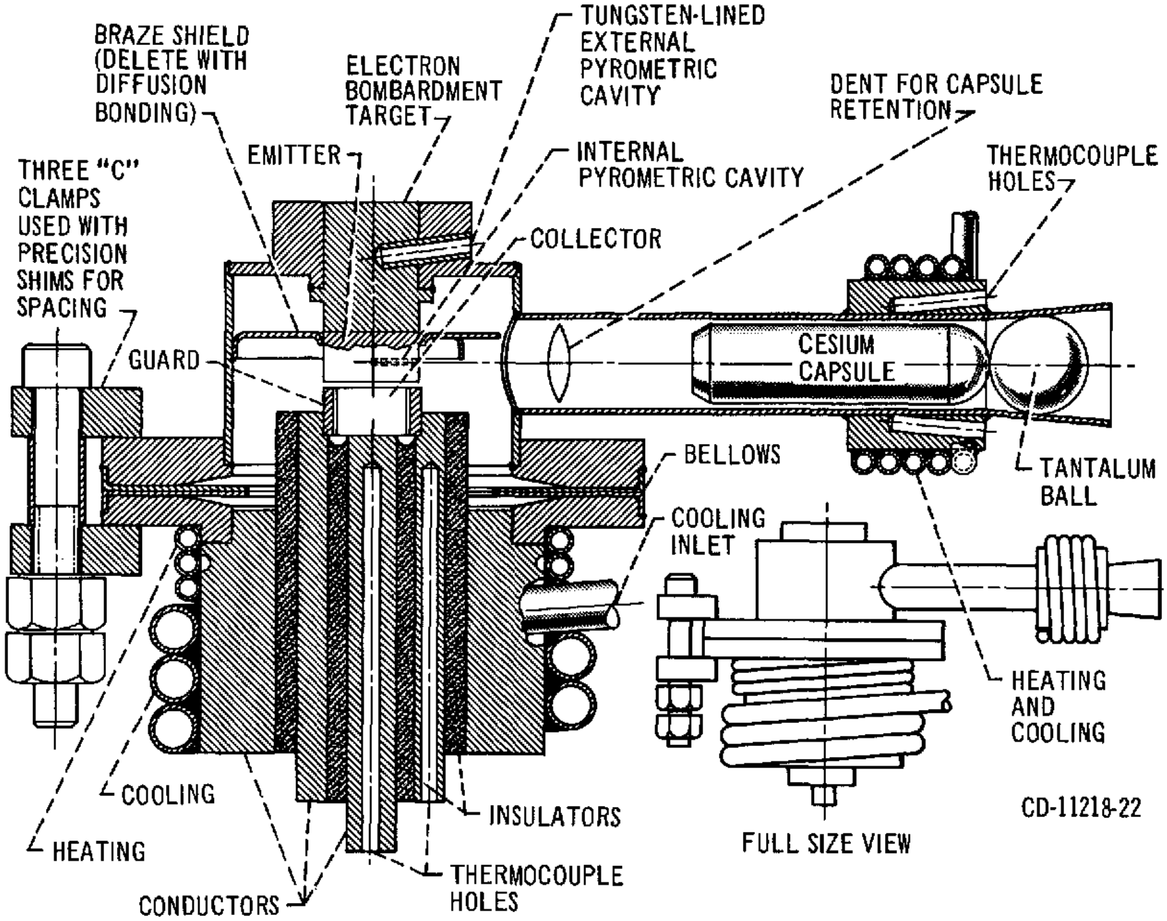


Figure 1(a). - Variable-gap diminiode (cross section).

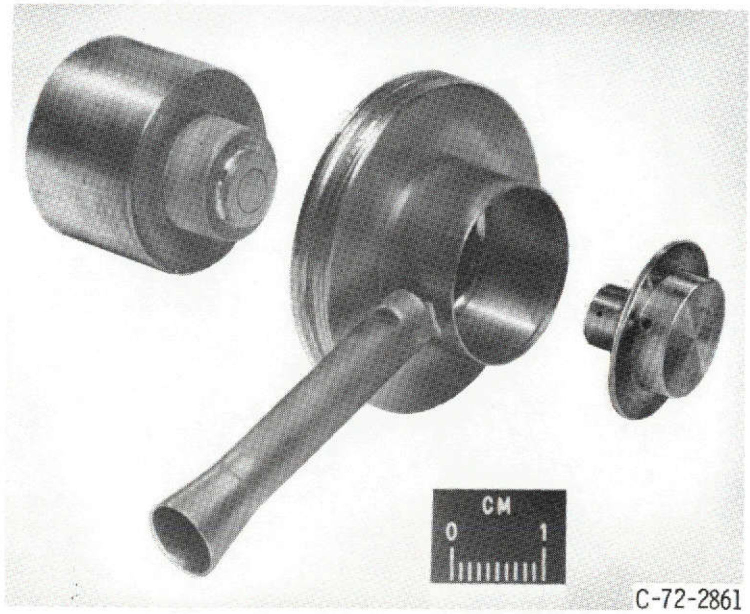


Figure 1(b). - Collector, envelope, and emitter sections of the variable-gap diminiode.

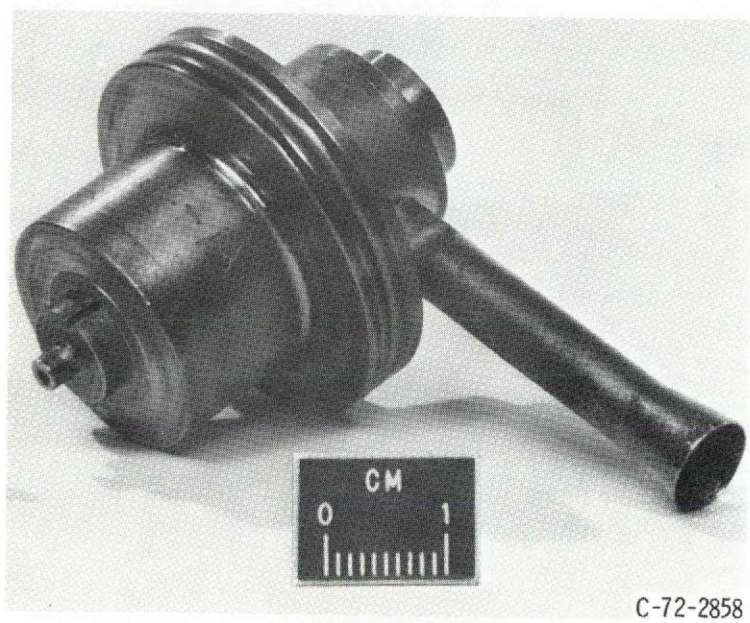


Figure 1(c). - Bare assembled variable-gap diminiode.

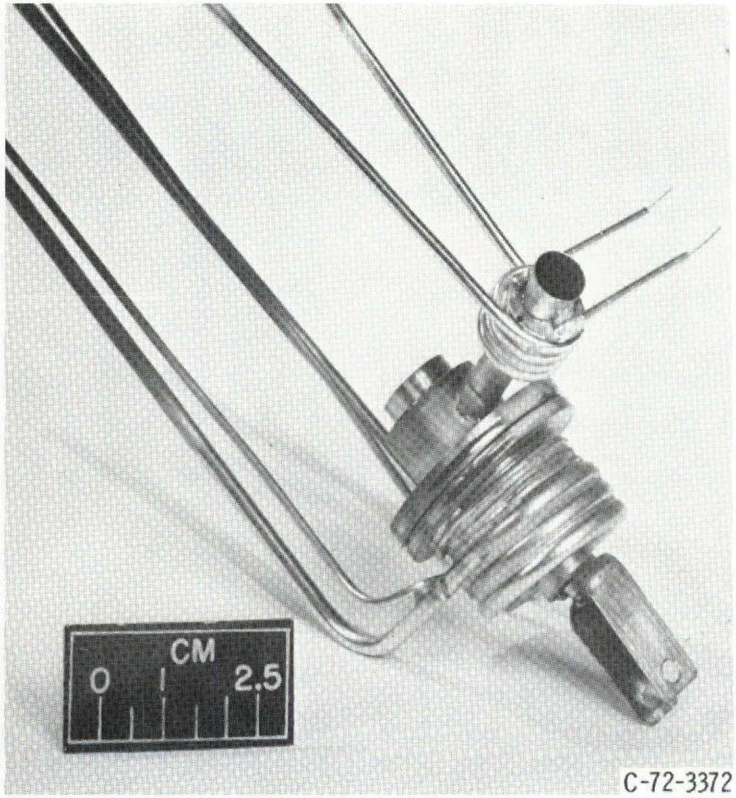


Figure 1(d). - Variable-gap diminiode with heating and cooling coils for the cesium reservoir and the collector.

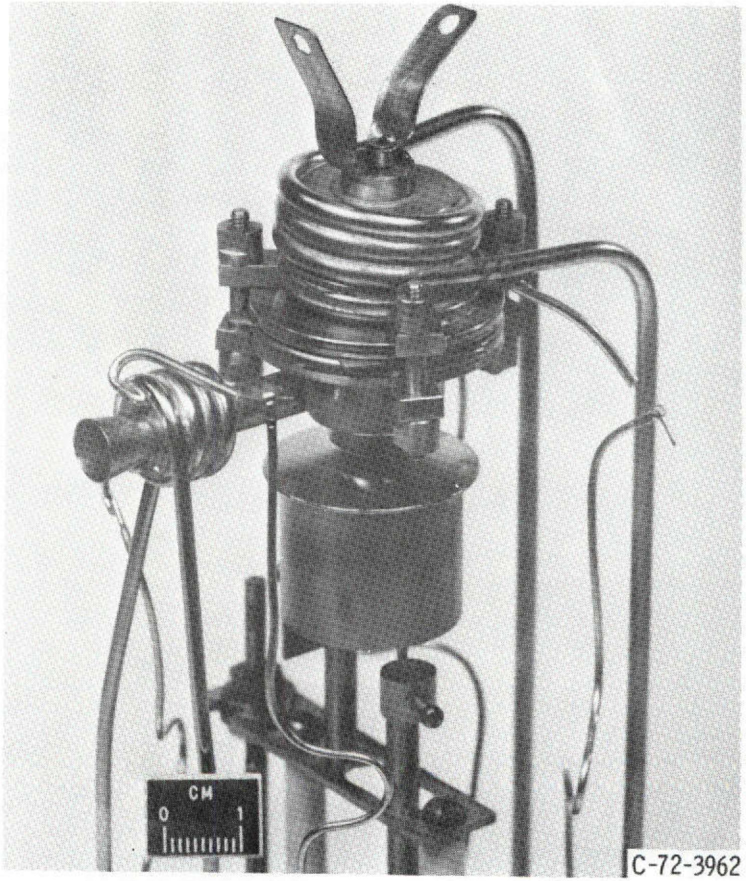


Figure 1(e). - Variable-gap diminiode with heating and cooling coils for the reservoir and collector and electron bombardment for the emitter.

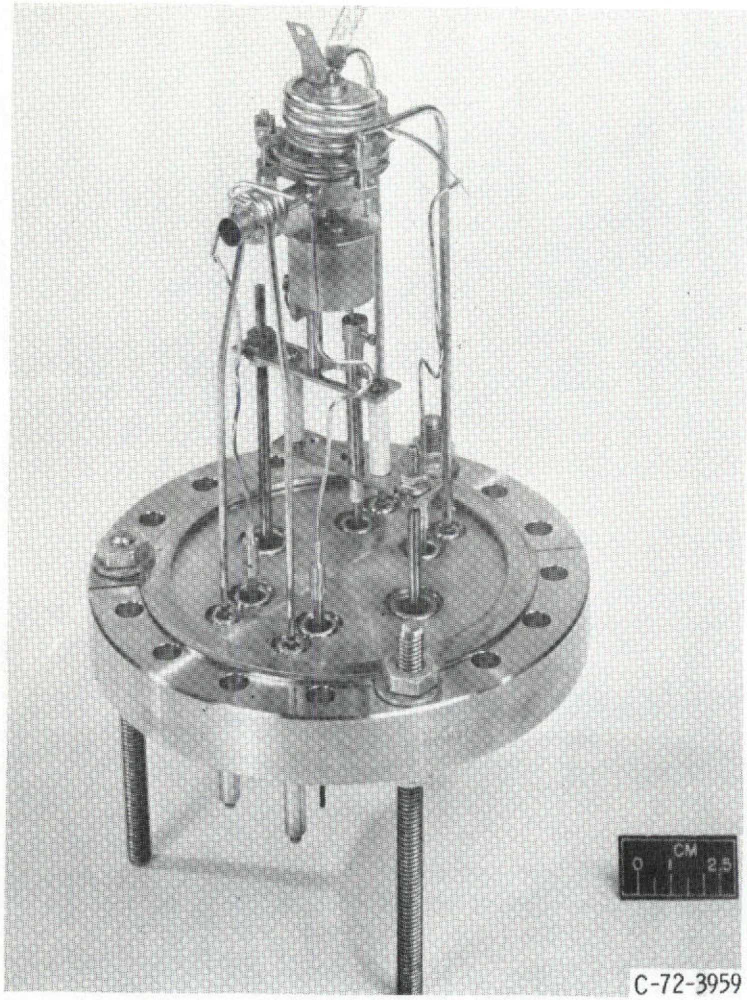
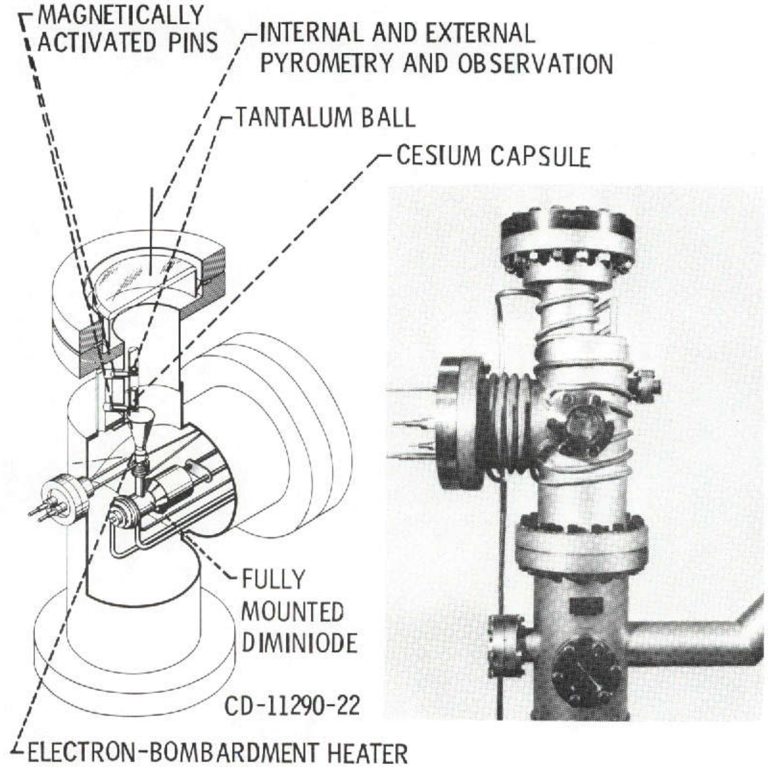


Figure 1(f). - Fully mounted variable-gap diminiode.



(a) CUTAWAY VIEW.

(b) OUTSIDE VIEW.

Figure 2. - Diminiode vacuum processing chamber (bake-out, calibration, cesium loading, and brazed closure).

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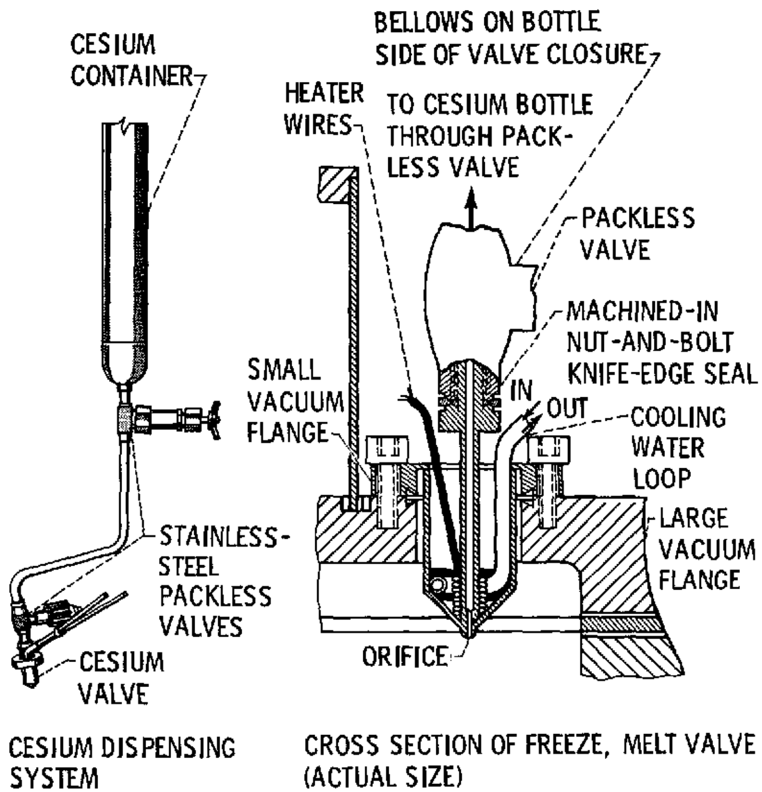


Figure 3. - Freeze, melt-velve dispensing system.

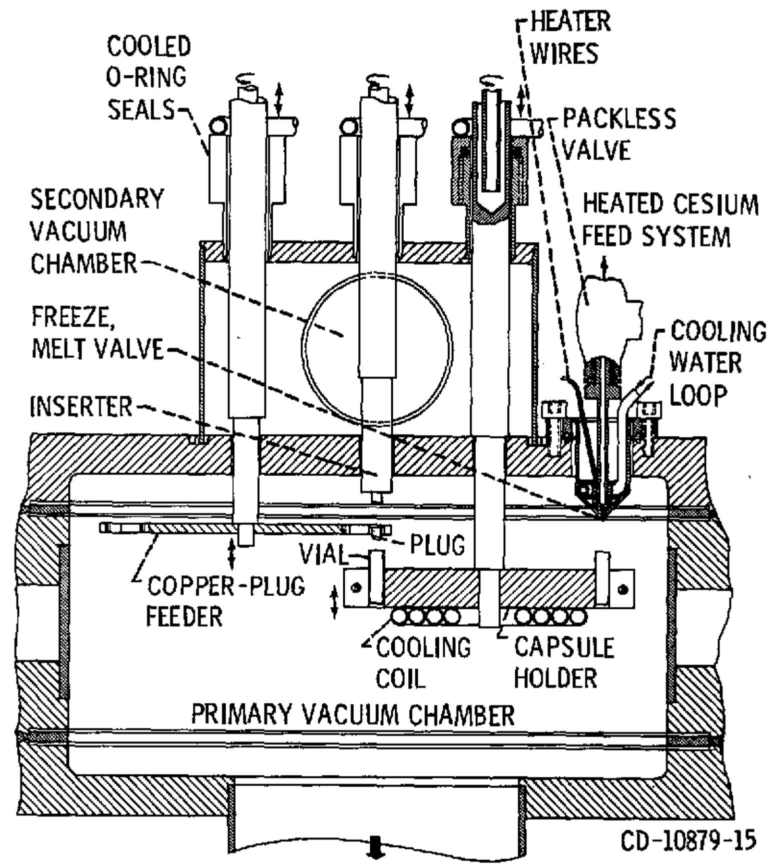


Figure 4. - Station for vacuum packaging cesium.

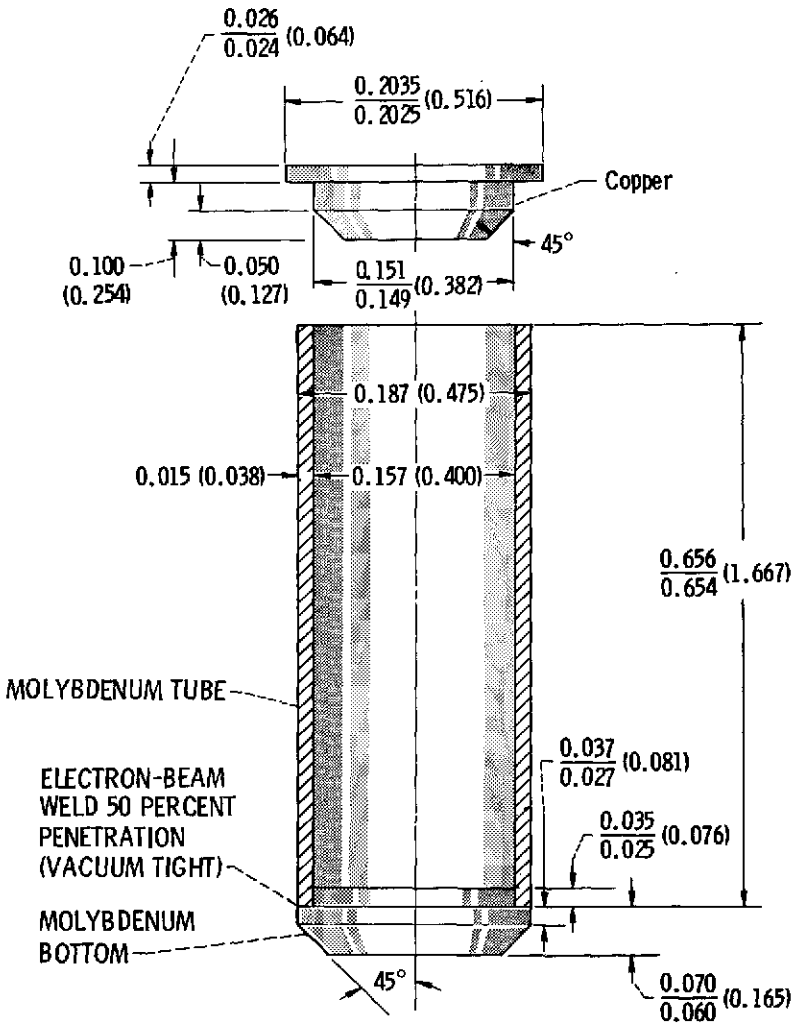


Figure 5. - Cesium capsule. (Dimensions are in inches (cm).)

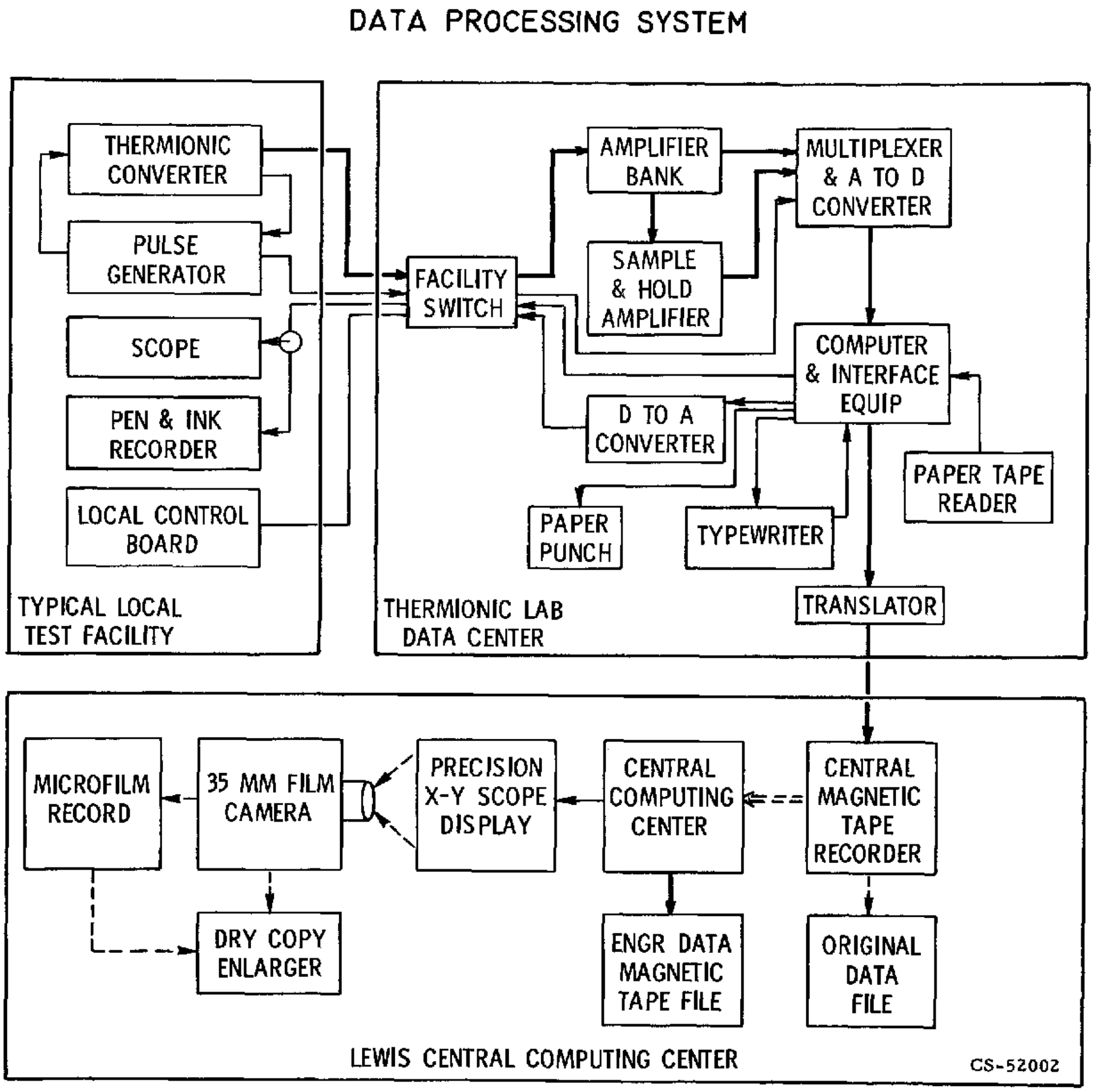


Figure 6. - Elements of the computerized thermionic DATA ACQUISITION SYSTEM.

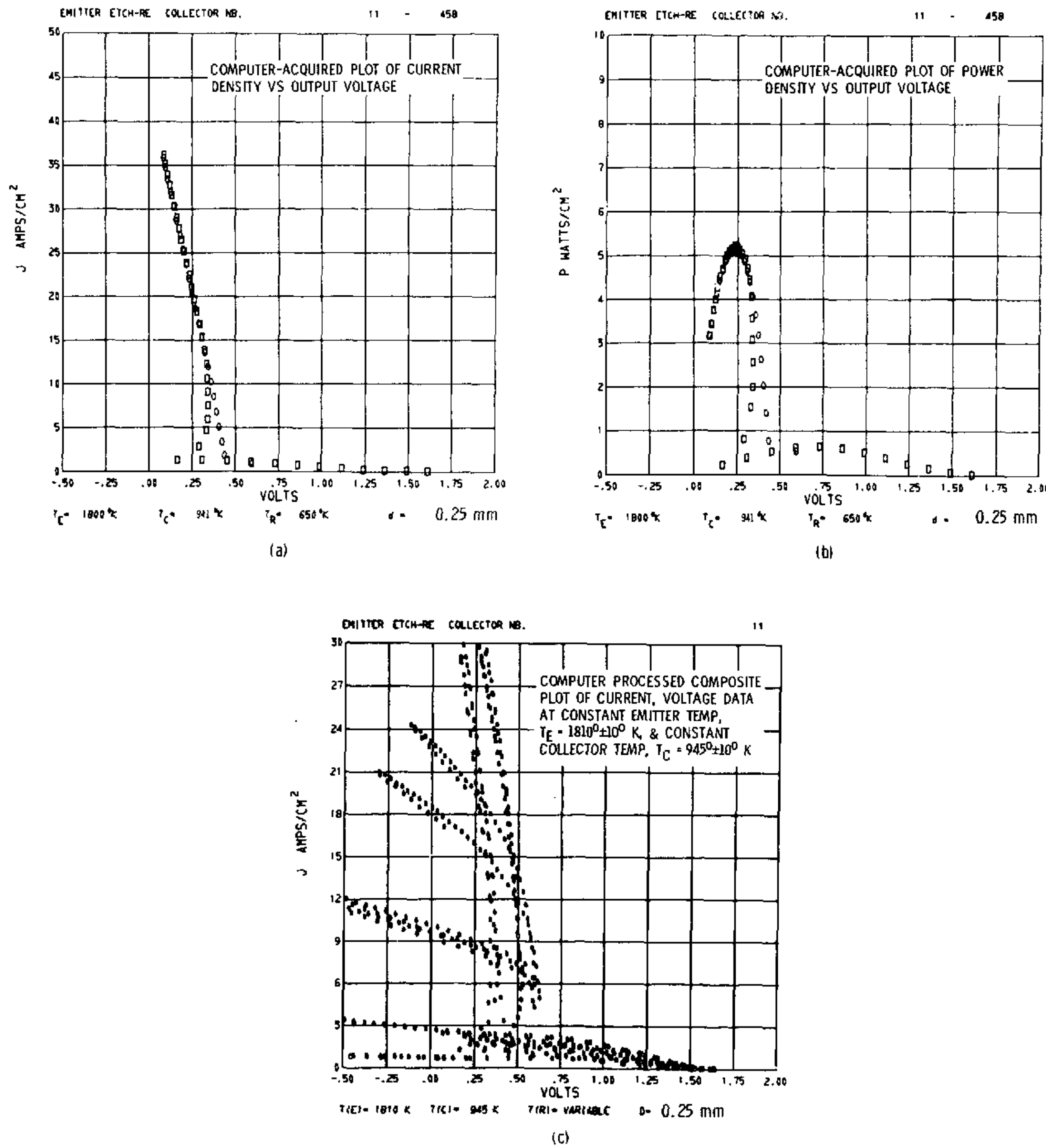
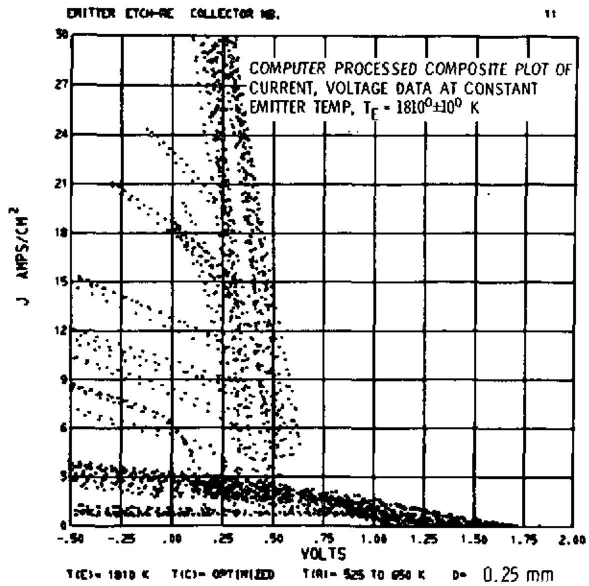
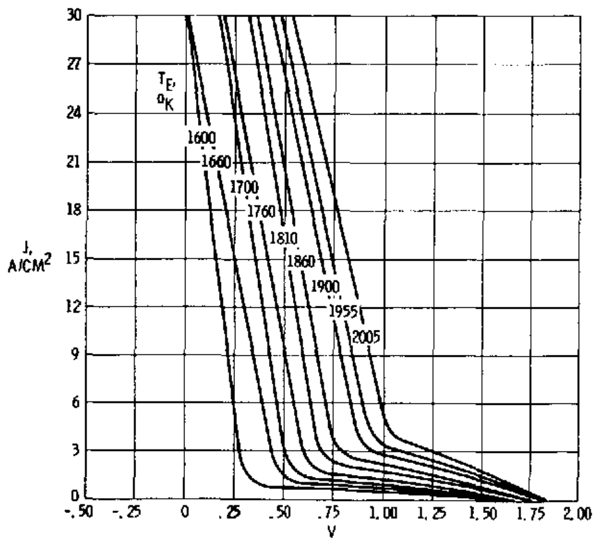


Figure 7. - Typical computerized thermionic performance mapping.



(d)

PERFORMANCE ENVELOPES FOR ETCHED-RHENIUM, NIOBIUM PLANAR CONVERTER AT VARIOUS EMITTER TEMPERATURES



(e)

Figure 7. - Concluded.