

The APS 350-MHz CW RF Test Stand



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Outline

- General Description and Layout
- Recent Statistics
- Successes & Failures
- Conditioning Techniques
- Recent Improvements
- Future Plans

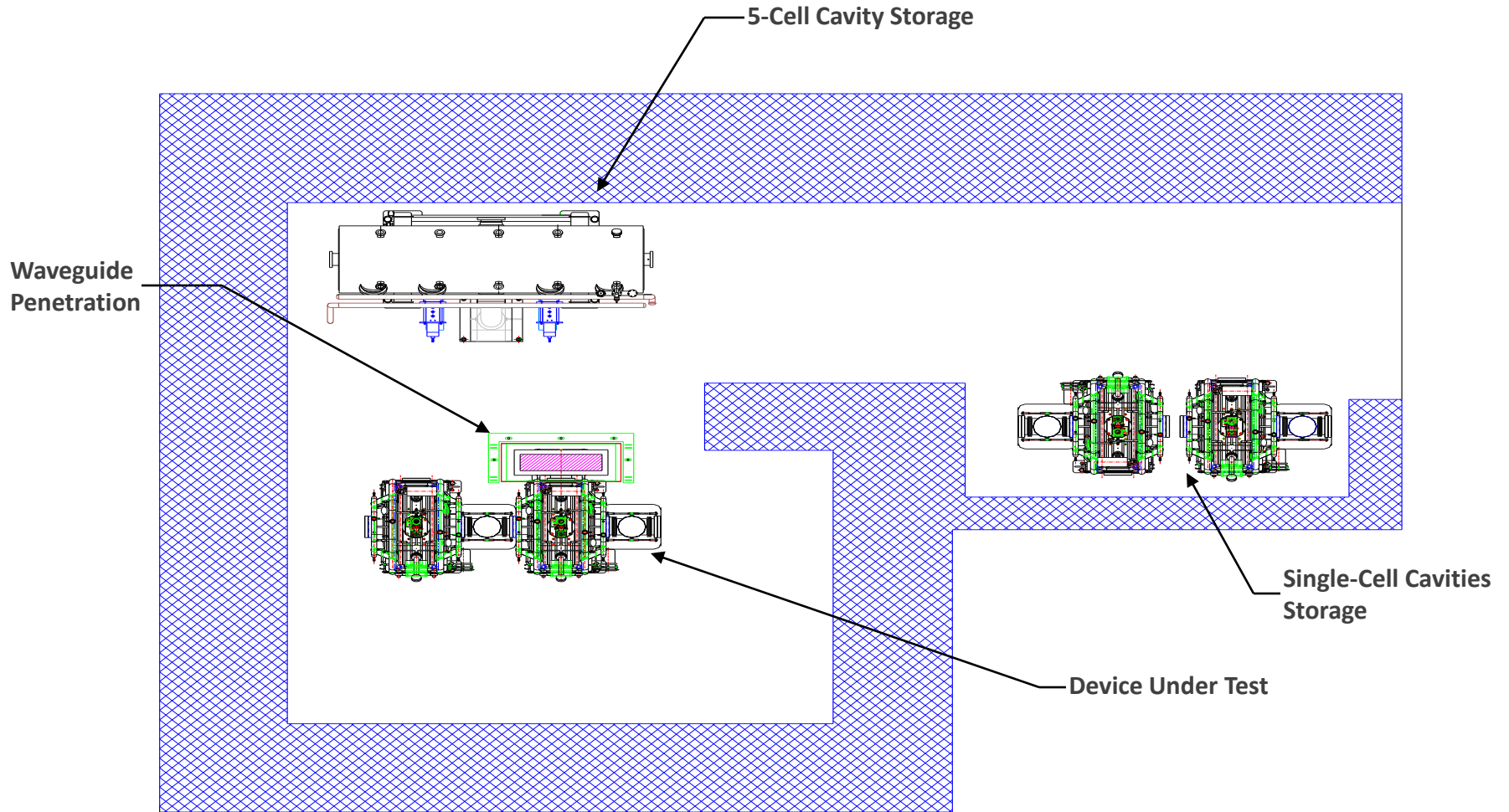


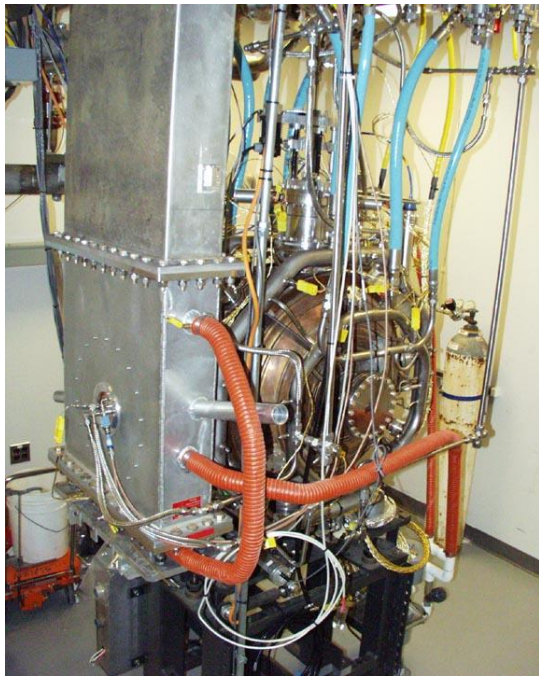
General Description and Layout

- RF source and LLRF system independent of APS operations
- Klystron and power supply (RF1), shared with operations
- Waveguide switching system and shutters
 - Switching system can direct rf power from RF1 to either the Storage Ring, the RF Test Stand, or a 1MW RF Load
 - Waveguide shutters are utilized as a personnel safety system to allow entry into the bunker with Storage Ring rf stations on-line
- Can be configured to power a single-cell cavity with one or two input couplers, or a 5-cell cavity
- Storage space for two single-cell cavities and one 5-cell cavity
 - Cavities stored under vacuum with cooling water

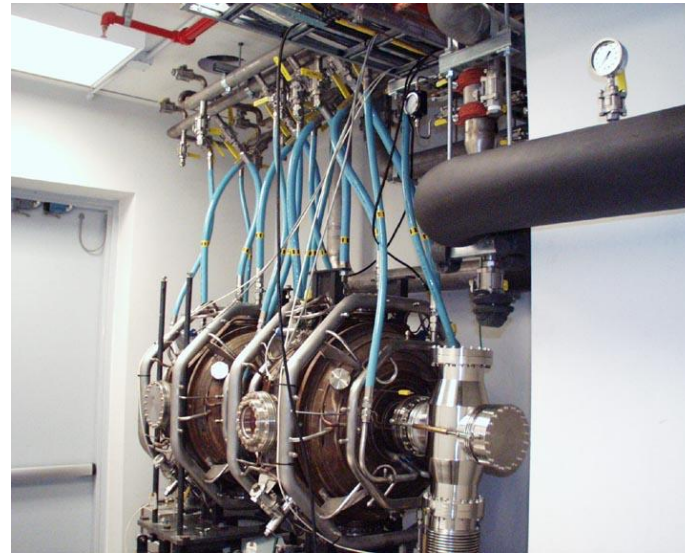


Test Stand Bunker Layout

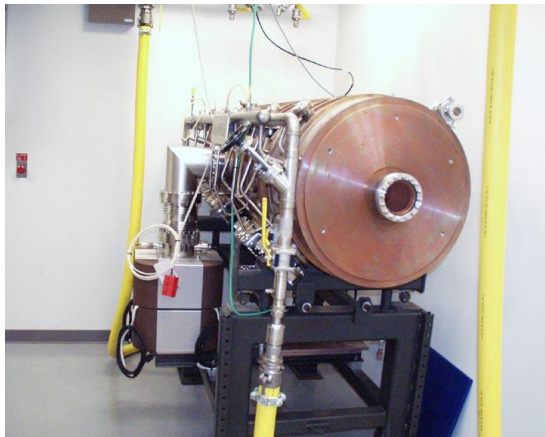




Device Under Test



Single-Cell Cavities in Storage



5-Cell Cavity in Storage

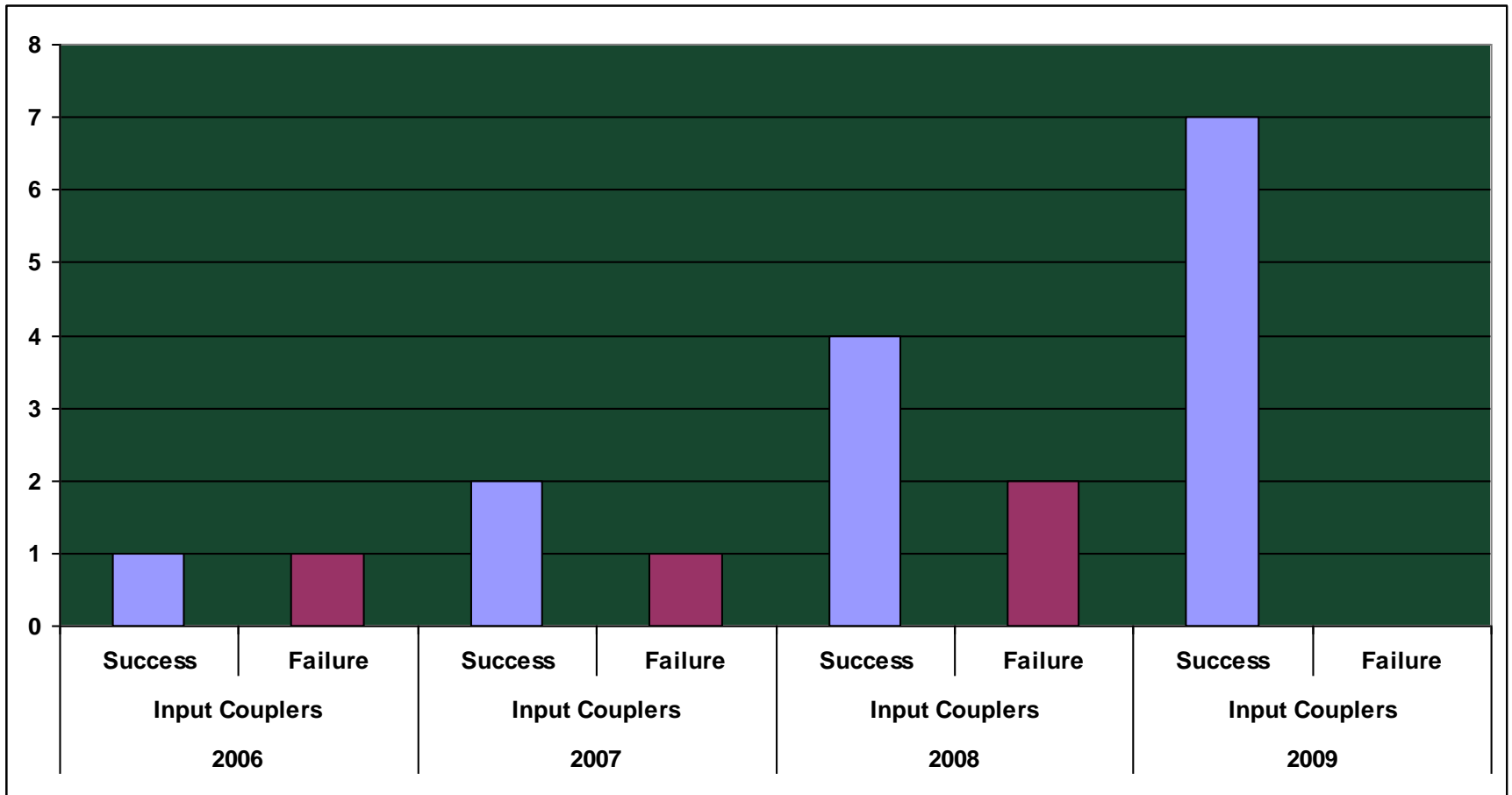


Device Under Test

View From Test Stand Doorway

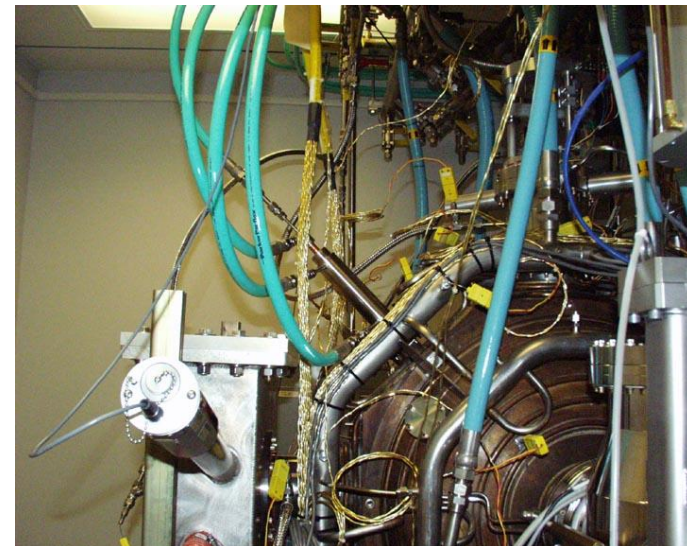


Recent Statistics



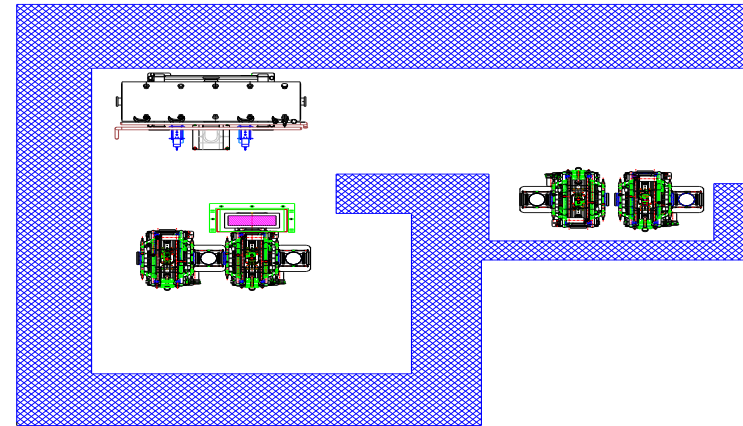
Recent Successes

- Successfully tested and conditioned HOM dampers prior to installation on the sector 38 cavities
- We now have an adequate stock of conditioned spare SR couplers (6), SR tuners (3), and Booster couplers (3)



Recent Successes

- 200kW “Two Coupler Test”
 - A success yes, but not without some degree of difficulty
 - Original thought was to use the existing penetration and plumb the waveguide and hybrid to the 2nd coupler on the inside of the bunker. Water for the hybrid load was available, so why not?
 - Real estate was an issue
 - Needed to add a second waveguide penetration (shielding modification)
 - Once we finally began the test, other problems surfaced

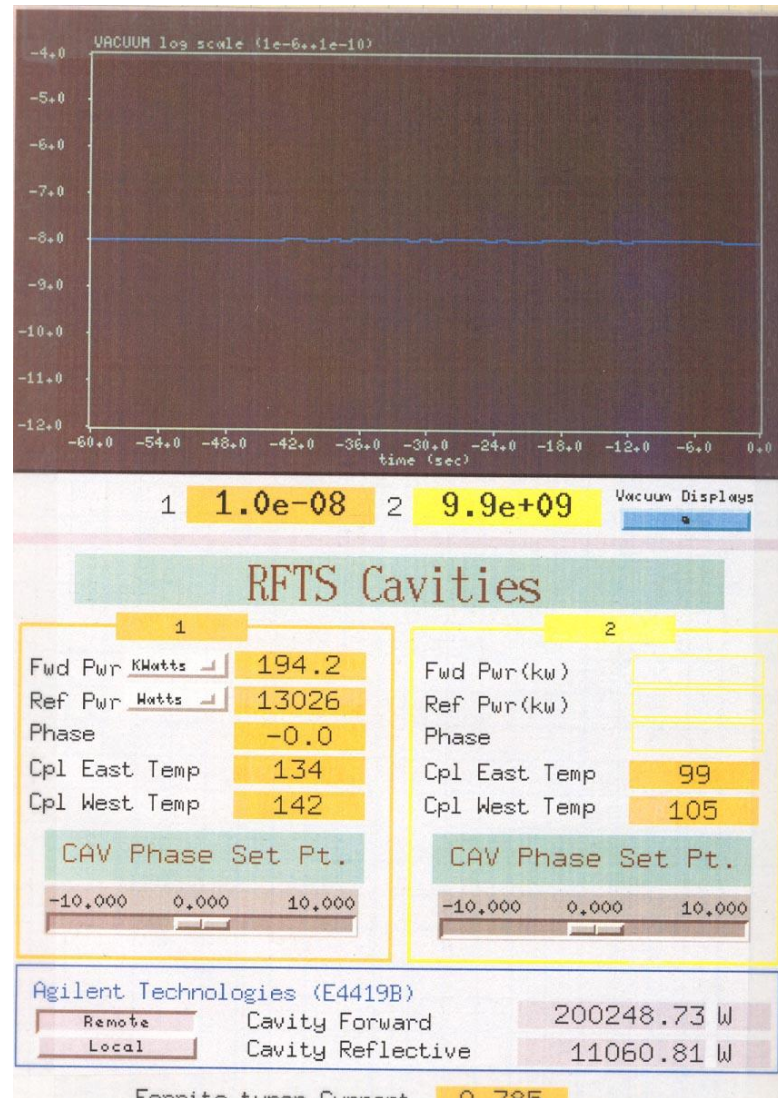


200kW “Two Coupler Test”

- Began rf operation in December 2006
- One of the couplers (ANL-14), took a hit at 60kW
 - Base pressure held at $\sim 1\text{E-}8$ torr and did not recover
 - Helium leak check revealed a pin-hole leak
- Removed the failed coupler and installed another (ANL-18)
- At $\sim 110\text{kW}$, tuner piston and cavity center temps went into alarm
- Raised these setpoints to the levels used during SR high current runs
 - Tuner Piston from 42C to 45C
 - Cavity Center from 65C to 80C
 - Also raised tuner body & tuner bellows setpoints
- Moved tuner water lines to a separate water header to increase both tuner and cavity water flow
- Regular Health Physics surveys revealed high radiation levels which had to be closely monitored. Engineering and administrative controls were put in place in some areas
- At $\sim 190\text{kW}$, the power monitor (fast interlock), began tripping on waveguide overpower
- Finally reached 200kW on 10/31/07



200kW “Two Coupler Test”

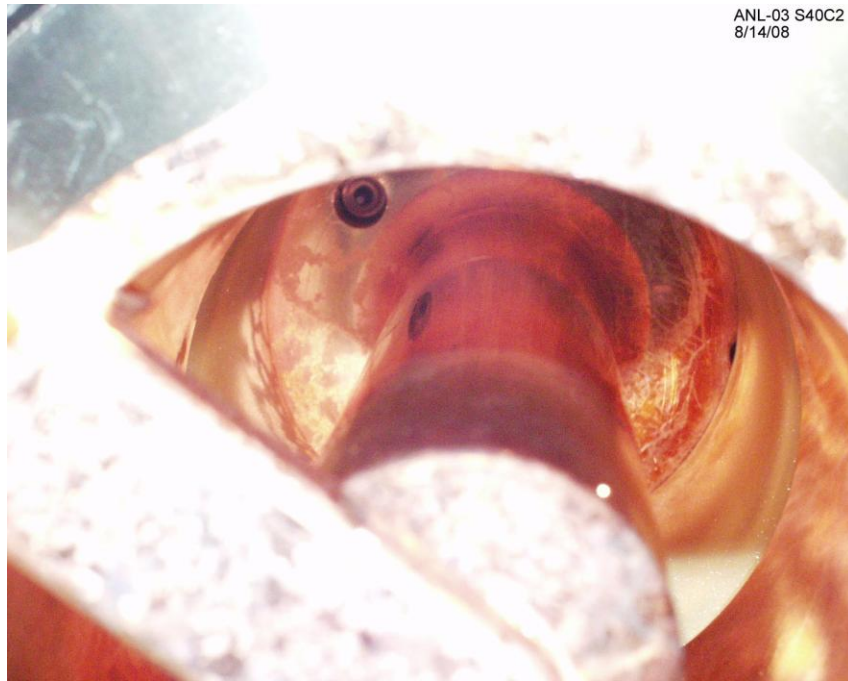


Ti Coated Copper Parts Coupler

- Selected ANL-03 as the test coupler
 - ANL-03 was removed from SR Sector 40 Cavity 4 due to repeated vacuum trips and elevated window IR temps
 - Waveguide was blanked-off to stop the trips
 - Removed the following shutdown. Inspection revealed a heavy coating of copper on the vacuum side of the window, and obvious signs of arcing on the copper parts
 - This coupler was chosen to make the test as difficult as possible. The arc marks were slightly polished down and a new window installed
- Inner and outer conductors coated with $>200\text{\AA}$ titanium
- Started on 3/20/09, encountered rough spots between 10kW-20kW with 2 vacuum trips at 11kW
- Smooth with no trips up to 75kW when coupler arc detector trips began
- Recorded trips on DVD, then reviewed the trips frame by frame and determined a coupler arc was not the cause
- Adjusted arc detector sensitivity to get through the trips
- Reached 100kW on 3/31/09

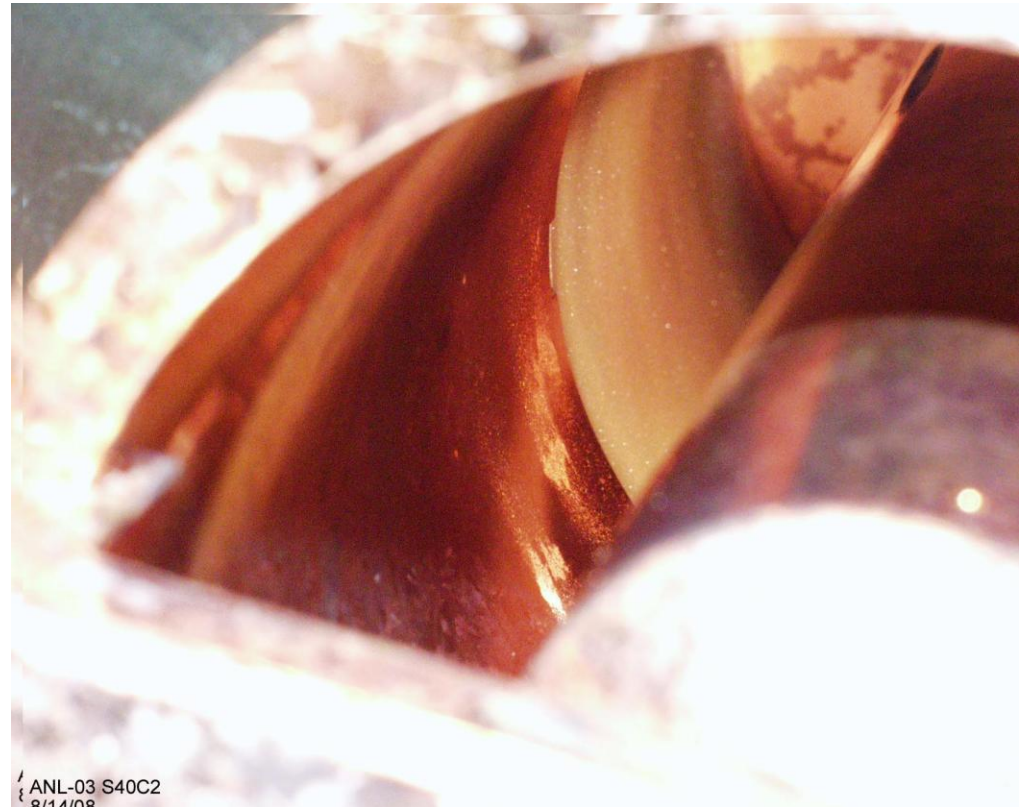


Ti Coated Copper Parts Coupler



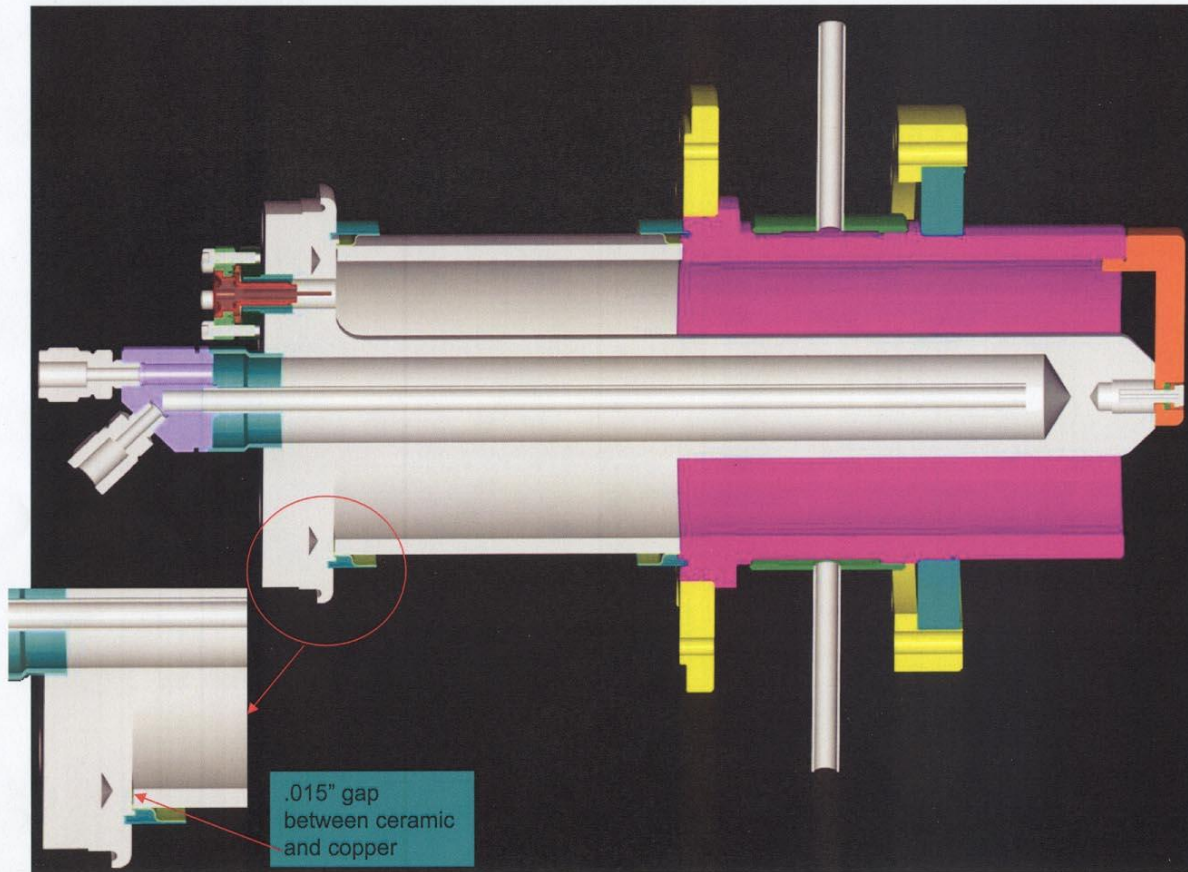
Common Failure Modes

- Ceramic window pin-hole leaks
 - High base pressure that does not recover, usually in the low E-8 torr range
- High infrared thermometer temperatures/Repeated Vacuum trips
 - Visible signs of arcing on inspection after removal
 - Vacuum side of window discolored by copper deposition, color varies with amount of deposition
 - Light Yellow
 - Green/Gray
 - Dark Gray
 - Copper



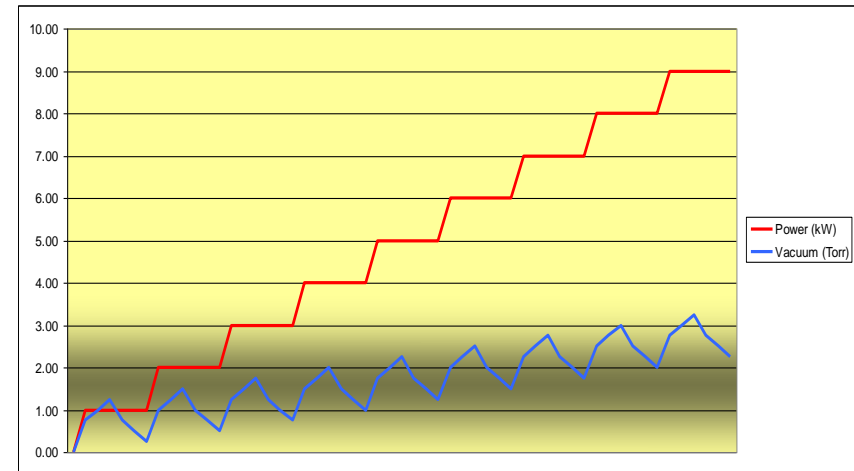
Common Failure Modes

Coupler with Current Ceramic Design

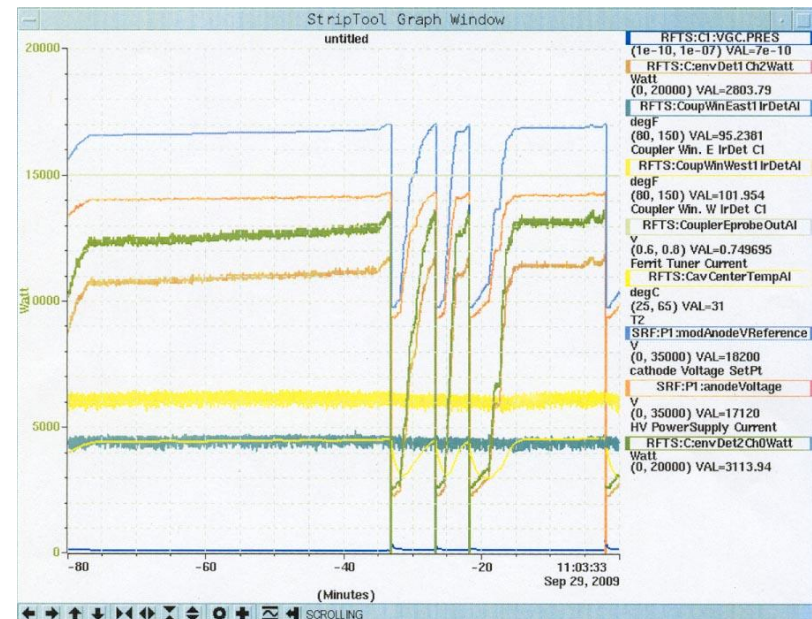


Conditioning Techniques

- Ideally conditioning would look like the chart on the top. Steady increases in power with a sawtooth vacuum waveform that has a slightly elevated base pressure with increased power.

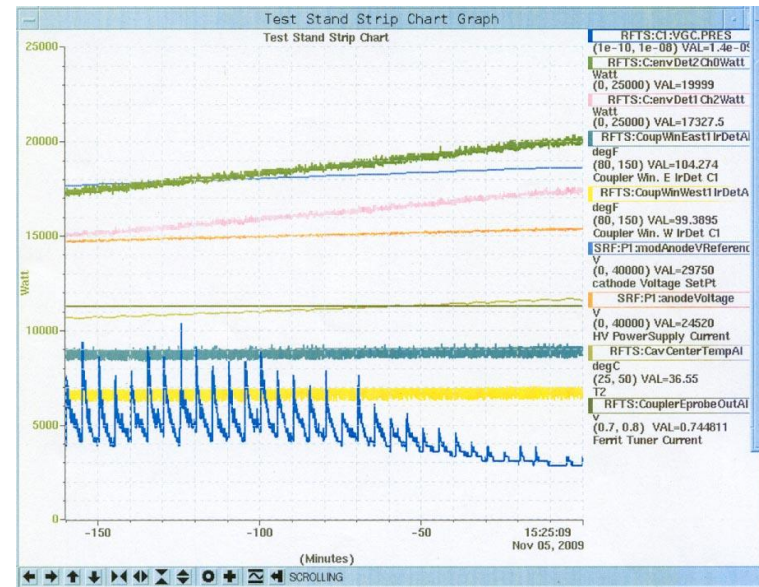
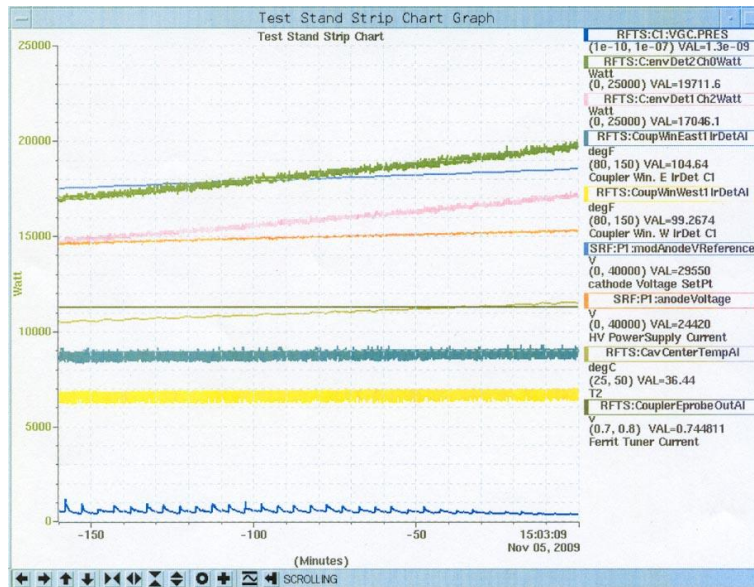


- In reality though, you're more likely to encounter something like the chart on the bottom.



Conditioning Slow & Steady

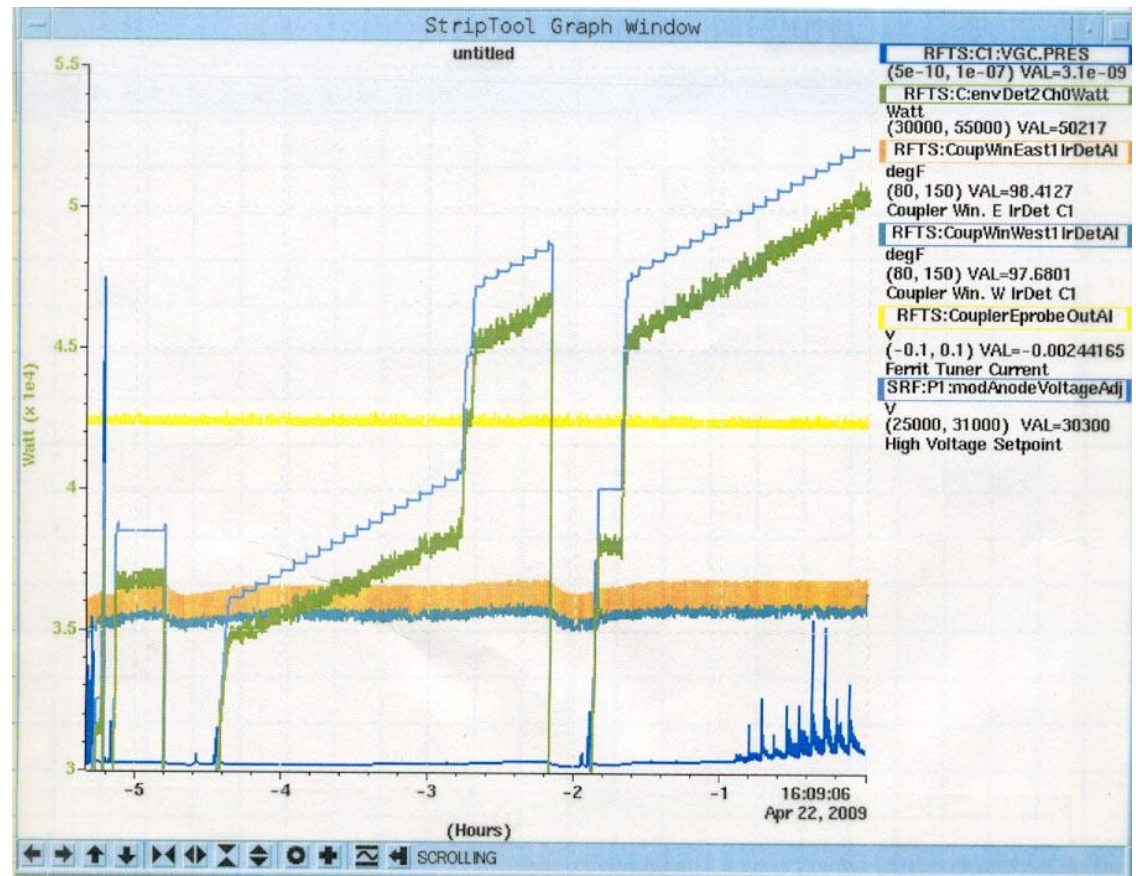
- Preferred method. Regular intervals of power increases. Pressure increases then settles down prior to the next power increase
- Classic “sawtooth” vacuum waveform



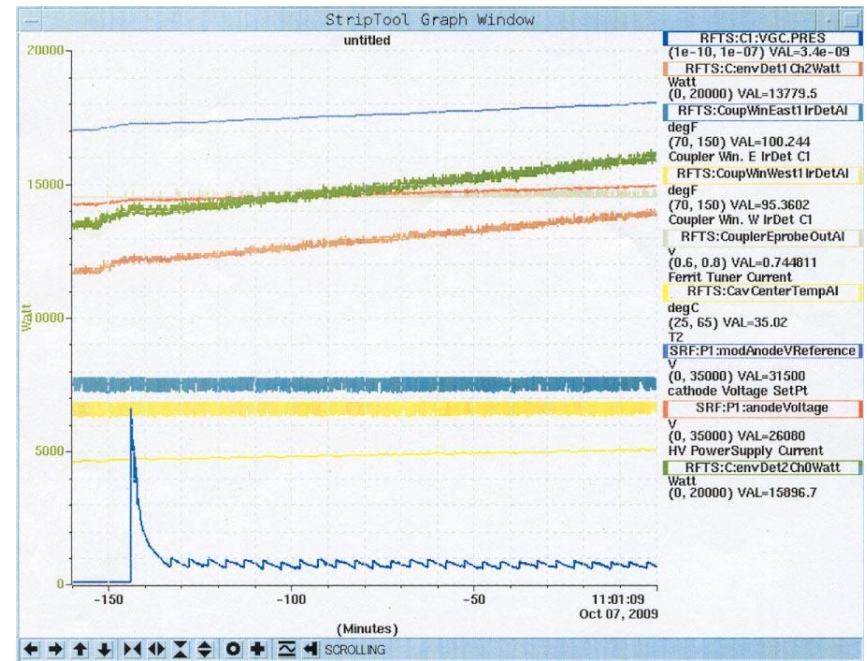
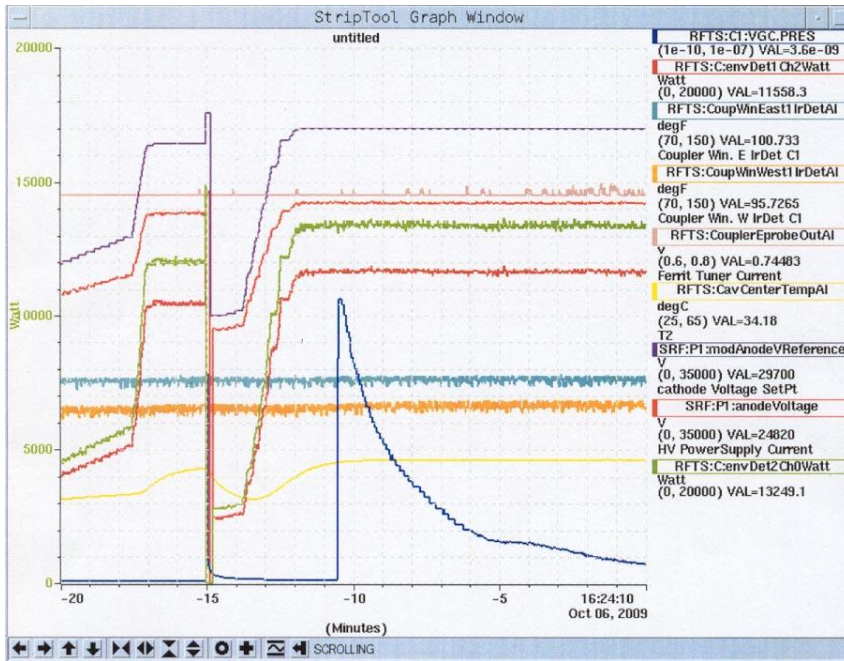
Conditioning

2 Steps Forward, One Step Back

- Effective when stuck at the same power level due to repeated vacuum trips
- Allows the cavity to momentarily see the power level you're stuck at, before it has a chance to trip
- Another effective method to use when stuck at a certain power level is to bring the power to a level just below the problem area, and just let it "cook" there for a few hours

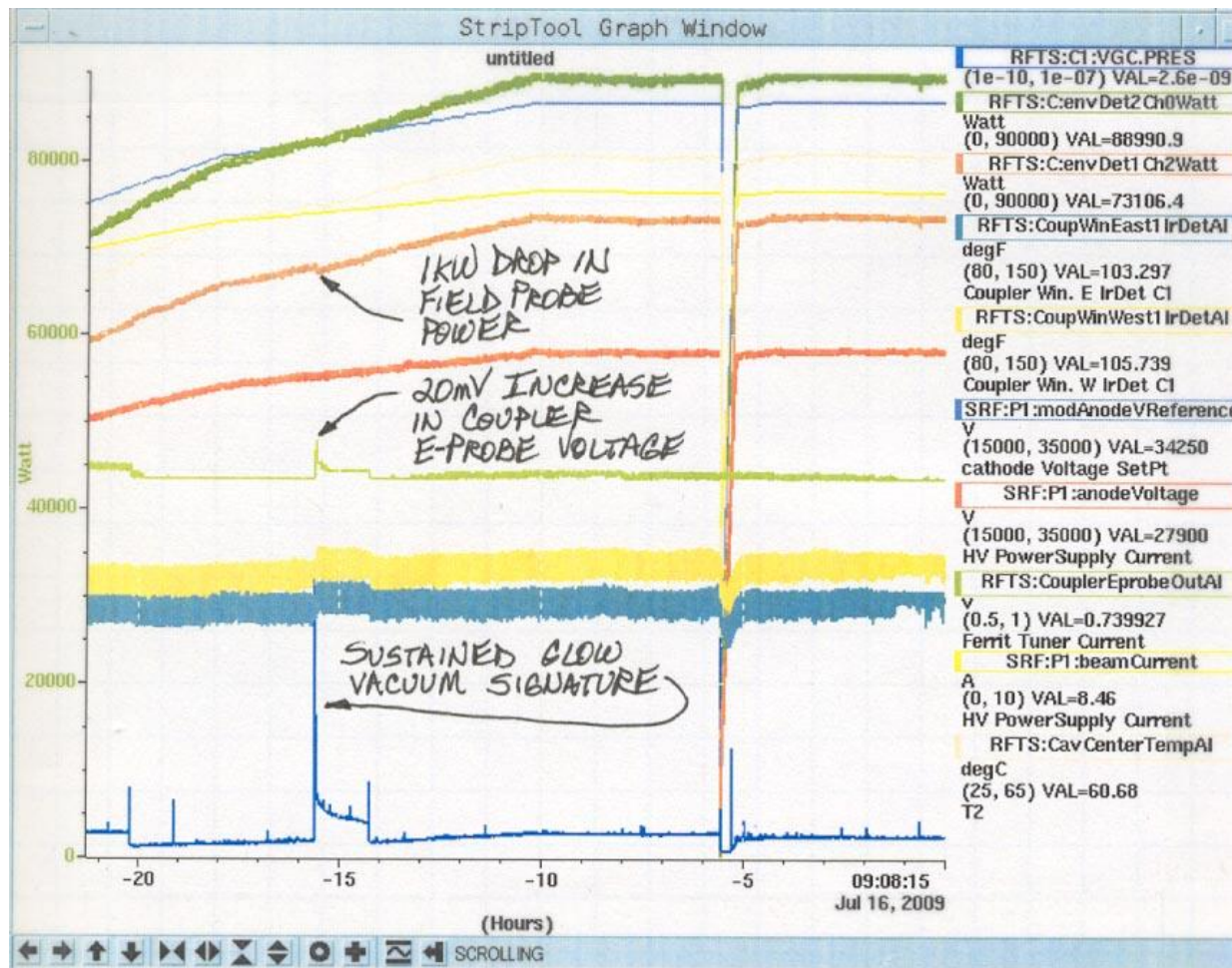


Conditioning Blast-Thru (Last Resort)



Conditioning

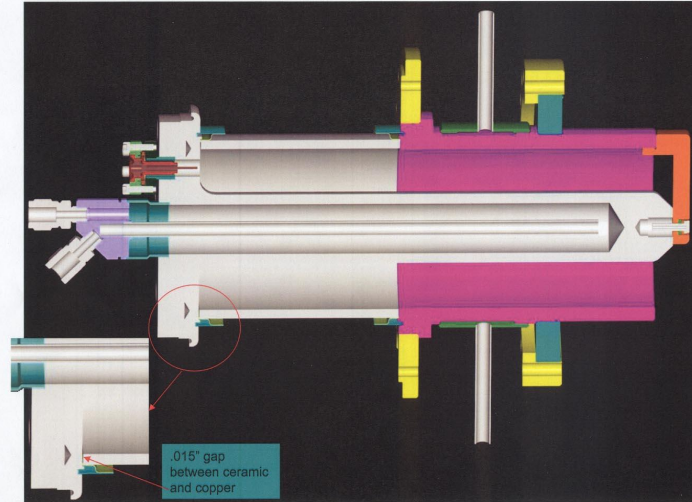
Another Signature Vacuum Waveform “The Glow”



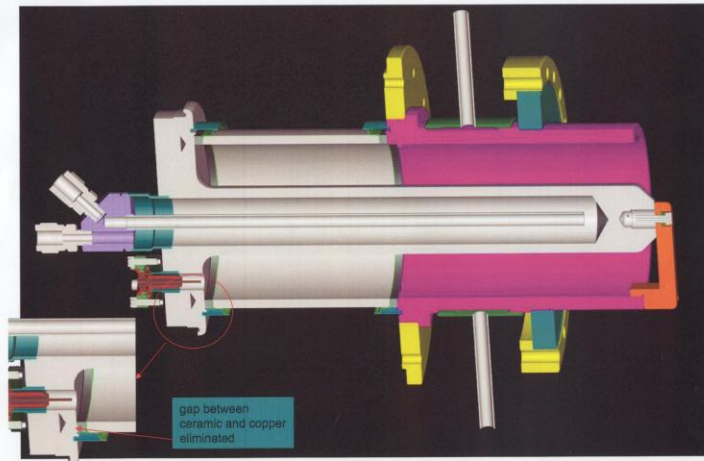
Recent Improvements

- Ti coated copper parts
- Metalized the ceramic edge gap caused by the ceramic to Kovar ring
 - 4 vacuum trips total to 100kW
- Full width Kovar ring to eliminate the gap (Yet to be tested)
- Installed an arc detector looking at the coupler through a quartz viewport
- Automated Conditioning Script
 - Several iterations with new features over the past 3 years
 - Mimics how an operator would react to events

Coupler with Current Ceramic Design



Coupler with Proposed Ceramic Design



Auto-Conditioning Main Screen

If cavity forward power limit is reached, program will go into a 'Hold' mode where conditioning will stop, but the restart facility will remain active (if enabled).

OK

If cavity reflected power is greater than this value in dB down from the forward power, then the cavity is assumed to be out of tune and the program will terminate

OK

If max beam current is reached, program will go into a 'Hold' mode where conditioning will stop, but the restart facility will remain active (if enabled).

OK

The mod-anode will be incremented by this value after allotted time

OK

Minimum time before mod-anode is incremented

OK

User Defined Parameters

Process Variable Readbacks

File Help

RFTS Conditioning Process Control

Cavity

- Forward Power: 100.0 kW
- Reflected Power: 15 dB

Mod-Anode

- Max Beam Current: 9.0 A
- Increment Value: 30 V
- Increment Time: 5.0 Min

Coupler Temp

- Warning Value: 120.0 F
- Maximum Value: 130.0 F

Maximum Vac Pressure: 1.0e-8 Torr

Maximum Num Faults: 4

Process Variable Readbacks:

- 0.00 kW
- 0.00 W
- M-A: 20.80 kV
- Next: 0.0 Min
- East: 84.25 F
- West: 84.49 F

Vacuum / Time Parameters Custom / Restart Parameters

Standby

Ready

Start Stop Clear Default

Auto-Conditioning Main Screen

The screenshot shows the 'RFTS Conditioning Process Control' window with the following parameters and controls:

- File** (Menu) | **Help** (Icon)
- Cavity**
 - Forward Power: 100.0 kW | 0.00 kW
 - Reflected Power: 15 dB | 0.00 W
- Mod-Anode**
 - Max Beam Current: 9.0 A | 5.07 A
 - Increment Value: 30 V | M-A: 20.80 kV
 - Increment Time: 5.0 Min | Next: 0.0 Min
- Coupler Temp**
 - Warning Value: 120.0 F | East: 84.25 F
 - Maximum Value: 130.0 F | West: 84.49 F
- Vacuum / Time Parameters**
 - Maximum Vac Pressure: 1.0e-8 Torr | 5.20e-10 Torr
 - Maximum Num Faults: 4 | 0
- Custom / Restart Parameters** (Dialog box)
- Standby** (Status indicator)
- Ready** (Text in status area)
- Start** | **Stop** | **Clear** | **Default** (Buttons)

Message window (Callout boxes):

- OK
- If warning coupler temperature is reached, the mod anode will not be incremented until the temperature drops below this value
- OK
- If maximum coupler temperature is reached, program will terminate. *****CAUTION***** This value will be used to determine if rf is disabled
- OK
- If vacuum exceeds the maximum vac pressure, a time delay will be introduced and the mod-anode will not be incremented until the vacuum is reduced below this value
- OK
- After maximum num faults reached the program terminates. This is only relevant if automatic restart is enabled.
- OK
- Vacuum-Time Parameters permits greater control of maverick vacuum behavior
- OK

Restart Dialogue (Callout box):

- Restart Dialogue defines restart parameters as well as recovery parameters
- OK

Status of program (Callout box):

- OK



Vacuum/Time Parameters Screen

If the difference in vacuum between two successive vacuum data points exceeds this moderate spike value, then a time delay will be introduced before the mod-anode is incremented

OK

If the difference in vacuum between two successive vacuum data points exceeds this large spike value, then a time delay will be introduced before the mod-anode is incremented

OK

The vacuum is required to settle to a level that is less than the previous vacuum level (prior to the mod-anode increment) plus this buffer value

OK

Defines erratic vacuum behavior range

OK

Number of vacuum data points to use to determine erratic behavior. Each data point is collected at a 2 Hz rate

OK

Vacuum Parameters

Mid Delta: Torr

Max Delta: Torr

Vac Buffer: Torr

Erratic

Vac Range: Torr

Samples:

Time Delay Parameters

Minor: Min

Moderate: Min

Major: Min

Delay Mode

Immediate

Num of Faults:

Pwr Envelope: kW

Delay Time: Hrs

Delay Pwr Level: kW

OK Cancel Default



Vacuum/Time Parameters Screen

Time delay due to a minor vacuum or coupler event
OK

Time delay due to a moderate vacuum or coupler event
OK

Time delay due to a major vacuum or coupler event
OK

Vacuum Parameters

Mid Delta: Torr
Max Delta: Torr
Vac Buffer: Torr
Erratic
Vac Range: Torr
Samples:

Time Delay Parameters

Minor: Min
Moderate: Min
Major: Min

Delay Mode

Immediate

Num of Faults:
Pwr Envelope: kW
Delay Time: Hrs
Delay Pwr Level: kW

OK Cancel Default

Number of consecutive faults within the 'power envelope' before 'delay mode' will be initiated
OK

If the number of consecutive faults exceeds 'num of faults' and the power levels are within 'power envelope' of each other, 'delay mode' will be initiated.
OK

If the number of consecutive faults exceeds 'num of faults' and the power levels are within 'power envelope' of each other, 'delay mode' will be initiated where the amount of time before normal conditioning begins is determined by 'delay time'.
OK

If the number of consecutive faults exceeds 'num of faults' and the power levels are within 'power envelope' of each other, 'delay mode' will be initiated where the power level will be brought to 'delay pwr level' of the lowest power level when the previous consecutive trips occurred.
OK



Restart and Custom Conditioning Screen

Custom M-A voltage increment in Volts

OK

Custom M-A time increment in seconds

OK

Cavity power level when custom conditioning schedule is started

OK

Custom Conditioning Parameters

Voltage (V)	Duration(sec)
30	15

Add Insert Delete

Custom Pwr Range: 0 kW 0 kW

Restart Parameters

Enable Restart? Yes No

Vac Pressure: 5.0e-9 Torr

Maximum Retries: 4

Mod Anode Decrement: Fixed Relative

Fixed: 16.8 kV

Relative:

Vac: 15 kV

Other: 15 kV

	Stage 1	Stage 2
Recovery Incr Value:	200 V	100 V
Recovery Incr Time:	0.25 Min	1 Min
Recovery Pwr Delta:	5.0 kW	1.0 kW

OK Cancel Default

Custom conditioning schedule listing. The entries here will be executed sequentially as part of the custom conditioning schedule. They will be executed as long as the fwd power level in the cavity remains between the values set in Custom Pwr Range. Custom conditioning may be interrupted momentarily if Delay mode becomes activated.

OK

Cavity power level when custom conditioning schedule terminates

OK



Restart and Custom Conditioning Screen

Restart will not be initiated until vacuum is reduced below this value

OK

Maximum number of retries during a restart.

OK

Prior to restart, the mod-anode voltage will be set to this value

OK

Prior to restart, the mod-anode voltage will be reduced by this value after a vacuum trip

OK

Prior to restart, the mod-anode voltage will be reduced by this value after a trip other than a vacuum trip

OK

Custom Conditioning Parameters

Voltage (V) Duration(sec)

Voltage: 30

Duration: 15

Add Insert Delete

Custom Pwr Range: 0 kW 0 kW

Restart Parameters

Enable Restart? Yes No

Vac Pressure: 5.0e-9 Torr

Maximum Retries: 4

Mod Anode Decrement: Fixed Relative

Fixed: 16.8 kV

Relative:

Vac: 15 kV

Other: 15 kV

	Stage 1	Stage 2
Recovery Incr Value:	200 V	100 V
Recovery Incr Time:	0.25 Min	1 Min
Recovery Pwr Delta:	5.0 kW	1.0 kW

OK Cancel Default



Restart and Custom Conditioning Screen

During recovery after a restart, the mod-anode voltage will be increased by this value until the forward power into the cavity is within 'fwd pwr delta' of the forward power prior to the restart. Once this condition has been achieved, normal conditioning resumes after stage 2.

OK

During recovery after a restart, the mod-anode voltage will be increased at this rate until the forward power into the cavity is within 'fwd pwr delta' of the forward power prior to the restart. Once this condition has been achieved, normal conditioning resumes after stage 2.

OK

During recovery after a restart, the forward power into the cavity will increase to within this value of what the forward power was prior to the restart. Once this has been achieved, normal conditioning resumes after stage2

OK

Custom Conditioning Parameters

Voltage (V)	Duration (sec)
Voltage: 30	[Empty Table]
Duration: 15	
[Add] [Insert] [Delete]	

Custom Pwr Range: 0 kW 0 kW

Restart Parameters

Enable Restart? Yes No

Vac Pressure: 5.0e-9 Torr

Maximum Retries: 4

Mod Anode Decrement: Fixed Relative

Fixed: 16.8 kV

Relative:

Vac: 15 kV

Other: 15 kV

	Stage 1	Stage 2
Recovery Incr Value:	200 V	100 V
Recovery Incr Time:	0.25 Min	1 Min
Recovery Pwr Delta:	5.0 kW	1.0 kW

[OK] [Cancel] [Default]

Future Plans

- Condition Booster tuners
 - Test full-width Kovar ring coupler with Ti coated copper parts
 - Test & condition HOM dampers
 - Improve auto-conditioning script as needs arise
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- Special thanks to Doug Horan, Geoff Waldschmidt, Dave Meyer, Leonard Morrison, John Pace, Andre McKenzie, John Hoyt, Mark Martens, Guy Harris, and Raul Mascote for their effort and support

