Solving the Carbon Dating Problem for the Shroud of Turin

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Abstract

There are multiple evidences that the Shroud of Turin is the authentic burial cloth of Jesus Christ. However, in 1988 samples from the corner of the Shroud were carbon dated to 1260-1390 AD (two-sigma). The "carbon dating problem" is how the Shroud of Turin could be the authentic burial cloth of Jesus yet the corner of the Shroud carbon date to 1260-1390 AD. This problem can be solved by understanding the assumptions in carbon dating and understanding how measurement errors can affect experimental results. Carbon dating indicates three things are true at the 1988 sample location on the Shroud: the date, slope, and range/distribution of the subsample dates. A fourth item is the carbon date obtained for the Sudarium of Oviedo, which is believed to be Jesus' face cloth (John 20:7) and thus related to the Shroud. The correct explanation for the carbon dating of the Shroud is required to be consistent with these four things. The neutron absorption hypothesis proposes that neutrons emitted from the body were absorbed in nitrogen in the cloth to form new C-14 in the fibers, thus shifting the carbon date forward. This is the only hypothesis that satisfies all four requirements. The assumption that the Shroud dates to 1260-1390 only satisfies the first of these four requirements.

1. Introduction

This paper documents the author's presentation March 26, 2022, at a two-day conference on Christian apologetics at the Southern Evangelical Seminary in Charlotte, North Carolina. This conference was organized by the International Society of Christian Apologetics (ISCA).

A large piece of cloth in which a person is buried is called a shroud. Turin, also called Torino, is a city in north-western Italy. Thus, the Shroud of Turin refers to a particular burial cloth that has been in Turin, Italy since 1578. The Shroud is a linen cloth about 4.4 m long by 1.1 m wide (14 feet 5 inches by 3 feet 7 inches). It is about as thick as a man's T-shirt (about 0.35 mm) and is very pliable. Ancient tradition has long claimed it to be the authentic burial cloth of Jesus Christ. This claim is supported by the full-size front and dorsal (back) images of a man who was crucified exactly as Jesus was crucified according to the Gospels in the New Testament, yet extensive testing in 1978 indicate these images are not due to pigment, scorch, liquid, or photography. These test results make it difficult to understand how the images could have been produced by a painter or forger, thus making it more likely the images were formed by the body that was wrapped in the Shroud.

According to the New Testament, Jesus died by crucifixion on a cross to pay for the guilt of our sin to reconcile us to God. After his death, while he was still on the cross, a cloth was probably wrapped around his head to catch blood that would have drained from his nose and mouth after his death. This allowed the collected blood to be buried with the body according to Jewish custom. This was the custom because "the life … is in the blood" (Lev. 17:11) was interpreted to mean that the soul was in the blood. The face or head cloth was evidently left on his head as the body was removed from the cross and transported to the tomb. In the tomb, his body was laid on top of half of the long linen body cloth purchased by Joseph of Arimathea (Mk. 15:46). The person at the front of the pit or standup area in the tomb, perhaps the Apostle John (John 20:8), evidently then removed the face or head cloth and folded or rolled it up and laid it aside in the tomb (John 20:7). The other half of the long body cloth was then wrapped over the top of his head and down to the feet. Narrow strips of cloth could have been used to tie the body cloth at the feet, to hold the arms down on the body, to hold up the lower jaw, etc.

The long body cloth and the smaller face cloth would have had Jesus' blood on them, so it is doubtful the apostles would have left them in the tomb. It is very doubtful they would have reused them, burnt them, or thrown them out, and they would have taken steps to prevent them from being destroyed by political or religious leaders. Linen is insect resistant and only decays very slowly by oxidation and dehydration. Under these conditions, we may expect them to still be in existence, but where should we expect them to be? Given church history, if they were still in existence, they would most likely be found in association with the Catholic Church. The Shroud of Turin is consistent with this expectation for Jesus' body cloth, since it is in the Catholic cathedral in Turin, Italy. The Sudarium of Oviedo is consistent with this expectation for the face cloth, since it is in the Catholic cathedral in Oviedo, Spain.

The solution to the carbon dating problem for the Shroud that is discussed in this paper is part of a larger hypothesis to explain the main mysteries of the Shroud including formation of the front and dorsal images on the Shroud, the carbon dating of the Shroud, and why blood that would have dried on the body is now on the Shroud. To explain these three mysteries, the radiation burst hypothesis [12, 13, 18] proposes that an extremely brief, extremely intense burst of vertically collimated radiation was emitted from within the body as it was wrapped in the Shroud. This hypothesis was developed by following the Shroud's scientific evidence where it leads. This hypothesis proposes that: 1) charged particles in this radiation burst produced the images by electrical heating and/or chemical attack by ozone produced by a static discharge from the top fibers facing the body, 2) neutrons in this radiation burst were absorbed in N^{14} to produce new C^{14} in the fibers that could have shifted the carbon date forward by thousands of years depending on the location on the Shroud, and 3) as these vertically collimated particles exited the body, they would have hit the blood that had dried on the skin, transferred momentum to the dried blood, thus forcing the blood vertically off the body onto the Shroud.

2. Images on the Shroud

In Figure 1, the top image shows the Shroud as it would normally be seen. It shows two long horizontal scorch marks caused by a fire in 1532 when it was in Chambery, France. Also shown are water stains resulting from water thrown onto the box containing the Shroud after the fire and sixteen patches used to repair one burned corner of the Shroud as it was folded in the box. The images of the crucified man can be seen between the scorch marks. The front image is on the left with head, arms, torso, and legs visible. The back or dorsal image is on the right, with the head toward the left and the feet on the right. The bottom image in Figure 1 is the photographic negative of the Shroud, but it shows the body as a positive image. This means the images on the

Shroud are negative images, with light and dark areas reversed. It is important to note there are no images of the sides of the body or the top of the head, and the front and dorsal images are head-to-head.

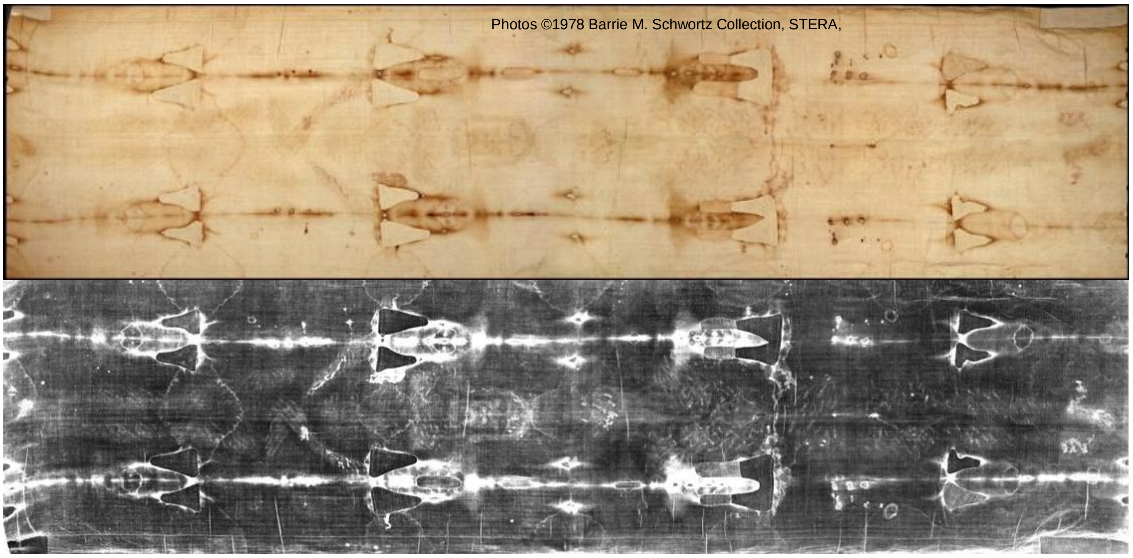


Figure 1. The Shroud of Turin, as Seen (Above: negative images) and the Camera Negative (Below: positive images)

Vertical views of the images are shown in Figure 2. The front image shows puncture wounds in the scalp as would occur from a cap of thorns. It shows a swollen cheek, bent nose, and a two-inch elliptical wound in the side the size of a Roman thrusting spear, with blood running down from it separated into red and clear components. The clear components contain blood plasma and clear watery fluid from the pleural cavity. This indicates the side wound is a post-mortem (after death) wound.

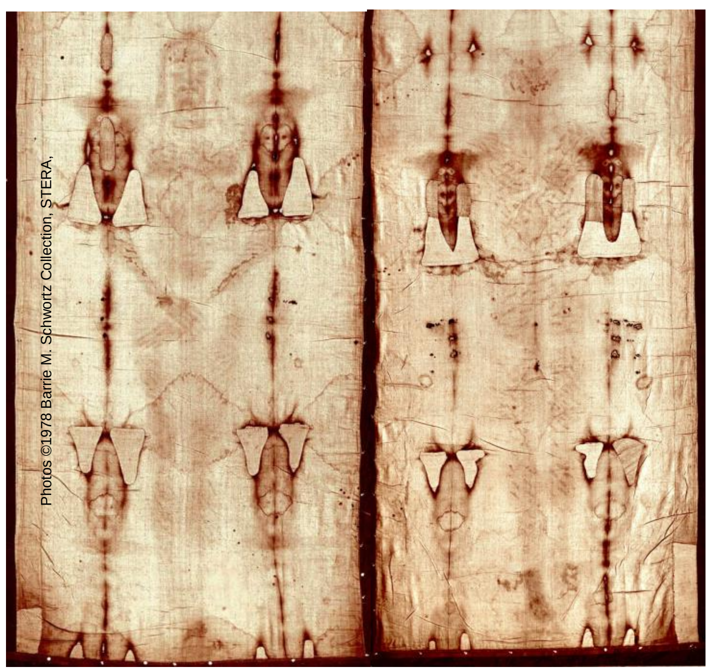


Figure 2. Front and Dorsal (back) Images on the Shroud, Negative Images

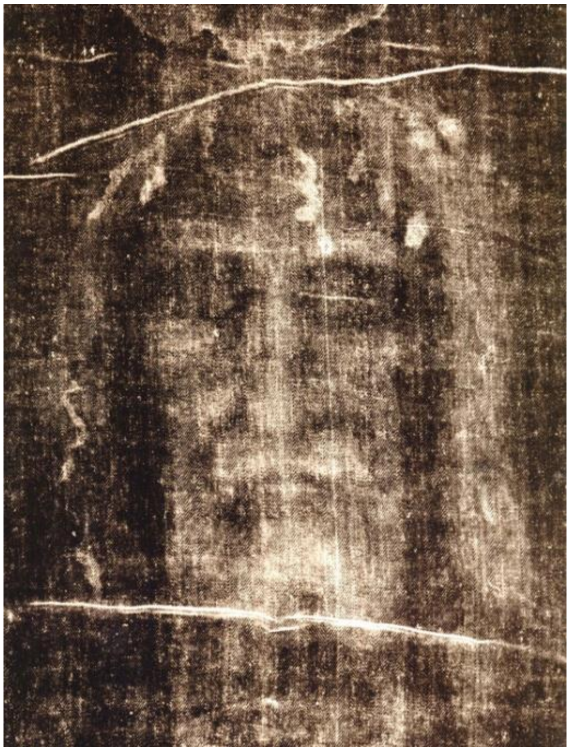
The front image also shows the nail wound through the wrist, contrary to paintings in the middle-ages which had the nails going through the palm. We now know a nail through the palm would not support sufficient weight because it would have no bones above it. The image does not show the thumbs, also contrary to paintings in the middle-ages. When the nail was forced through the wrist at that location, it would have crushed the nerve that passes through that location. All the nerves from the fingers and the thumb connect into this nerve, so crushing it would have forced the thumb to collapse into the palm. Thus, in both respects (location of the nail wound and no thumbs visible), the image indicates it was not made in the middle-ages, contrary to the 1260-1390 AD carbon date for the Shroud.

The front image also shows blood ran down the arms from the wrist wounds, with two angles of flow consistent with the man pushing up and down on the cross to breathe. There are abrasions on the nose and one knee, suggesting the man had one or more falls. There is also a 3.2-inch-wide side strip sown onto the main Shroud using a unique professional stitch most like a stitch on a cloth from Masada, which was destroyed in 73-74 AD. This stitch indicates the Shroud is probably from the first century.

The dorsal or back image in Figure 2 shows puncture wounds in the scalp and abrasions on the shoulders consistent with carrying a rough heavy object. About 120 scourge marks are visible on the body from two Roman flagra containing dumbbell shaped weights on the ends of three straps, along with a flow of blood and clear blood serum and clear watery fluid from the pleural cavity that drained from the side wound and ran across the small of the man's back. Also, two nails were evidently placed through one foot with only one of the nails through the other foot. This would permit one foot to be rotated to allow the man to push up and down to breathe while crucified. The shape of the feet, being twisted together, indicates the presence of rigor mortis. This indicates the man was dead on the cross for long enough for rigor mortis to set in.

There are several unusual or unique features to the images on the Shroud. The images are negative on the cloth with light and dark areas reversed. They have no outline or brush strokes, and they contain 3D information [1, 2], which allows a 3D statue to be reconstructed from the 2D Shroud. No painting or photograph contains 3D information. Also, the Shroud contains no products of body decay. The front and dorsal images are head-to-head because the cloth was wrapped up the back of the body, over the head, and then down the front of the body.

Figure 3. A 1931 photograph of the Face by Italian photographer Giuseppe Enri.

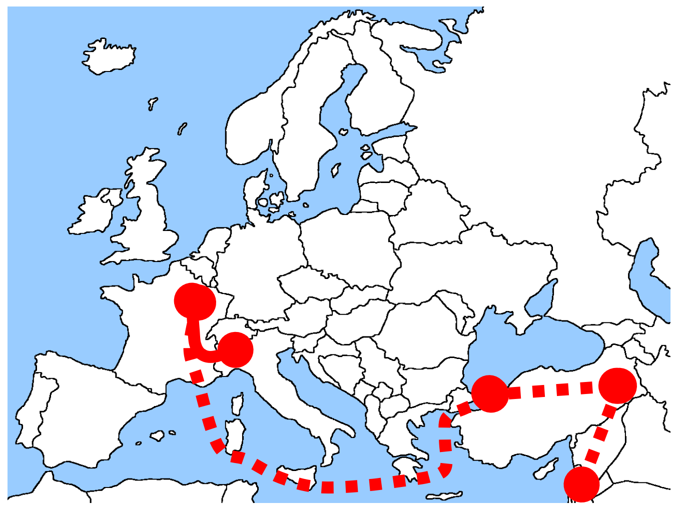


In 1931, the photo in Figure 3 was taken of the face on the Shroud by a professional photographer named Giuseppe Enri. This image shows that the face on the Shroud is an exact front view with long nose, mustache, beard, and hair parted in the middle coming down on both sides of the head, with the hair a little longer on one side than the other. This image appeared in paintings starting about 550 AD and was on coins starting about 692 AD. Thus, this image long predates the carbon date (1260-1390 AD) and is the source of our concept of Jesus' appearance.

3. History of the Shroud

Figure 4 shows the route most Shroud researchers believe the Shroud has taken. Based on evidence of pollen from the Jerusalem area and chips of Jerusalem limestone on the Shroud, it is generally believed the Shroud started in Jerusalem but must have been evacuated from the city before the city was destroyed in 70 AD. The Shroud may have been taken to Antioch on the coast along with other relics. It may have been used for apologetic and evangelistic purposes in Galatia in central Turkey according to Galatians 3:1. It was probably taken to Edessa (Urfa), Turkey before being taken to Constantinople either in 574 AD as the "Image of God Incarnate" or in 944 AD as the "Image of Edessa" or Mandylion. The last reference to the Shroud in Constantinople was in 1204 AD at the time of the fourth crusade's sack of the city. Some believe it briefly went to Athens before being taken to Lirey, France where it was exhibited as the burial cloth of Jesus in about 1355 or 1356. The Shroud was brought into Turin, Italy in 1578 and has been kept in the Cathedral of St. John the Baptist in Turin since 1694.

Figure 4. History of the Shroud



4. Previous Research on the Shroud

It is often said the Shroud is the most researched artifact in human possession. Research on the Shroud can be divided into four periods. These four periods and their conclusions are summarized below.

1. 1898 to 1974: The images were formed by the body of a crucified man that was wrapped in the Shroud. This is indicated primarily by the nature of the blood on the Shroud.
2. 1975 to 1987: 3D information is discovered on the 2D Shroud. This led to formation of the Shroud of Turin Research Project (STURP) which was allowed to perform 120 hours of extensive experimentation on the Shroud. The experimental results indicate the images are not due to pigment, scorch, liquid, or photography. The methodology for image formation could not be determined.
3. 1988 to 2016: The Shroud was carbon dated in 1988 to a range of 1260-1390 AD, two sigma. They concluded that "The results provide conclusive evidence that the linen of the Shroud of Turin is mediaeval." This supposedly proved the Shroud could not be the authentic burial cloth of Jesus.
4. 2017 to 2022: Details of the 1988 carbon dating measurements and data analysis were finally released by the British Museum in 2017. Statistical analysis of the data proved the samples were not homogeneous, i.e., representative of the rest of the Shroud. This indicates the 1260-1390 AD date should be rejected, i.e., given no credibility.

5. The Carbon Dating Process

To determine how Jesus' burial Shroud could be carbon dated to 1260 to 1390 AD, it is necessary to understand the carbon dating process. Carbon dating can also be called radiocarbon dating or C^{14} dating. The carbon dating process can be separated into three phases:

1) The first phase is to remove samples from the item to be dated. The item must contain carbon such as from a dead plant or animal. These samples will be consumed in the carbon dating process, so they are usually a very small fraction of the entire item. To produce a valid date for the entire item, the samples must be representative of the entire item. This is usually best achieved by taking the samples from a variety of locations throughout the item. As we will see, this was not done for the 1988 dating of the Shroud because all three of the samples were cut next to each other from one corner of the Shroud.

2) The second phase is to measure the ratio of carbon-14 to carbon-12 (C^{14}/C^{12}) in each sample. In this process, each sample can be divided into subsamples which each have their C^{14}/C^{12} ratio measured, as was done in the 1988 dating of the Shroud. Each C^{12} atom contains six neutrons and six protons in the central nucleus of the atom (6 + 6 =12, which is the superscript on C^{12}), with six electrons in orbits around the nucleus. Each C^{14} atom contains eight neutrons and six protons in the nucleus of the atom (8 + 6 = 14, which is the superscript on C^{14}), again with six electrons in orbits around the nucleus. The additional two neutrons in the nucleus of the C^{14} atom causes it to be unstable so that it decays with a 5730-year half-life, which means that in each 5730-year period half the C^{14} will decay, and thus will no longer be present. The C^{12} atoms do not decay, i.e., are stable, so the C^{14}/C^{12} ratio will naturally decrease with a 5730-year half-life as the C^{14} atoms decay. As will be explained, it is most reasonable to believe that the C^{14}/C^{12} ratios for the Shroud subsamples were accurately measured, so that both the C^{14}/C^{12} ratios and their uncertainties should be believed.

3) The third phase is to calculate the date of the item from the C^{14}/C^{12} ratios, assuming the C^{14}/C^{12} ratios have only changed due to the decay of carbon-14 since the plant or animal died. However, this assumption is not necessarily true due to carbon with a different C^{14}/C^{12} ratio either being added or removed from the samples since the plant or animal died, or possibly due to neutron absorption producing new C^{14} in the samples. Thus, if the C^{14}/C^{12} ratios in the samples were changed by anything other than the decay of C^{14}, then the date calculated from the C^{14}/C^{12} ratios would not be the true date.

6. Measurement Errors

Every experimental measurement, including carbon dating, should produce two types of data, the measured value, and the measurement uncertainty. It is the measurement uncertainty that informs us how to understand the measured value, including whether the measured value should have any credibility. The issue of a measurement's credibility arises because some types of measurement errors can cause the measured value to be significantly different than the true value.

Scientific measurements, including carbon dating, can involve two types of measurement errors, random measurement errors and systematic measurement errors. A random error can cause a measured value to be a little higher than the true value one time and a little lower than the true value the next time. This random effect can be minimized by taking many measurements and averaging the results so that high and low errors will tend to cancel. In contrast to this, a systematic error in a measurement can cause all measurements to be significantly different than the true value, and this difference can always be in the same direction. This type of error is called "systematic" because the measured value is always either higher than the true value or the measured value is always lower than the true value. As a result, this type of error cannot be minimized by taking many measurements.

An example of these two types of errors is the following. Consider trying to measure about a 100-foot distance between two points on a sidewalk with a ruler by putting your finger at the 12-inch end of the ruler and then moving the ruler to position the zero-inch end of the ruler at your finger. This process will produce a random error in the result, so that the measured value might be a little higher than the true value in one measurement of the distance and a little lower than the true value in another measurement of the distance. The effect of this random error can be minimized by taking many measurements of the distance between the two points on the sidewalk and averaging the results. But if the ruler is not an actual 12 inches, then the situation is much different. For example, if the ruler is 5% too long, then on the average the measured value will be 5% too small, and if the ruler is 7% too short, then on the average the measured value will be 7% too high. This is an example of a systematic error. It cannot be corrected by taking many measurements and averaging the results.

Another example is an hourglass. The flow of sand from the upper volume through a small tube to the lower volume can be used as a clock by marking off the lower volume in units of time. The time that the sand has been flowing in the hourglass can then be read by the height of the sand in the lower volume. However, there is an assumption in this – that the amount of sand in the hourglass is fixed. If, unknown to the observer, there was sand flowing into the lower volume from another source, then the time read on this clock would be shifted forward. This would be a systematic error from the true time the sand had been flowing into the lower volume.

The process of carbon dating a sample will typically include random errors. The effect of such random errors can be minimized by taking many measurements of the carbon date and averaging the results, as was done in carbon dating the Shroud. Carbon dating can also involve systematic errors in the results, so the measured carbon date could be significantly different than the true date. For example, for a cloth made in 33 AD, if neutron absorption produced new C^{14} in the cloth, and if the concentration of C^{14} at the sample location were increased by 16.9% by this mechanism, then samples removed from this location would carbon date to 1325 AD, which is the midpoint of the range of the carbon date for the Shroud (1260 to 1390 AD). The effect of this type of error would not be minimized by carbon dating additional samples from the same location because the C^{14} concentration in every sample taken from that location would have been increased by about 16.9%.

The magnitude of a systematic error is usually a function of some parameter such as location, temperature, contamination, degree of mixing, voltage to measurement equipment, etc. The magnitude of a systematic error is usually not known. This means that the measured value cannot be corrected by addition or subtraction of the systematic error to obtain the true value. Thus, if a systematic error is present in a measurement, the only option is to reject the certainty of the measured value. The measured value may still be correct, but there is no way of knowing whether it is correct, so that it is no more certain than many other values.

The above applies to the carbon dating of the Shroud. For example, if the Shroud was exposed to a significant number of neutrons, then absorption of the neutrons in the Shroud would have produced new C^{14} in the fibers by the [N^{14} + neutron → C^{14} + proton] reaction. This would have shifted the measured carbon date in the forward direction. The magnitude of this error would depend on how many neutrons were absorbed in the Shroud, and the spatial distribution of this error would depend on the spatial distribution of the neutrons in the tomb. For example, if neutron absorption in the samples shifted the measured carbon date forward from 33 AD to 1325 AD, then the difference between the measured carbon date (1325 AD) and the true date (33 AD) would be the systematic error (1325 – 33 = 1292 years) in the measurement.

The important issue then becomes how to determine whether a systematic error is present. It is important because if it is present, and if the magnitude of the systematic error is not known as is usually the case, then the measured value should be rejected, i.e., given no credibility. Fortunately, there are established procedures to determine whether a systematic error is likely present. This involves a statistical analysis of the measured values compared to the measurement uncertainties. If the distribution of the measured values is consistent with (can be explained by) the measurement uncertainties, then a systematic error is not implied. But if the distribution of measured values is not consistent with (cannot be explained by) the measurement uncertainties, then the measured values were most likely affected by a systematic error. If a systematic error significantly affected the measurements, the measured values should be rejected if, as is usually the case, the magnitude of the systematic error is not known. One standard methodology for determining whether a systematic error is present is to perform a chi-squared statistical analysis. When this analysis is performed on the carbon dates and their uncertainties obtained in the dating of the Shroud in 1988, the conclusion is that the distribution of the carbon dates has only about a 1.4% chance of being consistent with their uncertainties (Table 5 of Ref. 3). This means a systematic error was very likely present in the measurements so that the carbon date of 1260 to 1390 AD should be rejected.

Figure 5. Location of Samples for C^{14} Dating

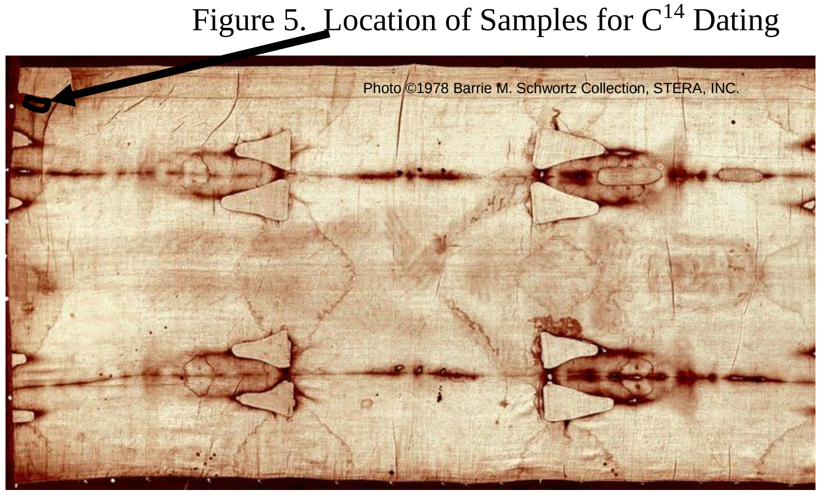
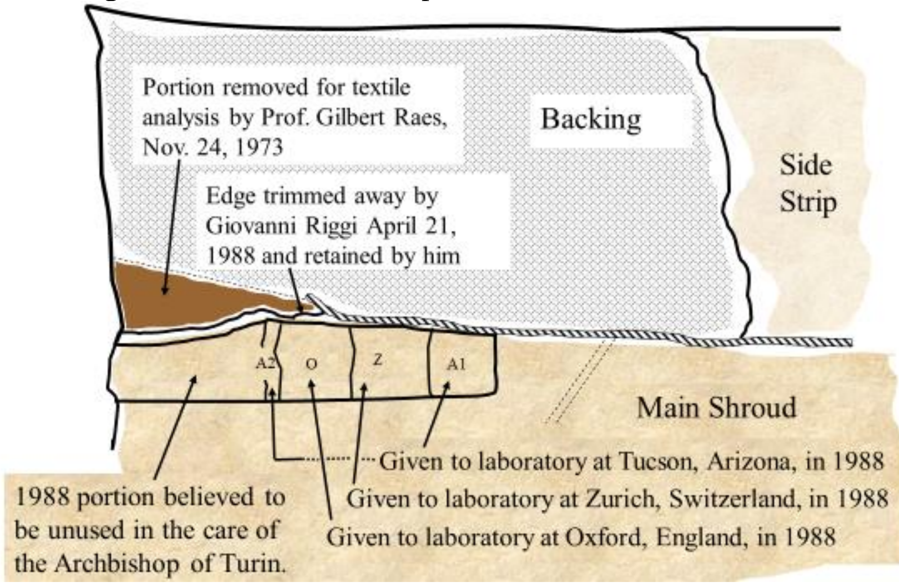


Figure 6. Location of Samples Cut from the Shroud in 1988



7. Carbon Dating of the Shroud

In 1988, samples were cut from a corner of the Shroud and sent to three laboratories in Oxford, Zurich, and Arizona (Tucson) for carbon dating (Figures 5 and 6). This can also be called C^{14} dating or radiocarbon dating. The samples sent to the three laboratories were cut into subsamples for measurement of their C^{14}/C^{12} ratios. These ratios, assuming they only changed due to decay of C^{14}, were used to calculate the subsample dates for the Shroud. These subsample dates were published in 1989 in the journal *Nature* [4]. The mean[1] of the three laboratory mean values was 1260 AD ± 31 years (one sigma[1]). This is called the uncorrected value. When corrected for the changing C^{14} concentration in the atmosphere, a range of 1260 to 1390 AD (two sigma) was obtained. However, there are several reasons why most Shroud researchers believe the certainty of the 1260-1390 AD date should be rejected because it may or may not be true [5]:

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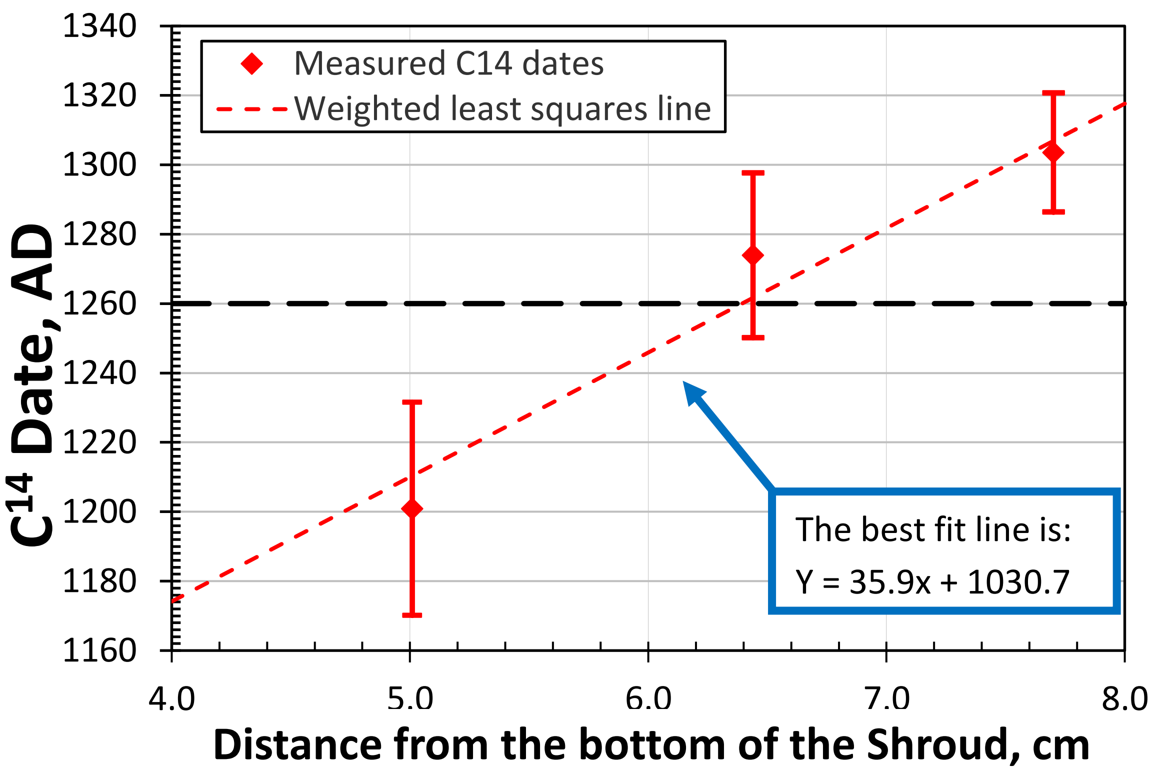
1. In statistical analysis, the average value of a series of measurements is called the "mean". The uncertainty associated with this mean value can be illustrated by a Gaussian distribution, which is also called a "bell curve". This curve plots the probability of how close the true value should be to the mean value, which is at the peak of the bell curve. The uncertainty of the mean value, and thus the width of the bell curve, is expressed in a calculated value known as the standard deviation. The symbol used for the standard deviation is the Greek letter sigma (σ), so that an uncertainty of one standard deviation is called a one sigma uncertainty. The mean value plus or minus one sigma (one standard deviation) should have about a 68% probability of having the true value within this range. The mean value plus or minus two sigma (two standard deviations) should have about a 95% probability of having the true value within this range. The mean value plus or minus three sigma (three standard deviations) should have about a 99% probability of having the true value within this range. However, these probability values depend on the number of measurements that were made to determine the values for the mean and standard deviation.

(1) The technology to make the images did not exist in 1260-1390. It does not exist even today. Every attempt to make the images today has failed macroscopically (large scale) and/or microscopically (small scale).
(2) There are 13 or 14 other date indicators that contradict the 1260-1390 date [6].
(3) The measured carbon dates depend on the distance from the bottom of the Shroud (Figure 7). This means the samples were not representative of the rest of the Shroud, i.e. they were not homogeneous. The non-homogeneity of the samples has been confirmed by four recent papers in peer-reviewed journals [7 to 10] and is consistent with previous statistical analysis of the measurement data [3].
(4) The carbon dates from Oxford and Arizona are different by 104 ± 35 years, which is a 3.0 sigma difference (104 / 35 = 2.97). The usual acceptance criterion for no statistically significant difference is 2.0 sigma, so this indicates the dates have a high probability of being different. This should not be the case since both samples came from the same piece of cloth. This indicates something strange is going on. Technically, this indicates the samples are evidently not homogeneous (not representative of the Shroud) due to the presence of a systematic error, which means the certainty of the carbon dates should be rejected.
(5) A Chi squared statistical analysis of the measurement data (values and uncertainties) indicates the distribution of the measured subsample dates has only a 1.4% chance of being explained by the stated uncertainties (significance level p = 0.014 in Table 6 of Ref. 3 and Table 4 of Ref. 9). This indicates a systematic error was likely present. If a systematic error was present then the certainty of the uncorrected mean value of 1260 ± 31 should be rejected, so the corrected range of 1260-1390 should also be rejected.

Figure 7. Measured Dates are a Function of Sample Location



When the three laboratories measured the C^{14}/C^{12} ratios of the Shroud subsamples, they also measured the C^{14}/C^{12} ratios of samples from three cloths of known historical dates [4]. The carbon dates obtained for these three standards were in reasonable agreement with their historical dates, which indicates the C^{14}/C^{12} ratios were being measured correctly. Thus, it should be assumed the C^{14}/C^{12} ratios of the Shroud subsamples were measured correctly. But if the C^{14}/C^{12} ratios were measured correctly, then the systematic error cannot be in the C^{14}/C^{12} ratio measurements so must have been in the samples. This means that something must have altered the C^{14}/C^{12} ratios in the samples to produce the systematic error.

8. Anomalies in the Carbon Dating of the Shroud

There are several anomalies regarding the carbon dating of the Shroud that should raise serious questions about the accuracy of the results.

- The individual dates calculated for the subsamples are given in Table 1 of Damon [4]. The values in Tables 2 and 3 of Damon are supposedly calculated from this data using a Chi-squared statistical analysis. However, some of the values in Tables 2 and 3 of Damon are significantly different than the author's Chi-squared statistical analysis of the values in Table 1 of Damon. For example, the value in Damon for the mean C^{14} date (years before 1950) for the Tucson sample was 646 ± 31 whereas the author, showing additional digits, calculated 646.44 ± 17.05 (compare Tables 1 and 5 in Ref. 3). The larger uncertainty in Damon allows the calculated dates to be in better agreement with the uncertainties, thus potentially hiding the presence of a systematic error.
- Damon reported that four subsamples were carbon dated at the laboratory in Tucson, Arizona. Much later it was admitted that eight subsamples were dated [7], with pairs of dates averaged to produce the four values listed in Damon. This process eliminated the extreme high and low values so that the dates appeared to be more consistent with the uncertainties. This suggests that the analysis methodology was being manipulated to produce the appearance that the measured dates were more consistent with the uncertainties than was the case, thus again, potentially hiding the presence of a systematic error.
- To confirm the accuracy of the measurements, three pieces of cloth of known historical age were also carbon dated along with the Shroud samples. In determining the final uncertainties for the dates of these cloths, the "weighted mean of the weighted means" was used. But this methodology was changed for the Shroud to use the "unweighted mean of the weighted means" to calculate the final uncertainty. This caused the final uncertainty for the Shroud to increase from 13 to 31 (Table 1 vs. Table 5 in Ref. 3), again giving the appearance that the measured dates were more consistent with the uncertainties than was the case, potentially hiding the presence of a systematic error.
- Since measured values can be significantly wrong if a systematic error is present, the original documentation of the carbon dating of the Shroud (Damon, Ref. 4) should have included evidence in their statistical analysis that a systematic error had not significantly affected the measurements. However, this was not done. Instead, this issue was assumed away by assuming the measurement uncertainties were understated. This is made clear in paragraph 23 of Damon [4] that begins with "More quantitively". This paragraph says

that "it is unlikely that the errors quoted by the laboratories for sample 1 fully reflect the overall scatter", with "sample 1" being the Shroud samples. No evidence was offered to support this claim. Making this assumption is the most significant error in the analysis of the carbon dating measurements because it eliminates the possibility of finding evidence of a systematic error. Reports of the technical reviewers prior to publication in *Nature* did not include a detailed statistical analysis to look for a systematic measurement error.

- For most people, the main takeaway from the paper by Damon, et al., would be the statement "The results provide conclusive evidence that the linen of the Shroud of Turin is mediaeval." This statement is in the first paragraph of the paper and in the first paragraph of the conclusions. The British Museum, who was analyzing the carbon dating results, asked Turin professor Anthos Bray for his opinion on the paper. Professor Bray recommended that this "conclusive evidence" claim should be deleted, probably because the statistical analysis in the paper was not adequate to justify this claim.
- An essential part of the scientific process is to make details of the measurements and data analysis fully available to others so they can review them and repeat the measurements if needed. This was not done in the 1988 carbon dating of the Shroud. Instead, the British Museum withheld the detailed results until 2017, a period of 29 years. They only released the details of the measurement data in 2017 in response to repeated legal actions in the form of Freedom of Information Act (FOIA) requests. Why would the British Museum withhold the details of the results for so long?

What is the cause of these above anomalies? The cause is apparently the human element in the process of doing science. There was an eager competition between the various dating laboratories in the world to carbon date the Shroud of Turin. This resulted from several factors: 1) Due to STURP's research on the Shroud in 1978, the Shroud in 1988 was very famous with many believing it to be Jesus' burial cloth, 2) Each laboratory wanted the notoriety of dating the Shroud and the benefits it would bring to the laboratory in funding and additional work, and 3) Many of the laboratories wanted to demonstrate the accuracy of their new small sample dating technique, which would bring additional funding and work. In this mix of motivations, the carbon dating of the Shroud apparently became the means to obtain the other goals, so that the correctness of their reported date for the Shroud could have easily become somewhat of a secondary issue, especially in view of the usual presupposition of naturalism often made by scientists. Scientists are normally trained from the perspective of naturalism, so only the laws of physics, as currently understood, are allowed to be used to explain a phenomenon. But with the Shroud of Turin, the ultimate question is whether it could be the authentic burial cloth of Jesus Christ. If it is Jesus' burial cloth, and if Jesus was physically resurrected from within this cloth as the New Testament claims, then there could have been phenomenon outside of our current understanding of the laws of science that could have shifted the Shroud's carbon date to the future, such as neutron emission from the body. To assume the impossibility of such an event, and then use this assumption to prove the Shroud could not be Jesus' burial cloth, is circular reasoning.

Their statement that the uncertainties were underpredicted was evidently made because their statistical analysis found that the distribution of the carbon dates was not explained by the measurement uncertainties. Instead of assuming the uncertainties were understated, they should have believed the uncertainties as they were calculated. This should have led them to conclude that the inability of the distribution of the measured values to be explained by their uncertainties indicated a systematic error was likely present in the measurements. However, this conclusion was not allowed because it would require the 1260-1390 date to be rejected. The dating laboratories were eager to date the Shroud because they wanted to promote the accuracy of their small sample dating technique to the rest of the world. Reporting that their 1260-1390 AD date should be rejected would have brought their small sample dating technique into serious question.

9. The Four Requirements for a Carbon Dating Hypothesis to be True

It is often thought that the only evidence produced from the carbon dating of the Shroud is its date (uncorrected date = 1260 ± 31, corrected range = 1260-1390). However, there are three other things known to be true based on carbon dating relating to the Shroud.

- The samples sent to the three laboratories were cut from the Shroud next to each other, so the carbon dates of these samples should agree with each other within the measurement uncertainties. However, this is not the case. When the carbon dates and one sigma uncertainties obtained by the three laboratories are plotted as a function of distance from the bottom of the cloth (Oxford, Zurich, and Tucson, left to right, in Figure 7), the sloped red dashed line in Figure 7 through the three points is a better fit to the data than assuming all three samples had the same date of 1260 AD, which is the black dashed line. This indicates the probable presence of a systematic error in the measurements, with the error increasing as a function of (depending on) the distance from the bottom of the cloth. The slope in the red line is about 36 years per cm, which is 91 years per inch. At this rate, if the sample point is moved by 10 inches then the carbon date would change by 910 years, i.e., from the uncorrected carbon date of 1260 AD to a future date of 2170 AD. Thus, this slope in the carbon date could be very significant.
- Each of the three laboratories cut the samples sent to them (Figure 6) into subsamples. Sample O in Figure 6 was sent to the laboratory in Oxford, England. They cut it into three subsamples [4] for measurement of their C^{14}/C^{12} ratios. Sample Z in Figure 6 was sent to the laboratory in Zurich, Switzerland, who cut it into five subsamples [4] for C^{14}/C^{12} ratio measurement. Samples A1 and A2 were sent to the laboratory in Tucson, Arizona. A1 was put into a vault without testing it. It was originally believed that sample A2 was cut into four subsamples for C^{14}/C^{12} ratio measurement [4] but it is now believed that A2 was cut into eight subsamples [7]. The carbon dates for pairs of these eight measurements were averaged together, based on which day they were measured, to produce the four values reported in Damon. This process eliminated the extreme measurements, which made the distribution of the measured dates more consistent with their uncertainties [3]. The total number of subsamples is thus 3 + 5 +8 = 16. The dates for these 16 subsamples were distributed over a range of 1155 to 1410 AD.
- The Sudarium of Oviedo is an 84 x 53 cm (37 x 21 inch) linen cloth that has been in the cathedral in Oviedo Spain since 1113 AD. Ancient tradition and documents claim the Sudarium is Jesus' face or head cloth mentioned in John 20:7 and thus is connected to the Shroud of Turin. Jesus' face or head cloth was probably left on while the body was transported to the tomb but was removed in the tomb and set aside prior to the body cloth being wrapped over his head. This explains why the Sudarium contains no image though it

does contain a blood stain in a pattern similar to that on the Shroud. Historical documents state the Sudarium left Palestine prior to 614 AD, but it was carbon dated to about 670 AD.

Therefore, for a hypothesis to correctly explain the carbon dating of the Shroud, it must be consistent with the following four requirements. At the 1988 sample location on the Shroud:

1. The uncorrected carbon date = 1260 ± 31,
2. The slope or gradient to the carbon dates is about 36 years per cm of distance from the bottom of the cloth,
3. The carbon dates for the subsamples are in the range of 1155 to 1410 AD,
4. And for Jesus' face cloth, which is believed to be the Sudarium of Oviedo, the carbon date is about 670 AD.

10. Hypotheses to Explain the Carbon Dating

Several hypotheses have been proposed to explain the carbon dating of the Shroud. In their approximate historical sequence, they are the following.

1. New C^{14} was produced on the Shroud by neutron absorption, which could have shifted the carbon date from the time of Jesus' death, about 33 AD, to 1260-1390 AD. This was first proposed in 1989 by Tom Phillips [11] in a letter to the editor in the same issue of *Nature* in which Damon, et al., reported the carbon dating results for the Shroud [4].
2. Contamination from handling or placing materials such as wax or talc on the Shroud could have shifted the date. This hypothesis has been generally rejected due to the large fraction of the sample that would have to be contamination to shift the date sufficiently, and due to the cleaning procedures used on the samples.
3. The Shroud was in a fire in 1532. Carbon from this fire could have shifted the carbon date. This hypothesis has also been rejected for the same reasons as hypothesis #2.
4. Bacteria could have produced a bioplastic film on the fibers that shifted the carbon date from about 33 AD to 1260-1390 AD. This hypothesis has been generally rejected because of the large fraction of the samples that would have to be bioplastic to shift the date sufficiently, and because careful inspection of fibers found minimal coating on the fibers.
5. The corner of the Shroud from which the samples were taken in 1988 had previously been rewoven so that the samples for carbon dating were a mixture of new and old threads. The new thread is thought to have been from the early 1500s and the old thread from the time of Jesus' death, about 33 AD. The inability of inspectors to find evidence of such a reweave around the 1988 sampling area is explained by the reweave being done using French reweaving technology of that era, which is claimed to produce an essentially invisible reweave. This is the "invisible reweave" hypothesis.
6. Certain physical processes can cause carbon monoxide to have a different C^{14}/C^{12} ratio than carbon dioxide. It is claimed this could have caused the carbon date to be shifted from 33 AD to 1260-1390. This hypothesis has been generally rejected because the mechanism does not seem credible and because it has not affected the carbon date of other fabric of known historical date.

Thus, hypotheses 2, 3, 4, and 6 have generally been rejected. The invisible reweave hypothesis (hypothesis 5) is currently the most popular explanation in the literature, but it has many problems. Of the above four requirements that must be explained for a carbon dating hypothesis to be true, the invisible reweave hypothesis, under the right assumptions, can explain #1 (1260-1390 date for the Shroud) and #2 (36 years/cm slope) but it is not consistent with #3 (distribution/range of the subsample dates). This is because the invisible reweave hypothesis predicts that some of the 16 subsamples should have dated to either the time of Jesus, about 33 AD, or the time of the reweaving in the early 1500s, yet none of them do. The dates for the subsamples were only over a range of 1155 to 1410 AD. The invisible reweave hypothesis also does not explain the 670 AD date for the face cloth since the hypothesized reweave is only on the Shroud.

French reweaving was called "invisible reweaving" in the 16th century. This term is probably appropriate for a casual inspection of the front side of a cloth, especially for a relatively thick cloth with a simple weave. It would not be invisible to a careful inspection by fabric specialists using a modern compound microscope on the front and back sides of a thin cloth with a complex weave such as the 3-to-1 herringbone weave of the Shroud. Multiple careful inspections of the fabric around the 1988 sample location have not found evidence of a reweave, so this hypothesis should be rejected.

The only remaining hypothesis is #1, the neutron absorption hypothesis. This hypothesis, though it was first proposed in 1989, had very little further consideration of it until desk computers became fast enough, and nuclear analysis software became sufficiently advanced to permit nuclear analysis computer calculations to be performed. These computer calculations were performed by the author in 2014 using the MCNP software. MCNP is an acronym for "Monte Carlo N-Particle" where "N" stands for neutron. MCNP was developed over many decades by a team of scientists at the Los Alamos National Laboratory (LANL) in New Mexico, US. It has been confirmed by comparison of MCNP calculations to thousands of nuclear experiments. As a result, it was approved by the US nuclear regulatory commission (NRC) for use in nuclear analysis for a variety of purposes.

11. MCNP Nuclear Analysis Computer Calculations

MCNP was used to model a human body using simple geometrical volumes. This body was modeled horizontally, wrapped in a linen cloth, laying on the back shelf in a limestone tomb as it would have been designed in first century Jerusalem. Each MCNP calculation followed one neutron at a time through all its interaction events with nuclei of atoms in the body, linen cloth, air in the tomb, and limestone walls, floor, and ceiling of the tomb. Each MCNP calculation followed thirty million neutrons, one after another, to minimize the uncertainty of the results. It was assumed in the MCNP calculations that neutrons were emitted uniformly (homogeneously) in the body. This was assumed for multiple reasons:

- Carbon dating is performed by measuring the C^{14}/C^{12} ratio in samples. If neutrons are emitted from the body, then a small fraction of them would be absorbed in the trace amount of nitrogen in the linen cloth. This would produce new C^{14} in the fibers by the

[N^{14} + neutron → C^{14} + proton] reaction that could shift the carbon date forward by thousands of years, depending on the location on the cloth. For example, the carbon date would be shifted from 33 AD to the midpoint of 1260-1360 by an increase in the C^{14} content in the Shroud samples of only 16.9%.

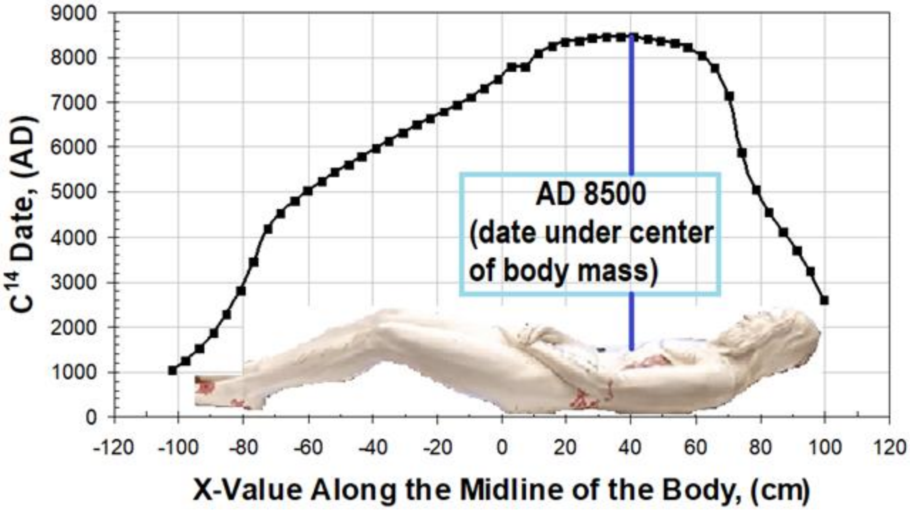
- The Shroud contains entire images of the front and back of the body, so whatever mechanism produced the images involved the entire body.
- The images were produced by discoloration of the top fibers in the images. The discoloration on each fiber is the same color on the front and back images and along the entire length of the body, so the process that discolored the fibers was the same over the entire body. The shades within the image are produced by the number of discolored fibers per area, and the length of the discoloration, but the color of the discoloration on the fibers is always the same.
- The best explanation for formation of the image is a very brief burst of radiation, probably charged particles such as protons and electrons, emitted throughout the body [12, 13, 18]. These charged particles would be released if certain nuclei were to fission throughout the body, which would also release neutrons throughout the body.
- It appears that bones near the surface of the body influenced the encoding process that formed the image. The teeth, bones in the hands, and vertebra in the backbone may be examples of this but further research is needed to confirm this. This would mean that the radiation that formed the image was emitted within the body, so that the associated neutrons would also have been emitted within the body.
- From a Biblical perspective, in Jesus' resurrection, his entire body evidently disappeared from within his burial Shroud (John 20:8-9). Whatever physical process was involved in this, it affected his entire body, so if neutrons were emitted in this process, they would have been emitted from his entire body.

Using this hypothesis of neutrons homogeneously emitted from within the body as it lay in a limestone tomb, a long series of MCNP nuclear analysis computer calculations were run in 2014 with each run taking about six to thirteen hours on a desk-top computer. This large number of calculations were needed to determine the effects of unknowns such as neutron energy, direction of emission, location of the body relative to the limestone walls, etc.

Figure 8 shows some of the results of these MCNP calculations. The vertical axis on this figure shows the carbon date calculated by MCNP for a location along the midline (backbone) of the body on the cloth under the body, i.e., on the dorsal image. The calculated carbon dates are quite variable, with about 90% of the locations dating to the future when the standard equations are used to calculate the date. A carbon date to the future is calculated when there is a higher C^{14}/C^{12} ratio in a sample than is present in our environment. The curve in Figure 8 is normalized to a date of 1260 AD at the second point from the left, which is the approximate location where the samples were cut from the Shroud in 1988, so the calculated results automatically agree with the first requirement (date of 1260-1390) above for a correct hypothesis. The MCNP calculated slope at the second point from the left agrees with the experimental slope, about 36 years per cm in Figure 7, obtained from carbon dating measurements at the three laboratories! The second requirement for a correct hypothesis is thus satisfied. The distribution of the MCNP calculated dates across the 1988 sample area also appears to be in good agreement with the 1155 to 1410 AD range of the subsample dates, thus satisfying the third requirement for a correct hypothesis.

The Sudarium of Oviedo does not include an image of the face, so Jesus' face cloth was evidently removed from the body prior to the Shroud being draped over the front of the body. If the person who removed the face cloth then dropped it on the right-side bench even with his body, which is reasonable to assume, then its carbon date calculated by MCNP would be about 670 AD, in agreement with the carbon date experimentally obtained for the Sudarium of Oviedo. This satisfies the fourth requirement for a correct hypothesis to explain the carbon dating. Thus, the only hypothesis to explain the carbon dating of the Shroud that satisfies all four requirements discussed above is the neutron absorption hypothesis.

Figure 8. MCNP Calculations: Carbon Date on the Shroud Below the Body



12. Neutron Absorption Hypothesis

The neutron absorption hypothesis [14] proposes that the radiation emitted from the body that caused the images [12, 13, 18] also included neutrons. A small fraction of these neutrons would have been absorbed in the trace amount of nitrogen in the cloth to produce new C^{14} in the fibers [15, 16] by the [N^{14}+ neutron → C^{14} + proton] reaction. This production of new C^{14} would cause the carbon dating process to produce a more recent carbon date than the true date. For example, the carbon date would be shifted from 33 AD to the midpoint of the range 1260-1390 AD by an increase in the C^{14} atom density in the samples of only 16.9%. Based on the MCNP nuclear analysis computer calculations, this would occur if 2×10^{18} neutrons were emitted from the body, which is only one neutron for every ten billion neutrons in the body, based on an estimated body weight of 170 pounds (77.1 kg). This would occur, for example, if only 0.0004% of the deuterium, or heavy hydrogen, atoms in the body were to fission. Deuterium is of special interest because it requires the least energy input to fission. This would release enough neutrons to shift the carbon date from 33 AD to 1260-1390 AD and approximately enough protons to produce the images, according to experiments of proton irradiation of linen [17]. This neutron absorption hypothesis is the best concept to explain the carbon dating of the Shroud to 1260-1390 AD because it is the only hypothesis consistent with the four things we know to be true about carbon dating as it relates to the Shroud: the date, slope, and range of carbon dates for the 1988 sample location, and the carbon date for the Sudarium.

13. Testing the Neutron Absorption Hypothesis

In science, a concept to explain a phenomenon is called a hypothesis. A good hypothesis has two main characteristics: 1) It is consistent with what is known to be true about the phenomenon, and 2) It makes predictions that are testable. If, when tested, the predictions are found to be false, then the hypothesis is falsified, at least as currently stated. But if, when tested, the predictions are found to be true, then the hypothesis gains in credibility. Thus, scientific testing can at best only cause a hypothesis to gain in credibility. Science can never prove, in an absolute sense, a hypothesis to be true. A good hypothesis should make predictions that are testable, and then these predictions should be tested. It is not known at this time whether the neutron absorption hypothesis is true, but it could be true because it is consistent with the four things we know to be true about carbon dating related to the Shroud, as discussed above. Any hypothesis to explain the 1988 carbon dating of the Shroud should make predictions that can be tested so that the hypothesis can either be disproven or have its credibility increased, depending on whether the predictions are found to be false or true.

The neutron absorption hypothesis postulates that neutrons were emitted from the body that would have taken on a characteristic distribution in the tomb as calculated by MNCP. These neutrons would have been absorbed in the trace amount of nitrogen in the cloth to produce new C^{14} in the fibers according to the neutron distribution in the tomb, thus shifting the carbon date as shown in Figure 8. Therefore, the neutron absorption hypothesis predicts that carbon dating of other locations on the Shroud should follow the distribution of new C^{14} produced in the cloth as calculated by MCNP.

The neutrons would also have been absorbed in other isotopes in the Shroud and in the limestone of the tomb to produce new long-lived isotopes such as Chlorine-36 (Cl^{36}) and Calcium-41 (Ca^{41}). These isotopes have half-lives of 99,400 and 301,000 years respectively, so very little of the Cl^{36} and Ca^{41} produced by neutron absorption would have decayed since the time of Jesus. Therefore, the neutron absorption hypothesis predicts that Cl^{36} and Ca^{41} were produced on the Shroud and in the limestone of his tomb with a distribution calculated by MCNP.

14. Conclusion

Other papers [12, 13, 18] hypothesize that the front and dorsal images on the Shroud were probably formed by an extremely brief, extremely intense burst of vertically collimated radiation emitted in the body, probably consisting primarily of charged particles. If neutrons were also included in this radiation burst, then a small fraction of the neutrons would have been absorbed in the trace amount of nitrogen in the Shroud to produce new C^{14} in the fibers by the [N^{14} + neutron $\rightarrow$ C^{14} + proton] reaction. Since carbon dating is performed by measuring the C^{14}/C^{12} ratio in samples, this new C^{14} could shift the carbon date forward by thousands of years depending on the location on the Shroud. This is called the neutron absorption hypothesis. This production of new C^{14} in the fibers would violate the main assumption of carbon dating - that the C^{14}/C^{12} ratio only changes due to decay of the C^{14}. This difference between the measured carbon date and the true date would constitute a systematic error in the measurement. At the corner of the Shroud where the samples were removed from the cloth in 1988, to shift the carbon date from the time of Jesus' death, about 33 AD, to the midpoint of the carbon date (1260 to 1390 AD) would require the number of C^{14} atoms in the fibers to be increased by only 16.9%. In terms of physics, it may or may not be possible to determine further details on the cause of this radiation burst from the dead body that was wrapped in the Shroud. If it is possible, it will probably include theoretical work between particle physicists and string theorists as well as further scientific experiments on the Shroud of Turin.

The neutron absorption hypothesis is the best explanation for why the corner of Jesus' burial cloth carbon dated to 1260-1390 AD. This is because it is the only hypothesis that is consistent with the four things known to be true about carbon dating related to the Shroud: the mean carbon date (1260-1390 AD), the slope of the laboratory mean dates (about 36 years per cm), and the range/distribution of the subsample dates at the 1988 sample location, as well as the carbon date for the Sudarium of Oviedo (Jesus' face cloth). The assumption that the Shroud dates to 1260-1390 AD only satisfies the first of these four requirements. The neutron absorption hypothesis can be tested by performing carbon dating at other locations on the Shroud and by measuring the amount of Cl^{36} and Ca^{41} on the Shroud and in the limestone of his burial tomb.

The most important questions regarding the Shroud of Turin are whether it could be the authentic burial cloth of Jesus Christ and whether the evidence on the Shroud could be the result of a unique event. There is no known example of a human body, dead or alive, emitting sufficient neutrons to shift the carbon date of its surroundings except for the Shroud of Turin. There is also no known example of a human body, dead or alive, producing an image of itself on a piece of cloth, except for the Shroud of Turin. These unique neutron emission and image encoding events appear to require a unique process or mechanism that is outside or beyond our current understanding of physics. If we look through all our historical records to determine whose dead crucified body could have produced the evidence on the Shroud, it is most reasonable to conclude that the only option is Jesus in his resurrection. Thus, the Shroud of Turin provides scientifically based circumstantial evidence for Jesus' resurrection that supplements and corroborates evidence from Old Testament prophecy, Jesus' predictions of his own resurrection, and eye-witness testimony of Jesus' empty tomb and post-resurrection appearances.

References

1. John P Jackson, Eric J Jumper, William R Ercoline, "Correlation of Image Intensity on the Turin Shroud with the 3-D Structure of a Human Body Shape", July 15, 1984, Applied Optics, Vol. 23, page 2244, https://shroud.com/pdfs/Correlation%20of%20Image%20Intensity%20Jackson%20Jumper%20Ercoline%201984%20OCRsm.pdf
2. John Heller, "Report of the Shroud of Turin", Houghton Mifflin Company Paperback, 1984, ISBN 0-395-36568-6 (paperback)
3. Robert A. Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 2: Statistical Analysis", August 7, 2018, paper 12 on www.shroudresearch.net/research.html

4. P.E. Damon, and 20 others, "Radiocarbon Dating of the Shroud of Turin", *Nature*, February 16, 1989, https://www.nature.com/articles/337611a0, and https://shroud.com/nature.htm
5. Robert A. Rucker, "Understanding the 1988 Carbon Dating of the Shroud", Sept. 19, 2020, paper 25 on www.shroudresearch.net/research.html
6. Robert A. Rucker, "Date of the Shroud of Turin", November 11, 2020, paper 29 on www.shroudresearch.net/research.html
7. T. Casabianca, E. Marinelli, G. Pernagallo, and B. Torrisi, "Radiocarbon Dating of the Turin Shroud: New Evidence from Raw Data", 2019, Archaeometry, 61(5), 1223-1231, https://onlinelibrary.wiley.com/doi/abs/10.1111/arcm.12467, and https://www.academia.edu/38607635/Radiocardon_Dating_of_the_Turin_Shroud_New_Evidence_From_Raw_Data?email_work_card=title
8. Paolo Di Lazzaro, Anthony C. Atkinson, Paola Iacomussi, Marco Riani, Marco Ricci, and Peter Wadhams, "Statistical and Proactive Analysis of an Inter-Laboratory Comparison: The Radiocarbon Dating of the Shroud of Turin", Entropy, August 24, 2020, https://www.researchgate.net/publication/343842262_Statistical_and_Proactive_Analysis_of_an_Inter-Laboratory_Comparison_The_Radiocarbon_Dating_of_the_Shroud_of_Turin
9. Bryan Walsh and Larry Schwalbe, "An Instructive Inter-Laboratory Comparison: The 1988 Radiocarbon Dating of the Shroud of Turin", Journal of Archaeological Science: Reports, Volume 29, February 2020, https://www.sciencedirect.com/science/article/pii/S2352409X19301865
10. Bryan Walsh and Larry Schwalbe, "On Cleaning Methods and the Raw Radiocarbon Data from the Shroud of Turin", International Journal of Archeology, 2021; 9(1):10-16, http://journalarchaeology.org/article/209/10.11648.j.ija.20210901.12
11. Thomas J. Phillips, "Shroud Irradiated with Neutrons?", Nature, Vol. 337, No. 6208, page 594, February 16, 1989, published in the same edition of Nature as Damon above, https://www.nature.com/articles/337594a0
12. Robert A. Rucker, "Holistic Solution to the Mysteries of the Shroud of Turin", July 16, 2020, paper 24 on www.shroudresearch.net/research.html
13. Robert A. Rucker, "How the Image Was Formed on the Shroud", Dec. 25, 2019, paper 27 on www.shroudresearch.net/research.html
14. Robert A. Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 3: The Neutron Absorption Hypothesis", July 7, 2018, paper 13 on www.shroudresearch.net/research.html
15. Robert A. Rucker, "The Carbon Dating of the Shroud is Explained by Neutron Absorption", Sept. 19, 2020, paper 28 on www.shroudresearch.net/research.html
16. A. C. Lind, M. Antonacci, G. Fanti, D. Elmore, J. M Guthrie, "Production of Radiocarbon by Neutron Radiation on Linen", https://www.testtheshroud.org/articles
17. Arthur C. Lind, "Image Formation by Protons", https://www.testtheshroud.org/articles, and Jean-Baptiste Rinaudo, "Modello protonico di formazione dell'immagine sulla Sindone di Torino" (Protonic Model of Image Formation on the Shroud of Turin) presented June 6, 1998, in Torino, Italy, at the III Congresso Internazionale Di Studi Sulla Sindone (3rd International Congress of Studies on the Shroud).
18. Robert A. Rucker, "Overview of the Shroud of Turin to Promote Testing", Nov. 21, 2021, paper 32 on www.shroudresearch.net/research.html