What Will It Take to Have a Viable Proton Source through 2010?

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Outline

- Pre-Accelerator and Linac
  - *Elliott, et al.*
  - *Vacuum tubes, power supplies, old equipment, personnel*
- Booster
  - *Eric, et al.*
  - *Activation, HL & LL RF, old equipment*

Overview of Linac Concerns

- Pre-Accelerator
- Low Energy Linac
  - *Vacuum Tubes*
    - Especially the 7835 Power Amplifier triode
    - LEL High Voltage Modulator
      - *F-1123 (switch tube)*
  - *"QPS" power supplies*
  - *Tank 1*
- High Energy Linac
  - *Radiation & Activation*
- All fixes are Band-Aid patches
  - *Big $ & personnel outlay that is otherwise useless to the needs of the Laboratory further in the future*

Pre-Accelerator

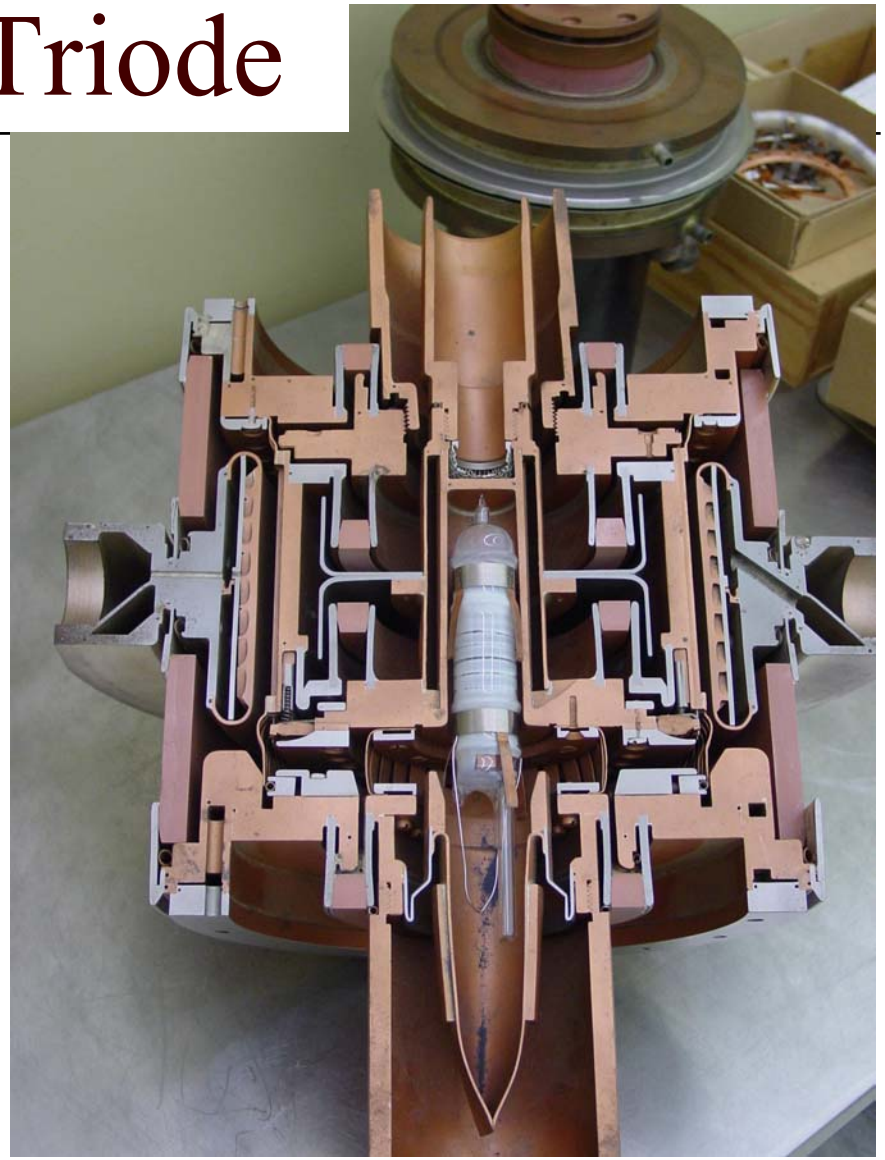
- Reliable operation is likely through 2010
  - *Retirement of Hren and Wendt: 2015?*
- No particular supplier problems
  - *Although we have had some interesting problems with the various components, e.g., power tubes.*
- Will need to replace the Haefley HV supply with a better regulated model
  - *Line voltage variations are barely acceptable now.*

Linac Vacuum Tube Docket

	Designation	Tube Type	Supplier	Cost New	Cost Rebld	Life (y)	# in use	Capital Cost	Cost/yr	# spare	Spare Inv.	Usage
1	VKP-7955	Klystron	Litton	$ 166,000	$ 120,000	15	7	$ 1,162,000	$ 56,000	7	$1,162,000	Power for 805 MHz systems
2	7835	Triode	Burle	$ 150,000	$ 80,000	1	5	$ 750,000	$ 307,692	1	$ 150,000	201 MHz primary power
3	4616	Triode	Burle	$ 50,000	$ 20,000	3	6	$ 300,000	$ 40,000	5	$ 250,000	Driver for 201 MHz power, drives buncher
4	L-5859	Klystron	Varian	$ 90,000		15	3	$ 270,000	$ 18,000	2	$ 180,000	Power for three "little klystron" systems
5	6544	Triode	CPI	$ 9,250		3	17	$ 157,250	$ 52,417	6	$ 55,500	Regulation for 4616 & modulator switch tubes
6	F-1123	Triode	Triton	$ 7,540		2	15	$ 113,100	$ 56,550	61	$ 459,940	We have supply for nominally 5 years
7	CX1154	Thyratron	English Elec. Valve	$ 3,000		15	4	$ 12,000	$ 800	2	$ 6,000	750 keV Chopper
8	7651	Triode	Burle	$ 1,795		1.5	6	$ 10,770	$ 7,180	8	$ 14,360	Pre-amp for 201 MHz systems
9	7703LP	Ignitron	Richardson	$ 1,300		7	7	$ 9,100	$ 1,300	2	$ 2,600	Klystron crowbar
10	GL-37248	Ignitron	Richardson	$ 1,470		5	5	$ 7,350	$ 1,470	4	$ 5,880	50kV 201 MHz crowbar for the 7835
11	3CW20000A1	Triode	Svetlana	$ 2,500		5	2	$ 5,000	$ 1,000	2	$ 5,000	Haefley Power Tubes
12	3CX3000F1	Triode	Richardson	$ 800		4	5	$ 4,000	$ 1,000	2	$ 1,600	Bias supply in Modulator
13	GL-7703	Ignitron	Richardson	$ 761		5	5	$ 3,805	$ 761	5	$ 3,805	4616 Driver Crowbar circuit
14	8613	Thyratron	Richardson	$ 700		3	5	$ 3,500	$ 1,167	3	$ 2,100	50kV 201 MHz crowbar for the 7835
15	4E27A15	Triode	Richardson	$ 550		4	5	$ 2,750	$ 688	5	$ 2,750	Bias supply in Modulator
16	4PR250C	Triode	Amprex/Richardson	$ 1,300		4	2	$ 2,600	$ 650	2	$ 2,600	Extractor
								$ -			$ -	
							Total cost per year		**$ 546,674**			
							Total cost to 2010		**$ 4,373,393**			

The 7835 Power Triode

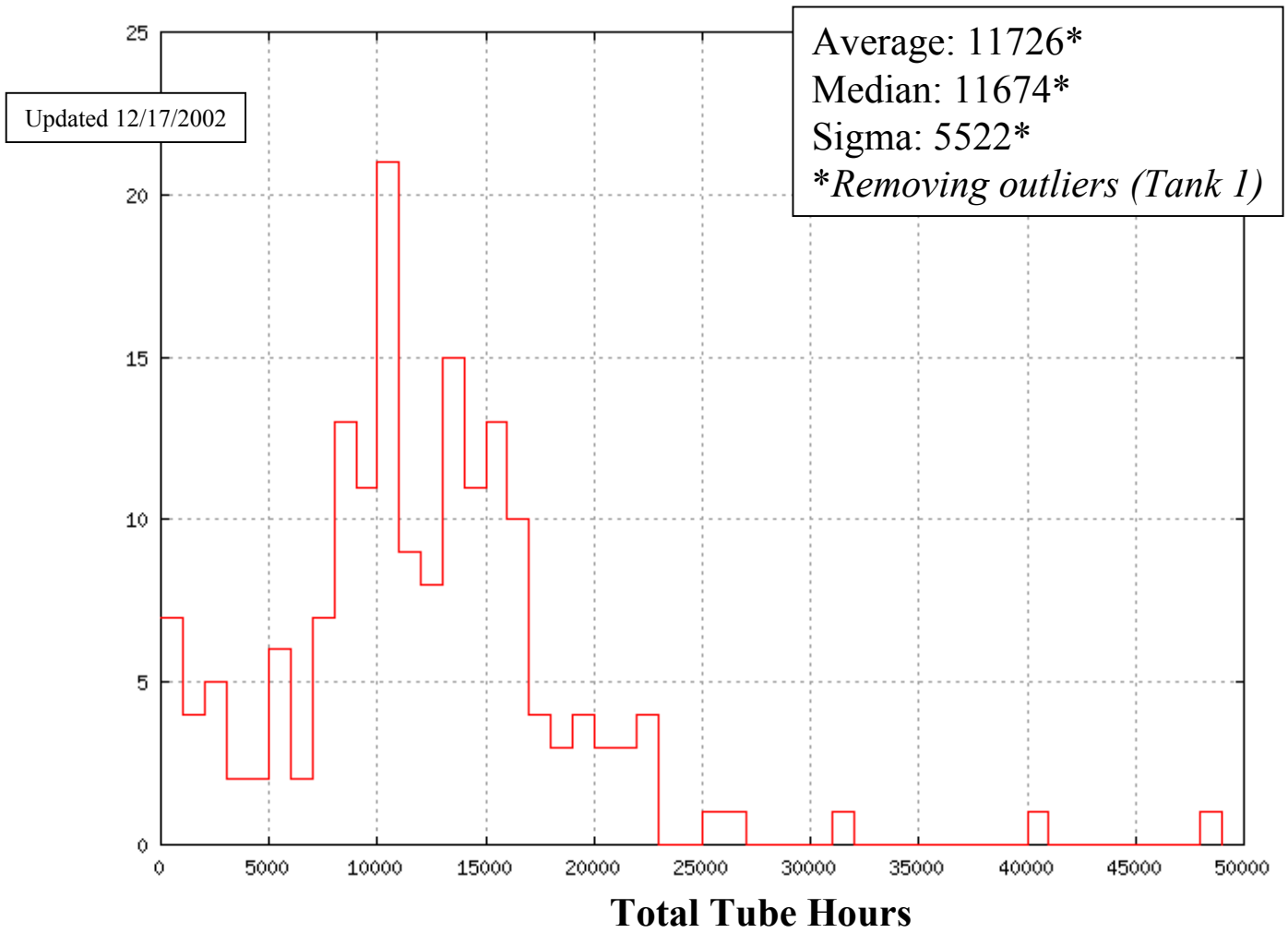
- Very complex technology
  - *RF, material science, vacuum, chemistry*
- Similar to other tubes made by Burle
  - *4616 & 4617*
- 7835 only used in the scientific community.
  - *One military user for 4617*
- Quality varies from decade to decade



Burle Industries, Lancaster, PA

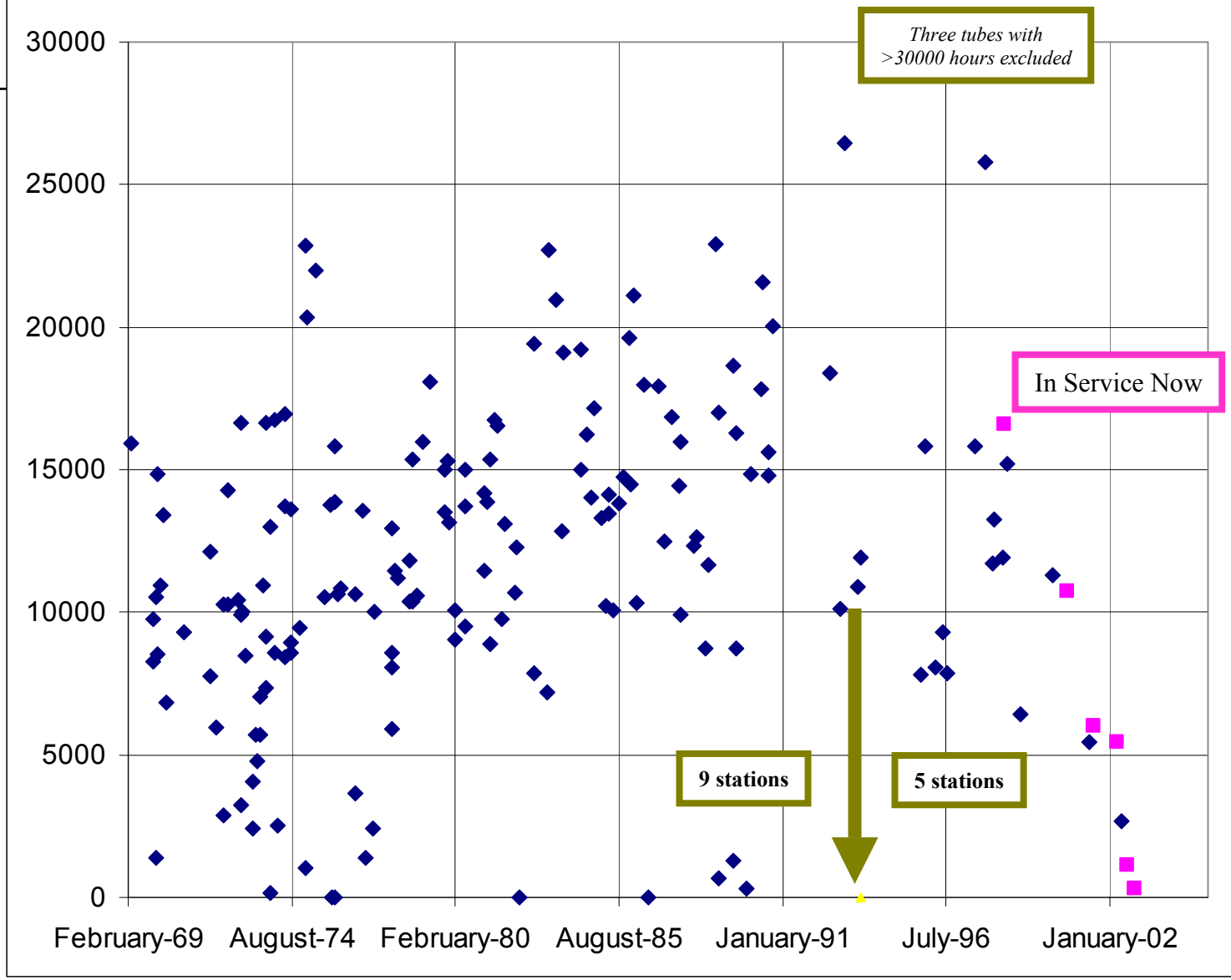
- Enormous facility
- Makes all kinds of tubes
  - *Power tubes*
  - *PMTs in competition with Hamamatsu*
  - *Some picture tubes*
    - Was RCA Tube plant
  - *Radar tubes for AWACS*

Histogram of Tube Lifetime



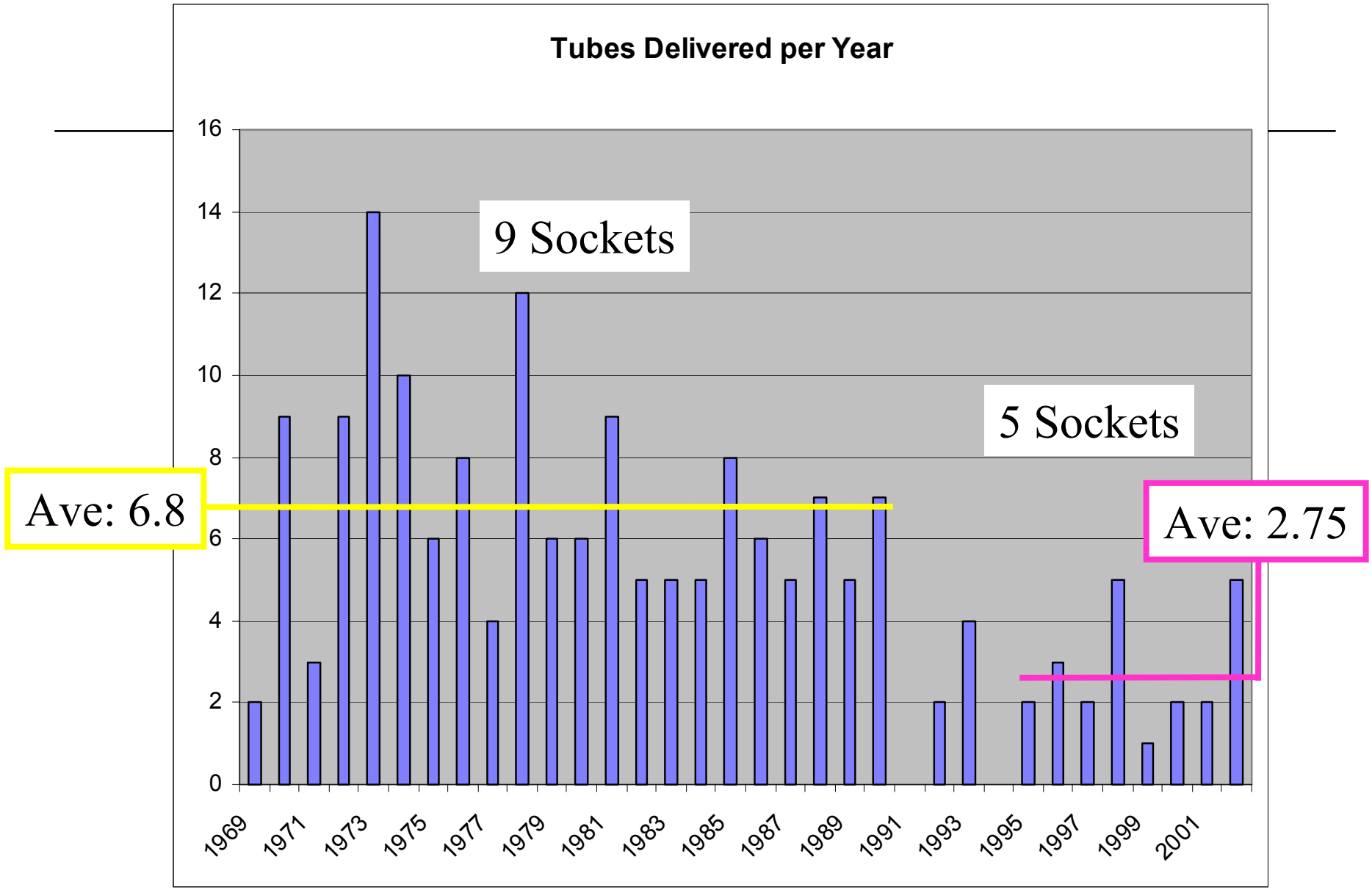
Updated 12/17/2002

Date Received vs. Hours on Tube



Tube Throughput with Burle

- Median lifetime: 16 months
  - *Recent lifetime: Less!*
- We need about 3.41 tubes/year to maintain
  - *Assuming historical median*
  - *With present tubes: twice that.*
  - *We have received 5 tubes in the last 12 months*
    - Including one borrowed from Argonne
    - Expect 7 tubes over the next 12 months; next in February
- Burle now can make/rebuild ~20/year
  - *Critical path: Final bakeout; two stands, 3-5 weeks bakeout*
  - *Also of concern: Supplier delivery time (e.g., ceramics, cathode)*
- Delivery time: ~8 months,
  - *But, often 12 months!*


Tubes Delivered per Year
16
14
12
10
8
6
4
2
0
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
9 Sockets
5 Sockets
Ave: 6.8
Ave: 2.75

Why Would Burle Stop Making 7835s?

1. If a supplier is not able to deliver raw materials
   - *~1987: Thorium content of cathode dropped from 2% to 1.5% due to EPA issues at supplier*
   - *Quality ceramics always hard to get*
2. If demand for 4616 tubes dries up
   - *E.g., our Switch Tubes (in modulator)*
   - *Military still uses lots of these*
     - ~100s of these per year currently
   - *Burle's "Bread & Butter" for this type of tube*
3. If life of tube is less than the delivery time!
   - *Tubes must last >>8 months in operation to be practical.*

Alternatives?

- To the 7835? None, really.
  - *This is the highest power 200 MHz tube in the world*
  - *Los Alamos is looking into 3.5 MW "Diachrode"*
  - *201 MHz Klystron? Not likely!*
- Pooling 7835s among the four US DOE Labs?
  - *BNL: 9 sockets, Argonne: 1, Los Alamos: 5, FNAL: 5*

Summary: Will We Have Power Tubes in 2010?

- Maybe, maybe not.
- Burle has every intention to make these tubes forever, but …
- Which "secondary" triode is going to stop being produced next???
- What can we do now?
  - *Not much*
  - *Use spare tubes from other labs*

LEL High Voltage Modulator

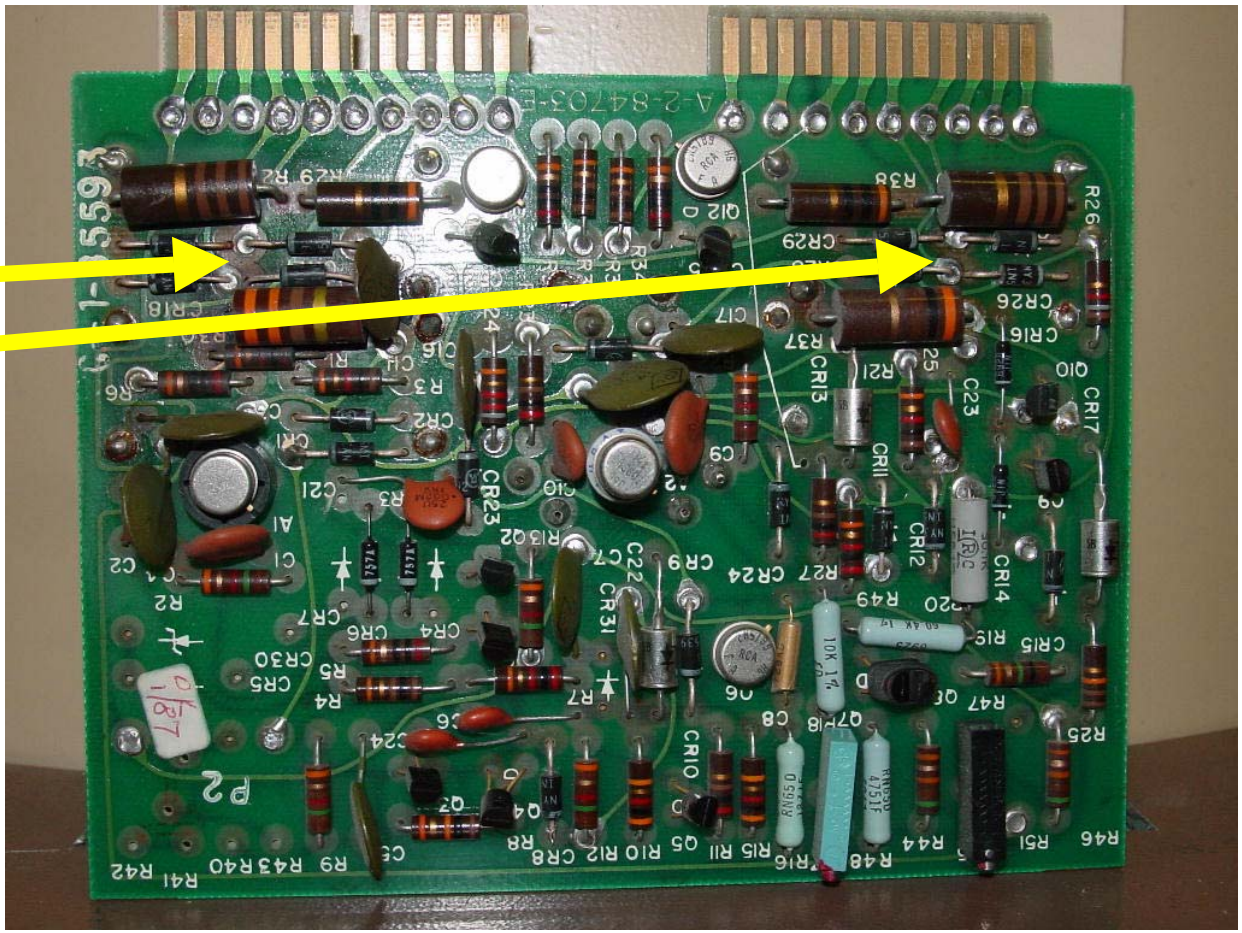
- Switch tubes are no longer made
  - *Military demand for F-1123 ended abruptly*
  - *Triton closed the one remaining production line in 2002*
- We have 61 spares right now
  - *2 y average life, 15 in service → replace 8 per year, 7 years left*
  - *Econco may be able to rebuild these tubes*
- ∴ 2010 is possible, but not much more.
  - *The clock is ticking!!*
  - *2020 is unlikely with this system*
- What can we do now?
  - *New Modulator design*

Low-energy End Quad PS

- 300 A, 200 V pulsed (15 Hz) power supply
  - *There are 116 supplies in service*
- Largest inventory of PCBs on site
- Ancient technology
- Circuits rebuilt many times
- What can we do now?
  - *Decide on replacement technology and replace them, starting now*

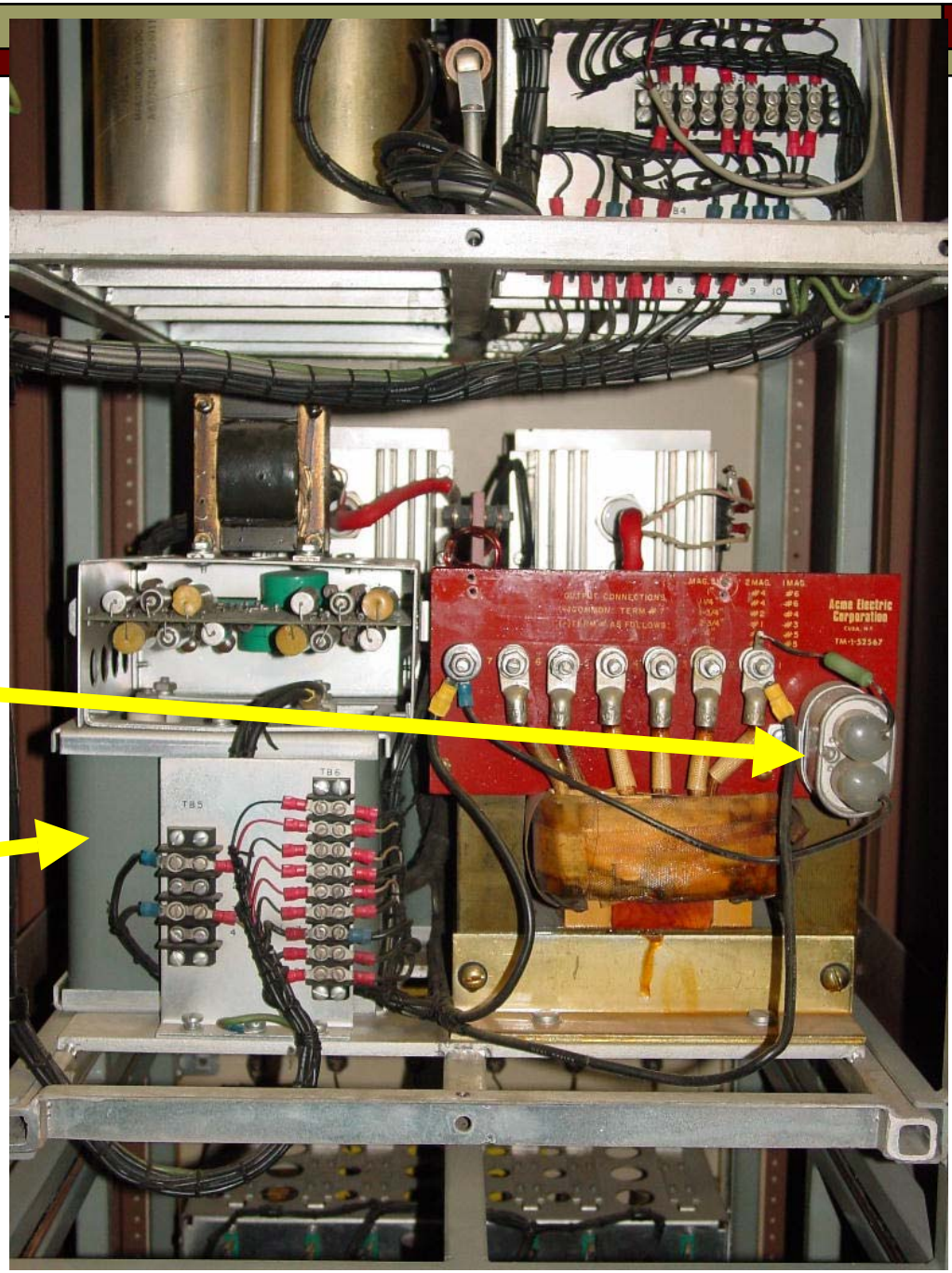
Ancient Technology

Note Burn Marks



The Inside of a QPS Chassis

- Small PCB caps
- 10 PCB capacitors at 2 pounds each



7835 Filament Power Supplies

- 7000A, 5VDC output (480VAC input)
  - *~35KW just to light the filament.*
- Hardware unreliable and hard to maintain
  - *One original spare exists (LRF6).*
- Upgrade Controller
  - *Begun by Ma and Wahl*
  - *One working new prototype at LRF7, but still needs minor interfacing work.*
  - *PLC used is now obsolete; better units available but means more development work.*
- 2010? Probable, with the controller upgrade
  - *This needs to be funded*

O-rings on LEL Quadrupole Stems

- Have lost ~10 (aside from Tank 1)
  - *16 years since the last failure*
- When will they become too old to hold vacuum?
  - *Tank 5: More radiation exposure that ever*
- 2010? January 2003 shutdown will give us information on the state of the o-rings now

Tank 1

- Remember: This was a prototype!
- If we lose a quad in Tank 1 (e.g., to a short), it may take months to recover
  - *No post couplers—will be difficult to realign the quad and, simultaneously, stabilize the RF fields; Bead pull?!*
- Continuous pumping on the stem box covers
  - *Some o-rings may be damaged*
  - *Cannot regulate field w/changes in atmos. Pres. unless we pump*
- 2010? With a little luck.
- O-rings and Tank 1: What can we do now?
  - *Nothing.*

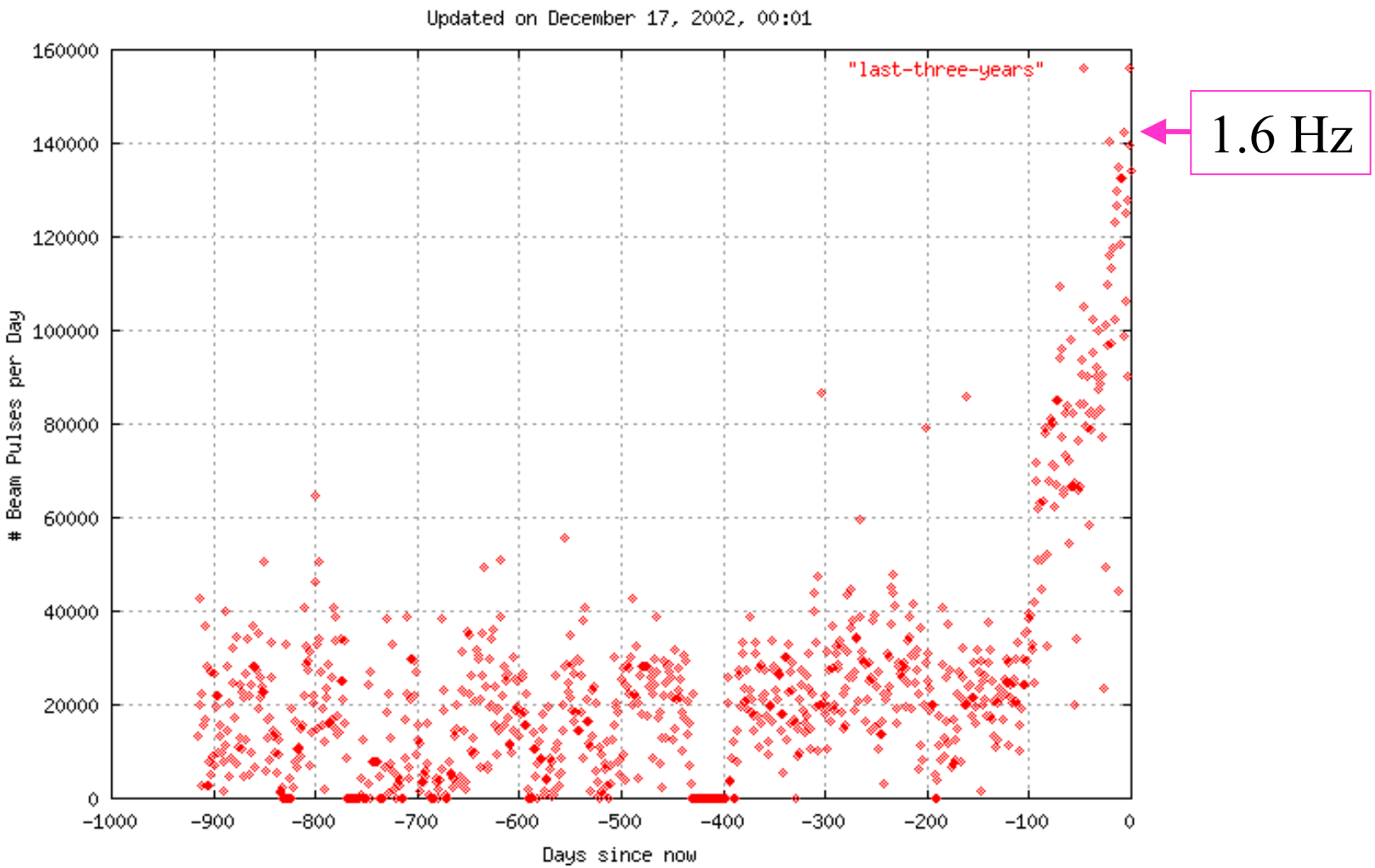
Other LEL Concerns

- LEL LLRF
  - *Should be relatively easy, inexpensive and interesting upgrade project*
- Water Systems
  - *Upgrade underway now, should get us to 2010, but not 2020.*

Radiation Concerns in the HEL

- Activation of components
  - *Delivering more beam than ever!*
    - And they want a lot more!!
  - *Areas at 100 mR/hr @ 1', but component damage seems unlikely*
  - *Hands-on maintenance may become problematic*
- External shielding
  - *At ~50% of the trip point for some detectors outside of the tunnel*
  - *Wire scan trips off the interlocked detectors quickly*
  - *Significant improvement in reducing losses required, or*
  - *Big redesign of the passive shielding*

Number of Beam Pulses/Day



Other Concerns in the HEL

- What is the real lifetime of the klystrons?
  - *Will they all fail at once?*
  - *Will need to send klystrons to Litton to keep their line active.*
- Are there other components that are going to fail *en mass*?
- Obsolete LLRF computers
  - *Upgrade in planning stages now*
  - *Need $$ for this upgrade*
- HEL 2010?
  - *Will need to reassess external shielding*
  - *Otherwise, no problems here*

2010? Gambles

- Can we get enough 7835s?
  - *And will they last long enough?*
- Will the supply of Switch Tubes be enough?
- Will Tank 1 break?
- Will the drift tube stem o-rings survive?
- Will radiation/activation become a problem?

2010? Specific Fixes

- Haefley HV Supply
- Inter-lab spares for 7835 power tube
- Redesign the LEL Quad PSs
- Replace filament supply controllers
- Continue design effort for LEL modulator
- Replace the LLRF in the LEL
- Upgrade the computers in the HEL LLRF
- More shielding may be necessary at high-energy end
- Big $ & personnel outlay that is otherwise useless to the needs of the Laboratory further in the future

Beyond 2010?

- Young's proposal for new LEL
  - *Two ion sources and injector RFQs to ~1 MeV*
  - *"Double alpha" injection into*
  - *RFQ to ~7 MeV*
  - *400 MeV commercial drift tube Linac*
  - *New, gentler transition section at ~70 MeV*
  - *New 805 MHz SCCL module(s) to 116 MeV*
- Price tag: ~\$N x 10^7.

402 MHz Parameters from Young

					DTL			CCL	
		RFQ	Tank 1	Tank 2	Tank 3	Tank 4	Match Section	Mod 1	Mod 2
Input Energy	MeV	0.035	3	13.4	32.9	51.6	70.3	70.3	93.3
Output Energy	MeV	3	13.4	32.9	51.6	70.3	70.3	93.3	116.5
Delta E	MeV	2.965	10.4	19.5	18.7	18.7	0	23	23.2
Beam Current	mA	70	60	60	60	60	60	60	60
Frequency	MHz	402.5	402.5	402.5	402.5	402.5	805	805	805
Beam Pulse Length	usec	90	90	90	90	90	90	90	90
RF Pulse Length	usec	130	130	130	130	130	125	125	125
Rep Rate	Hz	15	15	15	15	15	15	15	15
RF Duty Factor		0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Average Axial Field	MV/m		2.4 to 4.6	4.6	4.6	4.6	7.5 to 7.35	8	8
Length	m		4.5	6	6.1	6.2	3.25	4.8	4.9
Structure Power	MW		1	1.75	2	2		5.4	5.4
Beam Power	MW		0.63	1.17	1.12	1.12		1.38	1.39
Total Klystron Power	MW		2.5	3.8	4	4		8.8	8.8

- Price tag: About \$40 x 10^6.