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Title: Evaluation of RHIC Safety Relief System in Response to the LHC Incident

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Evaluation of RHIC Safety Relief System in Response to the LHC Incident

K. C. Wu

Abstract

During the commissioning of LHC in September 2008, an electrical bus connection failed causing major damage on accelerator magnets and a large amount of helium release to the LHC tunnel. Due to the incident, $25 million in repair is required and a delay of approximately one year is expected. As a result, RHIC has been investigated for a LHC type incident for safety relief system and related issues.

Introduction

Traditional superconducting magnets are cooled by liquid/cold helium in a cryostat. Low heat leak supports, multilayer insulating blankets, heat shield and vacuum are used to achieve low heat leaks. Cryogenic transfer lines are used so that a helium refrigerator can provide cooling throughout a large accelerator. Depending on the system design, cryogenic lines can be integrated with the magnet cryostat (such as RHIC) or in a separate transfer line (such as LHC).

If there is a failure on the helium system or on the insulating vacuum, temperature and pressure in the cryogenic system will increase at rapid rates. Relief valves must be installed to protect the cryogenic hardware.

For a superconducting accelerator, helium enclosure (helium vessel), vacuum tank (cryostat) and beam tubes are three major systems that require safety relief. Although the beam tube is normally not part of a conventional cryogenic system, major portion of the RHIC (and LHC) beam tube is installed inside cold magnets. Air could condense on the inner surface of the beam tubes. After a warm up, the pressure could rise and safety relief is required. The beam tube relief is also good for small helium leaks.

This report gives an overview of the RHIC cryogenic system with particular emphasis on the safety aspect. Descriptions of cryostat, vacuum envelope, vacuum barrier, relief valves and basic cryogenic operations are given. Failure modes are reviewed for all relief systems. Because accelerators are usually installed in tunnels, a large amount of helium release is a safety hazard on oxygen deficiency. Estimation on helium release will also be presented.

RHIC has had more than 10 years of proven safety record. The probability of having an electrical arc in RHIC is essentially nonexistent due to reliable hardware construction and a conservatively engineered quench protection system. If an arc does not occur, there will be no subsequent failure. The existing RHIC quench protection system is believed to offer equal or more protection than that of LHC after improvement. Detail feature is best given by the Electrical Group.

During the LHC incident, both bus connection and helium pipes were vaporized by energy from the magnets. As part of this study, amount of energy needed to melt stainless steel and copper have been investigated, and compared with the amount of magnetic energy may be released from RHIC. As can be seen later, a localized energy can damage copper or stainless easily. While magnetic stored energy of RHIC is less than that of the LHC, it is sufficient to damage the helium pipe.

Brief Description of LHC Incident

In the LHC incident, an electric arc punctured the helium enclosure leading to a release of helium into the insulation vacuum of the cryostat. Additional power from the magnets led to more helium release, degradation of the beam tube vacuum and pressure in the insulation vacuum to rise above its design pressure. Many magnets were damaged and a total of 6 tons (2 tons initially) of helium were released to the tunnel. No one was at risk - most likely because CERN limits persons in the tunnel when LHC is powered above 1 kA, as during the September commission.

Since the incident, CERN performed extensive investigation and adopted improvements for LHC. The corrective actions include enhancing the quench detection system to prevent electric arc from happening in the first place, and including additional relief valves on the vacuum tank should a major helium spill occur.

To evaluate potential consequences of a hypothetical LHC type incident in RHIC, the present study begins with a brief description of the cryogenic system and magnet construction for RHIC and LHC.

Brief Comparison between RHIC and LHC

The circumference is 27 kilometers (km) for LHC and 3.8 km for RHIC. Although LHC is seven times larger than RHIC, LHC is cooled by eight helium refrigerators and RHIC is cooled by only one.   Each LHC refrigerator provides cooling over a 3.3 km sector, comparable to 3.8 km ring that the RHIC refrigerator covers.

The superconducting magnet and associated cryogenic systems for LHC are very different from that of RHIC. The LHC magnets are designed for 8.4 Tesla, 11.8 kilo-ampere and to be cooled at 1.9 K using superfluid helium II. The RHIC magnets are designed for 3.5 Tesla, 5.5 kilo-ampere and to be cooled at 4.3 K using 100 g/s supercritical helium. Cross sectional view of an LHC arc dipole magnet and that of RHIC are shown below in Fig. 1. Major features of an arc dipole for RHIC and LHC are given Table 1.

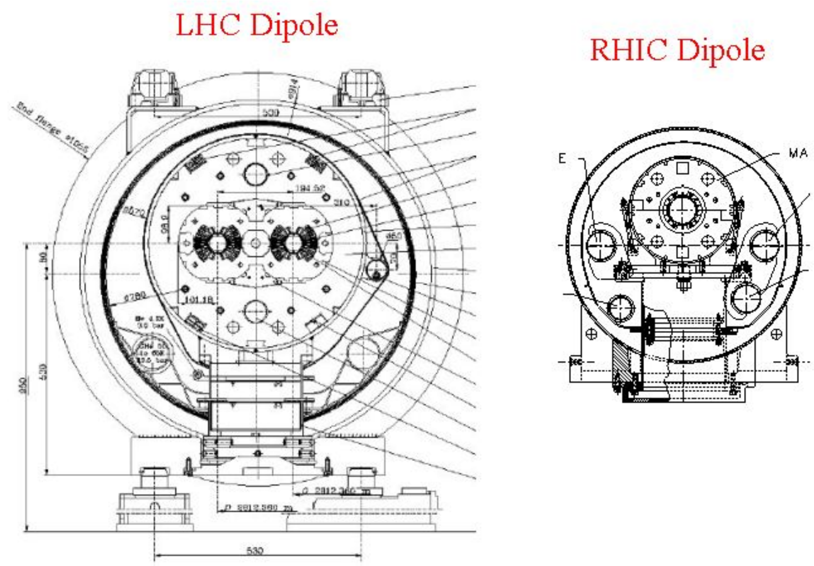

Figure 1. Cross section of arc dipole magnet for LHC and RHIC

Table 1. Major features of an arc dipole magnet for RHIC and LHC

RHIC - Arc Dipole	**LHC - Arc Dipole**
5000 A, 3.5 T	11800 A, 8.4 T (failure occurred at 8,700 A, ~ 74% of 11800 A)
1 in 1 magnet	2 in 1 magnet
610 mm dia. Cryostat	914 mm dia. cryostat
350 kilo-joule magnetic stored energy	7,100 kilo-joule magnetic stored energy (~ 20 RHIC dipole) (in the September incident, failure occurred at ~ 55% design energy)
3.5 bar, 4.5 K, ~ 120 g/s	1 bar, 1.9 K
Supercritical helium flow	Superfluid Helium II

A large accelerator consists of hundreds of magnets. It is convenient to combine some number of neighboring magnets into a module that can be treated as a cryogenic entity with its own safety protection. This greatly simplifies hardware construction and cryogenic operation. Similarly, a few modules can share an insulating vacuum. For example a 3.3 km LHC sector is divided into 27 cells, each cell consists of 2 sets of (3 dipole + 1 quadrupole) assembly. Two cells of magnets share one common vacuum.

In RHIC, there are two Rings each consisting of 6 sextants of magnets. The magnets are cooled in series using supercritical helium flow. Between two neighboring sextants, there are Valve Boxes where cooling flow can be controlled or switched over among different modes of operation. Relief valves for magnets and cryogenic lines are also installed on the Valve Boxes. In a sextant, there are four separate insulating vacuum spaces: one for each ring in the 500 meter long Arc Region, and two in the 50 m Insertion Region at both ends. Major features of RHIC and LHC are given in Table 2 for comparison.

Table 2. Major features of RHIC and LHC

RHIC	LHC
Cryogenic Module - Sextant	**Cryogenic Module - Cell**
~ 600 m (~ 24 D + 24 Q) + IR magnets Stored energy ~ 8.9 Mega-joule per sextant (excluding IR)	~ 110 m (2 Q + 6 D) Stored energy ~ 44 Mega-joule per cell (~ 6 D + 2 Q)
Ring (~ 3.8 km)	**Sector (~3.3 km)**
Tunnel radius ~ 2.4 m, Sea level No slope Cryogenic Distribution Lines are integrated in Magnet Cryostat 2 magnet cryostat in Tunnel	Tunnel radius ~ 1.9 m, approximately 100 m Underground with small slopes Cryogenic Distribution Lines and Magnet are in Separate Cryostats 1 magnet cryostat + 1 CDL in Tunnel
Supercritical Forced Flow 3.5 bar, 4.5 K, ~ 120 g/s	Superfluid Helium II 1 bar, 1.9 K
“Magnet Cooled in Series” 6 Sextants in series 2 Rings in parallel	“Magnet Cooled in parallel” 27 cells in parallel each cell is kept in a helium II bath
4 vacuum space in a sextant (vacuum barrier on VJR above Q4 and above Triplet)	14 vacuum space for Magnet in a Sector (13 barrier in 3.3 km, between magnets, also on every jumper)
~ 8,750 L liquid volume per sextant (~ 15 L/m)	~ 2,200 L per cell (assuming ~ 20 L/m)
Relief System	**Relief System**
Process Relief valves – sextant based Mostly located on Valve Box to be vented directly to outside	Process Relief valves – cell based located in Jumper and to be vented through Cryogenic Distribution Line to recovery / outside
4 safety relief valves for Magnet in a sextant (~ 600 m) Calculated capacity per sextant due to loss of vacuum ~ 5,400 g/s	~ 2 safety relief valves for Magnet in a cell (~ 110 m) Don’t know exactly, seems calculated for magnet quench with a capacity of ~ 2,000 g/s
Vacuum Tank Relief (~ one per magnet) installed mainly on Interconnect about 60 over 480 m arc region about 10 in insertion region (6 Vacuum tank relief on DX and Triple and 4 x 2” pump out relief on VJR) Relief to Tunnel	Vacuum tank Relief (originally 2 DN100 per 214 m, not full flow, Revised, DN200 per 214 m 40 fold original capacity) information not available Relief to Tunnel

RHIC Cryogenic and Superconducting System

RHIC uses one refrigerator to maintain its 3.8 km of magnets at 4.3 K and 3.5 bar. Two rings of magnets are cooled in parallel. Each ring consists of six sextants in series as shown in Figure 2. The installation of magnets in the RHIC tunnel is depicted in Figure 3. The cross section of the magnet cryostat including cryogenic distribution lines S (for liquid helium supply), R (for vapor return), H (for heat shield) and U (for utility) is given in Figure 4.

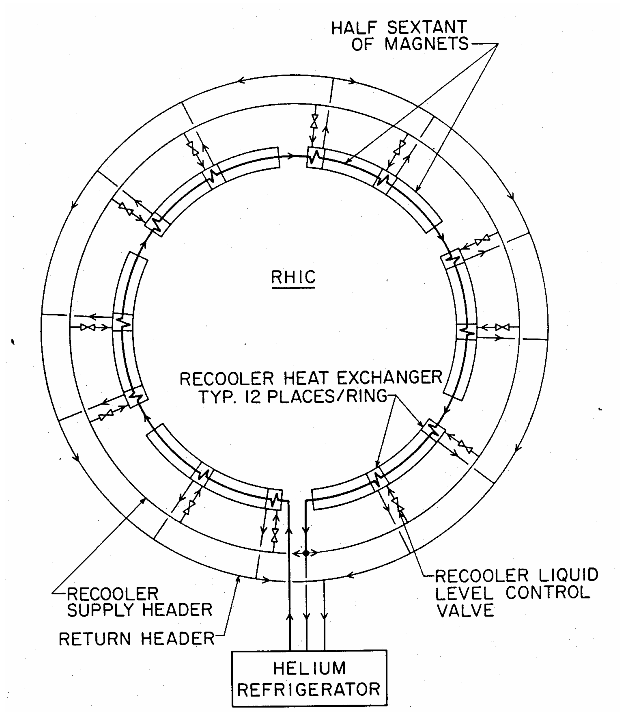

Fig. 2 Simplified schematic for cooling one ring of RHIC magnets

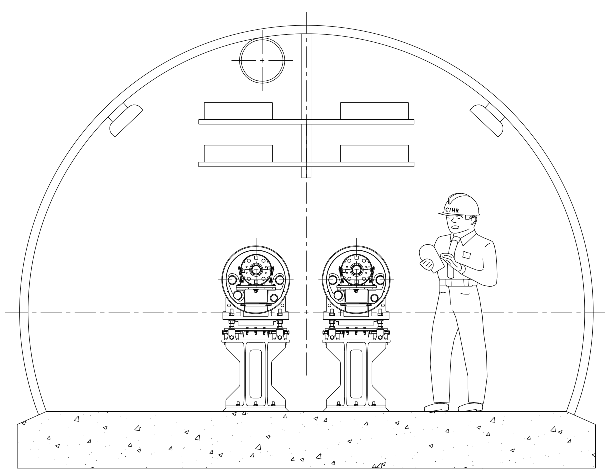

Fig. 3 Two Rings of Magnets in RHIC tunnel

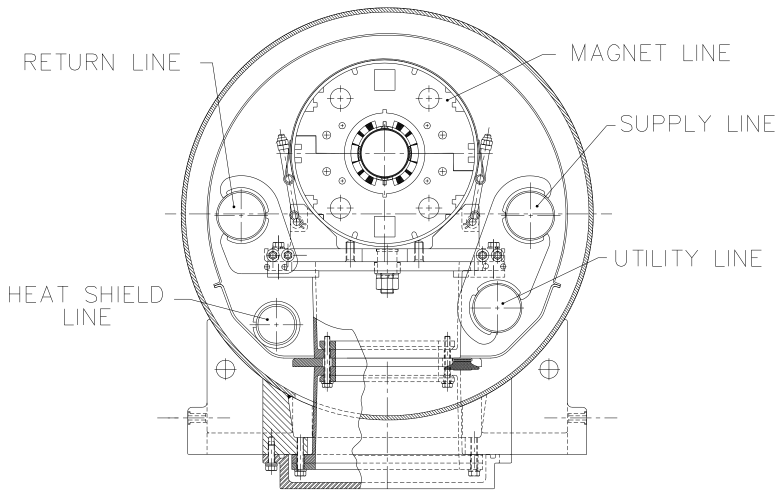

Fig. 4 Cross Section of RHIC magnets with four cryogenic lines in a cryostat

In recent years, the RHIC rings are cooled using helium directly from the refrigerator as given in the simplified flow schematic Figure 5. Supercritical helium, from the refrigerator, flows through one ring of magnets (M line) and enters Supply line S. S line is used to provide liquid helium to the recooler heat exchanger (not shown). Boil off helium vapor returns through R line to the refrigerator. U line is not used in normal operation. A small portion of helium in S must be provided from the helium refrigerator to meet total heat load requirement.

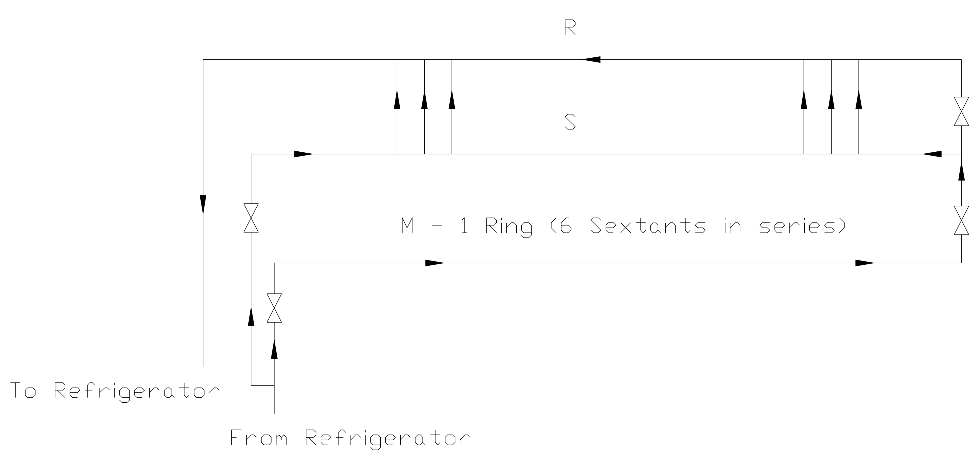

Fig. 5 Simplified flow schematic for cooling one ring of RHIC magnets

In order to understand failure mode, the insulating vacuum system will be explained next. As shown in Fig. 6, there are four vacuum envelopes in a RHIC Sextant. In the Arc Region (magnet Q4 to Q4), there is a vacuum space for the Blue and Yellow rings. In the Insertion Region in the ends of a Sextant, the Blue and Yellow rings share a common vacuum. The Insertion Region includes the Triplet magnet, the DX, and the Vacuum Jacketed Line (VJR from Triplet to Q4). The vacuum breaks are located in the Q4 end of the Q4 - Triplet VJR, and on the Triplet end of the Triplet - Valve Box VJR as shown in Fig. 7. The vacuum barrier is an end plate with holes and bellows to connect a vacuum jacket to inner process pipes as shown in Fig. 8. Detailed information on VJR can be found in RHIC specification CR-E-3201-004, 9/1/95.

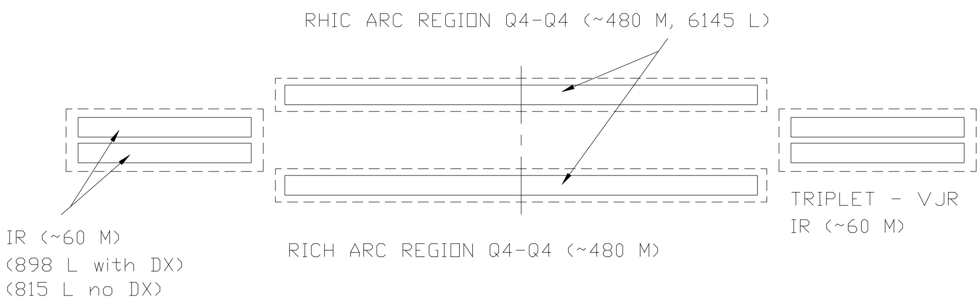

Fig. 6 Four vacuum envelopes in a RHIC sextant

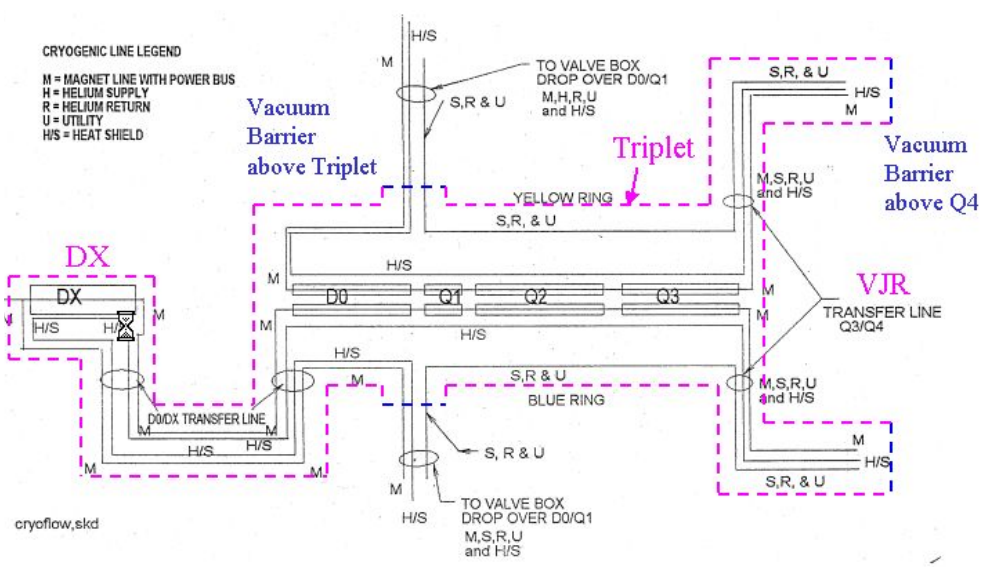

Fig. 7 Sketch shown locations of vacuum barrier in RHIC

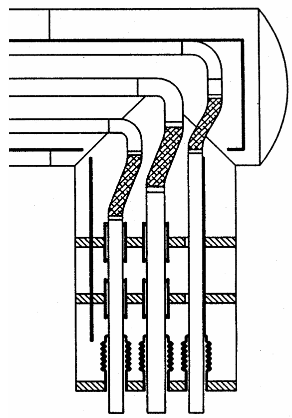

Fig. 8 Sketch for vacuum barrier on VJR

Failure Modes and Safety Relief

In both RHIC and LHC, superconducting magnets are surrounded by liquid/cold helium and are contained in a helium enclosure. Heat leak of the cryostat is kept low using multi-layer superinsulation and heat shield under high vacuum. Minor deterioration in insulating vacuum increases heat input to the magnet. As long as the refrigerator is able to provide the required cooling, the cryogenic system remains stable. There is no hazardous issue other than cold surface on cryostats.

A rapid increase in insulating pressure is a different phenomenon and is a safety issue. If any component connected to the cryostat in the warm region fails unexpectedly, ambient air will flow into the insulating space at sonic speed. Heat input to the magnet will increase by several orders of magnitude. As a result, temperature and pressure of cooling helium will increase rapidly. To protect the helium enclosure from over pressure, helium must be vented out through relief valves. A sizable helium leak that develops inside the cryostat could lead to similar consequences. With a separate vacuum, abnormal heat input will occur only to those magnets that share one vacuum space. Heat inputs remain normal to magnets in regions with good insulating vacuum.

If a major failure occurs in a cryogenic line, cold helium will be released to the vacuum space. To prevent over pressure of the cryostat, cold helium in the vacuum space must be vented through tank relief valves. Because cold helium could cause equipment damage or personal injury, amount of helium that enters the accelerator tunnel must be determined. This is what happened in LHC when an electrical arc from a bus connection “vaporized” helium pipes. Large amounts of helium were released into the insulating vacuum. Insufficient relief capacity on the vacuum tank led to over pressure as well as mechanical failure to the magnets and their cryostat. The LHC tunnel was under severe Oxygen Deficiency for several hours due to these large amounts of helium.

In RHIC, there are three types of relief systems for protecting 1) cryogenic process lines, 2) cryostat and vacuum jacket and 3) beam tubes.

Process relief valves for RHIC are sized for loss of insulating vacuum (but not rupture of helium pipes other than helium leaks into insulating vacuum) with a heat input of 500 kilowatt. Detailed calculation is given in reference 1 and a summary is given in the next section.

The vacuum tank relief for RHIC is mainly designed from the point of view of one dipole magnet. Calculation based on releasing cold helium into the vacuum tank of a RHIC dipole is given in reference 2. An estimation of helium discharge for RHIC ODH study based on one sextant of cold helium is given in reference 3. With the LHC incident, the vacuum tank relief valve and potential helium release have been revisited based on the entire RHIC ring. Results are given later in this report.

Beam tube relief for RHIC is developed and designed by BNL for releasing condensed air and small helium leak. It is not intended to manage a large helium spill. A full description of the valve is given in reference 4 and a summary given in this report.

Safety Relief on Cryogenic Process Lines in RHIC

There are five cryogenic lines (M, S, R, U and H) in the magnet cryostat as shown in Fig. 9. Piping connections of these lines in a RHIC sextant is shown on the screen display Fig. 10. Helium flows in the M line from one end of a sextant to the other to cool the magnets. There are five recooler heat exchanger in a sextant. Liquid helium is provided to the recooler from the S line and vapor returns to the refrigerator from the R line. On either side of Fig. 10, there is a Valve Box in which switching over among different modes of cryogenic operation can be performed and the relief valves are also installed it. A P&ID of VB is given in Fig. 11.

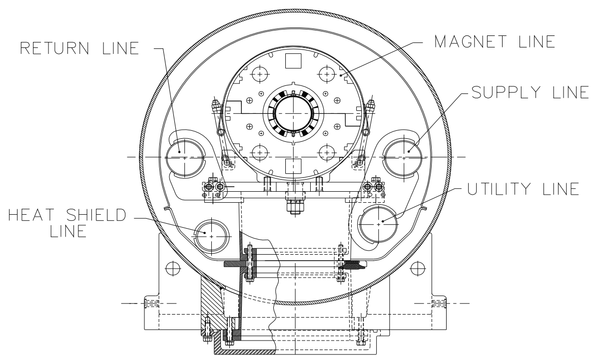

Figure 9 Cross Section of RHIC magnets and four cryogenic lines in a cryostat

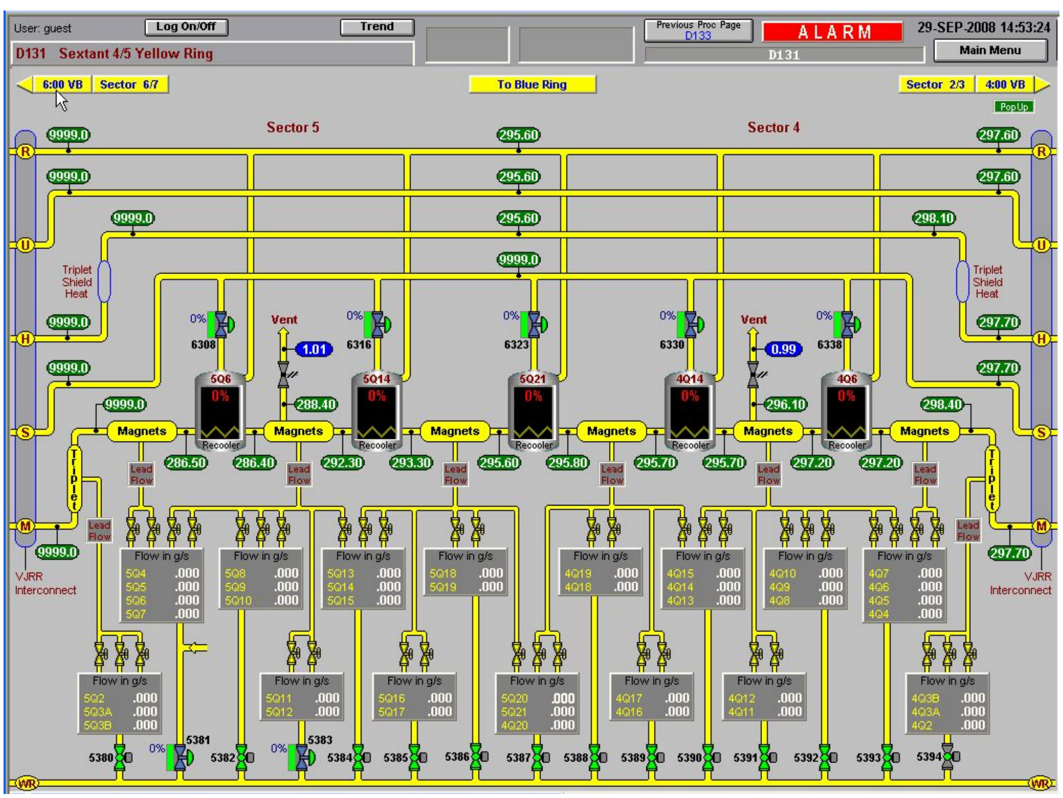

Figure 10 Screen display of cryogenic process for a RHIC Sextant

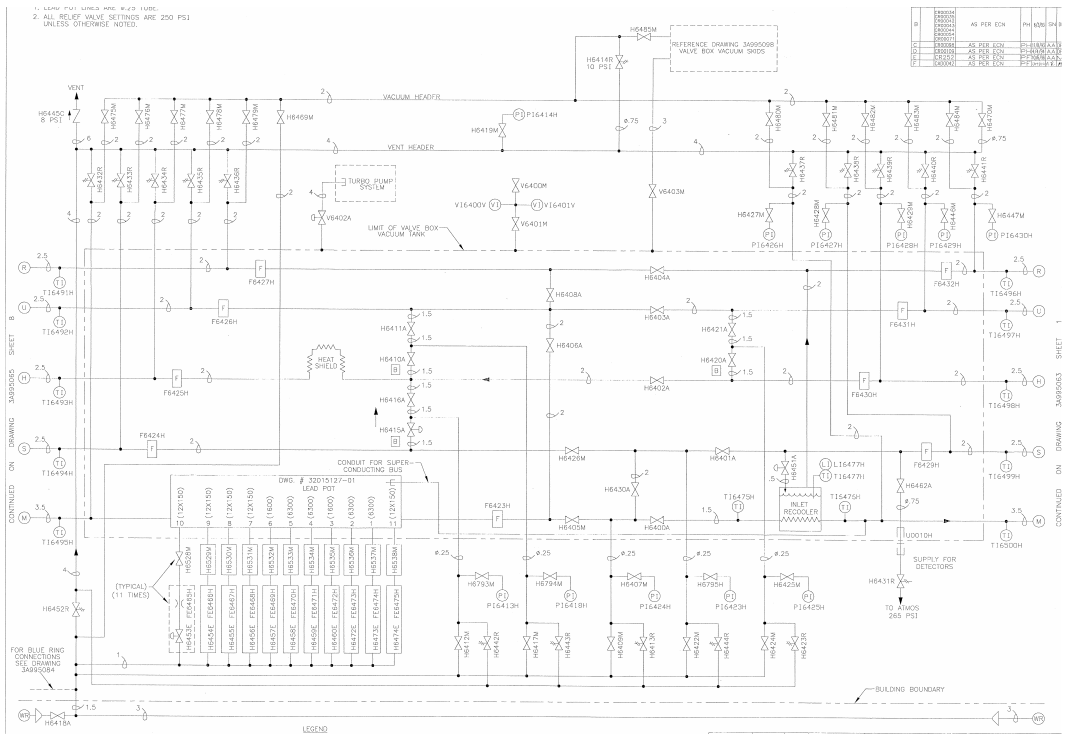

Figure 11 P&I D for a RHIC Valve Box

In RHIC, the M, S, R, U and H lines are all designed for 20 atm pressure. Relief valves for M, S, R & U lines are sized for a total of 560 kilowatts heat input from “loss of insulating vacuum” in the envelope Q4 – Q4. The heat input is divided according to the surface area of each line. For the H line (operated at 55 K as heat shield), 270 kilowatts is assumed. The set pressure for relief valve is 18.7 atm. The design condition of safety relief valves and number of units are given in Table 3. The relief system still has sufficient capacity even if one relief failed to open in any line.

There are two relief valves per sextant for each of S, R, U and H lines, and are installed on the Valve Boxes in RHIC service buildings, as shown in Fig. 12. The M line has four relief valves: two on the Valve Box and two near the D8 magnets as shown in Fig. 13. Discharge lines for all of these relief valves are connected to the outside and do not present an oxygen deficiency issue.

A detailed description can be found in the technical note “Pressure Relief for RHIC Cryogenic System”, K. C. Wu, AD/RHIC/RD-64, 1993. Since their installation in 1995, these relief valves have been certified periodically by outside shops according to ASME requirements. Design conditions remains applicable today.

Table 3 Design condition of RHIC cryogenic process lines

Line	Heat Inpu KW	No of Relief	Temp. K	Max. Flow g/s	Safety Margin
M	320	4	~ 7.3	5411	1.8
S	80	2	~ 7.3	1353	3.6
R	80	2	~ 54	269	4.7
U	80	2	~ 54	269	4.7
H	270	2	~ 68	728	2.7

Figure 12 Photo of 5 process relief valves on Valve Box

Figure 13 Photo of M line relief valves near magnet D8

Vacuum Tank Relief on RHIC Cryostats

Vacuum tank relief valves for cryostat are designed for keeping pressure in the insulating space below the typical 1.5 atm design pressure. In RHIC, the tank relief valve uses three springs on a plate. The relief assembly is constructed of a stainless steel tube with a 1.875 inch inner diameter as shown in Fig. 14 and Fig. 15. The set pressure is approximately 1.5 psig. The length of the tube from the vacuum tank to the relief plate is about 2.375 inches.

Fig. 14 Vacuum tank relief on the interconnect between magnets

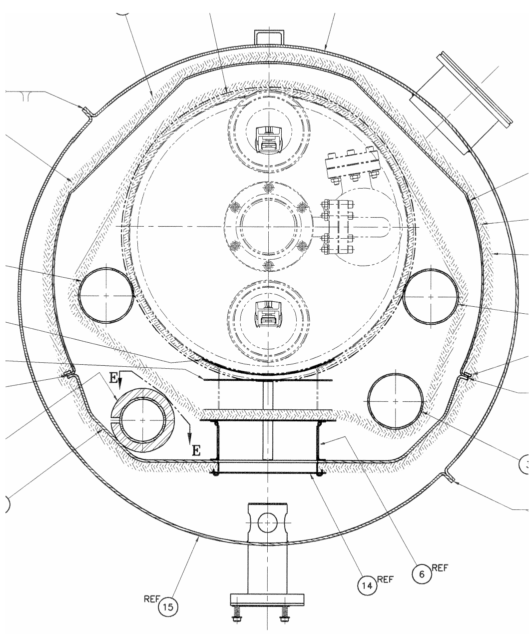

Fig. 15 Vacuum tank relief on the interconnect between magnets

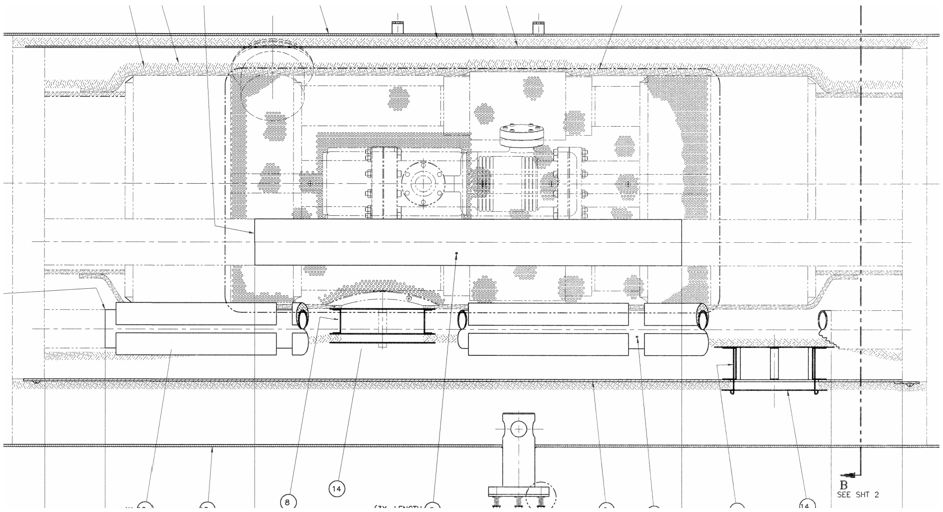

Fig. 16. Side view of an interconnect showing opening as helium passage

In the arc region, there is one relief valve installed on each magnet interconnect. The relief valve and multi-layer insulation have been designed with preventing blockage at the inlet in mind. The inlet consists of four holes on the side. Openings have been incorporated on superinsulation blankets so that helium may pass from the cold pipe to the tank relief without interfering with the blanket, as shown in Fig. 16. There are about sixty tank relief valves with a total flow area of 150 in^2.

In the Insertion Region, the vacuum envelope consists of the DX magnet, the Triplet and two spools of VJR. Six vacuum tank relief valves are installed under the DX and Triplet cryostats. Four 2 inch diameter pump out relief valves are installed on VJR as shown in Fig. 17. Total flow area of relief is approximately 29 in^2.

Fig. 17 Pump out and relief on VJR

Helium Release Rate for a Hypothetical Incident in One RHIC Ring

If an LHC type incident occurs in RHIC, M line (helium enclosure) will break. Liquid/cold helium from all magnets connected to the failed magnet will flow into the vacuum space of the affected area as shown in Fig. 18. Since M line is connected to the S line, helium from S line could also flow through M line to the failed section.

In the 1995 study[3], the worst credible accident is considered as releasing one sextant of helium (about 0.8 ton) into insulating vacuum space Q4-Q4. This is a valid assumption provided the failed sextant can be isolated immediately after an incident. Experience in LHC suggests the initial helium release is rather fast with helium coming from region beyond the affected area. Since it is hard to guaranty isolation of a failed RHIC sextant immediately after an incident, it is reasonable to include some helium from neighboring sextants for calculating release rate. In this study, helium from depressurization of one RHIC ring is added to that of the failed sextant. The good (not damaged) ring and the refrigerator are assumed to be isolated from the failed ring within a reasonable time frame in early stage of the incident.

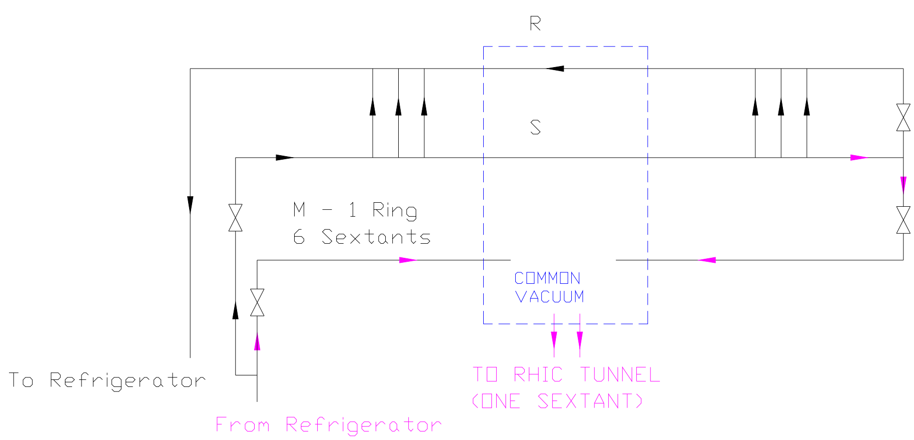

Fig. 18 Illustration of helium flow into RHIC tunnel after an incident

Liquid helium volume for the M, S, R, U and H lines are given in Table 4. Amount of helium at RHIC operating condition is also presented in the same table. As can be seen, majority of helium exists in the M and S lines mainly because these lines contain supercritical helium at 3.5 bar and 4.3 K where helium density equals 0.135 g/cc. During RHIC operation, the R and the U lines carries helium vapor which has a density of 0.02 g/cc. The volume of the recoolers is relatively small compared with the M and the S lines.

Table 4 Liquid helium volumes in RHIC rings

Liquid helium in RHIC Rings	Volume - L			Rho	Mass	Mass	Mass	Helium STP Vol.
	Two Rings	One Ring	Sextant	g/cc	kg Two Rings	kg One Ring	kg Sextant	m3 per Sextant
M	104975	52487	8748	0.135	14172	7086	1181	7381
S	32388	16194	2699	0.135	4372	2186	364	2277
Recoolers	7314	3657	610	0.125	914	457	76	476
R	32388	16194	2699	0.02	648	324	54	337
U	32388	16194	2699	0.02	648	324	54	337
H	32388	16194	2699	0.015	486	243	40	253
Total					21240	10620	1770	

If M line ruptures as shown in Fig. 18, helium flows into the vacuum space. Pressure in the M and the S lines will decrease. During the depressurization process, density of cold helium decreases and volume increases. Between the 3.5 atm operating pressure and the expected 1.4 atm in the vacuum tank during venting, this amounts 16% increase in volume and equals to 11,250 L for one ring of the M and the S lines. This helium, together with that contained inside the affected vacuum envelope, must be released through tank relief valves to the tunnel.

As shown in Table 4, the volume per sextant in the M line equals 8,748 L in which 6,000 L is in the Q4-Q4 region and about 1,374 L in the Triplet-DX_VJR region. The amount of helium released into the arc region equals 6,000 + 11,250 L or 17,250 L. With a density of 0.116 g/s at 1.4 atm, the amount of helium equals about 2,000 kg or 2 tons. In this study, 2 tons of helium is released into RHIC tunnel. There is no helium came from the good (not damaged) ring or from the refrigerator supply. The failed ring is assumed to have been isolated shortly after an incident. The cryogenic operation shall incorporate this requirement to justify the present results.

The calculating procedure is the same as previously did in 1995. Using a uniform temperature model, the initial condition assumes the 2 tons of helium appear in the vacuum tank instantaneously. Because the cryostat has a very large volume, initial pressure in the insulating space is below 1 atm. Heat input from vacuum vessel heat the cold helium through constant density process until relief valve opens at approximately 1.2 atm. After relief valves open, a constant pressure heating process follows. 300 and 500 kilowatts feat inputs are used to calculate the required venting rate and amount of helium enters the RHIC tunnel. Results are given in Fig. 19 and 20. Peak helium release rate is in the range between 15 and 25 kilogram per second. Total amount of helium release equals about 1700 kilogram, 1.7 ton.

The present model over estimate the rate cold helium enters the vacuum space. However, it also ignores potential helium that may come from refrigerator supply and the 2nd RHIC ring before the failed ring is isolated. Boil-off contribution from back ground heat load in other sextants is also ignored. Before better results are available, it is suggested to replace the helium release rate in reference 3 by the present results for tank relief and ODH calculation. More comprehensive model and more accurate helium release rate can be developed at a later time.

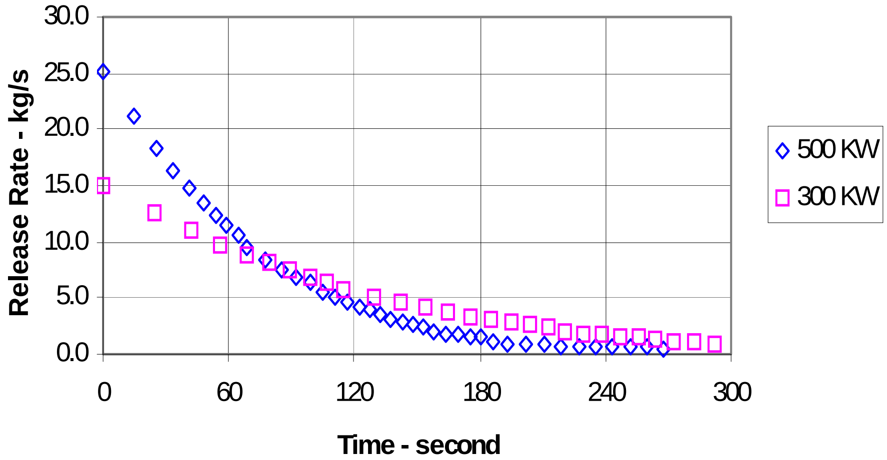

Fig. 19 Helium Release Rate through Tank Relief Valves to RHIC Tunnel

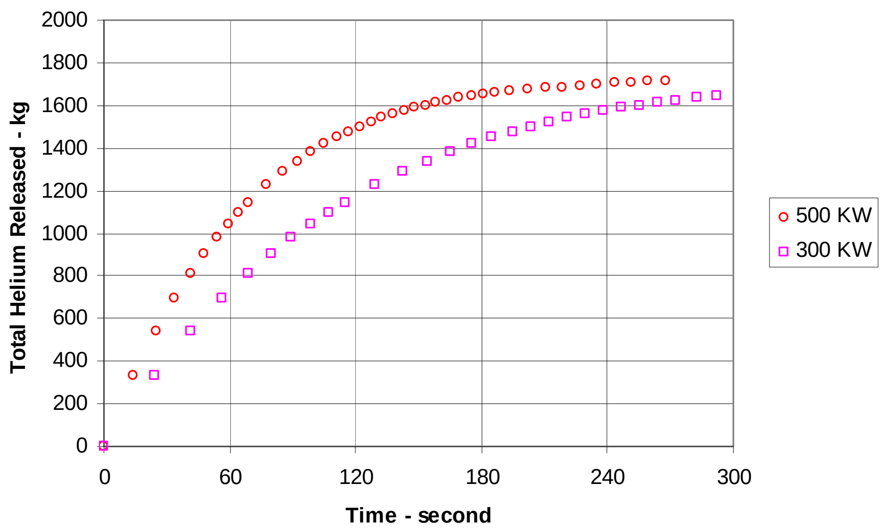

Fig. 20 Amount of Helium Release through Tank Relief Valves to RHIC Tunnel

Possible Ways to Limit Helium Release

Above helium release rates assume the failed ring is isolated from the helium supply from refrigerator and the Not Failed ring after an incident. It is believed to be a fair assumption because it takes some time to release helium in the failed ring. Nevertheless, the mechanism to isolate the failed system must be implemented for using these helium release rates.

Should an LHC type incident ever happen in RHIC, the amount of helium release could further be limited by closing isolation valves on Valve Box. If the affected sextant is isolated during early stages of the incident, total amount of helium release could probably be reduced by 30 – 40 %.

Read out for insulating vacuum (Thermocouple or Cold Cathode) is a good indicator for failure of the cryogenic pipe. Oxygen sensor shows helium in the tunnel. Both should be integrated to the cryogenic process control computer so that the cryogenic control room is able to determine occurrence of incident in an area.

Since an incident is a very rare and very fast event, there is little time for an operator to response. It is best be managed by the cryogenic process control computer. The Cryogenic Group could establish criteria for identifying major pipe failure and formulate a computer response accordingly.

Beam Tube Relief in RHIC

In an accelerator, beam tubes are used to provide an ultra high vacuum environment for particles. For a superconducting accelerator such as RHIC, a majority of the beam tubes operate at liquid helium temperature (cold bore). There are warm regions (warm bore) in the Insertion Region. For both cold bore and warm bore, there are connections from the beam tube to the components at ambient temperature for instrumentation or relief.

Small leaks from room temperature components could lead to condensation of air on the cold surface. After the system warms up, solid air will return to its gas form. Depending on the amount condensed, pressure in the beam tube could exceed the design pressure. Thus, safety relief is needed. This safety relief can also take care of a small helium leak. However, it is not intended for a large helium spill like the vacuum tank relief is.

Unlike ordinary relief valves, relief devices for beam tube require special features such as bakable and all metal construction. The RHIC beam tube relief, also called UHV burst diaphragm, is given in Fig 21. A detailed description of the RHIC beam tube relief valve is given in reference 5. The puncturing pressure is 8 psi and complete rupture occurs at 15 psi. The diameter of the main orifice is 0.95 cm. With an additional eight smaller holes, the total flow area equals about 1.34 cm^2.

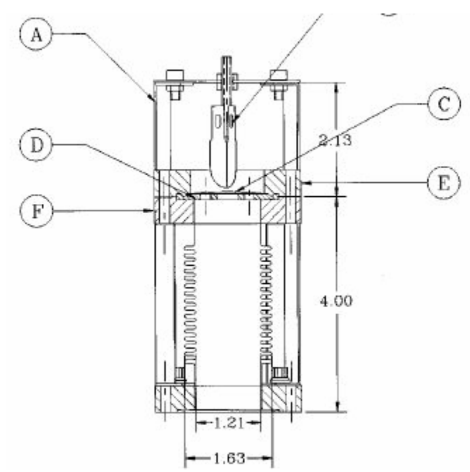

Figure 21 RHIC beam tube vacuum relief (UHV burst diaphragm)

In a RHIC sextant, there are four beam tube relief valves: two at the end of the arc region as shown in Fig. 22, and one on each Triplet. A one inch diameter line (approximately 2.75 meters long) is used for connecting the beam tube from the Interconnect of magnets to the top of the cryostat as shown in Fig. 23.

In the LHC incident, beam tubes were damaged after helium pipes were vaporized by an electric arc. The beam tube vacuum and insulating vacuum became common. Most of the helium has released from the helium enclosure to the vacuum tank and subsequently vented to the LHC tunnel through vacuum tank relief valves. The relief device on the beam tube system did not provide much venting capacity.

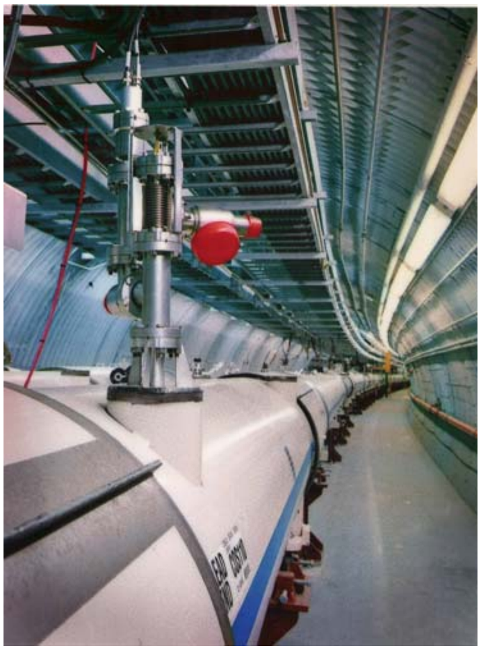

Figure 22 Beam tube relief in the end of a RHIC arc

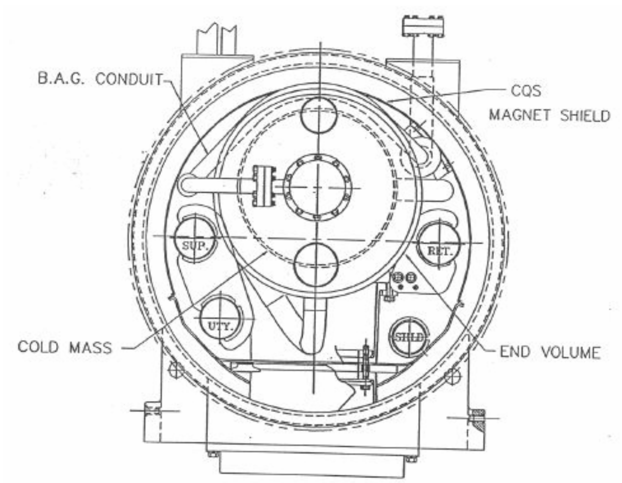

Figure 23 Connection of beam tube to its relief in a magnet interconnect

Energy Needed to Burn Stainless Steel or Copper Material

Some properties of stainless steel and copper are given in Table 5. As can be seen, it takes approximately 6 kilo-joule to heat 1 cc of stainless steel from 4 K to 1670 K (melting temperature).

For stainless steel pipes used in RHIC interconnect, the wall thickness is about 0.083 inch (2mm). 1 cc of material corresponds to a 2.5 cm hole on the pipe wall. Therefore, a 6 kilo-joule localized heat input could produce a sizeable damage on the pipe. Once an electric arc occurs, the pipe will be punctured easily.

It takes 4.5 kilo-joule to heat 1 cc of copper from liquid helium temperature to melting temperature. The copper piece will be melted with additional 1.9 kilo-joule.

Table 5. A few properties of stainless steel and copper

Material	SS304	Cu
Density – g/cc	7.8	8.9
Specific Heat at 300 K – J/g-K	~ 0.5	~ 0.4
Approximate melting temperature – K	1670	1350
Enthalpy change 4 – 300 K, J/g	~ 90	~ 80
Energy needed from 300 K to melting T, J/g	~ 686	~ 420
Enthalpy change 4 K to melting T, J/g	~ 776	~ 500
Enthalpy change 4 K to melting T, KJ/cc	~ 6	~ 4.5
Latent heat of fusion – J/g	Not Available	211
Latent heat of fusion – KJ/cc		~ 1.9

Comparison of Stored Energy for Dipoles in a RHIC Ring to that in an LHC Sector

According to a recent CERN release, an estimated 200 Mega Joules of energy was released during the LHC incident. This is slightly less than half of the stored energy in the dipoles of a sector because more than half of the energy was extracted through dump resistors.

Total stored energy of the dipoles in a RHIC ring is about 70 MJ compared with more than 1,000 MJ in an LHC sector at full energy. RHIC also uses dump resistors for energy extraction. Assuming there be an LHC type incident in RHIC, the amount of energy release in RHIC would probably be on the order of 30 MJ which is roughly 1/7 that experienced in LHC.

Nevertheless, a mega joule is very large compared to the kilo-energy needed to damage a bus bar or interconnect pipes. The system safety has to rely on a good quench protection system for detecting abnormal resistance, switching off the current and extracting energy in time. The quench protection system for RHIC has been used successfully for more than 10 years. Its features and capability are best given by the Electrical Group.

Summary

Safety relief valves and related issues for RHIC have been investigated for an LHC type incident. A description of the LHC incident, a comparison between the magnet and the cryogenic systems between LHC and RHIC and an overview of the RHIC cryogenic system are presented. This study emphases the safety aspect of the cryogenic system. Basic failure modes including that occurred in the LHC have been explained. Possible ways to limit helium release to RHIC tunnel is given. The amount of energy needed to damage either helium pipe or electrical bus has been determined.

While the probability of having an LHC type incident is essentially nonexistent in RHIC, the relief systems have been adequately designed in terms of capacity and units. The vacuum tank relief and helium release rate is the main subject of the present investigation.

It is found the helium release rate for sizing tank relief and estimating Oxygen Deficiency in RHIC tunnel is approximately twice that recommended in 1995. A total of 2 tons helium release is expected in this study. The tank relief has been found acceptable, but the helium release to tunnel requires updates. A safety analysis of Oxygen Deficiency based on new helium release should be conducted and proper action should be taken to ensure personal safety. At the same time, more realistic model could be developed as independent check of the present results. Proper control from the cryogenic process control should also be implemented to ensure isolation of the failed ring as assumed in this study.

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