Reliability/Availability considerations for a VLHC

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- Definitions and examples
- Relations between reliability measures
- SSC reliability analysis
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Definitions

$$T_S = \text{scheduled uptime}$$

$$T_D = \text{unscheduled downtime}$$

$$T_U = T_S - T_D \quad \text{uptime}$$

$$A = \frac{T_S - T_D}{T_S} \quad \text{availability}$$

$$U = \frac{T_D}{T_S} = 1 - A \quad \text{fractional downtime} = \text{unavailability}$$

Examples

System fractional downtime (unavailabilty) in %
(Table from SSC CDR p 86)

System	CESR	PEP	PETRA	Tevatron FT 800 GeV	CERN FT SPS	SSC (CDR) goal
Power supplies		3.0	4.2	4.1	1.0	4.0
Cryogenics				4.2		2.0
Vacuum	0.4	0.6	1.7	0.4	0.2	0.5
Control/Instru	1.1	1.6	0.6	0.7	0.8	2.0
RF	12.2	0.9	4.2	0.6	1.4	2.0
Injector complex	2.3	25.0	7.1	14.6	6.0	5.0
Injection/abort				0.7		1.5
Utilities	0.9	1.8	1.0	3.0	3.4	1.0
Interlocks	0.4	0.8				0.5
Magnets	3.3			6.2	1.8	4.0
Miscellaneous	1.7	6.0	4.0	1.1	3.0	0.0
Total	22.30	39.70	22.80	35.60	17.60	22.50
Availability	77.70	60.30	77.20	64.40	82.40	77.50

Relations between measures of reliability

Consider a system with N components, labeled by index i

The system is operated with an uptime $T_U = T_S - T_D$

For component i

$\lambda_i =$ failure rate $\quad T_{F,i} = \frac{1}{\lambda_i} =$ mean time to failure

$T_{R,i} =$ mean down time per failure

$$n_i = T_U \lambda_i = \frac{T_U}{T_{F,i}} = \text{ number of failures}$$

$$T_{D,i} = n_i T_{R,i} = T_U \frac{T_{R,i}}{T_{F,i}} = \text{ down time}$$

$$U_i = \frac{T_{D,i}}{T_S} = \text{ unavailability}$$

For the whole system

Number of failures $$n = \lambda T_U = \sum_{i=1}^{N} n_i = T_U \sum_{i=1}^{N} \lambda_i$$

Total failure rate $$\lambda = \sum_{i=1}^{N} \lambda_i$$

Total down time $$T_D = \sum_{i=1}^{N} T_{D,i} = T_S \sum_{i=1}^{N} U_i$$

System unavailability

$$U = \frac{T_D}{T_S} = \sum_{i=1}^{N} U_i = \frac{T_U}{T_S} \sum_{i=1}^{N} \lambda_i T_{R,i} = (1-U) \sum_{i=1}^{N} \lambda_i T_{R,i}$$

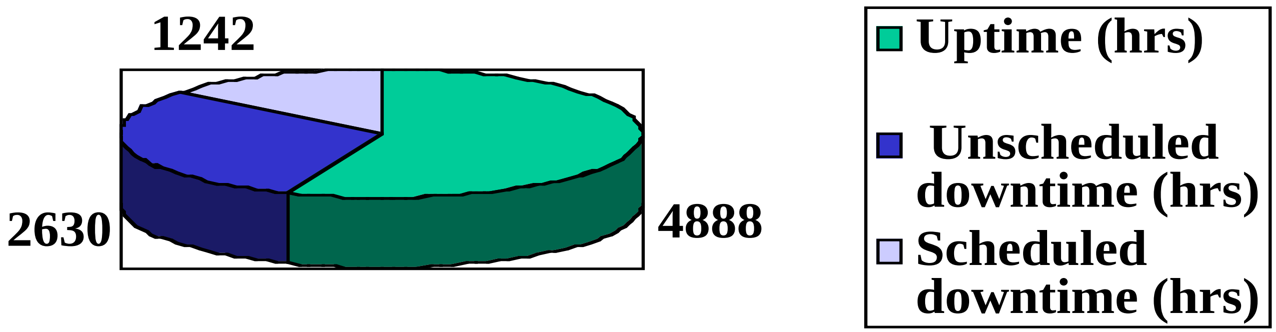
$$\sum_{i=1}^{N} \lambda_i T_{R,i} = \frac{U}{1-U} = \frac{1-A}{A}$$

Tevatron 1988-89 Collider run availability

Uptime	11257 hrs		Scheduled time	13259 hrs		

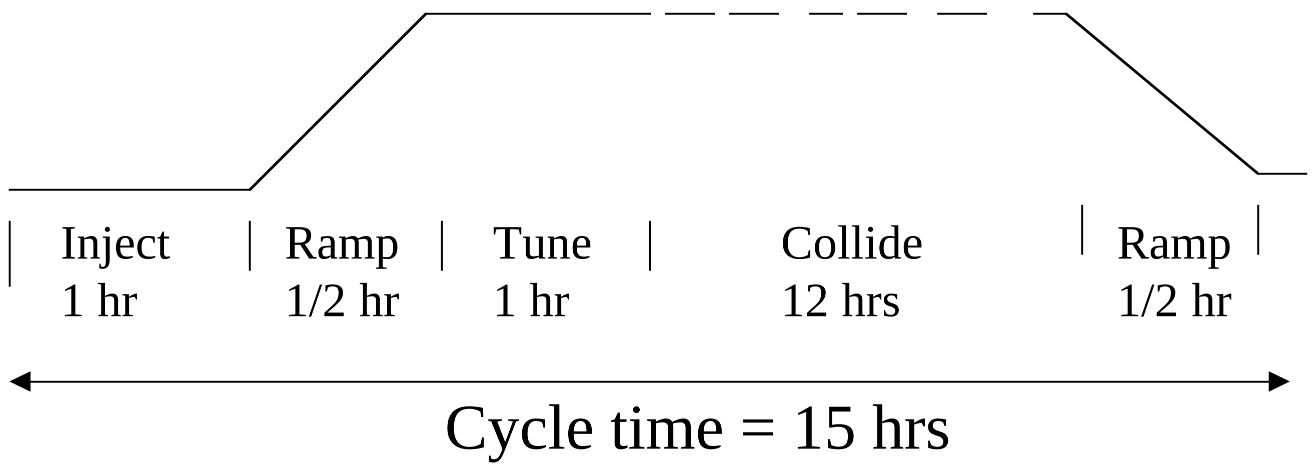
System	Number of failures	Mean down time per failure (hrs)	Total down time (hrs)	Unavailability	Availability	Mean time between failures (hrs)
Injector (total)	1607	0.55	881	6.64%	93.36%	7.00
Magnets	8	41.63	333	2.51%	97.49%	1407.13
Quench	113	1.73	195	1.47%	98.53%	99.62
Power supplies	74	1.81	134	1.01%	98.99%	152.12
Misc	84	1.18	99	0.75%	99.25%	134.01
Cryogenics	47	1.60	75	0.57%	99.43%	239.51
Correctors	46	1.35	62	0.47%	99.53%	244.72
RF	47	1.30	61	0.46%	99.54%	239.51
QPM	43	1.40	60	0.45%	99.55%	261.79
Controls	32	1.34	43	0.32%	99.68%	351.78
vacuum	9	3.33	30	0.23%	99.77%	1250.78
Injection	10	1.60	16	0.12%	99.88%	1125.70
Cent He Liq	4	3.25	13	0.10%	99.90%	2814.25
Tevatron (total)	517	2.17	1121	8.45%	91.55%	21.77
Tevatron+Injector (total)	2124	0.94	2002	15.10%	84.90%	5.30

SSC ANNUAL OPERATING TIME ALLOCATIONS



4888 hrs = 1.8 x 10^7 sec

Operating cycle and average luminosity



Average luminosity

For τ =luminosity lifetime=20 hours and T=15 hours,

$$\frac{\langle L \rangle}{L_{\max}} = 0.572$$

And the annual integrated luminosity is

$$\int_{year} L dt \approx L_{\max} \times 10^7 \mathrm{s}$$

SSC Availability Allocations

Uptime	4888.4	hours	Remainder Scheduled time	1242 7518	hours hours	
System	Number of failures	Mean down time per failure (hours)	Total down time (hours)	Unavailability	Availability	Mean time between failures (hours)
Magnet system	6	251.00	1506	20.03%	79.97%	814.73
Local controls	9	24.00	216	2.87%	97.13%	543.16
Cryogenics	24	8.00	192	2.55%	97.45%	203.68
Injector	18	5.30	95.4	1.27%	98.73%	271.58
Utilities	15	6.00	90	1.20%	98.80%	325.89
Misc	22	4.00	88	1.17%	98.83%	222.20
Ring PS/regs	17	4.60	78.2	1.04%	98.96%	287.55
QPS	19	4.00	76	1.01%	98.99%	257.28
Instrumentation	9	8.00	72	0.96%	99.04%	543.16
RF	15	4.00	60	0.80%	99.20%	325.89
Vacuum	6	8.00	48	0.64%	99.36%	814.73
Global Cntrls	8	6.00	48	0.64%	99.36%	611.05
Injec/abort	2	12.00	24	0.32%	99.68%	2444.20
Safety/Interlock	19	1.00	19	0.25%	99.75%	257.28
Quench	10	1.00	10	0.13%	99.87%	488.84
Correctors	7	1.00	7	0.09%	99.91%	698.34
Collider (total)	**206**	**12.77**	**2629.6**	**34.98%**	**65.02%**	**23.73**

Superconducting magnet failure: repair time estimate

Task	Time (hrs)	Source of estimate
Isolate to faulty magnet	16	CDR
Warm up ring sector	72	SSC Spec (CDR:24 hrs)
Spoil vacuum	1	CDR
Disconnect bad magnet	8	CDR: 4 hrs
Remove bad magnet	2	CDR
Prepare new magnet	4	CDR
Place new magnet	2	CDR
Align magnet	4	CDR
Connect, electrical	6	CDR
Connect, mechanical	6	CDR
Pump down/leak check	48	CDR: 36 hrs
Hi-pot	2	CDR
Cooldown ring sector	72	SSC Spec (CDR:48 hrs)
Pre-start checkout	8	CDR
TOTAL	**251**	**CDR+88 hrs**

SSC/Tevatron comparison
Mean down time per failure and number of failures

System	SSC Mean down time (hours)	Tevatron Mean down time (hours)	SSC Number of annual failures	Tevatron Number of annual failures
Magnet system	251.00	41.63	6	3
Correctors	1.00	1.35	7	20
Ring PS/regs	4.60	1.81	17	32
QPS	4.00	1.40	19	19
Cryogenics	8.00	1.60	24	20
Vacuum	8.00	3.33	6	4
Global Cntrls	6.00	1.34	8	14
Local controls	24.00		9	
Instrumentation	8.00		9	
RF	4.00	1.30	15	20
Injec/abort	12.00	1.60	2	4
Utilities	6.00	2.51	15	20
Safety/Interlock	1.00		19	
Quench	1.00	1.73	10	49
Misc	4.00	1.18	22	36
Collider (total)	**12.77**	**0.94**	**188**	**243**

SSC/Tevatron comparison
Mean time between failures

System	SSC Mean time between failures (hours)	Tevatron (hours)
Magnet system	814.73	1407.13
Correctors	698.34	244.72
Ring PS/regs	287.55	152.12
QPS	257.28	261.79
Cryogenics	203.68	239.51
Vacuum	814.73	1250.78
Global Cntrls	611.05	351.78
Local controls	543.16	
Instrumentation	543.16	
RF	325.89	239.51
Injec/abort	2444.20	1125.70
Utilities	325.89	239.51
Safety/Interlock	257.28	
Quench	488.84	99.62
Misc	222.20	134.01
Collider (total)	**23.73**	**21.77**

SSC/Tevatron comparison
Unit failure rates

System	SSC Mean time between failures (hours)	Tevatron (hours)	SSC Unit count	Tevatron	SSC Unit MTBF (years)	Tevatron (years)	SSC Unit Failure rate failures per million hour	Tevatron
Magnet system	814.73	1407.13	10420	900	969.12	144.57	0.12	0.79
Correctors	698.34	244.72	1700	400	135.52	11.17	0.84	10.22
Ring PS/regs	287.55	152.12						
QPS	257.28	261.79	10420	900	306.04	26.90	0.37	4.24

SSC-Tevatron differences

- SSC estimated a longer mean down time per failure (related to larger ring size)
- SSC needed smaller unit failure rates (related to larger number of units per system)

VLHC Availability allocations

- Start with SSC allocations
- Increase mean down time per failure by x2 for all systems except magnets (larger ring size)
- Reduce allowed number of failures per year (by 25%) to maintain same total downtime

VLHC Availability allocations

Uptime	4916	hours	Remainder Scheduled time	1242 7518	hours hours	
System	**Number of failures**	**Mean down time per failure (hours)**	**Total down time (hours)**	**Unavailability**	**Availability**	**Mean time between failures (hours)**
Magnet system	4	251.00	1004	13.35%	86.65%	1222.10
Local controls	7	48.00	336	4.47%	95.53%	698.34
Cryogenics	18	16.00	288	3.83%	96.17%	271.58
Utilities	11	12.00	132	1.76%	98.24%	444.40
Injector	13	10.00	130	1.73%	98.27%	376.03
Misc	16	8.00	128	1.70%	98.30%	305.53
Instrumentation	7	16.00	112	1.49%	98.51%	698.34
QPS	14	8.00	112	1.49%	98.51%	349.17
RF	11	8.00	88	1.17%	98.83%	444.40
Global Cntrls	6	12.00	72	0.96%	99.04%	814.73
Vacuum	4	16.00	64	0.85%	99.15%	1222.10
Ring PS/regs	12	5.00	60	0.80%	99.20%	407.37
Safety/Interlock	14	2.00	28	0.37%	99.63%	349.17
Injec/abort	1	24.00	24	0.32%	99.68%	4888.40
Quench	7	2.00	14	0.19%	99.81%	698.34
Correctors	5	2.00	10	0.13%	99.87%	977.68
Collider (total)	**150**	**17.35**	**2602**	**34.61%**	**65.39%**	**32.59**

VLHC unit reliability requirements (Low field machine)

System	Mean time between failures (hours)	System Unit	Unit count	Unit MTBF(yrs)	Failure rate (/10^6 hrs)
Injector	376				
Magnet system	1222	125 m magnet unit	5200	725	0.2
Correctors	978	Corrector dipole+power supply (250 m half-cells)	2600	290	0.4
Ring PS/regs	407	Main 100 kA power supply	20	1	122.7
QPS	349	Quench detection unit	5200	207	0.6
Cryogenics	272	Refrigerator	20	1	184.1
Vacuum	1222	Lumped pumps (every 20 m?)	32500	4534	0.0
Global Cntrls	815	Prinicpal nodes	100	9	12.3
Local controls	698	Distributed systems at half-cell locations	2600	207	0.6
Instrumentation	698	BPM's at half-cell locations	2600	207	0.6
RF	444	5 MV systems+power supp.	20	1	112.5
Injec/abort	4888	Kicker modules	100	56	2.0
Utilities	444	Distribution system nodes	10	1	225.0
Safety/Interlock	349	Interlock control nodes	100	4	28.6
Quench	698				
Misc	306				
Collider (total)	**33**				

VLHC unit reliability requirements (High field machine)

System	Mean time between failures (hours)	System Unit	Unit count	Unit MTBF(yrs)	Failure rate (/10^6 hrs)
Injector	376				
Magnet system	1222	20 m magnet unit	5200	725	0.2
Correctors	978	Corrector dipole+power supply (200 m half-cells)	520	58	2.0
Ring PS/regs	407	Main power supply	10	0	245.5
QPS	349	Quench detection unit	520	21	5.5
Cryogenics	272	Refrigerator	20	1	184.1
Vacuum	1222	Warm vacuum pumps	200	28	4.1
Global Cntrls	815	Prinicpal nodes	100	9	12.3
Local controls	698	Distributed systems at half-cell locations	520	41	2.8
Instrumentation	698	BPM's at half-cell locations	520	41	2.8
RF	444	5 MV systems+power supp.	20	1	112.5
Injec/abort	4888	Kicker modules	100	56	2.0
Utilities	444	Distribution system nodes	10	1	225.0
Safety/Interlock	349	Interlock control nodes	100	4	28.6
Quench	698				
Misc	306				
Collider (total)	**33**				

Conclusions

- Reliability requirements for VLHC will be more difficult than in existing machines because of the large size of the site (requiring longer times for repair) and the large number of components.
- With a goal of 65% availability, which provides about 4900 hrs of uptime per year, unit reliability requirements for systems with the most components (e.g., magnets, quench protection, correctors, local controls) are roughly 4-16 times more demanding than for the Tevatron (at 85% reliability)