Development of a High-Sensitivity Radiation Detector for Chromatography

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Abstract

High performance liquid chromatography (HPLC) is a method of chemical separation often used to separate radioactive products produced by a cyclotron from a chemical synthesis. These products are often used in PET imaging for diagnosing and treating various diseases. Most current HPLC systems utilize only a single detector at the end of the separation column to signal when the radioactive product has passed through the system. Our clients, Dr. Nickles and Dr. Barnhart, request we design a device that can track the position of the radioactive band continuously through the column, report the data to a computer, and provide an audio or visual cue as to the band's progress. We have selected a linear motor system to satisfy the design requirements that utilizes a linear motor with a scintillator-photodiode detection unit mounted on the motor. The motor-detection unit will travel along the axis of the HPLC column and provide continuous data about radioactivity and position. For the remainder of the semester we will begin programming the software necessary, fabricate the required housing, and begin testing the prototype.

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Background

High Performance Liquid Chromatography

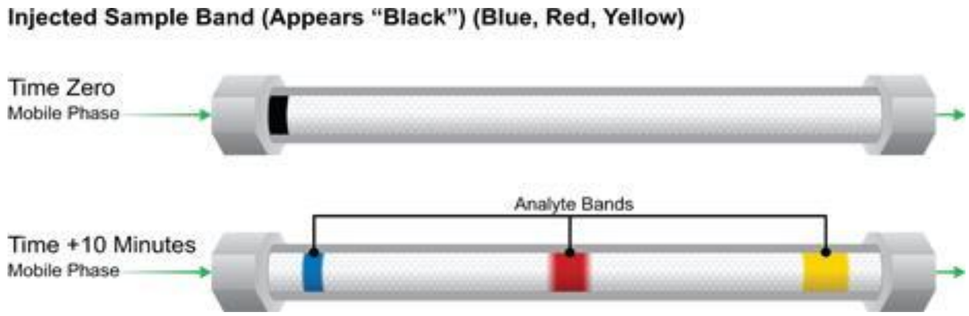

Figure 1: Image depicts the "end of synthesis" chemical entering HPLC, and the separation of species as they pass through the column.

Gamma radiation detection is widely used in conjunction with a process called High Performance Liquid Chromatography (HPLC) for the successful synthesis of radiobiological indicators in the field of medical imaging. Currently, applications of gamma-emitting sources in biological drug synthesis involve complicated synthesis processes with intricate "cocktail" products. In order to isolate the radioactive species, thereby giving a biological purpose to the drug, HPLC is used upon the conclusion of synthesis.

Unfortunately, synthesizing labeled drugs with the ability to emit gamma radiation that can garner valuable biological information is a difficult process. Products of this process often include species that would be more chemically harmful to subjects than the radiation itself. It is for this reason HPLC is required.

In order to separate the valuable radiobiological indicator from the harmful byproducts, HPLC integrates the cyclotron-synthesized radioactive product with a standard background substrate throughout a highly pressurized column, as seen in Figure 1[6]. As the product passes through the lipophilic compound on the inside of the column, product species are separated based on their unique polarities. As species leave the column, they can be directed to either a waste container or collected as product. Through careful calibration, scientists can identify retention times for a wide variety of species and selectively isolate desired products.

Gamma Radiation

The desired radioactive products described above are the biological indicators physicians and researchers use to diagnose disease or highlight certain biological processes. The mechanism used to convey this information is gamma radiation. Gamma radiation is a high-energy result of nuclear decay. With wavelengths often less than the size of an atom, gamma radiation is an ionizing radiation that is imbedded in the excretion of 511 keV photons[1]. This occurs by the process of beta decay within an atom, which releases a positron. The positron then travels one to two millimeters before colliding with an electron, annihilating both, and producing two coincidental (travelling in equal and opposite directions) 511 keV photons[2]. While one typically thinks of photons as nothing more than harmless "light" particles, gamma radiation is so high in energy that it can ionize and destroy strands of DNA. This leads to either mutagenesis or cell death[3].

Medical Imaging

Despite the obviously harmful effects of ionizing radiation, gamma radiation is an effective tool used by modern medical imaging modalities, including Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET). By specifically radio-labeling drugs that mimic those naturally found in the body with minute amounts of radiation, researchers can track concentrations of labeled drugs throughout the body. This is often done to track metabolic processes [4].

Figure 2: A standard PET Scanner

In both SPECT and PET, subjects are given doses of radioactive supplement derived from the HPLC separation process described above, by injection and then placed in a scanner as seen in Figure 2. This process images the body or brain to track the movement of the chemicals. In this way, doctors and researchers can use PET and SPECT for clinical value both in diagnosing diseases as well as monitoring treatment[5].

Design Motivation

Motivation

The most effective way to garner high quantities of radioactive species from HPLC separation is to calibrate the specific drug process with a standard containing non-radioactive supplements with properties similar to those of the radioactivity species. By observing the retention time, or duration of time the species takes to fully separate within the HPLC column, researchers can predict when the radioactive species will be ejected from the column and therefore capture the species most efficiently.

Despite closely calibrated retention times, alterations of the species incurred during synthesis can result in variant retention times. As a result, researchers are often required to closely monitor a single detector located at the end of the column in order to accurately acquire the desired product(s). Even with close monitoring, a passing peak of radioactivity by the detector can occur in a matter of seconds. This event can be easily missed over the entire 10 to 15 minute process. Missing any of this peak can result in inadequate amounts, if any, of radioactive product being collected, demanding the synthesis process be repeated.

The demand for a self-monitoring detection system of radioactive materials throughout the HPLC column is one that has yielded few successful designs. By implementing such a design, researchers and physicians would be able to conduct more consistent and efficient synthesis.

Problem Statement

The Cyclotron Group in the Medical Physics department at the University of Wisconsin - Madison lab routinely uses HPLC on cyclotron-irradiated materials in order to separate the radioactive product from the target stock. During this process, it is important to know when the radioactive band is passing through the column. Various systems are in place to do this currently, but the client requests a device that will detect the passage of the gamma-emitting product throughout the column, record its passage digitally, and send out either an audio or visual cue to indicate the product's progress before leaving the column.

Client Requirements

Regarding the hardware of the device, the detector should detect the peak wave at around 500 nm, the green portion of the visible spectrum. Once the radiation level passes the 10 milliCurie threshold, the signaling system should give a simple, reliable readout accompanied by an audio or visual cue. Since the purpose of the design is to locate radioactive components inside the HPLC column, high position accuracy is required; the device should be able to measure the movement of the components in real time and report its position within a two-millimeter tolerance. The entirety of the device must fit within a lead tube with an inner diameter of 5.08 cm.

Physically, four functional parts are required to achieve the design: a detector, a transducer, a cue (audio or visual), and software for observing and recording the data. The first two must be purchased for less than $500 and fixed together, and the last two will be coded using National Instruments LabView software. The irradiation time of the detector should be at least 1,200 seconds so that it can cover the length of time necessary for completion of the HPLC process. The software should be able to record the data in real time, save the data, and activate the cue device when the radiation level surpasses the threshold.

Existing Devices

There are devices commercially available that measure gamma radiation and output simple and clear signals, but many of these programs are specific to certain scenarios and not optimized for measuring radiation from HPLC columns. For example, the C12137 (pictured in Figure 5) high sensitivity radiation detector module from Hamamatsu is a design that detects gamma rays using a scintillator and an ultra-high sensitivity semiconductor sensor (MPPC). A signal processing circuit, an Analog-Digital Converter (ADC), and a USB interface are included in the device so that measurement of radiation could be shown on a Windows PC easily and with high accuracy. However, this device is not optimized for measuring radiation from an HPLC column for several reasons. First, the device has a relatively large size (111mm by 55mm by 30mm) and therefore would not fit into the 5.08 cm shell. In addition, the C12137 also has a high radiation sensitivity and accuracy, which is not necessary in the HPLC detector design. However, the required position sensitivity is not achieved in this device. Also, the price of this device is over $4000, significantly more than the project budget.

Figure 5: The Hamamatsu C9692 Photon Detector[9]

Figure 3: National Instruments LabVIEW software[7]

The C9692 series from Hamamatsu (pictured in Figure 5) is another photon detection unit that, when connected to a scintillator, could perform high sensitivity photon detection and provide a simple output signal through a USB interface. This design, however, has a large size, which makes it difficult to attach to the HPLC system. Similar to the C12137, it also has a high cost, low position sensitivity, and unnecessarily high radiation sensitivity.

Figure 4: The Hamamatsu C12137 Gamma Radiation Detector[8]

There is also precedence for the use of a large detector array to track high sensitivity radiation through the passage of a chromatographic column. The sensitivity for detection is on the order of nano-Curies. Although this has high radioactive detection sensitivity, it lacks a strong ability to separate peaks[10].

Design Proposal

The design alternatives center around the use of static or dynamic systems and the amount of detectors utilized. Numerous factors were considered including but not limited to: band passage tracking or point-specific tracking, detector size and cost, designs in use, detector sensitivity, and feasibility in programming.

Design 1: Linear Motor

Our first design involved a single scintillator/detector complex mounted on a linear motor or actuator. The motor would move back and forth along the length of the HPLC column at a constant frequency, tracking radiation levels at points specific to the passage of radioactive material through the column as opposed to a single point exterior to the column. The primary advantage of this system is its low cost; a single detector complex coupled with a linear motor will cost far less than the other designs that involve multiple detectors. Also, because the detector moves with the radioactive band, accurate position sensitivity of the radioactive band can be achieved with a low-sensitivity detector utilizing this method. This prevents the need for higher-sensitivity photon detectors, further lowering the cost.

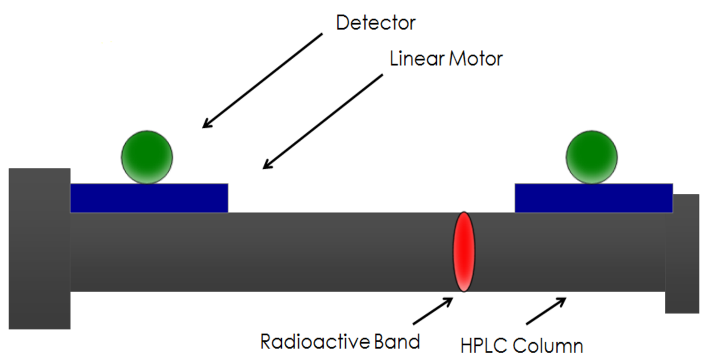

Figure 6: Linear Motor Design

One of the primary disadvantages of this system is that it involves moving parts, likely shortening the lifetime of the device. Unlike the other static designs, the use of a linear motor in this design introduces room for malfunction, but this factor is offset by the low cost. According to the client, at the price they would pay for a device of this design, they could afford to replace it every two years, which should be well within the lifetime of even a low-quality motor. Another potential disadvantage may be the microcontroller programming involved in getting a linear motor to move back and forth at constant frequency.

This introduces a factor of difficulty on the part of the engineers and lowers the feasibility of the design, but this difficulty can be overcome. An additional disadvantage may be the size of the linear motor. With the constraint of 5.08 cm, the inner diameter of the lead protective casing that the design must fit into, it could be difficult to find a linear motor system that thin. However, preliminary research reveals that such motors do exist. Also, even if the motor does not fit, it is permissible to slot the inside of the lead tube to fit the design into the tube.

Design 2: multiple detectors

Our second design is a static system of four or five detector/scintillator complexes mounted on the outside of the HPLC column. The detectors would sense the radiation levels at their respective positions exterior to the column and all of the data could be fed to a computer. In order to utilize point detection specific to the passage of the radioactive band, an algorithm would have to be written that combined the radiation data from each of the detectors and compared the readings against each other to determine, in real time, the point of high radiation output. The primary advantage of this system is that it does not involve moving parts, greatly increasing its longevity and reliability. Additionally, without a linear motor or a large volume of detectors, as utilized in design three, the device would be relatively small, likely easily fitting within the lead casing without rendering any modification necessary. Also, it is believed this design would be the most simplistic from a programming standpoint.

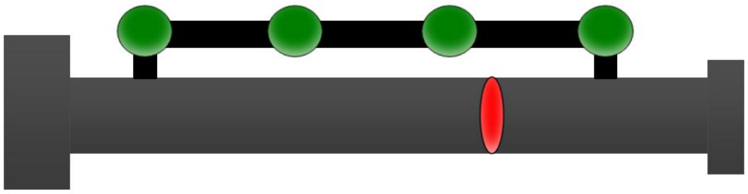

Figure 7: Multiple Detector Design

Creating an algorithm for coalescing radiation data to give position data would be difficult, but is believed to be mathematically well within the ability of the engineers. The primary disadvantage of this system is the high cost. Using multiple detectors greatly increases the cost of the device, especially when that cost is multiplied over the five to ten devices that the client eventually wants produced. Also, more sensitive detectors would have to be utilized in order to track the position of the band because the readings of detectors that are relatively far away from the band must be factored into the position tracking algorithm for it to be accurate, again raising the cost. Even with an algorithm in place, the design will still have lower position sensitivity than the linear motor design because the motor allows a detector to track the moving point directly rather than indirectly through mathematical means.

Design 3: Detector Array

Our third design is similar to the multiple detector design except many more detectors are utilized in an array that would run the length of the column. This design was included because there is much precedence for it in the research we have conducted on radiation sensors as they relate to imaging. However, many of the studies found using this detector array design were concerned with radiation sensitivity, which is not what we are looking for. Due to our interest in position sensitivity, this design is simply not practical as many of the disadvantages for design two also apply here, especially high cost.

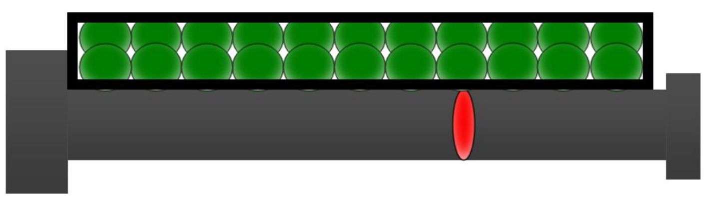

Figure 8: Detector Array Design

The algorithm for combining the data to determine position, although much more accurate due to increased detector density, would be more difficult to implement. In addition, the utilization of so many detectors would make for a very large device as well as introduce increased possibility of malfunction of at least one of the detectors.

Design Criteria

The weight of the categories of the design matrix reflects the best interests of the client and his expectations for the device. The categories, their respective weights, and the rating of each design in each category can be seen in Figure 9. Cost and position sensitivity were given high weight because the client wasn't interested in many of the expensive products on the market that have high radiation sensitivity. Not only was it too much to pay, but he was not even interested in radiation sensitivity because the passage of the radioactive band is an event that is clear to even the lowest resolution detectors. Position sensitivity was the goal and is the factor reflected in the design matrix.

Lifetime was given a medium weight because the client was willing to replace and update the devices every two years, but it would be ideal if they lasted longer than that. Size/weight also received a medium weight because although the lead tube presents a size constraint, it can be modified.

Ease of use received a low weight because the client and his research fellows have a high level of technical knowledge, so it was not a large concern. The only ease of use issue could potentially be the programming component of the device, but this is not a part of the device the client should have to interact with, so it is also of little concern. Reliability and safety received low weight because this device doesn't present any dangerous elements such as heavy or sharp objects.

It has been surmised that the device could harbor small amounts of radiation, but the system will be contained in a lead tube, so any human exposure would not only be minimal in amount but highly limited in time. The main issue is the reliability of the hardware, but ordering from legitimate sources and adequate testing will ensure that our final design works when and how it is intended.

Design	Multiple Detectors	Linear Motor System	Detector Array System
Cost (30%)	3	5	1
Accuracy/Sensitivity (30%)	3	5	4
Lifetime (15%)	4	2	4
Ease of Use (5%)	4	3	4
Reliability/Safety (5%)	3	2	2
Size/Weight (15%)	4	2	1
Total	3.35	3.85	2.55

Final Design

Design Selection

As can be seen in Figure 9, the linear motor design was determined to be the most practical for this project. The use of only one detector on a linear motor greatly lowers the cost of the device as well as maximizes its position sensitivity. Although the use of the motor increases the likelihood of malfunction and the size of the device, both of these factors can be compensated for and thus do not significantly detriment the practicality of the design.

Design Development

Our final design, thus far, will utilize a Cesium Iodide (Thallium activated) scintillator that is mounted onto the Hamamatsu S9269 Silicon Photodiode (with preamp). This detection unit will be mounted on a to-be-determined linear motor that will either have a track along the HPLC column axis, or will utilize a linear actuator with the detection unit mounted at the end. The linear motor and detection unit will be attached to the HPLC column via clamps. Because the size of the linear motor is subject to large variability, re-fabrication of the lead shielding outside of the HPLC column may be necessary. The electrical current signal emitted from the Si Photodiode will need to be converted into a signal that can be processed by a computer using an adapter. The last component of the final design is the program interface that will use LabView to plot the activity data with the position data and provide an audio/visual cue.

Fabrication

Final design and Assembly

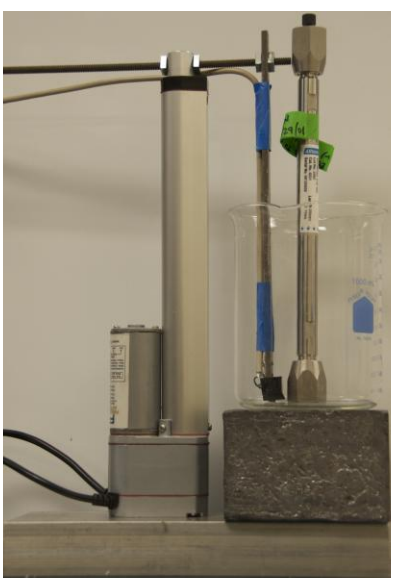

Figure 9: The actuator with arm connected as if scanning the HPLC

As seen in Figure 9. The linear motor is connected to the base and secured with a bolt, providing stability for the whole system. A lead block on the base provides a protective housing for the transport of material after it exits the HPLC column. The block also secures the HPLC column with a slot that the column fits snugly in. The bridge provides the connection between the motor and the detection unit, allowing the motor to exert lift on the detection unit. The detection unit itself hangs down from the bridge, secured by two nuts. The detection unit and HPLC column are housed in a lead cylindrical casing, as seen in Figure 9.

In order to maintain the stability of system, the linear motor was slotted snugly into a solid aluminum base utilizing the flats of the pin on the bottom of the motor. For additional stability, the pin and the aluminum base were threaded for the insertion of a bolt to hold the motor in place. The cylindrical lead housing sits on top of a slotted lead brick, allowing access inside the housing for the “final point” detector wiring and HPLC column tubing. The slot is carved in such a way that the base of the HPLC column fits snugly into the slot with room left on the bottom for leading the tubing out of the housing. A steel bridge was mounted to the top pin of the linear motor, and threaded for stability. Smaller threaded aluminum nuts can variably set the position of the arm relative to the housing.

Material selection

The client required the base to be elegant and heavy enough so as to not allow the structure to tip over. Three conventional materials were considered: polystyrene, aluminum, and steel. A simple calculation showed that the use of aluminum would result in a base weight of about 2.7 kg. Since the weight of the motor is about 1.4 kg, this base weight is heavy enough to combat tipping, but not so heavy as to be overly cumbersome. Polystyrene would have resulted in a weight of about 1 kg, too light to prevent tipping. Steel would have resulted in a base weight of 7.85 kg, too heavy for convenient transport.

Motor and Microcontroller

A Firgelli Linear Actuator Control (LAC) Board was purchased with a Firgelli linear actuator, model FA-PO-35-12-8. Firgelli provided only one option for the LAC, which kept options for the microcontroller limited. The motor was selected based on two factors: cost and length. The 8 inch version was selected over the 12 inch version simply because 12 inches were not required to span the length of the HPLC column. The price for each was comparable so this became a non-issue.

The controller receives power from a wall outlet and serves as the 12V power supply to the motor. The potentiometers in the motor send position information back to the controller through three distinct connections, manually performed by the user. The position data is analyzed by the controller and sent to the computer using a standard mini USB output. A LabVIEW program was available for download to be used with the LAC Board for controlling the movement of the motor and providing a display for the position data.

Testing

<u>Linear actuation accuracy</u>

Control the motor so that it extends and retracts to numerous set positions. These positions will be measured alongside a ruler with accurate length measurements. Once the motor extends or retracts to the desired position, a digital caliper will be used to measure the difference in desired position and actual position. This will repeated five times.

Desired Distance	Actual Distance 1	Actual Distance 2	Actual Distance 3	Actual Distance 4	Actual Distance 5
40 mm	44.5	45.5	38.0	38.5	38.0
80 mm	81.5	81.0	81.0	81.0	81.0
120 mm	123.0	123.0	123.0	123.0	123.0
160 mm	164.0	164.0	164.0	164.0	165.5

Statistic	40 mm Accuracy	80 mm Accuracy	120 mm Accuracy	160 mm Accuracy
Mean (μ)	40.9	81.1	123	164.3
Standard Deviation (σ)	3.76	0.224	0	0.671

After completing the linear actuation accuracy testing, the results suggested that there is some problems with the motor. All of the positions tested were consistently inaccurate by a few millimeters, but all positions did demonstrate good precision. The 40 mm position had an error of 2.25%, the 80 mm position had an error of 1.38%, the 120 mm had an error of 2.50% and the 160 mm position had an error of 2.69%. Although the margins of error were similar for the four positions, the higher positions had a larger average absolute difference in desired and actual position. Our design specifications indicated a desired maximum error of 2 mm and at this time, the motor fails to achieve that accuracy. We believe through calibration of motor using the LabVIEW software, this accuracy can be improved.

Linear actuation speed

Control the motor so that it fully extends and retracts. The speed of the actuation will be set using the control interface. A stopwatch will be used to measure the speed. Once the motor has begun movement, the stopwatch will be started, and once it has been determined that the motor has reached position zero again, the stopwatch will be stopped. The speed will be the quotient of the distance the motor travelled (maximum stroke length) and time necessary for movement. This will be repeated five times.

Desired Speed	Actual Speed 1	Actual Speed 2	Actual Speed 3	Actual Speed 4	Actual Speed 5
10 mm per second	12.5	9.7	11.1	11.1	11.6
20 mm per second	21.7	19.6 (escalate)	21.7	23.2	17.9 (escalate)
30 mm per second	Failed	Failed	Failed	Failed	Failed
50.8 mm per second	Failed	Failed	Failed	Failed	Failed

Statistic	10 mm per second	20 mm per second	30 mm per second	50.8 mm per second
Mean (μ)	11.2	20.82	NA	NA
Standard Deviation (σ)	1.01	2.08	NA	NA

After completing the linear actuation speed testing, the results suggested that there are further problems with the function of the motor. Only two of the tested speeds were functional with the higher speeds failing altogether. The 10 mm per second speed had an error of 12.00 %, the 20 mm per second speed had an error of 3.10%, and the 30 mm per second and 50.8 mm per second both failed. The two speeds that were functional when tested were both recorded manually and the errors do not take into account human error. The limitation in speed is non-ideal, but we believe that with further debugging and calibration, that higher speeds can be achieved. For the final product, the maximum speed of 50.8 mm per second would be ideal.

Future Work

At the time of this paper, the radioactivity testing has yet to be conducted. The first test that will need to be administered is an accuracy test. This test will be used to calibrate the software to make sure that the radioactivity readout is accurate to within 10 millicuries of the actual source strength. A second test will be used to confirm that the detection of the radioactive source falls exponentially with distance. This test is important because it will ensure that radioactive data at two distinct points are not aliasing each other. The last test will be a combined linear actuator – radioactivity test that will ensure that both systems are running in parallel properly.

Another goal is to make the entire system remote-controlled so that it can be controlled from anywhere in the lab. Remote controllers for the Firgelli linear actuator are available for purchase and would be simple to integrate into the current design.

We would also like to improve the software user interface to make it both streamlined and simpler to use. The current LabVIEW interface (derived from the sample code from the manufacturer) utilizes a lot of unnecessary elements and lacks a few features that our team would like to include. In the future, we hope to make this interface simple enough for any member of the Cyclotron Lab to use.

Lastly, we would like to consolidate the design so that it can be manufactured *en mass* for multiple HPLC columns in the lab. This would include building a shell for the motor and its wires that would make the setup more robust and less prone to failure by securing the wire connections, minimizing the size of the base among other components, and fabricating an enclosure to fix the position of the detector to the hood.

References

[1] *United States Nuclear Regulatory Commission : Radiation Basics*. USNRC, n.d. Web. 16 Oct. 2012. <http://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html>.

[2] *Radiopaedia*. UBM Medica Network, n.d. Web. 21 Oct. 2012. <http://radiopaedia.org/articles electron-positron-annihilation>.

[3] Tindall, Kenneth R., Judith Stein, and Franklin Huchinson. "Changes in DNA Base Sequence Induced by Gamma-Ray Mutagenesis of Lambda Phage and Prophage." *Journal of Genetics Society of America*: pag. Print.

[4] *Saha, Gopal B. Basics of PET Imaging. Print.*

[5] *Advances in PET Scanning*. Diagnostic Imaging, n.d. Web. 21 Oct. 2012. <http://www.diagnosticimaging.com/pet-mr/content/article/113619/1877446>.

[6] *How Does High Performance Liquid Chromatography Work? Waters HPLC, n.d. Web. 16 Oct. 2012. <http://www.waters.com/waters/nav.htm?cid=10049055&locale=en_US>.*

[7] <http://www.ni.com/labview/> 2012

[8] [Preliminary] C12317 High Sensitivity Radiation Detector Module, Hamamatsu Photonics K.K., Solid State Division, Mar, 2012;

[9] <http://jp.hamamatsu.com/resources/products/etd/pdf/C9692_TPMZ1010E01.pdf>

[10] Huber et al. *Development of a High Sensitivity Radiation Detector for Chromatography.* IEEE Transactions on Nuclear Science, Vol 58., No. 3, June 2011. Date Accessed:10 Oct 2012

Appendix A: Product Design Specifications

Development of a Miniature Giga-Becqerel Gamma Detector for Liquid Chromatography

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Date: September 19th, 2012

Problem Statement:

The Cyclotron Group in the Medical Physics department at the University of Wisconsin - Madison lab routinely uses high-pressure liquid chromatography (HPLC) on cyclotron-irradiated materials in order to separate the radioactive product from the target stock. During this process, it is important to know when the radioactive band is passing through the column. Various systems are in place to do this currently, but the client requests a device that will detect the passage of the gamma-emitting product through the column, record its passage digitally, and send out either an audio or visual cue to indicate the product's progress before leaving the column.

Client requirements:

- Hardware:
  - The device should detect the peak wave at around 500 um, green area.
  - The device should give simple, reliable readouts, and either an audio or visual cue when it detects an amount of radiation at the peak wave that surpasses the threshold level of 10 milli-curie.
  - The device should be able to measure the movement of the radioactive components in real time and the position of the components within 2 mm of tolerance.
  - Three functional parts are required: detector, transducer, a cue (audio or visual), and software for observing and recording the data. The first three will be purchased, and the last will be coded using LabView (see below).
  - The irradiation time of the detector should be more than 1200 seconds so that it can cover the length of time necessary for completion of the high-pressure liquid chromatography process.
- Software:

- A software component corresponding to the hardware should be programmed which shows the amount of radiation in real time.
- The software should be able to record the data in real time and save as a file.
- The software should also activate the cue device when the radiation level surpasses the threshold.

Design requirements:

- 1. Physical and Operational Characteristics
    - Performance requirements: The device must consist of a detector, a transducer, and a cue device that sense and alert the researcher to the passage of a radioactive band in a chromatographic tube and report this reading to a computer.
    - Safety: It is possible that the components of the device could absorb radiation. Care should be taken to minimize exposure to both the device and the chromatographic tube it is attached to.
    - Accuracy and Reliability: The device should be sensitive enough to detect low level radiation as little as several milli-curie,
    - Being used for scientific purposes, the data acquired from the device must be highly reliable. Specifically, the measurement of the band's position should be exact to within 2 mm and should have a resolution better than 1 second.
    - Life in Service: at least 5 years
    - Shelf Life: N/A
    - Operating Environment: The device will be attached to a chromatographic tube in a research lab and will be subject to potentially high amounts of radiation.
    - Ergonomics: The device should be easy to implement and use. The accompanying software should be easy to understand and learn.
    - Size: the device must fit around the 10 mm diameter column and together with this column, fit into a shell of 5.08 cm inner diameter.
    - Weight: less than 0.5 lb.
    - Materials: detector, transducer, cue device (optical or visual), possibly a linear motor, attachment device.
    - Aesthetics: The device must look professional and simple. It is being used in a research lab so it has to look like what it is: a scientific piece of equipment.

- 2. Production Characteristics
    - a. Quantity: 2
    - b. Target Product Cost: $500

- 3. Miscellaneous
    - a. Standards and Specifications: N/A

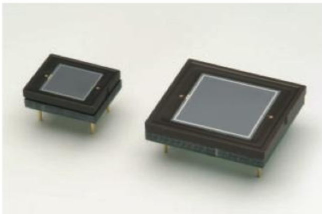
- b. Customer: The client stressed the use of a cueing device to alert the researcher to the passage of the radioactive band. The client also stressed the necessity of a simple readout in real time.
- c. Patient-related concerns: N/A
- d. Competition: The sensors currently used by the lab only detect the radioactive band at one point. They do not track the passage of the band. Products that do this are available, but lack a cue to notify the researcher of the band passage. Current devices that are available and fulfill the functions needed are too expensive and have features not necessary for the clients' purposes.

Appendix B: S9269 Data Sheet

HAMAMATSU

PHOTON IS OUR BUSINESS

Si photodiode with preamp



S9269 S9270

Photodiode and preamp integrated with feed-back resistance and capacitance

S9269 and S9270 are low-noise photosensors consisting of a Si photodiode, op amp, and feedback resistance and capacitance, all integrated into same package with a surface size equal to our standard ceramic packages. These photosensors are ideal for a wide range of photometric applications including analytical equipment and measurement equipment. The active area of the photodiode is internally connected to the GND terminal making it highly resistant to EMC noise. Combinations with various photodiodes such as UV sensitivity enhanced type, IR sensitivity suppressed type and IR sensitivity enhanced type are also available. (Custom order products)

Features

- **Si photodiode for visible to near IR Si precision photometry**
- **Small package**
  S9269: 10.1 × 8.9 × 40 ^{t} mm
  S9270: 16.5 × 15.0 × 4.15 ^{t} mm
- **Active area**
  S9269: 5.8 × 5.8 mm
  S9270: 10 × 10 mm
- **FET input operational amplifier with low power dissipation**
- **Built-in Rf=1 GΩ, Cf=5 pF**
- **Low noise and NEP**

Applications

- **Precision photometry**
- **General-purpose optical measurement**

Absolute maximum ratings (Ta=25 °C)

Parameter	Symbol	Value	Unit
Supply voltage (op amp)	Vcc	±20	V
Power dissipation	P	500	mW
Operating temperature	Topr	-20 to +60	°C
Storage temperature	Tstg	-20 to +80	°C

Note: Absolute maximum ratings are the values that must not be exceeded at any time. If even one of the absolute maximum ratings is exceeded even for a moment, the product quality may be impaired. Always be sure to use the product within the absolute maximum ratings.

Electrical and optical characteristics (Ta=25 °C, Vcc=±15 V, RL=1 MΩ)

Parameter	Symbol	Condition	S9269			S9270			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	
Spectral response range	λ		-	340 to 1100	-	-	340 to 1100	-	nm
Peak sensitivity wavelength	λp		-	960	-	-	960	-	nm
Feedback resistance (built-in) *	Rf		-	1	-	-	1	-	GΩ
Feedback capacitance (built-in) *	Cf		-	5	-	-	5	-	pF
Photo sensitivity	S	λ=λp	0.5	0.62	-	0.5	0.62	-	V/nW
Output noise voltage	Vn	Dark state, f=10 Hz	-	7.3	-	-	9.7	-	μVrms/Hz$^{1/2}$
		Dark state, f=20 Hz	-	6.5	-	-	9.1	-	
Noise equivalent power	NEP	λ=λp, f=10 Hz	-	12	-	-	16	-	fW/Hz$^{1/2}$
		λ=λp, f=20 Hz	-	12	-	-	17	-	
Output offset voltage	Vos	Dark state	-	±4	-	-	±4	-	mV
Cut-off frequency	fc	-3 dB	-	32	-	-	32	-	Hz
Output voltage swing	Vo	RL=10 kΩ	-	13	-	-	13	-	V
Supply current	Icc	Dark state	-	0.3	0.6	-	0.3	0.6	mA

* Custom devices available with different Rf, Cf, etc.

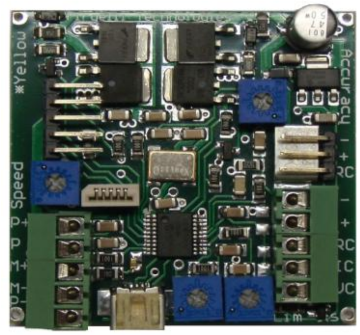
Appendix C Firgelli Lac Datasheet

LAC • Firgelli Linear Actuator Control Board

The Linear Actuator Control Board is a stand-alone closed-loop control board specifically designed for Firgelli actuators. The LAC greatly simplifies designs by saving the development time, cost, and processor overhead associated with direct motor control. As little as 1 digital or analog output is required for position control. Supported input signals include USB, Voltage, Current, RC Servo, and PWM. Firgelli's motor control IC uses a software based algorithm to optimize position and speed control. This makes the LAC compatible with a wide range of actuators, using only the default settings. Firgelli's Advanced Configuration Program allows full customization of actuator response. A stall detection feature provides a great increase in actuator life for applications that may briefly exceed the rated force.

The LAC can be operated as both an interface board, or as a stand alone controller with the addition of an external potentiometer and power supply.

(Accessory kit and housing sold separately)



Specifications

Control input modes	**Digital: USB, RC Servo, 1 kHz PWM** **Analog: 0–3.3 V, 4–20 mA**
Controller	**10-bit Dual Sample Rate Quasi PD**
Compatible actuators	**PQ12 Actuators with position feedback, 6 or 12 volts** **L12–P Actuators with position feedback, 6 or 12 volts** **L16-P Actuators with position feedback, 12 volts** **Larger Actuators such as FA-PO-xxx-xxx, 12 or 24 volts**
Dimensions	**50 mm x 50 mm** (excluding battery holder)
Power	**5–24 VDC, 4 Amps peak current at 10% duty cycle**
Operating environment	**–10 to +70°C at 10–80% relative humidity**

Operation

When the LAC is powered up, it will repeatedly scan for an input signal that is valid under any of the five supported interface modes (see reverse for External Connections Detail illustration). When a valid signal is first detected, the actuator will self-configure to the corresponding interface mode, and all other interface modes and input leads are disabled until the actuator is next powered on. The sensitivity or accuracy of the actuator control algorithm can be set by adjusting the "Accuracy" trim potentiometer. Turning clockwise will allow the actuator to move in smaller increments and be more accurate. However, due to the differences in actuator types this may cause jittery or unstable behaviour. If this occurs, consider using the USB configuration program to more finely tune the controller for your application. Each time a control potentiometer is adjusted, power must be cycled to the LAC board prior to the new settings taking effect. Adjusting the "Speed" potentiometer will set the maximum actuator speed. The two "Limits" potentiometers allow user settable digital limit switches. These set the minimum and maximum acceptable positions. Control inputs that exceed these limits will cause the actuator to position to the limit.

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External Connections Detail

X1 PQ12 actuator connector

5 pin, 1 mm Pitch FPC connector

X2 L12–P/L16-P actuator connector

Pin	*Function*
1	**Potentiometer Reference Negative** (yellow)
2	**Motor Terminal** (black)
3	**Motor Terminal** (red)
4	**Potentiometer Feedback (wiper)** (purple)
5	**Potentiometer Reference Positive** (orange)

X3 Radio control receiver connector

Pin	*Function*
1	**Ground** (black)
2	**Power** (red)
3	**Control** (white)

X4 Large actuator connector

Pin	*Function*
1	**Potentiometer Reference Positive** (white)
2	**Potentiometer Feedback (wiper)** (yellow)
3	**Motor Terminal** (red)
4	**Motor Terminal** (black)
5	**Potentiometer Reference Negative** (blue)

NOTE: If the actuator moves to one end then stops, swap pins 3 and 4 to change the motor direction.

X5 Universal Serial Bus (Male Mini-B)

Pin	*Function*
1	**N/C**
2	**Data**
3	**Data**
4	**N/C**
5	**Ground**

X6 Control interface

Pin	*Function*
1	**Ground**
2	**5–24 VDC Power**
3	**RC / Hobby Servo input signal**
4	**Current input signal** (4–20 mA)
5	**Voltage input signal** (0–3.3 V) or 1 kHz PWM

P1 Speed Control

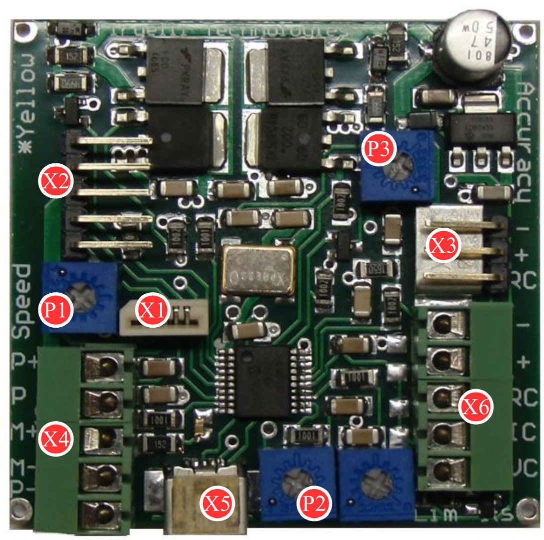
Sets maximum actuator speed
CW Faster
CCW Slower

P2 Limit Controls

Left Potentiometer controls Retract Limit
CW Maximum Stroke
Right Potentiometer controls Extend Limit
CW Maximum Stroke

P3 Sensitivity adjustment

CW Smaller dead-band
CCW Larger dead-band



Connector Pins numbered from Top to Bottom or Left to Right

Control Modes

0–3.3 V Interface Mode: This mode allows an actuator to be controlled with just a battery, and a potentiometer to signal the desired position to the actuator – a simple interface for prototypes or home automation projects. The desired actuator position (set-point) is input to the LAC on connector X6 pin 5 as a voltage between ground and 3.3 V. The set-point voltage must be held on pin 5 to reach and maintain the desired actuator stroke position. The wiper pin of an external potentiometer connects to X6 pin 5. Pins 1 and 5 of X4 can be used as the 3.3V Reference. The other two potentiometer pins connect to these. When a Potentiometer is not used, ensure the control signal ground is connected to LAC ground.

RC Servo Interface Mode: This is a standard hobby-type remote-control digital servo interface, compatible with servos and receivers from manufacturers like Futaba™ and Hi-Tec™. The desired actuator position is input to the LAC on connector X6 pin 3 as a positive 5 Volt pulse-width signal. A 1 ms pulse commands the controller to fully retract the actuator, and a 2 ms pulse signals full extension. Connector X3 can also be used for the RC control signal, and uses the standard 3 pin 0.1" spacing typical on most hobby servo receivers. **Do not connect power to both X6 and X3 at the same time** (If the supply voltages differ, large currents will flow).

4–20 mA Interface Mode: This mode is compatible with PLC devices typically used in industrial control applications. The desired actuator position (set-point) is input to the LAC on connector X6 pin 4 as a current between 4 mA and 20 mA. The set-point current must be held on pin 4 to reach and maintain the desired actuator stroke position.

PWM Mode: This mode allows control of the actuator using a single digital output pin from an external micro controller. The desired actuator position is encoded as the duty cycle of a 3.3 Volt, 1 kHz square wave on LAC connector X6 pin 5, where the percent duty cycle sets the actuator position to the same percent of full stroke extension. 100% duty cycle represents full extension, and 0% duty cycle represents full retraction. This input is 5V tolerant, however the % duty cycle range will differ.

USB Mode: This mode allows control of the actuator using a Computer. In addition advanced settings allow fine control over the controller response. Default settings can be reverted to, using the reset command. When custom settings are turned on, P1, P2, and P3 are ignored. These settings will be saved even when power is cycled. This allows custom configuration for all inputs even when USB is not connected. Details of the DLL are given in a separate document so that custom programs can be created by the customer. An example Labview program is available for download. The Dynamic Link Library(DLL) allows Programming in many windows languages including Labview.