Environmental sampling for radioisotopes on the Hampden-Sydney College campus

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INTRODUCTION

Radioactivity was first discovered in 1896 by Henri Becquerel, a French scientist, who first believed it was similar to x rays. Becquerel was attempting to study aspects of x rays by exposing potassium uranyl sulfate to the sunlight. The naturally occurring phosphorescent material used in the experiment was subject to sunlight before being placed on photographic plates which were then covered in black paper. Becquerel believed the sunlight would be drawn in by the uranium and then be released as x rays. On the day of the experimentation, the weather in Paris was overcast. Even though the material had not been exposed to sunlight, Becquerel decided to develop the plates anyways. The developed images were clear and evident that even without the sunlight, the uranium was discharging another form of radiation. This was the first discovery of radioactivity.

Research was continued by Becquerel along with other scientists, including Ernest Rutherford, Frederick Soddy, Marie Curie, Pierre Curie, along with others. Marie Curie was the first to coin the term radioactivity for this phenomenon. Soddy along with his teacher Rutherford heavily studied the decay processes of radioactive elements. They were the first to discover that many times elements would convert from one element to another when they would undergo decay processes. These mutations are shown in diagrams called decay chains. Decay chains show an elements resulting isotope from radioactive decay as well as what isotope the element decayed from and ends with a stable element that is formed from radioactive decay. The decay chain of Uranium-238 can be seen in Image 1.1.

Environmental radioactivity comes from radioisotopes in the ecosystem. The formation of these radioisotopes are the result of naturally occurring processes, human intervention, or a combination of the two. The experiment conducted in this report uses environmental sampling, the collection and testing of samples from the ecosystem, to test the levels of environmental radioactivity on Hampden-Sydney's campus. Samples were collected from the dust in air in the basement of the Gilmer science building, plant life around the campus, and water from the bodies of water on campus.

Radioisotopes can be taken in by humans without their knowledge. Potassium-40 is commonly found in fertilizers and is the highest concentration of natural radiation in living creatures. Along with Uranium-238, it is a naturally occurring isotope found in the earth's mantle. Radon-222 comes from the decay chain of Uranium-238 and is a colorless, odorless gas commonly found in basements. This isotope of radon, often called "radon gas", can cause serious health effects including cancer. The Gilmer science building on Hampden-Sydney's campus was built in 1968 and houses the physics students in the basement. If high levels of radon gas are present in the basement, it could cause health problems for the students.

Theory

Radioactive decay is separated into three types; alpha (α), beta (β), and gamma (γ). Ernest Rutherford was the first to categorize the types of decay. When an element undergoes alpha decay, it emits a helium nucleus containing two neutrons and two protons. During beta decay, a neutron from inside the nucleus is converted into a proton while an electron and an antineutrino are added to the element. Gamma decay is an emission of gamma rays from excited states within the nucleus.

The Multi Channel Analyzer (MCA) provides a gamma spectrum for the sample, allowing us to look at peak energies of samples that decay by gamma decay. The MCA was composed of a Spectech UCS 30 spectrometer connected to a Sodium Iodine Tube (NaI Tube). The NaI Tube was mounted on top of a housing structure with shelves to place the samples on. The housing structure was shielded from external radiation by surrounding it with lead bricks. The radioactivity emitted by the sample is collected by the NaI Tube and sorted into bins. These bins have a range of energy, with the range dependant on the calibration and scale of the MCA. The MCA graphs the counts, or amount of particles detected within each bin's range, versus the bins themselves. This graph is the gamma spectrum from each isotope. Every gamma emitter has one or more peak energy levels. By matching the peaks of gamma spectrums of unknown samples with those of known isotopes, we are able to identify which isotopes are within each sample.

The Geiger-Muller Tube (GM Tube) was used to monitor the decay rate of isotopes emitting all types of radiation; alpha, beta, and gamma. The GM Tube measures a total count of activity for a set period of time, or run. The decrease in counts over time is from the decay of the isotope. From this, the half lives of beta emitting isotopes are able to be calculated. A Spectech ST360 Counter with a Spectech GM35 GM Tube was used.

Half-life calculations were made using the formula

$$N(t) = N_0 e^{-\lambda t}$$

where N is the number of particles remaining from decay after a time t, N_0 is the initial number of particles present, λ is the positive decay constant, and t is the time. Using the GM Tube in addition to this half-life formula allows for samples under the GM Tube to be identified by their half-life.

Radon-222 decays by alpha decay. This can cause serious health effects, namely lung cancer. Radon gas is the second leading cause of lung cancer in the United States. Due to the fact that the gas is colorless and odorless, it can go undetected easily and can be exposed to humans inside their own homes. The national average level of radon gas in the outside air is measured at 0.4 pCi/L, or pico Curies per liter. The Environmental Protection Agency (EPA) in the United States recommends taking steps to reduce contact with radon gas if measurements read above 4.0 pCi/L. The agency has also estimated that if national levels were to drop below 2.0 pCi/L, annual deaths due to radiation from radon gas would drop by 50%.

Potassium-40 can also lead to serious health concerns. The most prominent of them being cancer from cell damage due to the radiation associated with the isotope. Inhaling and ingesting the isotope are the two most common avenues of exposure for Potassium-40, although humans can also be exposed if there are high levels within soil they are exposed to.

Methods – Collection of Samples

In order to sample the air a Staplex TFIA air sampler was used. Samples were collected for hours at a time, many times overnight, until the pads were a dark grey color from the dust collected. The dust samples were collected from various locations in the Gilmer basement. Air samples were collected on FisherBrand Glass Fiber Filters. Samples were then put under a Multi Channel Analyzer (MCA).

To see if any naturally occurring radioactive isotopes were not only in the water supplies on campus but also being absorbed into the ecosystem, dogwood leaves were analyzed. Dogwoods were chosen because of their natural tendency to absorb high amounts of calcium. Calcium and radium have similar relative sizes which in turn allows the dogwood to also absorb high amounts of radium. The locations of the dogwoods from which leaves were collected are marked on Image 1.2 with red arrows. Leaves were then dried under a heat lamp and crushed in a coffee grinder to reduce the volume in order to place under the MCA. The branches from which the leaves were taken were also collected, burnt in a controlled fire to reduce volume and then sampled under the MCA.

Potassium 40 (K-40) is a naturally occurring radioisotopes which can also be found in high quantities in fertilizers. Many times water runoff will carry the K-40 with it into a large body of water. Hampden-Sydney's campus features multiple lakes, ponds, and streams in different areas. Water samples were collected from Chalgrove Lake, Lake Mayes, Tadpole Hole, the water fountain in the Gilmer basement, and the stream on the Wilson Trail. These locations are underlined with blue in Image 1.2 with the Gilmer building having a blue arrow pointed to it.

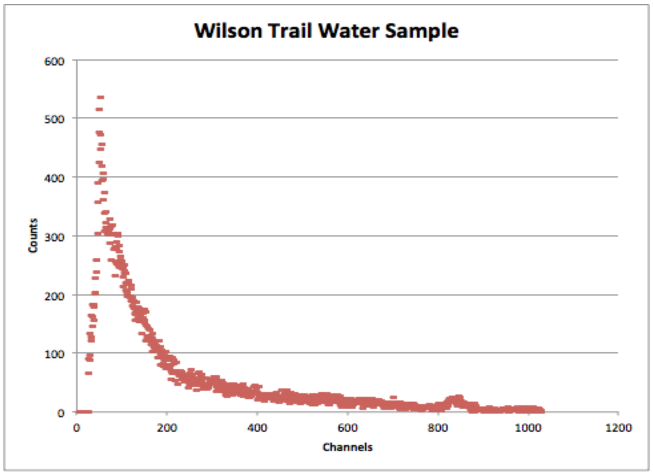
From the dust, the radioisotopes Bismuth-214 (Bi-214) and Lead-214 (Pb-214) were expected to be found. Pb-214 is the granddaughter of Radon-222 (Rn-222). Alpha decay, the process by which Radon-222 decays, is difficult to detect which is why the elements down the decay chain are expected to be seen. The radioisotopes Bi-214 and Pb-214 have 19.9 and 26.8 minute half lives, respectively, and both decay by beta decay. Using the Geiger-Muller Tube, these isotopes had half lives that could be identifiable to suggest there may be a concentration of either of the two within the dust.

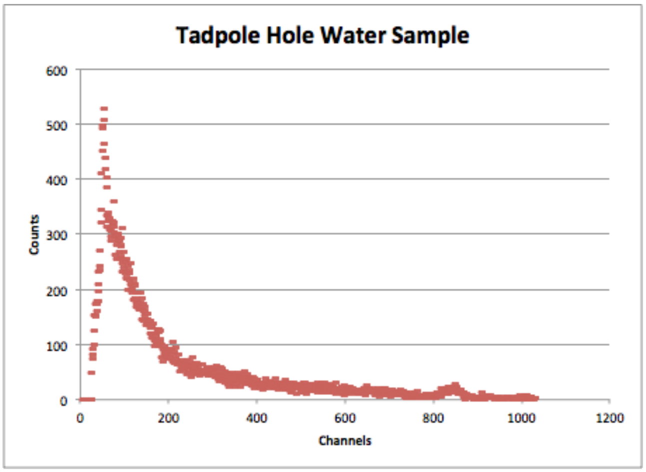
The dust samples were also placed under the MCA and NaI Tube. The MCA gives a graph with peak energy levels, which can be matched to theoretical values. Looking at the energy spectrum of the dust provided for another form of identification for the isotopes within the dust.

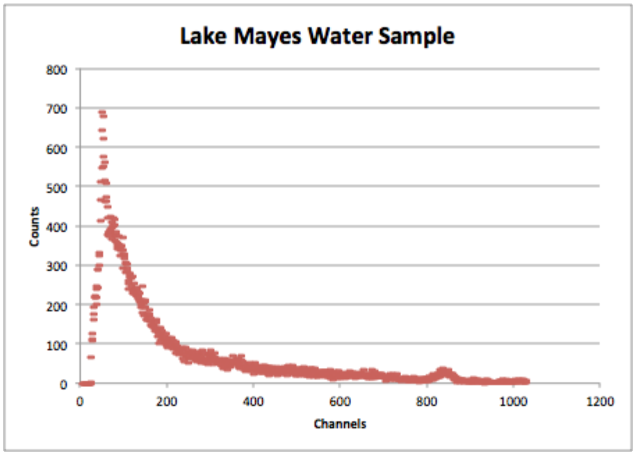
Samples of the crushed dogwood leaves were packed into small metal discs. These discs were then placed under the MCA inside the lead housing, providing a gamma spectrum of the sample. A gamma spectrum was used because the isotope being measured, Potassium-40, decays by gamma decay with a peak energy at 1.460 MeV. The ash burnt down from the dogwood branches were also compressed into the same style metal discs as the leaf samples, as well as analyzed under the MCA in the same fashion. This was due to the fact that the same radioisotope was being looked at.

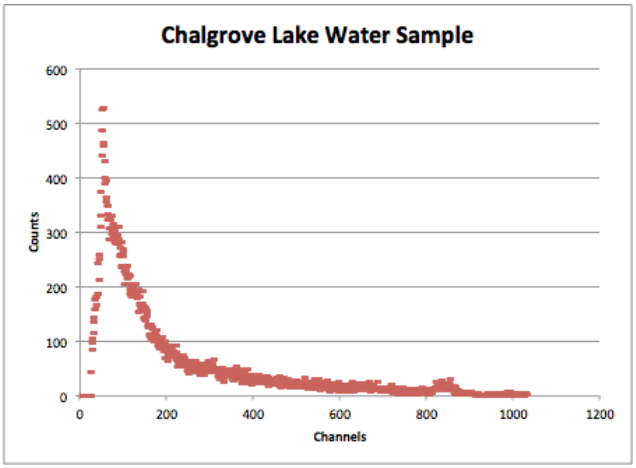
Water samples were poured over Fisherbrand glass fiber circles. The G8, G6, and G4 filters were tested to see which provided the clearest gamma spectrum under the MCA. The G6 and G4 provided the best spectrums, but due to availability the G4 was used. The G4 filter has a particle retention of 1.2 μm and a thickness of 0.28 mm. Water from each of the locations were poured over a G4 filter until it was soaked through and then placed under a heat lamp to dry. Once dry, filters were placed under the MCA to look for radioisotopes contained in the water.

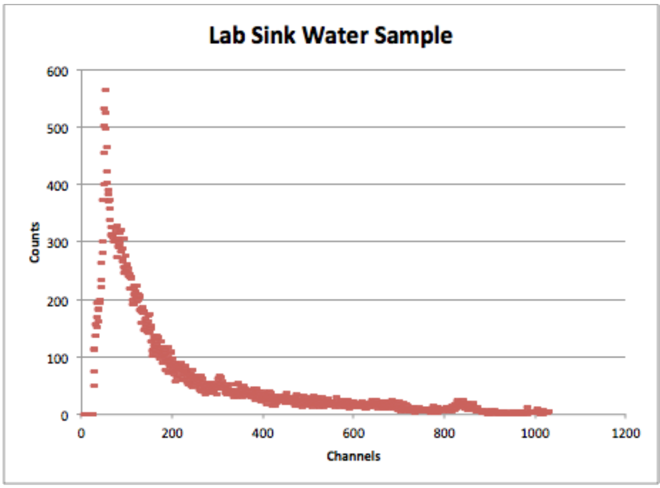
Type of Radiation	Nuclide	Half-life
α	Uranium-238	4.5 x 10^9 years
β	Thorium-234	24.5 days
β	Protactinium-234	1.14 minutes
α	Uranium-234	42.33 x 10^5 years
α	Thorium-230	8.3 x 10^4 years
α	Radium-226	1590 years
α	Radon-222	3.825 days
α	Polonium-218	3.05 minutes
β	Lead-214	26.8 minutes
β	Bismuth-214	19.7 minutes
α	Polonium-214	1.5 x 10^-4 seconds
β	Lead-210	22 years
β	Bismuth-210	5 days
α	Polonium-210	140 days
	Lead-206	stable

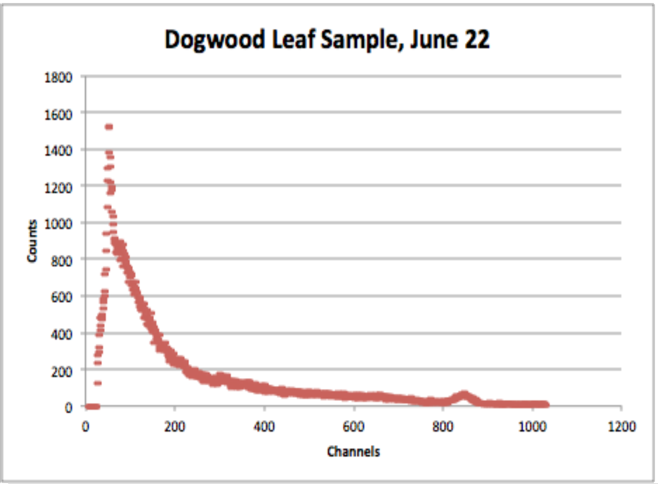


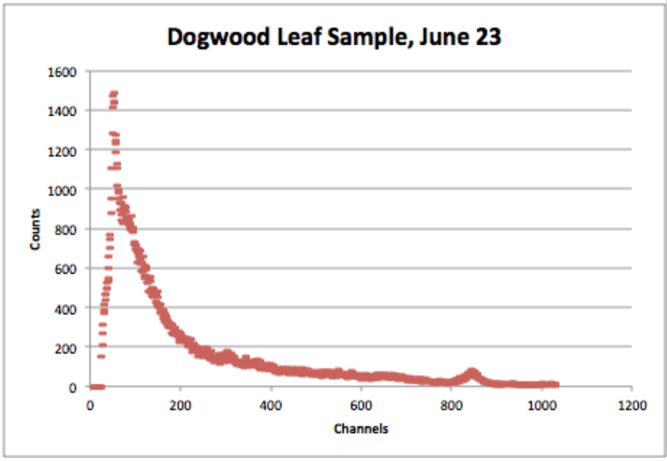


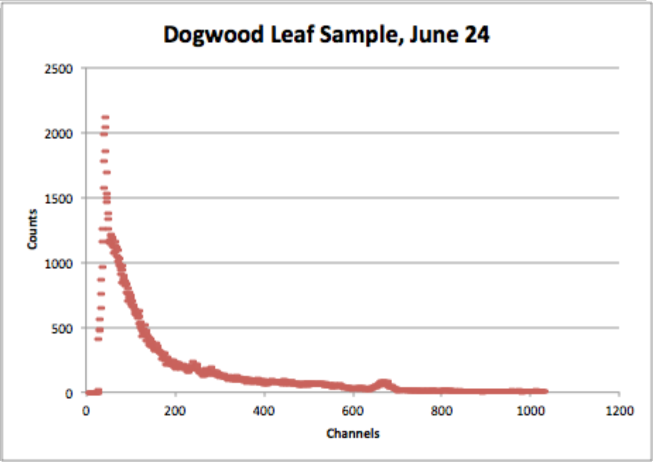

Lake Mayes Water Sample

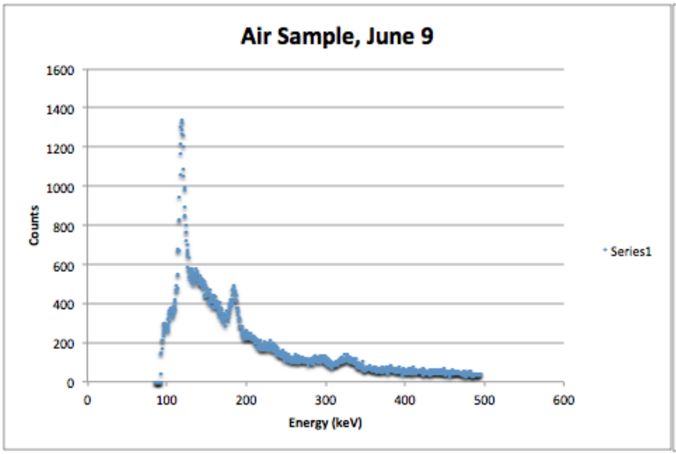

Chalgrove Lake Water Sample

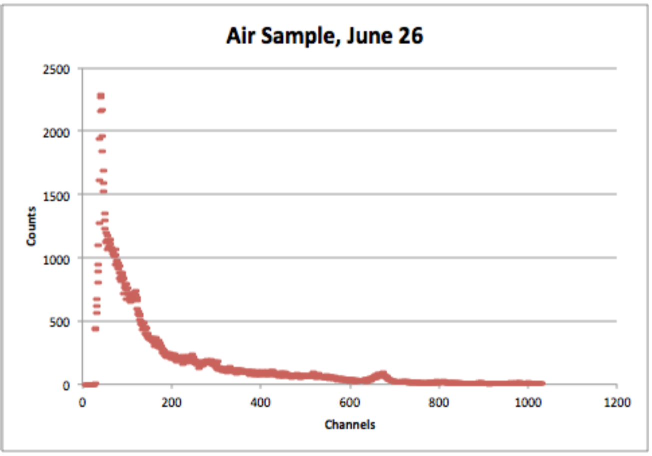

Lab Sink Water Sample

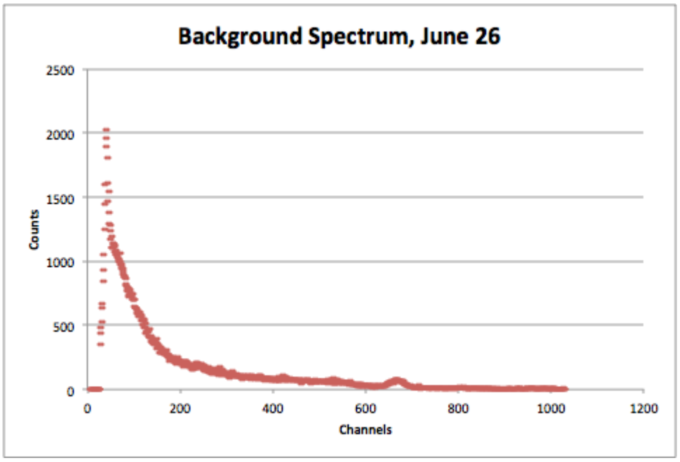

Dogwood Leaf Sample, June 22


Dogwood Leaf Sample, June 23


Dogwood Leaf Sample, June 24







Graphs from left to right:

Row 1: Image 1.1; Image 1.2

Row 2: Graph 1.1; Graph 1.2

Row 3: Graph 1.3; Graph 1.4

Row 4: Graph 1.5; Graph 1.6

Row 5: Graph 1.7; Graph 1.8

Row 6: Graph 1.9; Graph 1.10

Row 7: Graph 1.11

Image 1.1: Decay Chain of Uranium-238
Image 1.2: Map of Hampden-Sydney College campus
Graph 1.1: Gamma Spectrum of the water sample collected from the stream on the Wilson Trail
Graph 1.2: Gamma Spectrum of the water sample collected from Tadpole Hole
Graph 1.3: Gamma Spectrum of the water sample collected from Lake Mayes
Graph 1.4: Gamma Spectrum of the water sample collected from Chalgrove Lake
Graph 1.5: Gamma Spectrum of the water sample collected from the lab sink in the Gilmer basement
Graph 1.6: Gamma Spectrum taken same day of collection of the sample
Graph 1.7: Gamma spectrum taken day after collection of the sample
Graph 1.8: Re-calibrated gamma spectrum taken two days after collection of the sample
Graph 1.9: Gamma Spectrum of the dust sample collected in the Gilmer Lab
Graph 1.10: Gamma Spectrum of the dust sample collected in the Gilmer Lab

Graph 1.11: Background spectrum with the Potassium-40 peak at Channel 645

Data & Analysis

For much of the experiment, there was not conclusive enough data to support claims of higher than normal concentrations of radioisotopes on Hampden-Sydney's campus. The crushed leaf samples from the dogwoods were collected, dried, and placed under the MCA the day of collection and in the days after. All of the gamma spectrums from the leaf samples suggest that there was no more than background radiation, namely Potassium-40, present in the leaves. The spectrums are seen in Graph 1.6 through Graph 1.8. For the first two spectrums of the leaf samples, Graph 1.6 and Graph 1.7 show a small increase around channel 840. On the re-calibrated Graph 1.8, this increase is at channel 663. Both of these channels are at the location of the expected Potassium-40 peak, at 1416 keV. However, these peaks are not large enough to indicate there is any radiation above the background spectrum from Graph 1.11.

The water samples collected were also placed under the MCA after they had been dried on the glass fiber circles. From the gamma spectrums of the water samples, no heightened levels of Potassium-40 were seen. Graphs 1.1 through 1.5 show each of the gamma spectrums of the collected water samples. The peak for Potassium-40 occurs at 1416 keV, which in the spectrums is at channel 645. At this channel on all of the gamma spectrums, there are no peaks in counts to suggest a high concentration of Potassium-40. In addition to the leaf and water samples, the dogwood branch ash samples did not provide any peaks in their gamma spectrum to suggest levels of radioisotopes above the background, seen in Graph 1.11.

However, in the dust samples collected from the air, there was some evidence of radioisotopes. The gamma spectrums collected from the dust samples suggest there may be gamma emitting isotopes in the air. However, a conclusive way to detect for the alpha radiation emitted by Radon-222 was not created or discovered during this duration of the experiment. Graph 1.9 and 1.10 show the gamma spectrums of the dust samples collected from the air in Gilmer on the dates indicated. Graph 1.10 is calibrated to the same degree as Graph 1.8. There is evidence of low level gammas being emitted which could be from a radioisotopes further down the decay chain of Radon-222.

Hampden-Sydney College should be encouraged by these results because there are no current signs of large amounts of natural radiation on the campus. If there were high levels of radioisotopes, the health effects from the radiation could not only be detrimental to the college's reputation but also to the students' health.

The results from the air need to be further analyzed to confirm what exactly is in the air. Due to the age of the Gilmer building, the radon protection in the building may not be as apt as new systems.

Conclusion

During the course of the experiment, the radioisotopes of Potassium-40 along with Radon-222 were attempted to be detected in the ecosystem of Hampden-Sydney's campus, both outside and in the basement of Gilmer. The result of the gamma spectroscopy along with almost no conclusive data from a faulty GM Tube seem to indicate that there are no heightened levels of Potassium-40 on the campus. Indefinite results from the dust samples require further analyzation to determine the true levels of radon gas in the Gilmer basement. Error during this experiment came from equipment not being as efficient as expected. The use of a germanium tube would have helped with accuracy. Also, an effective way to measure alpha decays would have improved results.

Future Work

Further studies of the air in the basement of Gilmer is recommended. Using a radon test kit bought commercially along with looking more at the half lives could help to identify the amount of radon gas.

To further investigate the levels of Potassium-40 in the ecosystem of Hampden-Sydney, an analysis of the soil at various locations around the campus would give a larger range of data analyzed.

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