Accelerator Systems RAM Analysis

George W. Dodson
Accelerator Systems Division
Operations Manager

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Topics

- RAM Calculation of the SNS
  – Methodology
  – Assumptions
  – Results
- Experience at other modern accelerators (JLab, APS)
- SNS reliability goals and approach to tracking reliability data
- Projections for increased reliability

Accelerator Availability

- Neutron scientists desire a 90% steady state availability
  - Travel, many are small groups with small travel budgets
  - Targets, time sensitive materials

- A top-down apportionment sets reliability goals for subsystems

- A bottom-up analysis

RAMI

- Reliability
  - System reliability, steady state or R(t) – Time dependent examples include the "bathtub curve"
- Availability
  - Availability of systems until the next maintenance period
- Maintainability
  - Ability to diagnose and repair faults
  - Ability and knowledge to schedule and perform preventative maintenance before systems fail for systems that show no pre-failure behavior
- Inspectability
  - Ability to PREDICT failure by periodic inspection and do PM to prevent failure

Reliability/Availability Calculation

- Calculated using Markov chains
  - Code obtained from APT,
- Steady state code (after infant mortality curve)
- Mean Time between failures
  - Manufacturer's data, Industrial database, Laboratory experience
- Mean time to repair
  - Engineering estimate, Laboratory experience
- Spares and Repair
  - Type (hot, cold)
  - Replacement (on line, off line)
  - Repair (on line, off line, on line for first and off line for second)

RAM Spreadsheet Example

System	Subsystem	Assembly	Equipment/Failure Mode	Failure Rate (1/h x 10^{-6})	Failure Rate Source	MTBF (h)	Percent of Anticipated Failures	Effective MTBF for Unanticipated Failures (h)	Effective Failure Rate (1/h x 10^{-6})
		RCCS							
			Pump	40.00	Bernardin/Dortwegt	25000	75	100000.0	10.00
			Variable Frequency Drive	20.00	Bernardin/Dortwegt	50000	0	50000.0	20.00
			Control Valve	0.30	Bernardin/Brown (7/9/01)	250000	0	250000.0	4.00
			Piping Leak	3.00	K. Kern (5/18/99)	333333	0	333333.3	3.00
			Constant Flow Valve	1.00	Bernardin/Dortwegt	1000000	0	1000000.0	1.00
			Temperature/Pressure Sensor	30.00	Bernardin/Brown (7/9/01)	33333	0	33333.3	30.00
			Hose Leak	1.80	K. Kern (5/18/99)	555556	0	555555.6	1.80
		RCCS						**25125.5**	**39.80**
		Transmitter (Titan SNS1) 402.5 and 805 MHz		**124.00**	**Maxwell**	**8065**	**0**	**8064.5**	**124.00**
		Interface/control		12.95	Titan FDR	77220	0	77220.1	12.95
		AC distrubution Chassis		12.87	Titan FDR	77700	0	77700.1	12.87
		HV Enclosure		8.71	Titan FDR	114811	0	114810.6	8.71
		Magnet, Filament,Amp, Ion pump Supply		39.73	Titan FDR	25170	0	25169.9	39.73
		PPS Chassis		28.50	Titan FDR	35088	0	35087.7	28.50
		Water cooling		18.95	Titan FDR	52770	0	52770.4	18.95
		Titan SNS1 Transmitter Total		**121.73**				**8214.7**	**121.73**

RAM Spreadsheet Example continued

No. of Spares Included	Type of Redundancy (1=hot 2=cold)	Repair (0=off-line, 1=on-line, 2=supermod)	Effective Total Failure Rate (1/h x 10^{-6})	Estimated Average Annual Frequency of Repairs (=Spares)	Repair Personnel Required	Mean Time To Repair MTTR (h)	Other Delays $MTTR_d$ (h)	Switch-over Time MTTS (h)	Mean Down Time MDT (h)	Estimated Average Total Annual Repair Time (h)	Steady State Availability
1	0	0	10.00	0.08	1	0.5			0.5	0.16	0.999995
1	0	0	20.00	0.16	1	0.5			0.5	0.08	0.999990
1	0	0	4.00	0.03	1	0.5			0.5	0.02	0.999998
1	0	0	3.00	0.02	1	0.5			0.5	0.01	0.999999
1	0	0	1.00	0.01	1	0.5			0.5	0.00	1.000000
1	1	1	30.00	0.23	1	0.5			0.5	0.12	1.000000
1	0	0	1.80	0.01	1	0.5			0.5	0.01	0.999999
	0	**0**	**69.80**	**0.54**					**0.5**	**0.39**	**0.999980**
1	**0**	**0**	**124.00**	**0.96**	**2**	**2.0**	**0**	**0**	**4.0**	**7.69**	**0.999504**
1	0	0	12.95	0.10	2	4.0	0		**4.0**	0.80	0.999948
1	0	0	12.87	0.10	2	4.0	0		**4.0**	0.80	0.999949
1	0	0	8.71	0.07	2	4.0	0		**4.0**	0.54	0.999965
1	0	0	39.73	0.31	2	4.0	0		**4.0**	2.46	0.999841
1	0	0	28.50	0.22	2	4.0	0		**4.0**	1.77	0.999886
1	0	0	18.95	0.15	2	4.0	0		**4.0**	1.18	0.999924
	0	**0**	**121.71**	**0.94**					**4.0**	**7.55**	**0.999513**

Accelerator Systems Initial RAM using an Industrial Database

System	Subsystem	MTBF(h)	Failure Rate (1/h x 10**6)	Mean Downtime	Est. Annual Repair Time	Steady State Availability
LINAC						
	DTL	629.0	1598.9	11.2	448.73	98.25%
	CCL	575.3	1738.2	10.6	514.03	98.27%
	Med. Beta SCL	469.5	2130.1	5.4	298.3	97.35%
	Hi. Beta SCL	341.3	2930.2	5.4	325.4	96.29%
	Crypolant	685.0	684.9	2.8	63.4	99.59%
	HEBT RF	3007.3	332.5	7.2	98.75	99.76%
Linac Total		95.6	10462.5	6.8	1748.8	89.92%
Linac RF		104.0	9612.3	5.4	988.4	95.04%

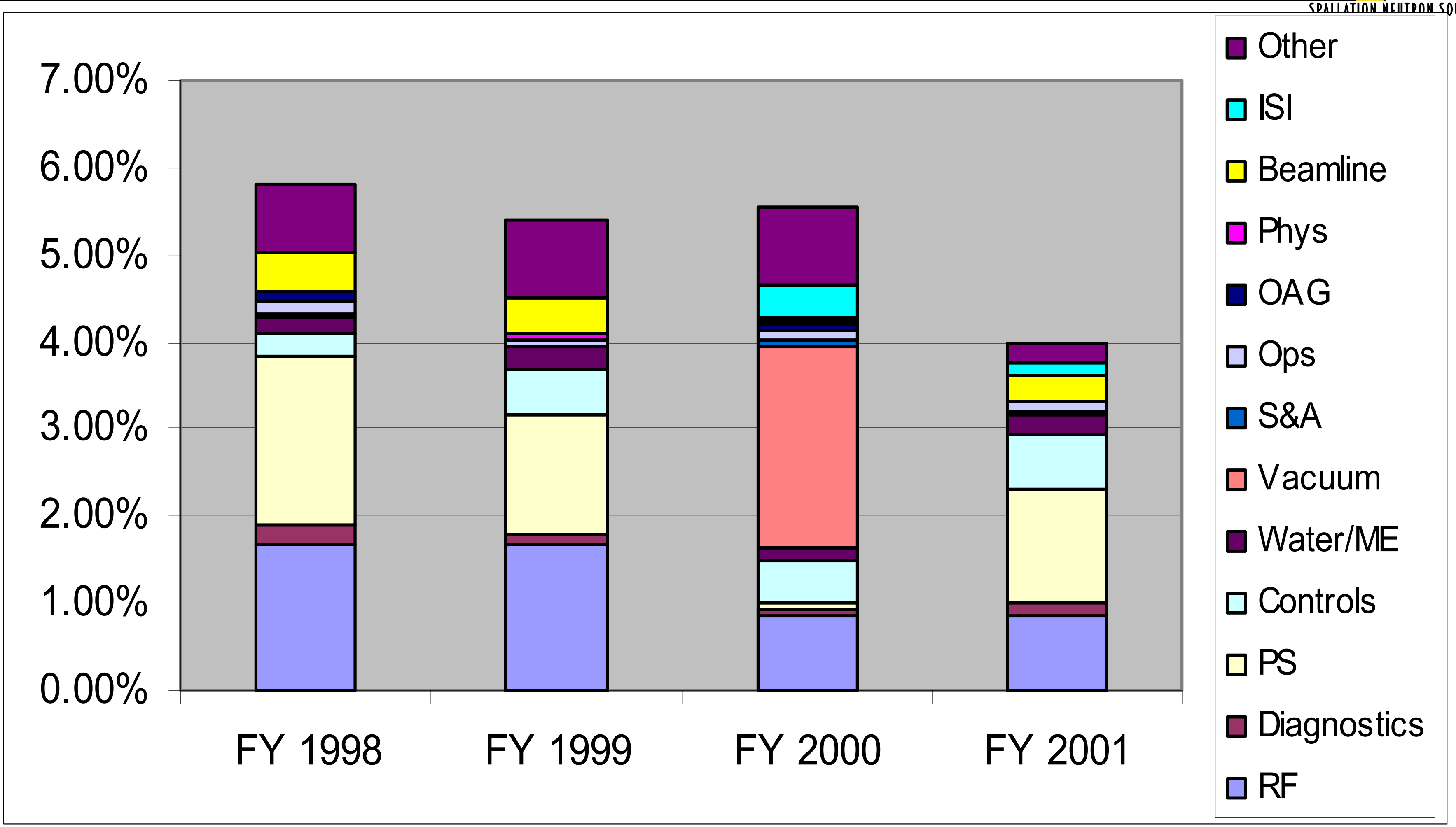
Note: This does not include the Front End

Accelerator Systems Initial RAM using an Industrial Database

System	Subsystem	MTBF(h)	Failure Rate (1/h x 10**6)	Mean Downtime	Est. Annual Repair Time	Steady State Availability
Magnets	Magnets	2317.2	431.6	10.1	67.43	99.56%
	Power Supplies	252.2	3965	2.0	122.3	99.12%
	PS Controllers	133.0	7520	2.0	183.7	98.82%
HEBT-Ring-RTBT Vacuum		702.4	1423.7	12.0	581.4	98.32%
Ring Systems						
	Ring RF System	1544.0	2550	8.0	1265	94.10%
	Extraction Kicke	12500.0	155	2.0	347	97.78%
	Injection Foil Dri	2000.0	500	8.0	327	99.40%
	Collimators	83000.0	1.2	100.0	13	99.92%
Controls						
	EPICS	26800.0	207.8	2.0	415.5	94.78%
	Timing System	350.0	2.27	2.0	5.34	99.93%
	PPS	8310.0	64.42	2.0	128.8	98.35%
	MPS	2000.0	15.5	2.0		99.60%
	Total	37460.0	290.4	2.0	580.8	92.78%
Accelerator Systems Total						73.11%

2000-0xxxx/vlb

APS Unavailability



Comparison of Industrial and Accelerator Databases

Industrial Database	
Magnetics Total	97.53%
Controls Total	92.78%
Accelerator Database using JLAB and APS	
Magnetics Total	99.78%
Controls Total	99.22%

Revised RAMI Summary

System	Subsystem	Initial Analysis Availability	Revised Analysis Availability	Justification
LINAC				
	DTL	98.25%	98.25%	
	CCL	98.27%	98.27%	
	Med. Beta SCL	97.35%	**99.81%**	one cavity off line
	Hi. Beta SCL	96.29%	**99.53%**	one cavity off line
	Crypolant	99.59%	99.73%	
	HEBT RF	99.76%	99.76%	
Linac Total		**89.92%**	**95.43%**	
Magnetics				
	Magnets	99.56%		
	Power Supplies	99.12%		
	PS Controllers	98.82%		
	Total	97.53%	**99.78%**	APS-JLAB Scaling
Ring Systems				
	Ring RF System	94.10%	**99.80%**	one cavity off line
	Extraction Kickers	97.78%	**99.70%**	one module off line
	Injection Foil Drive	99.40%	99.40%	
	Collimators	99.92%	99.92%	
	Total	**91.38%**	**98.82%**	
HEBT-Ring-RTBT Vacuum		98.32%	98.32%	
Controls				
	EPICS	94.78%		
	Timing System	99.93%		
	PPS	98.35%		
	MPS	99.60%		
Controls Total		**92.78%**	**99.22%**	APS-JLAB Scaling
Accelerator Systems Total		**73.11%**	**91.79%**	

Suggested Paths to High Availability

- Add redundancy and fault tolerance to the systems, e.g.
  - Front End - Modify Front End for two ion sources
  - RF Systems - Add another hot standby transmitter
  - Superconducting LINAC - Add more cryomodules
- Purchase Power supplies rated for higher power
- Operate beam at a lower average power

Paths to High Availability: Comments from Engineers

- Purchase over-rated power supplies
  - MTBF increases as ($I_{operating}/I_{rating}$)
  - Using the APS-Jlab scaling, power supplies are already above 99.8%,
- Cooling – get a factor of 2 in MTBF for 10^{o}C in cooling for electronics
  - Air cooling in power supply rooms
  - Water cooling – parallel cooling not series
- Use 1/2 or 2/3 model (NLC talk P. Bellomo)
- Use MIL-HDBK- 217 parts. (MTBF goes to ~140,000h)

Paths to High Availability: Comments from Engineers

- Operate beam at a lower average power
  - 60 Hz at half peak current
    - No effect on DC systems
    - AC systems run at same PRF, some more lightly loaded - slight increase in MTBF – but, run twice as long for the same neutron flux
  - 30 Hz at full peak current
    - Users want 60 Hz operation
    - No effect on DC Systems
    - AC systems run at half the PRF – but, run twice as long for the same neutron flux
- Operate at reduced power while repairs are underway (Klystron, Kickers, Ring RF)

Approaches to High Availability: Operating Schedule

- Availability is not steady state reliability.
- Schedule one shift of PM and one, plus recovery shifts per week. These do not count against availability
- Tactical approach: “ tune around it until the PM day” not “run until it breaks”.

Maintenance

- Initially use reliability calculation to predict MTBF of systems and components.
- Schedule proactive PM to replace components at an agreed percent of the anticipated lifetime.
  - Increases MTBF, does not act as “hot spares”
- Use “lessons learned” from actual failure rate to validate the real MTBF and MTTR

Use Operational Experience

- Track reliability/availability/maintenance with off-the-shelf MIS software
- ERAMS
  - integrated into SNS Oracle database
  - Cradle-to-grave equipment tracking using barcode
    - Direct access to: Installation data, maintenance history, fault history, vendor travelers, partner laboratory travelers, RATS testing results
  - Fault reporting
  - Work planning
  - Spares inventory
- Identify the systems that contribute the most to downtime

Reliability Improvement Program

- Identify the largest contributor to downtime
- Upgrades to the hardware specifications
  - Purchase overrated power supplies
- Upgrades are possible to hardware as supplied
  - Suggest hardware modifications based on operational experience
- Upgrades are possible to hardware as it is operated
  - Cooling
  - PM

Conclusion

- Presented reliability goals, a calculation with an industrial database and a comparison to recent accelerator experience.
- Described how a proactive PM program utilizing a MIS system for tracking the sources of beam unavailability will be used to increase availability.
- Showed a reliability improvement program focusing on system fault tolerance, redundancy and operating conditions.