ADDENDUM

Safety Assessment Document
For the
BaBar Detector Project

May 12, 2005

1.0 BACKGROUND

A Safety Assessment Document (SAD) – BaBar (SLAC-I-023-302TP-000) was completed for the BaBar Detector Project at the Stanford Linear Accelerator Center (SLAC) in June, 1998. The BaBar Detector Project is located in the PEP-II Research Hall at Interaction Region 2 (IR-2). The IR-2 hall and all PEP-II facilities are located inside the SLAC Radiological Control Area.

The purpose of the initial SAD was to identify hazards associated with the design, assess risk, and establish controls needed to eliminate or reduce the associated risk to acceptable levels. Hazards capable of causing injury to personnel, damage to the environment, or damage to the detector were considered in the analysis.

A separate Fire Hazard Analysis (FHA) prepared by Hughes Associates Inc. was completed in December, 1996. The first addendum to the FHA was completed in 2001. A second addendum to the FHA is currently under final review and will be released in the near future.

2.0 PURPOSE AND SCOPE

This addendum documents the ongoing hazard analysis associated with the modifications to the BaBar Detector including the barrel Instrumented Flux Return (IFR) upgrade. These modifications are generally due to the desire to improve the performance of detector systems. Reference should be made to the original SAD for detailed descriptions and analysis of BaBar and its associated equipment and facilities. That information is not repeated here.

The purpose of the ongoing hazard analysis is to identify hazards associated with the modifications to the detector, assess risk, and establish controls needed to eliminate or reduce the associated risk to acceptable levels.
3.0 SUMMARY AND CONCLUSION

The methodology for the SAD safety analysis was based on the guidance given in DOE SAN Management Directive 5481.1A of September, 1989. Summary Hazard Reports were developed for each energy source that had the potential to cause injury to personnel, damage to the environment, or damage to the detector. Hazard consequence (severity) and hazard probability establish the basis for risk assessment. The hazard severity categories provide a qualitative measure of the worst credible mishap resulting from personnel error, design inadequacies, procedural deficiencies, or equipment failure. The probability that a mishap will occur during the planned life expectancy of the system is categorized qualitatively and is based on the probability of the occurrence per year. The risk assessment matrix (section 4.1, initial SAD) provides the level of risk based on the consequence (severity) and probability of the identified hazard.

For each of the identified hazards in the initial SAD, hazard controls and mitigation were established to drive the risk to a low level. The hazards introduced as a result of system design changes and upgrades, and the control measures and mitigation established to reduce the associated risk, have been reviewed against the initial SAD risk assessment. None of the hazards identified as a result of the modification to the detector increase the risk assessment above the initial risk assessment of low.

Most hazards posed by the operation of the BaBar Detector are conventional ones normally associated with the industrial environment. These are either routinely encountered and accepted by the general public or dealt with through national codes or standards. These hazards include: electrical, fire, earthquake, occupational, pressure, and hazardous material. The unusual hazards posed by the operation include flammable gases, cryogenics, radiation and large magnetic fields.

4.0 DETECTOR SYSTEM DESIGN CHANGES

4.1 Silicon Vertex Tracker (SVT)

The initial SAD included a detailed description of the SVT electrical systems. One of the values identified in this description is wrong. Section 3.3.1.2, Electrical Description, page 3-10, 3rd paragraph, fourth line: “The Maximum capability of the power supplies is plus and minus 40 V at 1uA (nominal requirements and active limits are set much lower).” The correct value is 40 V at 1mA.

Since 2002 there have been two diamond sensors installed in the backward side of the SVT for radiation monitoring and protection purposes. The diamonds require 500V DC to be fully functional. The voltage is supplied by High Voltage-rated coax cables connected to a high voltage power supply located on top of the electronic hut. The power supply maximum current capability is 1mA.
The initial design of the SVT included a system to flush the SVT with dry nitrogen for the purpose of humidity control. Dry air was substituted for the nitrogen in order to eliminate one of the hazards in the Permit Required Confined Space at the backward end of the detector. Subsequently the SVT dry air supply system was turned off because the PEP dry air system installed for the beam pipe bellows effectively isolates and controls the SVT humidity problem.

The effect of these changes does not change the risk assessment established in the initial SAD.

4.2 Drift Chamber (DCH)

The design changes to the DCH include the following. A humidification system has been added in the gas shack inside an existing DCH gas mixing rack. A monitoring (gain) chamber also was added to the return line of the circulation system. The latest DCH gas system schematic is provided below. This is the as-built drawing and reflects the current operational state of the system.

Neither the humidification system nor the monitoring chamber has an effect on the DCH established safety systems and therefore does not change the risk assessment established in the initial SAD.

The DCH bulkhead flush gas was initially CO$_2$. This gas was changed to Nitrogen.

The substitution of CO$_2$ with Nitrogen does not change the risk assessment established in the initial SAD.

In the summer of 2002, the BaBar Drift Chamber beryllium inner cylinder was damaged during the extraction of the support tube. The Web page identified below is a repository and archive for information related to the damage and repair. Multiple activities were conducted to understand the risk associated with the damage, repair, and continued operation. These included the following. Consultation with beryllium safety experts (Brush Wellman – manufacturer of the inner cylinder), a Beryllium Monitoring Program (no detectable traces were found in any samples), a Finite Element Analysis (FEA) to understand the effect on the structural integrity of the tube against buckling, hazard analysis for all procedures and related activities to accomplish the repair, multiple formal safety reviews, and a Support Tube Review Committee.

http://www.slac.stanford.edu/BFROOT/www/Detector/CentralTracker/mechanical/inner_cylinder/damage/

The damage to the DCH inner cylinder reduced the safety factor for this cylinder against a buckling failure. The FEA shows that for the damaged cylinder the safety factor remaining is between 5.9 and 7.3. Given this safety factor, the risk assessment established for the DCH hazards in the initial SAD remains current.

7/22/2005
4.3 Particle Identification System DIRC

The DIRC system remains essentially unchanged from the originally design and therefore the risk assessment established in the initial SAD remains current.

4.4 Electromagnetic Calorimeter (EMC)

The EMC system remains essentially unchanged from the originally design and therefore the risk assessment established in the initial SAD remains current.

4.5 Instrumented Flux Return (IFR)/Muon and Neutral Hadron Detector

There have been several upgrades to the IFR system since 1998 because of problems with the original resistive plate chambers (RPCs). The Forward Endcap RPCs were replaced with new improved RPCs in 2002. The RPCs in sextant 1 & 4 of the barrel were replaced with limited streamer tube detectors (LSTs) in the summer of 2004. The remaining barrel sextants will be upgraded with LSTs in late 2006. A separate section for each system is provided below.

The LST system is new and therefore will be described in detail. The format will match the initial SAD with a functional description, a physical description, and a discussion of the hazards and hazard controls. Due to the distribution of these chambers throughout the barrel flux return, a safety requirement was established at the initial stage of the design to prohibit the use of a flammable gas mixture.

4.5.1 Resistive Plate Chambers

The IFR now contains 300 planar and 32 cylindrical RPC chambers. In the forward endcap five of the old RPC planes were replaced by 2cm thick brass absorber inserted into the flux return gap. A water cooling system was introduced in 1999 to control the temperature of the BaBar steel (and RPCs) and to cool IFR electronics. As part of the forward endcap upgrade, all of the front-end electronics cards (FECs) were mounted in minicrates located in two large racks on each door. In addition to all of the forward end-cap minicrates, these racks contain a VME data acquisition crate, two gas distribution boxes, two gas return bubblers, and a crate with general purpose monitoring boards (GMBs) and scaler multiplexers. A small separate rack on each door contains the low voltage power supplies for the forward minicrates. The gas supply and return boxes were redesigned and rebuilt in 2002 and now are mounted in a few central locations on the detector for easier access. The barrel supplies are located in the racks on top of the detector (east side). The forward gas units are split between the large electronics rack and a small dedicated rack on each side of the door.
**Electrical systems – High Voltage**

The RPC High Voltage is supplied by five commercial CAEN High Voltage mainframes containing a total of ~ 90 channels. Each channel operates at < 10 kV and < 2 mA. New High Voltage distribution boxes were built and installed in 2002. The boxes had the same functionality as before, but feature several safety improvements.

**Electrical systems – Low Voltage**

The front-end electronics cards (FECs) in the endcaps and outer barrel layers were mounted into minicrates containing 16 FECs and mounted in various locations on the detector. The FECs in the inner barrel share the steel gaps with the RPCs. Each FEC requires 300mA (150mA) at +7 (-5.2) Volts. The low voltage power is supplied by supplies mounted in a few central locations on the detector. The LV power is then sent to LV distribution boxes mounted on the detector which supply individual minicrates or FECs. The wires to the distribution boxes and minicrates are protected by fuses. The low voltage on the FEC boards are protected by fuses on the FEC.

**Gas Mixing and Distribution Systems**

**Gas Composition and Flow Rates**

The RPC gas mixture has been altered to 61.2% Argon, 34.4% H-134a (Freon), and 4.4% isobutane. The overall flow rate has been increased to ~12.5 liters/minute to reduce RPC aging effects thus providing for 2-7 RPC gas volume changes per day.

**Gas Distribution System**

The mixed gas from the storage tank is reduced to 5.5 psig and sent to the detector. On the detector the pressure is further reduced to 0.1 psig before being split into 5 circuits. New gas distribution boxes of 16 channels were installed. Each box further split the gas flow into 16 metered streams (< 100 cc/min). Each stream feed one RPC. As before each channel had a pressure relief bubbler to ensure that the pressure at the RPC was less than 1 cm of oil. New return bubblers of 16 channels each count the number of bubbles per minute and send the information to the Electronics House. In some cases the humidity of the return gas is measured before being vented locally.

**RPC Hazards/Hazard Control**

**High Voltage**

Although the present HV pods can supply more current (2 instead of 1 mA) than originally planned, the stored energy levels are still small (<10 J) and an electrocution hazard does not exist. This voltage does present a startle hazard. However, in the new HV distribution box design all HV connectors prevent physical contact with the HV. The acrylic boxes of the old design were also eliminated, reducing the fire hazard. No interlocks are needed for the new boxes to maintain the safety of the system.
Gas
The RPC gas mixture has been altered to 61.2% Argon, 34.4% H-134a (Freon), and 4.4% isobutene. The mixing system still limits the maximum isobutane percentage to be < 5% (as established in the initial SAD) and is thus nonflammable. The LEL for this mixture is 6.5%.

Fire
The HSSD (VESDA) system for BaBar has been modified to provide air sampling points in the large and small racks that were added to the forward door platforms.

The hazards associated with these modifications are essentially the same hazards identified for the original RPCs. The risk assessment for the improved RPC system remains consistent with the assessment established in the initial SAD.

4.5.2 Limited Streamer Tubes (LST)

Functional Description

In its original configuration the barrel region of the BaBar muon and neutral hadron system consisted of 19 layers of Resistive Plate Chambers (RPC) interspersed between the iron slabs of the flux return. The purpose of the barrel IFR upgrade is to increase the detection efficiency and to improve the muon-pion discrimination. To this end the ageing RPCs in 12 layers are replaced with plastic Limited Streamer Tubes (LST), whereas the gaps corresponding to layers 5, 7, 9, 11, 13 and 15 are filled with 2 cm thick brass absorber plates. The outermost layer of RPC’s (layer 19) is not accessible, and will be decommissioned because the RPC efficiency is too low to be useful.

Physical Description
A BaBar LST consists of a gold-plated wire, 100 µm in diameter, located at the centre of a cell of 15×17 mm² section. A plastic (PVC) extruded structure, or “profile”, contains 7 or 8 such cells, open on one side. The profile is coated with a resistive layer of graphite, having a typical surface resistivity between 0.2 and 1 MΩ/square. The profiles, coated with graphite and strung with wires, are inserted in plastic tubes (“sleeves”) of matching dimensions for gas containment. The length of an LST along the beam direction is 358 cm except for layer 18, where it is 318 cm. Other components which complete the detector configuration are: end pieces with gas inlets, HV and ground connectors; spacers installed typically every 50 cm to fix the wires at the centre of the cell; small printed circuit boards and their supports at the two ends of the profile, for soldering the wires and providing electrical connections.

To improve the mechanical rigidity of the structure and to make cabling easier, LSTs are assembled into modules. Each module consists of 2 or 3 tubes, which are glued onto so-called Φ planes. The purposes of the Φ planes are to provide grounding and to transmit the wire signals from the rear end where they exit the tubes; to the forward end where the readout cables bring them to the front-end electronics (there was not sufficient room to bring the signals out directly from the rear).
The signals for the measurement of the coordinate perpendicular to the tube length are read directly from the wires. The measurement of the coordinate along the tube length (z-coordinate) is carried out by means of segmented cathode strips capacitively coupled to the wires. The cathode strips are a composite structure 1 mm thick, stratified as follows:
- the strip, which is facing the tube, onto which the signal charge is induced;
- the insulator foil, made out of two layers of PET with a total thickness of 500 µm;
- the ground plane, which shields the strips and forms with them a transmission line that guides the signal to the collection junctions.

The overall length of a z-strip plane is 370 cm; the width is that of the layer, ranging from 190 cm for layer 1 to 313 cm for layer 18. The z-strips are not glued to the tubes, but are inserted separately into the magnet gaps before the modules. The weight of the modules presses them sufficiently close against the strips.

**High-Voltage System**

**System Overview**

A multi-channel high voltage system is required to operate the new LST detector. Details of the LST detector design and the results of an extensive R&D program can be found in the LST proposal to the SLAC EPAC (June 2003).


Pairs of two wires are formed inside the tubes resulting in 4 independent detection elements per tube. Connectors for the four segments are located in the end pieces (end caps) of each LST tube. To operate the detector high voltage has to be applied to each segment. The HV ranges between 5 and 6 KV with a typical working point at 5600 V. Based on our simulations we estimate typical currents for an entire LST tube to be around 200 nA without beams and to reach approximately 1000 nA with colliding beams. See Table 1 for more details.
<table>
<thead>
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<th>LST Detector</th>
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<tbody>
<tr>
<td>Individual LST tubes</td>
<td>1164</td>
</tr>
<tr>
<td>HV Segments</td>
<td>4656</td>
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<tr>
<td>HV Channels (18 Power Supplies in IR2)</td>
<td>5760</td>
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<tr>
<td>Independent Current Monitor Channels (required)</td>
<td>1164</td>
</tr>
<tr>
<td>Independent Current Monitor Channels (available in IR2)</td>
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<td>Worst case rate per tube estimate (2 Hz/cm²)</td>
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<tr>
<td>Max. tube current</td>
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<td>Max. current per Current Monitor channel (1 tube or 4 HV segments)</td>
<td>1140 nA</td>
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<td>Typical rate per tube estimate (0.2 Hz/cm²)</td>
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<tr>
<td>Typical tube current</td>
<td>110 nA</td>
</tr>
<tr>
<td>Typical current per Current Monitor channel (1 tube or 4 HV segments)</td>
<td>110 nA</td>
</tr>
</tbody>
</table>

**Table 1: HV Requirements**

The HV system for the BaBar LST detector consists of the following building blocks:
- HV power supply with current monitor and overcurrent protection.
- HV distribution and 1 to 4 fan out built into the power supply back panel.
- HV cables from the electronics house to the detector.
- A so-called HV Box at the detector end of the HV cable that houses the circuit for the wire signal pickup, including 8 HV decoupling capacitors. The HV box connects directly to the endcap of an LST tube. It provides a connector for the readout cable.

The following photo is a picture of a LST HV supply with the top cover, rf shields and support mechanics removed. The view shows the back panel and 40 of the 80 current monitor modules.
Estimate of the Energy Stored in the HV System

The typical operating voltage for the BaBar LST detector is 5500 V to 5600 V. For the following calculations, we assume the detector is running at 6000 V – the maximum voltage the HV supplies can provide.

**LST Tube**

The capacitance of a two wire segment of an LST tube with respect to ground is approximately 75 pF. Each tubes has 4 segments and hence a total capacitance of 300 pF. At 6000 V this leads to a stored energy per LST tube of 0.0054 J

\[
PE_{\text{Tube}} = 0.0054 \text{ J}
\]

There are currently 388 LST tubes in BaBar. After installation is complete in 2006 this number will rise to 1164.

**HV Box**

Each HV box contains 4 pairs of two 470 pF HV capacitors in series -- total capacitance 940 pF. At 6000 V this leads to a stored energy per HV box of 0.017 J

\[
PE_{\text{HV Box}} = 0.017 \text{ J}
\]
HV Cable
The approximate capacitance of an individual wire in the HV cable with respect to ground is 10 pF per foot. With 8 wires at HV in most of the cables (a few have 12 conductors at HV and are used for 3 tube modules) and a cable length between the detector and the electronics hut of 100 ft we estimate the total capacitance to 10 nF. At 6000 V the energy stored in a HV cable is 0.14 J

\[
PE_{HV \text{ Cable (2 tube module)}} = 0.14 \text{ J} \\
PE_{HV \text{ Cable (3 tube module)}} = 0.22 \text{ J}
\]

HV Power Supply
Each of the 80 output channels includes a 1 nF filter capacitor. With a total capacitance of 80 nF and at 6000 V we calculate the energy stored in one supply to 1.44 J.

\[
PE_{HV \text{ Power Supply}} = 1.44 \text{ J}
\]

Safety and Over Current Protection
Safety is of course the highest priority – both for the people working with the high voltage system and for the LST detector itself. The LST high voltage system complies with all applicable SLAC safety standards. It has been inspected by the Electrical Safety Committee.

An interlock system has been implemented that prohibits the HV system from turning on the outputs when the conditions are not safe. For the LST high voltage supplies this includes

- **External HV Enable**
  An external signal is required before the outputs can be turned on. This signal can be used to ensure that BaBar is in a condition where it is safe to turn on the LST detector.

- **Front-panel HV Enable**
  A switch on the front panel of each HV power supply has to be set before the outputs can be enabled.

- **Software HV Enable**
  A (software) HV enable command has to be issued by the detector control system before the outputs can be turned on. This feature insures that the firmware and slow control software is working properly before the system is activated.

- A switch lock with a removable switch is used as power switch.

LED indicator lights on both the front and the back panel are on when the HV outputs are enabled.

LED indicator lights (one for each of the four HV segments) on the front panel are on when high voltage is present.

The 80 output channels are grouped in 4 segments with 20 channels each. The output voltage for each of the 4 channels can be set independently. The maximum output voltage is 6000 V.
The maximum current per output channel is limited to 14 µA by an internal resistor.

A hardware circuit in each output channel forces an automatic reduction of the output voltage of this channel (Note: this mechanism works on individual channels. The remaining 19 channels in this HV segment as well as the 60 outputs in the other 3 HV segments are not affected by a high current condition in a single LST tube). The following plot shows the actual output voltage as function of the output current.

We are operating the LST HV supplies with the internal voltage, $V_{in}$, set to 7000V so that the overcurrent protection sets in a 3 µA. With this circuit the two extremes given above for $V_{max}$ and $I_{max}$ can not be reached simultaneously as the actual output voltage drops to 0 as the current approaches 14 µA.

In addition to the over current protection mechanism described above the HV power supply system also includes standard trip logic. Individual trip thresholds can be configured for each of the 80 outputs. A time over threshold (before a trip occurs) can be set for each of the 4 HV segments. In addition, an independent, second trip level common to all channels can be set.

**Slow Control (EPICS) Requirements**
Personnel and detector safety features have been implemented in the HV supplies themselves. Other control and monitoring tasks are handled by the BaBar detector control system, which is based on EPICS. The LST HV system is fail safe toward EPICS so that if the remote control link hangs for some reason the system can run safely by itself.
**HV Cables**

We use multi-conductor HV cables made by Kerpen-Kabel, Germany. A picture of a similar cable is shown below (we use fewer wires). The outer jacket is halogen free and flame retardant. It comes in 10-wire or 20-wire configurations. The cable has been approved for usage by the LHC experiments. It is rated for 6 KV (wire to wire) and was tested at 12 KV at the factory. We use one 10 (15) wire cable per 2 (3) tube module.

![HV Cable Image](image)

**Electronics**

**Introduction**

The various elements of the readout system are: LST-FE cards (motherboard and daughter card), the LST-FE crate and crate controllers, the LST-FSD card and the LST-FE CSC/Trigger card.

The LST Front End ReadOut (LST-FERO in the following) includes 12 crates which are installed in racks located around the detector.

An LST-FERO crate is powered by 110Vac and uses commercial AC-DC switching converters to produce the +5/-5V @ +/-40A (Kniel FP 5.40/PFS) needed by the front-end and service cards or the +24V (GOMA PSU-ZWS50-24) needed by the fan and the crate controller.

The total operating power for which the crate is specified is 450W.

The crate features a CAN-Bus controller which allows remote turn-off and monitoring of the operational status, such as supply voltages, fan speed, crate temperature.

As a general remark, thus, the LST_FEROs operated at low voltage and relatively low power do not present particular hazards to the operators.
All connectors to the LST-FERO crates are keyed and provided with locks so that connections cannot be done improperly or become loose.

**Location of the LST-FERO crates**
The 12 crates of the LST-FERO system are 19” wide and 9U tall and are located in racks distributed around the BaBar detector as shown in Fig.1 and Fig. 2 of next page:

- **Location A, 5 crates:** on top of the platform built in 2004 are/will be located the crates for:
  - Sextant 4, wires (PHI view)
  - Sextant 4, strips (Z view)
  - Sextant 5, wires (PHI view)
  - Sextant 5, strips (Z view)
  - Sextant 0, strips (Z view)

- **Location B, 1 crate:** near the cryogenic assembly, on a retractable platform built in 2004, is located the crate for:
  - Sextant 1, strips (Z view)

- **Location C, 2 crates:** hanging from the solenoid dump resistor platform there will be the crates for:
  - Sextant 2, strips (Z view)
  - Sextant 3, strips (Z view)

- **Location D, 1 crate:** hanging from the solenoid dump resistor platform there will be the crate for:
  - Sextant 3, wires (PHI view)

- **Location E, 1 crate:**
  - Sextant 2, wires (PHI view)

- **Location F, 2 crates:**
  - Sextant 1, wires (PHI view)
  - Sextant 0, wires (PHI view)

Note: Sextant 1 is the top sextant; sextant numbers increase counter clockwise when viewed from the front of the detector.
Signal cables
The largest amount of cabling involved in the LST-FE ReadOut is for bringing the signals from the LST detectors to the LST-FERO crates. This cable, provided by Amphenol SpectraStrip, meets the safety TIS standards adopted by CERN. It is flame retardant and halogen free.
The remaining signal cables, like the ones used for connecting the LST-FERO crates to the IFR DAQ crates and to route the trigger and CAN-BUS signals, comply with the BaBar standards.

**LST-FE card overview**

The “LST Front End” (LST-FE) card provides amplification, comparison against a programmable threshold discrimination, storage and readout processing for 64 LST signals.
Its basic functions are equivalent to those performed by 4 of the earlier “FEC” cards (FrontEnd Cards) developed by INFN-Napoli for the RPC based muon detector, but to this basic functions the LST-FE card adds the additional features detailed below.

The LST-FE board has been built, for the sake of flexibility, as a modular unit, whose components are:

- a motherboard, featuring:
  - the DC power regulators and power monitors;
  - 64 discriminators, ganged in 4 groups of 16, each group having a common, programmable, threshold voltage;
  - an FPGA which performs the standard “FEC-like” data acquisition functions plus programmable threshold and mask setting/readback by means of a “soft-coded” processor (NIOS) and its associated peripherals.
- 4 “Integration-Amplification Daughtercard” (IAD cards) each featuring 16 dual-stage integrating amplifiers.

The LST-FE motherboard is a single width (4TE), 6U (233 mm x 160 mm) VME-Eurocard module and connects to the INFN- Genova designed custom backplane through a standard
96pin DIN41612-C connector. Power/ground pin assignments are consistent with the VME standard for the J2 connector, while signal pin assignments will match the custom-backplane ones.

The IAD cards have dimensions of 47.5mm x 120mm and feature one 34pin header on the front side for the signal flat cable and one IEEE-1386 board-to-board connector at the back-bottom side.

The stacking height of the daughtercard above the host PCB is 10 mm.

The complete LST-FE draws approximately 1.5A and 1.3A respectively from the +5V and -5V power supplies.

A detailed description has been presented in the BaBar Note #0586, Dec 07 2004.

**Gas Mixing and Distribution System**

**Gas Composition and Flow Rates**

The LST gas consists of three components: argon, isobutane, and carbon dioxide. The three gases are initially stored in individual containers and then combined and mixed together in the BaBar gas shack before being piped into the IR hall. Please see SAD section 3.3.2, “Drift Chamber,” Gas Mixing Shack, for a brief description of the BaBar gas shack. Under nominal conditions gas is supplied to the LST at a rate sufficient to change the entire volume once every day. For a full barrel installation, this rate is 9000 liters per day, or 6.25 liters per minute.

**Gas Mixing System**

Figure 3 shows the mixtures of argon, isobutane, and carbon dioxide that would be considered non-flammable and hence safe to use in the BaBar detector. The red line shows the boundary separating the flammable from the non-flammable region. Gas mixtures above the line are considered to be flammable in air.
Part of the design of the gas mixing system is intended to provide a margin of safety between the gas mixtures which are actually used in the detector and the boundary between flammable and non-flammable gas mixtures. Consequently only mixtures which lie in the region below the blue line in figure 3 are actually allowed to be used in the detector; the limitation of the operation of the gas system to mixtures in this region provides sufficient separation between the ‘runnable’ region of gas mixtures and the flammable region to account for any foreseeable drifts in the gas mixing system. The blue line determines the region containing permissible values for the set points of the system.
An outline of the functionality of the gas mixing system is shown in Figure 4.

A flow control box determines the values for the individual gas flows through a set of MKS mass flow controllers. To prevent a flammable mixture from being sent to the detector due to a malfunction of any one of the controllers, the LST Gas Safety Interlock Panel monitors the flows in an independent set of gas flow meters and compares those measured flows with a set of limits intended to keep the gas mixture within a window of the set point. If any component wanders outside of the limits, the gas delivery is shut off and an alarm made to the monitoring system. A procedure has been set up whereby a particular gas setting is verified to be within the acceptable region of gas mixtures before being used in the mixing system.

**Gas Distribution System**

The mixed gas is piped from the mixing system in the gas shack to a panel on the top of the BaBar detector. An outline of the distribution within IR-2 is given in Figure 5. Here the gas first passes through a parallel set of 25 mm long flow restricting tubes with 0.53 mm diameter orifices; these produce a pressure drop in the gas lines to a value less than approximately three inches of water equivalent. The gas passes next through a flow meter; a
safety bubbler is connected to the output of the flow meter; and finally the gas is divided into two parallel flows to each layer of LST tubes through individual flow restrictors. These are tubes that are also 25 mm long with 0.53 mm diameter orifices. The final use of flow restrictors keeps each half layer of LST tubes independent of any of the other layers due to the fact that the value of any half layer’s gas flow is determined entirely by its flow restrictor. Individual gas lines returning from each half layer are routed to a system of gas return bubblers which monitor the return gas flow. From the exit bubblers, the gas streams are joined and vented in the IR hall.

![Diagram of gas distribution system in the IR hall](image)

**Figure 5 Outline of the gas distribution system in the IR hall.**

**LST Hazards/Hazard Control**

The first concern involves the gas mixture which contains a flammable component, isobutane. Isobutane is present in its pure form in the supply bottles, supply lines, and the front end of the gas mixing system and is a fire hazard when mixed with air. A fundamental criterion used for the gas mixture is that it is not flammable.

A flow control box determines the gas flows through a set of MKS mass flow controllers. A procedure has been set up whereby any particular gas setting is verified to be within the acceptable region of gas mixtures before being put in use. The LST Gas Safety Interlock...
Panel monitors the flows in an independent set of gas flow meters and compares those measured flows with a set of limits intended to keep the gas mixture within a window of the set point. If any component wanders outside of the limits, the gas delivery is shut off to prevent a flammable mixture from being sent to the detector. The LST Gas Safety Interlock Panel will also shut off all gas going to the IR if the GMS safety system detects a fault condition.

Flammability concerns associated with the presence of pure isobutane in the mixer front end are controlled through the selection of proper components, assembly by qualified technicians, system-level pressure leak tests, and the BaBar Gas Shack ventilation system. The gas shack features to control the flammable gas hazard of the isobutane supply have been discussed in the initial SAD section for the DCH, section 3.3.2.3. In summary, these include the shack ventilation system with its monitors, gas line restrictors, gas line automatic shut-off valves, and in line pressure switches.

The only high pressure component is the argon supply; this is shared with the RPC gas system, and consequently shares its controls and oversight. The carbon dioxide is supplied from a commercial carbon dioxide delivery system which is certified to be manufactured to ASME pressure vessel specifications. The unit is accessible for maintenance and monitoring. The vent and fill lines for the carbon dioxide dewar have been routed to be well protected from accidental damage.

Hughes Associates Inc., a fire safety and engineering consulting service, has provided an independent review of the gas safety hazards and hazard controls discussed above. Hughes Associates Inc. is in agreement with the approach described above and is currently developing the second addendum to the Fire Hazard Analysis. Based on the above, the risk associated with the LST gas system hazards is consistent with the risk assessment of low established in the initial SAD for the RPC nonflammable gas system hazards.

The LST high-voltage system is powered from current limited power supplies. The current limit and the stored energy levels are sufficiently low such that an electrocution hazard does not exist. However, a startle hazard is a possibility. All accessible HV connections utilize connectors that prevent physical contact with the high voltage. The risk associated with the LST electrical system is consistent with the risk assessment of low established in the initial SAD for the RPC electrical system hazards.

4.6 Magnet Coil and Flux Return

The Magnet and Flux Return system remains essentially unchanged from the original design and therefore the risk assessment established in the initial SAD remains current.
4.7 **Electronics**

The electronic systems except where discussed in the previous sections remain essentially unchanged. Where equipment has been replaced equipment with equivalent or improved safety features have been utilized. The risk assessment established in the initial SAD remains current.

4.8 **Online Safety Control and Monitoring**

The online safety control and monitoring system remains essentially unchanged from the originally design and therefore the risk assessment established in the initial SAD remains current.
### Review Record

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### Detector Systems

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Date

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DCH  
Date

**Reviewed by:**
DIRC  
Date

**Reviewed by:**
EMC  
Date

**Reviewed by:**
IFR-RPC  
Date

**Reviewed by:**
IFR-LST  
Date

**Reviewed by:**
Trigger  
Date

**Reviewed by:**
Electronics  
Date

**Reviewed by:**
Online  
Date

7/22/2005