Overview of the Shroud of Turin to Promote Testing

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Abstract

Ancient tradition has long claimed the Shroud of Turin to be the authentic burial cloth of Jesus Christ. This is supported by full-size images on the Shroud of the front and back of a man who was crucified exactly as the New Testament says Jesus was crucified. Extensive testing of this linen cloth by the Shroud of Turin Research Project (STURP, 1978) indicates these images are not due to pigment, scorch, liquid, or photography. This paper is an overview of the Shroud including its images, history, materials, and previous testing. It also includes the author's hypothesis to explain the main mysteries of the Shroud including image formation, carbon dating of the Shroud in 1988, and features of the blood on the Shroud. The purpose of this paper is to encourage the development of a program for future testing of the Shroud. There are rumors the Shroud may go on exhibition in Turin, Italy, in 2025. To help obtain authorization for further scientific testing possibly following the exhibition in 2025, a comprehensive testing program should be developed for the Shroud to take advantage of advances in technology since the last extensive testing in 1978.

1. Introduction

There are many websites and books that discuss the Shroud of Turin [1] because the Shroud is one of the most mysterious and potentially significant items in human possession. It has been on the cover of U.S. News and World Report (March 1, 2002), Time magazine (April 20, 1998), and the June 1980 edition of National Geographic included a 24-page article with a beautiful four-page foldout of the Shroud. In the 1980s, the Shroud was briefly headline news around the world, but for reasons that will be discussed, the Shroud has received little media attention for the last three decades. That is now starting to change due to four recent papers on statistical analysis published in peer-reviewed journals.

The author's objective in his research is to explain the Shroud's mysteries [2], including the images, carbon dating, and the blood. This is to be accomplished by following the evidence where it leads, based on a neutral mindset, i.e., without presuppositions such as naturalism. This process of following the evidence where it leads is the essence of forensic science. It can be described as reverse engineering from the evidence back to the cause.

2. What is the Shroud of Turin?

A shroud is a piece of cloth in which a person is buried. 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 14 feet 4 inches long by 3 feet 8

inches wide (437 by 111 cm). It is about as thick as a man's T-shirt (about 0.35 mm) and is very pliable. Many people regard this cloth to be a holy relic because 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 indicated these images are not due to pigment, scorch, liquid, or photography.

3. What do the images show?

In Figure 1, the top image shows the Shroud as it would normally be seen. It shows two long 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.

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.

The front image 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 that 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 of the Shroud.

The front image also shows blood that ran down the arms from the wrist wounds, with two angles of the blood flow consistent with the man pushing up and down on the cross to breathe. About 120 scourge marks are visible as well as 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 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. Scourge marks are visible down 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 [3, 4], which allows a 3D statue to be reconstructed from the 2D Shroud [5]. 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 as shown in Figure 3 which is a painting from the middle 1500s.

Figure 4 shows a closer view of the face in a positive image. This image contains 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 dating (1260-1390 AD) and is the source of our concept of Jesus' appearance.

4. History of the Shroud

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 5 shows a photo of the cathedral taken in 1978 when the Shroud was on exhibition in the cathedral. The Shroud goes on exhibition only a few times a century and when it does, millions of people slowly file past it and see the front and back images of the crucified man.

Figure 6 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 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.

Figure 6 shows a continuous line from Lirey to Turin, Italy because there is continual historical documentation for this route. Figure 6 shows a dashed line from Jerusalem to Lirey, France because the routes are not known. There are significant problems in knowing certain aspects of the Shroud's location prior to its presence in Lirey, France because it has only been called the Shroud of Turin since it came into Turin. Its previous names often create uncertainties in the historical records.

5. Materials of the Shroud

The Shroud is woven from linen thread made from the stems of the flax plant. On the left side of Figure 7, the background scene shows how flax looks as it is growing, and the foreground scene shows flax that has been cut and bundled for drying. The long stems indicate the length of the fibers in the flax.

The right side of Figure 7 shows a cross sectional cut of a flax stem. It shows a hollow space at the center surrounded by a woody body which is encircled by bundles of flax fibers. These flax fibers extend the length of the long stems. In making linen thread, these flax fibers are separated from the rest of the stem by allowing the stems to rot in water. This process is called retting. The diameter of these fibers is about 15 to 20 μm (microns or micrometers), which is about a fifth the diameter of a human hair. A typical linen thread contains about 100 of these fibers.

Figure 8 shows that the flax fiber looks like bamboo with nodes along the length. This characteristic makes it easily distinguishable from other fibers such as cotton. The flax fibers are twisted or spun together to make linen thread. The thread used to make the Shroud was spun by hand rather than on a spinning wheel, indicating use of this older technology. This indicates the fabric was probably made earlier than about the 12^{th} century.

6. Microscopic View of Threads in the Shroud

Figure 9 shows a photomicrograph of the Shroud at the small of the back on the dorsal image at a magnification of 32. This shows how the linen thread was woven together to make the 3-to-1 herringbone weave of the Shroud. This weave makes a stronger more durable cloth but requires more time to produce so is more expensive. It also shows a significant amount of blood at this location. This is evidently blood that ran down from the side wound shown on the front image.

Figure 10, at a magnification of 64 is a closer view to help us understand how the images of the crucified man were formed on the Shroud. This photo shows the tip of the nose where the image is strongest. It should be noticed this photo indicates no evidence of pigment, binder, clumping of the fibers or threads, or capillarity (soaking up of a liquid). The only thing we see is that in some areas the top one or two layers of fibers in a thread are slightly discolored with a straw-yellow or sepia color. All fiber discoloration has the same color, so the various shades in the images are due to the number of discolored fibers and the length of the discoloration in each area. This is what forms the images.

7. 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 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 leads to extensive experimentation on the Shroud, which indicates the image is not due to paint, 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. This allegedly proved the Shroud could not be authentic.
4. 2017 to 2021, The 1988 measurement data was finally released 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.

Scientific testing of the Shroud began in 1898 when an Italian amateur photographer named Secondo Pia took the first photograph of the cloth. He would have expected his photographic plate to show a poor resolution negative image of the face, but instead it contained a good resolution positive image. This meant the image on the Shroud was a good resolution negative image, with light and dark areas reversed. Therefore, the image could not be a painting because an artist prior to 1898, or 1578 or 1355, could not have painted a good resolution image of what he had never seen, i.e., a negative image of a face. Research continued over the next eight decades by very qualified people in the United States and other countries, including the following with their years of research on the Shroud.

- Dr. Yves Delage, Prof. of Comparative Anatomy, Paris 1900 - 1902
- Dr. Paul Vignon, Professor of Biology, Paris 1900 - 1943
- Dr. Pierre Barbet, Prof. of Anatomy, Paris 1932 - 1961
- Dr. Robert Bucklin, M.D., Forensic Examiner, LA 1941 - 1993
- Dr. Frederick Zugibe, Chief Medical Examiner, NY 1953 - 2002
- Dr. Alan D. Adler, Prof. of Chemistry, Conn. State U. 1978 - 2000
- Dr. John Heller, Prof. of Medical Physics, Yale 1978 - 1995
- Dr. John Jackson, Prof. of Physics, Air Force Academy 1978 - 2021
- Dr. Baima-Bollone, Chief of Forensic Medicine, Turin 1978 - 2021

These individuals in general concluded that the dead body of a crucified man was wrapped in the Shroud and in some unknown way had encoded front and dorsal images of itself onto the burial cloth in which he was wrapped. This belief was largely based on the pristine unbroken appearance of the edges of the blood clots, with their indented center and raised edges, and the clear blood serum extending beyond the blood clots due to capillarity.

The only opportunity for a comprehensive scientific examination of the Shroud occurred in 1978. The discovery in 1975 by John Jackson, professor of physics at the Air Force Academy, that the images contained 3D information led to formation of the Shroud of Turin Research Project (STURP). In 1978, the Vatican allowed STURP, led by John Jackson, to send 26 American scientists to Turin to perform nondestructive experiments on the Shroud for a total of 120-hours. They worked in three shifts over a period of five days [8, 9, 10]. The members of STURP made extensive preparations for testing and obtained donations of about 2.5 million dollars' worth of scientific equipment. STURP's experiments on the Shroud included:

- Light (up to 1000x) and electron microscopy
- Photography, various wavelengths, front & back
- UV spectrophotometry of fluorescence
- X-ray fluorescence and absorption radiography
- Thermal photography
- Mass spectrography
- Laser-microprobe Raman spectroscopy
- Attempts to alter color on fibers using acids, bases, oxidants, reductants, and organic chemicals

Testing was also done for the presence of protein in the images, and multiple tests were done to determine whether what appeared to be blood was blood. The conclusion of these tests indicated the presence of blood on the Shroud. But the main objective of STURP was to determine how the images were formed. They concluded the images could not be the product of paint, dye, or stain because there was:

1. No pigment on the fibers.
2. No evidence of a binder to hold pigment.
3. No brush strokes
4. No clumping of fibers or threads.
5. No stiffening of the cloth.
6. No cracking of the images along fold lines.

STURP found no capillarity (soaking up of liquid) in the fibers or threads, so the images could not be due to a liquid such as an acid or an organic or inorganic chemical in a liquid form.

A scorch caused by a hot object will fluoresce (emit light in the visible range) when exposed to ultraviolet light. When the Shroud was exposed to an ultraviolet light, the scorches caused by the fire in 1532 did fluoresce but the images did not fluoresce. This indicated the images were not formed by contact of a hot object with the cloth. The images on the Shroud could also not be the result of a photographic process because the images contain 3D information. Photographs and paintings do not contain 3D information.

STURP also concluded that only the top one or two layers of fibers were discolored out of about 100 fibers in a thread. This discoloration did not extend across the entire 15 to 20 μm diameter of the fibers but only discolored the fibers to a thickness of less than 0.2 μm, which is about 2%

of the radius. In general, this thin discolored layer extends around the entire circumference of a fiber over much of the length of the discoloration.

STURP concluded this discoloration is not due to any substance or material, i.e., atoms, added to the fibers but rather is the result of a rearrangement of the atoms already in the fibers. The discoloration process can be described as a dehydration-oxidation process that formed the images of the crucified man. Specifically, the discoloration is due to some of the single electron bonds of the carbon atoms in the cellulose being changed to double electron bonds. This causes the molecule to vibrate differently so it reflects light differently, so it appears discolored.

What could cause the fiber to be discolored only on the outer 2% of the fiber's radius? Various concepts have been proposed to explain this and other individual features of the Shroud, but the hypothesis below of an extremely brief intense burst of radiation is attractive because it is the only concept that is consistent with the evidence and can explain the three main mysteries of the Shroud, namely, image formation, carbon dating, and features of the blood [11].

8. Mystery #1: Formation of the Images

The first mystery to be considered is formation of the images on the Shroud [12, 13, 14, 15, 16]. Three things are needed to form the images: a mechanism to discolor the fibers, energy to drive the discoloration mechanism, and information to control the discoloration mechanism. This information is needed to control which fibers are discolored and the length of the discoloration on each fiber, because it is the discoloration on the fibers that forms the images of the crucified man.

It is difficult to determine how the images were formed, so the solution methodology will be similar to solving a maze. A maze is a type of puzzle that has a start point at the entry into the maze and a finish point at the exit from the maze. The objective is to draw a line that goes through the maze from the start point to the finish point. In a difficult maze, it is often best to start from both the start and finish points and work toward the middle, where hopefully the two lines will meet. How the images were formed on the Shroud will be solved in a similar fashion by working from both the starting point (8A. Why can we see the images?) and the ending point (8B. What could have caused the fiber discoloration?) to determine if the two approaches can be part of a consistent solution.

8A. Why can we see the images?

The key to answering this question is information. For example, why can we recognize a person in a photograph? It is because the information that defines the person's appearance (colors, shades, positions) has been encoded into the pattern of the pixels in the photo. The same is true for the Shroud. We can see the images of a crucified man on the Shroud because the information that defines the form of a crucified man has been encoded into the pattern of the discolored fibers on the cloth [17, 18]. The information that defines the form of a crucified man was only inherent to the body that was wrapped in the cloth. It was not inherent to the limestone of the tomb.

Thus, this information had to be carried, transported, or communicated from the body and be deposited on the cloth.

However, this information is not the information that defines how we would see the body in reflected light. Instead, it is the information that specifies the vertical distance between the body and the cloth at each point. This is the 3D information that is encoded into the images [19, 20]. Because this information is the vertical distance between the body and the cloth at each point, this information was most likely deposited on the cloth by something that traveled vertically from the body to the cloth and was altered as it travelled vertically across the air gap. Radiation is the only option that can satisfy these requirements [17]. It can travel vertically from the body to the cloth because both particles and photons of light travel straight in the direction in which they are emitted. They can communicate the vertical gap distance by their intensity (number of particles or photons), with the intensity being diminished by absorption and scattering in the air, and possibly by decay for particles.

Many, if not most, Shroud researchers believe the images were formed by radiation. Only vertically collimated radiation emitted from the body can communicate to the Shroud the information that is encoded in the images and deliver this information in a focused manner [9]. This would be necessary to produce the good resolution front and dorsal images with the correct width of the face while not producing images of the sides of the body or the top of the head.

Vertically collimated radiation allows each point on the cloth to have received information from only one point on the body, the point vertically above or below it. This one-to-one correspondence is required to prevent the information from becoming confused, which would cause a significant loss of resolution in the images. If the radiation had been emitted uniformly in all directions, then innumerable lenses would have been required between the body and the cloth to focus the radiation on each fiber to form the good resolution images. Since such lenses would not have been between the body and the cloth, the radiation must have been vertically collimated [18]. The radiation being vertically collimated is also the best option to produce the realistic width of the face that is on the Shroud.

Other characteristics of the radiation can also be determined. Laser experiments indicate that to produce the extreme superficiality of the images, with only the top one or two layers of fibers in a thread discolored and only the very thin outer layer of the fibers discolored, the radiation must have been emitted in an extremely brief intense burst of radiation [21 to 25].

8B. What could have caused the fiber discoloration?

It is the discoloration on the fibers that forms the images. Thus, how the fibers were discolored to a thickness of less than 0.2 μm must also be explained. One possibility is the molecular structure of the fibers could have been altered by a chemical attack from outside the fibers, for example by ozone produced by an electrical discharge from the fibers. Another possibility is the molecular structure of the fibers could have been altered by heat deposited in this very thin 0.2 μm region. Due to electromagnetic effects, an alternating current in a conductor will flow primarily near the circumference of the conductor. If the frequency of an alternating current in a

fiber is high enough, the electron flow and thus the heat deposition could be in the thin 0.2 μm outer region of the fiber. This could also be related to an electrical discharge between the body and the top fibers facing the body, with the electrical discharge rapidly alternating in direction, as occurs between a lightning rod and a thunder cloud in a lightning strike.

Since both ozone production and this heat deposition could have resulted from an electrical discharge from the top fibers facing the body, the radiation that caused it was probably primarily charged particles rather than electromagnetic radiation. These charged particles had to have low energy because the fibers on the Shroud do not show an increase in the number of ion tracks.

Thus, it is hypothesized the images were formed by an extremely brief intense burst of vertically collimated low energy radiation, primarily charged particles, that transported energy and information from the body to the cloth. This energy and information were required to form the images. Radiation from the body can explain why the images are on the inside of the wrapped configuration, why the images are negative images, why there is 3D information in the images, why bones (teeth, hands, etc.) in the body can apparently be seen in the images, why threads that are discolored produced a shadow in the discoloration on the fibers below them, etc. Ref. 18 lists 17 reasons for this radiation hypothesis and Ref. 28 lists 21 reasons. It is hypothesized this radiation caused an electrical discharge from the top fibers facing the body [11, 26, 27, 28] which produced heating and/or ozone that altered the molecular structure in the thin 0.2 μm circumferential region of the fiber. This could have led to the images slowly developing as the fibers were gradually discolored in the thin region probably over a period of months to years as the atoms settled into their lowest energy states. This gradual process is evidenced by experiments involving proton irradiation of linen [29].

9. Mystery #2: Carbon Dating

The second mystery is the carbon dating of the Shroud. It is helpful to first discuss how carbon dating is performed. 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 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 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), 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), 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 of the C^{14} will decay, and thus will no longer be present. The C^{12} atoms do not decay, i.e., are stable, so that the C^{14}/C^{12} ratio will naturally decrease with a 5730 year half-life. As will be explained, it is believed that the C^{14}/C^{12} ratios for the Shroud subsamples were accurately measured, so that both these 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 having produced new C^{14} in the samples. It is believed this last option is the best explanation for the 1988 carbon dating of the Shroud, as explained below.

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 11 and 12). Results were published in 1989 in the journal *Nature* [30]. 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 [31, 32].

(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 macro and/or microscopically.
(2) There are 13 other date indicators that contradict the 1260-1390 date [6, 33].
(3) The measured carbon dates depend on the distance from the bottom of the Shroud (Figure 13). This means the samples were not representative (not homogeneous) of the rest of the Shroud. The non-homogeneity of the samples has been confirmed by four recent papers in peer-reviewed journals [34, 35, 36, 37], and is consistent with previous statistical analysis of the measurement data [38, 39].
(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

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.

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. 39 and Table 4 of Ref. 36). This indicates a systematic error was likely present. If a systematic error was present then the certainty of uncorrected mean value of 1260 ± 31 should be rejected, so the corrected range of 1260-1390 should also be rejected.

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 [30]. 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. Some believe this occurred when newer cloth was invisibly interwoven into the older cloth of the Shroud [40, 41], but this hypothesis cannot explain all the evidence.

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 13), a sloped red dashed line 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. 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.

The hypothesis that is consistent with everything we know to be true about carbon dating as it relates to the Shroud is the neutron absorption hypothesis [31, 42, 43]. If the radiation emitted from the body that caused the images also included neutrons, then a small fraction of these neutrons would be absorbed in the trace amount of nitrogen in the cloth to produce new C^{14} in the fibers [44] by the [N^{14}+ neutron $\rightarrow$ C^{14} + proton] reaction. Tom Phillips, in 1989 in the journal *Nature* [45], was the first to document his hypothesis that neutron absorption could have altered the date obtained in the 1988 carbon dating of the Shroud.

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 MCNP nuclear analysis computer calculations discussed below, 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 on linen [29].

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:

(1) The uncorrected carbon date at the 1988 sample location is 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) The Sudarium of Oviedo is an 84 x 53 cm linen cloth that has been in the cathedral in Oviedo Spain since 1113 AD. It contains no image but does contain blood stains similar to the Shroud of Turin. Ancient tradition claims the Sudarium is Jesus' face cloth mentioned in John 20:7 and thus is connected to the Shroud of Turin. Historical documents state it left Palestine prior to 614 AD. It was carbon dated to about 670 AD.

Using this hypothesis of neutrons homogeneously emitted from the body as it lay in a limestone tomb, a long series of MCNP nuclear analysis computer calculations were run. MCNP is an acronym for Monte Carlo N-Particle, where "N" stands for neutron. MCNP was developed at the Los Alamos National Laboratory over many decades and is approved by the United States Nuclear Regulatory Commission (NRC) for nuclear analysis for a variety of purposes. It has been confirmed by comparison of thousands of nuclear experiments with MCNP calculations.

Figure 14 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 second point from the left in Figure 14 is approximately where the samples were cut from the Shroud in 1988 for carbon dating. The MCNP calculated slope at this point agrees with the experimental slope, about 36 years per cm in Figure 13, obtained from carbon dating measurements at the three laboratories! The results of the MCNP calculations appear to have also received independent confirmation from the position dependence of the fluorescence on the Shroud [46] based on photos taken by STURP in 1978.

10. Mystery 3#: Blood

The third mystery is related to the blood. About a dozen tests have been performed on the blood. Results of these tests proved that what appears to be blood is blood. All results are also

consistent with it being human blood, though further testing is needed to exclude other possible options. Blood could have drained from the body onto the cloth where there were wounds in the scalp, wrists, side, and feet. However, the problem is explaining how the blood that would have dried on the skin could have transferred to the cloth. Examples are the blood that drained from the wrist wounds and ran down the arms, and the blood from the scourging.

Since dried blood does not absorb into cloth, why is the blood that would have dried on the body now on the cloth? The hypothesis of an extremely brief intense burst of radiation emitted in the body offers a possible explanation. If the radiation burst were sufficiently brief and sufficiently intense, it would thrust wet or dried blood off the body onto the cloth by a natural process called radiation pressure. This is a process by which radiation transfers momentum to an object which causes it to move. But the radiation would have to be particle radiation. Examples of particle radiation include neutrons, protons, and electrons. Electromagnetic radiation such as ultraviolet light would vaporize the blood before it caused the blood to move significantly.

11. Future Testing of the Shroud

The last extensive testing of the Shroud was performed in 1978 after the Shroud was put on exhibition in Turin. There are rumors of another exhibition in 2025 and it is hoped the Vatican will allow additional testing following the exhibition. To encourage a decision to allow such testing, a carefully planned program for future testing of the Shroud should be developed for the Vatican to consider. The Shroud was owned by the Savoy family in Italy starting about 1453, but in 1983 the Shroud was willed to the reigning pope, so he will make the final decision. This testing program should take advantage of the significant advances in nondestructive testing (NDT) technology since the last extensive testing in 1978. The following are some of the questions that should guide future testing of the Shroud:

Image Formation:
- Nature & location of discoloration?
- Evidence of bones, backside image, coins over the eyes?
- Cause of banding and mottling?
- Distribution of fluorescence on the Shroud?
- Other evidence of radiation on the Shroud?

Dating:
- Carbon dates for other locations? [47]
- Other long-lived isotopes produced by neutron absorption, such as Cl^{36} and Ca^{41}, on the Shroud or in the tomb? [48]
- Evidence of an invisible reweave at the 1988 sample location? [40, 41]
- Other dating methods: reflectance, tensile strength, etc.?

Blood:
- Location, shape, composition, serum rings?
- Is blood human, male, type AB?
- DNA genome? What race?
- Why is it reddish? Is neutron absorption a possible explanation?
- Has the blood been retouched with paint?

History:

Pollen?
Limestone chips, dust, debris?
Side piece and stitch?

The following techniques have been suggested for future testing of the Shroud:

- Light and electron microscopy
- Multispectral & Hyperspectral imaging
- X-ray fluorescence
- Fourier Transform Infrared Spectroscopy
- Raman and Energy Dispersive Spectroscopy
- Atom probe tomography
- Nuclear Activation Analysis
- Radiation detection methods

12. Conclusion

There is no known example of a human body producing an image of itself on a piece of cloth, except for the Shroud of Turin. In our current understanding of physics, there is no mechanism or process that can do this. Yet, in the Shroud, there is evidence a dead human body produced front and dorsal images of itself on linen cloth. From the perspective of science, this unique encoding event appears to require a unique process or mechanism that is outside or beyond our current understanding of physics. Thus, to help humanity gain a more complete and accurate understanding of reality, further scientific testing should be performed on this unique historical artifact.

This paper has discussed what is visible on the Shroud, its history and materials, the history of Shroud research, and questions along with methods to be used in further testing. The main mysteries to be explained were identified as formation of the images, carbon dating, and certain features of the blood that is now on the cloth. To explain these mysteries, the evidence on the Shroud should be followed where it leads, with a neutral mindset not restricted by presuppositions. Many papers have been written attempting to explain a single mystery, but the hypothesis of an extremely brief intense burst of radiation from the body is attractive because it can explain features of all three mysteries:

- We can see the images because the information that defines the appearance of a crucified man has been encoded into the pattern of discolored fibers on the cloth. To form the images with good resolution, this information could only be transferred from the body to the cloth by radiation. The density of the images at any point is a function of the vertical distance between the body and the cloth, which is the 3D information encoded into the images. This is best explained by an extremely brief intense burst of vertically collimated radiation, probably charged particles, emitted in the body that was deposited on the cloth. This radiation delivered to the cloth the energy required to drive the discoloration mechanism and the information required to control the discoloration mechanism so that the images could be formed. It is hypothesized that this radiation,

when absorbed on the cloth, caused an electrical discharge from the top fibers facing the body. This caused electrical heating and/or ozone production which discolored the fibers in the pattern that can be recognized as a crucified man.

- If neutrons were present in this burst of radiation, it would explain how the carbon date could be shifted from the time of Jesus' death, about 33 AD, to the carbon date of 1260-1390. This would occur due to new C^{14} produced on the Shroud by neutron absorption in the trace amount of nitrogen in the cloth by the $N^{14}(n,p)C^{14}$ reaction.
- If this burst of radiation from the body were sufficiently brief and sufficiently intense, it would thrust blood, wet or dry, off the body onto the cloth by a natural process called radiation pressure.

This hypothesis was discussed to suggest experiments that should be included in development of a program for future testing of the Shroud. To assist in developing such a testing program, or if you have questions or comments, please contact the author at robertarucker@yahoo.com.

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Author’s Biography

Robert A. Rucker (Bob) earned an MS degree in nuclear engineering from the University of Michigan and obtained Professional Engineering (PE) certificates in nuclear engineering and in mechanical engineering. He worked for 38 years in the nuclear industry performing nuclear analysis calculations for design of advanced nuclear reactors and criticality safety calculations and documentation for nuclear fuel production and storage. This included about four years conducting nondestructive testing (NDT) or assay (NDA) measurements of fissile material in equipment and sealed containers, as well as statistical analysis of the measurement data. He published 42 documents with US Government agencies. He has been researching the Shroud of Turin since 2013 including application of MCNP nuclear analysis computer calculations to solve the carbon dating problem for the Shroud. He has written 32 papers (as of Nov. 2021) on his

research that are available on the research page of his website www.shroudresearch.net. He also organized a four-day international conference on the Shroud in 2017. Proceedings of this conference are on his website at http://www.shroudresearch.net/conference-2017.html .

Figure 1. The Shroud of Turin, as Seen (Negative images) and the Camera Negative (Positive Images)

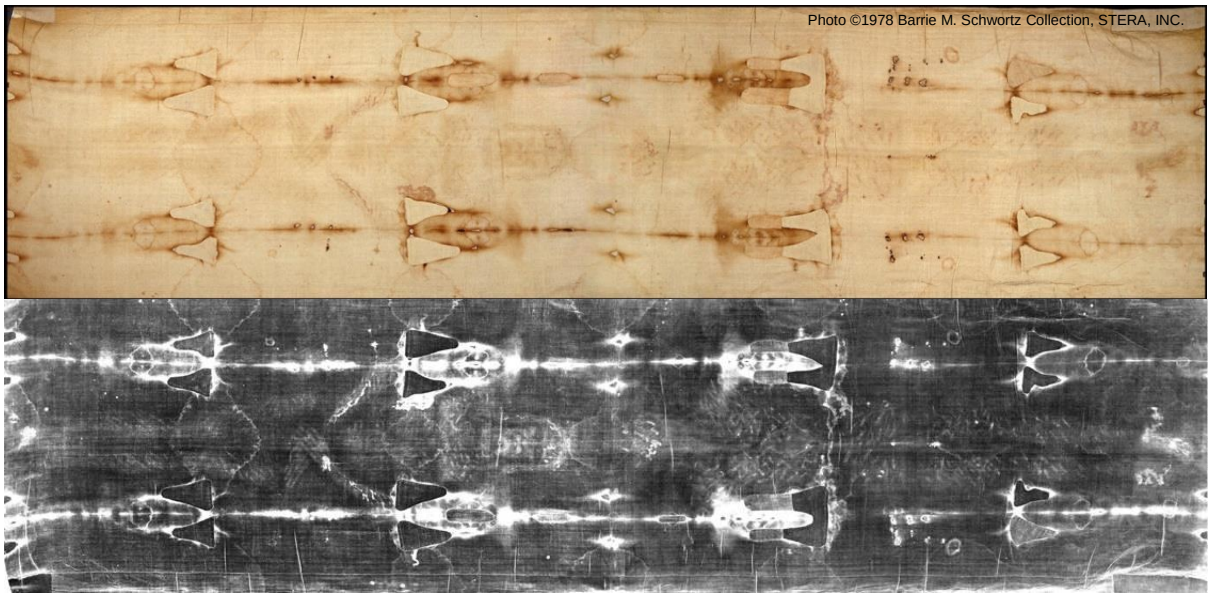

Figure 2. Front and Dorsal (back) Images on the Shroud, Negative Images

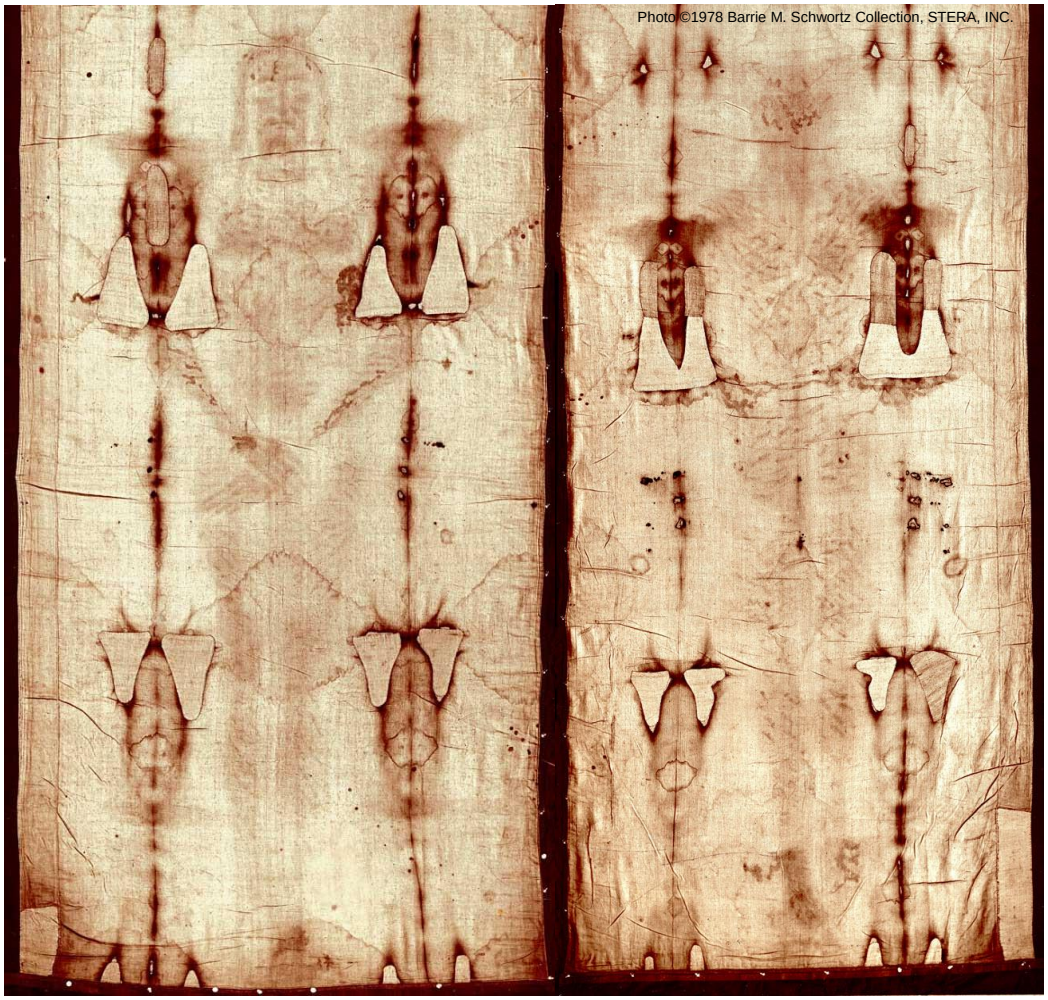

Figure 3. Descent from the Cross with the Shroud of Turin
by Giulio Clovio, 1498-1578, Bottom Half

Photo ©1978 Barrie M. Schwortz Collection, STERA, INC.

Figure 4. The face on the Shroud, Positive Image

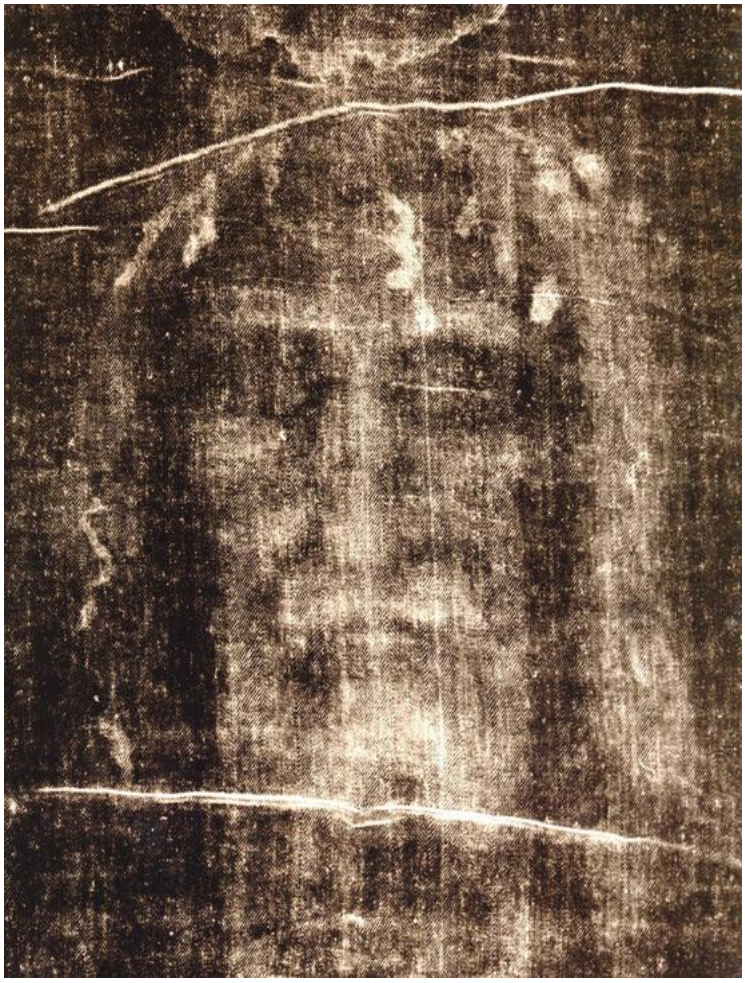

Photo ©1978 Barrie M. Schwortz Collection, STERA, INC.

Figure 5. The Shroud has been in the Cathedral of St. John the Baptist in Turin, Italy, since 1694, and in Turin since 1578

Figure 6. History of the Shroud

Figure 7. Flax as Grown and Dried, and Cross Section of the Stem

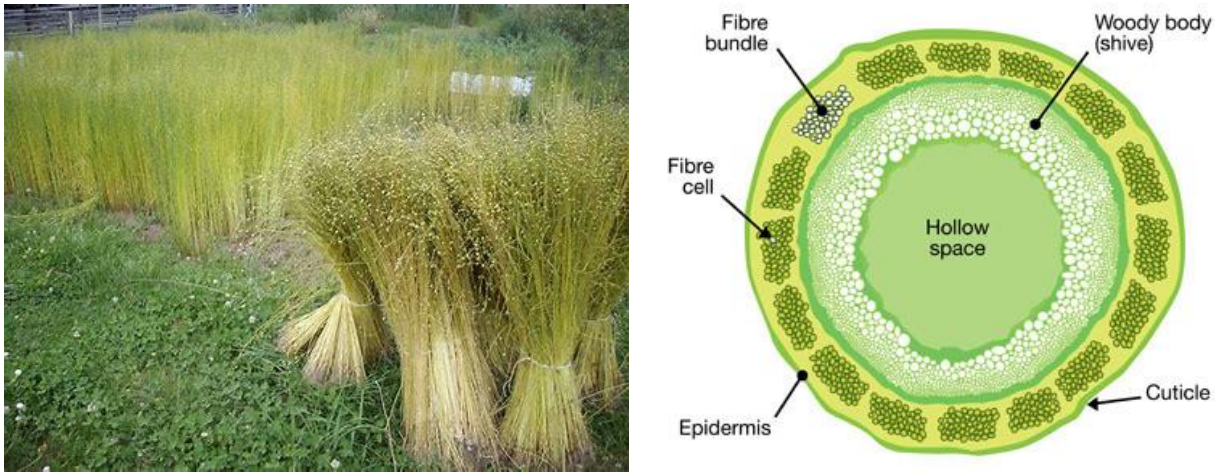

Figure 8. Fibers from the Flax Plant

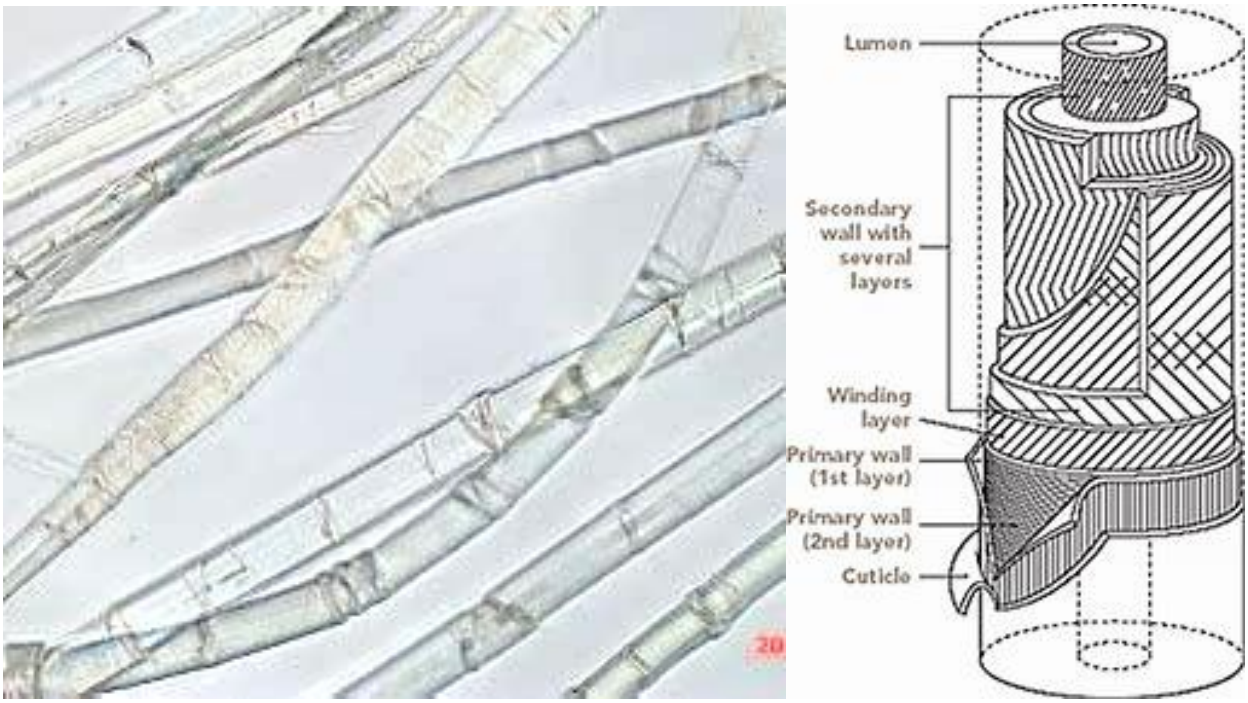

Figure 9. Small of the Back on the Dorsal Image (32X)

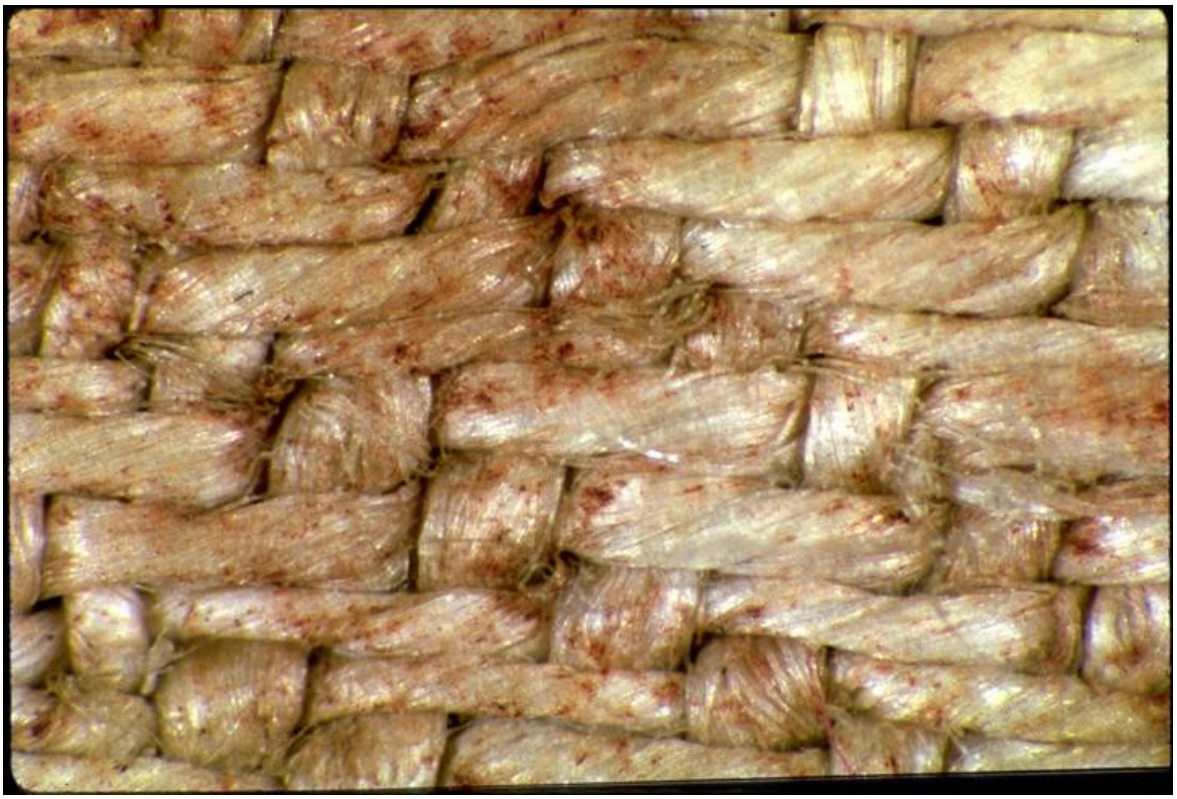

Figure 10. Tip of the Nose (64X)

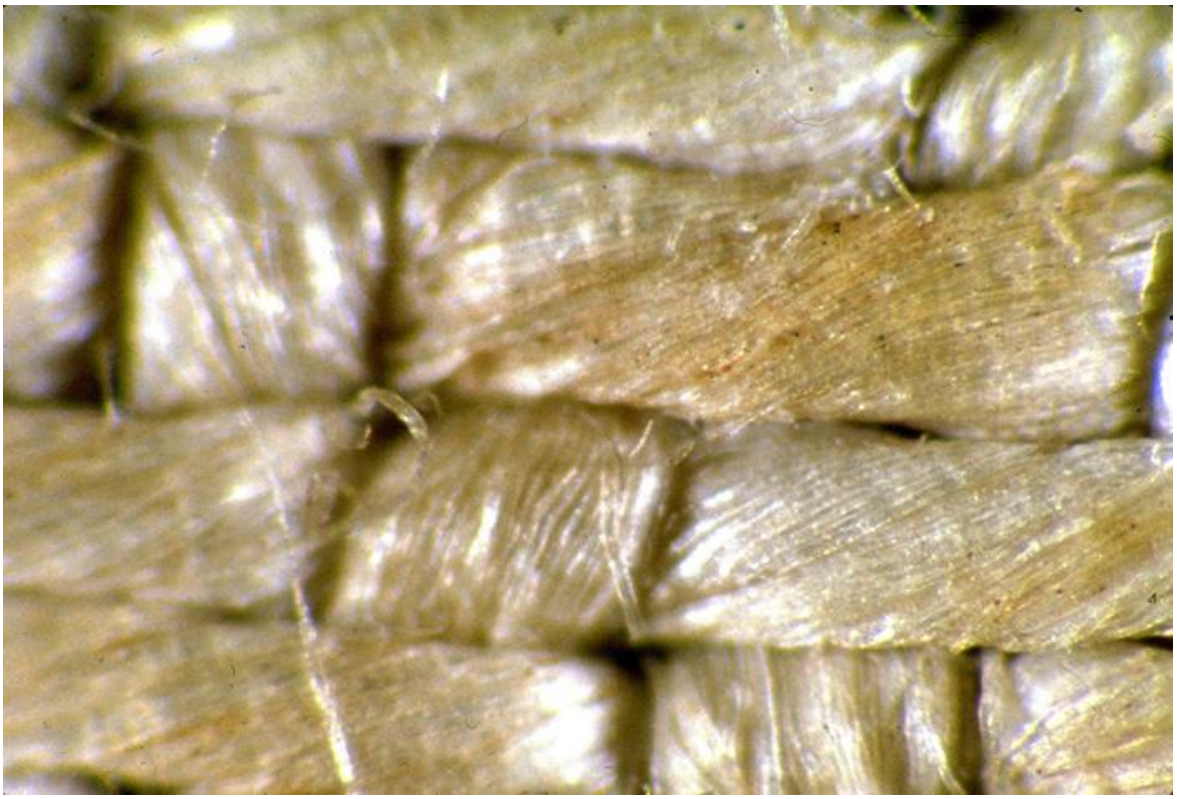

Figure 11. Location of Samples for C^{14} Dating

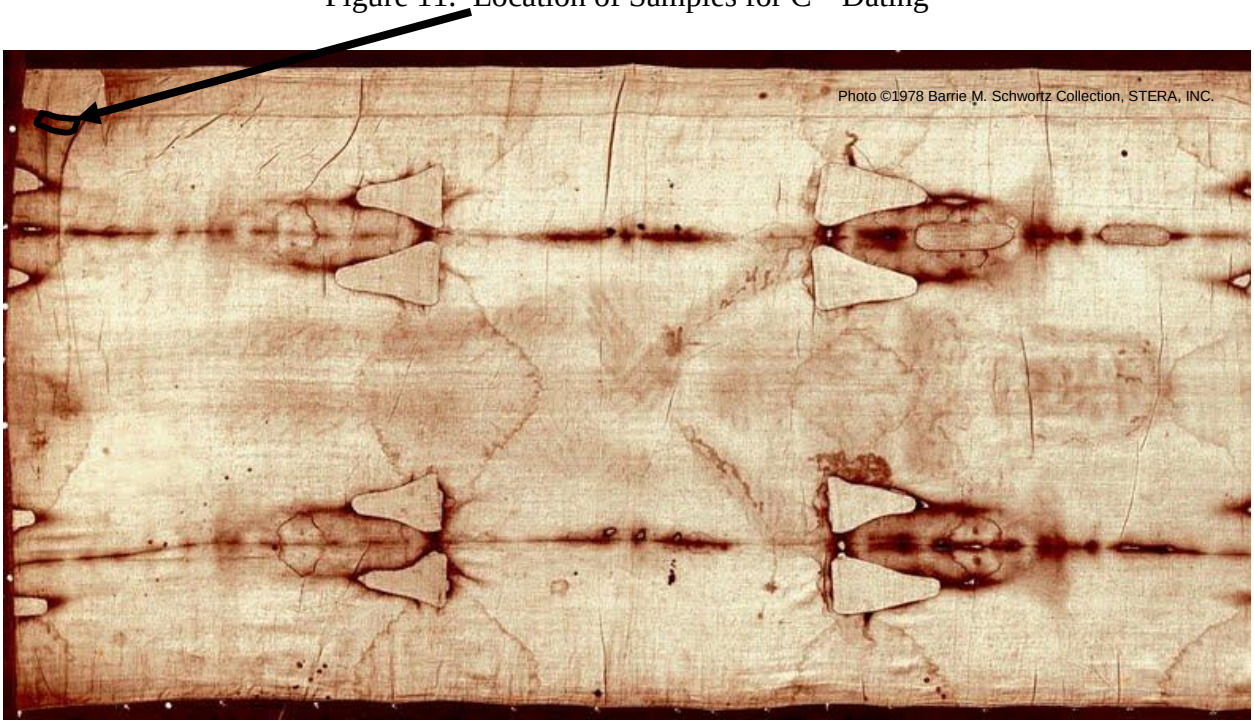

Figure 12. Location of Samples Cut from the Shroud in 1988

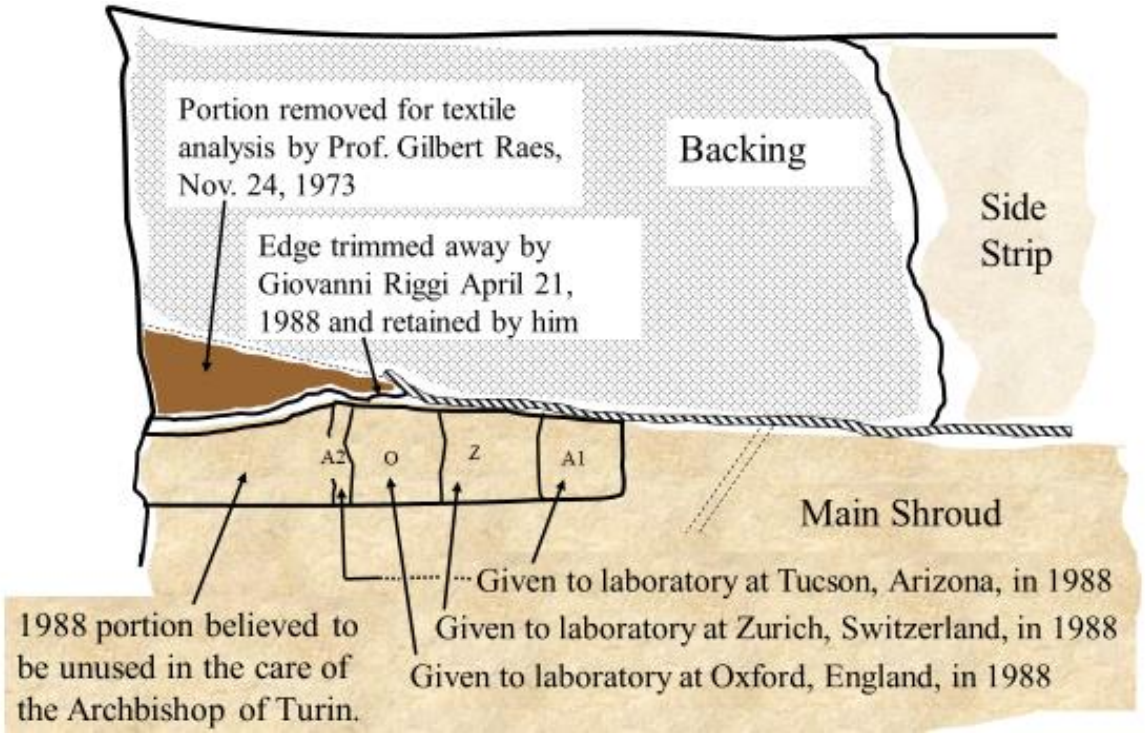

Figure 13. Measured Dates are a Function of Sample Location

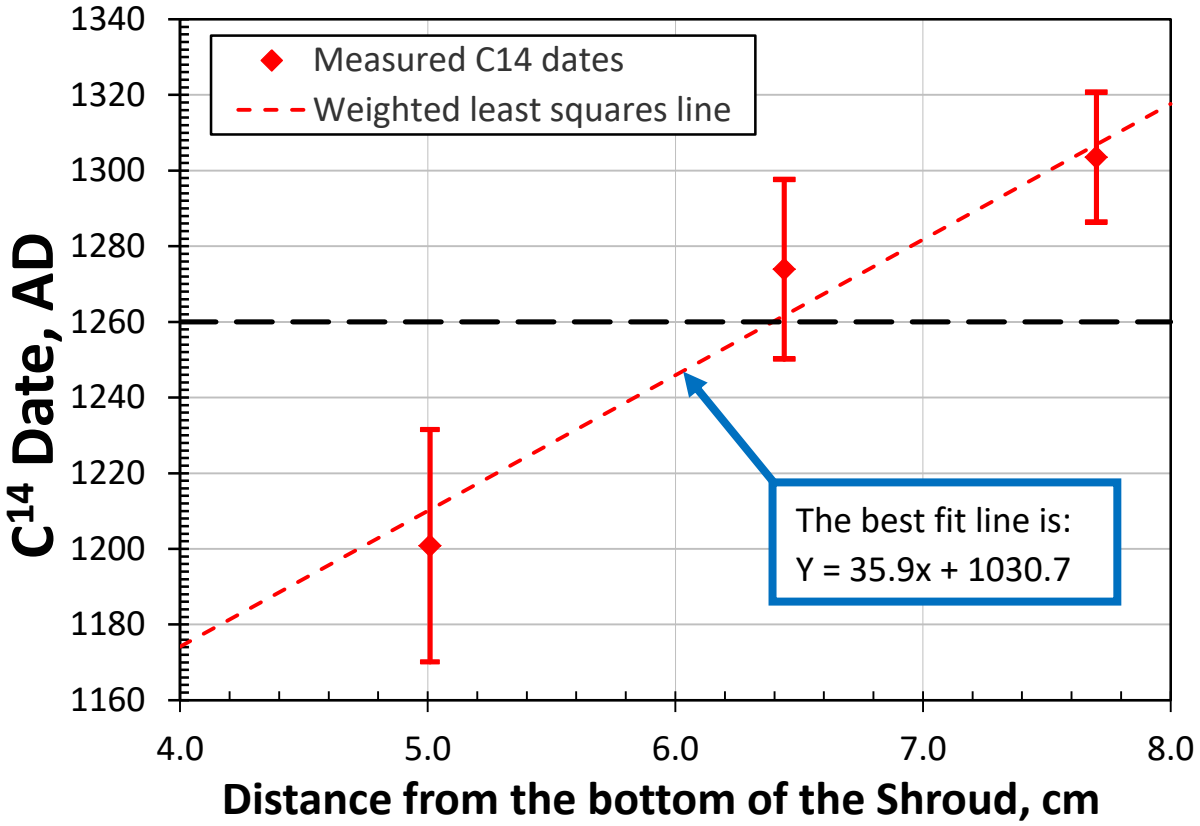

Figure 14. C^{14} Date on Shroud Below the Body