

Non-Destructive Testing of the Shroud of Turin, Narration

Robert A. Rucker, August 12, 2021, ISNDCM-2021, Baltimore, MD

Slide 1.

This presentation was a keynote address delivered on August 12, 2021, at a three-day (Aug. 10-12) technical conference in Baltimore, MD, on nondestructive testing. It was organized by the American Society for Nondestructive Testing (www.asnt.org). The title of the conference is the “16th International Symposium on Nondestructive Characterization of Materials” (ISNDCM-2021) and was led by Dr. Shant Kenderian of Aerospace Corporation. Some material has been added to the presentation for further explanation.

Slide 2. Nondestructive Testing of the Shroud of Turin

My name is Bob Rucker. I will be talking about the Shroud of Turin. The Shroud is probably 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, Time magazine, and the June 1980 edition of National Geographic included a 24-page article with a beautiful 4-page foldout showing the Shroud.

In this presentation, I will discuss the Shroud’s characteristics and materials, previous testing, current concepts to explain its mysteries, and the need and opportunity for future testing.

Slide 3. Bob Rucker

I earned an MS degree in nuclear engineering at the University of Michigan and spent 38 years in the nuclear industry performing nuclear analysis computer calculations for nuclear reactor design and criticality safety. I also spent about five years performing nondestructive testing (NDT) or assay (NDA) of fissile material in equipment and sealed containers.

I have spent the last 8 years doing independent research on the Shroud of Turin. This includes writing 30 papers that are on my website www.shroudresearch.net and organizing an international conference on the Shroud in 2017. Proceedings of this conference are on my website at <http://www.shroudresearch.net/conference-2017.html> .

My objective in this research is to explain the mysteries of the Shroud, including the image, carbon dating, and the blood, by following the evidence where it leads with a neutral mindset apart from bias or presuppositions such as naturalism or religious concepts. 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 to the cause.

Slide 4. Images on the Shroud of Turin

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 of Turin is 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 and is very pliable. Many people regard this cloth as a holy relic because, according to ancient tradition, it is the burial cloth of Jesus Christ. This is supported by the full-size frontal and dorsal images of a man on this cloth. These images show a man that was crucified exactly as Jesus was crucified according to the Bible, yet the images are not due to pigment.

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 Chambéry, 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 can be seen between the scorch marks. The frontal image is on the left with head, arms, and body 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 is the photographic negative of the Shroud, but it shows the body as a positive image. This means that the images on the Shroud are negative images, with light and dark areas reversed. It is important to note that there are no images of the sides of the body or the top of the head, and that the frontal and dorsal images are head-to-head.

Slide 5. Descent from the Cross

This is 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 this painting from the middle 1500s.

Slide 6. Frontal Image

The frontal image shows puncture wounds in the scalp as would occur from a cap of thorns. It shows a swollen cheek, torn nose cartilage, and a two-inch elliptical wound in the side just the size of a Roman thrusting spear, with blood running down from it separated into red and clear components. This indicates the side wound is a post-mortem (after death) wound.

It shows the nail through the wrist, contrary to paintings in the middle-ages which had the nails going through the palm. We now know that a nail through the palm would not support a 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, because the thumbs would have been turned under the palms by the nail going into the wrist. Thus, in both respects, the image indicates that it was not made in the middle-ages, contrary to the carbon dating.

The image 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. The front image also shows about 120 scourge marks and abrasions on the nose and one knee,

suggesting that the man made 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 similar to a stitch that was found on a cloth from Masada, which was destroyed in 73-74 AD, thus indicating the Shroud is probably from the first century.

Slide 7. Photographic Negative of the Face

This is a closer view of the face. It shows 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, apparently, this image is the source of our concept of Jesus' appearance, as has been shown on the cover of *Life* magazine.

Slide 8. Dorsal Image

The dorsal image shows puncture wounds in the scalp, abrasions on the shoulders evidently from carrying a rough heavy object, scourge marks down the body from two Roman flagrum containing dumbbell shaped weights on the ends of three straps, a flow of blood and clear blood serum from the side wound that ran across the small of the man's back, and two nails through one foot and evidently only one nail through the other foot. This permitted one foot to be rotated to allow the crucified man to push up and down to breath while crucified. The shape of the feet, being twisted together, indicates the presence of rigor mortis, which indicates that the man was dead.

There are several unusual or unique features to 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, 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.

Slide 9. Cathedral in Turin (Torino), Italy

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. This picture was 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.

Slide 10. History of the Shroud

This is the route that most Shroud researchers believe the Shroud has taken. Based on evidence of pollen and DNA from the Jerusalem area and chips of Jerusalem limestone on the Shroud, it is generally believed that 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 Mandylian.

The last reference to the Shroud in Constantinople was in 1204 AD at the time of the 4th 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 figure shows a dashed line from Jerusalem to Lirey, France because the routes are not known, but shows a continuous line between Lirey and Turin, Italy because there is continual historical documentation for this route.

Slide 11. Opportunity for NDT of the Shroud

The last extensive testing of the Shroud was performed in Turin in 1978 after an exhibition. There are rumors of another exhibition in 2025 and we hope that the Vatican will allow additional testing following the exhibition. To encourage a decision to allow such testing, a carefully planned program for nondestructive testing of the Shroud should be developed for the Vatican to consider.

The Shroud was owned by the Savoy family in Italy since 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 NDT technology that have been made since 1978.

Slide 12. Linen is Made from the Flax Plant

The Shroud is woven from linen thread made from the stems of the flax plant. The background scene in this picture shows how flax looks as it is growing. The foreground shows flax that has been cut and bundled for drying. Note the long stems.

Slide 13. Stem of a Flax Plant

A cross sectional cut of a flax stem shows a hollow space at the center surrounded by a woody body, surrounded by bundles of flax fibers. These flax fibers are separated from the rest of the stem and then dried to make linen thread. The diameter of these fibers is about 15 to 20 μm , which is about a fifth the diameter of a human hair. A linen thread contains about 200 or more of these fibers.

Slide 14. Flax Fiber

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 Shroud probably dates earlier than about the 12th century.

Slide 15. Dorsal Image, Small of the Back (32x)

This 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.

Slide 16. Tip of the Nose (64x)

A closer view (64x) shows how the image of the crucified man is formed on the Shroud. This is a photo of the tip of the nose where the image is strongest. Note there is no evidence of pigment, binder, anything clumping the fibers or threads together, 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. This is what forms the image. I will discuss this further later.

Slide 17. Shroud is the Most Researched Artifact in Human Possession

Scientific testing of the Shroud began in 1898 when an Italian amateur photographer named Secondo Pia took the first photograph of the Shroud. Research continued over the next eight decades by very qualified people in the United States and other countries who concluded, in general based upon the blood, that the body of a crucified man had in some unknown way encoded an image 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, the indented center with raised edges of the blood clots, and the clear blood serum extending beyond the blood clots due to capillarity.

Slide 18. STURP Scientific Investigation, 1978

But the only opportunity for a comprehensive scientific examination of the Shroud occurred in 1978. The discovery by Dr. John Jackson in 1975 that the image contained 3D information led to formation of the Shroud of Turin Research Project. The acronym is STURP. In 1978, the Vatican allowed STURP, led by Dr. John Jackson, to send 26 American scientists to Turin to perform nondestructive experiments on the Shroud for a total of 122-hours, working in three shifts over a period of five days.

Slide 19. Shroud of Turin Research Project (STURP)

The members of STURP made extensive preparations and obtained donations of 2.5 million dollars' worth of scientific equipment.

Slide 20. Testing by STURP in 1978

Here I list some of the methods that were used to examine the Shroud in 1978. I will not discuss the specific methods used for testing. I am only listing these to communicate the extent of their testing and for future reference.

Slide 21. Testing by STURP in 1978

Testing was also done for the presence of protein in the image, 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.

Slide 22. STURP's Conclusions

The main objective of STURP was to examine how the image was formed. They concluded the image 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, and
6. no cracking of the image along fold lines.

They found no capillarity (soaking up of liquid) in the fibers or threads so the image 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 tested, the scorches caused by the fire in 1532 did fluoresce but the image did not fluoresce. This means 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.

Slide 23. STURP's Conclusions

STURP also concluded that only the top one or two layers of fibers were discolored out of 200 or more fibers in a thread. They also concluded that the 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. This thin discolored layer, over much of the length of the discoloration, in general extends around the entire circumference of a fiber.

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

image of the crucified man. Specifically, the discoloration is due to some of the single electron bonds of the carbon atoms being changed to double electrons bonds, which causes the molecule to vibrate differently so it reflects light differently, so we see it as discolored.

Slide 24. Discolored Fiber

What could cause the fiber to be discolored only on the outer 2% of the fiber's radius. Various explanations to the mysteries of the Shroud (image, carbon dating, and blood) have been proposed by Shroud researchers, but my hypothesis is attractive because it is the only concept that is consistent with the evidence and can offer an explanation to all three mysteries.

Slide 25. Mystery #1: Image Formation

The first mystery to be considered is the image on the Shroud. Three things are needed to form the image: 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 image of the crucified man.

It is helpful to first determine why we can see the image. The key is information. For example, why can we recognize a person in a photograph? It is because the information that defines his 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 image 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.

However, this information is not the information that defines how we would see the body in reflected light but, very strangely, 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 image. 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 that was altered as it travelled vertically across the gap. Radiation is the only option that can satisfy these requirements. 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 and can communicate the vertical gap distance by its intensity (number of particles or photons), with the intensity being diminished by absorption and scattering in the air, and possibly by decay.

Many, if not most Shroud researchers believe the image was formed by radiation. Only vertically collimated radiation emitted from the body can communicate to the Shroud the information that is encoded in the image and deliver this information in a focused manner to produce the good resolution front and dorsal images while not producing images of the side of the body or the top of the head. This is discussed further in my papers 5 and 6 on the research page of my website shroudresearch.net.

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, so that the information did not become confused, resulting in significant loss of resolution in the image. 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 image. Since such lenses would not have been between the body and the cloth, the radiation must have been vertically collimated.

Also, laser experiments indicate that to produce the extreme superficiality of the image, with only the top one or two layers of fibers discolored, the radiation must be emitted in an extremely brief intense burst of radiation.

How the fibers were discolored to a thickness of less than $0.2 \mu\text{m}$ must also be explained. One possibility is that 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 that the molecular structure of the fibers could have been altered by heat deposited in this very thin $0.2 \mu\text{m}$ region. Due to electromagnetic effects, an alternating current in a conductor will cause the electrons to 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 $0.2 \mu\text{m}$ outer region of the fiber. This could 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 had to cause it was probably primarily charged particles rather than electromagnetic radiation. These charged particles had to have low energy because the fibers do not show an increase in the number of ion tracks.

Thus, my hypothesis is that the image was probably formed by an extremely brief intense burst of vertically collimated low energy radiation, primarily charged particles, from the body that caused an electrical discharge from the top fibers facing the body. This electrical discharge produced heating and/or ozone that altered the molecular structure in the thin $0.2 \mu\text{m}$ circumferential region of the fiber. This gradually discolored the thin region probably over a period of months to years as the atoms settled into their lowest energy states.

Slide 26. Mystery #2: Carbon Dating

The second mystery is the carbon dating of the Shroud. In 1988, samples were cut from a corner of the Shroud and sent to three laboratories in Tucson, Zurich, and Oxford for carbon dating. Results were published in 1989 in the journal *Nature*. The mean of the three laboratory mean values was $1260 \text{ AD} \pm 31$ years, one sigma. 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.

Slide 27. 1260-1390 AD Should be Rejected

There are several reasons why most Shroud researchers believe the 1260-1390 date obtained by carbon dating should be rejected, i.e., given no credibility (See section 7 of my paper 25 on my website).

- (1) The technology to make the image did not exist in 1260-1390. It does not exist even today.
- (2) There are 13 other date indicators that contradict the 1260-1390 date. (Section 4 of my paper 29)
- (3) The experimental carbon dates depend on the distance from the bottom of the Shroud. This means that the samples were not homogeneous with the rest of the Shroud. The non-homogeneity of the samples has been confirmed by three recent papers in peer-reviewed journals (Casabianca, Walsh & Schwalbe, and Di Lazzaro, et al.)
- (4) The carbon dates from Oxford and Arizona are different by 104 ± 35 years, which is a 3.0 sigma difference. The usual acceptance criteria 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 that a systematic error is probably present, which means that the carbon dates should be rejected.
- (5) A Chi squared statistical analysis of the measurement data indicates that the distribution of the laboratory's mean values has only a 1.4% chance of being explained by the stated uncertainties (Paper 12 on my website). This indicates that a systematic error was likely present. If a systematic error was present then the uncorrected mean value of 1260 ± 31 should be rejected, so the corrected range of 1260-1390 should also be rejected.

Thus, I believe that the C^{14}/C^{12} ratios of the samples were measured correctly, but that evidently the C^{14}/C^{12} ratios in the samples had been altered, which gave rise to the systematic error. Many believe this occurred when newer cloth might have been invisibly interwoven into the older cloth of the Shroud, but I do not believe this hypothesis is consistent with all the evidence.

Slide 28. Dates are a Function of Sample Location

When the carbon dates obtained by the three laboratories are plotted as a function of distance from the bottom of the cloth, a sloped red line through the three points is a better fit to the data than the assumption that 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 about 91 years per inch. This means that if the sample point is moved by 10 inches, then at this rate, the carbon date would change by 910 years, so this effect is very significant.

Slide 29. Neutron Absorption Hypothesis

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 (papers 13 and 25 on www.shroudresearch.net). If the radiation, predominantly charged particles, emitted from

the body that caused the image 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 Shroud by the $[N^{14} + \text{neutron} \rightarrow C^{14} + \text{proton}]$ reaction. This is Tom Phillips hypothesis first documented in 1989 in the journal *Nature*.

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 of only 16.9%. This would occur if only one neutron were emitted from the body for every ten billion neutrons that were in the body.

This would occur if only 0.0004% of the deuterium, or heavy hydrogen, atoms 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.

I believe neutron absorption is the best hypothesis to explain the carbon dating of the Shroud to 1260-1390 AD because it is the only hypothesis that is consistent with the four things we know to be true about carbon dating as it relates to the Shroud. The four things we know to be true are:

- (1) the uncorrected carbon date at the 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, and
- (4) the Sudarium of Oviedo, which ancient tradition indicates is Jesus' face cloth (John 20:7), was carbon dated to about 700 AD.

Slide 30. C^{14} Date in Shroud Below the Body

Using this hypothesis of neutrons homogeneously emitted from the body as it lay in a limestone tomb, I ran a long series of MCNP nuclear analysis computer calculations. 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.

This curve shows the carbon date on the vertical axis that was calculated by MCNP for a location along the midline of the body on the cloth that was under the body. 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. Also, the second point from the left is approximately where the samples were cut from the Shroud for carbon dating. The MCNP calculated slope at this point agrees with the experimental slope obtained from carbon dating measurements at the three laboratories! My MCNP calculations have also recently received apparent confirmation from the position dependence of the fluorescence on the Shroud (paper by Tom McAvoy).

Slide 31. 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 confirm this. Blood could have drained from the body onto the cloth where there were holes in the skin, such as the wounds in the scalp, wrists, side, and feet. However, the problem is regarding the blood that would have dried on the skin, such as the blood that drained from the wrist wounds and ran down the arms, as well as blood from the scourging.

Since dried blood does not absorb into cloth, why is this blood 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 could 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 can transfer 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.

Slide 32. Questions for Future Testing

These are some of the questions related to image formation and dating that should guide future testing of the Shroud.

Slide 33. Questions for Future Testing

And these are some of the important questions related to the blood on the Shroud and the history of the Shroud. These questions are also listed to guide future testing of the Shroud.

In this presentation, I have discussed why the Shroud is worthy of future testing and the basis for that testing. This presentation was done in hopes of promoting interest in the Shroud so that assistance can be obtained to develop a nondestructive testing (NDT) program that could be used in testing the Shroud hopefully in 2025. If you would like to assist us in this project, please contact me at robertarucker@yahoo.com .

Slides 34. NDT Methods for Testing the Shroud

These are some of the nondestructive tests that could be used to analyze the Shroud in the future. There are probably many more that could also be used.

Slides 35. Further Information

Further information regarding the Shroud can be found on the listed websites as well as many others. Helpful books are also listed.

Slide 36. Thank You

This is my contact information (robertarucker@yahoo.com, 509-375-3770 in the US). Thank you for the opportunity to talk with you.