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The Effect of Beta and Gamma Radiation on the Growth and Development of *Phaseolus vulgaris* and the Optical Properties of Aerogel

Abstract

Radiation is as essential in human life as it may be harmful. For example, the heat and light produced from nuclear reactions in the sun are necessary for human existence. According to the Environmental Protection Agency, the average American receives three hundred and ten mrems of manmade radiation per year, and another three hundred and ten mrems of background radiation. These doses are well under the amount of radiation which initiates harmful symptoms; however, recent research implies that this radiation, despite the small doses, may have an impact on biological life forms. Scientists now hypothesis that low doses of ionizing radiation, under that of background radiation, may in fact have beneficial effect on biological organisms. Thus, the low dosages of beta and gamma radiation were tested on the growth and development of *Phaseolus vulgaris.* The same radiation was also tested on aerogel, a material used in Cherenkov detectors. Aerogel will be used in experiments at 12 GeV Jefferson Laboratory and has been previously observed to change its optical characteristics following experiments; therefore, SP-30 aerogel tiles were exposed to beta and gamma radiation and their appearance and optical properties observed. To determine the level of cosmic ray flux and possible contribution to these experiments, the current detector at Catholic University of America was optimized. Overall, the plant data showed hormetic trends; yet, high uncertainty nullified the results. Furthermore, only beta radiation had any effects on the optical properties of aerogel and a third scintillator paddle decreased the amount of random coincidences drastically.

Introduction

Radiation is inescapable. Each year, the average American is susceptible to six hundred and twenty mrems of radiation: approximately three hundred and ten mrems result from background radiation, such as cosmic rays, and the other half stem from manmade sources, such as medical procedures [1]. This ionizing radiation causes changes in cells by breaking chemical bonds that group molecules together, which in turn affects health [2]. In frequent and larger doses radiation may have detrimental effects on biological life forms, as recently seen in the nuclear disaster at Fukushima. However, the negative connotation attached to radiation develops from one-sided knowledge, as radiation is also essential to human existence. Radioactive materials occur naturally everywhere, including the Earth's crust and even in our bodies. In fact, about forty mrems of the radiation humans are exposed to annually occur internally [1]. Furthermore, revolutionary technology that has aided in elongating the human lifespan and that is vital in everyday life, including smoke detectors and medical equipment, leaks radiation. Although much research surrounding the effect of radiation on biological life has been conducted, the subject matter remains reasonably shrouded in mystery. Therefore, this experiment focused on the effect of radioactive isotopes on the growth and development of *Phaseolus vulgaris*, as well as the optical properties of SP-30 aerogel.

As previously mentioned, radiation is fundamental and thus unavoidable in humans' lives. Radiation seeps from the Earth's crust and bombards humans from outer space in the form of cosmic rays, high emery particles from an unknown source outside the Earth's atmosphere. Cosmic radiation accounts for five percent of the radiation humans are exposed to yearly [1]. In a cosmic ray detector the muons resulting from cosmic radiation are transformed into photons by scintillator paddles vertically aligned, which are attached to photomultiplier tubes that transfer the photons into a cascade of electrons. Then, the electronics module, e.g., a discriminator, a logic unit, and a counting module, converts the signals and records coincidences as a count. The radioisotopes utilized in this experiment were Cesium-137, Americium-241, and Strontium-90. The sources ranged in activities from 0.09 to 5.92 µcuries. Theses radioisotopes play imperative day to day roles in society, making them ideal for testing. Smoke detectors in households and medical diagnostic equipment across the world contain small amounts of Americium-241; Cesium-137 remains essential in cancer treatment; and Strontium-90 is commonly found in bone cancer and eye treatments [3, 4, and 5]. Despite the large role these radioisotopes have in everyday life, the resulting radiation is said to be too low and sporadic to have any negative impacts on human health. Smoke detectors generally only leak less than 1/100 mrems of gamma radiation annually due to the small amount of Americium-241 with an activity of 1 µcurie, whereas diagnostic radiation results in fifty of the six hundred and twenty mrems of radiation Americans are exposed to annually [3]. These amounts remain well under the five to ten rems that begin to cause changes in blood chemistry and higher dosages that initiate symptoms ranging from fatigue to death [6]. Anything under the natural amount of background radiation is considered a negligible amount of radiation.

Widespread research on the effect of high dosages of radiation on plant growth has taken place; however, the effect on lower, frequent doses of radiation on plant growth is a subject of controversy and mystery in the science community. Scientist began to feverishly research the effect of radiation on plant growth following the Second World War [7]. Some scientists conclude that radiation has harmful effects on biological life no matter the dose; while others claim that small amounts of ionizing radiation, less than the three hundred and ten mrems, stimulate plant growth, a newer theory called hormesis [8]. Hormesis refers to positive biological response to minute quantities of normally damaging substances or stressors, in this case radiation. Higher levels of ionizing radiation, such as 500 rads per day completely killed off plants with high tolerance levels following the Chernobyl disaster, whereas lower doses resulted in withered crowns, misshaped leaves, and excessive growth [9]. Likewise, seeds exposed to high doses of radiation will not germinate, but seeds exposed to intermediate levels of radiation will grow taller, albeit a decrease in the number of seeds that germinate [9]. An experiment at Osaka University of Japan deducted that one cGy to several tens Gy of D-T fusion neutron radiation stimulated plant growth by five to twenty-five percent, which may be attributed to the hormetic effect [8]. Yet, it remains difficult to investigate hormesis due to the fact that much data must be obtained and analyzed, possible causes of hormesis are unclear, and no project showcasing hormetic trends has been replicated successfully to yield similar results [8]. Consequently, experiments often focus on linearly extrapolating the results of higher dose experiments to predict the responses plants would have to lower doses [10].

Therefore the effect of low amount of the three radioactive isotopes on *Phaseolus vulgaris*' growth and development was tested in order to determine if it might have any effect on biological life. *Phaseolus vulgaris* is an ideal plant for testing due to several reasons, the first being its relatively short life span. These plants harvest in 52 days, which reduces experimental downtime. Plus, they are relatively small and easy to grow. Furthermore, *Phaseolus vulgaris* are commonly eaten in households. To further analyze the effect of radiation on the plants, they were also exposed to 298 µSv ±10% of gamma radiation from Cesium-137 per day at different stages of development, e.g., three weeks after germination, two weeks after germination, a week after germination, right after germination, and during germination in the soil.

Additionally, radiation may have damaging effects on other materials that are crucial to current experiments. Aerogel is a material utilized at Jefferson Laboratory to detect pions and kions in the Cherenkov detector. In the past, it has been observed to change its optical characteristics and develop a yellow tinge after being used in an experiment. This change in color has been blamed on radiation, humidity, etc. Therefore, the effect of beta and gamma radiation on the transmittance and appearance of aerogel tiles was tested.

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Materials and Methods

This experiment consisted of three parts: the effect of radiation on *Phaseolus vulgaris'* growth and development, the effect of radiation on the optical properties of aerogel, and the effect of number and placement of scintillator paddles on a comic ray detector's moun count. To begin, a hundred and twenty-five *Phaseolus vulgaris* seeds, a hundred and five Stringless Blue Lake beans and twenty Top Notch Golden Wax Bush beans, were individually wrapped in soaked paper towels and placed in a zip lock bag. This bag was cracked open and taped to a window. Placing seeds in moist paper towels, rather than directly in the soil, drastically quickens the germination process. No radiation was applied to the germinating seeds, as it would then be impossible to distinguish between the seeds that did not germinate due to the radiation or a different cause. After a week, once the seeds had sprouted, forty similarly sized Stringless Blue Lake bean plants were transplanted into 320 mm x 270 mm by 200 mm cardboard boxes lined with plastic and filled with 4250 mL of Miracle Gro® potting soil. In each of the fives boxes, sixteen plants were organized into a square formation. Three of these squares had a width of eight centimeter, the control that received no radiation, a beta box, and a gamma box, while the other two had a width of ten centimeters, a beta and gamma box. Therefore, there were two different dosages in each box, as showcased in Figure 1, and two boxes per form of radiation, along with a control box. Overall, there were four doses of gamma and beta radiation,

Figure 1

Distance from Source (cm)	Cesium-137 (µSv/hr)	Cesium-137 through the soil (µSv/hr)	Total Gamma Dose (µSv)	Strontium-90 (µSv/hr)	Total Beta Dose (µSv)
5.00	6.70	1.87	20.1	21.8	130
5.59	5.36	1.30	16.0	17.8	53.4
8.00	2.62	0.23	8.61	8.02	24.1
8.94	2.10	0.16	6.78	6.34	19.0

These are the dosages of beta and gamma radiation the bean plants were exposed to for three hours a day Monday through Friday. These measurements have a 10% uncertainty due to the placement of the source.

with four repeated trials for each dose.

The plants were left without treatment for another two days after having been transplanted in order to assure any stunts in growth due to the shock of the relocation would not be blamed on the radiation. Then, the radiation treatment began. Each box was watered 100 mL in the morning and then exposed to radiation for three hours every weekday, except for the control. The boxes were incased in thick plastic and lead, so that other students in the lab were exposed to negligible amounts of radiation. During these three hours, the plants were devoid of natural light, the set-up is displayed in Figure 2. The control box was placed under a desk inside the lab for three hours to ensure that all the plants received the same conditions, e.g., sunlight. When the plants were not receiving radiation, they were positioned by a window to receive sunlight. Every day, quantitative and qualitative measurements were made to record plant growth characteristics, e.g., diameter, height, number of leaves, color, and appearance. Additionally, after the three weeks and five days, once the experiment ended, the plants were gently removed from the soil, taken in photo, and the cross sections of the stems were analyzed on the microscopic level. A compound microscope was utilized to examine the plants and record any effect on the cells, e.g., changes in color, cell size, and cell count. The size of the cells was approximated by comparing their breadth at 20x to that of a human hair, which measured 0.071 ±0.001 mm, at the same objective. For these tests,

Figure 2

The Cesium-137 was placed on the right side, while the Strontium-90 was placed on the left side.

the samples were prepared from the stem using a razor blade to cut a fine horizontal layer near the base of the plants and water as the observation medium.

Additionally, thirty-six wax beans were planted in twelve smaller pots, three in each pot, and exposed to higher dosages of alpha, beta, and gamma radiation for seventeen hours every night, as shown in Figure 3. These pots were watered 50 mL every day and exposed to the radiation after the lab was emptied. Every day, the plants' diameter, height, number of leaves, color, and appearance were recorded. Yet, this experiment only lasted two weeks, as over a weekend the pots were accidentally left with the radioisotopes and therefore their growth stunted radically due to a lack of sun, lower temperature, and possibly the radiation. Furthermore, the control plants had not been moved inside of the lab. These two mistakes skewed the data severely, leading to the discontinuation of this portion of the experiment. As the data was too minimal to analyze effectively, the plants were used as a preliminary test to determine the ideal method to prepare slides and provided preliminary cell samples to observe.

Figure 3

Source	Current Activity	Radioactive Particle Distribution	Radiation 1 cm from source (µSv/hr)	Radiation Through the Soil (µSv/hr)	Total Radiation (µSv)
Cs-137	1.3 µCi	Gamma and Beta	36.79	28.65	1112.48
Cs-137	5.92 µCi	Gamma and Beta	167.53	130.47	5065.83
Cs-137	1.28 µCi	Gamma and Beta	36.22	28.21	1095.31
Am-241	0.09 µCi	Alpha and Gamma	0.13	0.10	3.91
Sr-90	0.1 µCi	Beta	635.75	0	10807.75

These are the dosages of alpha, beta, and gamma radiation the bean plants were exposed to seventeen hours a day. These measurements have a 10% uncertainty.

While progress on this first experiment continued, every week, ten Top Notch Golden Wax Bush were germinated in the same way as the previous beans and after a week transplanted into a cardboard box, without plastic lining. The first batch was germinated at the same time as the beans for the dosages experiment. These beans were being prepared for an experiment that would test the effect of one dosage of a single type of radiation on the bean plants at different stages of development. After growing in these boxes for three, two, one, or zero weeks, two plants from each stage of development were transplanted into circular pots with a diameter of 8.5 cm. The next day, the radiation was tested on the beans at five different stages of growth, three weeks after germination, two weeks after germination, a week after germination, right after germination, and during germination in the soil. The beans were exposed to 298 μSv ± 10% of Cesium-137, gamma radiation, for an hour every day for four days. Each day, the plants were watered 50 mL and quantitative data was recorded on the diameter, height, and number of leaves of the plants.

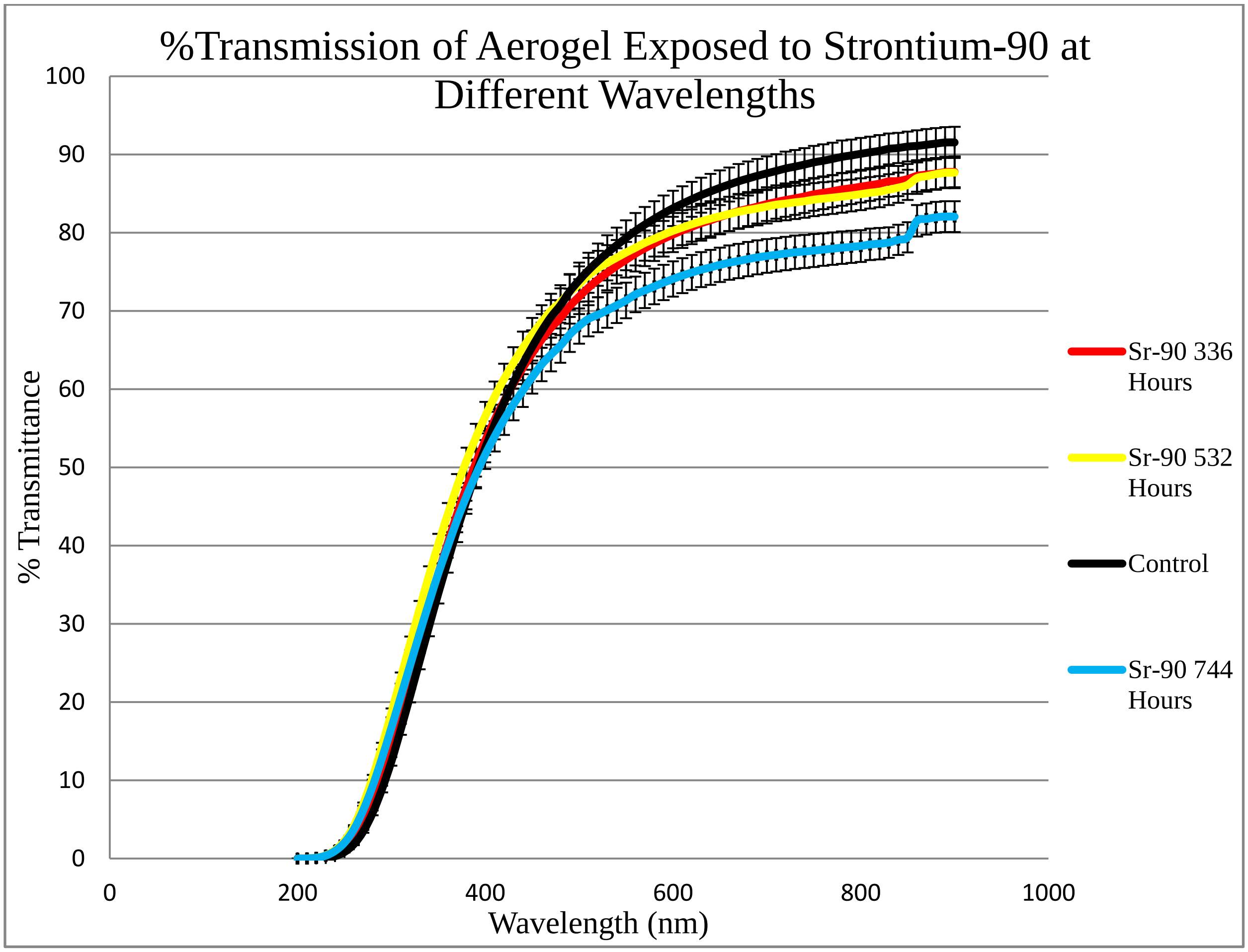
The effect of radiation on SP-30 aerogel tiles from Matsushita Electric Works was studied by comparing the optical properties of the tiles exposed to radioactive isotopes to those of the control tile. Two broken tiles were placed in a lead brick structure. Strontium-90, with an activity of 0.1 μcuries, was placed on top of one of the broken tiles and Cesium-137, 2.3 μcuries, over the other, six days after the Sr-90 was placed over the first tile. They were exposed to the radiation every day, all day for about four weeks and only removed for the transmittance tests. Their appearance and transmittance were recorded about once a week. To measure the optical properties a UV/Vis photospectrometer scanning every 10nm between 200nm and 900nm was used. Each time the results from the test were compared to previous transmittance tests. Furthermore, it was noticed during the first test that the two irradiated tiles had a fair amount of dust on them; therefore, they were cleaned with a makeup brush before the second test. This cleaning method left small scratches on the surface of the tiles, adding to the systematic error. To prevent further distorting of the data, the tiles were not cleaned again to ensure that any changes in transmittance between the second and third or fourth test were due to the radiation rather than more scratches.

To study the cosmic ray flux, a cosmic ray detector was constructed using two scintillator paddles, photomultiplier tubes, and electronics modules, e.g., a discriminator, a logic unit, and a counting module. The detector that was already present at the university had a twenty-five percent uncertainty [11]. Therefore, the current detector's system needed to be optimized to more accurately determine an uncertainty of the fluctuation of cosmic radiation that contributed to the uncertainty of the overall radiation affecting the plants and aerogel that was tested. To test the accuracy of the counter, data was recorded using a data acquisition system and the results compared. Interestingly, there were discrepancies between module and computer counts that could not solely ascribe to computer dead time.

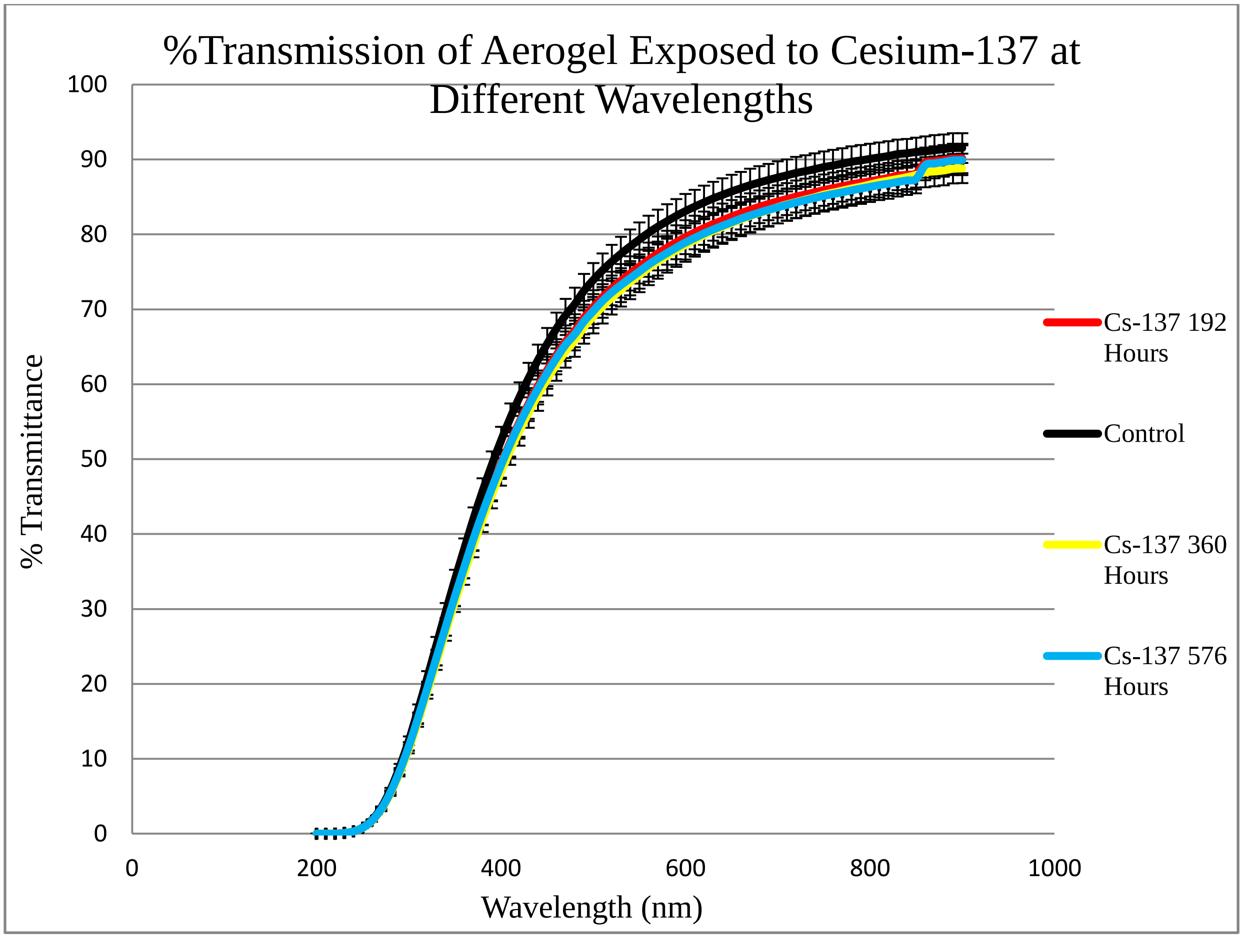
To further investigate the efficiency and systematic uncertainties and reduce random coincidences a third scintillator paddle, with the dimensions 4.5 cm ± 0.1 cm x 14.4 cm ± 0.2 cm x 0.97cm ± 0.01 cm, was sanded and polished with alumina and then added 44 cm ± 1 cm under the lowest of the two paddles already set –up. The gluing of the scintillator material to the PMT provided a problem; the 7.5 to 1 ratio of Sylgard® 184 silicone elastomer base and Sylgard® 184 silicone elastomer curing agent must be precise in order to avoid the glue from being not strong enough or too brittle. Also there must be a small pressure on the components in order to ensure that they stick together, therefore it may be glue vertically or horizontally. In this experiment it was found that gluing vertically, by using s ring stand to hold the PMT and scintillator paddle in place, provided better results. However, with both methods the scintillator eventually detached from the PMT, most likely due to its rounded edges that resulted in less contact points between the scintillator material and the PMT. Moreover, it is difficult to perfect the ratio since the components are not supposed to be mixed with water, so no utensils that are important or will be used in the future may be used. Since the glue generally held for a week at a time, it was enough time to test all combinations of two paddles, along with all three paddles were tested.

Results

The Effect of Radiation on Aerogel Results

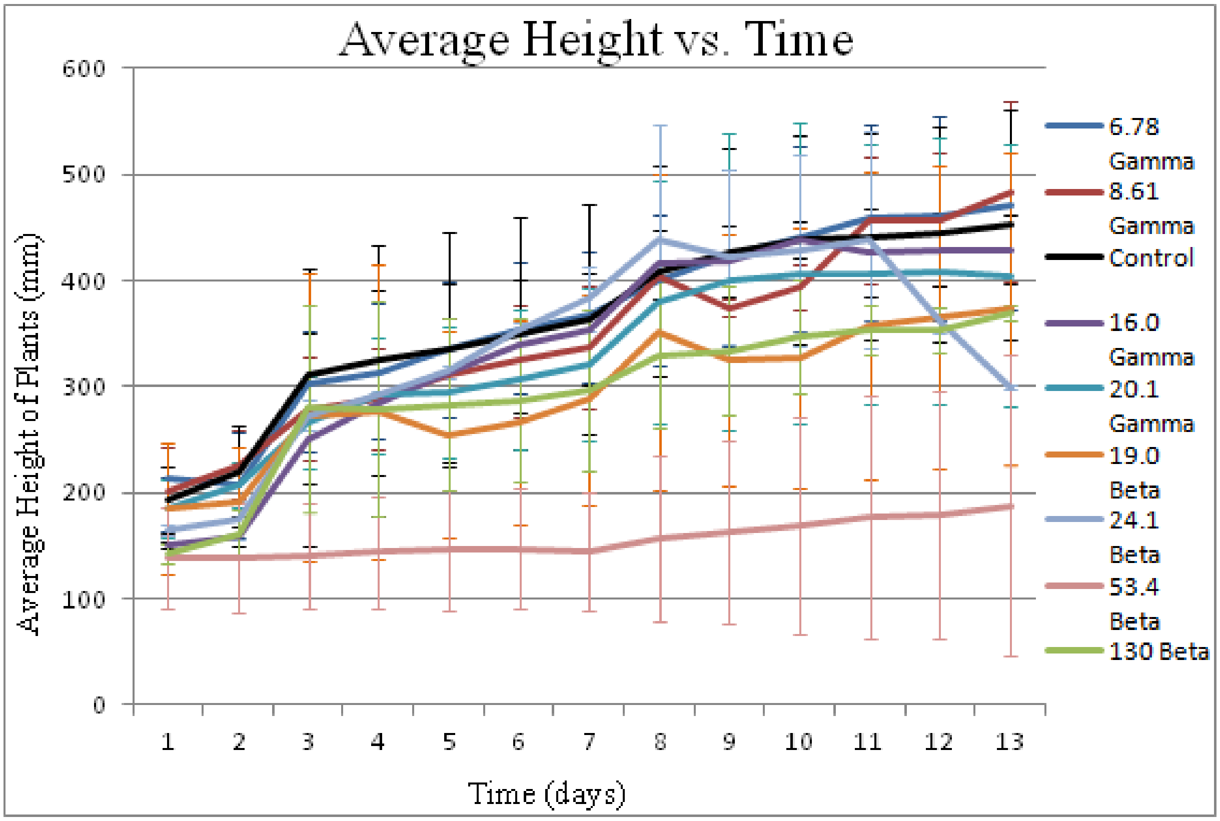


This graph displays the transmittance of the aerogel tile exposed to strontium-90 after 336, 532, and 744 hours compared to the transmittance of a tile not exposed to radiation. The transmittance of the tile exposed to the beta radiation remained lower than that of the control and by the third test, the transmittance of the tile noticeably decreased. The vertical error represents the standard deviation of the average of five repeated measurements of the control tile's transmittance.

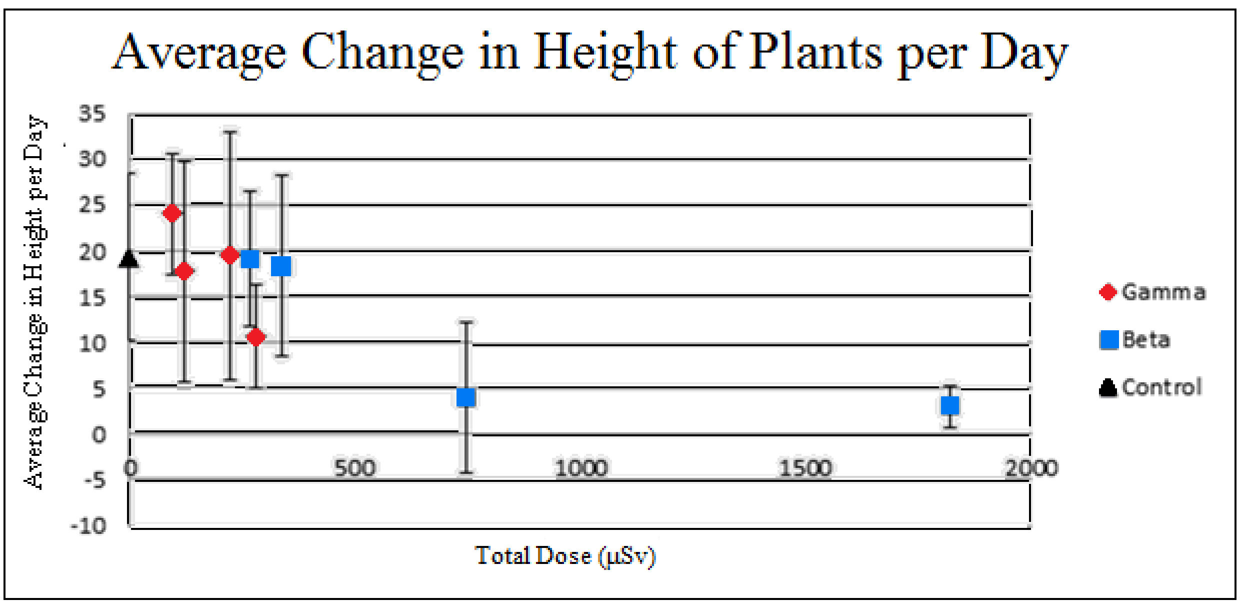


This graph displays the transmittance of the aerogel tile exposed to cesium-137 after 192, 360, and 576 hours compared to the transmittance of a tile not exposed to radiation The transmittance of the aerogel tile exposed to cesium-137 remained slightly lower than that of the control tile, yet all changes throughout the course of the experiment remained within the limits of the error bars. The vertical error was calculated using the same method as in the previous graph.

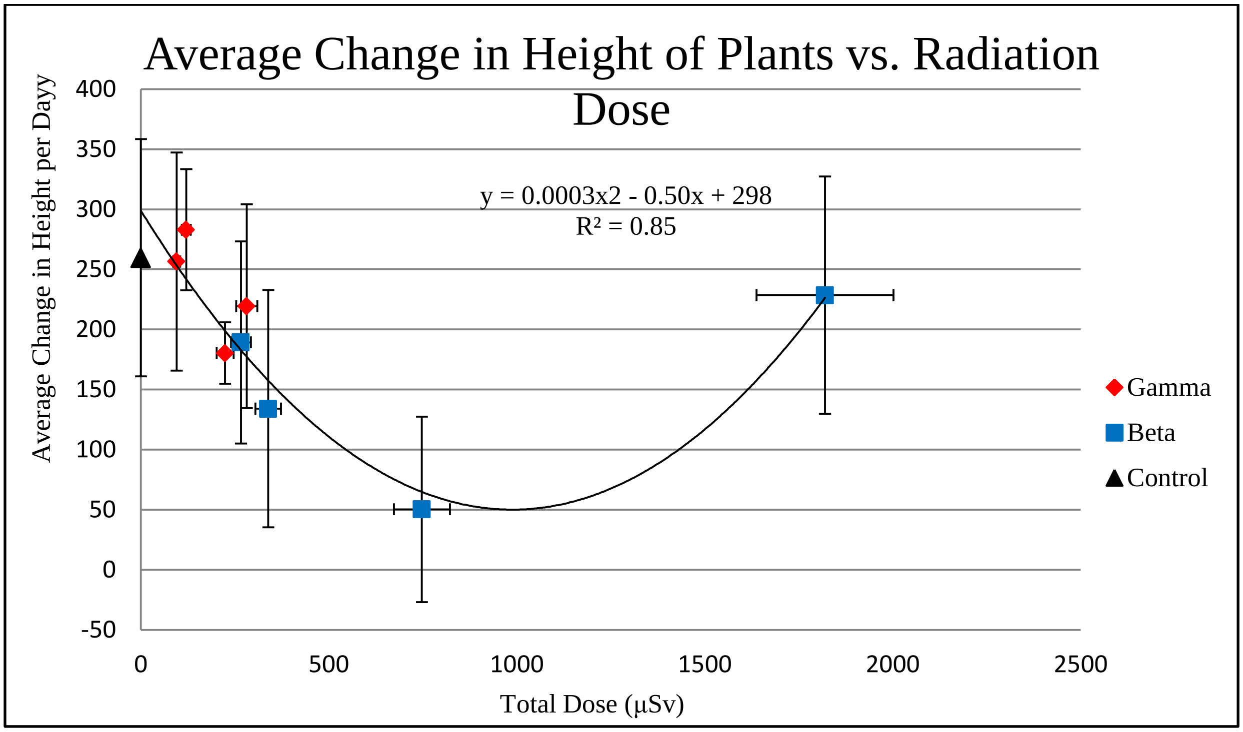
The Effect of Beta and Gamma Radiation on *Phaseolus vulgaris* Results



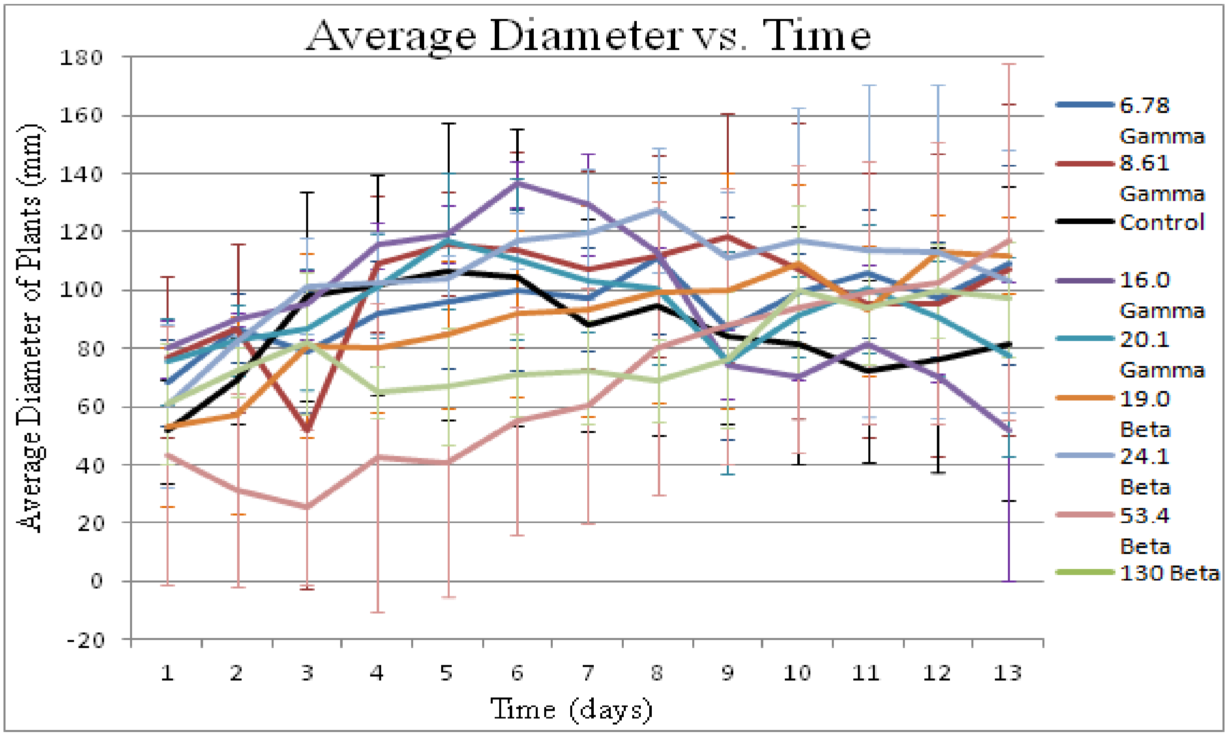
This graph displays the average change in plant height for each dose of radiation overtime. The two lowest gamma doses resulted in a slightly elevated plant height compared to the control, while the higher doses of gamma had little effect on the height of the plants. Beta radiation had a more negative effect on plant height, especially the middle amount of beta radiation.



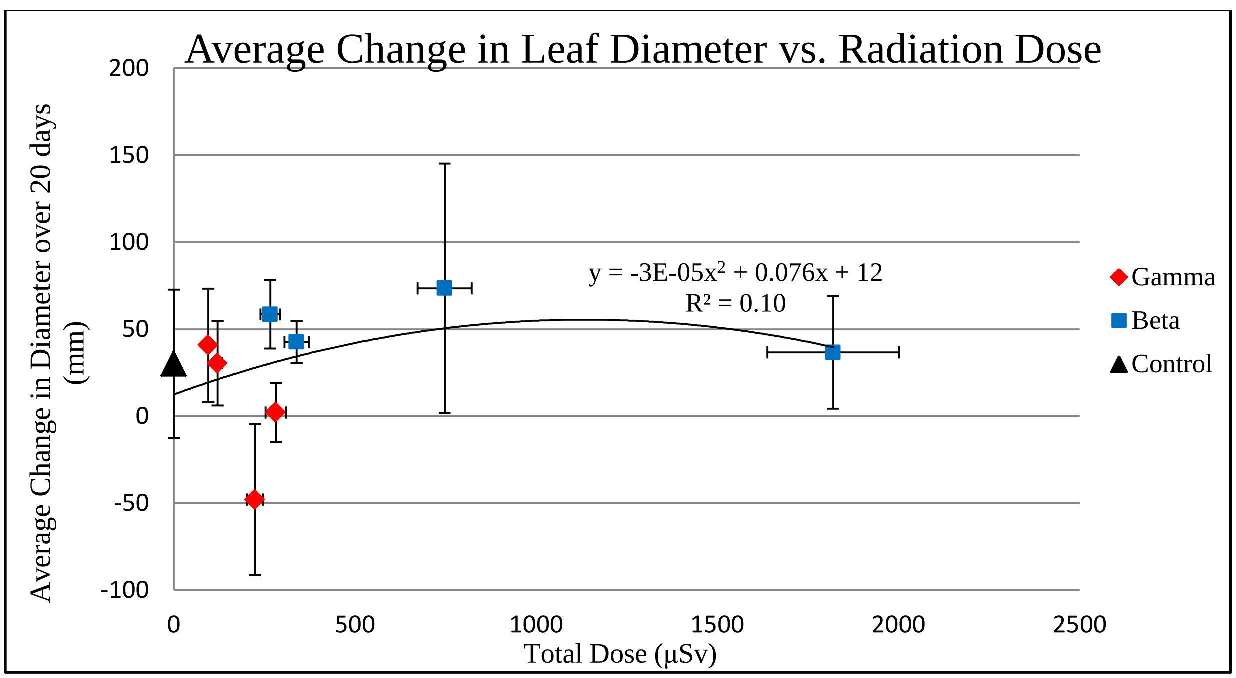
This graph displays the average change in height of the plants per day. The graph follows the hormetic trend very closely, as the lowest amounts of gamma had the most positive effect and the largest amount of beta the most negative effect.



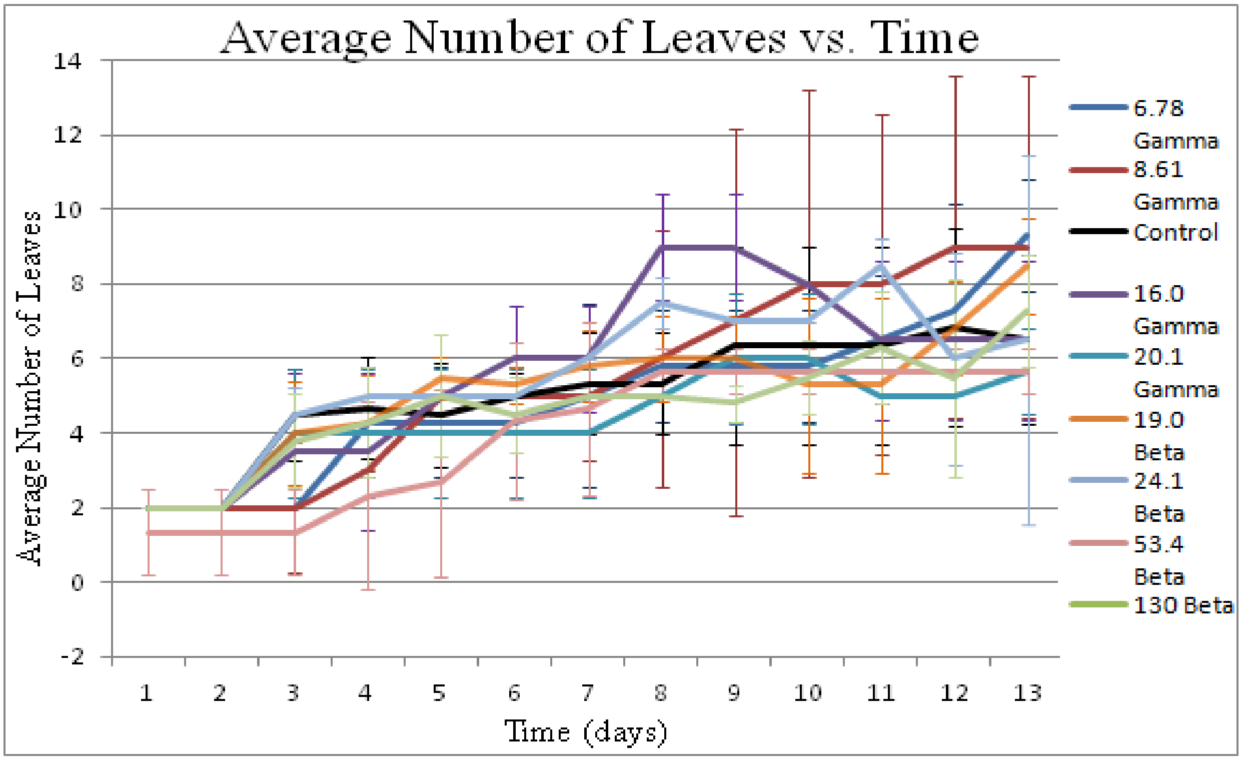
This graph displays the average change in height of the plants over the course of the experiment. The plants exposed to the second lowest gamma dose are the only plants that grew taller than the controls. Both the plants exposed to gamma and beta radiation roughly followed a “U” shaped trend.



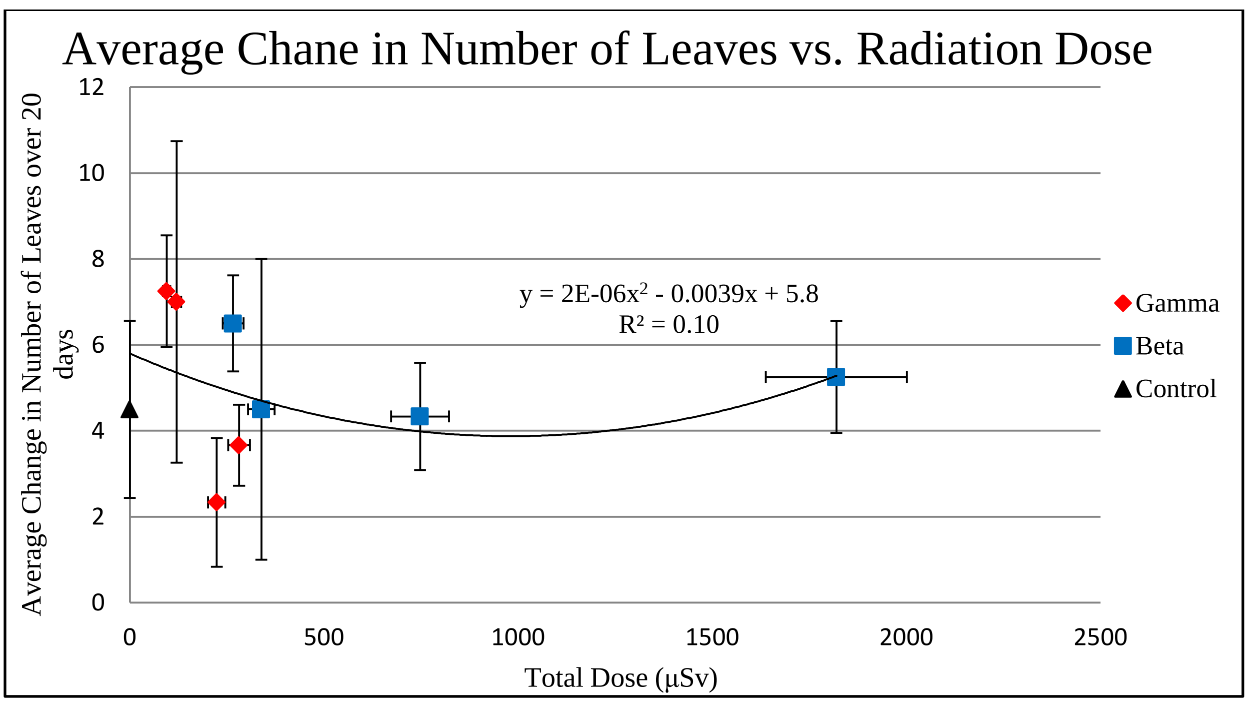
This graph displays the average change in plant diameter for each dose of radiation overtime. All of the plants exposed to radiation, except those exposed to the higher doses of gamma, had wider diameters than the control plants. Overall, beta had the most positive effect on diameter.



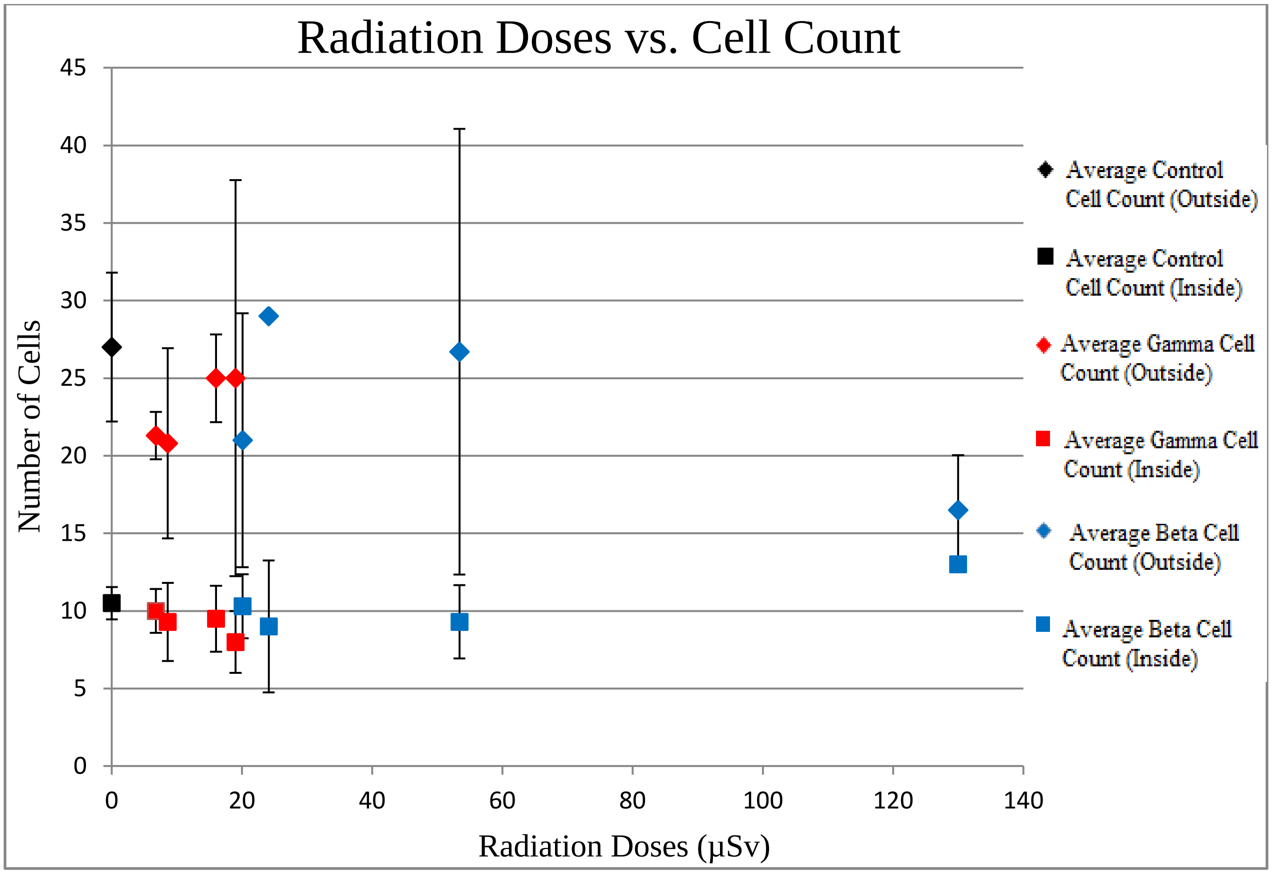
This graph displays the average change in diameter of the plants over the course of the experiment. The beta radiation and lowest gamma dose had slightly positive effects on the plants growth. Gamma radiation generally had a negative effect on the diameter of the plants.



This graph displays the average change in number of leaves for each dose of radiation overtime. The lower doses of gamma and lowest and highest doses of beta radiation surpassed the control in number of leaves.

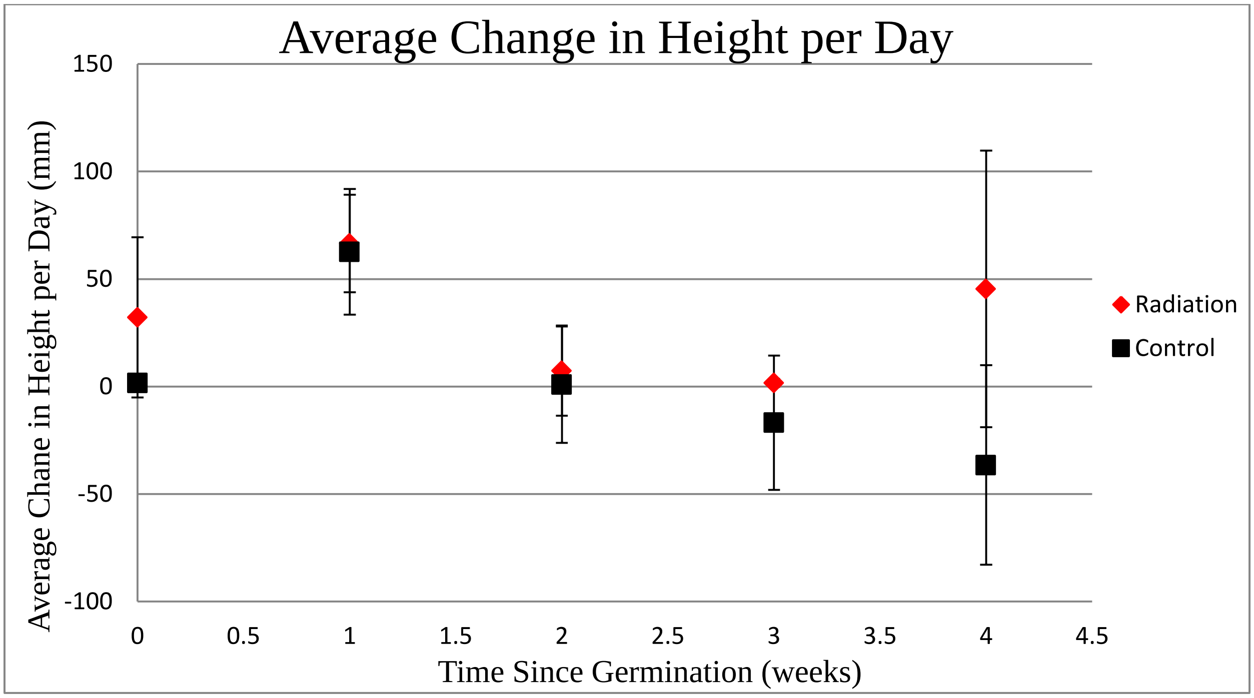


This graph displays the average change in number of leaves of the plants over the course of the experiment. The change in number of leaves follows a “U”-shaped trend.

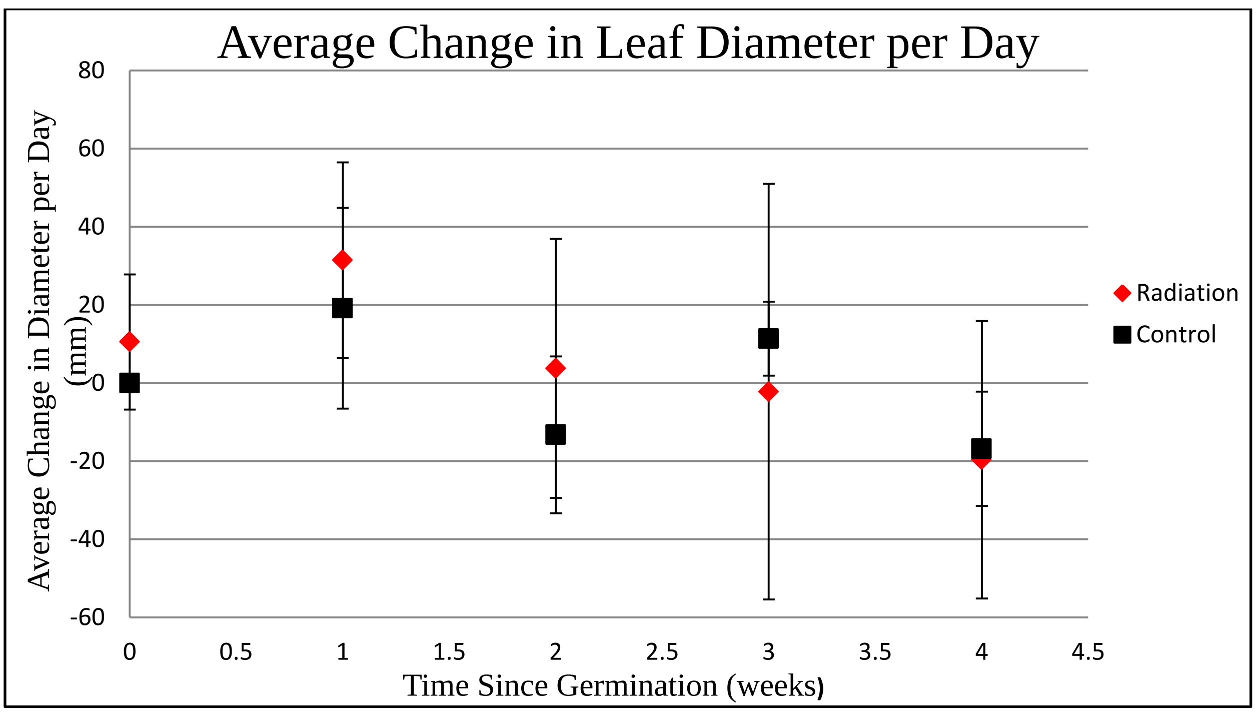


This graph displays the average cell count for each radiation dose near the middle and edges of the samples. The average cell count for cells near the inside of the stem varied very little. The control, higher doses of gamma radiation, and middle doses of beta radiation had slightly more cells near the outside of the samples.

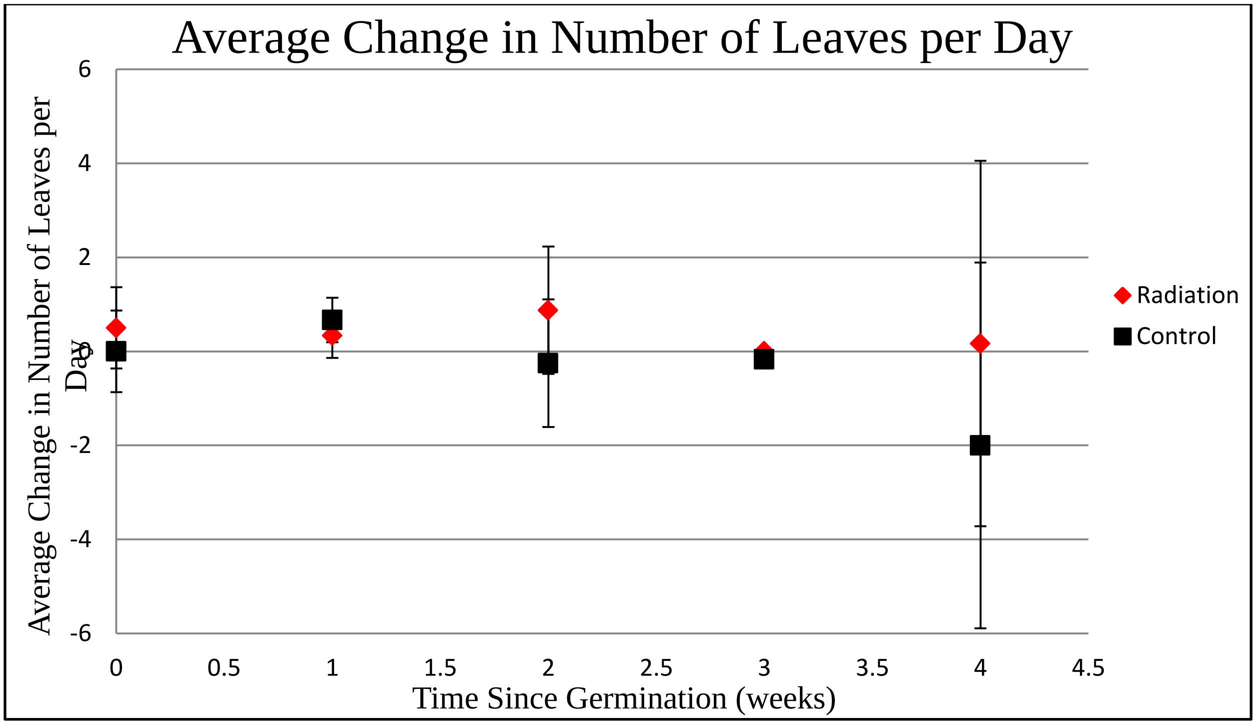
The Effect of Gamma Radiation on *Phaseolus vulgaris* at Different Stages of Development
Results



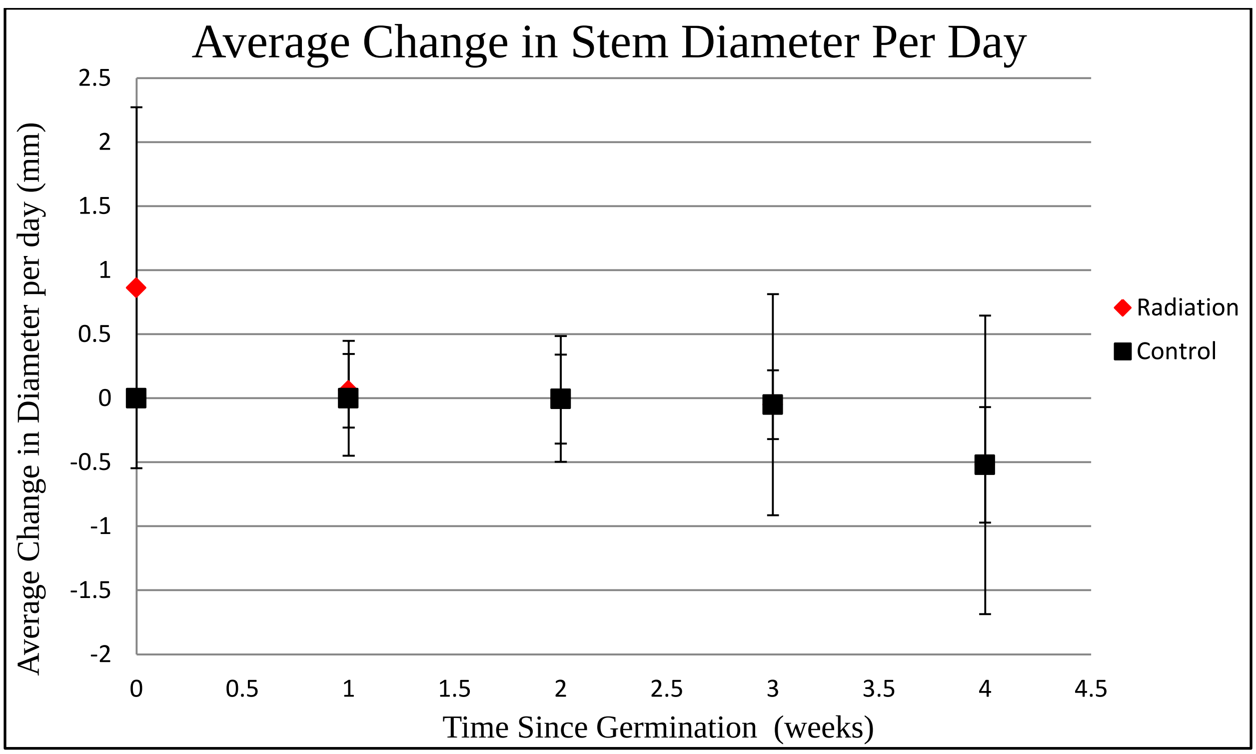
This graph displays the average change in height per day at different stages of development. In each case the irradiated plants grew more than the control plants.



This graph displays the average change in leaf diameter per day at different stages of development. The younger irradiated plants had wider diameters than the control plants.



This graph displays the average change in number of leaves per day at different stages of development. The irradiated plants, except for week two, had more leaves than the control plants.



This graph displays the average change in stem diameter per day at different stages of development. The only difference in stem diameter was weak one, in which the irradiated plants had thicker stems than the control plants.

Cosmic Ray Detector Trigger Efficiency Results

		Computer		**Module**		Mean				
Signals	Time (h)	Count	Count/ min	**Coun t**	**Count/ min**	Count	Count/ min	STDE V	%Error	Dead Time
1,2	18.0	1469	1.36	**1486**	**1.37**	1478	1.37	8.5	0%	1%
2,3	24.7	NA	NA	**1720**	**1.16**	1720	1.16	0	15%	NA
1,3	65.0	NA	NA	**1876**	**0.48**	1876	0.48	0	65%	NA
1,2,3	65.5	NA	NA	**1388**	**0.35**	1388	0.35	0	74%	NA

This chart showcases the results from the trigger efficiency test between all paddle combinations. The count per minute drastically decreased when all three paddles and the top and bottom paddles were used. The computer count is not always shown, as it was not available for three of the tests.

Discussion

Similar trends were noticed in the plants' height, number of leaves, and cell size near the outside of the samples: the irradiated plants followed a sine wave shaped trend, roughly mimicking a hormetic trend. Overall, the plants irradiated with the two lowest gamma doses had stimulated growth patterns, the plants exposed to the lowest and highest beta doses had similar growth patterns as those of the controls, and all the other irradiated plants had stunted growth patterns. This hormetic trend is most noticeable in the height measurement and was especially defined in the change in the height per day graph, as the higher dose of beta did not crest. These results may have been in part due to systematic error, as many of the plants exposed to gamma radiation, which received the least amount of fluorescent light since they were placed under lead bricks, showcased symptoms of etiolating. This is when due to a lack in sunlight, plant grow taller, with thinner stems, smaller leaves, and lose many leaves, also increasing uncertainty [12]. Otherwise, the irradiated plants may have been affected by abnormalities caused by the radiation, such as rapid growth in plant [9]. Yet, these changes in growth become insignificant when the error bars are acknowledged. Similarly, the difference between the amount of cells near the outside of the stem was nullified by the error bars and the increased difficulty in counting more and smaller cells. Yet despite the small amount of variation between cell count, which is inversely proportional to cell size, the size of the cells followed an almost identical trend as that of height and number of leaves.

The results for the diameter of the plants however did not follow the same hormetic trend as the other quantitative measurements. The plants exposed to gamma radiation somewhat followed a "U" shaped trend; yet, the overall trend of the graph and of the plants exposed to beta radiation was hill-shaped. All of the plants exposed to radiation, except for the plants irradiated with the two higher doses of gamma, and had wider diameters than those of the control plants. Furthermore, although the plants exposed to 53.4 μSv ± 10% of beta radiation daily began with the smallest diameter, they ended up with the largest diameters. The beta radiation had slightly positive effects on the plants' diameters, along with the smallest dose of gamma radiation. In general, beta radiation had more of a positive effect on diameter, while gamma radiation generally had a negative effect on the diameter of the plants. However the difference in leaf diameter is also nullified when the error bars are taken into account. As it is a different person measuring the beta boxes than all the rest the slight disparity can be account for by differences in individual methods of carrying out measurements. Also, the leaf diameter measurement is the most unreliable method of measuring growth utilized in this experiment, as leaves fall off, begin to shrivel, and close and open depending on sunlight.

Due to the small amount of repeated trials, four in this portion of the experiment, and the randomness of plant growth, outliers were removed from the data. Instead of removing an outlier from each box, as originally planned, any plant that died or were broken while taking measurements were removed from the data. It was noticed that the box with the higher doses of gamma radiation had the most outliers, especially the plants receiving the higher dose of radiation. This dose had two outliers as there plants were extremely fragile and thin. The smallest amount of beta radiation had two outliers as well; however, directly after the transplanting, these plants were small and unhealthy due to the shock of the transition. The control box also had two outliers, but this is to be expected as it had eight repeated trials, unlike the four for all the other dosages. Finally, the lowest gamma doses and highest beta doses had only one outlier, which is to be expected. It seems as though the higher dosages of gamma increased mortality and feebleness of the plants.

Similar sine wave shaped or “U”-shaped trends were apparent in much of the data. Generally hormesis curves are represented by a hill-shaped trend, while disease is showcased by a “U”-shape trend; however, some hormesis graphs have a similar, almost sine wave shaped trend, as displayed in the majority of the graphs [10]. Yet, there are not enough smaller doses of gamma radiation to tell for sure if evidence of hormesis is present in the results of this project. Not only dose radiation have such a small effect on growth that it is negligible, it also increases the fragility of the plants. Overall, with error and uncertainty taken into account, radiation has a negative effect on plant growth, even in smaller dosages.

In the stages of growth experiment, there were no repeated trends throughout the different measurements recorded. However, it seems as though radiation generally had a positive effect on plant growth, especially for the germinating plants. The irradiated germinating plants sprouted after a couple of days and grew taller quickly, with very thick stems, while the control plants did not germinated within the time period of the experiment. It had been found in previous research that irradiated bean seeds grew much quicker; however, the percentage of seeds that germinated was low [9]. Moreover, the irradiated plants grew taller than the control plants and the majority of the irradiated plants had wider diameters and more leaves. If the irradiated plant did not exceed the control plants in growth, they were very close. In general, the low dose of gamma radiation had small stimulating effects on the plant growth, supporting the hormesis theory. Yet, the difference in growth remained within the error bars. This may be a result of the short experimental downtime; the plants were only irradiated three times over the course of four days.

For the cosmic ray detector, it was found that there were discrepancies between the computer and module’s count. This deviation in count sometimes amounted to a seventy-four percent difference. This large distinction is due in part to the computers lag time, as it cannot count as quickly as the module, as well as the fact that the module counts background noise, such as changes in light. It has not yet been determined if the computer or module's counting is more accurate. Additionally, adding a third scintillator paddle and PMT to the cosmic ray detector's set-up resulted in a decrease of about fifty percent in counts. The efficiency of the three paddle set-up was .99.

For the effect of Strontium-90 and Cesium-137's effect on the color and transmittance of aerogel project, there was no noticeable change in the coloring of the tiles over the course of the four weeks. Furthermore, the gamma radiation seemed to have no effect on the transmittance of the aerogel, as the minimal difference between the first test and the control is contributed to the dust which gathered on the tile's surface. The beta radiation did have an effect on the transmittance: after being exposed for seven hundred and forty-four hours the tile's transmittance dropped significantly. This is most likely due to the fact that aerogel is a dense material that will stop beta radiation, but not block gamma radiation. Additionally, the tile exposed to the gamma radiation was irradiated for only five hundred and seventy-six hours instead of seven hundred and forty-four hours. The tiles in the Jefferson Laboratory are exposed to radiation for much longer time spans, so perhaps more significant results would appear after more time.

Conclusion

Overall radiation at such low dosages have such a small effect on plant growth that it is negligible; however, slightly higher dosages or dosages less frequently for a longer duration in time might arise the hormesis effect. It is possible that irradiation only once a week, to give the plants time to recuperate, or simply one radiation treatment at the beginning of the project would yield interesting results. For future experiments in this subject, wooden sticks should be placed next to the bean plants for them to curl and grow on. Also, more repeated trials are necessary due to the drastic irregularities in plant growth and a wider array of doses should be tested to ensure any hormetic trends in the data. Furthermore, a fluorescent light source will ensure that the plants receive the full-sunlight they need and avoid any changes in growth due to a lack of light or lead brick covering. A fluorescent light source will be more constant so that plants germinating at different times will still have constant environments.

Additionally, it was found that adding a third scintillator paddle decreased the count by about fifty percent. Plus, it was noticed that the computer and module have ranging discrepancies between counts, even up to seventy-four percent; future research on which of the two is more accurate should take place. Additionally to continue research on decreasing systematic error and uncertainty in the cosmic ray detector's count the effect of paddles thickness and a delay test could take place. Two scintillator paddles have already been sanded and polished; they must simply be glued to the original two paddles. Furthermore, a test using different wire lengths would test how dramatically the count is changed depending on the delay of a signal based on varying cable lengths.

For the testing of the aerogel tiles it was found that there were no changes in the coloring of the tiles or the transmittance of the tile exposed to gamma radiation. However, the tile exposed to beta radiation had a decrease in transmittance after seven hundred and forty-four. Therefore, it may be interesting to test the effect of alpha particles on the transmittance of aerogel as they are stopped by even less material than beta particles. Also, all three forms of radiation should be tested on the tiles for longer time spans and on different types and brands of aerogel. Moreover, the refractive index of the tiles should be measured before and after exposure to radiation in order to see if radiation changes anything other than the optical properties of the tiles. For these projects, be careful that no dust or damaging handling of the tiles takes place by accident. If the tiles were placed in cardboard boxes within the lead brick structure, it would avoid any dust or dirt from the floor or that the bricks forming the roof of the structure to skew results of the transmittance test. Also, then the tiles would not have to be moved into boxes to be then transported to the photospectrometer, resulting in less handling and chips or cracks in the very delicate material.

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