JPL NUCLEAR ELECTRIC PROPULSION TASK

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LITHIUM MPD THRUSTER TECHNOLOGY DEVELOPMENT AT JPL

- Funded by NPO in FY92 to develop a lithium feed system
  - Reservoir and vaporizer designed and under construction
  - Flow rate calibration system design complete, components under construction
- Test facility design nearly complete, construction to be completed in FY93
  - 6' x 15' double-walled stainless chamber with 27' long extension to be used as a beam dump pumped by a 20" diameter oil diffusion pump
- Initial testing of 100 kWe-class radiation-cooled engine to begin in FY93

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COMPARISON OF MEASUREMENTS WITH THEORY FOR MERCURY PHASE SEPARATOR

- DATA OBTAINED WITH A SMALL DEVICE AND AT LOW TEMPERATURES
- FOR LITHIUM MPD REQUIRED TEMPERATURE AND FLOW AREA MUST BE GREATER

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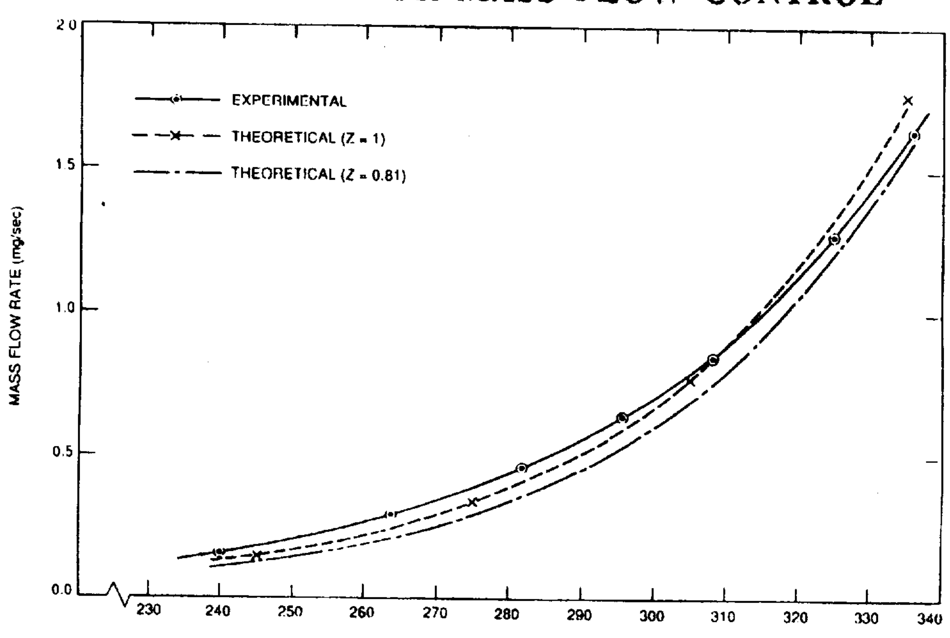
MERCURY VAPOR MASS FLOW CONTROL



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INITIAL EXPERIMENTAL HARDWARE DESIGN

- HIGH TEMPERATURE WILL BE CONFINED TO THIN LITHIUM LIQUID SHEET BETWEEN HOUSING AND SEPARATOR
- CAN EASILY REPLACE SEPARATOR

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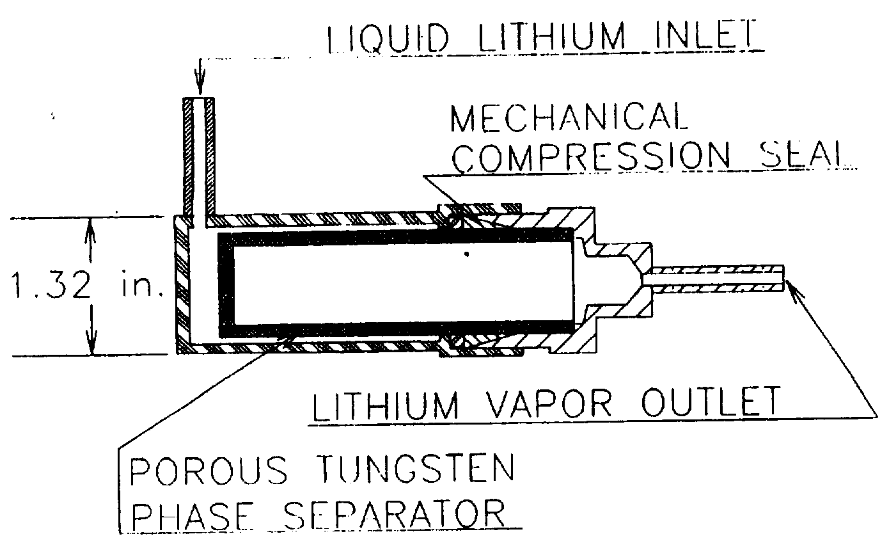
POROUS TUNSTEN VAPORIZER AND HOUSING



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EXPERIMENTAL SETUP

- VAPOR COLLECTOR WILL BE LIGHT
- HEAT OF CONDENSATION WILL BE REMOVED THROUGH OIL BATH
- LIQUID PRESSURE AT SEPARATOR WILL BE KEPT WITHIN ACCEPTABLE RANGE WITH REGULATED ARGON PRESSURE

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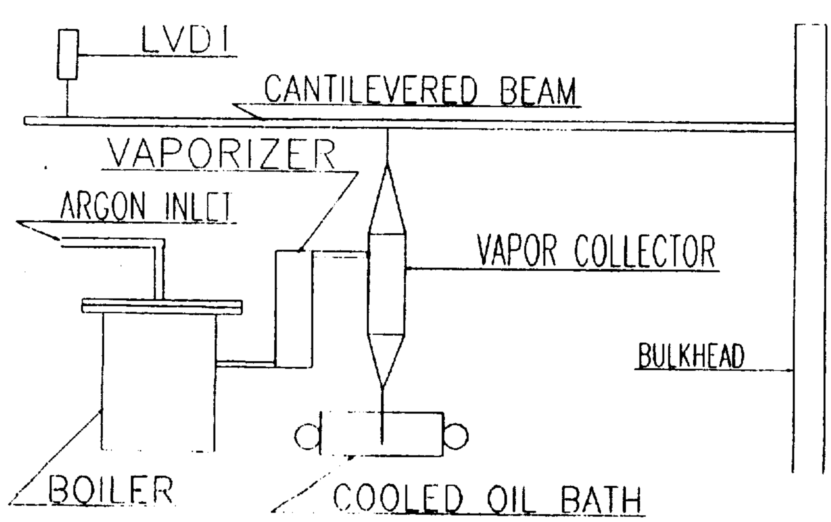
LITHIUM VAPORIZER EXPERIMENT



HEATERS NOT SHOWN

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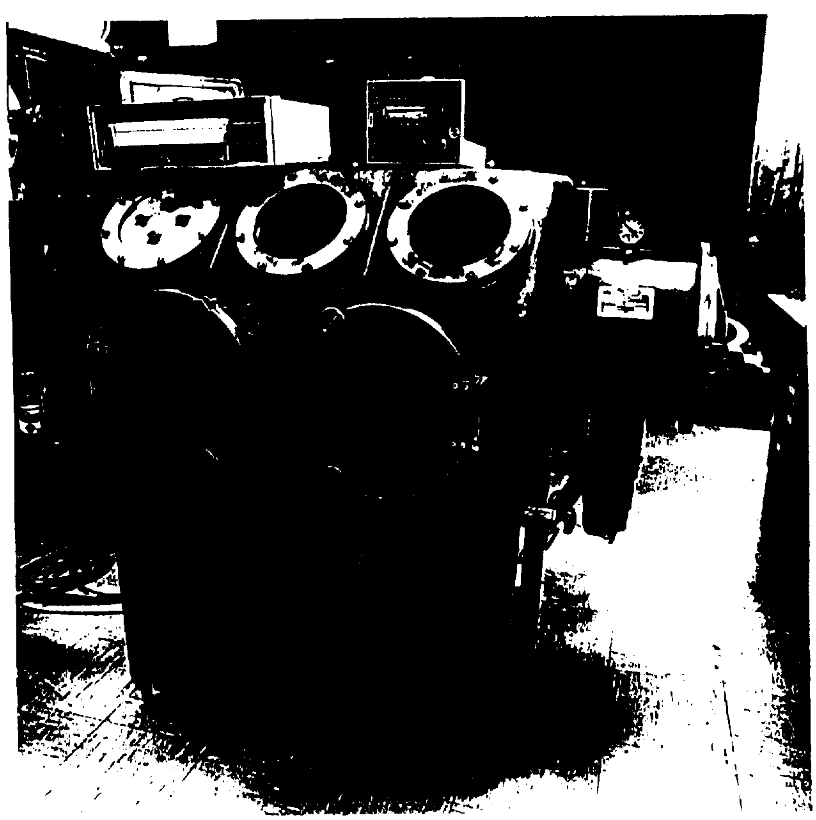
DRY BOX FOR HANDLING SOLID LITHIUM

- ZERO CONTACT BETWEEN SOLID LITHIUM AND AIR



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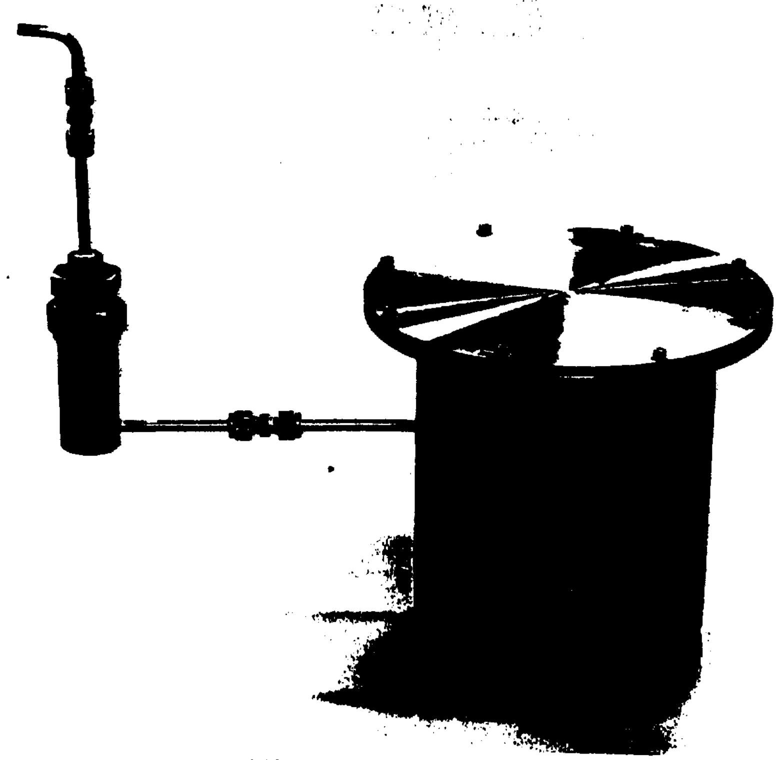
EXPERIMENTAL HARDWARE

- BOILER CAN HOLD 900 G OF LITHIUM
- HARDWARE EASILY DISASSEMBLED FOR CLEANING



TEST FACILITY

- VACUUM TANK IS 45 x 45 x 80 CM
- PUMP OUT PRESSURE TO LESS THAN 1 MTORR

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MPD THRUSTER ELECTRODE MODELLING

- Cathode - Emphasis is on lifetime assessment:

  Methodology
  Modelling
  Experimental Verification

- Anode - Primary focus is thermal management:

  Impact of anode work function
  Assessment of heat rejection methods

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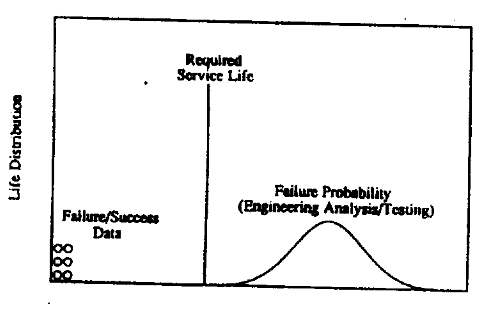
DEFINING ENGINE LIFETIME



Engine lifetime, requirements and operating experience

- CURRENT STATUS
  - Required service life is not well defined
  - Critical failure modes have not been identified
  - No theoretical or experimental characterization of life distribution
- IMPORTANT OBSERVATIONS
  - Life distribution characterization by system-level operating experience is not feasible
  - Engine lifetime is inherently probabilistic

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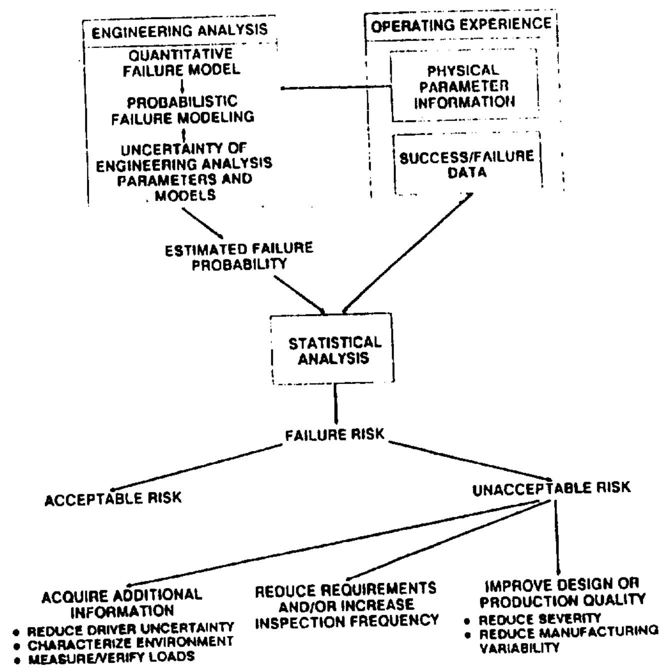
PROBABILISTIC FAILURE ASSESSMENT



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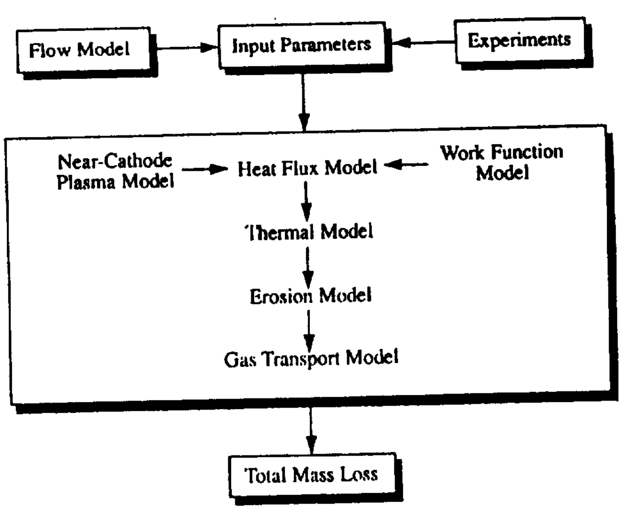
QUANTITATIVE CATHODE FAILURE MODELLING



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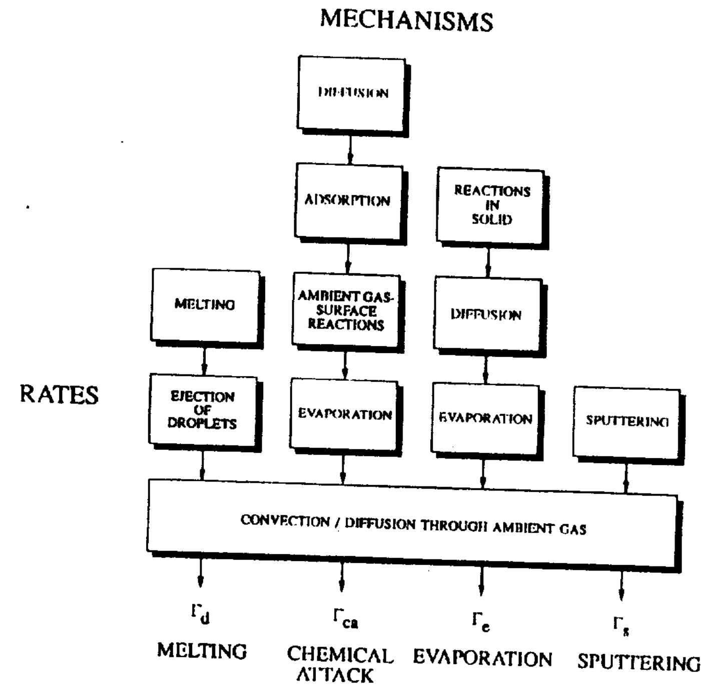
CATHODE EROSION MODELLING



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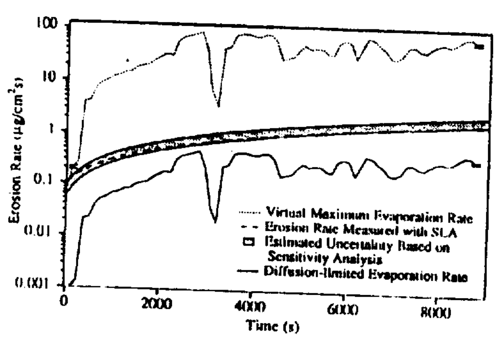
COMPARISON OF CALCULATED AND MEASURED CATHODE EROSION RATES



Cathode erosion measurements performed with Stuttgart thruster NCT-1 at 2500 A, 1.0 g/s of argon, 71 kWe and 20 Torr ambient pressure

- Diffusion-limited evaporation of tungsten is the dominant mechanism
- Model underpredicts erosion rate by a factor of 6, reflecting uncertainties in transport rate through concentration boundary layer
- Calculated erosion rates are based on measured temperatures--thermal model required for fully predictive capability

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CATHODE THERMAL MODELLING

- HT9: 1-1/2 D thermal model with variable grid spacing and non-linear thermal and electrical conductivity. Allows specification of radiation, conduction, convection and arc attachment boundary conditions on ends and inner and outer radii.
- AFEMS: Commercial 2D finite-element model with nonlinear material properties. Very flexible solid modeller for geometry specification, but definition of boundary conditions is more cumbersome than in HT9.
- Fully 2D version of HT9 to be developed in FY93.

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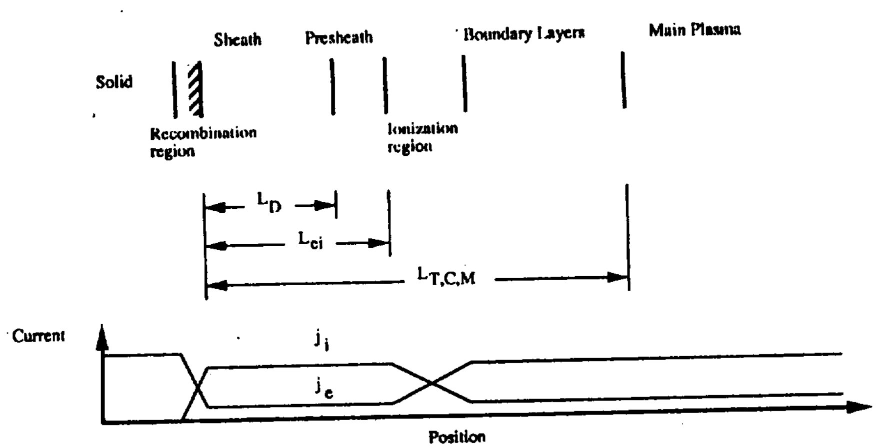
NEAR-CATHODE PLASMA MODEL REGIONS



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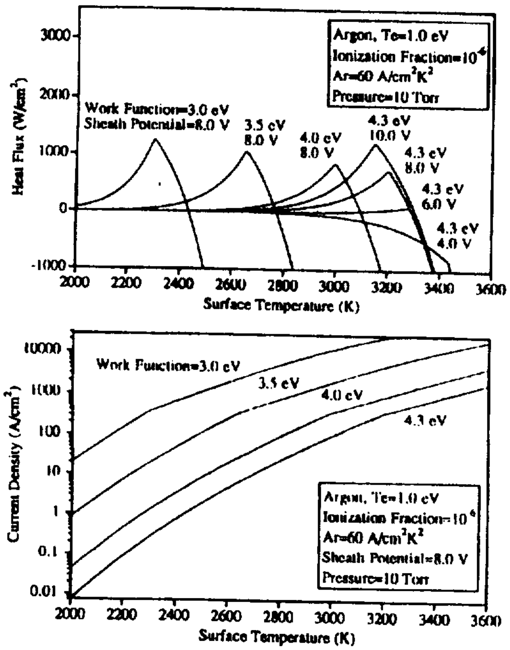
NEAR-CATHODE PLASMA MODELLING



- The model describes the electrostatic sheath, presheath and ionization zones
- Current and heat fluxes are calculated as functions of gas properties, thermionic properties, surface temperature and sheath potential
- Terms normally neglected in high-pressure noble gas arc models are included to allow accurate modelling of low-pressure alkali metal arcs

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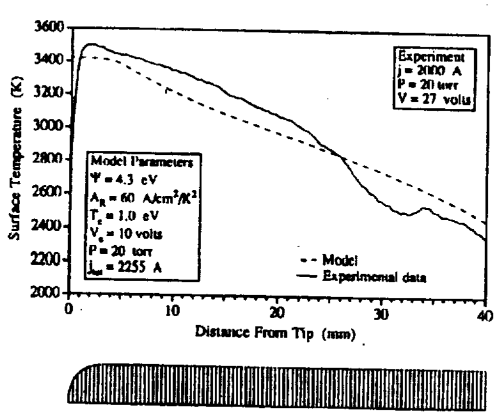
COMPARISON OF CALCULATED AND MEASURED TEMPERATURE DISTRIBUTIONS



Cathode model geometry and results

- The model includes radiation, conduction out the base and heat input over the first 5 mm from the near-plasma model
- The model reproduces the tip temperature and shaft behavior for reasonable values of the input parameters
- Errors may be due to experimental data not in equilibrium and thorium effects on spectral emissivity

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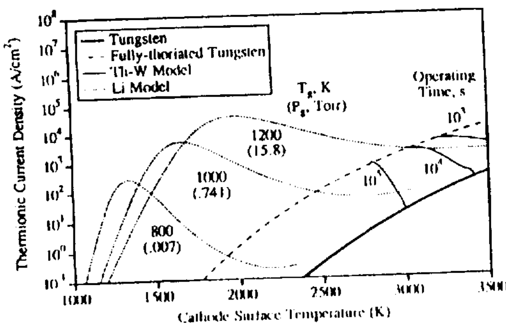
CATHODE WORK FUNCTION MODELLING



Emission capability of tungsten metal with Th and Li adsorbed on the surface.

- "Activator" may be electropositive material in the cathode bulk or in the propellant
- Two models were developed for cathode additive transport and propellant-surface interaction
- Th-W effect on work function is limited by depletion of thorium additive
- Li supply from propellant is unlimited, but surface coverage depends on gas pressure and temperature
- There is considerable uncertainty in model input parameters

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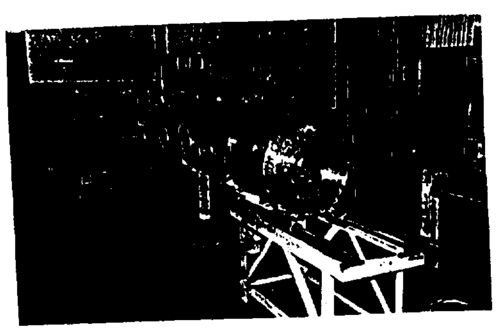
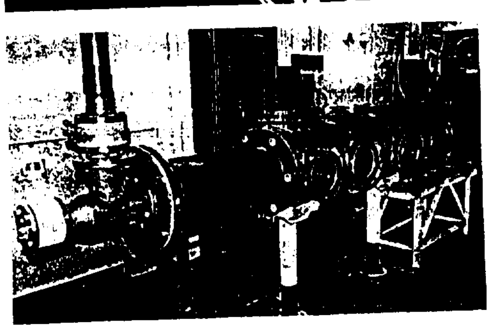
CATHODE TEST FACILITY





- Demonstrate feasibility of new cathode concepts
- Measure cathode temperature distributions and erosion rates to validate models
- Measure model input parameters
- Collect success/failure data in long endurance tests

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IMPACT OF ANODE WORK FUNCTION

Two limiting cases examined:

- Strong positive anode sheath, $V_s >> kT_e/e$

  Thermionic current can be neglected, heat transfer rate is lower for a low work function anode.

- Negative anode sheath

  Preliminary sheath model results indicate lower anode heat transfer rate for low work function anodes at moderate temperatures (Example: For 100 A/cm^2, $n_e = 10^{14}$ cm^{-3} (Argon), T_e = 1 eV, an anode with a work function of 3.5 eV has lower heat transfer rates than one at 4.5 eV for temperatures below about 2600 K.)

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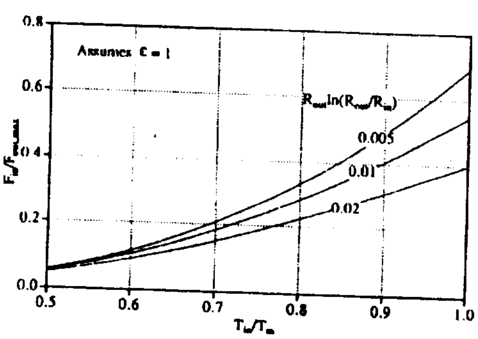
ASSESSMENT OF RADIATION-COOLED ANODES



Analytical model of thin-walled, cylindrical anodes.

T_{in} = Temperature on inner surface

T_m = Melting temperature of material

F_{in} = Power/unit axial length

$F_{out,max}$ = Maximum possible radiated power/unit length from exterior, σT_m^4

- Analytical model of thin-walled anodes completed--neglects axial conduction, internal radiation and Joule heating.
- Example: 10 cm dia. tungsten anode with 10 mm wall thickness and maximum allowable T_{in}=0.8 T_m can reject 18 kW of power per cm of length.
- Effect of axial heat conduction and Joule heating is being studied with finite element analysis.
- Comparison between thin-walled anodes and anodes with large radiators is being performed using finite-element analysis.