# QUALITY ASSURANCE FOR THE CONSTRUCTION OF THE BCAL[1]

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## Abstract

The quality assurance plan for the construction of 48 production modules for the GlueX Barrel Calorimeter is laid out herein. Details are provided on procurement and inspection of materials, construction methodology and procedures, document control and quality records.

[1] This document was created by updating the procedures and streamlining the text in two part documents and merging them: 'Quality Assurance and Acceptance Plans for the GlueX Barrel Calorimeter Project' and 'Quality Assurance for the Construction of the BCAL', GlueX-doc-1372.

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# Preamble

The methods of material preparation and matrix build up, which have been developed during the extensive R&D phase (2002-2006), resulted in good matrix uniformity for the first two full-scale Prototypes (1 & 2). In early October 2009, a third, full-scale prototype was completed. This module, termed 'Construction Prototype' (CP), followed the 'Mayan Pyramid' design of the second full-scale prototype, although with four steps instead of the previous seven. Procedures were not adhered to throughout all phases of the Construction Prototype's build, primarily due to inadequate personnel training and supervision. Misalignment errors during construction were compounded and resulted in the produced matrix having regions of non-uniformity.

As a result the construction procedures and quality control at all construction steps were completely overhauled. The new procedures were applied to the last 40 layers of the CP producing a uniform matrix, and also for all production modules constructed thus far (12 at this point in time). Additionally, an important correction ('patch') technique was developed and proven successful in the unlikely occurrence of that type of misalignment in the future.

Student labour for the first year of construction had been secured and recently also for the second, in a manner allowing continuity with already fully trained and experienced students staying on. New students undergo rigorous hands-on training, in addition to becoming familiar with our construction manuals, developed procedures, and training video.

# 1 Scope

The quality of a finished BCAL module is judged on two separate criteria.

1. First is the dimensional uniformity in meeting the stated objectives of all the geometric characteristics of the BCAL. To achieve this goal, quality control is required in all construction steps: lead processing, fibre handling, gluing, lay up of fibres and lead sheets and alignment checks.
2. Second is the optical quality of the BCAL, which reflects the quality control of the SciFi's, as well as the machining and polishing of the BCAL read-out ends.

The construction steps, procedures and quality control in accepting/rejecting materials and/or matrix layers, as well as the overall quality assurance (QA) are overviewed herein, with details presented in separate documents.

## *1.1 Key components to control and the methodology to be followed*

### 1.1.1 Fibre QA

The response of randomly selected Kuraray SCSF-78MJ (blue-green) scintillating fibres from every production shipment measured. All canes are subsequently inspected for length and visual imperfections during fibre sorting. The uniformity in diameter, spectral response, effective attenuation length and number of photoelectrons are extracted and reported to JLab and Kuraray, as per the Statement of Work (SOW). If the fibres meet or exceed the specifications, as laid out in the contract with the vendor, that lot from the same pre-form will be used for matrix construction. If the number of rejected canes exceeds 1% of the lot, the lot will be rejected and returned to the vendor with a record of the canes that failed minimum length and/or visual inspection.

Specifically, the objective is to evaluate whether the principal characteristics of Kuraray SCSF-78MJ scintillating optical fibres, namely the uniformity in diameter, the produced spectral shape, the effective attenuation length, and the light output in terms of the number of photoelectrons measured, meet GlueX specifications so that the fibres can be used in the construction of BCAL modules*. The contract specifications are summarized below.

1. *Diameter*: Dimensional uniformity of the diameter is specified at 1mm with a RMS<2%.
2. *Spectral shape*: The spectral shape is required to fall in the wavelength range of 430-550nm.
3. *Effective attenuation length*: The bulk attenuation length must be greater than 300cm when measured with a bi-alkali photomultiplier tube and with RMS<10%.
4. *Light output*: The GlueX Collaboration quantifies this as the number of photoelectrons (pe) collected at the fibre's end and must be greater than 3.5 pe and with RMS<15%, using a bi-alkali PMT at 200cm from the source.

The quality assurance for fibre testing and acceptance is comprised of several steps.

1. *Shipment receipt and inspection*. Each shipment received is inspected for damage to the exterior of the wooden crate. If any significant marks, gashes or breaks are noted, photographs are taken. Otherwise the crate is opened and the interior is inspected and photographed if anything appears out of the ordinary. Next, the cardboard boxes are counted and

* Other parameters were cladding thickness, time structure of the scintillation light and base material components, but these were not evaluated and thus not reported herein.

their labels checked and compared to the shipment information provided by the vendor. All this information is recorded in a logbook and in our electronic Log (Elog), and communicated to JLab and the vendor.

2. *Fibre testing for attenuation length*. Fibres a randomly selected for testing in the attenuation length station, where they are coupled to a photodiode, readout by a picoammeter, as described in a separate document[2]. If their condition does not meet expectations, this is recorded and reported as in Step 1. During data acquisition the operator notes deviations from the expected intensity and exponential behaviour and, if observed data is re-measured then or the next day following the, more detailed, offline analysis. Data and observations are recorded in Excel sheets, in the 'attenuation' logbook, the Elog and a password-protected web site, and reported to JLab as per the SOW.
3. *Fibre testing for number of pe*. The same fibres tested in Step 2 are moved over to the photoelectron station (in the same lab) and coupled to a PMT readout by a data acquisition system, as described in a separate document[3]. The operator runs an online script that provides graphical feedback on the quality of coupling to the PMT. If the requirements are not met, the fibre is recoupled up to 4-5 times. If all is ok, data is recorded, analyzed overnight, and inspected the next day. Data and observations are recorded in ascii files on a computer and backed up on another, in the 'phototelectron' logbook, the Elog and a password-protected web site, and reported to JLab as per the SOW.
4. *Fibre diameter measurements*. At the photoelectron station, the diameter of a few fibres (typically 30) is measured using a micrometer caliper. Data and observations are recorded in an Excel sheet, in the 'phototelectron' logbook, the Elog and a password-protected web site, and reported to JLab as per the SOW.
5. *Fibre usage in the builds*. Based on the evaluation of the first five shipments, the fibres meet contract specifications, but clear variation from batch to batch and shipment to shipment exist. The Regina measurements track with those from Kuraray, lending legitimacy to the findings. As a result, the fibres were grouped into two coarse categories, termed A and B, based on their attenuation length. Specifically, Caterogy A is composed of Shipments 1-3, totaling about 100,000 fibres, exhibit lower attenuation length as a group in comparison to Shipments 4-5 that also total 100,000 fibres and form Category B. Fibres from a single category in the build of each module. It should be noted that the number of photoelectrons does not exhibit any strong dependency, although patterns are observable as well. Feedback was sent to Kuraray and they informed us of a second dopant change following Lot 83, in Shipment 3. The next eight shipments exhibited similar (to shipments 4 and 5), high attenuation length numbers, and continue to satisfy specifications.

The fibres are stored in their crate in the Detector Lab until acceptance of that shipment is confirmed, and then they are moved to the Construction Lab for use in the matrix building.

### 1.1.2 Press Leveling and Base Plate Alignment

To assure dimensional uniformity of the matrix, the two press tables need to be level and their upper frames and locking links square, when in the 'press' position. Both presses have been leveled carefully, achieving a table height variation of no more that 0.004" across their surface. Each aluminum base plate with its cold-rolled steel bars must be machined perfectly flat to avoid 'crowning'.

The relative position of the matrix with respect to the aluminum base plate is a critical in starting the build correctly, since it defines the centreline of the module in the mounting frame. The relative position of the matrix with respect to reference points on the plate define the precision with which the BCAL modules can be mounted and assembled to complete the BCAL cylinder.

### 1.1.3 Lead Sheets

Lead swaging is one of the two critical operations in ensuring a uniform build of the matrix. Past errors, resulting from not following established procedures, have identified that: a) lead sheets were used in the build that did not have an integral number of grooves all parallel to the long edge of the sheet, meaning that grooves vanish from one edge and appear on the other side, and b) one lead sheet had a kink or similar deformity lead to a change in direction from that parallel to the long axis of the module.

As a result of this experience, the Swager was inspected, its table adjusted, and, most importantly, the procedures were overhauled and improved. This included a re-training of all students in swaging, tagging, and recording, and swaged sheets are coiled and now tagged and separated into perfect ('P'), 1-groove off ('1-off'), and scrap (anything more than one grooves off or having any other structural deformity). The step-by-step procedures are provided in a separate document[4]. The students now alert the Construction Manager to inspect every sheet that does not comes out perfect or 1-off. A custom-made brass gauge was constructed to facilitate the thickness measurements of swaged sheets.

The Pb sheets delivered by the vendor at the specified length and widths are visually inspected for coil straightness. One coil from each width is cut to length in order to verify the quoted number of cuts/pieces by the vendor. The first Pb sheet from each coil is checked for uniformity in thickness and width, with random measurements at various spots along the length and width using a micrometer caliper; the numbers are recorded. A custom-designed brass gauge is employed to facilitate the thickness measurements of swaged sheets. Only if the sheets are within contract specifications, are they swaged, as this is the ultimate test of both uniformity and purity. If swaged sheets exhibit higher than normal curvature (an indication of either thickness or alloy variations), additional, detailed measurements will be carried out. Deviations from contract specifications are handled in a manner detailed in Sections 4 and 6.

Each sheet is cut to 396 cm length and inspected for straightness along its entire length before and after the swaging operation. A) Sheet curvature is usually correctable; otherwise, the sheet is rejected. B) Occasionally, a sheet is damaged in passing through the swager. C) After swaging, a toothpick is run along a groove from one end to the other to classify the sheet as 'P', '1-off' or scrap. The combined rejection fraction A)-C) has been kept at < 2%. 'P' sheets are used for the bottom layers of each Mayan step, then '1-off' sheets off are used near the top of each step. The upper left corner of each sheet is clipped after swaging for identification purposes, as one edge of the lead sheets is consistently thinner after swaging.

***The straightness of each swaged lead sheet is crucial. The sheets must be roughly the same length after swaging (404±1) cm and have perfect or near perfect alignment of all grooves.***

The lead is stored at three locations on our two campuses as well as at Ross Machine Shop (RMS), in protected environments.

1.1.4 Epoxy

Each epoxy shipment is inspected for the condition of resin cans and hardener bottles, and for the expiration date. The arrival dates, expiration dates and lot numbers are recorded.

The epoxy, the quantity used, and its viscosity, are also key components in the uniformity and integrity of the completed modules. The mixture of resin and hardener needs to satisfy short curing times (eight hours) while remaining fluid enough for long enough period of time (during layer building) so that excess epoxy will flow out the ends by the pressing/curing stage.

The epoxy is mixed in a ratio of 100:28 by weight for the resin and hardener, respectively, in ordinary 9 oz. plastic drinking cups. The scale is calibrated daily using standard weights of 100g and 25g, and is zeroed after placing the plastic cup on it. The quantity of the epoxy used during construction can vary from operator to operator, however, the electro-pneumatic press -- that compresses the matrix during the epoxy curing phase -- successfully pushes excess epoxy out of the two ends of the module assuring uniform epoxy migration and coverage.

The epoxy remains fluid enough for 120-150 minutes; the time depends on temperature and humidity. The construction space is climate controlled and the stability has been such that computer recording of the temperature and humidity has not been necessary and only visual inspection and recording of the gauges are carried out during each build. Nevertheless, at the start of each construction shift, a small portion of epoxy from the first mixed batch is kept in a labeled plastic cup as a control reference of viscosity.

## *1.2 Methodology for meeting specifications during construction*

There are two objectives that need to be achieved to assure dimensional uniformity of the finished modules and strict adhesion to dimensional tolerances.

1. The most critical reference of matrix-base plate alignment is the centreline of the aluminum base plate.

A 1-mm-wide and 0.5-mm-deep groove is machined along the centreline of each base plate length and is used as the main reference line. A 1-mm diameter fibre is inserted and glued into the groove to act as a guide for the first swaged lead sheet. This fibre also acts as a restraint preventing the base Pb sheet from “floating” on the viscous industrial epoxy during curing under pressure. The base Pb sheet is surveyed after epoxy curing to verify that it is straight, and if not it is removed and replaced. This method, coupled with the ‘Mayan’ alignment plates and alignment wire and runner system referred to below, assure a matrix build centered on the base plate’s centreline groove.

2. The matrix construction must be kept to tight dimensional controls.

Each lead sheet must be rolled onto the build in a precise manner, so that its grooves perfectly ‘lock’ into place, on top of the fibre layer below.

The alignment of each lead sheet is checked using a 4-m-long piano wire, that at one end is attached to a ring that can slide down an alignment post, while the other end wraps around a second post and is tensioned using suspended weights. The posts are aligned to the centreline groove and the first post has a setscrew to keep the ring in place and the wire just above the build. A high-density polyethylene ‘runner’, which has a comb-like bottom surface that fits in the lead sheet grooves and an optical sight (corrected for parallax) is run along the sheet, just under the wire. This takes 30 seconds, and any deviation from straightness is immediately apparent; in such cases the sheet is carefully removed and repositioned, or discarded if the problem persists.

The matrix height from its aluminum base plate is measured after the curing phase of each build. This is done at 16 points along the length. Deviations from uniformity had been observed in a front/back height difference. Initially, a 180-degree rotation of the module on the press table, partly through the build, compensated for this. Later on, the foam rubber sheet – that was used under the aluminum press plate – was removed, and this effectively eliminated the front/back asymmetry.

The avoidance of `stacked tolerances' is accomplished by laying the swaged sheets alternatively, so as to avoid height differentials between the front and back edge due to a small thickness variation from the swager. The swaged lead sheets have the same corner clipped but are rolled up alternatively from left to right, and right to left. Both types of rolls are dispensed always from the same end of the build, thus ensuring a close alignment on one side with a slightly varying alignment on the other due to small variations in the sheet length following swaging.

- The machining of each module along its long sides, and at the two ends, must conform to the signed drawings in the contract (D00000-01-07-1000 to D00000-01-07-2005).

Custom laminar, aluminum alignment plates (about 1 foot long) were built to ensure each 'Mayan' step is aligned with the centreline of the Al base plate, which guides a straight construction. Four sets of plates were made, each plate being 5cm, 5.5cm, 6cm and 6.5cm wide, so that each set totaled 10cm, 11cm, 12cm and 13cm in width when the plates were placed next to each other. The centreline between the adjacent edges of each set was plumb lined to the base plate that ensured alignment with the 1mm groove in the plate.

***Custom Mayan step alignment plates as well the a post, wire and runner system are utilized to assure that each successive step in the pyramid is built within height and location specifications and that each step will be built with enough tolerance in width to assure that machining of the sides at the* 3.75° *angle will conform to specified tolerances*.**

The matrix build is a multi-step process and tolerances have to be strictly adhered to in each step in order to achieve the desired goal:

1. Both presses must be level. This has been accomplished for both to 0.004" (1/10 of a millimeter).
2. The 1.25" aluminum base (outer) plate must be flat and the guide groove must be 0.54mm deep to allow a firm sitting of the guide fibre. Each plate is machined at Ross Machine Shop (RMS) together with its 'double-spine' support, consisting of cold-rolled steel bars, to ensure these and re-measured at the UofR before starting a build.
3. The guide fibre is glued into the guide groove using optical epoxy. This is straightforward and has not resulted in any issues to date.
4. The first (perfect) lead sheet is bonded to the base plate by judiciously applying industrial epoxy. The sheet's centre groove is aligned and set over the guide fibre. This is also straightforward. The straightness of the lead sheet is checked the next day using a toothpick and a straightedge and wire with posts that are aligned with the base plate's centerline. If the sheet is not

straight it will be removed and the procedure starts again with a new plate. The old plate will be machined to remove the epoxy and can be reused.

5. Epoxy is applied to the top grooves. Its amount is hard to control precisely, but we err on applying more rather the less. Care is exercised to ensure that adequate epoxy is applied to the perimeter of the sheet. The epoxy is monitored for stiffness and the amount used and discarded is tracked. The module is inspected daily to observe the epoxy runoff along its four vertical sides.
6. Fibres are laid in the grooves. We have seen no problems in this step.
7. Perfect or 1-groove off lead sheets are employed, as described in the previous section, laid alternatively to avoid stacking tolerances front to back (accounts for thickness difference between one edge and the other as extruded by the swager) and top to bottom (to account for differences in the swager's rollers/drums). When sheets are straight they roll nicely over the fibres and they are felt 'clicking' onto them. The straightness of each is checked with our posts plus wire and runner system. If not straight, the sheet is removed and repositioned or discarded.
8. The foam rubber and Teflon sheet are no longer used during the pressing; the former was mainly responsible for front/back asymmetries in the builds. A thin polyethylene sheet is used between the matrix and top 2" aluminum press plate, to avoid friction and movement when the plate is laid down. Fettuccini was used at the two ends to block epoxy migration, but is no longer employed. Lead sheets wider than the current layers (e.g. 13-cm wide sheet on the 12-cm builds, etc.) are placed at the top of each build, and this has proven adequate to block epoxy migration and a time saver, thus replacing the foam rubber and fettuccini.
9. The height of the build is measured each day after pressing, at several spots along both of its long edges.
10. Misalignments in any step will face immediate corrective measures or if not possible stoppage of the build until the situation is correctly assessed and a suitable corrective action is chosen.
11. The top (inner) aluminum plate is affixed to the completed matrix using industrial epoxy and a set of custom jigs. No issues are expected here.
12. The finished module is craned off the press, crated and shipped to RMS. We have enacted a contract between the UofR and RMS for the construction of all 48 modules.
13. RMS machines four modules in sequence to the dimensions and tolerances specified in the contract drawings and record the final dimensions into the traveler document. UofR personnel inspect the module and check all measurements. In particular, a gauge designed at UofR is used to check the alignment pin and bushing locations and sizes to ensure that the module can mate properly with its adjacent neighbour during BCAL assembly.
14. Optical testing of the module takes place using digital photographs to inspect the matrix and compare with the logged information during the build.
15. All the information above is recorded in the traveler documents, logbooks, E-log, etc.

All conceivable improvements in our past procedures have been considered and implemented towards the quality assurance of the modules. The crew has been re-trained in procedures and the crucial aspects of the swaging and building have been impressed on them. They have also completed a refresher course in safety.

### *1.3 Quality of machining to tolerances specified*

All aluminum top and base plates are machined to achieve the required dimensions and uniformity in thickness. The machining of the Al base (outer) and top (inner) plates includes the centreline and O-ring grooves. Before used, each plate is thoroughly cleaned to render its surface ready for maximum adhesion.

Machining of each module is done at RMS. The final machining of the Al base plates includes the reference and mounting fixtures, and the top plate includes the O-ring groove. Each machined plate will be surveyed and the exact location of the mounting and alignment will be recorded in the traveler documents and that will accompany the module constructed using these specific plates. Custom gauges have been developed and are used to check the alignment holes on the long edges of each module.

Machining the module to specified length (390 cm) and final polishing of the read out ends has been performed successfully on all three full-scale prototypes and and eight production modules to date. The cutter head at the CNC lathe used at RMS is of a tilting-head type. However, since this head cannot feed, jigs were built to `tilt' each module to 3.75° in order to machine the features on the sides of the aluminum base plates and the O-ring grooves.

We plan to machine 47 modules according to specifications - and install them in the BCAL frame - before machining the last “keystone” module. The latter will be machined to exact dimensions as a result of actual precision measurement of the remaining gap. Nevertheless, errors in construction can stack up and should be avoided at the assembly phase. RMS indexes and records the dimensions of each finished module at six points. Each module will be engraved with a serial number for identification purposes. This will allow the JLab crew to optimize placement of the modules in their cylindrical configuration.

## 2 Responsibilities

All components in the contract related to the modules are considered the responsibility of the UofR, including the assembly frame and Drift Chamber parts, even though these were not explicitly costed in the contract.

The construction of all 48 modules will take place at the UofR facilities. By construction, we mean the actual Pb/SciFi/Epoxy matrix build-up starting from pure lead strips, SciFi canes and epoxy as received from their respective vendors. The Pb sheets will be swaged at the UofR, while the Al plates will be machined at RMS prior to their use in matrix construction.

RMS carried out the machining of all 48 inner and 48 outer plates upfront, in order to save costs. RMS machines the modules, from their "build" state after construction to the specified final dimensions. The completed modules are inspected for dimensional and alignment specifications and for their optical transmission properties. Digital photographs of their two read-out ends are taken to document integrity of the fibres in the matrix and to map the location of any damaged fibres.

The overall responsibility for the QA and acceptance of the modules lies with the UofR group. Any quality problems identified will be resolved by consultation with JLab. Problems that can be rectified by either the UofR or by RMS will be corrected before shipment. Otherwise, he decision will be either to accept the module(s) or incorporate them in the BCAL assembly, with corrective measures taken to either adjust the construction techniques and dimensions of subsequent modules, or to construct new module(s) to replace the defective one(s).

Each module that passes the QA tests is crated and shipped directly from RMS to JLab. This approach reduces module handling and risk of damage by not transporting the modules back to the UofR for optical testing. Deflection tests have shown that a finished module – suspended eight inches from each end – sags by no more than 2mm in the middle. This implies that the modules can be shipped without their double-spine bars, and this why only ten pairs of bars have been acquired and machined. Fourty eight crates will be constructed taking into account rigidity, stability (no tipping over) and loading/unloading. Moreover, the long sides will be trimmed of fibres that stick out the sides as a result of machining. Finally, in order to protect the modules from exposure to light their machined ends will be covered with yellow UV-blocking fliter and a tedlar 'hood'. The latter will be easy to remove and reinsert during inspections by Customs.

# 3 Document Control

JLab has provided the final specifications and signed drawings. Changes, if necessary, need to be agreed upon by UofR and JLab and implemented in revised drawings. Additions or modifications need to be mutually agreed to by JLab and the UofR and funded from supplemental sources.

During the module construction, detailed documentation is kept that allows tracking of used (and discarded) materials, consumables, SciFi lot numbers and their location in the matrix and the environmental conditions during the various stages of each module construction. The documentation methods implemented during the building of the Construction prototype are:

1. Detailed fibre testing, lead swaging and matrix build is recorded in dedicated paper logbooks, one for fibre attenuation length tests, a second for photoelectron measurements, a third for lead handling and a fourth for matrix building.
2. Work summaries are posted in a password-protected electronic log (Elog) available via the web running on a UofR server.
3. Detailed fibre testing, lead processing and matrix build data is inserted into Excel sheets and are available upon request.
4. Digital photographs are taken as additional documentation and made available on the above web sites.
5. RMS logs the final dimensions of each machined module and supplies them to the UofR, tracked by the module's serial number, and become part of the traveler documentation.

All five documentation systems have been employed successfully thus far.

# 4 Procurements

- The aluminum plates were custom ordered, as they were not of standard thickness and length.
- Lead is supplied by Vulcan Resources, as contracted by JLab.
- Fibres are supplied by Kuraray Industries, as contracted by JLab.
- Epoxy is supplied by St. Gobain Crystals & Detectors, as contracted by UofR.
- The UofR acquires consumables as needed.

The epoxy is ordered in batches because it has a finite shelf life. The same is true for the industrial epoxy used to glue the base Pb sheet to the base Al plate. The consistency and viscosity of the epoxies, as well as their setting and curing times is known to us from experience and any abnormalities will result in rejecting the batch; e.g. mixed epoxy is not clear after thorough mixing, excess bubbling, too runny or two viscous immediately after mixing.

# 5 Quality Records

## *5.1 Inspection Records*

The quality assurance and acceptance records are referred to as ***'traveler documentation'***, and will accompany each module shipped to JLab as listed in Section 4, above. The 'travelers' also contain statistics from the build and fibres used therein.

Each aluminum plate and module is surveyed after machining is completed and dimensions are logged in the 'traveler'. Each finished module will be surveyed for conformity to specifications in angles cut, length and alignment. Integrity of the matrix itself will be tested and recorded with digital photography that clearly show any non-uniformities in transmission.

A copy of the 'traveler' and the total labour and materials used for the construction of each particular module will accompany each module. In addition, all documentation will be accessible electronically, as detailed in Section 4.

Additional measurements are recorded but not entered into the 'traveler'. All materials (SciFi's, Pb, Al plates) are recorded according to lot number, shipment number or any other identifying method used by the vendor and the dates the testing took place. All aspects of fibre testing, lead swaging and building are recorded. RMS keeps records of the settings on the module and cutter head and the results of the first measurements after the initial passes of the cutter along the long sides. Any corrections made will be also recorded in the log.

### *5.2 Calibration*

The RMS lathe is calibrated as per their set procedures. The instrumentation that will be used to check and record dimensions is mostly mechanical and is recalibrated at set intervals. The scale used for the epoxy weighing is calibrated using standard weights.

The testing of the SciFi's, on the other hand, requires the use of a spectro-photometer, photomultipliers, photodiodes and their accompanying computerized readout units. The former are tested periodically against sources of known wavelength (calibration LED's and/or UV laser) and a reference SciFi (gold standard) for both spectral shape and number of photoelectrons generated and detected by the photo-sensors.

### *5.3 Personnel Qualification*

The UofR group within GlueX/Hall-D (The SPARRO group) has two faculty members (Lolos and Papandreou) who have been involved in the construction of all BCAL module prototypes so far and who have been trained by the physicists and technicians who built KLOE. A large number of GlueX reports, a training video, and two, refereed journal publications serve as a measure of the group's expertise in module construction and quality assurance and testing methodology. These individuals trained the initial complement of student and technical personnel that will carry on the construction and evaluation.

Mr. Dan Kolybaba, a UofR machinist for over 30 years, is the BCAL Construction Manager. He is an experienced instrument maker and has been involved in the project from its original project definition studies and over several BCAL prototypes. He designed and built the earlier (smaller) press-frames, designed the currently used full-scale press-frame and also designed and built the swaging machine. He is has proven to be an excellent person in checking tolerances, overseeing the construction and correcting any problems early on and in interacting with the personnel at RMS. He oversees every detail of the builds and now trains and supervises the students on all construction tasks. Mr. Kolybaba is also in charge of shipping and receiving.

Dr. Semenov is a Research Scientist in the Regina group. He and Dr. Papandreou train the students in fibre testing and QA by overseeing the results of measurements and determining whether retesting is required by a standard set of protocols.

The technicians and engineers at RMS have long experience in large and demanding projects and are certified to all safety and operational requirements necessary for the machining of the modules to the tolerances and specifications laid out. They machined the long sides of Module 2, the two read-out ends of a 2 m-long module that now resides at JLab, the CP, and eight production modules so far. No major issues of concern have been observed, and minor non-conformities in the first four machined modules were used as feedback to improve processes at RMS.

# 6 Non-Conforming Items

There are two potential sources of non-conformity: optical and mechanical. Non-conformities are reported to JLab and solutions/decisions will be sought by consultation.

- Optical non-conformity arising from vendor-supplied SciFi's will invariably become manifest on the SciFi QA testing. In such cases, the results of the testing will be communicated to JLab and the vendor (Kuraray); this has occurred once, revealing an inadvertent change in procedures by Kuraray. Testing of the production fibres are periodically communicated to JLab and Kuraray. So far, the fibers meet specifications for each batch/lot, shipment and cumulatively.

- Dimensional non-conformity of the lead sheets in thickness, width and length of coils.

- Dimensional non-conformity of machined aluminum plates and final machining of module.

- Mechanical non-conformity is one that results in either deviation from dimensional tolerances or de-lamination. The former was encountered during the build of the CP and lessons were learned on how to avoid it or correct it in the unlikely recurrence; procedures have been revamped as a result. If the module does not align precisely with the centreline groove, there can be a displacement towards one of the long sides; this can be corrected by machining to smaller width with the correct angle. This will necessitate the construction of another module with larger width to compensate, a process that does not involve any major adjustments in the construction process. De-lamination is a catastrophic failure of epoxy related nature and the module must be rejected and replaced. In order to protect against de-lamination during the positioning of the modules, thin Al foil (tape) that has glue on one side and can be wrapped around the modules can be used, a technique employed by KLOE. JLab and the UofR will take such a decision jointly should circumstances dictate.

[2] Fibre Handing at the Attenuation Length Station, GlueX-doc-1372, attachment.
[3] Fibre Handing at the Photoelectron Station, GlueX-doc-1372, attachment.
[4] Lead Handling Instructions, GlueX-doc-1372, attachment.