OVERVIEW OF RECENT STUDIES AND MODIFICATIONS BEING MADE TO RHIC TO MITIGATE THE EFFECTS OF A POTENTIAL FAILURE TO THE HELIUM DISTRIBUTION SYSTEM *

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Abstract

In order to cool the superconducting magnets in RHIC, its helium refrigerator distributes 4.5 K helium throughout the tunnel along with helium distribution for the magnet line recoolers, the heat shield, and the associated return lines. The worse case for failure would be a release from the magnet distribution line which operates at 3.5 to 4.5 atmospheres and contains the energized magnet but with a potential energy of 70 MJoules should the insulation system fail or an electrical connection opens. Studies were done to determine release rate of the helium and the resultant reduction in O_2 concentration in the RHIC tunnel and service buildings. Equipment and components were also reviewed for design and reliability and modifications made to reduce the likelihood of failure and to reduce the volume of helium that could be released.

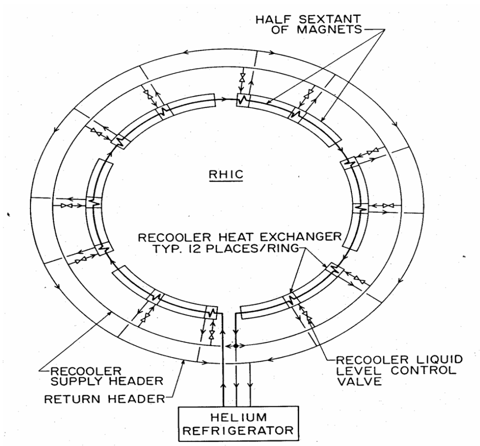

Figure 1: RHIC Distribution System.

INTRODUCTION

The RHIC distribution system (see Fig. 1) consists of 3 high pressure transport systems in parallel, a low pressure return system, and a high pressure heat shield system. The magnet cooling distribution line is supplied directly from the RHIC refrigerator with 450 g/s of Helium flow at 4.5 atm. which is split between both rings. The outlet of the magnet line is routed to the recooler supply line at 3.5 atm. The recoolers return gas at 1.2 atm. to the refrigerator. The heat shield line is supplied separately from the refrigerator at 3.5 atm. and 100 g/s.

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The major concern is that helium will escape confinement within the vacuum insulated cryostat creating a oxygen deficiency hazard (ODH) in the tunnel or service buildings. Many systems were put in place during RHIC construction to prevent and mitigate the effect of a failure. The helium distribution system failure at CERN [1] drove a study to re-evaluate the assumptions made during RHIC construction about a helium release.

SAFETY SYSTEMS IN PLACE

RHIC was designed to be pressurized as high as 17 atm. in the magnet line. This allowed significant overhead for quench events and for long power interruptions. During construction and after major repairs the piping was tested to 10% over this value in accordance with ASME code requirements. All of the distribution piping in the RHIC tunnel and in valve boxes in the RHIC service buildings have relief valves which vent outside the enclosures (Fig. 2) to prevent off normal events from creating ODH issues.

Figure 2: Process Line Reliefs with External Vents.

The magnets cryostats, the vacuum jacketed helium transfer pipes between magnets, and the cryostats for the valve boxes in the service buildings are equipped with safety relief devices. Unfortunately, these reliefs vent locally in the tunnel or the service buildings (see Fig. 3). An arc failure of the magnet bus at full current could release up to 70 MJ of energy which could breach the 4.2K helium line in the insulating vacuum volume. In addition, gas cooled leads for the main magnet bus and for corrector magnet systems are located in both the tunnel and the power supply buildings.

The RHIC tunnel and service buildings were constructed with an ODH detection, warning (lights and audible alarm), and large air supply/helium exhaust systems. Training for response to an ODH alarm is included in the tunnel access training. In the event of an alarm, staff members were trained to exit the tunnel and service building immediately via the closest exit away from a visible vapor cloud [2]. A helium release test was done in the tunnel to verify the effect of a point source release of helium. It verified that the ODH alarms were effectively placed and that personnel could safely move away from a single point helium release.

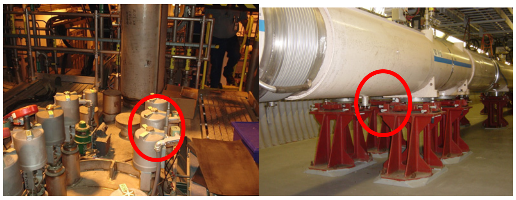

Figure 3: Vacuum Volume Pressure Reliefs, Service Building (left) and Tunnel (right).

PREVIOUS SYSTEM FAILURES

RHIC has had problems with systems and components associated with the cryogenic system.

- (2000) During commissioning, a bellows restraint on the magnet line failed in multiple locations as the result. The magnet bus within was not damaged.
- (2002) Chaffed wire insulation occurred because the expansion joint for cooldown and warm-up did not provide enough travel. (Fig. 4).
- (2005) Corrosion on ceramic feedthroughs resulted in minor helium leaks at the valve boxes.
- (2008) High resistances as the result of poor solder joints repaired in the high current quadrupole bus.
- (2009) Insulators for the high current (up to 6000A) bus lead feedthroughs began to deteriorateFortunately, none of them caused high value damage or resulted major release of helium. But it was recognized that there is potential for an arc flash or helium release.

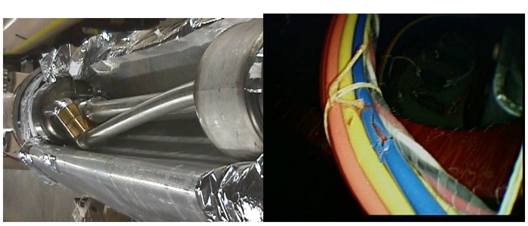

Figure 4: Left side, (2000) failed bellows restraint. Right side, (2002) damaged electrical insulation.

SAFETY SYSTEMS REVIEW

Studies and calculations were done during RHIC construction and re-evaluated in 2004 to determine the effect of a helium distribution system failure; but, two critical factors were found to be incorrect.

- The study considered only the release of the helium inventory from one sector in RHIC. This assumed that a system was in place to detect the failure and then isolate the helium distribution lines. This mitigation was never put in place.
- The RHIC magnet vacuum insulating cryostat is a continuous assembly in both the blue or yellow ring for each 60^{o} segment in RHIC. Distributed along this ~500 M length are over 80 relief devices. Arc flash failure release of LHe into this volume would expand quickly as it is heated by the cryostat surfaces opening reliefs far from the point of failure.

Those two factors taken together indicated a higher level of risk for workers in the tunnel and service buildings while the RHIC cryogenic system and magnets were on. Without a system to detect and isolate helium from the adjacent sectors in RHIC and the refrigerator itself, they could introduce a large volume of helium gas into the tunnel or a service building. Detailed calculations were done to quantify this effect and found that oxygen levels could fall to as low as 4% after a catastrophic failure into the insulating vacuum (Fig. 5).

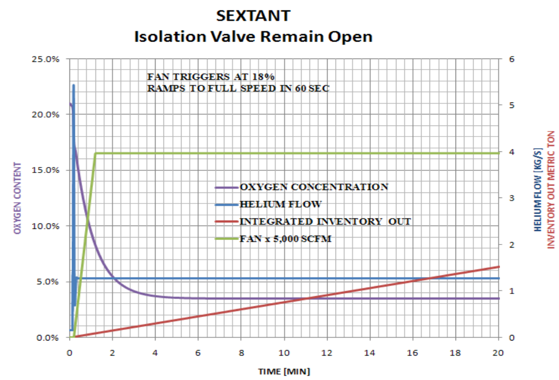

Figure 5: ODH Calculation Result for Unchecked Helium Release into the RHIC Tunnel

Immediately, the personnel access rules were changed. The RHIC tunnel and service buildings were reclassified as ODH 1 areas. The following changes were made:

- All workers entering the tunnels and service buildings needed ODH 1 training and needed to carry personal protection equipment for ODH 1: a personal oxygen monitor and an oxygen bottle escape pack.
- To reduce the probability and energy in an arc flash failure, magnets in RHIC were no longer ramped above injection current with personnel in the tunnel.

Most important, the entire RHIC system has been reviewed with consideration to previous failure modes and the early system plans. Detailed calculations and analysis for Helium release rates have been redone using software not available during construction [3].

RHIC SERVICE BUILDING UPGRADES

As a result of this review the following upgrades have been implemented in the valve box service buildings:

- The valve box vacuum vessel relief system was upgraded and piping for external venting was added.
- The gas cooled lead feedthrough electrical insulators on the valve boxes were upgraded and plexiglass covers was added over the lead area to direct gas flow up and away from the personnel access walkways in the event of a failure.
- The gas cooled lead feedthrough assemblies were upgraded with improved heater systems and thermal

insulation to eliminate iceballs and condensation that were leading to corrosion and stress [4].

As a result of these upgrades, the ODH safety level for the service buildings was returned to its previous state. Escape packs and personal ODH monitors are no longer required. The changes did not eliminate the possibility of a lead failure; but, the flow cross-section through a lead is restricted so the previous safety systems can keep the area safe. The buildings still have O_2 deficiency monitors, alarms, and exhaust fans to mitigate the effects of a lower flow lead failure.

RHIC TUNNEL UPGRADES

The challenges in the tunnel are tougher. The distance to escape from the tunnel is much longer; up to 300 M from the center of a sector. The 80+ relief valves for the vacuum cryostats are distributed throughout the sector. Installing piping to vent outside would have created a trip and access hazard for quick escape from the tunnel and would have restricted the low pressure relief flow from the cryostats. The gas cooled leads in the tunnel were not a major concern because they would be single point low flow release. In addition, they had been upgraded prior to the evaluation and have been working well.

A related issue with the larger volume of helium that could be released in the insulating vacuum cryostat is the pressure that could be reached within the cryostat. Some of the inter-magnet vacuum jacketed piping lines have much smaller insulating vacuum volumes and fewer pressure relief devices so detailed calculations were performed on these locations as well [5]. To bring these stresses for these vessels within ASME code compliance and to keep the oxygen levels within acceptable levels, the tunnel improvement project is concentrating on limiting the helium release.

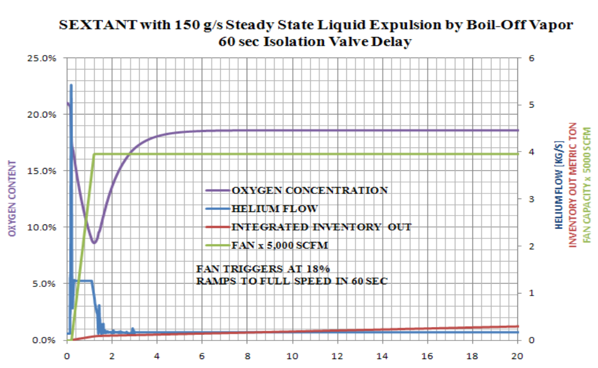

Figure 6: ODH Calculation Result for Helium. Release into the RHIC Tunnel with Intervention

In 2009, sector isolation tests which closed off the distribution lines and the refrigerator supply to the ring with existing cryogenic valves were performed in the RHIC tunnels. Now the cryogenic control room can monitor indicators and implement this intervention when personnel are in the tunnels for maintenance and repair. As shown in Fig. 6, with a 60 second delay in implementing isolation, the oxygen level in the tunnel reaches 9% but quickly recovers to safe levels as the exhaust fans start and the helium loss rate diminishes.

Automatic Response

The last step is implementing faster automated response that takes the human element out of an off normal occurrence. Numerous existing inputs such as ODH sensors and vacuum gauges were investigated and each had issues. Therefore; normally closed mechanical diaphragm pressure switches are being installed that will monitor all of the insulating cryostat volumes in the RHIC tunnel. There will be dual redundant systems for providing feedback to the RHIC control system. If one of the systems loses continuity while personnel are in the RHIC tunnel, the RHIC distribution control system will automatically isolate all of the RHIC sectors and start the ODH tunnel exhaust fans. The response of this system will be less than 15 seconds after a break occurs and is not affected by electronic noise resident in the accelerator tunnel. The O2 level will reach 14% but will quickly recover to safer levels. This system is scheduled to be installed this summer.

CONCLUSION

Significant effort has been spent to re-evaluate the safe guards in RHIC to mitigate the effects of a helium distribution system failure. As a result existing components were upgraded and new components were installed. If a failure should occur, system intervention will keep O_2 levels in the tunnels and service buildings at a safe level and allow safe evacuation from these locations.

RECOGNITION

Many groups provided support, attended meetings, and provided background information for this paper and to upgrade the safety systems in RHIC:

- Technicians in the Acc. Comp. and Inst., Controls, Cryogenics, Mechanical, PS, and Vacuum Groups.
- The C-AD ESSHQ and the BNL PCSSC (safety) attended meetings, tracked design modifications, and gave final approval for implementation.

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