The Optical Properties of Aerogel

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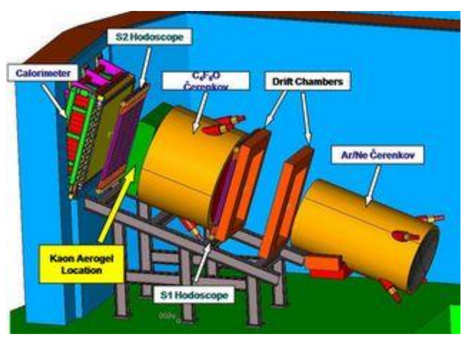
Abstract

Aerogel is being used in the construction of the kaon aerogel Cerenkov detector. This detector will be used at Jefferson Lab Hall C, to be part of the Particle Identification system of the Super High Momentum Spectrometer (SHMS). Kaons are identified through Cerenkov radiation. Depending on the refractive index of the aerogel, kaons of different momenta can be detected and distinguished from protons. Therefore, a uniform refractive index in the detector is important to reduce uncertainty in particle identification. The refractive index of aerogel is also directly related to its density. The density of the aerogel has the potential of being changed if the aerogel absorbs the humidity in the air around it or comes into direct contact with liquid water. To test how likely this is to happen, we used a humidity controlled environment calibrated between 80 and 100 percent relative humidity on aerogel from Matsushita Electric Works, Ltd and Japan Fine Ceramic Center and tested direct water contact on tiles from Matsushita Electric Works, Ltd Japan Fine Ceramic Center and Novosibirsk . We found that the effect on the tiles from Matsushita Electric Works, Ltd and Japan Fine Ceramic Center was little to none and that the effect on the Novosibirsk was severe. Finally, we tested the transmittance of aerogel tiles with a UV/Vis photospectrometer to find the correlation between transmittance and the tile's properties. Tiles with the highest transmittance will allow for the most accurate detection of Cerenkov radiation. The properties of aerogel from Matsushita Electric Works, Ltd and Japan Fine Ceramic Center were found to not be affected by the humidity in their environment.


Introduction

As explained in Reference 1, silica aerogel is a light, porous material that consists mostly of air. Aerogel can be made at different densities which in turn affects its refractive index. Within the field of nuclear physics, aerogel is used as a detector for kaons using Cerenkov radiation. One of these detectors is located at Jefferson Laboratory. At Jefferson Lab, there is an electron accelerator which connects to each of the different halls. In Hall C, the electron collides with a proton. The proton, due to the velocity at which the electron is coming, either flies off as a whole or breaks into smaller particles, often including kaons, and the different parts fly off. In order to distinguish which of the two happened, the particles go through a series of detectors including the Kaon Aerogel Detector which distinguished protons from kaons. A picture of a detector can be seen below in Figure 1. Within the Kaon Aerogel Detector the momentum of the kaons must be greater than the aerogel's threshold so that it will create Cerenkov radiation and the momentum of the proton must be less than the aerogel's threshold so that it will not create Cerenkov radiation. Because only the kaons will create Cerenkov radiation the protons and kaon can be distinguished. The threshold changes depending on the refractive index of the aerogel. To calculate at what range the above situation will be true the threshold must first be identified. Then, using that velocity and the mass of the particles it can be calculated at what momentum each will create Cerenkov radiation. The momentum of the incoming particle must be between that range. In order to ensure that particles with the correct momenta are going through the detector they are first sent




***(Figure 1: Kaon Detector)***

through a magnetic field. Depending on their velocity they will travel different distances through the magnetic field and therefore will separate out into their different velocities. Detectors are positioned at the different distance. The information generated from the detector positioned for desired velocity is then analyzed. The particle that travels through the aerogel will then either create Cerenkov radiation as it goes through or it will not. If there is Cerenkov radiation it was a kaon, if there is not it was a proton. The momentum range for SP-30's is (3.8009, 2.001), for SP-20's is (4.667, 2.458), and for SP-15's is (5.395, 2.841) GeV/c. Because the range for the momentum is small, it is important to have a uniform refractive index within the detector. Therefore, we tested the aerogel that is going to be put into the detector. Nominally the refractive indices were 1.03, 1.02, and 1.015; we tested specific tiles to see how tightly they were clustered.

The porous nature of aerogel could allow for the humidity in the air around the aerogel to be absorbed. In absorbing more moisture, the density of the aerogel would increase which would in turn increase the refractive index. The possibility of this occurrence is looked at in Reference 1. Depending on how much water was absorbed by the different tiles, the refractive index would lose its uniformity and the results from the Cerenkov radiation would not be accurate. Therefore, we tested the effect of humidity on the tiles. Using a Honeywell HCM-630 Quietcare™ Cool Moisture Humidifier, an airtight Snapware container and water-resistant clear polyurethane tubing we built a humidity controlled environment. We then tested the aerogel from Matsushita Electric Works, Ltd and Japan Fine Ceramic Center.

We then tested the effect of water drops on aerogel tiles to test their hydrophobicity by putting drops of water on the different tiles and taking pictures of them. We tested tiles from Matsushita Electrical Works, Ltd, Japan Fine Ceramic Center and Novosibirsk. Depending on the shape of the drop the material was either hydrophobic or hydrophilic. Reference 1 explains the chemistry behind this process.

The transmittance of the aerogel can affect the ability to detect Cerenkov radiation. To test and see how uniform the transmittances of tiles from the same refractive indices were we used a PerkinElmer Lambda 750 UV/Vis/Nir Spectrometer.

## Materials and Methods

### Testing Refractive Index

A picture of the set-up can be seen below in Figure 2. To find the refractive index, we raised the Craftsman Laser Trac Level (laser) up 59 mm using 2 lead bricks with a metal rod protruding from the middle that supported the laser. 385 mm away (measured from the laser to where the tip of the aerogel tile would be) there was a base made from 4 lead bricks all laid horizontally with two on the bottom and two on the top. On top of the base were graph paper and 2 bricks covered in paper that made a 45 degree angle in order to correctly place the aerogel, as can be seen in the picture. Finally (measuring from where the corner of the aerogel would be) a lead brick standing vertically and covered in paper was placed 1143.8 mm away. To find the refractive index we used the following equation: $n = 1.0003\sqrt{sin^2(\alpha)((1+1/tan(\beta))^2) + \left(\frac{2\sin(\alpha)\sin(\gamma-\alpha+\beta)}{\tan(\beta)\sin(\beta)}\right) + ((\frac{\sin(\gamma-\alpha+\beta)}{sin(\beta)})^2)}$ . This equation was derived using Snell's Law. $\alpha$ is the incident angle of the laser and the aerogel. It was kept constant at 45 degrees. $\beta$ is the angle of the corner of the aerogel being tested and was assumed to be 90 degrees. $\gamma$ is the angle between the refracted beam and the unrefracted beam that went above the aerogel. It was measured by finding the arctangent of the distance from $\beta$ and the wall (L) and the distance between the refracted and unrefracted beams(x). L was kept constant by keeping the placement of the aerogel and the wall

constant. x was the only variable to measure and was measured using a Mitutoyo CD-6" B electric caliper. Using the value for x the refractive index was then found and recorded using Excel. Note: do not touch the aerogel with your bare hands, it will damage the tile***.***

***(Figure 2: Refractive Index Set-Up)***

Testing the Effect of Humidity

A picture of the set-up can be seen below in the Figure 3. In order to test humidity's effect on aerogel we first found the original refractive indices using the method above. We then built a humidity controlled environment. Starting with a Honeywell HCM-630 Quietcare™ CoolMoisture Humidifier we attached a funnel to the output area of the humidifier using electrical tape. We then attached the clear tubing to the end of the funnel by fitting the funnel inside of the tubing and securing it with electrical tape. In order to attach the tubing to the Snapware we drilled a 5/8" hole through one of the sides of the Snapeware, inserted the tubing into the hole and secured it with electrical tape (electrical tape was used for its water proof qualities). Finally, to avoid a buildup of pressure within the humidity controlled box we drilled 18 small holes into the lid of the Snapware container. We then ran tests on the aerogel for 24 hours at the humidifier's highest setting, 84% +/- 2% relative humidity. To increase the humidity we then added 100 ml of water to the bottom of the container and placed the aerogel on top of a plastic base inside. These tests were also run for 24 hours and had an average relative humidity of 91% +/- 2%. The humidity was monitored using an Extech 445815 Humidity Meter and a GSI Quality Handheld Pen-Shaped Hygro Thermometer. Finally, to test the effect of water directly placed on the aerogel we put the aerogel on a flat surface and, using a dropper, added 2 or 3 drops of water. We then took pictures of the outcomes and analyzed the shapes of the drops.

***(Figure 3: Humidity Testing Set-Up)***

Testing Aerogel's Transmittance

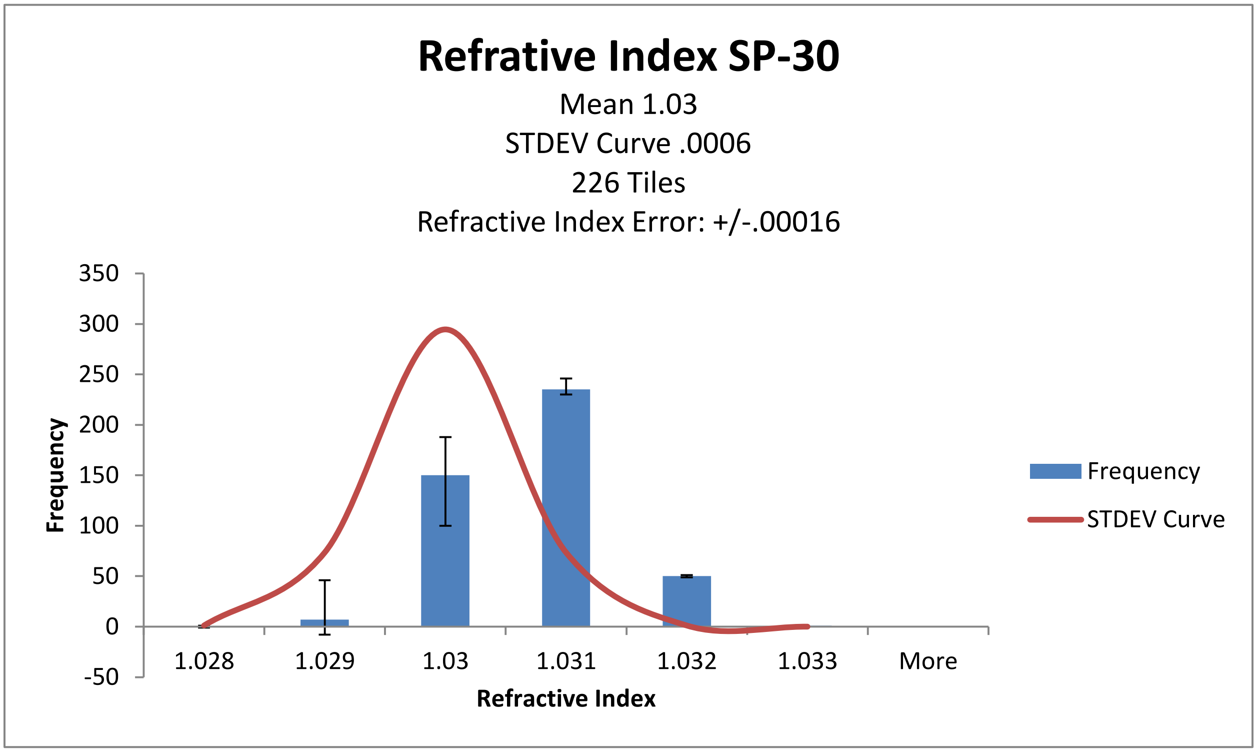
Using a PerkinElmer Lambda 750 Uv/Vis/Nir Spectrometer we tested the transmittance of the aerogel tiles. Using wavelengths of 900 nm to 200 nm in 10 nm steps the spectrometer tested how much light could travel through the aerogel as opposed to air. This tells us how well we will be able to detect the Cerenkov radiation within the tiles. We analyzed the data using Excel.

<u>Results</u>

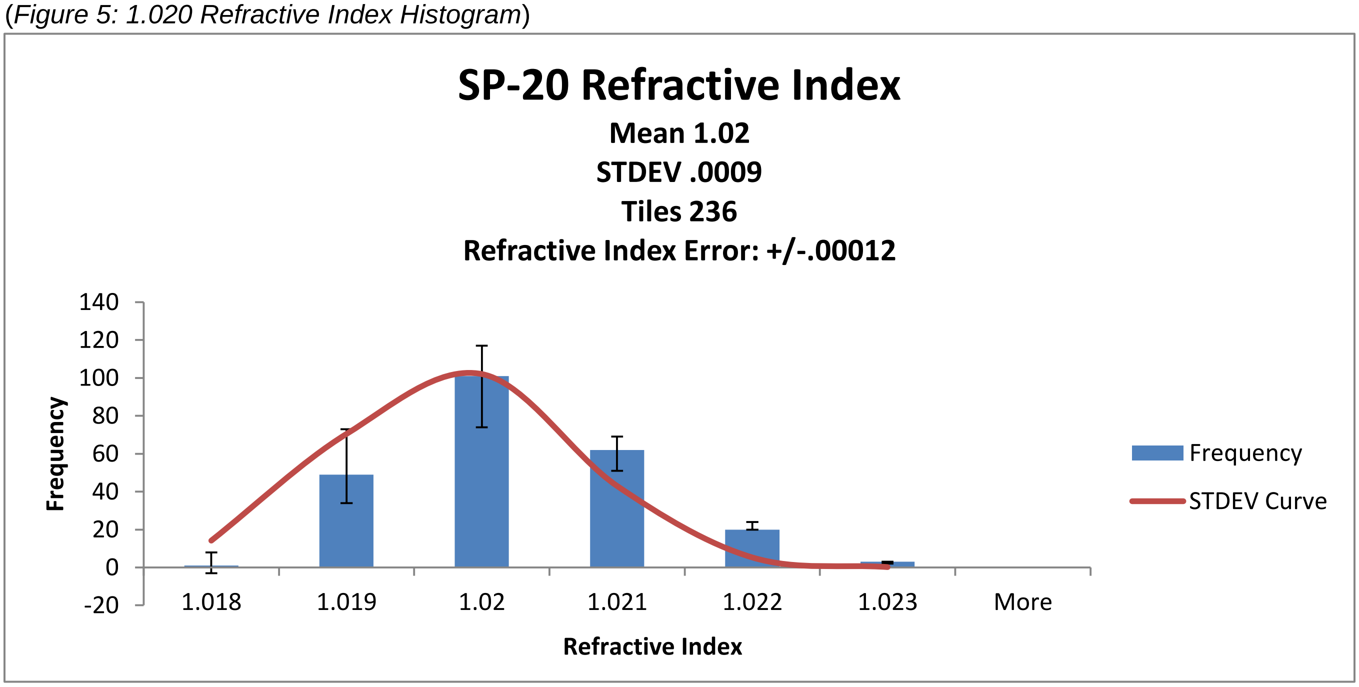
Testing Refractive Index

The results can be seen in the Figures 4 through 6 below. Figure 4 shows the distribution of tiles with a refractive index of 1.03. The tiles are clustered around the mean of 1.03 and have a standard deviation of .0006. In Figure 5 are the tiles with the refractive index of 1.015 which center around 1.015 and have a standard deviation of .0003. Figure 6 shows the tiles with a refractive index of 1.02. The tiles are centered around the mean 1.02 and have a standard deviation of .0009. Tiles of the same refractive index are very uniform and follow a Gaussian curve.

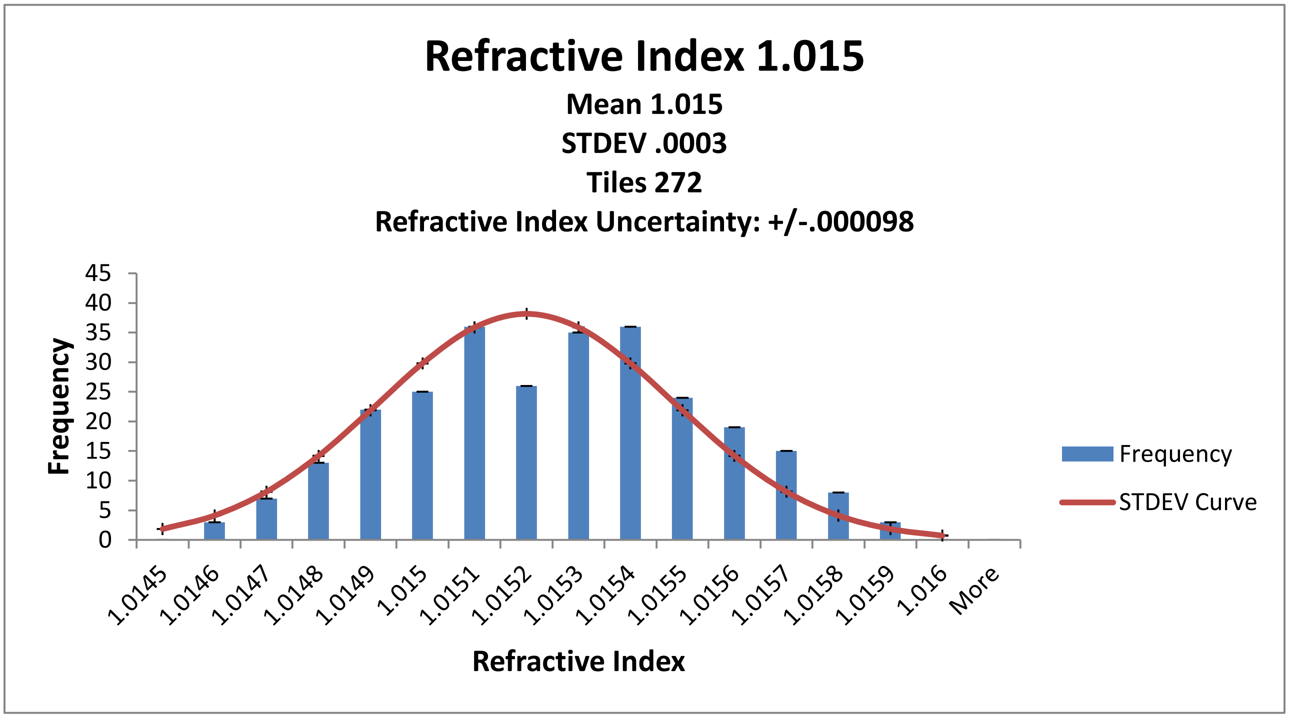
(*Figure 4: 1.030 Refractive Index Histogram)*




(*Figure 5: 1.020 Refractive Index Histogram*)



*(Figure 6: 1.015 Refractive Index Histogram: Error bars not shown because the scale of the graph is such that every point would change)*

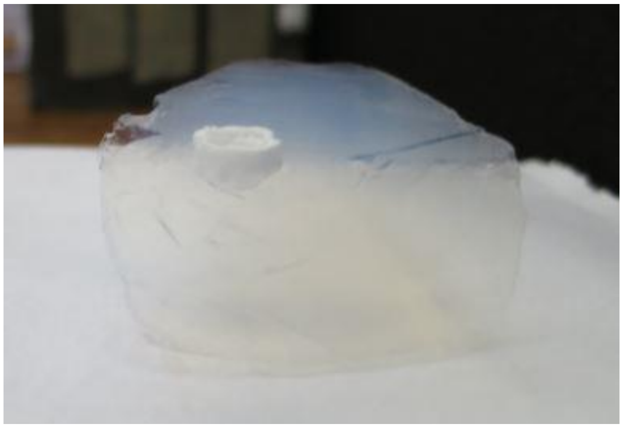



Testing the Effect of Humidity

Humidity does not affect aerogel from Matsushita Electric Works, Ltd and Japan Fine Ceramics Center because of their hydrophobic coating (as can be seen in Figure 7) but severely damages the aerogel from Novosibirsk which does not have the hydrophobic coating (as can be seen in Figure 8).

*(Figure 7: Hydrophobic Tiles Humidity Testing)*

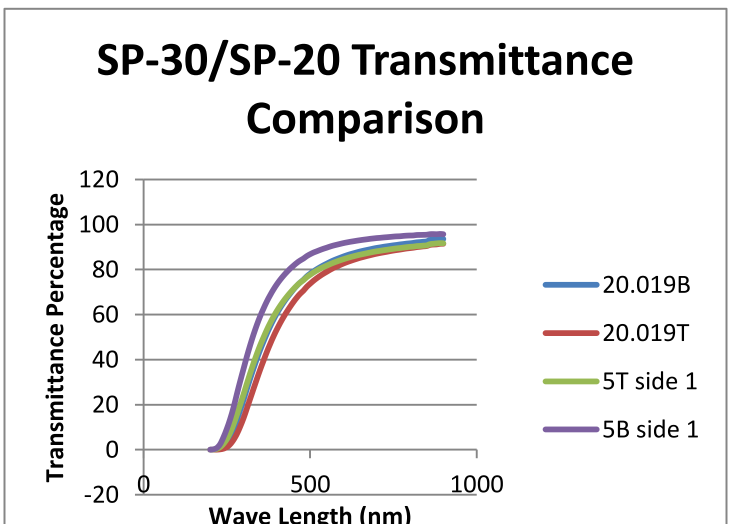
| Tile Number | Refractive Index Before | Average Humidity | Refractive Index After 24 Hours | Change in Refractive Index |
|---|---|---|---|---|
| **Control** | | | | |
| **20.012B** | 1.01966+/-.00012 | 55%+/-2 | 1.01966+/-.00012 | 0 |
| **Tests** | | | | |
| **15.022B** | 1.01511+/-.000098 | 84% +/-2 | 1.01586+/-.000098 | +.00075 |
| **15.112B** | 1.01573+/-.000098 | 83% +/-2 | 1.01577+/-.000098 | +.00004 |
| **15.127B** | 1.01524+/-.000098 | 83% +/-2 | 1.01514+/-.000098 | -.00010 |
| **30.035B** | 1.03063+/-.00016 | 83%+/-2 | 1.03059+/-.00016 | -.00004 |
| **20.035B** | 1.02000+/-.00012 | 92%+/-2 | 1.02033+/-.00012 | +.00010 |
| **20.02B (Dry)** | 1.02025+/-.00012 | 95%+/-2 | 1.02028+/-.00012 | +.00003 |
| **20.02B (Wet)** | 1.02025+/-.00012 | 100%+/-2 | 1.02032+/-.00012 | +.00007 |



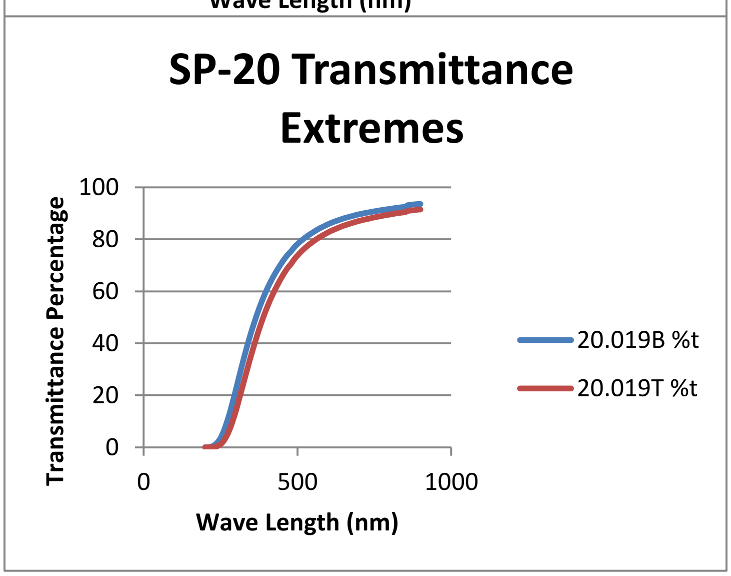
*(Figure 8: Hydrophilic aerogel damaged due to water drops)*

Testing Aerogel's Transmittance

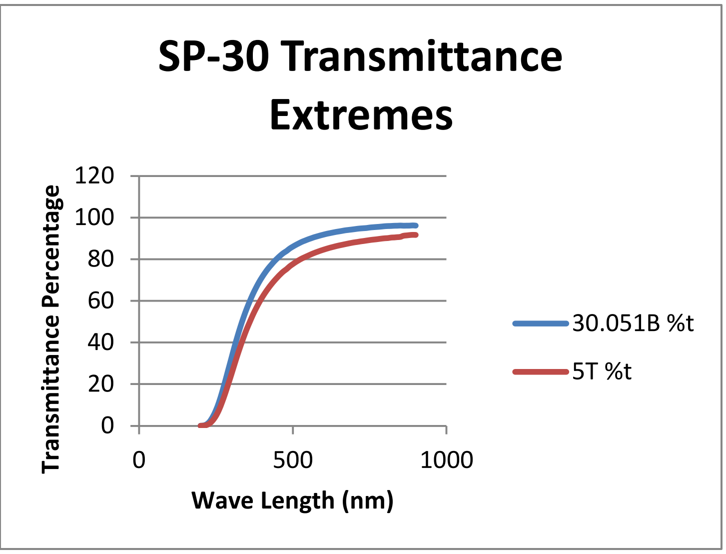
SP-30 tiles have a higher transmittance than SP-20 tiles from the same company. A comparison can be seen in Figure 9. The transmittances for different tiles of the same refractive index are tightly clustered. This can be seen in Figures 10 and 11. There is a transmittance uncertainty of +/-0.1%.




*(Figure 9: SP-20/SP-30 Transmittance Comparison)*




*(Figure 10: SP-20 Transmittance Extremes. Transmittance within the same refractive index was largely uniform)*




*(Figure 11: SP-30 Transmittance Extremes. Transmittance within the same refractive index was largely uniform)*

## Discussion

### Testing Refractive Index

The majority of the aerogel tiles were tightly clustered with their nominal refractive index. The SP-30 tiles had a mean value of 1.030 and a standard deviation of .0006. The uncertainty in the refractive index measurements was +/-0.000160. For the SP-20 tiles, the mean was 1.020 and the standard deviation was 0.0009. The uncertainty in the refractive index measurements was +/- 0.000120. Finally, the SP-15 tiles had a mean of 1.015 and a standard deviation of .0003. The uncertainty in the refractive index measurements was +/-0.000098. Because of their tight clustering the tiles should give uniform Cerenkov radiation readings and distinguish between protons and kaons accurately.

### Testing the Effect of Humidity

The average change due to humidity for the hydrophobic tiles from Matsushita Electric Works, Ltd and Japan Fine Ceramic Center was +0.00012. The effect of humidity and direct liquid water contact was minimal and should not affect the uniformity of the refractive indices of the aerogel in the Kaon Aerogel Detector. The hydrophilic aerogel from Novosibirsk was severely damaged from direct water contact and should not be used in the detector. We could not measure the refractive index of the Novosibirsk aerogel because of the damage it had already sustained and therefore did not run humidity tests on it.

### Testing Aerogel's Transmittance

The transmittance of tiles from the same refractive index was largely uniform allowing for Cerenkov radiation reading to be uniform as well. SP-30 tiles were found to have a higher transmittance than SP-20 tiles.

## References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