SB2009 Availability

John Carwardine
For the SB2009 Availability Task Force

Task Force membership

- Task Force
  - **Tom Himel**
  - **Eckhard Elsen**
  - **Nick Walker**
  - **Ewan Paterson**
  - **John Carwardine**
  - **Marc Ross (chair of full group)**
  - **Ewan Paterson**
  - **Tetsuo Shidara (lead)**
  - **Nobuhiro Terunuma**

- Plus major contributions from
  - **Chris Adolphsen**
  - **Shigeki Fukuda**
  - **Nobu Toge**
  - **Akira Yamamoto**

Availability Task Force objectives

- To address the question… *Are the SB2009 Main Linac configurations viable from an availability stand-point?*

- Specific objectives
  - **Study the relative technical risk to availability of the SB2009 Main Linac configurations relative to the RDR baseline**
  - **Aim to show the SB2009 configurations could meet the availability criteria without unduly increasing technical or cost risk over the RDR**
  - **Evaluate the relationship between energy overhead and availability**

- ILC availability requirements (unchanged from the RDR):
  - **9 months of scheduled running time per year plus 3 months of shutdown for maintenance and upgrades**
  - **Total unscheduled downtime should be less than 25% (we use 15% as the criteria, leaving 10% as contingency)**

Availsim Methodology

- Inputs to the Availsim simulations
  - **ILC overall configuration + each Main Linac configurations**
  - **A set of 'Starting MTBFs' and MTTRs for the technical components (largely derived from MTBFs achieved in the field)**
  - **A set of underlying assumptions: ILC operations model; maintenance model; recovery model following downtime, etc**
    - Covered in detail in Himel's talk at the Albuquerque meeting

- General approach to the SB2009 Availsim studies
  1. **Run an initial Availsim simulation using the prescribed inputs**
  2. **Review resulting downtime, adjust input MTBFs for components with proportionately highest downtime**
  3. **Re-run Availsim using the updated MTBFs**
  4. **Iterate, revising the input MBTFs until availability goals were met**

- (Not all MTBFs were treated as free parameters, eg klystron MTBFs were kept constant)

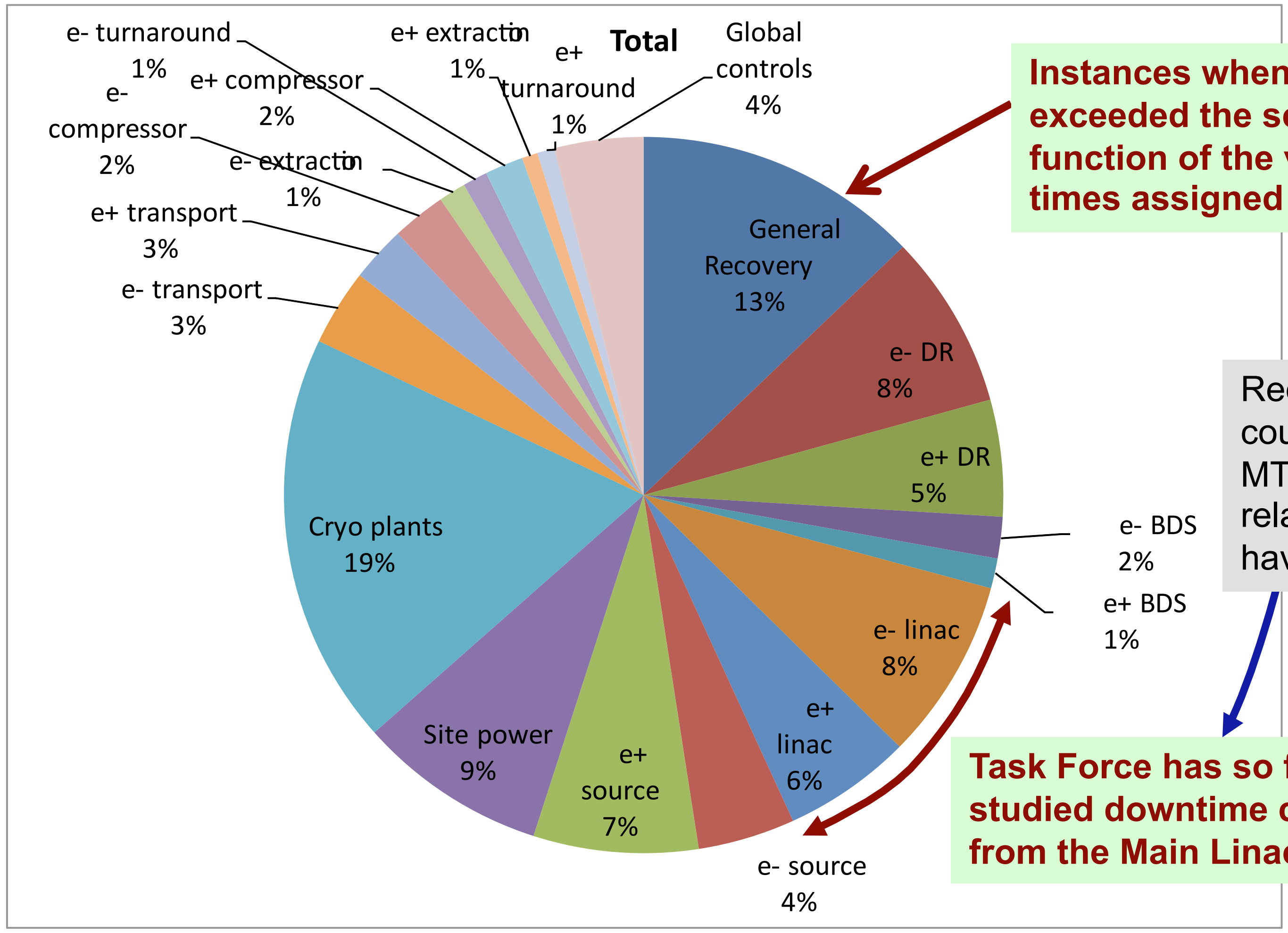
…Availsim methodology

- Final outputs once the availability criteria have been met
  - A candidate set of MTBFs that would meet the ILC availability requirements (‘Final MTBFs’)
  - A breakdown of the predicted machine downtime
  - A measure of the effect of energy overhead on machine downtime
  - The necessary MTBF ‘improvement factors’ with respect to in-the-field experience (ie ratios of the Final MTBFs to the Starting MTBFs)

- Four Main Linac HLRF configurations were simulated for several fractions of energy overhead
  - RDR 10MW RF unti in two tunnels (RDR baseline)
  - RDR 10MW RF unit in a single tunnel
  - SB2009 configurations (KCS and DRFS), both in a single tunnel

- Several machine maintenance models were simulated
  - A 3-month shutdown per year with opportunistic maintenance
  - A 3-month shutdown per year with no opportunistic maintenance
  - 24hrs shutdown every 2 weeks + a 1-month shutdown per year

Downtime by accelerator area for KCS simulation (percentages of 15% total downtime)

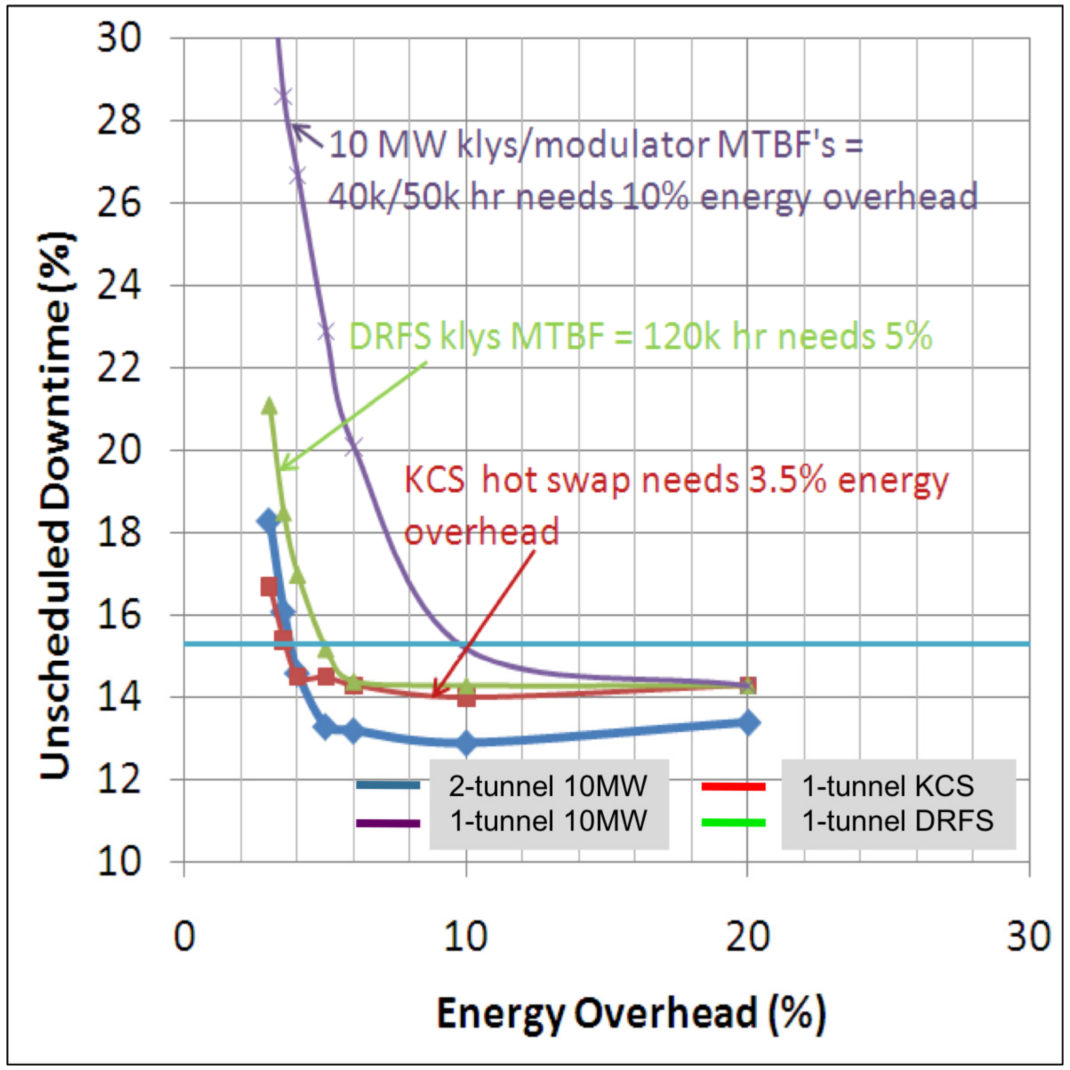


Instances when recovery times exceeded the scheduled 9hrs (a function of the variance in recovery times assigned to Availsim model)

Reducing recovery times could allow Main Linac MTBF requirements to be relaxed (such optimizations have not yet studied)

Task Force has so far only studied downtime contributions from the Main Linac

Total unscheduled downtime vs energy overhead



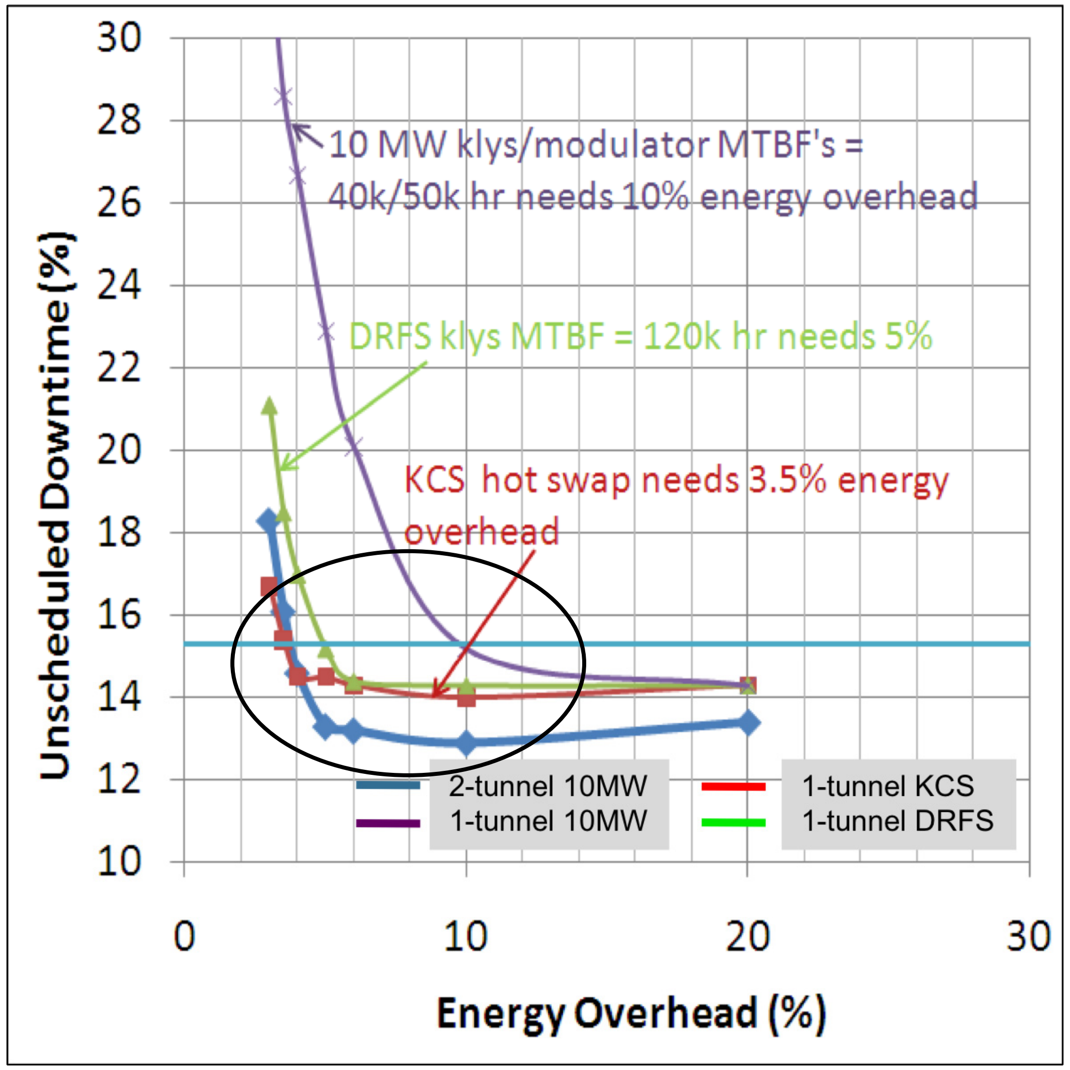
Notes

- Chart shows **total** unscheduled downtime for all technical systems
- Failures that require energy overhead fall into two groups
  - **Components such as couplers, piezos, tuner motors, etc**
  - **HLRF failures (subject of study)**
- Vertical asymptote: downtime from couplers, piezos, tuner motors, etc
- Horizontal asymptote: downtime from all non-RF systems (overhead-independent)

Observations

- KCS and DRFS require similar overhead
- 1-tunnel RDR RF unit needs more overhead (but note the lower klystron/ modulator MTBF compared with DRFS)
- KCS model assumes there are no common-mode failures (all hot-swap)

Total unscheduled downtime vs energy overhead



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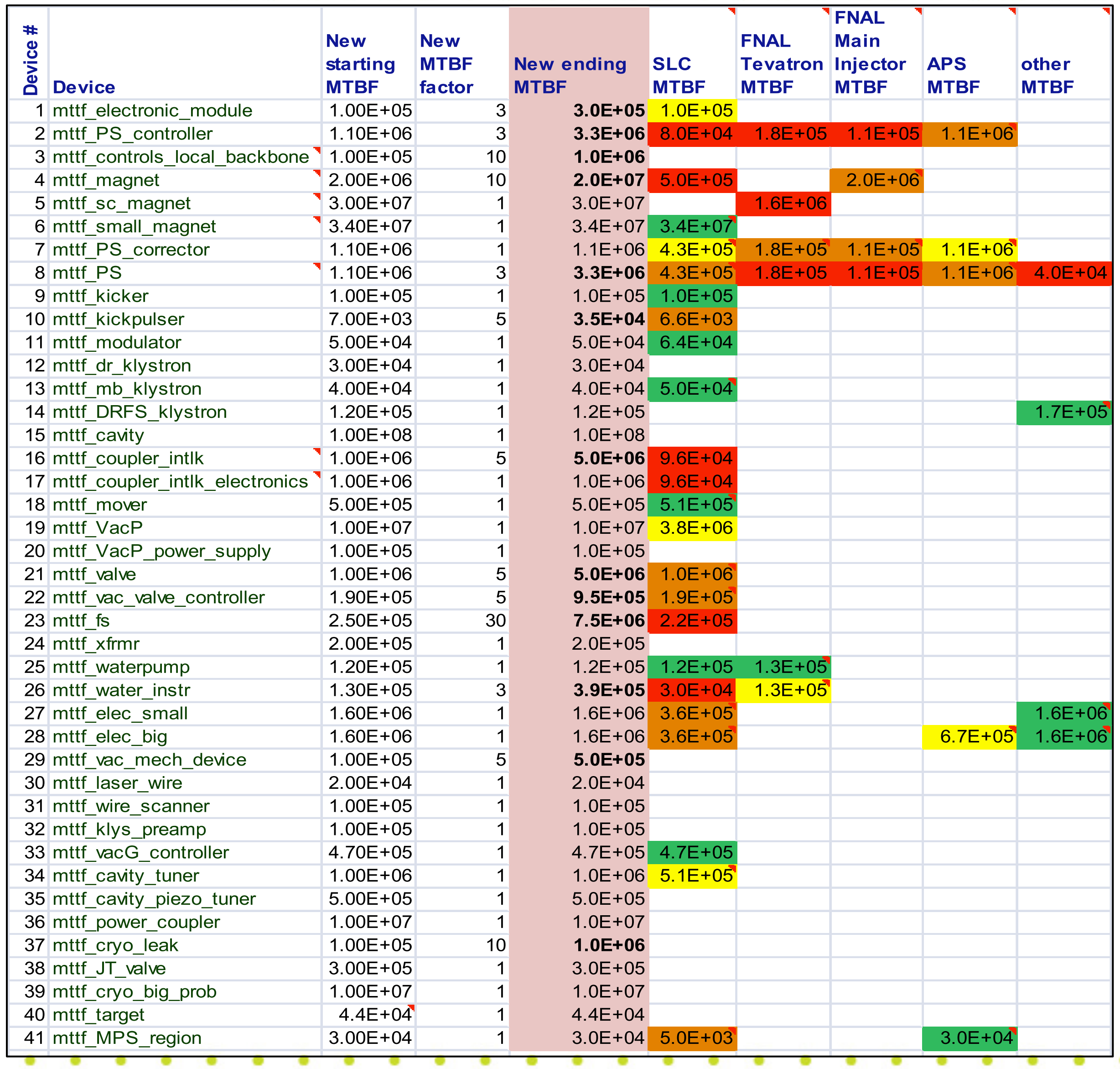
Starting MTBFs and (final) adjusted MTBFs for SB2009 configurations



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1	mttf_electronic_module	1.00E+05	3	**3.0E+05**	1.0E+05				
2	mttf_PS_controller	1.10E+06	3	**3.3E+06**	8.0E+04	1.8E+05	1.1E+05	1.1E+06	
3	mttf_controls_local_backbone	1.00E+05	10	**1.0E+06**					
4	mttf_magnet	2.00E+06	10	**2.0E+07**	5.0E+05		2.0E+06		
5	mttf_sc_magnet	3.00E+07	1	3.0E+07		1.6E+06			
6	mttf_small_magnet	3.40E+07	1	3.4E+07	3.4E+07				
7	mttf_PS_corrector	1.10E+06	1	1.1E+06	4.3E+05	1.8E+05	1.1E+05	1.1E+06	
8	mttf_PS	1.10E+06	3	**3.3E+06**	4.3E+05	1.8E+05	1.1E+05	1.1E+06	4.0E+04
9	mttf_kicker	1.00E+05	1	1.0E+05	1.0E+05				
10	mttf_kickpulser	7.00E+03	5	**3.5E+04**	6.6E+03				
11	mttf_modulator	5.00E+04	1	5.0E+04	6.4E+04				
12	mttf_dr_klystron	3.00E+04	1	3.0E+04					
13	mttf_mb_klystron	4.00E+04	1	4.0E+04	5.0E+04				
14	mttf_DRFS_klystron	1.20E+05	1	1.2E+05					1.7E+05
15	mttf_cavity	1.00E+08	1	1.0E+08					
16	mttf_coupler_intlk	1.00E+06	5	**5.0E+06**	9.6E+04				
17	mttf_coupler_intlk_electronics	1.00E+06	1	1.0E+06	9.6E+04				
18	mttf_mover	5.00E+05	1	5.0E+05	5.1E+05				
19	mttf_VacP	1.00E+07	1	1.0E+07	3.8E+06				
20	mttf_VacP_power_supply	1.00E+05	1	1.0E+05					
21	mttf_valve	1.00E+06	5	**5.0E+06**	1.0E+06				
22	mttf_vac_valve_controller	1.90E+05	5	**9.5E+05**	1.9E+05				
23	mttf_fs	2.50E+05	30	**7.5E+06**	2.2E+05				
24	mttf_xfrmr	2.00E+05	1	2.0E+05					
25	mttf_waterpump	1.20E+05	1	1.2E+05	1.2E+05	1.3E+05			
26	mttf_water_instr	1.30E+05	3	**3.9E+05**	3.0E+04	1.3E+05			
27	mttf_elec_small	1.60E+06	1	1.6E+06	3.6E+05				1.6E+06
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31	mttf_wire_scanner	1.00E+05	1	1.0E+05					
32	mttf_klys_preamp	1.00E+05	1	1.0E+05					
33	mttf_vacG_controller	4.70E+05	1	4.7E+05	4.7E+05				
34	mttf_cavity_tuner	1.00E+06	1	1.0E+06	5.1E+05				
35	mttf_cavity_piezo_tuner	5.00E+05	1	5.0E+05					
36	mttf_power_coupler	1.00E+07	1	1.0E+07					
37	mttf_cryo_leak	1.00E+05	10	**1.0E+06**					
38	mttf_JT_valve	3.00E+05	1	3.0E+05					
39	mttf_cryo_big_prob	1.00E+07	1	1.0E+07					
40	mttf_target	4.4E+04	1	4.4E+04					
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- **Bold**: had to improve MTBF above start value:
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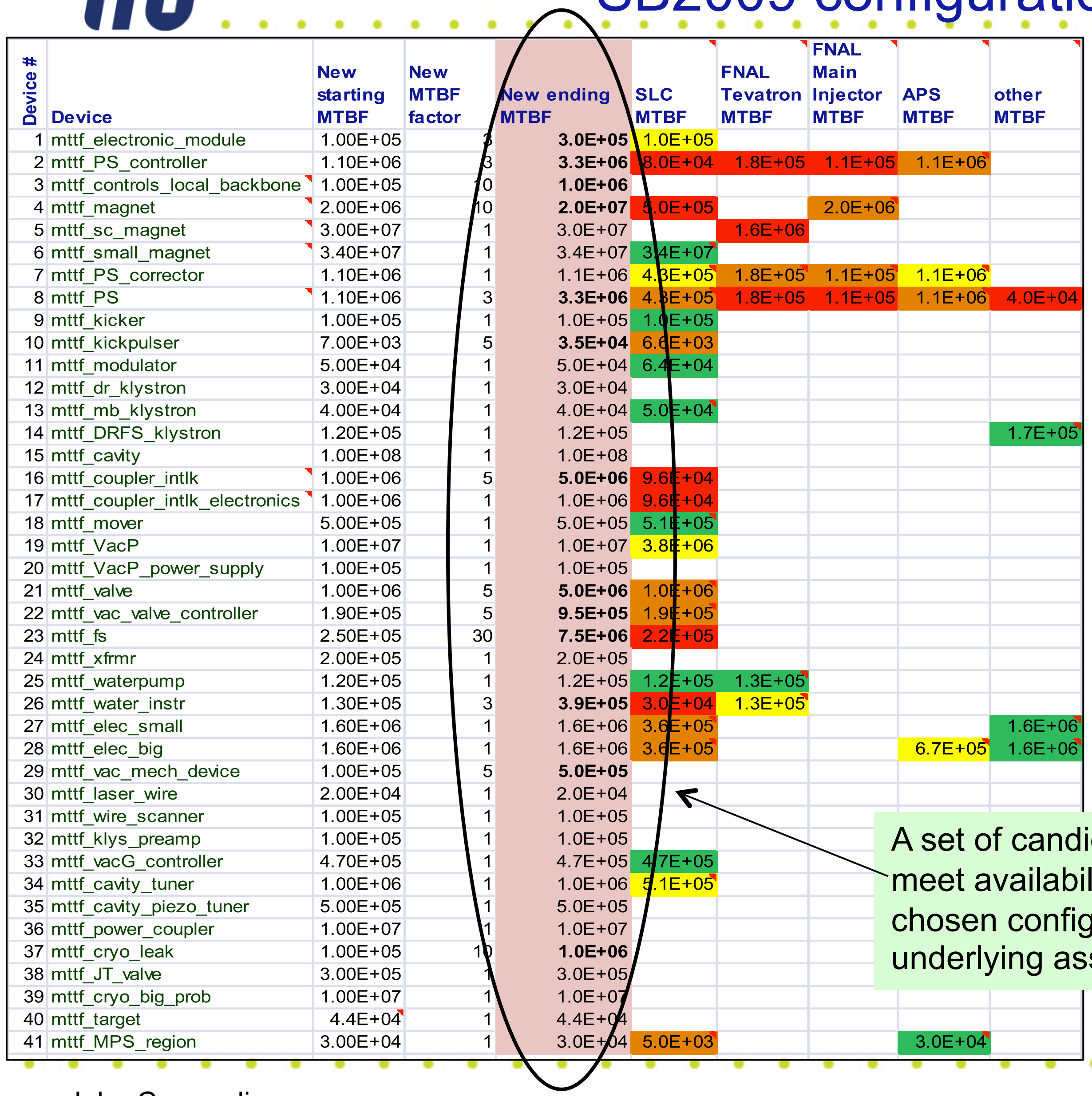
The Improvement Factors can be considered an indication of technical risk

Starting MTBFs and (final) adjusted MTBFs for SB2009 configurations



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41	mttf_MPS_region	3.00E+04	1	3.0E+04	5.0E+03			3.0E+04	

A set of candidate MTBFs that meet availability goals for the chosen configuration and underlying assumptions

- **Bold**: had to improve MTBF above start value:
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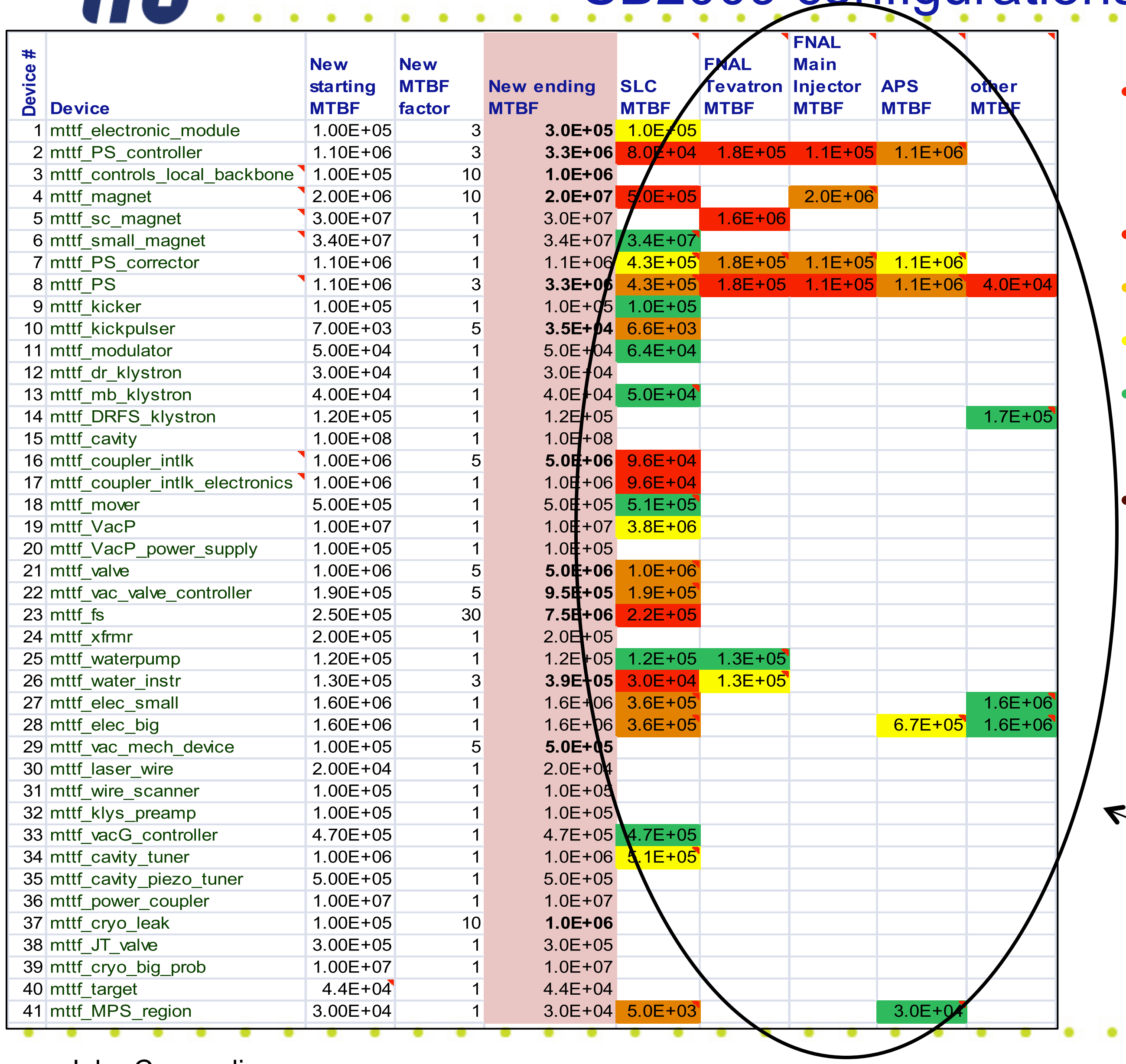

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The Improvement Factors can be considered an indication of technical risk

In-the-field experience

‘Ingredients’ in context

- The set of needed MTBFs is beyond operational experience
  - **Very difficult for all configurations (RDR included)**

- Improvement Factors from Availsim modeling give a sense of the technical risk in achieving the availability
  - **Relative to operations experience (largely at SLAC and FNAL)**
  - **‘Best-in-class’ MTBFs gets us closer to the needed MTBFs (lower risk)**
    - Commercial and industrial experience
    - Other accelerator facilities, eg light sources

- In practical terms, there is more to Availability than MTBFs
  - **Integrated approach to mitigating failures, repair/recovery times**
  - **Engineering processes, eg consistent designs, design margins, QC/QA**
  - **Redundancy is not always the answer**

- Proactive maintenance during scheduled shutdowns will be essential to achieving availability during operations

IEEE Gold Book: power distribution reliability data from in-service surveys

(Estimated Times To Failure)

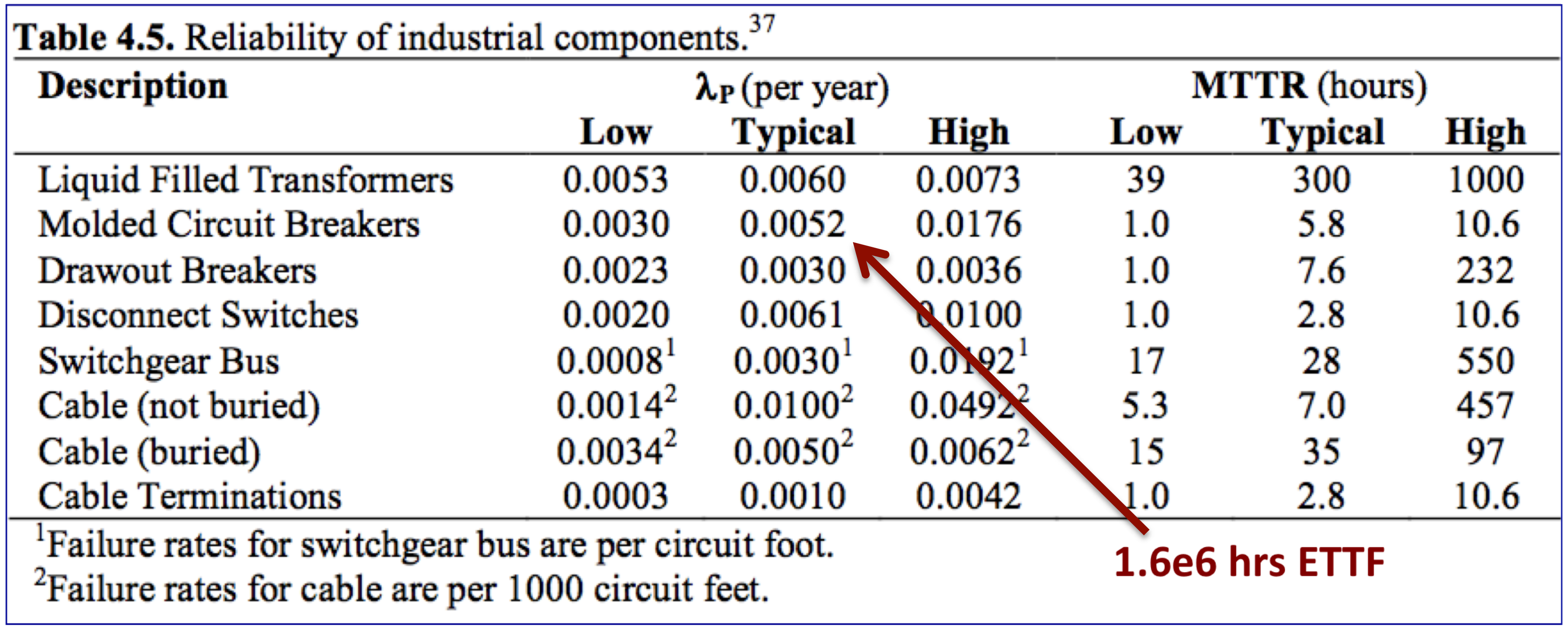


Table 4.5. Reliability of industrial components.[37]

Description	λ_P (per year)			**MTTR** (hours)		
	Low	**Typical**	**High**	**Low**	**Typical**	**High**
Liquid Filled Transformers	0.0053	0.0060	0.0073	39	300	1000
Molded Circuit Breakers	0.0030	0.0052	0.0176	1.0	5.8	10.6
Drawout Breakers	0.0023	0.0030	0.0036	1.0	7.6	232
Disconnect Switches	0.0020	0.0061	0.0100	1.0	2.8	10.6
Switchgear Bus	0.0008[1]	0.0030[1]	0.0192[1]	17	28	550
Cable (not buried)	0.0014[2]	0.0100[2]	0.0492[2]	5.3	7.0	457
Cable (buried)	0.0034[2]	0.0050[2]	0.0062[2]	15	35	97
Cable Terminations	0.0003	0.0010	0.0042	1.0	2.8	10.6

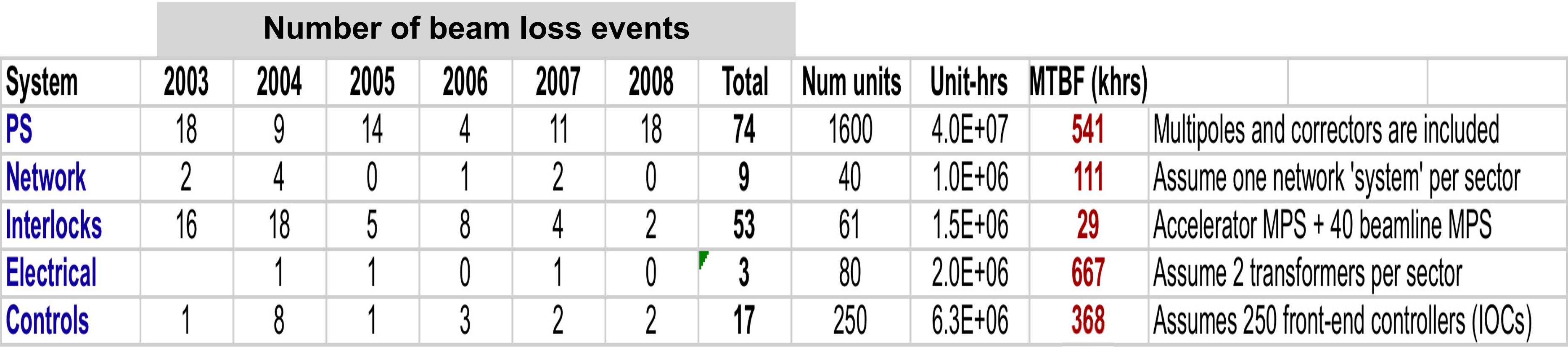
[1] Failure rates for switchgear bus are per circuit foot.

[2] Failure rates for cable are per 1000 circuit feet.

1.6e6 hrs ETTF

Source: 'IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems' (IEEE "Gold Book")

“Crude estimates” of some MTBFs for Advanced Photon Source storage ring



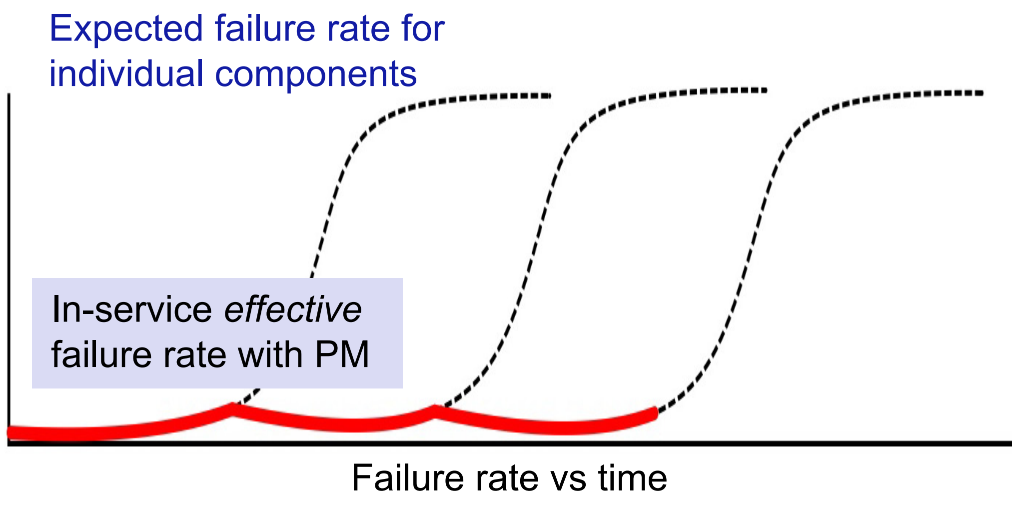
	Number of beam loss events										
System	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**	**Num units**	**Unit-hrs**	**MTBF (khrs)**	
PS	18	9	14	4	11	18	**74**	1600	4.0E+07	**541**	Multipoles and correctors are included
Network	2	4	0	1	2	0	**9**	40	1.0E+06	**111**	Assume one network 'system' per sector
Interlocks	16	18	5	8	4	2	**53**	61	1.5E+06	**29**	Accelerator MPS + 40 beamline MPS
Electrical		1	1	0	1	0	**3**	80	2.0E+06	**667**	Assume 2 transformers per sector
Controls	1	8	1	3	2	2	**17**	250	6.3E+06	**368**	Assumes 250 front-end controllers (IOCs)

↑

Crude numbers!

- Total run time is ~30,000 hrs (5000hrs/year)

Proactive Maintenance
(Increase effective Availability)



Failure rate vs time

Basic premise
- Take advantage of scheduled downtime to increase the effective availability during scheduled uptime

Approach
- Preemptively replace or service components that degrade or have finite life

- Assumed for both RDR and SB2009

Power converter examples
- Replace water hoses before they rot and cause a leak
- Use thermal imaging to identify loose joints on busbars, poor contact between power transistors and heatsink, etc
- Replace power transistors that show signs of leakage

- Perform ‘stress tests’ on power converters during downtime periods to deliberately cause the weakest ones to fail
    - Example of stress test: repeatedly cycle power converter output from low to maximum output at a rate that causes maximum thermal cycling.

Possible further Availsim studies

- Availsim detailed results are strongly dependent on the input assumptions, eg operations and recovery models
  - **Need to better understand sensitivities**

- SB2009 specific
  - **Trade studies on energy / RF power overhead**
    - Evaluate sensitivity to klystron/modulator MTBFs
    - Separately evaluate sensitivity to ‘cold mass’ failures
  - **Further evaluate sensitivities to underlying assumptions, eg mitigating specific failures, recovery model**

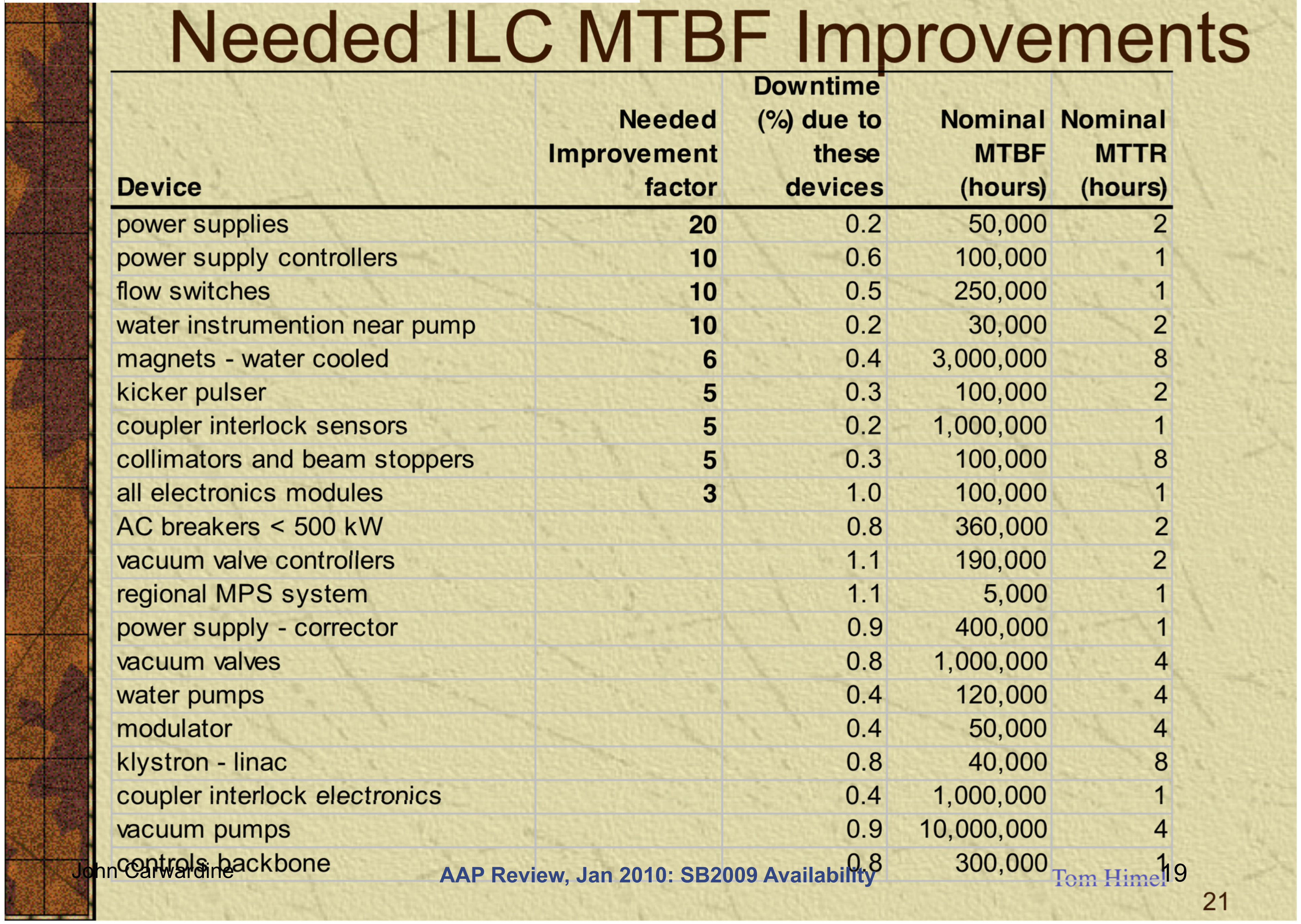
- Trade studies on technical risk across entire machine
  - **Relative allocations of downtimes across areas/systems**
  - **Continue to survey in-the-field experience – take credit for best-in-class MTBFs (lower the technical risk)**

Summary

- As specified, both SB2009 Main Linac configurations appear viable from an availability perspective
  - **A set of ingredients has been established**
  - **Degree of difficulty appears similar to RDR 2-tunnel**
- Availability simulations do not discount an RDR HLRF single-tunnel configuration, but we have not evaluated this in any detail
- We need to use Availsim to better understand sensitivities
- The technical risk is lower than described in the RDR if we take credit for system-by-system ‘best-in-class’ availability

Backups

MTBF improvement factors used in RDR

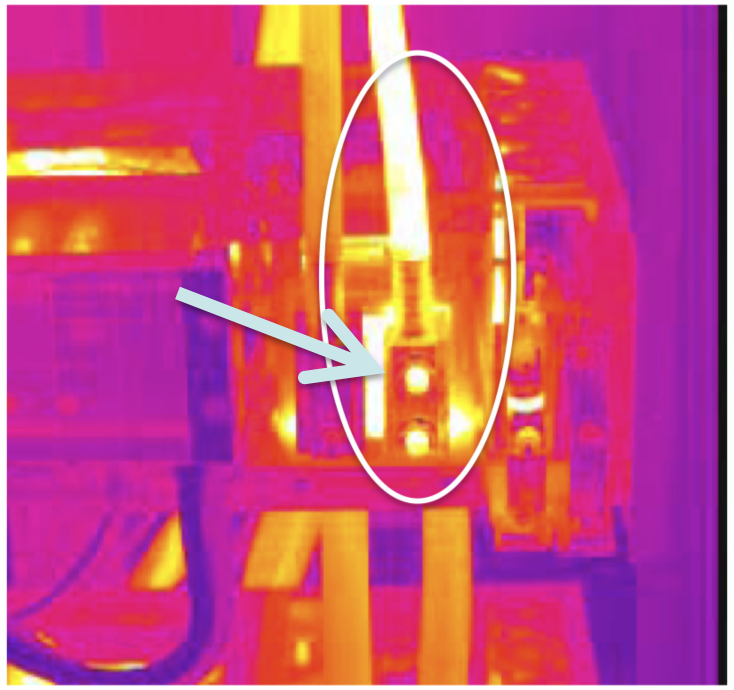


Needed ILC MTBF Improvements

Device	**Needed Improvement factor**	**Downtime (%) due to these devices**	**Nominal MTBF (hours)**	**Nominal MTTR (hours)**
power supplies	**20**	0.2	50,000	2
power supply controllers	**10**	0.6	100,000	1
flow switches	**10**	0.5	250,000	1
water instrumention near pump	**10**	0.2	30,000	2
magnets - water cooled	**6**	0.4	3,000,000	8
kicker pulser	**5**	0.3	100,000	2
coupler interlock sensors	**5**	0.2	1,000,000	1
collimators and beam stoppers	**5**	0.3	100,000	8
all electronics modules	**3**	1.0	100,000	1
AC breakers < 500 kW		0.8	360,000	2
vacuum valve controllers		1.1	190,000	2
regional MPS system		1.1	5,000	1
power supply - corrector		0.9	400,000	1
vacuum valves		0.8	1,000,000	4
water pumps		0.4	120,000	4
modulator		0.4	50,000	4
klystron - linac		0.8	40,000	8
coupler interlock electronics		0.4	1,000,000	1
vacuum pumps		0.9	10,000,000	4
controls backbone		0.8	300,000	1

PM on APS power converters using thermal imaging (examples of problems)

One of the four filter capacitors failed open circuit and is running cooler than the others. This causes stress on the other caps, which will eventually fail and cause downtime.



Loose cable connection causing excessive heat in lugs and cables