Operating Experience and Reliability Update on the 5 kW CW Klystrons at Jefferson Lab

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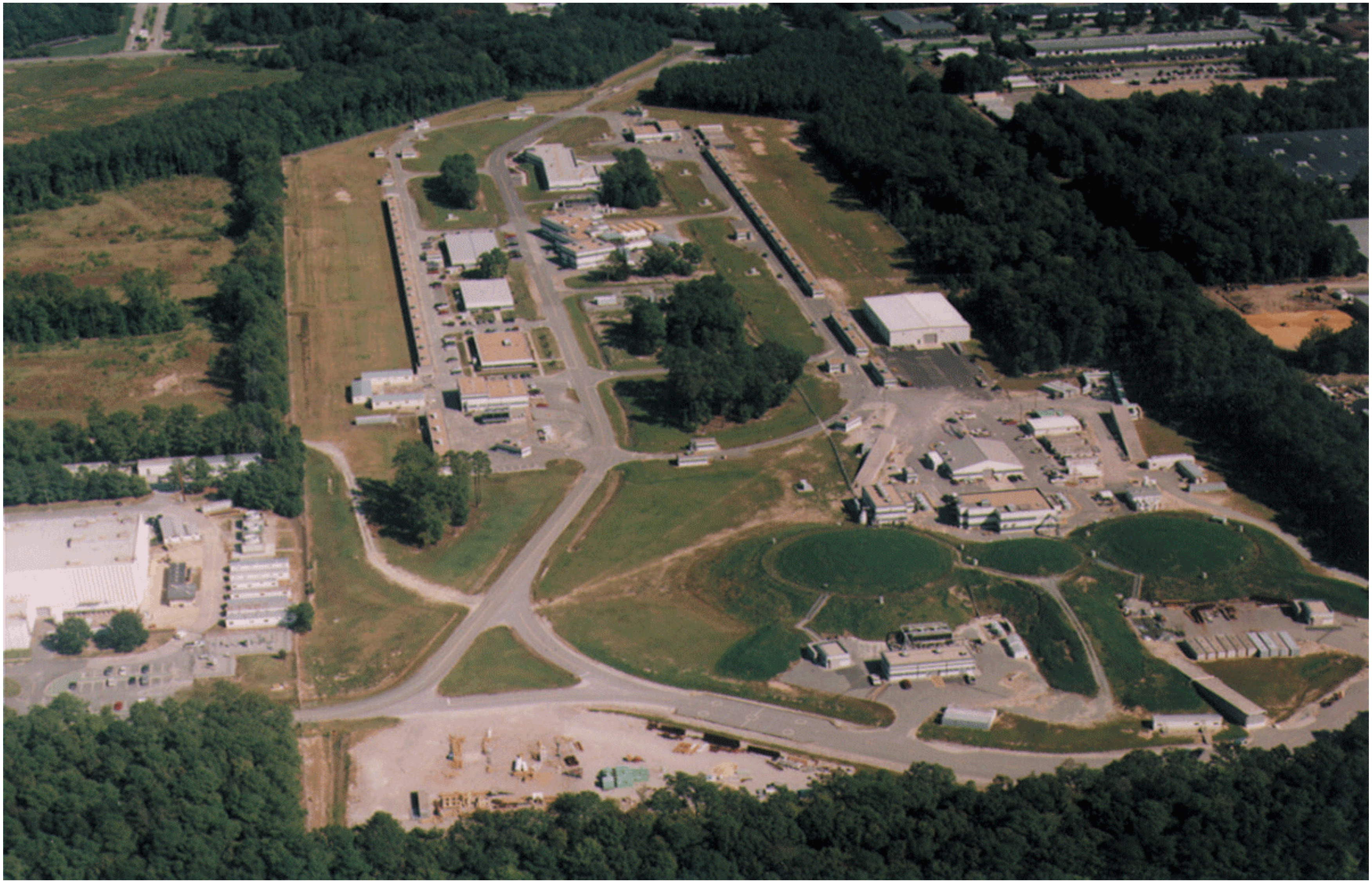
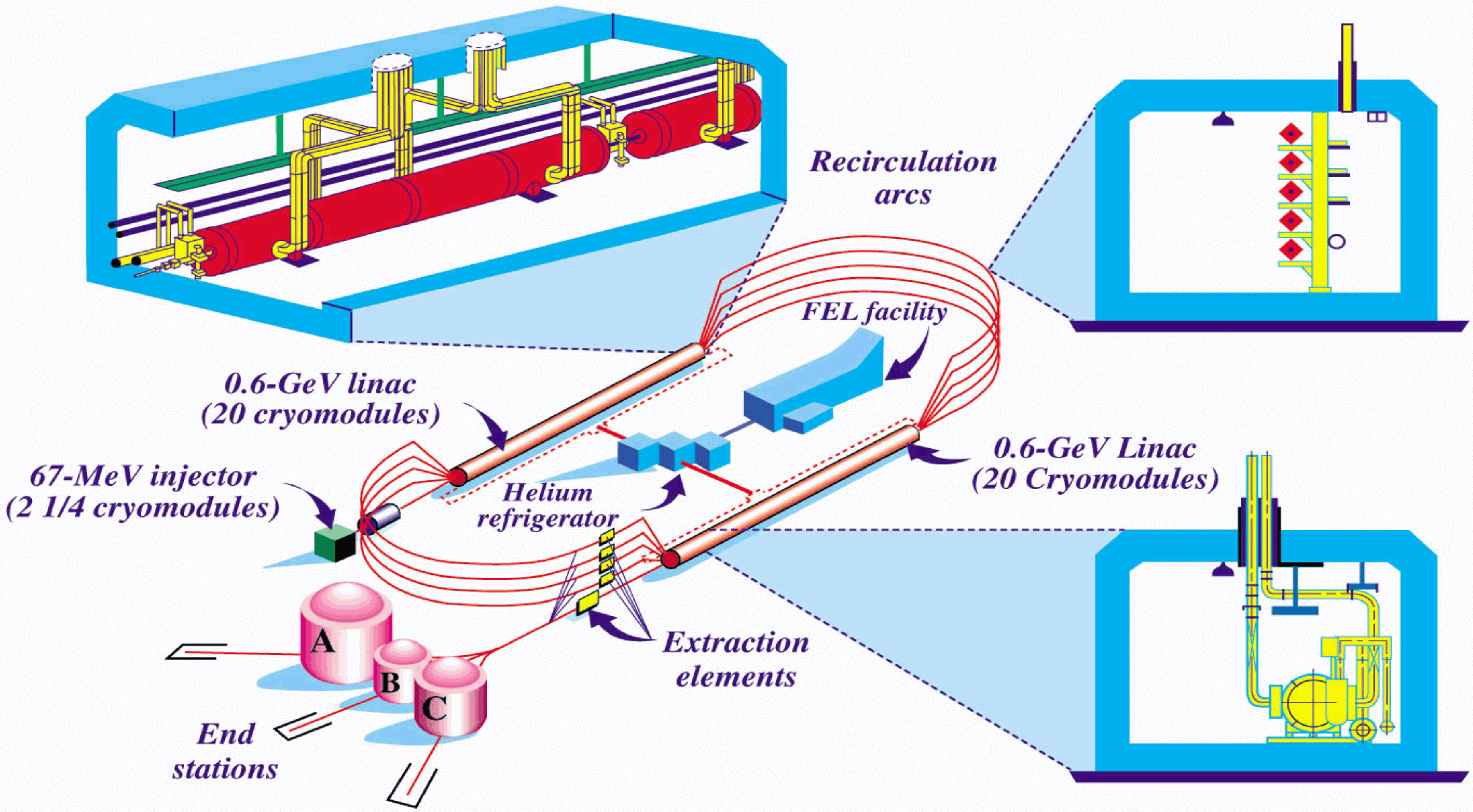
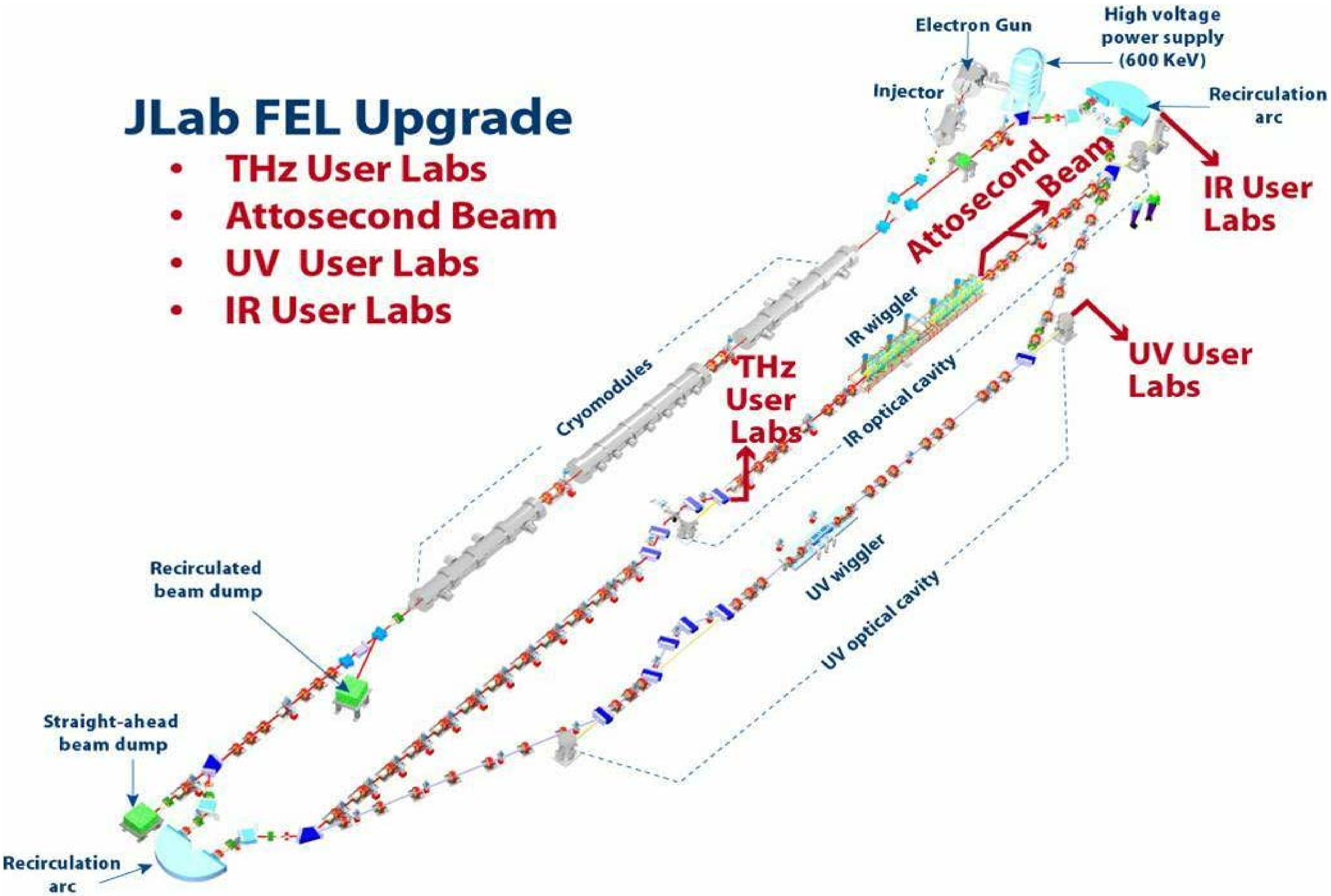
Jefferson Lab Site



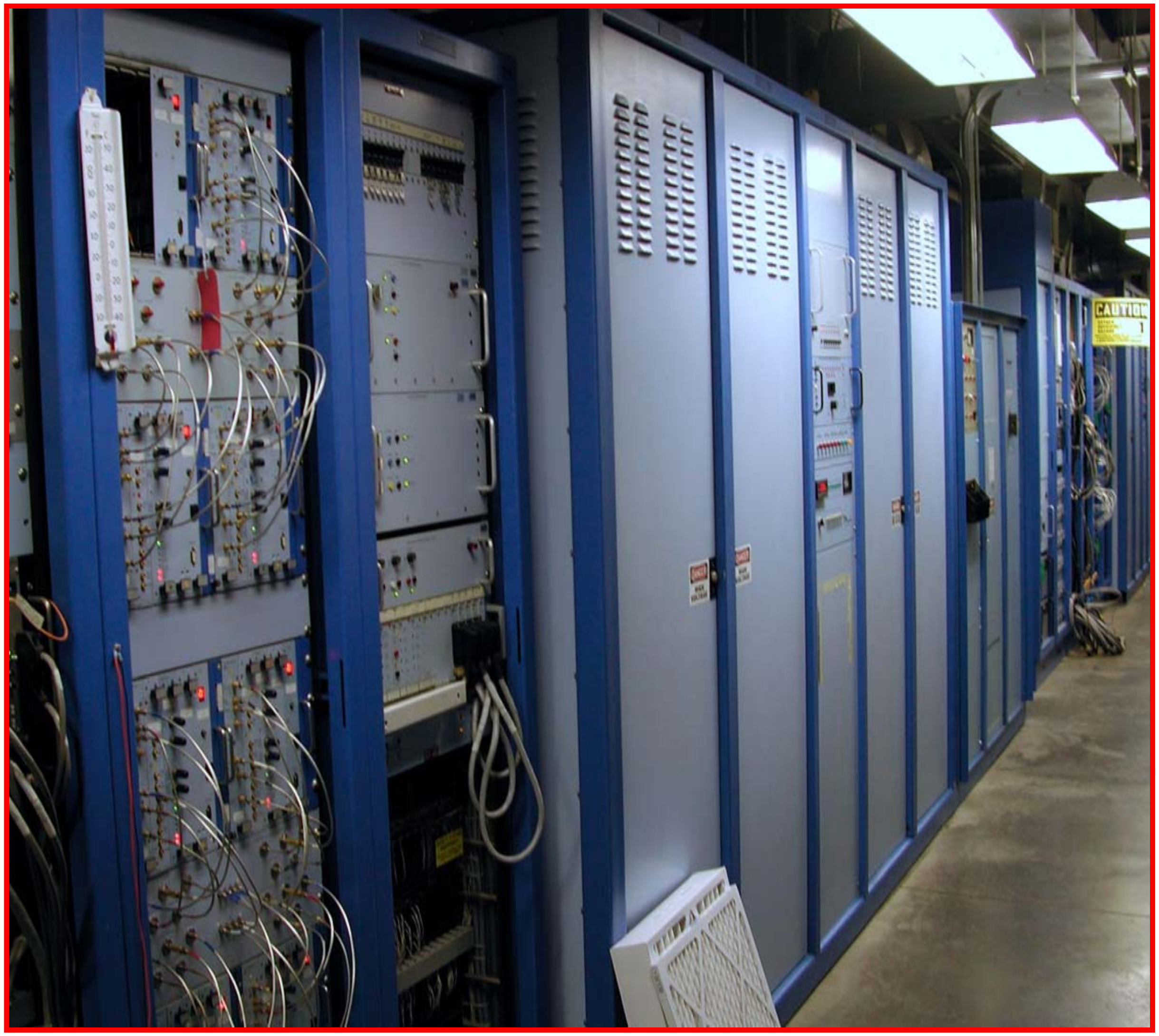
Machine Configuration



JLab FEL Upgrade



RF Zone Configuration

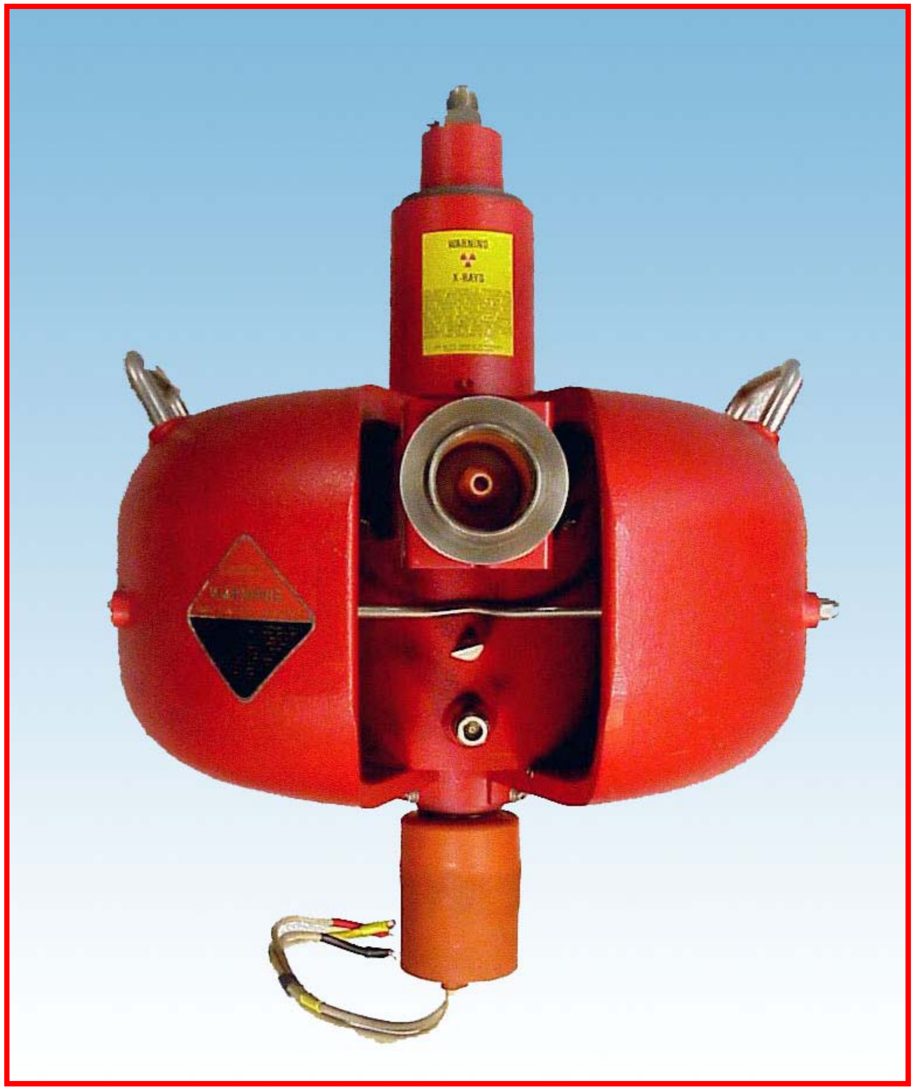


- 3 control racks
- 5 racks for klystrons
- Single shared HV power supply
- 42 systems in CEBAF
- 3 more in FEL

Klystron Configuration

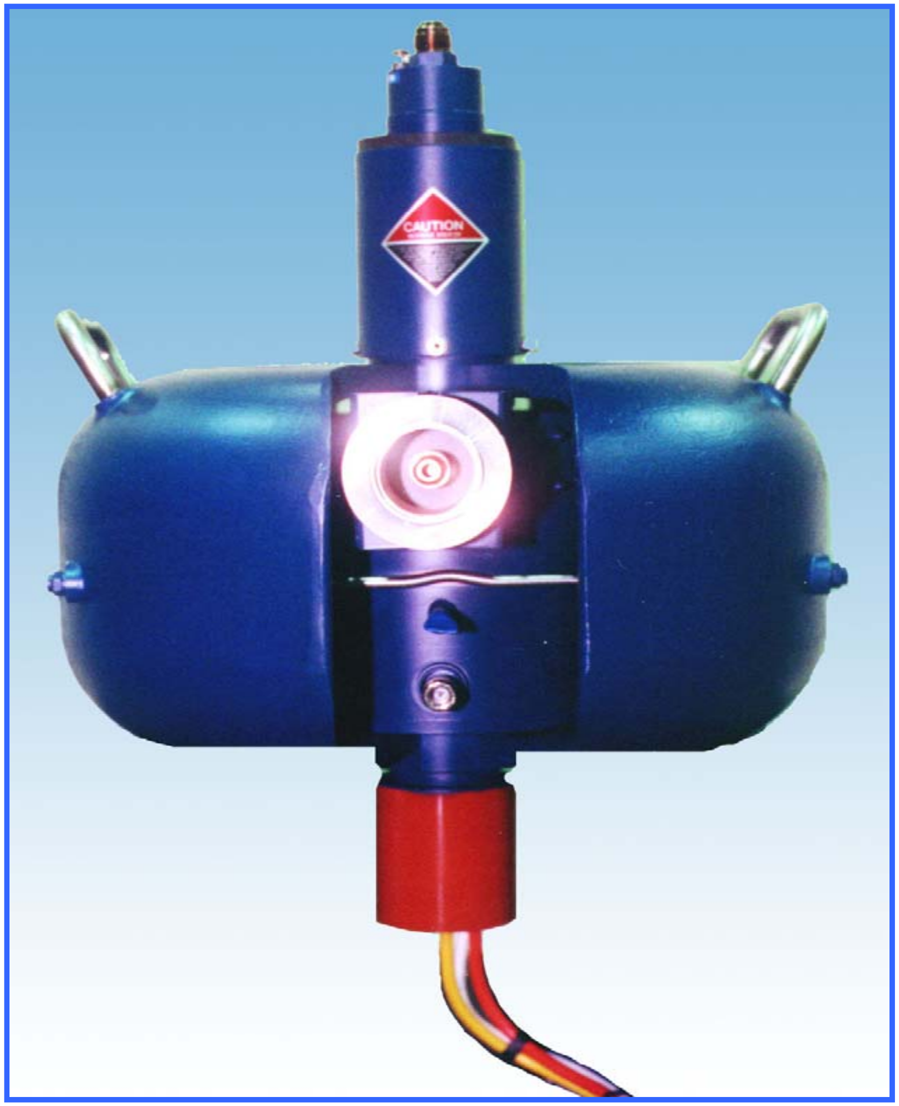
- 8 klystrons per zone
- Powered from single HV power supply
- Circulators, couplers, etc.
- 4 waveguides per penetration to tunnel

Varian VKL7811W



- Purchased through competitive bid
- Order of 350 units
- 3 year delivery period

Litton L491



- Replacement from competitive bid
- Multi-year order
- Purchase in lots of 10 or 20 units
- 119 received

VKL7811W

- Specifications (voltage, current, gain, power, etc.)
  - 5 kW CW
  - 11.6 kV @ 1.33 A
  - 32.4% efficiency (min)
  - 38 dB gain
  - 4 cavity design
  - Coaxial output
  - Permanent magnet focusing
  - Potted gun
- Size limitations (to fit our application)

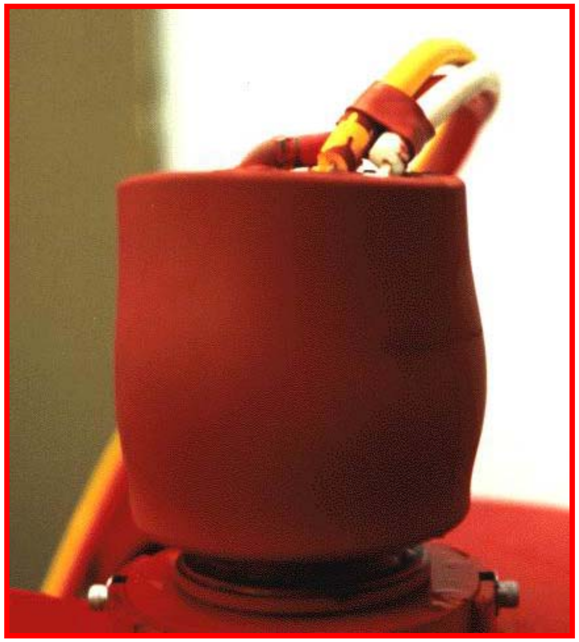
Klystrons Arrive

- Testing Plan
  - Begin by testing all incoming klystrons
    - Tuning problems
    - Gain problems (related to tuning)
    - High body current - added magnetic shunts
  - Reduce sampling when results are good
  - End result was to test all tubes

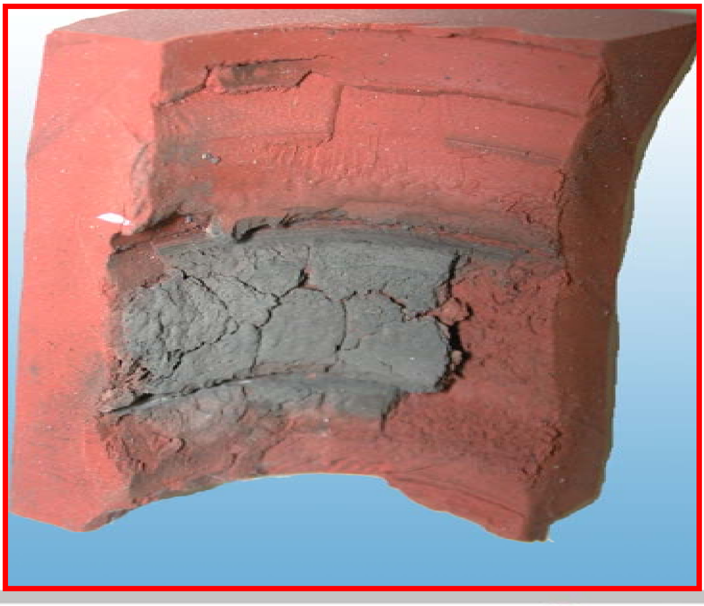
Gun Treatment

- Gun is potted with RTV
  - Provides electrical insulation against humidity
  - Adds breakdown resistance
  - Protects against dust & dirt
    - Minimize maintenance & cleaning
  - Constrains connecting leads
  - Mechanical protection from damage

Potting Problems

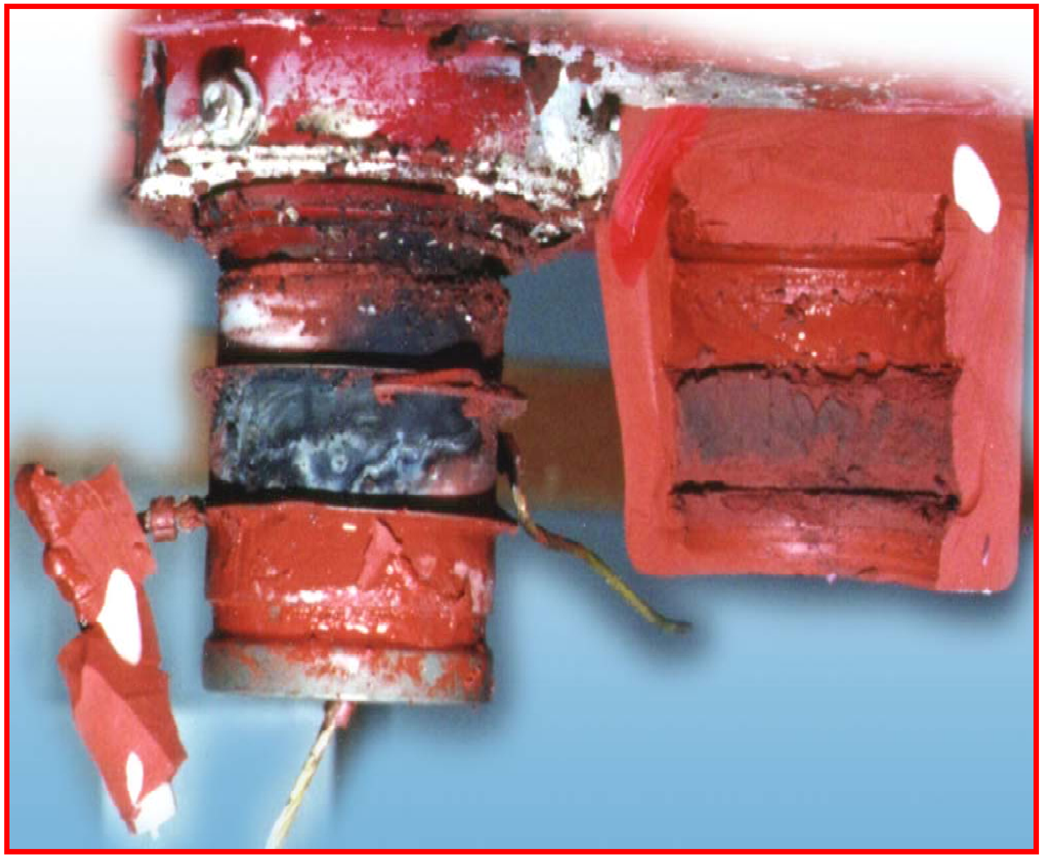


Liquefied, dried, and decomposed



Failure Types

- External arcing
- Internal arcing
- Potting failure
- High leakage
- Ceramic fracture

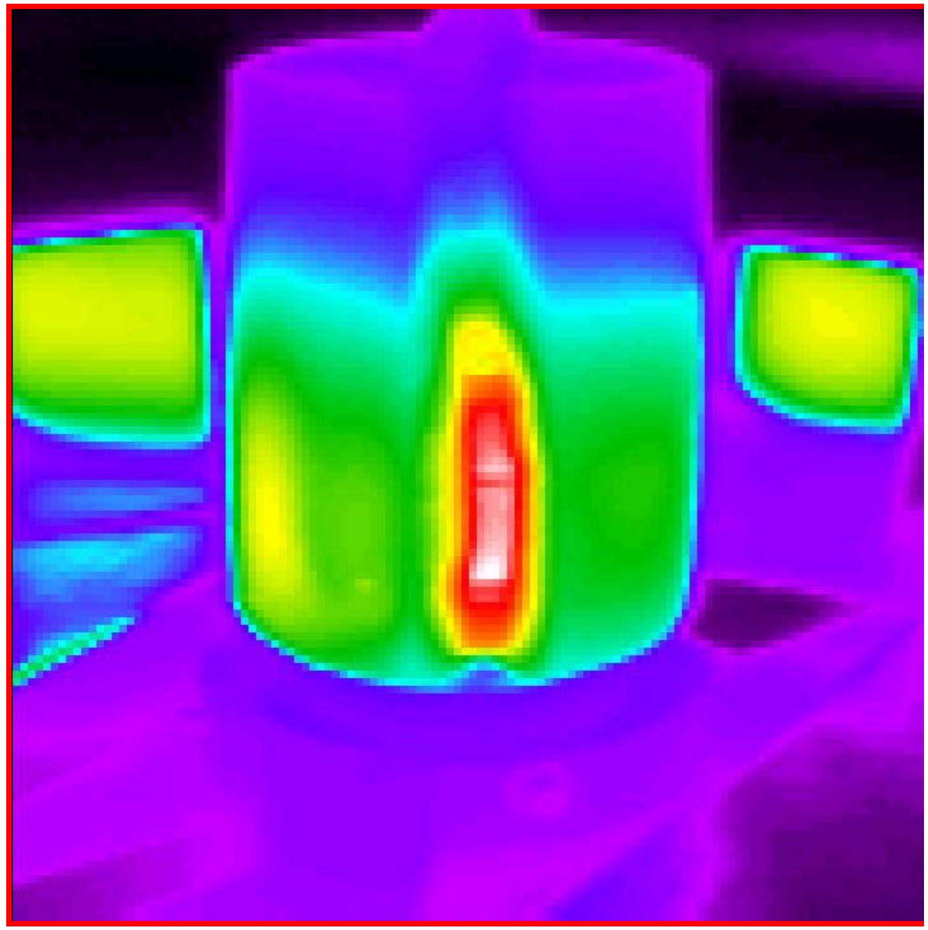


Locating Bad Potting

- Try to find potential bad potting
  - Visual inspection
  - Tactile (Charmin® test)
  - Ultrasound examination
- All methods found *some* pending failures; no test proved 100% reliable
- Result - All surviving tubes were repotted (4/95 – 6/96)

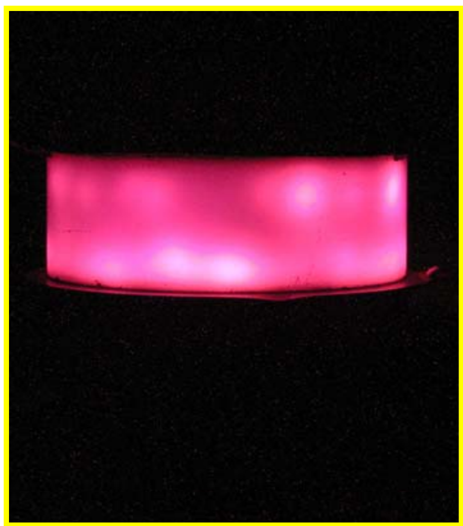
Potting and Ceramic Failure

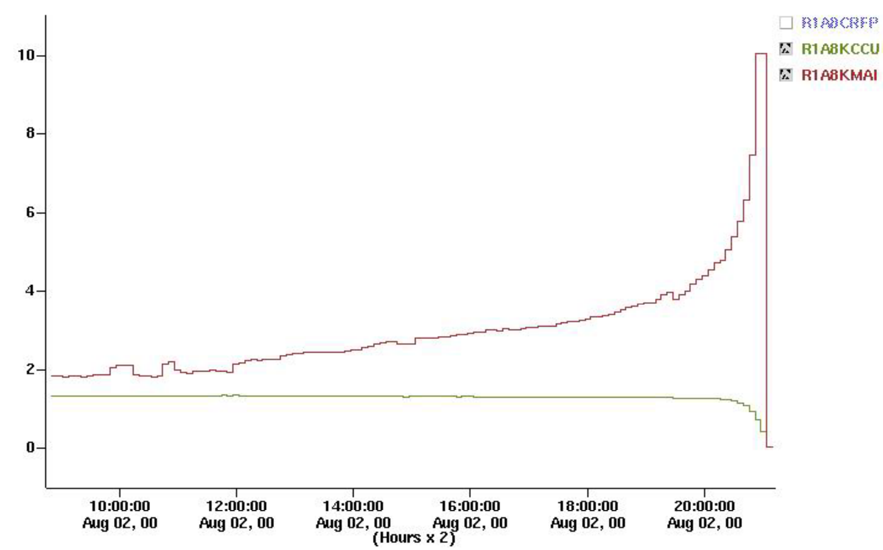
- Due to excessive heating from
  - Heater power
    - ~30 watts
    - Found 60 watts met rated RTV temperature
  - Intercept currents on modulating anode
  - Leakage across gun ceramic insulators



Internal Barium Deposition

- Tubes exhibit linear and non-linear leakage
- Non-linear due to field emission
  - Conditioned out by hipotting or controlled operation
- Linear due to internal leakage across ceramic
  - Thermal runaway can occur resulting in ceramic breakage
  - Catastrophic runaway can occur in hours, if left unchecked



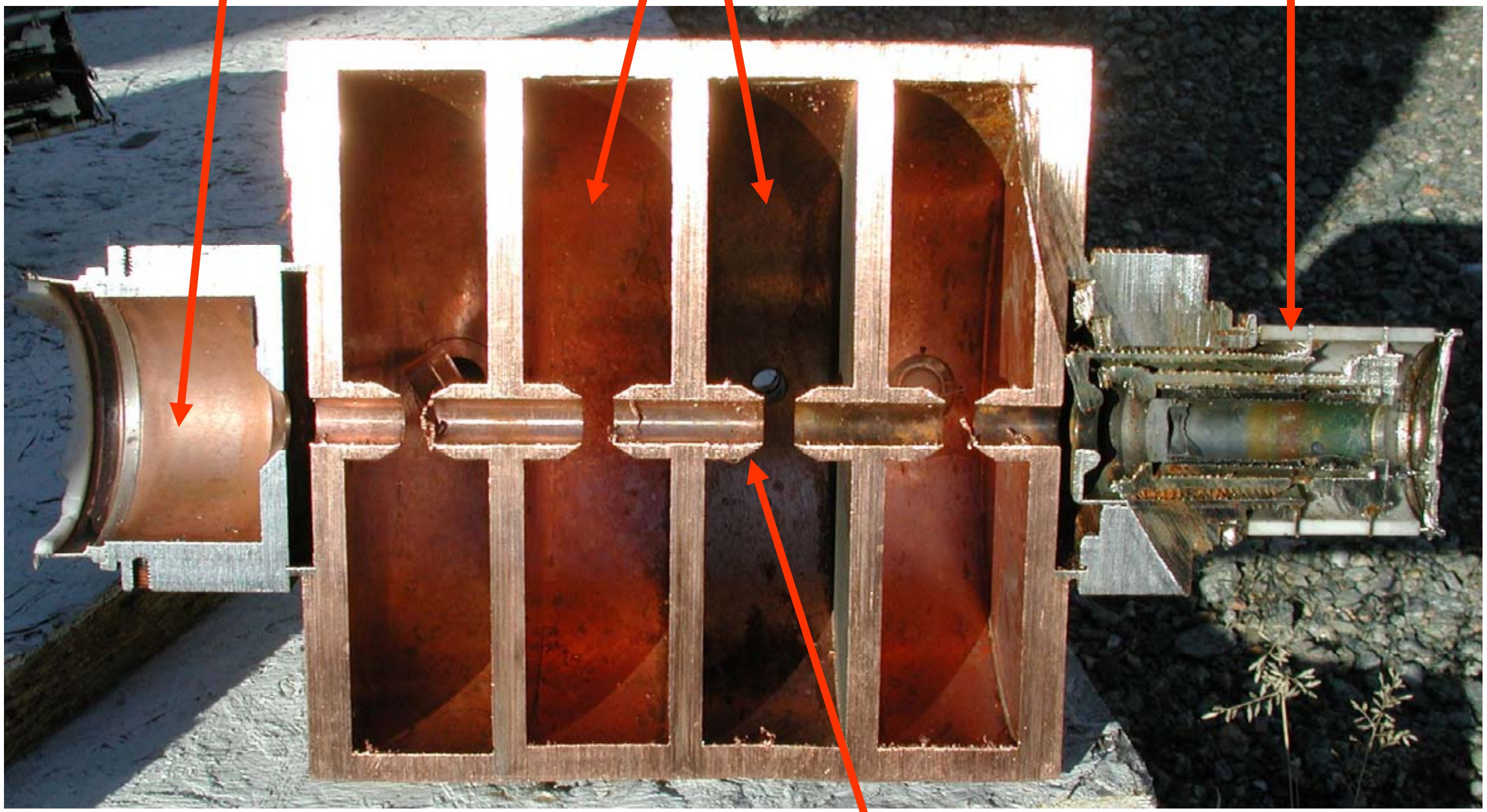


Klystron Cross Section

Collector is Removed

Cavities

Gun



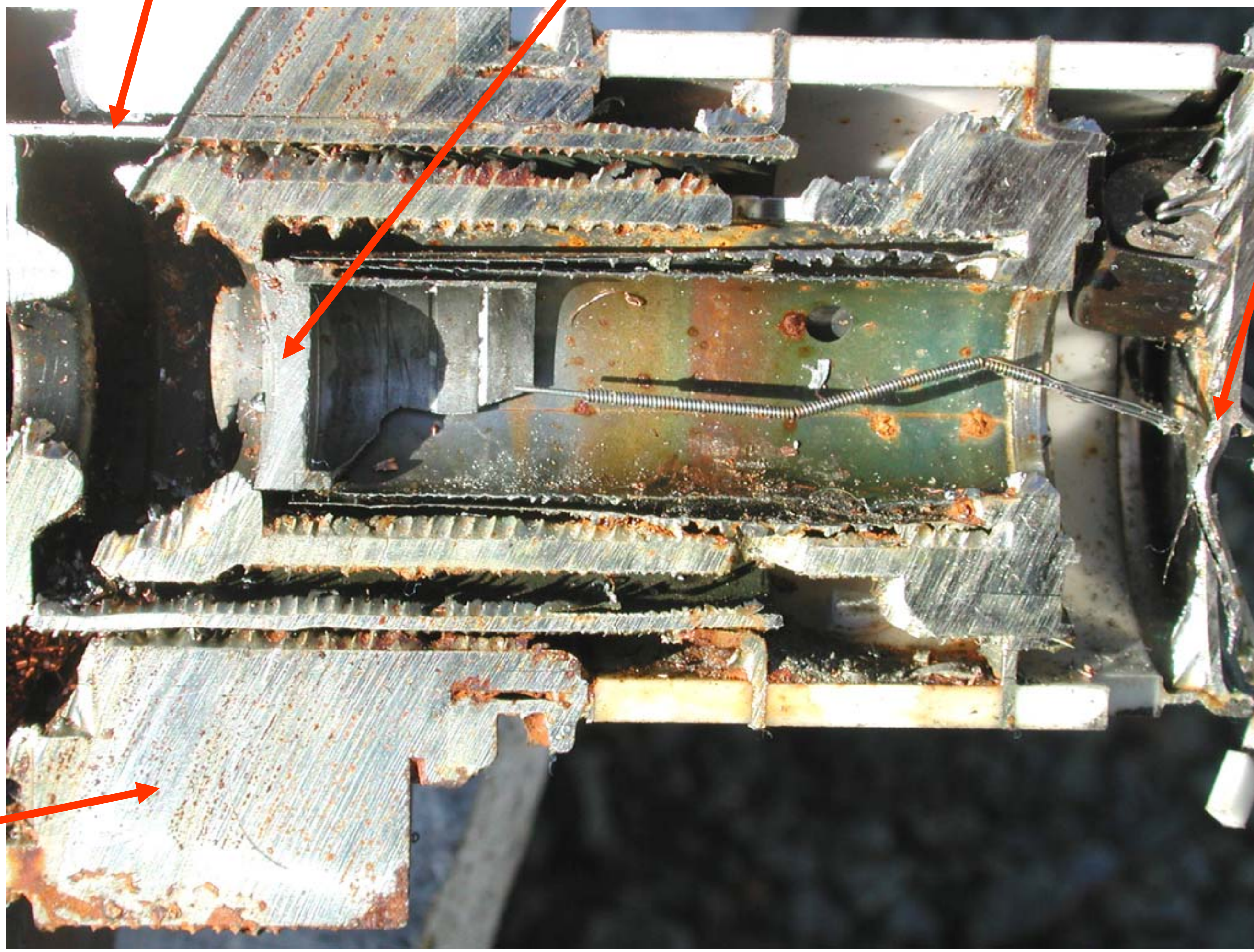
Drift Tubes

Gun Cross Section

Mod Anode

Cathode

Filament



Body

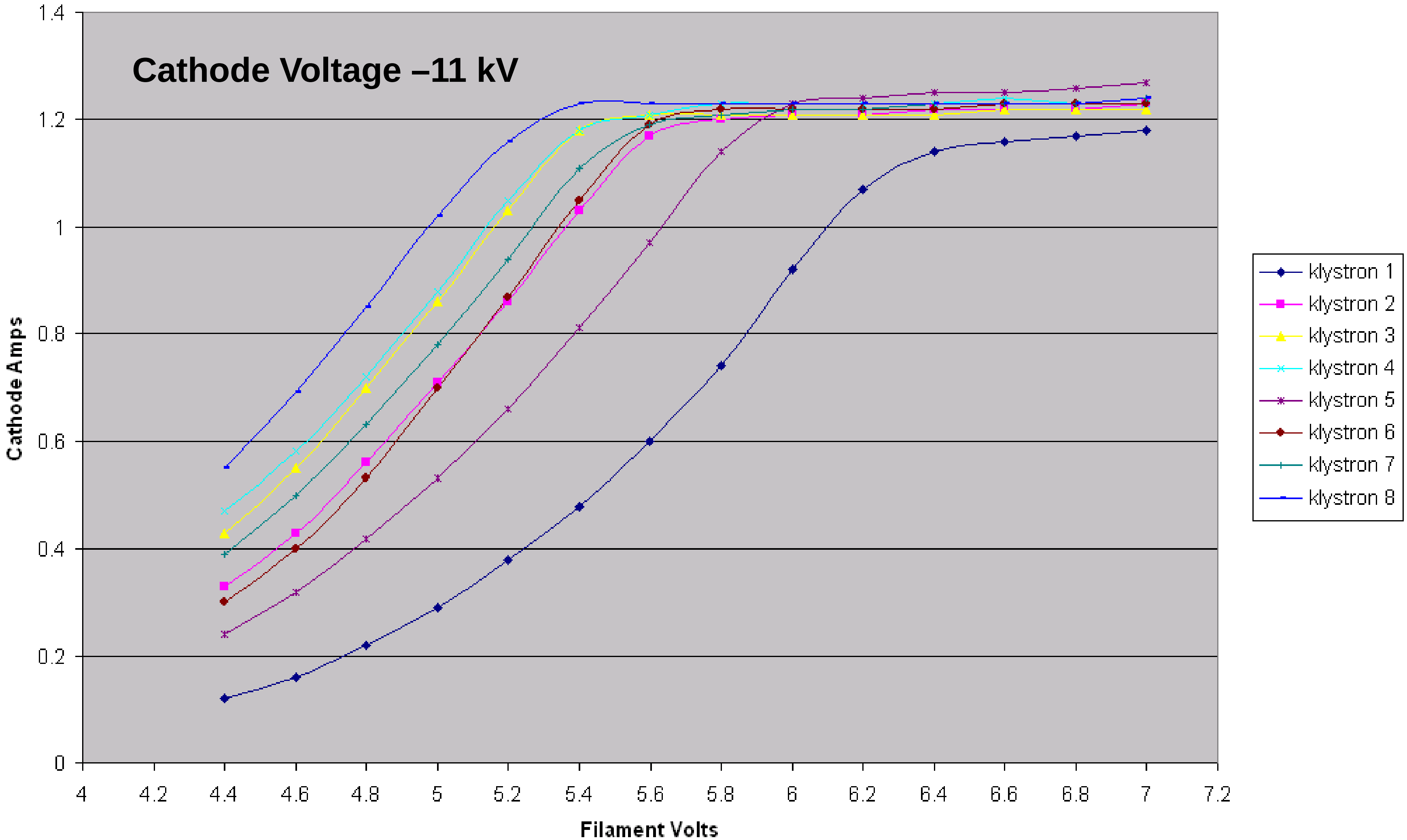
Failures When We…

- Increase operating cathode voltage
- Lower mod anode voltage
  - This increases voltage across the ceramic
- Demand higher RF power
  - Additional mod anode intercept with RF
- Fail to observe the onset of problems and take action before catastrophic failure

Other Failures

- Emission failure from cathode depletion
- Open heater element
- RF output connector
- Damage to HV lead insulation (silicone) from rough handling
- Vacuum leaks from tuner diaphragm failure
- LCW (cooling water) interlock failure
  - Collector copper melted into drift tubes

Temperature & Space Charge Limits



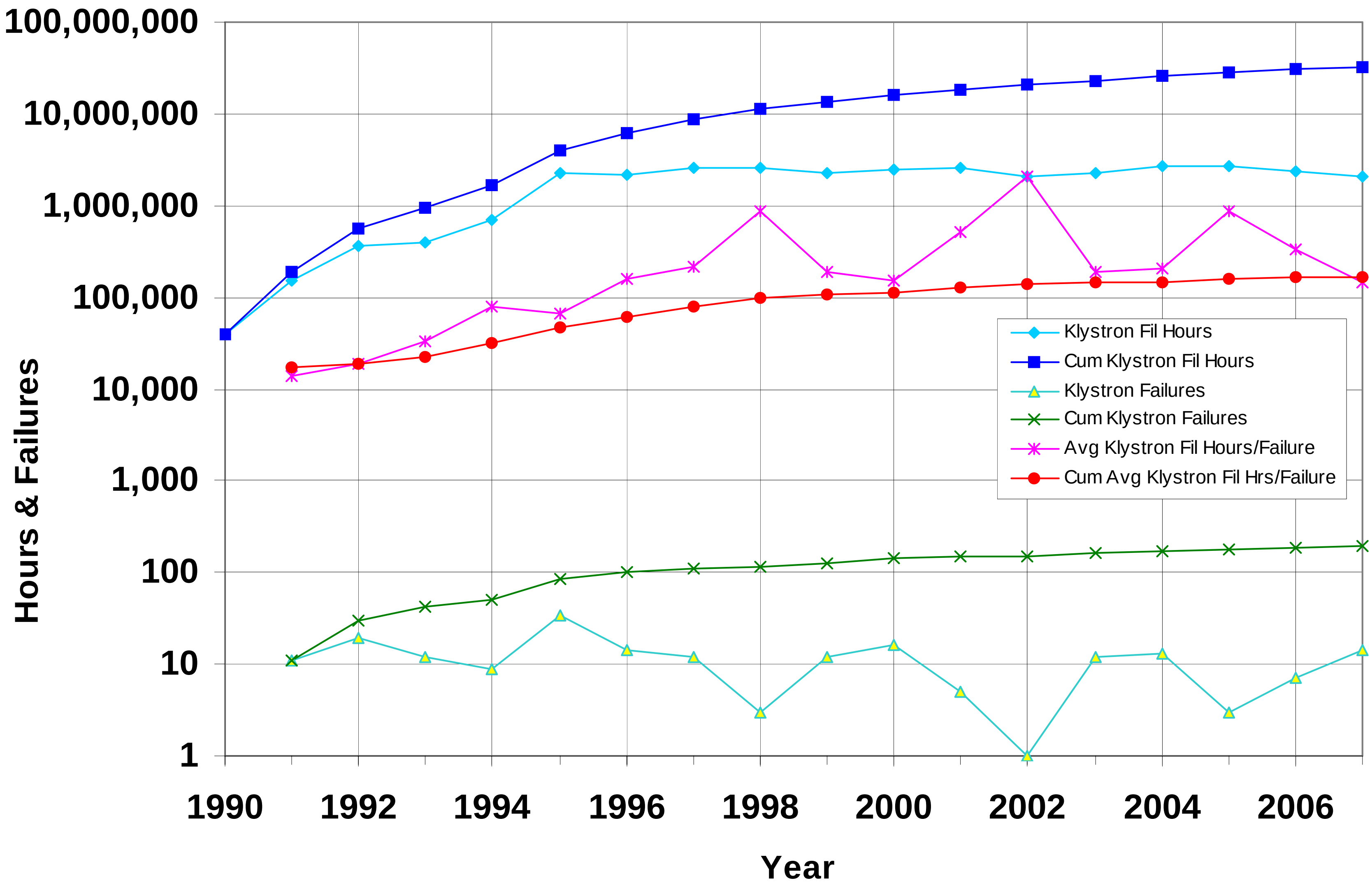
Operational Changes

- Minimize filament power
  - Voltage is remotely monitored & settable
- Monitor mod anode current
  - Increase mod anode voltage to reduce mod anode current & ceramic leakage current
- Minimize beam voltage
  - Adjust tap settings on cathode power supply for each RF zone for power required
  - Lowers the power from leakage on ceramic

Mechanical Changes

- Lengthen mod anode to cathode ceramic
  - Reduce mod anode to body ceramic length
  - Allows existing gun design to otherwise remain unchanged
  - Provides more surface area to receive barium boil off
  - Results in longer time to develop serious leakage
- Relocate gun stem vent holes (holes are between gun interior, heat shield, and exterior)

Klystron Reliability Graph



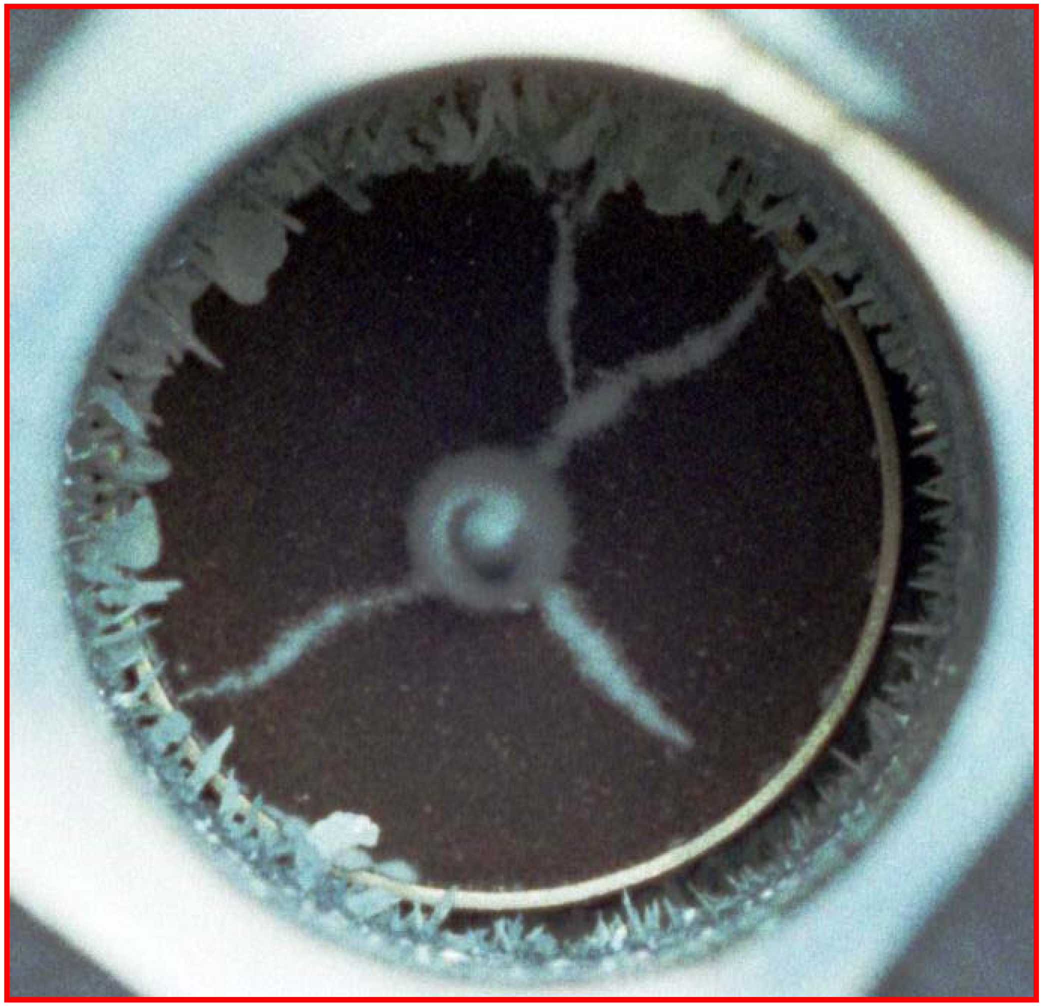
Klystron Reliability Table

Year	Klystron Filament Hrs	Cum Klystron Filament Hrs	Klystron Failures	Cum Klystron Failures	Avg Klystron Fil. Hrs / Failure	Cum Avg Klystron Fil. Hrs / Failure
1990	40,000	40,000	0	0	0	0
1991	150,000	190,000	11	11	13,636	17,273
1992	365,000	555,000	19	30	19,211	18,500
1993	390,000	945,000	12	42	32,500	22,500
1994	700,000	1,645,000	9	51	77,778	32,255
1995	2,268,000	3,913,000	34	85	66,706	46,035
1996	2,187,000	6,100,000	14	99	156,214	61,616
1997	2,546,000	8,646,000	12	111	212,167	77,892
1998	2,626,000	11,272,000	3	114	875,333	98,877
1999	2,277,000	13,549,000	12	126	189,750	107,532
2000	2,424,000	15,973,000	16	142	151,500	112,486
2001	2,538,000	18,511,000	5	147	507,600	125,925
2002	2,032,000	20,543,000	1	148	2,032,000	138,804
2003	2,309,600	22,852,600	12	160	192,467	142,829
2004	2,715,456	25,568,056	13	173	208,881	147,792
2005	2,657,232	28,225,288	3	176	885,744	160,371
2006	2,343,600	30,568,888	7	183	334,800	167,043
2007	2,077,440	32,646,328	14	197	148,389	165,717

Summary

- Several failure modes have been addressed
  - Reduced failure rate though
    - Operating mode changes, when possible
      - Lowered filament voltage
      - Reduced cathode voltage
    - Constant monitoring and adjustment of Mod Anode
    - Potting changes
      - Used better material (higher temp. & conductivity)
    - Internal mechanical design changes
- Present average life is 165,000 hours
- After repotting all klystrons in mid-1995 to 1996, 61.7% have not failed nor even been moved

Pictures of Problems

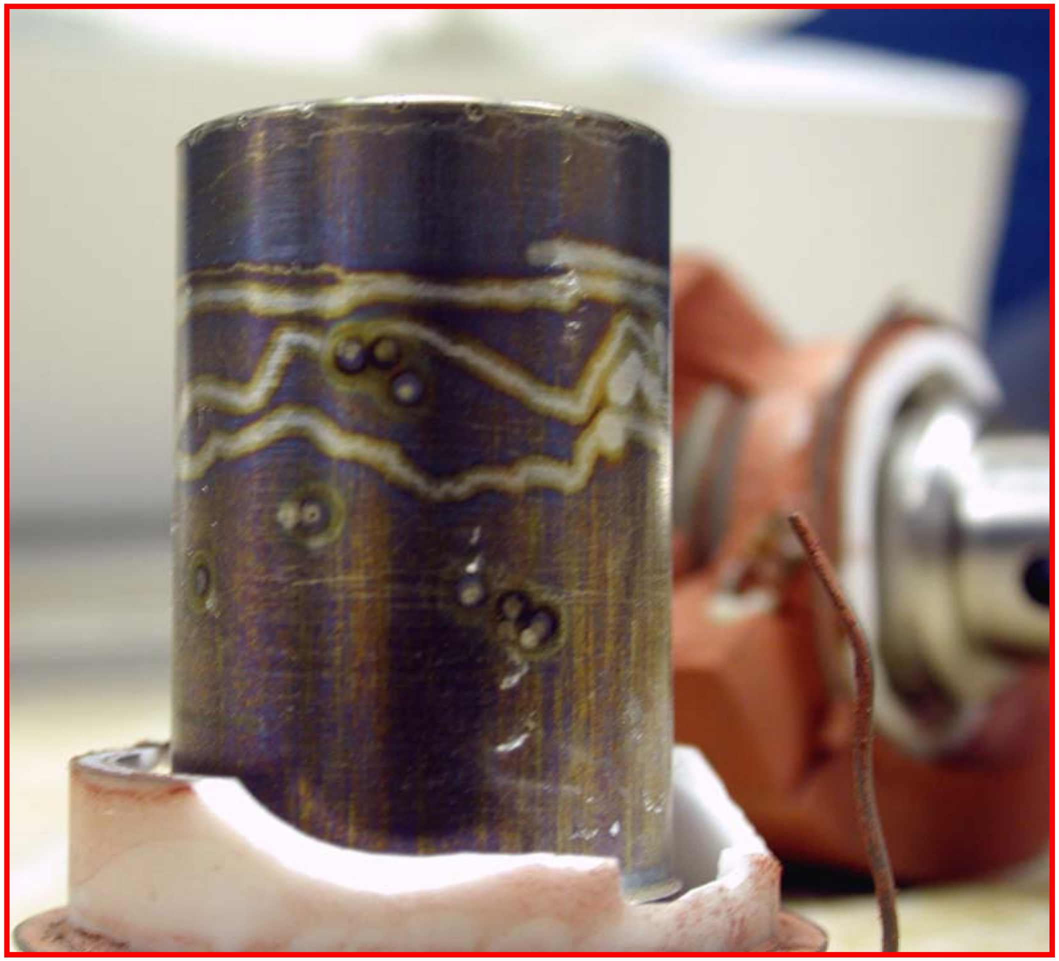


- Crystal growth behind cathode heater
  - View inside gun stalk showing heater potting with cracks

Ion Burn

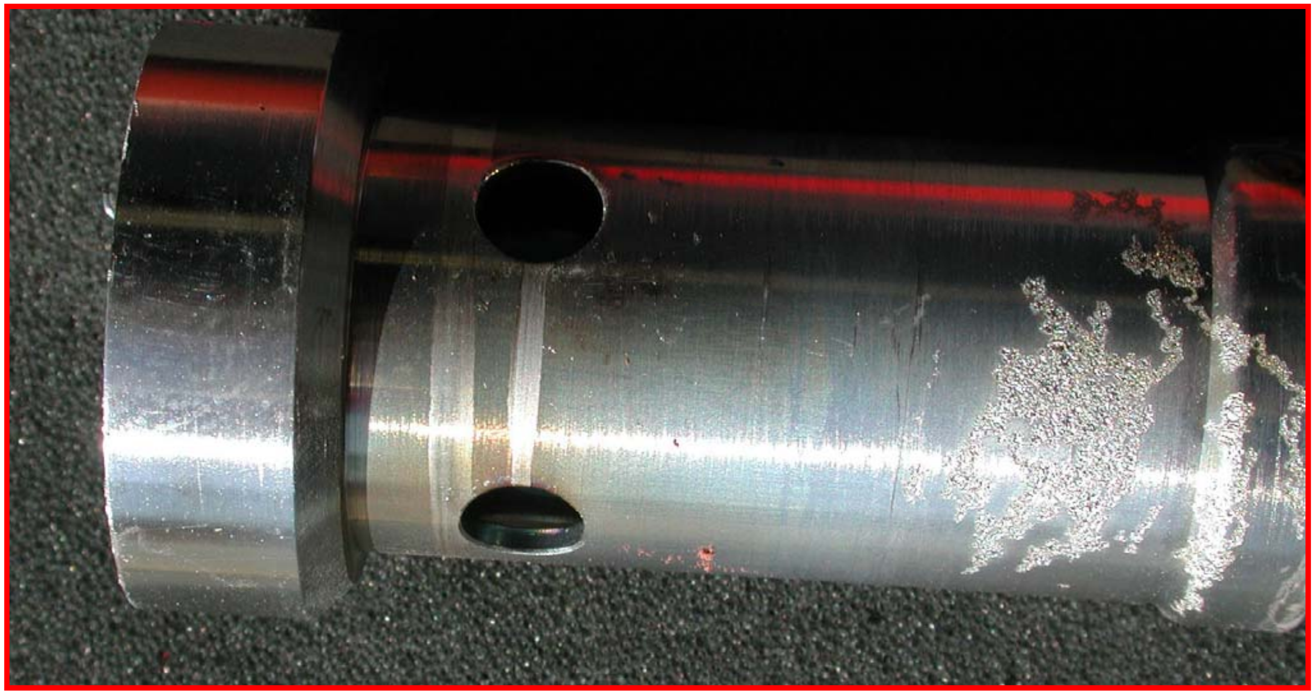
- Cathode shows ion burn
- Tube has no separate ion pump

Pictures of Problems



- Mod anode arc tracks

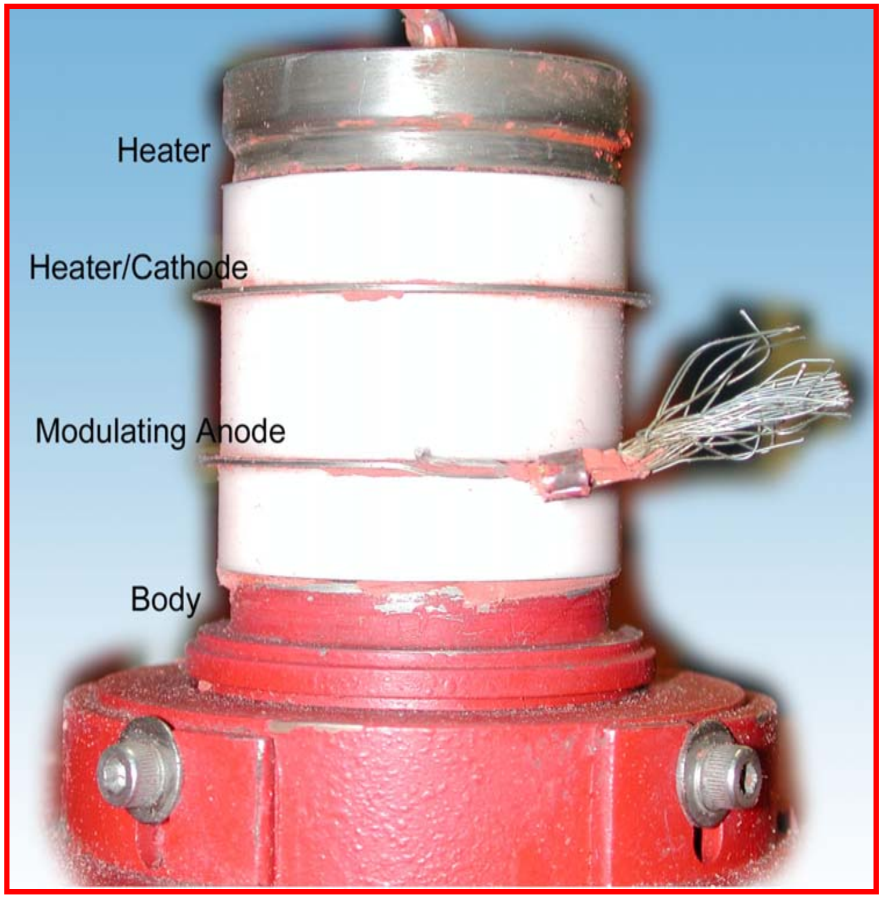
Pictures of Problems



- Gun stem arc tracks

Output Connector

Gun Externals



- Gun with potting removed
- Connections for
  - Heater
  - Heater/Cathode
  - Mod Anode