Remotely Controlled Radiation Detection Laboratory for Online Education

CM Marianno[1], A Galindo, G Emery

Department of Nuclear Engineering, Texas A&M University

Abstract

Remote education capabilities make up an important component of an institution's services. A challenge in improving remote education capabilities has been developing experiments for remote laboratory education that mimic the experience found in the traditional laboratory setting. To meet this challenge, a remote laboratory for radiation detection education has been developed for the nuclear engineering and health physics disciplines. The laboratory makes use of robotics for linear and rotational movements that imitate the hands-on motion found in an in-person laboratory setting. Once logged into the system, students have access to industry-standard software and can view the experiment apparatus through a live-time camera feed. The experiments developed for this remote laboratory include counting statistics and dead time, inverse square law, Compton scattering, gamma spectroscopy with scintillation detectors, gamma attenuation, and uranium enrichment determination.

Introduction

Online and distance education courses are becoming prevalent for many university nuclear engineering programs. Telecommunication technology and software have improved to allow better connectivity for students and faculty to participate via distance. These advancements are well suited for lecture-style classes. Through the internet students and faculty can more easily interact with each other live-time. Improved video quality and audio recording equipment are available with editing software to record classes or make instructional videos for asynchronous education. Research has also been done to improve methods for student involvement for distance education formats [Lee et. al, 2019, Kelleher and Hulleman, 2020].

[1] Corresponding author: marianno@tamu.edu

While current collaborative software naturally lends itself to lecture style classes, it introduces challenges in the presentation of distance instructional laboratories. Experimental laboratories are vital in helping students link concepts and theories described in lectures. For instance, in a lecture involving radiation a student can learn about photon interactions, but it is in the laboratory where they can visualize the concepts through gamma spectroscopy experiments. The purpose of this research was to develop a series of remotely controlled radiation detection laboratories for distance education. Using current collaborative software, these laboratories were designed for students to conduct laboratories with as much of an "in-person" feel as possible.

Different methods have been attempted to provide radiation laboratory experiences for distance students. Virtual laboratories (VLs) have been developed for gamma-ray detection (Tlaczala and Zaremba, 2007). Here, experiments were pre-programmed with data from physical experiments into a series of simulations. Students were allowed to vary several inputs that affected results based on deterministic methods. VLs give students the ability to think about the experiments, but they cannot execute them in real-time. Similar to VLs, some instructors have completed experiments over video while students watch and record data (Amendola and Miceli, 2016). This is more limiting than VLs in that students cannot vary parameters, but they at least get to observe the experiments taking place. Unlike these presentation methods, the laboratories introduced in this current research allow students to manipulate apparatus and take data while the lab is running in real-time.

Remotely controlled laboratories have previously been proposed (Kopp, 2011). Research at Clemson University proposed a series of experiments for an online radiation detection course. These labs utilized a host computer with software-controlled equipment to manipulate apparatus and sources to complete experiments. Custom-written LabVIEW programs were created to acquire and analyze data from a multichannel analyzer (MCA). Students could manipulate equipment and software to take data live time, but it required custom-made software for analysis. The current research discussed below introduces a method to complete online laboratories without the need for custom software for acquisition or analysis.

The purpose of the current research was to design an online, automated laboratory that can be replicated at other institutions without the need of custom software. This is accomplished using industry-standard radiation detection software and native applications available on Windows or Apple OS. Procedures have been developed for students to utilize the Remote Desktop application to operate a laboratory host computer to conduct experiments. Through the host computer, students can manipulate apparatus and use proprietary software to complete experiments in radiation detection. This paper will highlight how the system was set-up in the hope that others may develop similar systems at their home institutions.

System Architecture

It was desired to make the system architecture as simple as possible. For each laboratory students needed to connect to a host computer through the internet. The host computer was also connected to a local area network (LAN) which in turn was connected to Ethernet enabled motors and radiation detection systems. Students could watch the laboratory as it progressed with the use of a camera connected to the computer. A simplified block diagram of the architecture is illustrated in Figure 1.

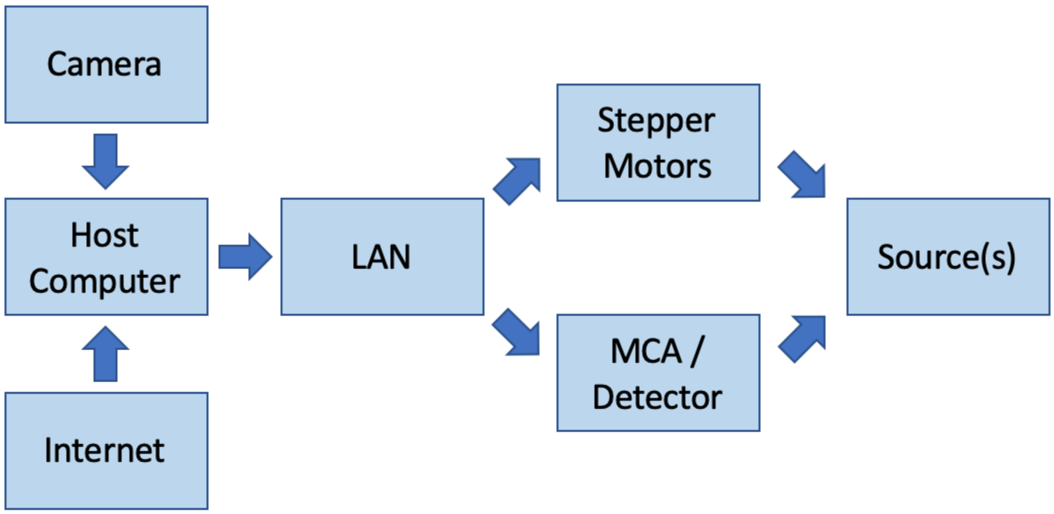

Figure 1. Diagram illustrating the connections for the online radiation detection laboratory.

Host Computer.

The central component of the online laboratory is the lab station computer. For this work, the desktop workstation was a Lenovo ThinkCentre M720q Tiny computer containing an Intel Core i7 8700T processor with 32 GB random access memory (RAM) and a 512 GB solid-state drive (SSD). It was equipped with six universal serial bus (USB) ports and a server-grade network interface card that included four gigabit Ethernet ports in addition to a single, onboard gigabit Ethernet port that connected to the Texas A&M University network. The additional Ethernet ports connected to a LAN comprised of the host computer and the experiment components such as motors, detectors, and acquisition systems. The computer contained industry standard software that communicated with the laboratory components. In order for online students to gain access to the computer, the university's Division of Information Technology (IT) added them as a remote desktop user. Students also needed to access the system through the university firewall. This was accomplished through a password-protected virtual private network

(VPN). Once inside the system, students only had read and execute permissions and were unable to copy or download the proprietary software. An Aluratek – 1080 HD Webcam with tripod was connected via USB to the computer so students could watch the experiment being performed.

Software

For this project, only three commercially available software packages were required to complete the laboratories. One software package controlled motors through Ethernet connections to move sources and apparatus. The other two programs communicated with devices that operated detector systems in addition to acquiring data from these devices.

To physically manipulate laboratory apparatus, LabVIEW System Design Software from National Instruments™ was employed (LabVIEW, 2018). This software package has been used in the past to create online laboratories for other types of courses (Azad, 2011). For the purposes of this work, LabVIEW's SoftMotion module was used to operate Ethernet based stepper motors that controlled experimental component positioning. To operate the motors, virtual instruments (VIs) were created through the software's application programming interface (API). VIs are developed using a visual programming interface that resembles a block diagram (Figure 2). Once finished, the diagram is converted into a VI graphical user interface (GUI) that students use to manipulate equipment (Figure 3).

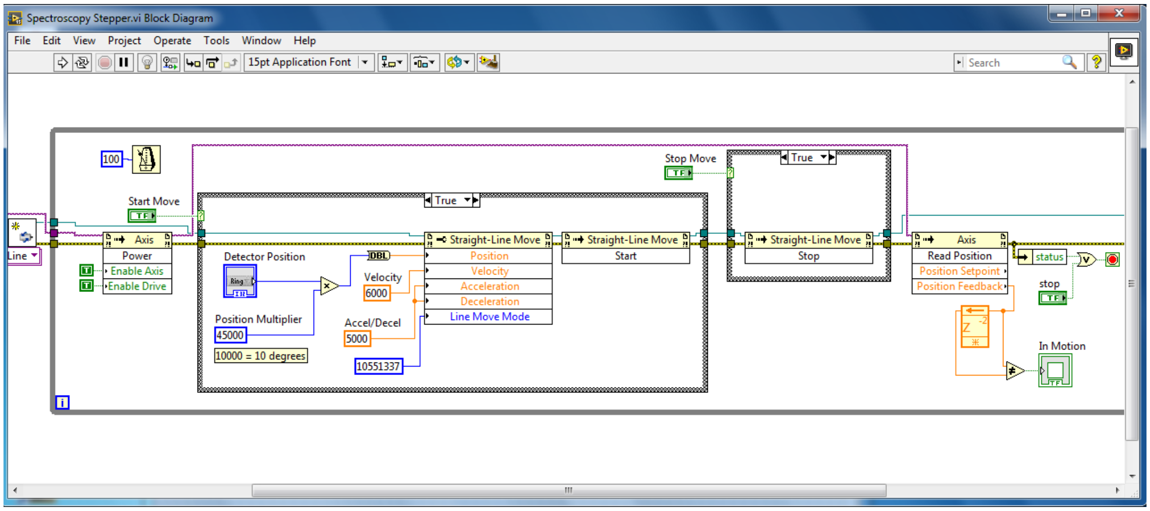

Figure 2. This is a block diagram view of a LabVIEW VI used to rotate a table that was employed to move sources in and out of a detector's viewing area.

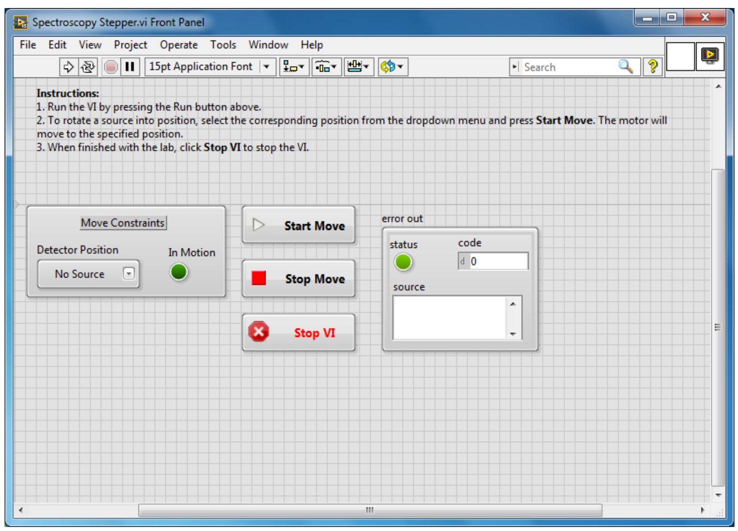

Figure 3. GUI VI produced from the block diagram shown in Figure 1.

Another piece of software controlled and recorded data from a gas-filled detector known as a Geiger-Muller (GM) tube. These instruments can detect alpha, beta and gamma radiation. For the purposes of this remote laboratory course, GMs were used to demonstrate a method of radiation detection, provide lessons on counting statistics and introduce a detector property known as dead time. For in-person laboratories, students are able to operate a Ludlum Measurements scaler ratemeter that provides high voltage (HV) to the GM tube and displays the count rate of the instrument as it is exposed to radiation sources (Ludlum, 2020). Ludlum provides a complementary software package through its website that can set acquisition times, start/stop counts and record/display data from the instrument. The laboratory computer connected to this device through a USB and the online students controlled the ratemeter using the software.

The remaining online radiation experiments are completed using a MCA from Mirion Technologies. To operate instruments attached to the MCA, the software package Gamma Acquisition & Analysis software is required (Mirion, 2016). This software is also called “Genie”. To analyze data collected by this program, an additional software package from Mirion is used, Gamma Analysis Software. Because online students had remote access to the computer, they operated the software as if they were standing in the class. They could start the program, open detector files, apply high voltage, and collect and analyze data. What they would do at home is completely analogous to what they would do as if they were completing the experiment physically in the laboratory.

Equipment

Only linear and circular motion were needed to move equipment and sources for the various laboratories. National Instruments, the creators of LabVIEW, produces a NEMA 23 size Ethernet Integrated Stepper Motor (ISM-7411E) (Figure 4). The motor directly connects to the host computer through the LAN where its movement is controlled by LabVIEW (National Instruments, 2016). Custom VIs were created for each laboratory so that movement was precisely controlled. To rotate radiation sources, a Velmex B4818TS Rotary Table (Velmex, 2016) was employed (Figure 5). Its movement was controlled by the stepper motor through a NEMA 23 coupling. This specific table was used due to the expectation that lead bricks would be employed during the laboratory for shielding. This rotary table has a 200 lbs. weight limit. Linear motion was completed using a 3-foot long LinTech 140 series Belt Driven Linear Actuator (LinTech Motion Control, Inc, 2017) (Figure 6). It is important to note that the actuator could be damaged if the platform is moved beyond its bounds. Therefore, the VI must be properly programmed so that the student does not accidently drive the platform too far.

Figure 4. The ISM-7411E Stepper Motor connects through the laboratory LAN to the host computer to control the movement of sources and equipment.

Figure 5. The Velmex B4818TS rotary table was used to move sources in relation to the different types of detectors. It has a weight limit of 200 lbs so the lead bricks can be used to shield the moving sources. The stepper motor is attached to the device.

Figure 6. The 3-foot long linear actuator employed to move sources and detectors for the online laboratory.

Gas-filled detectors are useful instruments in a radiation detection laboratory because they detect several forms of radiation. For the online laboratories, a Ludlum 44-9 GM tube was connected to a Ludlum 2200 Scaler-Ratemeter (Ludlum, 2018) (Ludlum, 2020) (Figure 7). This meter can operate a variety of instruments including scintillation, proportional and GM detectors. An RS-232 serial port on the back of the instrument was connected to the host computer using an RS-232/USB adapter. When using this meter, the only thing that cannot be done remotely is to apply high voltage. Therefore, the teaching assistant after setting up the experiment would turn on the ratemeter and turn on the detector high voltage.

In order to operate the detectors for the remaining experiments, two different types of Mirion Technologies MCAs were employed. Sodium-iodide (NaI) and lanthanum-bromide (LaBr) detectors were both utilized for online gamma spectroscopy experiments. These each had 2-inch diameter, 14-pin photomultiplier tubes that were connected to the Osprey™ MCA (Mirion

Osprey™, 2017) (Figure 8). The Osprey™ was connected to the host computer through USB. This MCA also has the ability to connect directly to the computer through an Ethernet connection, but this was not used. The InSpector™ 2000 was the second MCA employed for this work and was used to operate a high purity germanium detector (HPGe) (Mirion InSpector™, 2017). This MCA was also connected to the host computer using USB. Both MCAs were controlled using the Genie software discussed above.

Figure 7. The Ludlum 2200 Scaler Ratemeter was used to control and take data from a GM detector.

Figure 8. The Mirion Technologies Osprey™ MCA with LaBr (left) and NaI (right) detectors.

The remote laboratory benefitted from custom-made platforms to hold sources and other equipment. Platforms were designed using the computer-aided software (CAD) SolidWorks, and were printed with polylactic acid (PLA) material using the FlashForge Guider II 3D Printer (Dassault, 2019) (FlashForge, 2017). These platforms were made so that the rotary table and linear actuator could hold sources in the ideal geometry in each experiment. Additionally, a platform was made to hold the Ludlum 44-9 probe at a fixed vertical height over a source. Multiple platforms were also made to hold varying thicknesses of polyethylene, copper, aluminum, and lead with screw designs to hold the materials upright in front of a detector.

Figure 9. The FlashForge Guider II 3D Printer used to print source and equipment platforms.

Online Experiments

A total of six experiments were created for the online radiation detection class. Each experiment was meant to provide students with experience operating industry standard software in addition to gaining insight into radiation detection principles. Three of the following experiments were completed by students during the COVID-19 pandemic. The remainder were created or perfected during the pandemic and will be used as part of an online detection course presented in the Spring of 2021.

1. **Counting Statistics and dead time.** Using the Ludlum 2200 and the Ludlum 44-9 GM tube, students completed experiments to explore counting statistics. In addition, students had to determine the GM tube dead time by using a ^{204}Tl split source. The linear actuator and the rotary table were employed to move the half sources in relation to the detector. The apparatus is shown in Figure 10.

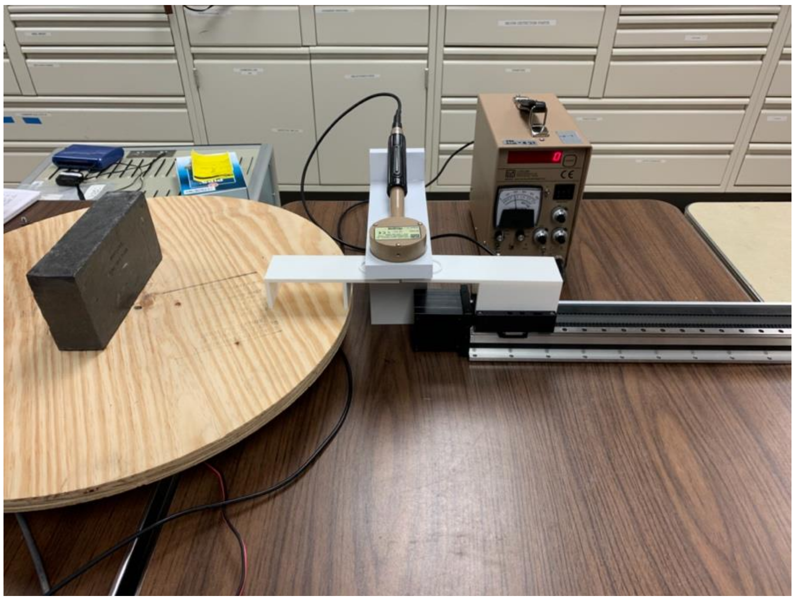

Figure 10. Apparatus of the counting statistics and dead time experiment.

2. **Inverse Square Law.** The relationship between the intensity of a source with respect to distance was explored by students using a collimated NaI detector and the linear actuator. The linear actuator moved a ^{137}Cs source away from the detector from 10 cm to 100 cm with increments of 10 cm. The apparatus is shown in Figure 11.

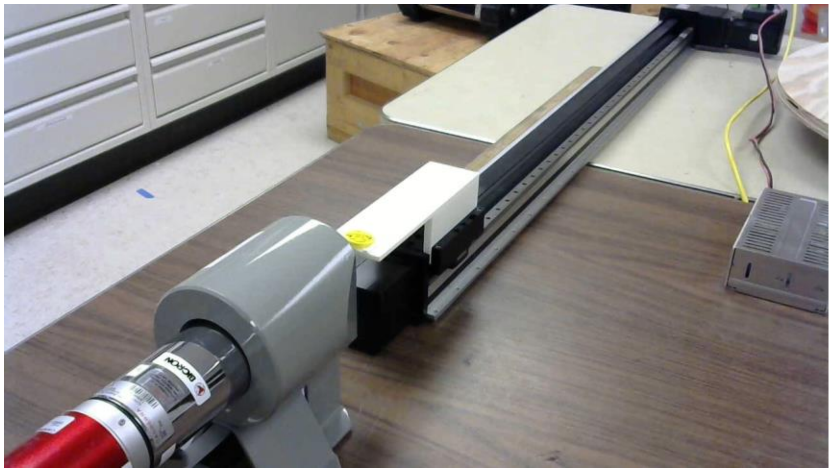

Figure 11. Apparatus of the inverse square law experiment.

3. **Compton Scattering.** By rotating a 400 μCi ^{137}Cs source around an aluminum scattering rod, a collimated NaI detector can detect scattered photon energies with respect to the scattering angle. The students used gamma spectroscopy to compare the detected photon peak with the estimated photon peak based on the scattering angle. The apparatus is shown in Figure 12.

Figure 12. Apparatus of the Compton scattering experiment. The ^{137}Cs source is shown making a 70° angle with the aluminum scattering rod.

4. **Gamma Spectroscopy with Scintillation Detectors.** The resolutions of NaI and LaBr detectors were compared by the students. The collimated detectors were positioned such that each detector face pointed towards the same source on the rotary table. The rotary table then cycled different sources in front of the detectors for energy calibration, and the experiment ended with the student identifying an unknown source. The apparatus is shown in Figure 13.

Figure 13. Apparatus of the spectroscopy with scintillation detectors experiment.

5. **Gamma Attenuation.** The attenuation coefficients of different materials were determined by the student using the rotary table and a collimated NaI detector. Varying thicknesses of polyethylene, copper, aluminum, and lead were cycled to be placed between a ^{137}Cs source and the detector so that the student could calculate the attenuation coefficient of each material. The apparatus is shown in Figure 14.

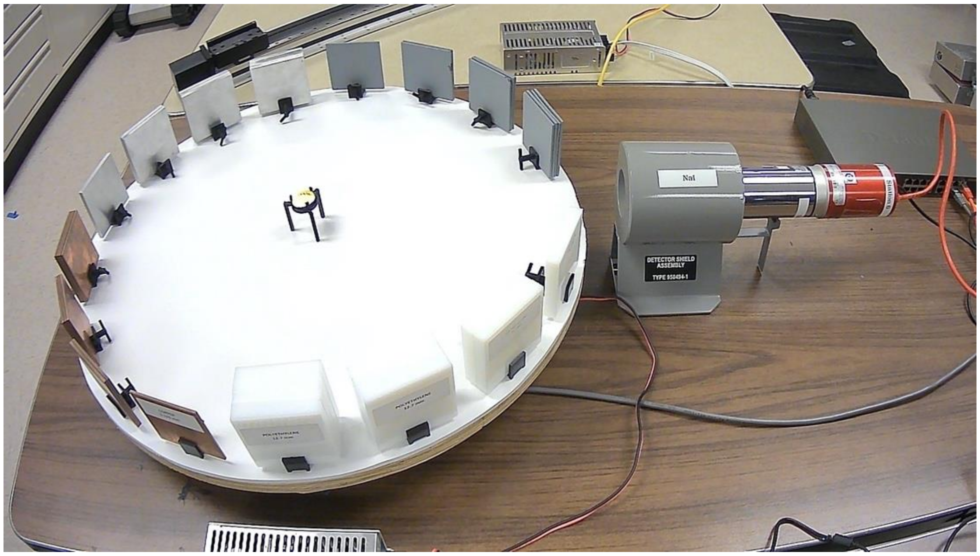

Figure 14. Apparatus of the attenuation coefficients experiment.

6. **HPGe Gamma Spectroscopy and Uranium Enrichment Determination.** The student was able to determine the enrichment of a uranium sample using the rotary table, HPGe detector, and InSpector™ 2000. The rotary table cycled sources in front of the detector for energy and efficiency calibration before providing the student with a uranium sample of known enrichment. Then, using the comparator method, the enrichment of an unknown uranium sample was determined.

Conclusion

The ability to conduct an online radiation detection laboratory would be a useful addition to distance education programs like nuclear engineering. Current collaborative software has made lecture-style classes more accessible for online education. Using this same technology in addition to commercial-off-the-shelf software and equipment, a series of experiments were developed that can be completed by online students. Students connected through a host computer with the Remote Desktop application and access detector systems and operate software as if they are present in the laboratory. The six experiments described in this research provide students hands-on access to equipment and software they would find in any instructional laboratory. The six experiments allowed students the opportunity to link concepts learned in lecture to physical processes they observed. The techniques described above that integrated equipment and software in order to create online experiments can be applied to apparatus mentioned in the research but also to different types of commercially available equipment/software. It is hoped that this work will provide a blueprint for other programs to create similar laboratories for their distance programs.

References

Amendola, D., Miceli, C. (2016). *Online Physics Laboratory for University Courses,* Journal of E-Learning & Knowledge Society, 75-85

Azad, A. K. M., et al. *Internet Accessible Remote Laboratories : Scalable E-Learning Tools for Engineering and Science Disciplines*, IGI Global, 2011. *ProQuest Ebook Central*, https://ebookcentral.proquest.com/lib/tamucs/detail.action?docID=3311528.

Dassault Systèmes, *Introducing SolidWorks*, Dassault Systèmes, Waltham, MA, 2019.

FlashForge Corporation, *FlashForge Guider II 3D Printer User Guide*, FlashForge Corporation, 2017.

Kelleher I, Hulleman C, *The Science of Keeping Kids Engaged—Even From Home,* https://www.edutopia.org/article/science-keeping-kids-engaged-even-home, edutopia.org, Aug. 2020

Kopp, D. (2011). Development of an On-line Radiation Detection and Measurements Laboratory Course. Clemson: Clemson University.

Lee, J.; Song, H.-D.; Hong, A.J. *Exploring Factors, and Indicators for Measuring Students' Sustainable Engagement in e-Learning*. Sustainability **2019**, *11*, 985

LinTech Motion Control, Inc, *140 series Belt Driven Linear Actuators*, LinTech Motion Control, Inc, Monorovia, California, https://www.lintechmotion.com/products2.cfm?ModelNo=140&t=Group11, 2020.

Ludlum Measurements Inc, *Ludlum 2200 Scaler Ratemeter,* Ludlem Measruements Inc, Stillwater, Texas, Nov. 2020.

Ludlum Measurements Inc, *Ludlum 44-9 Alpha, Beta, Gamma Detector*, Ludlum Measurements Inc, Stillwater, Texas, Jan. 2018.

Mirion Technologies, *GENIE 2000 Basic Spectroscopy Software,* Mirion Technologies, San Ramon, CA, 2016.

Mirion Technologies, *GENIE 2000 Gamma Analysis Software*, Mirion Technologies, San Ramon, CA, 2016.

Mirion Technologies, *InSpector™ 2000 DSP Portable Spectroscopy Workstation*, Mirion Technologies, San Ramon, CA, 2017.

Mirion Technologies, *Osprey™ Universal Digital MCA Tube Base for Scintillation Spectrometry*, Mirion Technologies, San Ramon, CA, 2017.

National Instruments, *User Manual NI ISM-7411/7412 Ethernet Integrated Stepper*, National Instruments, Austin, Texas, 2016.

National Instruments, *LabVIEW 2018 User Manual*, National Instruments, Austin, Texas, 2018.

W. Tlaczala and M. Zaremba, "Virtual experiments in nuclear physics," *2007 IEEE Instrumentation & Measurement Technology Conference IMTC 2007*, Warsaw, 2007, pp. 1-6, doi: 10.1109/IMTC.2007.379423