Degradation of Fibers with UV Exposure and Construction Aspects of the 4m Calorimeter Module

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Abstract

Results from new research on the effects of UV radiation on scintillating fibers, as well as discussion on the production of 4m lead strips and methods of laying fibers during construction are reported. While the overall intensity of the scintillating fibers was monotonically reduced, a small shift in the peak of the transmitted spectra was also observed. Production of the 4m strips of lead went smoothly and, due to a new type of lead being used, most problems observed in the production of the 2m strips were avoided. The various methods for laying the fibers during the gluing stages of construction are now ready for testing in the construction of the first full length (4m) prototype Pb/SciFi Matrix.

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I. INTRODUCTION

The construction of the barrel calorimeter (BCAL) to be used in the *GlueX* detector is an enormous task. The BCAL will consist of 48 4 m-long wedge-shaped modules fit together to form a cylindrical, hermetic detector. Already, two prototype modules, one and two meters in length, have been built and tested by SPARRO at the University of Regina. The next step, taken during the winter of 2004, was to begin construction of a 4m prototype module. To do this, 4 m-long strips of lead had to be cut, swaged and shipped to the Centre for Subatomic Research (CSR) in Edmonton, Alberta, where construction is expected to commence during the summer of 2004. In addition to the difficulty of producing such long strips of lead, suggestions of methods for laying and gluing the fibers, arguably the most difficult aspect of constructing such a large module, were put forth by the SPARRO group. The pros and cons of various methods will be discussed within this report. In addition to the construction of the BCAL, the effect of UV radiation on scintillating fibers was also researched. It is known only qualitatively that the intensity of the spectra emitted by the fibers decreased with exposure, and, therefore, a quantitative investigation was carried out. Such knowledge is important as it may allow the use of previously exposed fibers in the construction of the BCAL, provided a suitable read out system is used that matches the fibers' spectral response.

II. RESEARCH AND DEVELOPMENT ON SCINTILLATING FIBERS

A. Motivation for Further UV Testing

Previous research performed by SPARRO had indicated that exposing scintillating fibers to UV light caused degradation in transmission intensity. The next step was to understand the reason for this decrease in light emission. One possibility was that UV exposure created cloudiness in the fiber, causing a decrease in attenuation length. Another theory was that after exposure, the fibers were absorbing light in different regions, shifting the output spectrum away from the PMT's peak efficiency. Using the Ocean Optics Inc. (OOI) [1] SD2000 spectrometer along with a 480 nm diode, scintillating fibers were exposed to UV light emitted from normal fluorescent room lights while periodically measuring the fibers' output spectra.

B. Experimental Method

The experimental method was consistent with that which was previously used for quality control testing on the 2m fibers [2]. Light from a 480 nm diode was divided into two channels. The master channel passed through a clear reference fiber that allowed us to monitor the stability of the diode. The sample scintillating fibers were placed into the slave channel. Five scintillating fibers and one Bicron light-guiding fiber were chosen at random to be tested. The six fibers were placed parallel to each other on a table and irradiated by leaving the room lights on for long periods of time. During the measurement of the output spectra of the fibers, all room lights were turned off and only lamps with UV filters were on. One by one, the fibers were carefully carried from the exposing table to the testing table and placed into our OOI system.

Data reproducibility was a major concern for our experiment. If the fibers were not coupled into the OOI system in a consistent fashion, it would be impossible to compare recorded spectra from one hour to the next. Furthermore, it had been discovered that small rotations in the reference fiber at the connection point to the spectrometer could change the intensity of the reference spectrum by up to fifty percent. Clearly, a method of precise coupling needed to be developed.

To ensure the integrity of our data two checks were instituted. The first involved placing overlays of previously recorded spectra onto the current, real-time measurement. By comparing the initial and current readout, one can quickly identify obvious coupling problems. The second check involved recording what was deemed a good spectrum, removing and replacing the fiber and re-measuring. If the results were reproducible and seemed reasonable when compared to the initial spectrum, the data was considered valid and saved for future analysis.

C. Results

Data from sixty-four hours worth of exposure were collected in the first attempt at this experiment. In this initial effort, problems with the spectrometer became obvious. A decrease of roughly twenty-five percent in intensity across both channels and increased sensitivity to fiber movement were a result of a build up of dirt in the spectrometer. While the spectrometer was being cleaned, analysis on the collected data began.

The OOI software saves the recorded spectra in a spreadsheet format. All sixty-four hours of data for wavelengths between 400 and 500 nm were entered into a common spreadsheet. Even with the quality control measures, the spectra rarely matched up at higher wavelengths, where intensity degradation was not expected to occur. As a result, the exposed spectra were scaled to match the initial (non-exposed) spectrum in the 480 to 500 nm region, as displayed in Fig. 1. The scale factor was found by taking the ratio of the exposed spectra to the initial. An average factor from the 480 to 500 nm region was then applied to the full spectral range. The results showed a monotonic degradation that was roughly linear.

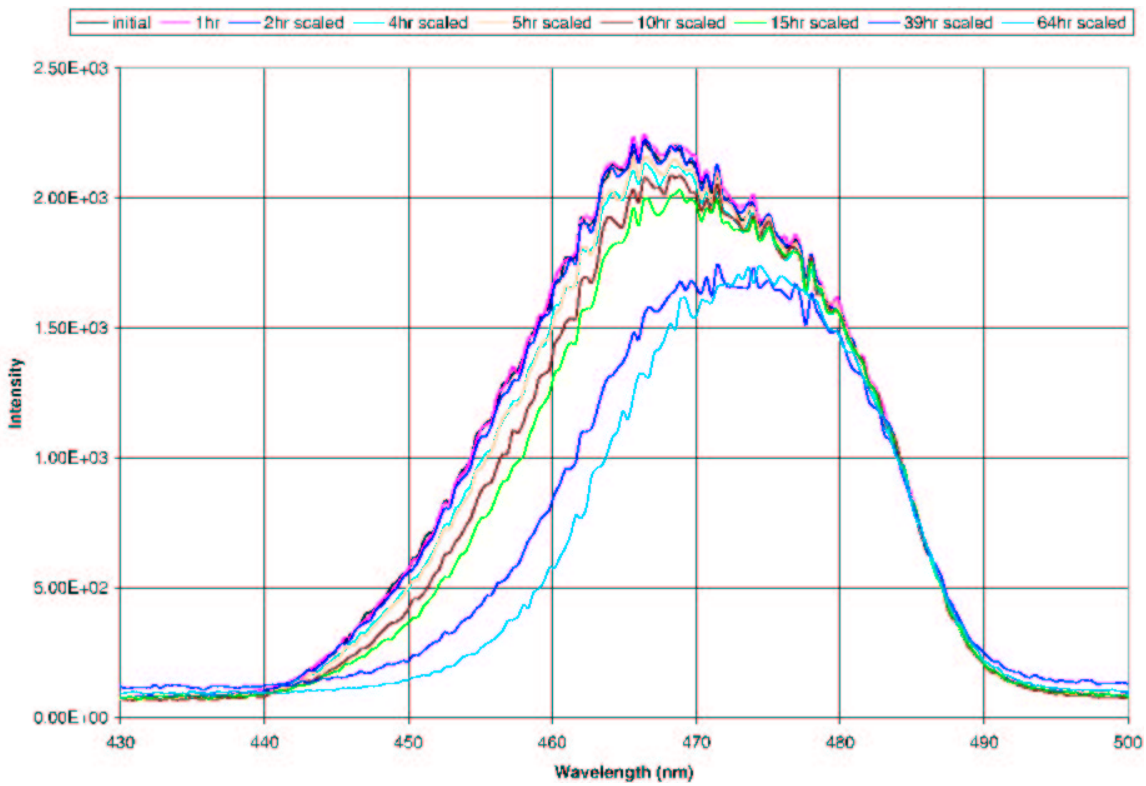

FIG. 1: *Degradation of fiber intensity as a function of UV exposure time. Effects of scaling can be seen in the noise levels.*

Since the PMTs used by SPARRO are most sensitive to the 400 nm region, some intensity loss could be observed due to a "shifting" spectrum. However, a linear decrease in the integral of the spectra was also observed, indicating a true loss of intensity, as shown in Fig. 2. Due to the problems with the spectrometer, the data were sufficient for qualitative analysis only after this set of measurements. In order to collect more trustworthy data, a new approach

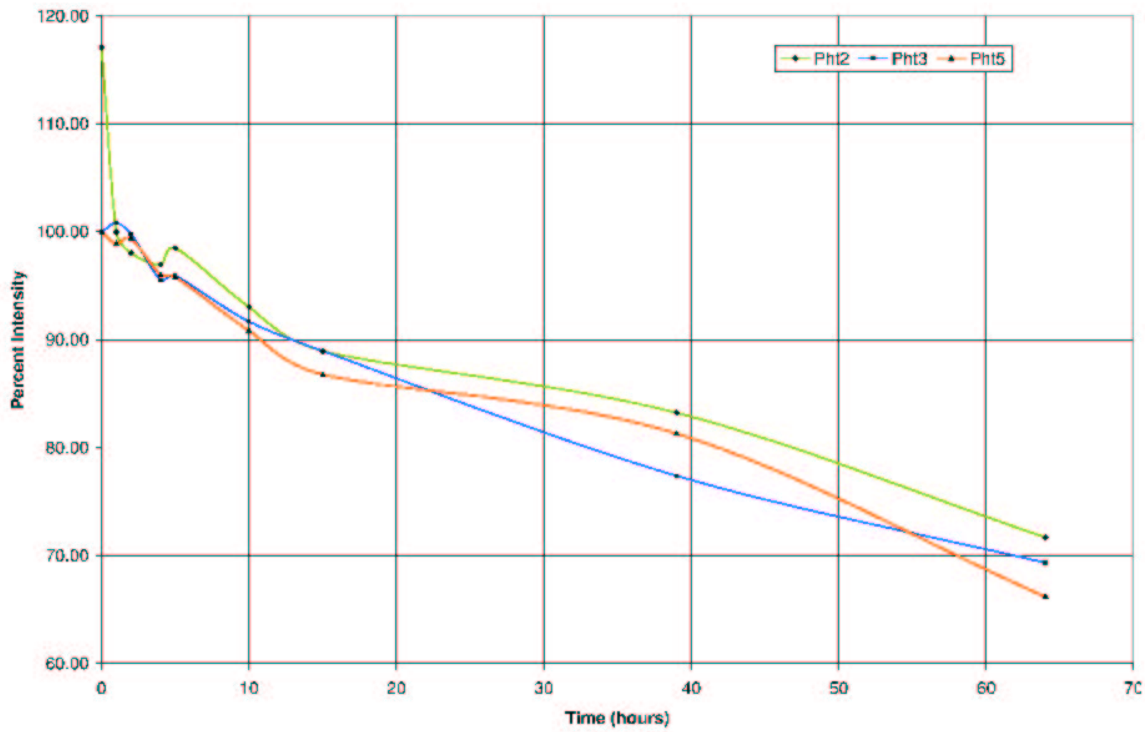

FIG. 2: *Spectral integral as a function of time. An approximately linear relationship can be seen.*

was taken.

With the newly cleaned spectrometer, a method that eliminated coupling as a contributing factor was sought. It was decided to perform the experiment one fiber at a time, leaving it connected to the OOI system even during exposure. One fiber was placed into the system and left unexposed over night. When re-tested in the morning, the results were found to be nearly identical. This gave a degree of confidence in the data to be collected.

As seen in Figure 3, similar results to the first attempt were found, however, a scale factor was not required for this set of data. Unfortunately, the full analysis of this data was not completed in time for publication prior to the end of the authors' workterm but will be completed over summer 2004.

D. Suggestions for Future Research

Many lessons were learned that will help future measurements of the spectral response of scintillating fibers. The first and most important lesson is that data reproducibility is hard to achieve if one attempts to study more than one fiber at a time. While this drastically

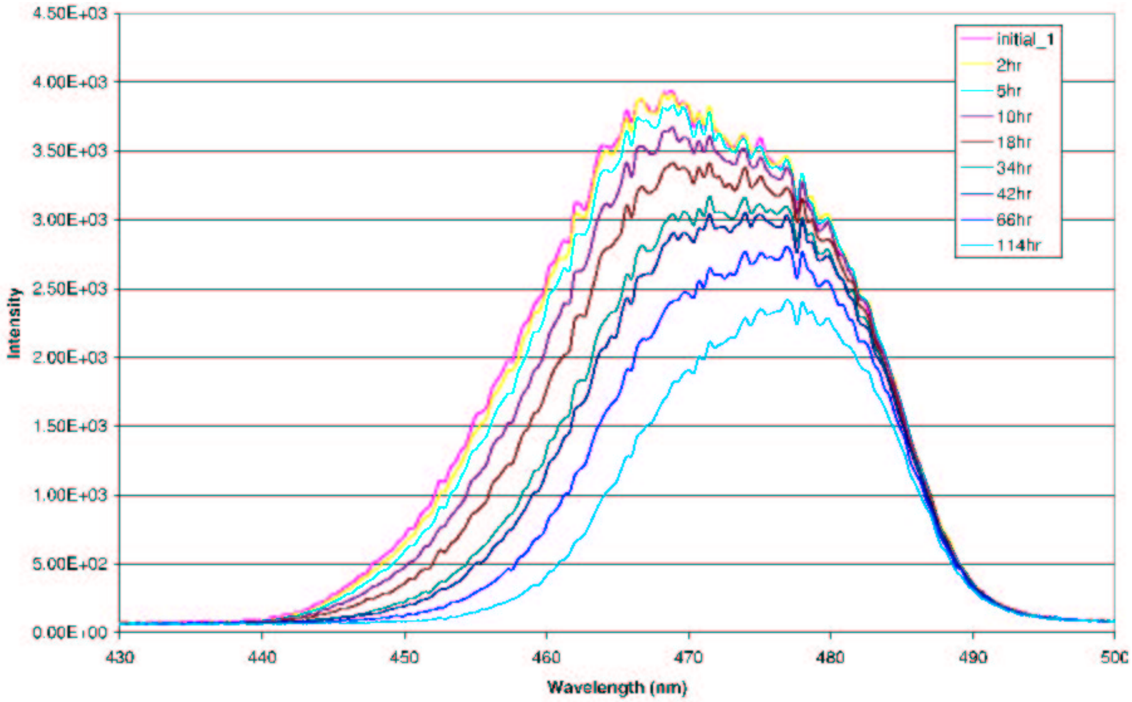

FIG. 3: *Degradation of fiber intensity as a function of UV exposure time. Scaling was not required due to new methodology.*

increased the length of time required to study a group of fibers, leaving one fiber in the system for the entire length of exposure allowed for reproducible, reliable data. Attempting to remove and replace fibers from the system created unnecessary problems with coupling and this should be avoided. The second lesson was concerned with the use of overlays in the OOI software. It is advantageous to place an overlay onto the screen as one is measuring spectra as it allows one to check the integrity of the data in real time. There are two approaches that one may take for overlays. In the first attempt at the experiment, for the current measurement, the previous spectra can be chosen as the overlay. If the current spectra are slightly less intense than the previous ones, they may still be accepted. Likewise, the next measurement may also be slightly less than the current measurement, and so on. This method is not optimal, as it allows one to propagate error through the rest of the measurements. Thus, it is preferred to consistently use the initial spectrum as the overlay and observe that the two spectra match in the higher wavelengths.

With the recent arrival of a UV diode (380 nm), it would be interesting to repeat this experiment to observe how the UV region of the spectra changes as a function of UV exposure time. It may also be of interest to use the UV diode to irradiate the fibers. In addition to further UV damage investigation, the long term effects of cosmic rays on scintillating fibers should be studied to give an idea of the longevity of the barrel calorimeter. This can be achieved by placing a select group of fibers into a tube made of UV filter and measuring the spectra every few months. Due to the extreme length of this investigation, it is not feasible to study one fiber at a time. In this case, plenty of care must be given to ensuring consistent coupling between the fibers and the OOI system.

III. PRODUCTION OF LEAD FOR MODULE CONSTRUCTION

The initial stages of construction for the 4m module calorimeter took place this winter at the University of Regina. The main focus was to produce the needed lead rolls for a module more representative of the length that will used in the barrel calorimeter at Hall D. A total of 240 rolls were cut, swaged and shipped to Alberta where the construction of the module will resume and finish. The testing of this module will commence once construction is complete, probably in July and August of this year.

A. Steps Involved in Lead Production

The production of lead was similar to that of the past modules. Certain procedures were followed each time. It was essential to clean the area and for this a 95% ethanol solution was used. The lead came from the manufacturer [3] on a giant roll. Rolling the lead out from this roll had to be at a controlled pace so that the lead would not be damaged in the process. Initially, there were problems rolling the lead out without creating excess ripples. To fix this, the table was covered in a few layers of heavy black polyethylene to create a smoother surface. In an attempt to smooth the lead out during the rolling process, a smaller guide roller was inserted at the edge of the table. This did not result in a significant difference because the weight of the lead sheet prevented the roller from rolling freely. Once the lead sheet was on the table, it was cleaned with ethanol and flattened. It was then placed under the new cutter, manufactured and designed by the machinist at the University of Regina, and cut to a length of 396 cm and a width of 12.93 cm. The lead was then swaged to have 96 lengthwise grooves on both sides and trimmed to 404 cm. Finally, the lead was prepared for packaging.

B. Quality of Lead

The quality of lead used for this module was superior to that used for the 2m module. The lead used for the 4m module had a lower percentage of copper than the roll used in the 2m module and was consequently softer and easier to manoeuvre. *Bananas* (curved sheets resulting from uneven pressure of the rollers during the swaging process, or from impurities in the lead itself) were a continuous problem with the 2m module. Bananas rarely occurred for the lead used in the 4m module. Out of 240 sheets there were approximately three bananas that were irreversible which implies just over 1% of the lead was unfit for use in the module. If there were bananas after the swaging process, they were easily fixed by aligning the edge of the lead with the straight edge of the table and "massaging" them out manually.

C. The New Cutter

The new cutter implemented for the 4m module consists of two parallel blades, separated by 12.93 cm, attached to a roller on tracks. This cutter greatly reduced the cutting time by making the process faster and easier than the mask and box cutters used in the previous modules. Despite its overall efficiency, there were a few design problems with the cutter. There is insufficient distance between the frame of the cutter and the table; this should be increased so those cutting the lead can properly smooth and hold down the lead. Also, changing the blades of the cutter is not trivial. When taking the roller off to switch the blades, the ball bearings can easily come out. To actually switch the blades requires one to unscrew the metal blocks that hold the blades in position. It is hard to return the blades to their exact position. However, during the entire lead production the blades only needed changing twice.

D. Number of People Involved and Time Required

At the beginning of the lead production, there were concerns as to how many people were needed to carry out the job in an expedient and efficient manner. At first, three people

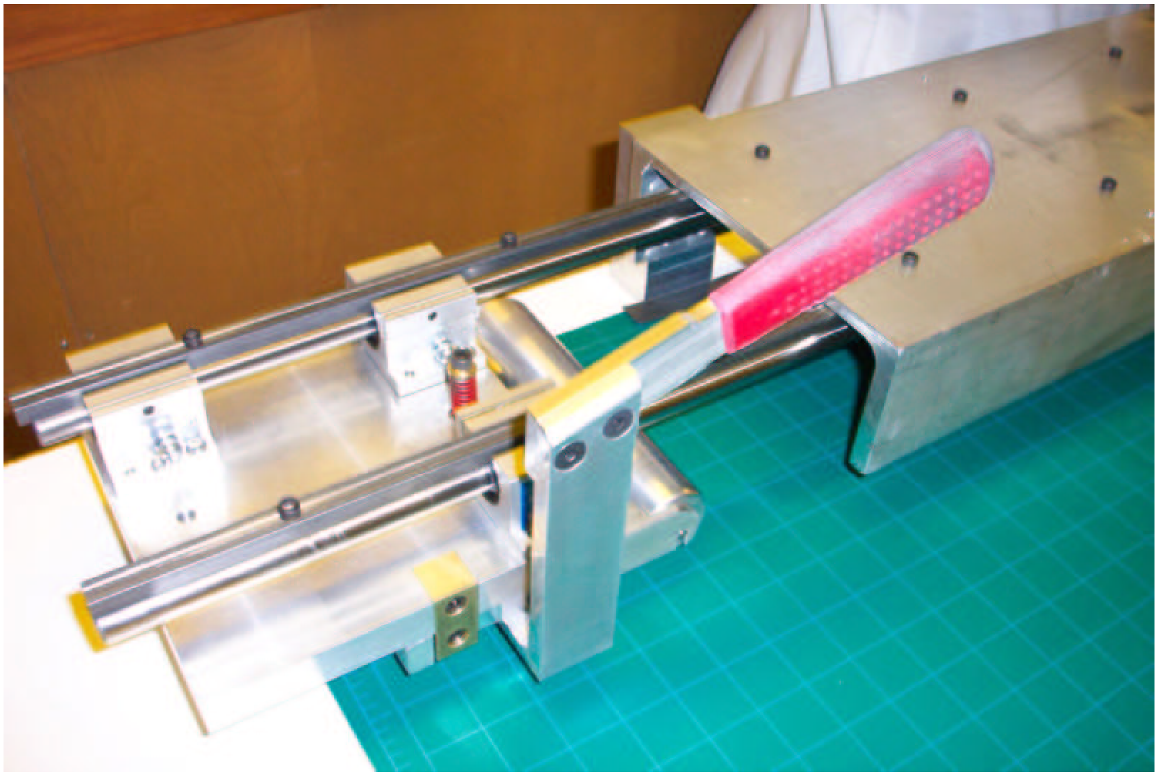

FIG. 4: *The new cutter.*

were needed for the swaging. The first person lubricated the lead with ethanol as it went into the swager, the second lined the lead to the edge of the swager and the third person helped the lead along as it left the swager. Eventually, the person directing the lead into the swager could also lubricate the lead. Therefore, only two people were required but four were optimal, two for cutting and two for swaging. The total number of days required to produce 240 swaged lead rolls was 22. The time required to cut and swage a sheet of lead, where one sheet contains 4-5 rolls of lead, changed with experience. Initially, it took approximately 60 min/sheet or 15 min/roll. Once a rhythm was established, on a good day with four workers, the time had reduced to approximately 9 min/roll with a daily total of about 30 rolls.

E. Packaging

To ensure that the lead would not be damaged in the subsequent shipping process, a packaging procedure was established. It is most important to keep the edges of the lead from bending or folding over. The grooves should not distort if there is a relatively small force applied to them. After swaging, each lead roll was rolled over a hard plastic tube of 7.5 cm diameter. This tube gave the lead needed support. To keep the lead clean during the shipping process, each roll was wrapped in heavy poly. As an attempt to keep the rolls safe from deformations, they were also wrapped in bubble wrap (see Figure 5). However, it was found that over time the weight of the lead deflated the air pockets. To compensate, a hard foam was inserted in the bottom of each crate. Each crate contained 18 rolls of lead and weighed approximately 150 lbs. In total, 13 crates were shipped to the University of Alberta, where the construction of the module will take place.

FIG. 5: *Lead rolls ready for shipping.*

IV. FIBER LAYING METHODS TO BE TESTED

One component of the construction of the 4m module involves laying down the fibers during the gluing process. Since the fiber length has doubled from the last module, there have been a few suggestions on new methods to simplify this process. At this point, only one of these methods has been attempted. The others are still in development.

The first dry (without glue) trial involved placing the fibers on a lead sheet without using any glue. It was soon discovered that the 4m fibers do not cooperate. Not only are they long and awkward, they build up a lot of static charge between each other. The following process required the attention of three people. The fibers were initially placed on a table and it was attempted to straighten them. This did not work well with all the static and braids in the fibers. It was decided to set the fibers directly on the lead and try combing them there. While one person held down one end the other two combed and separated the fibers, starting from one end. It took approximately two hours for all the fibers to be placed into the grooves of the lead. Although this method can be done, it requires a lot of patience and is very labour intensive. It seems as though laying the fibers in the grooves one at a time would be faster and would require fewer people than this method. Adding glue to the sheet may produce yet different results.

A very promising idea for laying the fibers into the grooves relies on a spooling method. This requires all 96 fibers to be placed on a spool which has 96 grooves, one for each fiber. The grooves could be made from plastic annuli of the needed height. The height of the grooves depends on the length of the fibers. Ideally, one could have a kilometer of fiber on the spool. The spool would have a length of approximately 30 cm and an inner radius comparable to the minimum radius of curvature of the fibers. One would have to ensure that each fiber wrapped around and onto itself. At the time of gluing, one could just pull the fibers out and directly lay them into the lead grooves. Two clamps would be needed in this method. The first clamp would be used to ensure that the fibers are pulled uniformly by holding them together. The second clamp is required to hold the fibers in place when the spool is not in use. If implemented, this method would be advantageous because of its simplicity. It is not labour intensive. There are some possible downfalls however. Static could build up between the fibers when pulling them from the spool resulting in the fibers repelling each other. Another issue might be the awkwardness of the spool's dimensions. Overall, this method could make the fiber laying process quick and easy.

The approaches used in past modules could be applied to the 4m module with some minor alterations. The process could start by placing all 96 fibers on an electrically grounded table. This could be done by using grounded copper foil on the table. The grounding process would reduce the static charge between the fibers. While on the table, the fibers could be straightened and clamped at one end. After the fibers are placed on the lead, the fibers could be straightened starting from their middle and going towards one end at a time. This method would require approximately four people. While one person holds the middle down, another holds one end of the fibers up. The third person can straighten the fibers as they go along the length and the fourth person presses the fibers down into the grooves of the lead. After one side is complete, the same process can be applied to the other side. A possible fault with this method could be the amount of time it requires to place all 96 fibers into their respective grooves.

V. CONCLUSION

Many hours were spent studying the effect of UV radiation on scintillating fibers. During this time, a new methodology for testing fibers using the OOI system had to be developed in order to record valid, trustworthy data. Previously, a group of fibers would be chosen to be tested simultaneously, and each repeatedly placed into the OOI system. It was found that this method made it very difficult to reproduce data. The new approach, testing one fiber at a time while always leaving it connected to the system, resulted in very reproducible data. The overall integrated intensity of the scintillating fiber was observed to reduce monotonically to a higher wavelength due to a reduction predominantly at a lower wavelength which naturally lead to a slight shift in the peak ($\approx$ 10 nm). In the future, the experiment will be repeated with a UV diode (380 nm).

With the addition of a new cutting device to replace the aluminum masks previously used to cut the strips, production of the 4m strips of lead went better than expected. The main concern for the 4m lead after the completion of the 2m strips was the banana effect, a curve in the swaged lead. However, due to a new, softer type of lead being used, any curvature after swaging was rare and very easily fixed if it occurred. With some experience, 4m lead strips were being produced at a rate greater than one every ten minutes. When the full scale production begins, it is recommended to modify the cutting device so as to facilitate use.

An unresolved R&D task concerns the exact method to use when laying the fibers during construction. Because of their length and ability to hold static charge, laying 4m fibers will prove to be a much greater task than laying the 2m fibers. The appropriate method for laying the fibers will be determined once the testing of the various methods is finished.

VI. ACKNOWLEDGMENTS

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