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VELO Module Production - Clean Room Layout, Procedures and Monitoring

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Abstract

This note describes in detail the procedures for access and gowning in the clean rooms.

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1. Introduction

This document outlines the clean room operational procedures for the production of the LHCb VELO modules in the Liverpool Semiconductor Detector Centre (LSDC). The current version includes all revisions made after the mid-term review.

The cleanliness of the production and testing areas and the monitoring and control of the environment is critical to accurate and reproducible fabrication of the modules. The first section of the document covers the dress codes and other clean room procedures put in place by the team in order to ensure the maintenance of high quality VELO modules. Subsequent to this is a summary of the environmental monitoring in place during the production.

2. Production Facility Layout

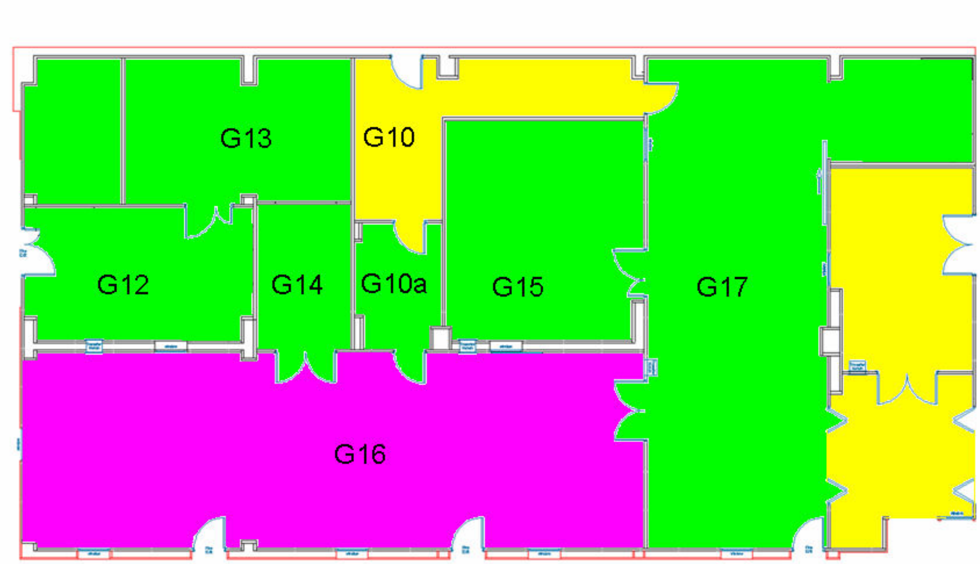

Figure 1: A schematic of the areas used within the LSDC for LHCb VELO module production. The cleanest area was Class 100 and is indicated in purple. The Class 10,000 areas are coloured in green and access areas are in yellow.

A view of the production area is given in Figure 1. The layout is critical to the safe production of modules. We describe in detail the layout of LSDC as arranged for the LHCb production. The cleanest area is the Class 100[1] area (ISO class 5 at present 14644-1 standard) which is maintained at an overpressure (relative to atmospheric) of 75Pa. The Class 10,000 areas (ISO class 7 at present 14644-1 standard) are maintained at 50Pa overpressure and the entry and egress areas are at 25Pa overpressure. (See also 6.1.2). Figure 1 also shows the room numbers (e.g. G10) which will be used in this document.

The function of each of the clean room areas will be discussed in the rest of this section. An attempt was made to minimize contamination where this would affect production yield, thus process steps with the highest need for cleanliness were performed in the Class 100 area. Steps such as cleaning or testing which would either contaminate the production process or require unnecessary imposition of restrictions on staff were performed in the Class 10,000 area. No LHCb VELO module production happened outside of the controlled environment.

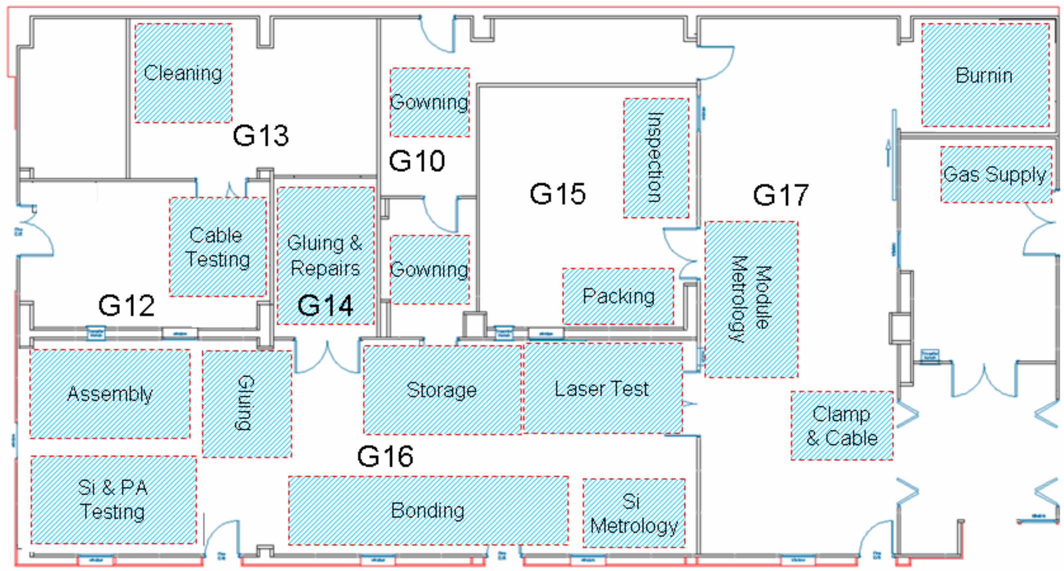

Figure 2: Schematic of the LSDC showing the LHCb production zones performed in each of the rooms.

2.1. Entry and Egress

The production facilities have one normal entry point, through G10, sometimes referred to as the lobby. The lobby can be accessed by anyone in possession of an access key and is shared with other groups utilizing the LSDC facilities.

The lobby houses the computer controls for the clean room, the clean room monitoring log books and garments (and lockers) for people entering the Class 10,000 [1] areas. Sticky mats were installed outside the entrance to the lobby and within the lobby area in front of the entries to G13 and G17. The sticky mats were changed daily during production. G10a, directly below the lobby in Figure 1, served as the gowning area for the Class 100 area G16 and G14. Materials brought into G16 through G10a were required to have been cleaned in G13 to avoid contamination. Access to G13, G15, G16 and G17 was permitted through G10.

2.2. Silicon and Pitch Adaptor Testing

The testing of the silicon wafers and pitch adaptors occurred using the two probe stations (1 and 2) positioned at the lower left of the schematic – in the Class 100 area g16. The pitch adaptors were stored in clean boxes adjacent to Probe Station 2, see Figure 3. The sensors were stored adjacent to the fume cupboard.

Although the two probe stations were in principal identical, probe station 2 was dedicated to pitch adaptor testing and probe station 1 for silicon testing for the entire production.

The workbench next to Probe Station 1 was used for inspection of the silicon and also for the precision weighing[2] of the Si to determine its thickness.

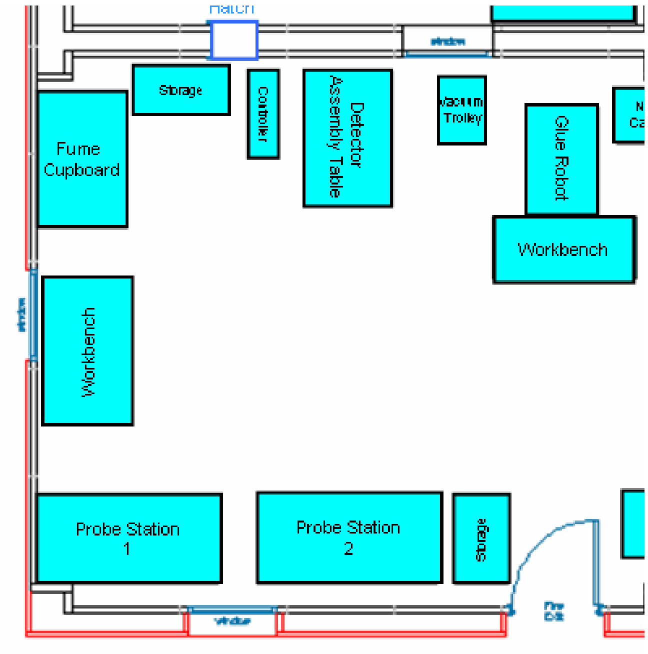

Figure 3: Detail of the Si and pitch adaptor testing zone of G16. Also shown is the gluing zone.

2.3. Hybrid Cleaning

These activities took place within room G13. The fume cupboard allowed the use of solvents well away from the main production area. Hybrids were normally cleaned with a degreasant, Prozone®, and rinsed with deionised water and dried with clean N_2. The fume cupboard was cleaned after each use.

2.4. Repairs and Glue Curing

An environmental oven and its control PC were housed in G14 along with an inspection microscope. The oven was used to accelerate the curing of the glues for chips and pitch adaptors.

All repairs (chip and pitch adaptor removal) took place in G14. If necessary these could be taken to G13 for cleaning. The removal of pitch adaptors and chips was performed in this room in order to avoid particulate contamination in G16.

In addition all gluing of pitch adaptors to the hybrid was done in G14 except for the application of the glue to the hybrid.

2.5. Glue Application

The glue for the pitch adaptors and Si sensor and hybrids was applied by a glue robot in the gluing zone in G16. This was immediately adjacent to the assembly zone to allow the double sided gluing of the hybrids to proceed with minimum movement and to preserve the cleanliness of the sensor, see Figure 3.

2.6. Hybrid and Materials Storage

Hybrids at all stages of the production process were placed in a storage zone next to the G10a/G16 entrance, until completion as modules. The hybrids were kept in a dry a N_2 atmosphere to avoid problems associated with long term exposure to humidity and oxygen. Other sensitive materials, such as the bond wire, were also stored in controlled conditions in these areas.

Some materials, such as the silver epoxy used for production, required storage in cold conditions and were stored separately

2.7. Bonding

The bonding was performed by two H&K 710 and a K&S 8090.[3-5]. The machines were located in the bonding zone. The zone also contained the Dage 4000 series wire pull tester used for quality control of the bonding process.

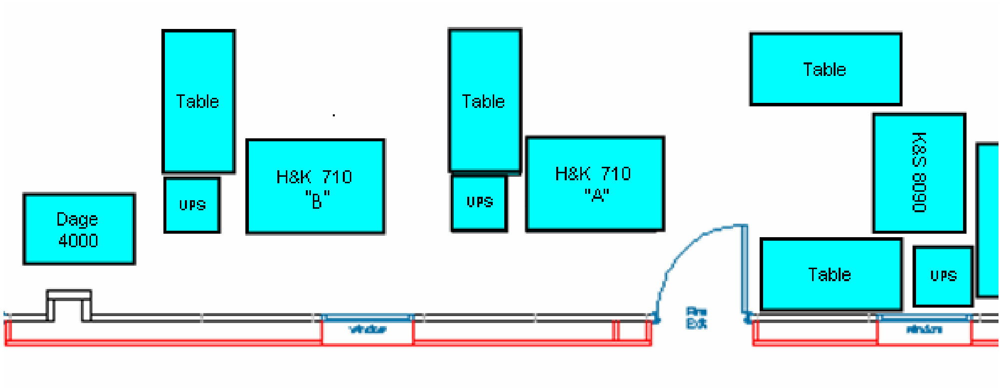

Figure 4: The layout of the bonding zone in G16.

Figure 5: View of bonding zone showing H&K. The K&S 8090 can be seen in the background.

2.8. Si Metrology

The qualification of the sensors before the modules were built required both detailed electrical testing and a precise metrology of their dimensions. In addition post double-sided gluing of the sensors to a hybrid required another metrology step [6] to verify the success of this step. This precise metrology is performed in the Si metrology station adjacent to the bonding station using a Smartscope.

The relatively long distance between the Si metrology and this station was a source of concern before production. Ideally this station should have been close to the LHCb Si testing zone. However given the “delicacy” of the Smartscope it was decided to leave this zone in its distant position. The only handling accident during production arose from transport of sensors between the metrology and testing zones.

2.9. Hybrid and Laser Testing

The production process contained many steps during which the hybrid was electrically read out. The electrical tests were performed using the NA-60 data acquisition system (DAQ). This DAQ was adjacent to a computer controlled IR laser [7] system that permitted a complete test of the responsiveness of finished modules. This DAQ and laser system was inside the G16 in order to retain cleanliness in case repairs to the modules were required.

2.10. Burnin and Vacuum Tests

Prior to shipping all modules experiences a vacuum burnin. [8]. These were performed in the environmental chamber within the G17 area, Figure 6.

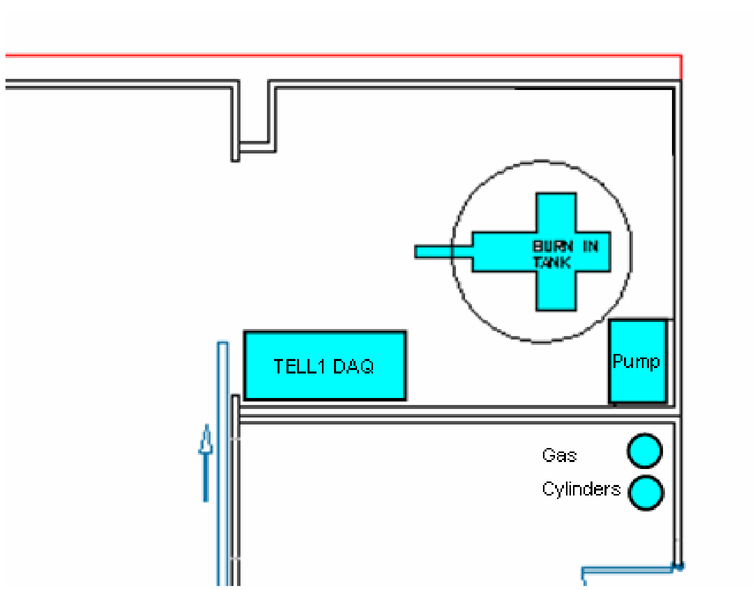

Figure 6: The layout of the burnin system. The vacuum system occupied the centre of the environmental chamber in G17. The TELL1 DAQ system was adjacent to the vacuum chamber. CO_2 liquid was supplied through the wall of the chamber from the adjacent room.

The use of CO_2 in a restricted area required substantial safety measures. The vacuum system, including a Turbo pump, was installed in this area.

2.11. Module Metrology

The assembled modules received several stages of metrology prior to shipping to CERN. The metrology was performed using a video head on the “small” Wenzel coordinate measuring machine (CMM) in G17.

2.12. Cable Attachment and Testing

Space was allocated in G17 for the attachment of cable clamps[9] and cables. This was subsequently moved to the inspection area in G15 when it became available. All testing of the cables prior to attachment was performed in G12.

2.13. Final Inspection and Packing

During production it was decided to commission an area specifically for the final inspection, photography and packing of the modules. This was chosen to be in the G15 area that had, at the start of LHCb production, been utilized by ATLAS (and hence unavailable).

3. Dress Code

In this section we document the procedures put in place throughout the clean rooms. This is reproduced essentially unchanged from the version circulated to all staff members working in the production facility.

3.1. General Procedures

It is now a requirement that ALL production staff wear a full coverall, head garment, ESD shoes or over shoes, ESD wrist strap and gloves. If you require access to G15, G17 or the environmental chamber you should now use the gowning area to the left in G10 (lobby). If you require access to G12 or G13 you need to use the gowning area immediately to your right in G10. To work in G16 and G14 you must gown up in G10a (See Figure 7). You must adhere to the dress code and gowning procedures for all of these areas. It is no longer permitted to use G10 (lobby) as a through route to other labs within the complex whilst wearing any clean room garments.

Figure 7: Dress code for Class 100 area.

3.2. Class 100 Production Area - G16 (+ G14)

To gain access to the clean room complex the user will be required to adhere to the following:

3.2.1. Before entering G10 (lobby) from corridor step on tacky mat ensuring that the soles of both feet come into contact with mat and repeat several times.

3.2.2. Proceed from G10 to G10a (class 100 gowning area) again ensuring correct tacky mat procedure as above before entry.

3.2.3. G10a is the gowning room for the class 100 area. Firstly remove shoes (including any woollen garments) and locate dedicated coveralls, hood and class 100 ESD shoes from storage cabinet, these are clearly marked with unique personal numbers. Garment packaging should be inspected for tears before use.

3.2.4. Garments should be put on from top to bottom starting with face mask, veil or beard cover (ensuring nose is covered) and then hood. (use mirror provided to ensure hair is tucked in)

3.2.5. Coveralls can be gathered together at the 4 corners i.e. the 2 wrists and 2 ankles. It should then be possible to put first one leg and then the other into the garment without the trouser legs touching the floor. The veil should be tucked into coveralls and cuffs and ankles should tightened using poppers.

3.2.6. Proceed to stepover bench, this is used to demarcate the slightly soiled changing area from the cleaner entrance zone, and allows cleanroom footwear to be correctly put on. Sit on bench and place one shoe on before stepping onto the clean side followed by the second shoe. Using tacky mat, take several steps to ensure the soles of the shoes are clean.

3.2.7. ESD straps and gloves should now be put on ensuring sleeves of coveralls are tucked into gloves.

3.2.8. Perform an ESD safety check using test station provided.

3.2.9. You are now ready to proceed into the G16 and G14 production areas

3.2.10. Visitors or staff who have not been allocated any clean room garments should wear a disposable coverall (tyvek suit), ESD overshoes, face mask/veil and gloves.

3.3. Class 10,000 Testing Area – (G12 and G13)

To gain access only to G12 and G13 production areas the user will be required to adhere to the following:

3.3.1. Before entering G10 (lobby) from the corridor step on the tacky mat ensuring that the soles of both feet come into contact repeat several times.

3.3.2. Once in G10, use gowning cupboard to the right

3.3.3. Firstly remove shoes and locate dedicated coveralls, hood and class 10000 ESD shoes from the storage cabinet, these are clearly marked with unique personal numbers. Garment packaging should be inspected for tears before use.

3.3.4. Garments should be put on from top to bottom, starting with face mask, veil or beard cover (ensuring nose is covered) and then hood (ensuring hair is tucked in)

3.3.5. Coveralls can be gathered together at the four corners i.e. the two wrists and 2 ankles. It should then be possible to put first one leg and then the other into the garment with the garment legs touching the floor. The veil should be tucked into the coveralls and the cuffs and ankles should be tightened using the poppers.

3.3.6. Proceed to the step over bench, this is used to demarcate the slightly soiled changing area from the cleaner entrance zone, and allows cleanroom footwear to be correctly put on. Sit on the bench and place one shoe on before stepping on to the clean side followed by the second shoe. Use the tacky mat several times to ensure that the soles of the shoes are clean

3.3.7. ESD straps and gloves should now be put on; ensuring sleeves of coveralls are tucked into the gloves.

3.3.8. Perform an ESD safety check using the test station provided.

3.3.9. G12 and G13 can now be accessed.

3.3.10. Visitors or staff who have not been allocated any clean room garments should wear a disposable coverall (tyvek suit), ESD overshoes, face mask/veil and gloves.

3.4. Class 10,000 Checkout and Metrology Area – (G15 and G17)

To gain access only to G15, G17 and the environmental chamber production areas the user will be required to adhere to the following:

3.4.1. Before entering G10 (lobby) from the corridor step on the tacky mat ensuring that the soles of both feet come into contact repeat several times.
3.4.2. Once in G10 use gowning cupboard to the left
3.4.3. Firstly remove shoes and locate dedicated coveralls, hood and class 10000 ESD shoes from the storage cabinet, these are clearly marked with unique personal numbers. Garment packaging should be inspected for tears before use.
3.4.4. Garments should be put on from top to bottom, starting with face mask, veil or beard cover (ensuring nose is covered) and then hood (ensuring hair is tucked in)
3.4.5. Coveralls can be gathered together at the four corners i.e. the two wrists and 2 ankles. It should then be possible to put first one leg and then the other into the garment with the garment legs touching the floor. The veil should be tucked into the coveralls and the cuffs and ankles should be tightened using the poppers.
3.4.6. Proceed to the step over bench, this is used to demarcate the slightly soiled changing area from the cleaner entrance zone, and allows cleanroom footwear to be correctly put on. Sit on the bench and place one shoe on before stepping on to the clean side followed by the second shoe. Use the tacky mat several times to ensure that the soles of the shoes are clean
3.4.7. ESD straps and gloves should now be put on; ensuring sleeves of coveralls are tucked into the gloves.
3.4.8. Perform an ESD safety check using the test station provided.
3.4.9. G15 and G17 and the environmental chamber can now be accessed.
3.4.10. Visitors or staff who have not been allocated any clean room garments should wear a disposable coverall (tyvek suit), ESD overshoes, face mask/veil and gloves.

4. Clean Room Materials

Only a limited number of substances or materials were allowed into the production areas. Below these are listed.

4.1. Containers

No cardboard or non-cleanroom paper products were normally allowed into the Class 100 area. Storage of materials supplied by the manufacturer in unsuitable containers was normally outside of the cleanroom or in the G10 (a) lobby areas.

For some limited material, for example bonder documentation which was produced on non-cleanroom paper these were stored in plastic bags in storage cupboards within the clean room complex. Tools were stored in cleaned plastic boxes within the clean room.

4.2. Writing Materials

Paper for writing on, including notebooks and printer paper, were all of cleanroom grades. Only clean room pens and non-shedding marker pens were used inside the complex.

4.3. Cleaning Materials

Prescribed materials for cleaning were as follows.

4.3.1. Hybrids

All hybrids were washed prior to use in the assembly using Prozone®, isopropyl alcohol and deionised water. During production three hybrids exhibited poor adhesion. For these hybrids cleaning with a dilute mixture of sulphuric acid was attempted. Only one of these hybrids was delivered to CERN as part of the production.

Hybrids were always stored dry. They were dried using the dry N_2 supply.

4.3.2. Cables and Clamps

Cables and clamps were cleaned prior to assembly. The cables were cleaned with Prozone®, isopropyl alcohol and deionised water. The clamps were just cleaned with isopropyl alcohol and deionised water.

4.3.3. Parts and tooling from Workshop

All materials entering the clean room were cleaned. For parts produced, or modified, in the machine shop the parts were cleaned twice. They were first degreased and washed with isopropyl in the machine shop. Then before entering the Class 100 area they were cleaned with lint free cloths and isopropyl in G10a. Particularly sensitive pieces, such as sensor holding jigs, were cleaned every time before use in the clean room.

4.3.4. Swabs and Cloths

Special cloths and swabs were used for the production. The mid-term review revealed that the first 30% of the modules produced appeared to have somewhat more debris than was expected on the surface of the silicon. See Section 7.

A major contributor to the debris came from hybrid rework and resulted in small white particulates of dried epoxy. This led to all repair work being performed in G14. However additional contamination was isolated as being due to the brand of Class 100 swabs and cloths being used within G14. All cleaning materials, and especially the swabs, were replaces by Class 1 compliant materials. A substantial reduction in the visible debris was noted.

5. Safety Hazards and Precautions

The following describes some of the safety procedures in place for the VELO production. It is not meant to be an exhaustive list of the safety precautions in place in the Oliver Lodge laboratory. These may be found on the second floor of the Oliver Lodge.

5.1. Multiple User Rules

At all times more than one operator was required to be in the LSDC. For work over weekends and outside of normal work hours this rule was also enforced.

5.2. Carbon Dioxide

Carbon dioxide presents a substantial risk to personnel. Liquid CO2 was used for the cooling in the burnin zone. During operation a portable CO2 meter was used. Also an oxygen deficiency alarm was present in G17 and G19. If activated in G19 this alarm would initiate floor level extraction of any gases, and fresh air replacement, pumped in at high level. The alarm was also linked directly to the cleanroom control system (BMS) by displaying constant oxygen levels in these areas. The liquid delivery system fully complied with university regulations and each component was certified for pressured use. The CO_2 was vented in a suitable way to the outside of the building.

5.3. Power

All electrical equipment was checked for safety and ground leaks and fully complied with university regulations. The single biggest hazard was the source measure units that acted as HV power supplies for the sensors. These were limited to deliver a maximum current of 100μA. Furthermore only trained personnel used these power supplies.

5.4. Laser

An IR laser (1060nm) was used for the testing of modules. The laser test zone was clearly indicated and only trained personnel were allowed to use the equipment. The laser was always covered during operation.

Figure 8: View of some of the plant room above the LSDC. Leaks in this area can damage equipment below.

6. Clean Room Operation

The LSDC is a large complex and its utilities require careful control and monitoring to maintain ideal conditions. It is not our purpose to review the operation of the LSDC but we will briefly mention the aspects which involved the day to day involvement of the LHCb staff. The most important of these were alarms which provided the first indicator that something abnormal had compromised the operation of the LSDC and hence LHCb production.

6.1. Alarms

6.1.1. Water

Each of the three air handler units (AHUs) contains a heater battery, refrigeration unit and humidifier, in order to sustain a controlled environment within the cleanrooms. Any serious leak from this equipment could potentially damage equipment in the cleanrooms below. To safeguard and provide maximum forewarning against such occurrence, extensive bunding of the plant room area was installed together with a sophisticated leak detection system. If a leak was detected both local and remote alarms to security control would be activated resulting in the cleanroom manager being notified via mobile phone. The system would also render itself safe by dumping all water in the system to waste, in order to minimise any damage.

6.1.2. Air Pressure/Temperature

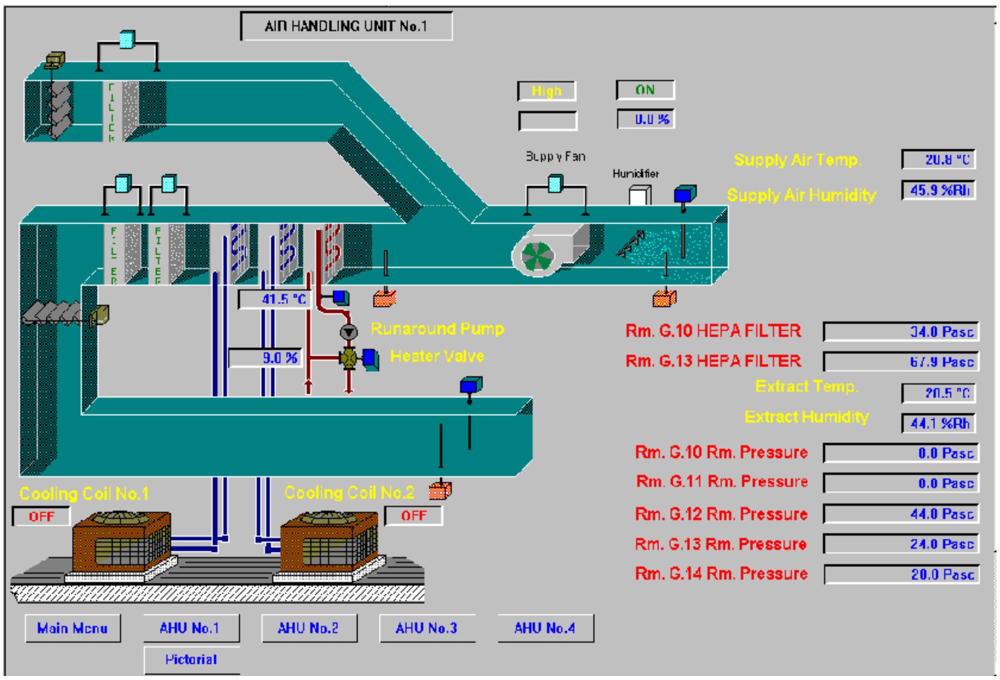

Figure 9: Control screen for the air handling units; this is displayed in G10.

As mentioned in section 2, the air pressure and room temperatures are controlled via a BMS, this being operated from a PC in G10. Alarms are in place for air flow and high room temperatures. A lack of air flow or excessive extract temperatures will trigger both local visual and remote alarms to security control. The cleanroom manager would be automatically notified and work would be halted.

6.1.3. Compressed Air

Many machines including the bonders are operated by compressed air. The failure of the compressed air, or contamination with water (or other liquids including oil) could seriously damage the machines. Because of its vital nature to LHCb production the compressed air was linked into the BMS, resulting in alarms being raised both within the cleanrooms and remotely. A failsafe system was also adopted, by automatically shutting off the air supply to the cleanrooms if a contaminant such as water was detected in the system.

6.1.4. Nitrogen

A constant supply of nitrogen into the cleanrooms was also a requirement for LHCb production. Consequently a nitrogen generator was installed. Any failure of this equipment resulted in both local and remote alarms to security control being activated, (a back up system using bottled nitrogen would then initiate) and the cleanroom manager would be automatically notified.

6.1.5. Computer Lockup

A lock up of the controlling BMS could result in drifts of temperature or humidity outside of the production limits of LHCb. The system was therefore set up to self test every 15 minutes, if a lock up was detected a remote alarm would be activated to security control and the cleanroom manager notified.

6.2. Cleaning

6.2.1. Clean room areas

The clean room areas were cleaned weekly to remove dust. Ceilings, walls and floors were cleaned. Sticky rollers were used to clean the walls and ceilings. A clean room vacuum cleaner together with clean room compatible mop was used on the floors.

It was not possible to ensure daily cleaning of the production zones although these were periodically inspected.

6.3. Monitoring

6.3.1. Humidity and Temperature

The temperature and humidity of the clean room were monitored and controlled. The temperature was kept stable to approximately 20±1ºC in the Class 100 area and approximately 21±1ºC in the Class 10000 areas. See Figure 10 and Figure 11.

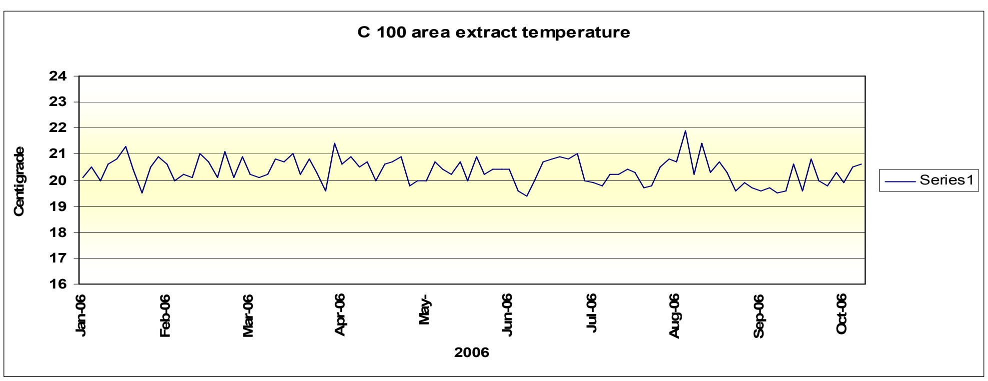

Figure 10: Temperature of the Class 100 area up to Nov 2007.

This was important as precise gluing was required to maintain the precision of the modules. The tooling was predominantly made of aluminium and steel so the mechanical tolerances would be best if the temperatures during production were kept even.

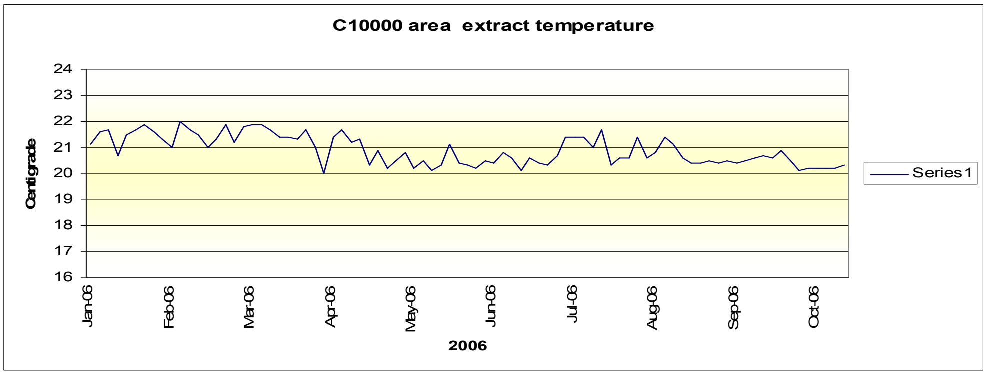

Figure 11: Temperature of the Class 10000 area up to Nov 2007

The humidity was also controlled although not to the same degree. The humidity varied between 35 and 55%. (See Figure 12 and Figure 13.)

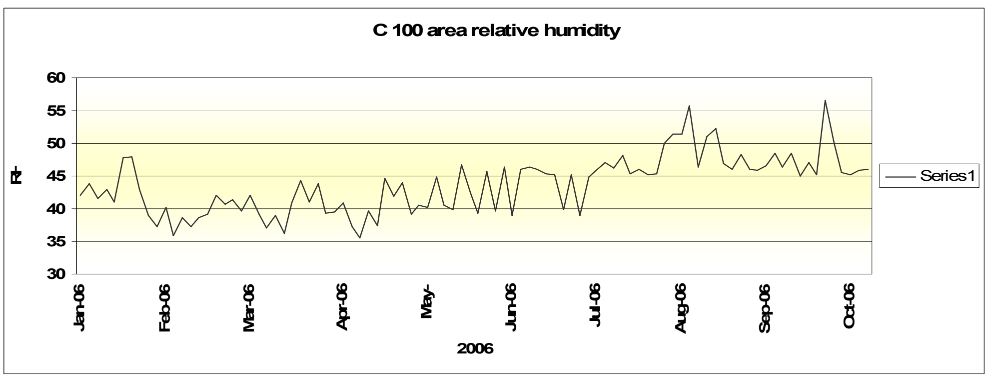

Figure 12 Relative humidity in the Class 100 area.

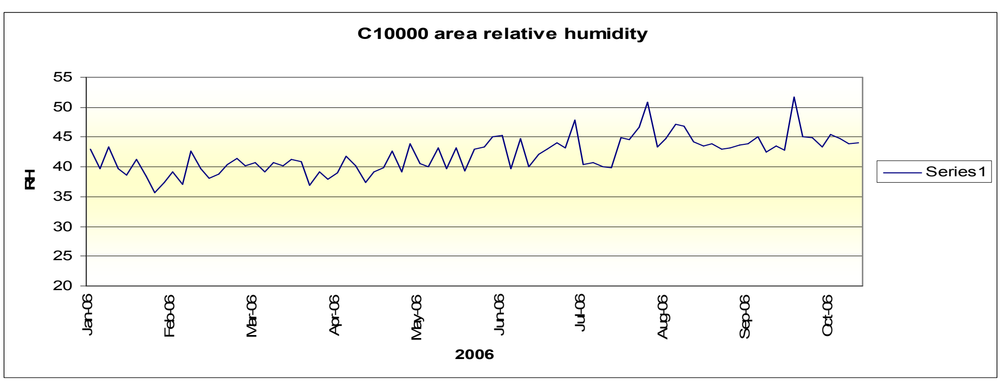

Figure 13: Relative humidity in the Class 10000 area.

6.3.2. Particulate Count

The clean room cleanliness was monitored through the LSDC. There were 5 sniffers placed in the ceilings and walls around G16 and also in each of the Class 10000 areas. These enabled the airborne particulate count to be measured. This acted as an immediate monitor of the conditions inside the cleanrooms and warned if non-sanctioned materials were being utilized. Further spot measurements were made using a tripod mounted particulate counter. Results from a typical month (Jul 2006) can be seen in Figure 14. This clearly shows the effects of reduced manpower at weekends (typically either 0 or 2 people working over weekends) compared with 6 people in the Class 100 area during the week. Over the weekends the particulate count drops to Class 1 levels whereas during the working week it reaches approximately 200 0.5 microns particles per Cu ft.

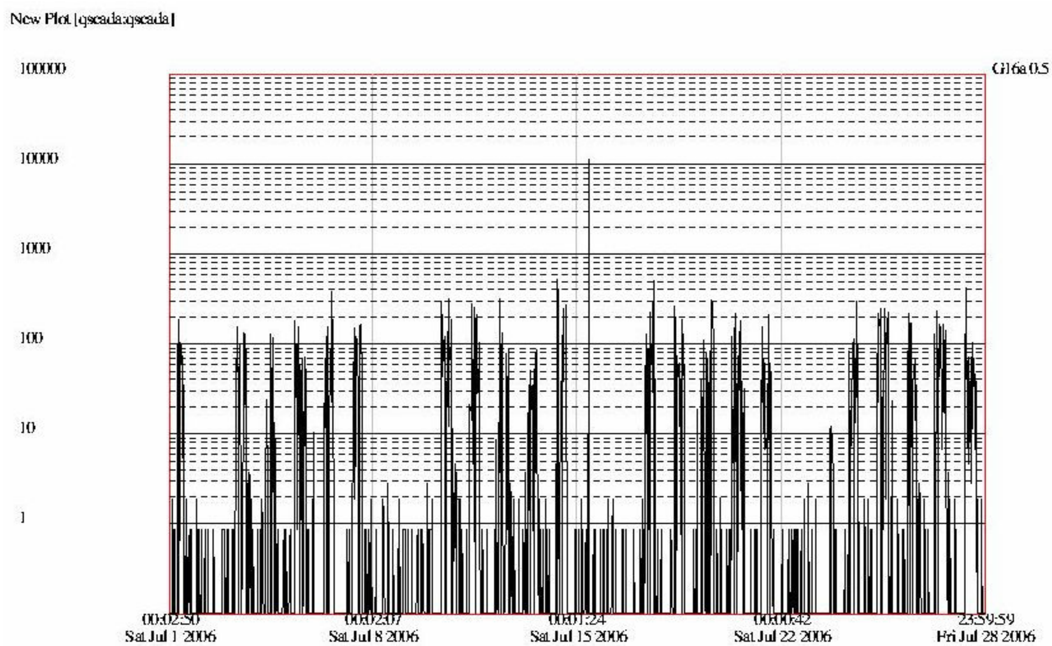

Figure 14: Particulate count in the Class 100 areas.

6.3.3. Vibration

An unexpected problem that manifested itself during production was that of vibration. Due to the narrowness of the pads used for bonding the H&K 710 machines were working at the limit of their resolution. Minor vibrations in the floor could cause an enhanced failure of bonds – or of weakened bonds as shown in Figure 15.

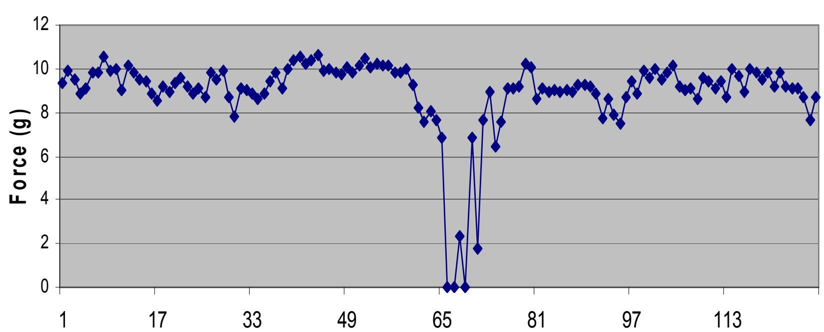

Figure 15: Wire bond strengths on the front-end of one chip. The weak bonds correspond to a period of vibration

During the production period the building opposite the Oliver Lodge was suffering extensive severe renovation that produced large 10μm or greater excursions in the positioning of the bonds.

In order to avoid the time intensive process of repairing bonds it was decided to halt production during periods of vibration. Although sometimes these were easy to spot visually, a vibration sensitive device was installed to monitor, log and give an audible alarm when vibrations were detected.

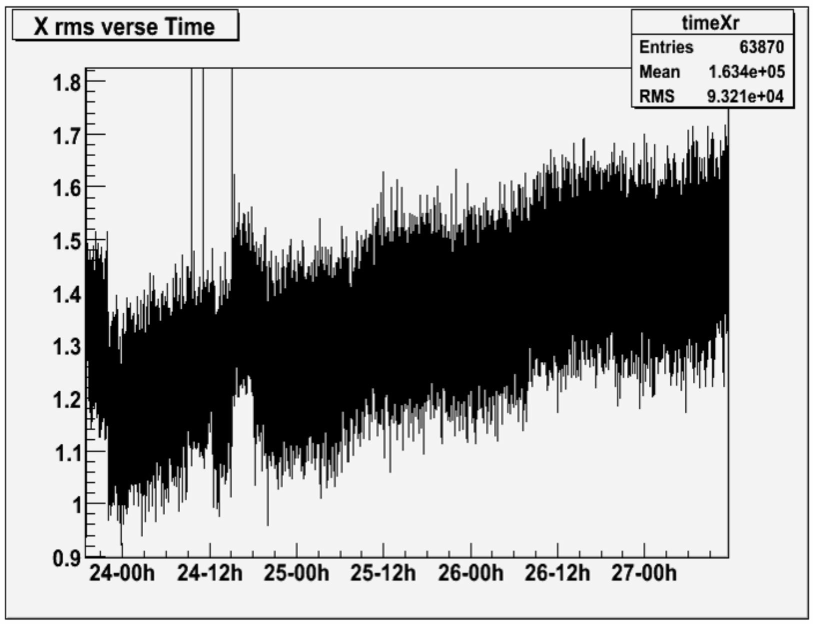

Figure 16: A display from the vibration sensor (Mac Notebook), showing a step which signified a period of vibrations in the clean room.

The cheapest device available was the 3D motion sensor on the Mac notebook, which could also display and record activity, an example is shown in Figure 16. The Mac was placed on the floor of the clean room and was visible to the bonders. In periods of activity (visible at the most sensitive scale of 0.02g) bonding was halted.

7. Particulates

The identification of sources of contamination on the VELO modules was not trivial. Whilst every effort was made to limit and eradicate all possible contaminants this proved impossible. One difficulty lay in that the observation of contamination depended on visual inspection and whilst this was done many times, for example on receipt of sensors, during assembly and on checkout these inspections focused mainly on the observation of different kinds of problems. No systematic evaluation measurement of debris was made.

7.1. Particulates external to LSDC

Despite the lack of quantifiable results on particulate contamination some general remarks can be made. First it was clearly observed that there was contamination on many "clean" components on receipt at Liverpool. Components such as the sensors and ASIC chips were only opened in the Class 100 area and could not be contaminated from exposure to a non-clean environment.

In particular the sensors were opened and immediately inspected. Many small white specks could be observed (at a rate of ~ 1cm2) and we would contend that this was contamination from the manufacture. Typical contamination on a sensor is shown in Figure 17 and that on a chip Figure 18. This could not necessarily be blown off using a N2. These particles have been seen on reception when parts arrive from Stevenage and Hawk On close inspection they appear to be sponge like and some seem to be tacky.

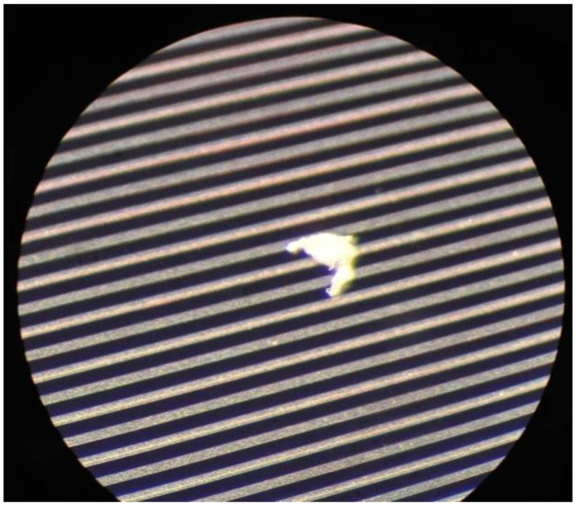

Figure 17: Contamination on a sensor “out of the box”

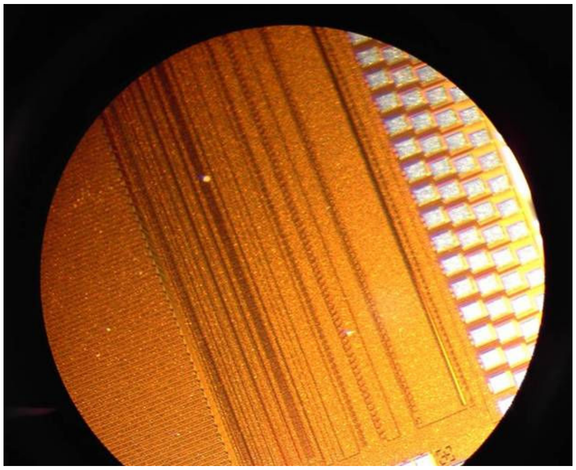

Figure 18: Contamination on a chip out of the box.

7.2. Strands

Another class of contaminants manifest themselves as strands, both fibrous (Figure 19) and sometimes translucent (Figure 20). Although it cannot be stated categorically it is believed that these emanate from work in the LSDC.

The strands themselves are peculiar in that close inspections shows them to be neither bond wire nor hair. One postulate is that they could be strands of glue produced during the gluing (or repair) process. Figure 21 shows (an unusual) case where glue has spread over the pads of a pitch adaptors. Bonding is only possible if this is removed. This can give rise to particulates or strands.

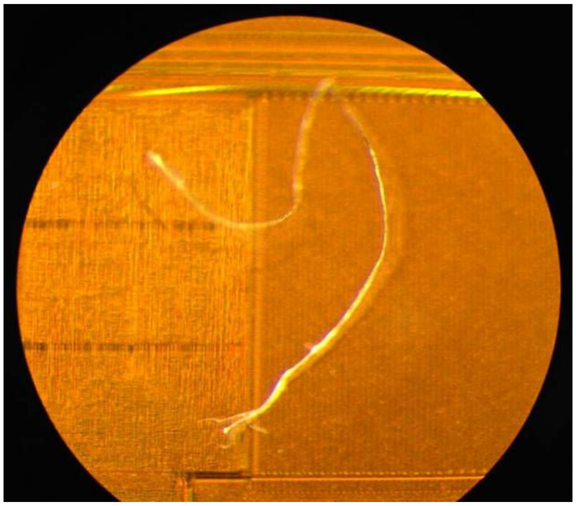

Figure 19: Fibre observed in a chip.

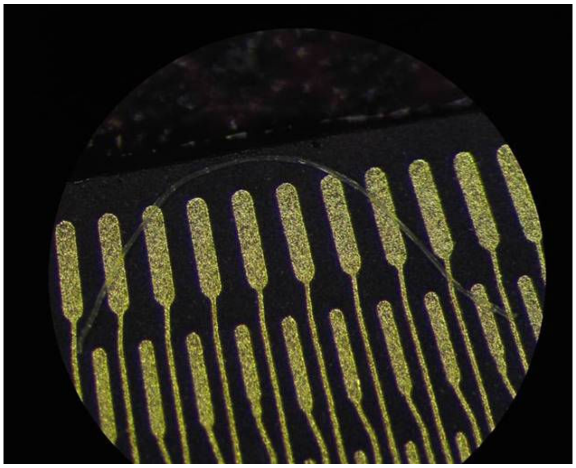

Figure 20: Translucent strand on a pitch adaptor

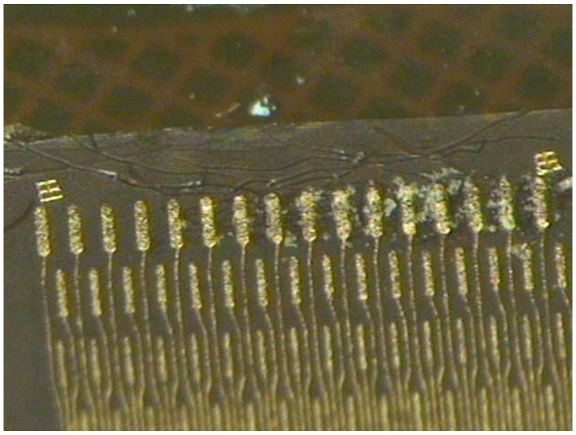

Figure 21: Glue on a pitch adaptor. Removal of the epoxy can lead to contamination.

7.3. Clean Room Wipes and Swabs

An important source of contamination is believed to have been the original clean room wipes and swabs chosen for the LHCb production. These were all chosen to be Class 100 compatible. However closer inspection of the original wipes (see Figure 22) showed that there were fibres similar to some of those observed on the hybrids present on the wipes. These were non-woven wipes made from cellulose added to a polyester foundation (Cellulose – 55%, Polyester – 45%). These wipes were removed from the Class 100 area and subsequently only used for "pre-cleaning" in the Class 10000.

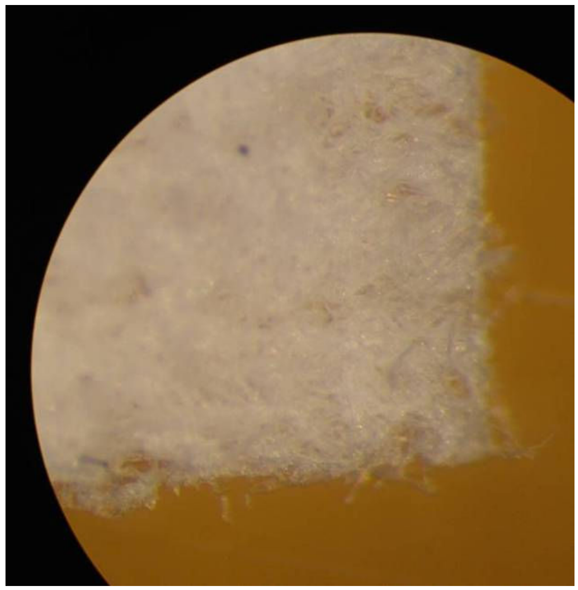

Figure 22: Photograph of original Class 100 wipes. These showed fibres at the edge.

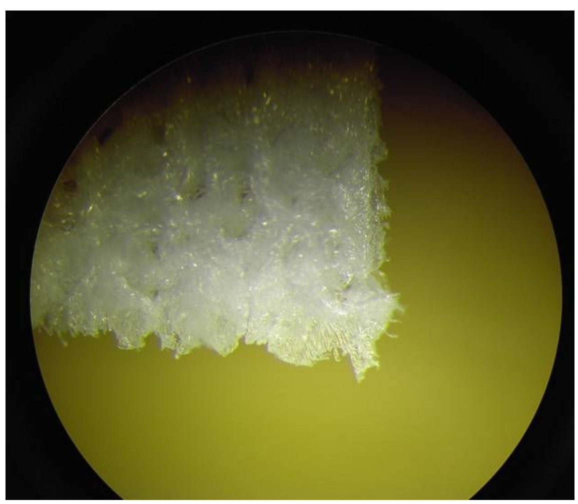

Figure 23: Photograph of the current Class 100 wipes

The wipes were replaced by a new brand of Class 10 compatible wipe which were found to shed substantially less than their predecessors. (See Figure 23) These wipes had their four edges cut and sealed by ultrasonic method, to prevent linting and scratching. They were 100% continuousfilament double knitted polyester wipe. In addition they were also processed and packaged in double bags in a Class 10 clean room.

Two types of swabs, the cleanest of their kind were selected; typical use included placing chips and removing contaminants. The first was the “TX757B2” flexible head paddle with a compact handle. See Figure 24. This had a Micro clean foam of 100 pores per inch and was composed of an open cell polyurethane foam. This was observed to only generate very low levels of non volatile residue and particles. The second type of swab also used was the TX741B semi-rigid head paddle, compact handle swab. See Figure 25. On the TX741B the heads are thermally welded on to polypropylene handles without any contaminating adhesives. These are the cleanest foam swabs available.

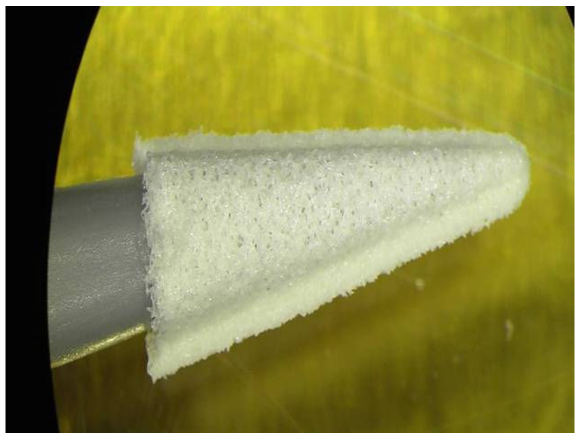

Figure 24: Photograph of TV757B2 swab.

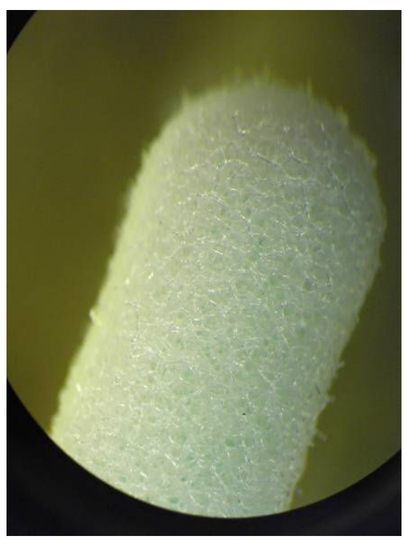

Figure 25: Photograph of the TX741B swab.

Further research into suitable swabs resulted in a type sourced from the U.S.A. This product being Constix SP-5 shown in Figure 26, the head being constructed from a sealed polynit polyester cleanroom fabric (similar to that used in C10 polyester wipes). These swabs were found to produce exceptionally low residue and particulate levels, and were ideal for applications of critical contamination sensitivity and use with harsh solvents.

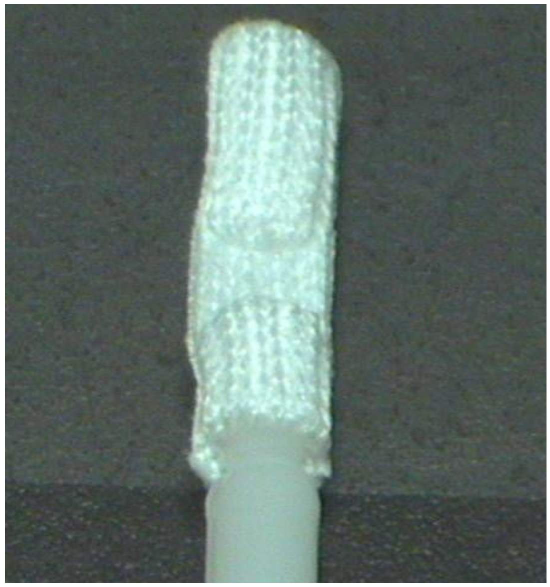

Figure 26: Photograph of the Constix SP-5 swab.

7.4. Particulates generated by personnel

Personnel are the major source of particulate contamination within the cleanroom, releasing skin, hair and other substances. The airborne dispersion rate from people varies from person to person, the greater their activity the more particles they disperse. Dispersion is dependant on the clothing worn, but can be in the range of 10^6 to 10^7 per minute for particles $\geq 0.5\mu m$, i.e. up to10^{10} per day. People may disperse particles from:

- Skin (approximately 10^9 skin cells per day)
- Mouth and nose (sneezing 10^6 particles)
- Clothing worn under cleanroom garments

The cleanroom clothing is intended to minimise substances released from the wearer's body from contaminating the environment. Although the dress code (see section 3) was strictly enforced, other factors had to be considered in order to keep particulate contamination to a minimum:-

a) Activity

- A motionless person can generate about 10^5 particles ≥ 0.5 µm / min.
- A person moving head, arms and body can generate about 10^6 particles ≥ 0.5 µm / min
- A person walking can generate about $5 x 10^6$ particles ≥ 0.5 µm / min.

b) Correct positioning of the operator to prevent particles or fibres falling directly onto the product (making sure they are not directly between the flow of clean air and the product)

c) Due consideration given as to how products are moved or manipulated. i.e. 'no-touch' technique (use of tweezers and vacuum pens)

Other contamination in the cleanroom was attributed to the equipment itself and work related activities, typical particle sizes ranging from 0.5µm to 300µm.

8. Summary

Substantial care was made to ensure a stable and clean environment for LHCb production. This included careful operation and monitoring of the clean rooms. The main production areas had strict rules imposed on their usage to ensure minimum contamination of the modules.

9. References

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