ANALYSIS OF AVAILABILITY AND RELIABILITY IN RHIC OPERATIONS *

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Abstract

RHIC has been successfully operated for 5 years as a collider for different species, ranging from heavy ions including gold and copper, to polarized protons. We present a critical analysis of reliability data for RHIC that not only identifies the principal factors limiting availability but also evaluates critical choices at design times and assess their impact on present machine performance. RHIC availability data are typical when compared to similar high-energy colliders. The critical analysis of operations data is the basis for studies and plans to improve RHIC machine availability beyond the 50-60% typical of high-energy colliders.

INTRODUCTION

Availability data for RHIC operations are first analyzed with a particular emphasis on the last 3 years of regular operations after the initial commissioning phase. Run-4 consisted mostly of Au-Au collisions, followed by 3 weeks of polarized protons (PP) development. Run-5 was equally divided between Cu-Cu and polarized protons operations; Run-6 consists entirely of PP operations. We then examine the role of system reliability, original design choices and machine running parameters in determining machine availability. We finally discuss the strategy to increase RHIC machine availability and time at store that includes improving reliability of critical systems, operation procedures and maintenance management.

RHIC OPERATIONS DATA

The figures below compare data for the 3 last runs of operation, for ions and PP operations. Heavy ions operations have become routine. The lengths of stores for physics are fixed to 4-5 h (to optimize the integrated luminosity, mostly limited by IBS), predictable and under control. (Figure 1)

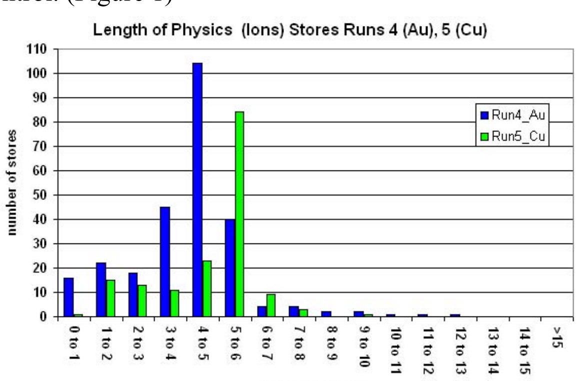

Figure 1: Length of stores, for Run-4 (Au) and 5 (Cu).

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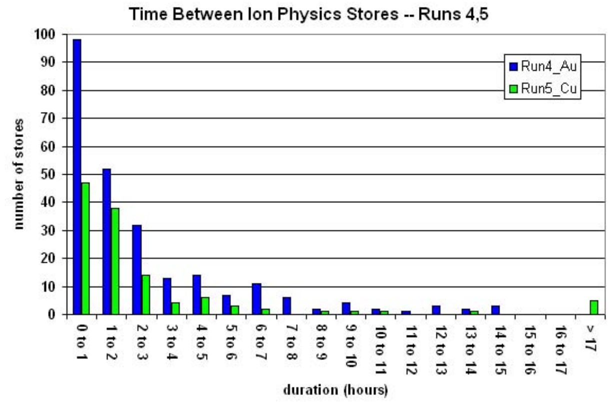

Figure 2 : Time between stores for Run-4 (Au) and 5 (Cu).

The length of time between physics stores is also under control. Sixty percent of stores were begun within two hours of the end of the previous store during Run4 while sixty nine percent of stores were begun within two hours of the previous store during Run5 (Figure 2).

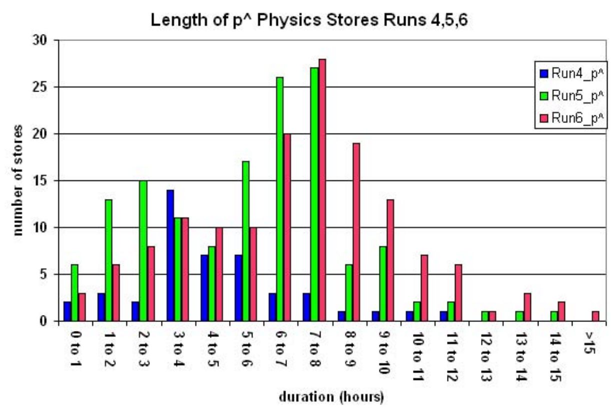

Figure 3 : Length of stores for PP Runs 4,5 and 6.

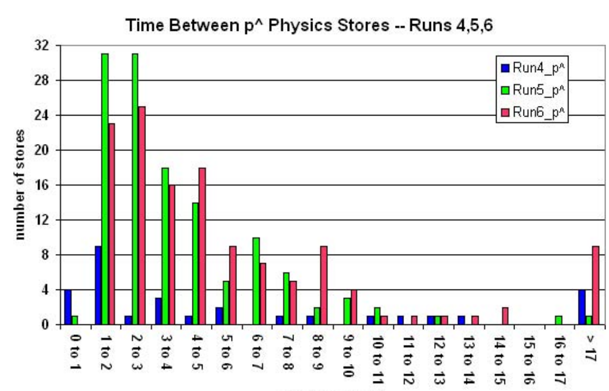

Figure 4: Time between stores for PP Runs 4, 5 and 6.

Operation with PP is more challenging and accelerator availability reflects that fact. Store length was less predictable and the distribution of store lengths much broader, and that is reflected in machine availability.

Availability for Physics, defined at RHIC as the ratio of the *hours in physics at store* vs. the *calendar time* hours, is with luminosity the fundamental figure of merit for accelerator operations. During Run-4 the mean value of the number of physics hours per week was 87 (52%), while the corresponding numbers for Run-5 were 83 (49%). (Figure 5) The goal is 100 physics hours per week (60%).

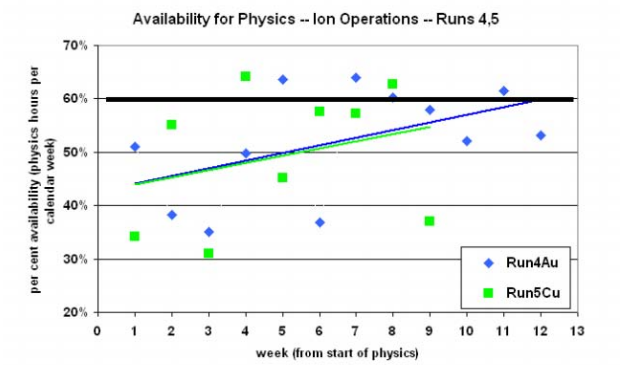

Figure 5: Availability for heavy ion operations.

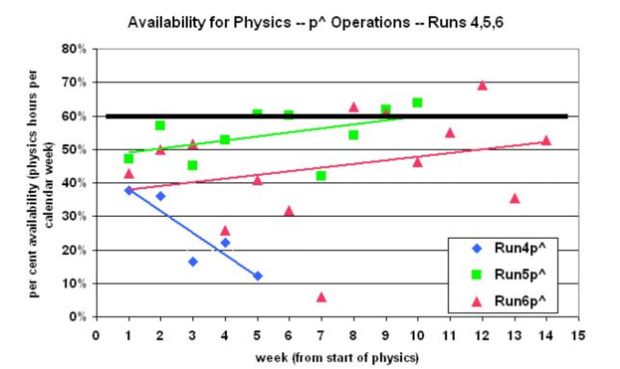

Figure 6: Availability for polarized protons operations.

Accelerator availability for physics was high for PP during Run-5 where the average number of physics hours per week was 91 (54%). Availability shrank during Run-6 to 72 h/week (43%). This motivated the present analysis of availability and a plan to reach the goal of 60%.

ANALYSIS OF MACHINE AVAILABILITY

Effect of System Reliability

Unscheduled downtime due to system failure is easy to track to identify the systems that contribute most to the downtime. Controls, power supplies and cryogenics consistently appear in the list of such systems. More recently reliability problems appeared in access controls, electrical power services and in the area of human error, the latter often a hidden factor behind many system failures.

A more detailed analysis of FY-2005 system operational failures [1] includes in the analysis a breakdown of failure time by system and by shift. This data reveal interesting information: for some systems there is a striking difference between failures during the day and owl shifts. For example, the vacuum system had 16 failure hours in the day shift, and 44 failure hours in the owl shift, while the control system conversely had 83 hours of failure time during the day shift and 19 the owl, reflecting not only difference in function but also in operation management in the system groups.

Effect and Mitigation of Design Choices

Choices are made during the design and construction time that can greatly affect the future machine availability. An analysis has identified design factors with the greatest impact on RHIC availability and in some cases mitigating measures.

Design margin is paramount: the RHIC main dipoles and quadrupoles have respectively 30% and 15% margin in their operating fields and in 6 years of operation we never had a single magnet failure.

The single factor affecting the most the RHIC Power supply system over the life of the project has been the lack of air conditioning and air quality in the PS service buildings. The lower performance in the field than in the testing lab caused delays in the commissioning phase and downtime now in warm weather. AC in the service building is planned.

Radiation damage in the electronics has also been a major factor in system reliability, for instance in the cryogenics system and the BPM diagnostics. Radiation damage in cryogenics electronics has been the primary cause of cryogenics associated downtime. 15 out of 42 racks have been moved out of the tunnel already and the plan is to have 80% out in the next 2 years. Radiation damage has been also a factor in initial reliability problems with the BPM system. Again, moving the BPM cards to shielded alcoves virtually eliminated this failure mode. Another step towards system reliability has been the elimination of relays in the signal path of the BPM cards, a major rework of the electronics that paid dividends in the reliability of the diagnostics.

Effect of Running Parameters

Overall machine availability also directly depends on the machine running mode. It is intuitive that more conservative machine parameters lead to more reliable operations. Run-5 operations at RHIC with copper ions provide an example: 2 weeks of low energy operations at 31.2 GeV/u followed a 9-week long physics run at 100 GeV/u. Being a shorter run with lower luminosity requirements we ran the low energy program with more conservative machine parameters:

Table 1: Parameters for high and low energy Cu run

config	energy	ions/bunch	#bunches	β^*
High E	100 GeV/u	4.5×10^9	41	0.9m
Low E	31.2 GeV/u	3.8×10^9	37	3m

The resulting machine availability jumped form 49% to 70% for the low energy run. Lower bunch intensity translated in fewer permit pull on the ramp due to losses, higher luminosity lifetime from reduced beam-beam effects, less problems with single bunch instabilities. A higher β^* means less permit pulls during the β^* squeeze on the ramp, and fewer losses in the triplets, the aperture limitation of the machine at store.

Clearly pushing beam current, β^* and machine parameters maximize instantaneous luminosity, but overall integrated luminosity must be based on an optimization of performance and availability.

PLAN TO IMPROVE AVAILABILITY

RHIC availability during the recent PP Run-6 dropped to 43% from the 53% achieved in Run-5 PP operations; the goal for more efficient operations of the physics detectors, is 100 hours at store/week or about 60% machine availability.

We will discuss a plan to improve availability in the next 2-3 years towards the stated goals, based on parallel intervention on many fronts.

System reliability

Table 2 : Systems most affecting machine availability during PP operations in Run-6

	FY06	
Rank	System	total hours
1	Controls	65
2	AccessControls	44.2
3	Services Electrical	33.9
4	RHIC Blue PS	33.6
5	Human Error	30
6	Linac Rf	28.8
7	AtR cooling/PS	26.51
8	Preinjector (Source)	23.7
9	BtA PS	21.9
10	Cryogenic	21.31

The systems with most failure hours are in the process of preparing a reliability analysis, including system upgrades, cost and schedule. The proposed upgrades will be reviewed and prioritized during the summer shutdown and progressively implemented

Machine maintenance

Scheduled accelerator maintenance and unscheduled accesses requested by the detectors contribute significantly to machine downtime. RHIC has so far operated on a bi-weekly scheduled maintenance, typically of 8-10 hours. A regular schedule for access is mainly determined by the experiments needs for detector access and upgrades. In order to optimize the maintenance process the following steps are being taken:

- Reduction of frequency of maintenance from bi-weekly to every 3 weeks
- Optimization of maintenance scheduling and coordination, respectively by WEB based job requests and schedules, and the creation of an overall maintenance coordinator.
- Optimization of operation recovery time after maintenance, with formal scheduling of system testing after repair, and more formal hand-over of systems to operations.

Further automation of operation procedures

A Sequencer program choreographs most of automatic procedures in RHIC operation, from simple instrumentation set-up to the entire ramp process. Progress in automation can still made in a few areas, for example the process of setting the beam in collisions, optimizing lifetime, collision rates and collimation is not yet entirely automated.

Human error

We are starting to realize that human error is not only explicitly caused 30 failure hours in the last run but it is also a contributing factor behind many system failures. Improved training not only for control room personnel but also for system experts and support personnel, and increased use of online help are among the measures that can be taken to minimize human error in operations.

Online availability monitoring

We are beginning to research options for online continuous analysis of failure data. An operations journal log is currently used to log the machine state and identify the general cause of failures. However, analyzing this data is not straightforward and significant time is required. Online analysis tools will provide continuous failure tracking for trending and analysis during the running period. Responsible personnel from all groups will be able to identify creeping system failure issues early, thereby allowing corrections to be implemented sooner than in the past. Monitoring using the online tools will provide straightforward methods for determining the effectiveness of the corrective actions.

Integration of operations

A plan is also in place to centralize in main control room the monitoring and control of the cryogenics, the AGS power supplies, and the support personnel that provide the first technical line of response in case of failure. Integration and better communication will reduce probability of human error issues and improve the overall efficiency of RHIC operations.

REFERENCES

[1] R. Michnoff, C-AD Note 242