

# Image Formation on the Shroud of Turin

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## Abstract

The Shroud of Turin contains full-size front and dorsal images of a man who was crucified exactly as Jesus was crucified according to the New Testament. One of the main mysteries of the Shroud is how these images were formed. Scientific examination of the Shroud in 1978 determined these images were not formed by pigment, scorch, liquid, photography, or contact between the body and the cloth. These front and dorsal images have a good resolution and are formed by a mottled pattern of discoloration on the top two or three layers of fibers in the threads. The discoloration thickness is less than 0.2 micrometers around the outer circumference of the fibers, with 3D or topographical information encoded into the images that relates to the vertical distance of the cloth from the body, without side images of the body. By following this scientific evidence where it leads, a hypothesis was developed that is consistent with this evidence. This hypothesis explains how the images were formed by an extremely brief intense burst of vertically collimated low energy charged particles, probably protons, emitted in the body that was wrapped in the Shroud. According to this hypothesis, when the protons deposited their charge onto the cloth, it produced electrical currents in the fibers which caused localized heating of the fibers which discolored them to form the images of the crucified man. It is proposed these protons were emitted in the body by the splitting of deuterium nuclei. This process would have also emitted neutrons. Absorption of a small fraction of these neutrons would have produced new C-14 on the cloth which can explain why the Shroud was carbon dated to 1260-1390 AD.

## 1. Introduction

The Shroud of Turin is one of the most mysterious and potentially significant items in human possession. The Shroud of Turin is a long piece of linen cloth that inspired paintings and images on coins starting in the sixth and seventh centuries in the Byzantine Empire, was exhibited as Jesus' burial cloth in Lirey, France in about 1355, and has been in Turin, Italy since 1578. The Shroud is made of linen thread made from the flax plant and woven into a 3-to-1 herringbone weave with each linen thread containing about a hundred or more fibers. The unique thing about the Shroud is that it contains full-size front and dorsal (back) images of a man who was crucified exactly as Jesus was crucified according to the New Testament. Based on these images, ancient tradition has long claimed that the Shroud of Turin is Jesus' burial cloth.

Jesus' dead body would have been brought into the tomb and laid on half of the long cloth used to wrap his body. The face or head cloth that was placed around his head to catch draining blood after he died on the cross would then have been taken off and laid aside. The other half of the body cloth would then have been wrapped over his head and brought down over his feet. There may have also been cloth tie strips and wash cloths in the tomb. Jesus' face or head cloth is believed to now be in Oviedo, Spain, based on documentation that arrived with it. It is usually

called the Sudarium of Oviedo. It is a low-quality linen cloth about 84 by 54 cm (about 33 by 21 inches). It contains no image but contains blood with a similar pattern to the blood on the Shroud.

The long linen cloth that covered Jesus' body is now in the cathedral in Turin, Italy. It measures about 441 cm long by 112 cm wide (about 14 feet 6 inches by 3 feet 8 inches). The images on the cloth are caused by fibers in some of the threads being discolored with a straw-yellow or light sepia discoloration. There are many papers, books, and websites that discuss the Shroud [1]. What the front and dorsal images show and the carbon dating of the Shroud are discussed in [2].

## 2. Research on the Shroud

The Shroud of Turin can be researched based on history or science. The most recent book (2021) in English on the history of the Shroud is titled "The Hidden History of the Shroud of Turin" by Jack Markwardt [1]. His research concludes that Jesus' burial cloth was probably taken from Jerusalem to Antioch prior to the destruction of Jerusalem in 70 AD, then up to Constantinople where it remained for hundreds of years. Sometime after the sacking of Constantinople in 1204, the cloth was taken to Lirey, France, where it was shown as the burial cloth of Jesus in about 1355. It was finally brought into Turin in 1578 where it is to this day.

Scientific research on the Shroud of Turin began in 1898 when Secondo Pia took the first photographs of the Shroud. 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 dead body of a crucified man that was wrapped in the Shroud. This is indicated 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). Their research is discussed below.
3. 1988 to 2016: In 1988, the Shroud was carbon dated to a range of 1260-1390 AD [2], with a claimed 95% probability the true date is within this range. They concluded "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 as the result of multiple Freedom of Information Act (FOIA) actions. Statistical analysis of the data proved the samples were heterogeneous and thus not necessarily representative of the rest of the Shroud. This indicates the 1260-1390 AD date should be rejected, i.e., given no credibility.

As listed in #2 above, the only comprehensive testing of the Shroud was performed over a 120-hour period in 1978 by about 26 researchers from the United States associated with the Shroud of Turin Research Project (STURP). Their main goal 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 in the image.
2. No evidence of a binder to hold pigment.
3. No clumping of fibers or threads.
4. No stiffening of the cloth.
5. No cracking of the images along fold lines.
6. No brush strokes
7. No outline

STURP also 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 ultraviolet light, the scorches caused by a fire in 1532 fluoresced but the images did not fluoresce. This indicated the images were not made by contact of a hot object with the cloth. The images on the Shroud were not the result of a photographic process because no light sensitive chemicals were detected on the cloth and because the images contain 3D or topographical information related to the vertical distance from the body to the cloth [3, 4, and 5]. Normal photographs and paintings do not contain 3D information. The images were also not due to contact between the body and the cloth because there are discolored fibers in the images where there would not have been contact between the body and the cloth, such as images of the nostrils on either side of the tip of the nose.

STURP also concluded [6, 7] that only the top two or three layers of fibers were discolored out of about 100 fibers in a thread. This discoloration did not extend across the entire diameter of the fibers, which is about 15 micrometers ( $\mu\text{m}$ ) which is about one-fifth the diameter of a human hair, but only discolored the fibers to a depth of less than 0.2  $\mu\text{m}$  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 also concluded [8, 9] this discoloration is not due to any substance or material (atoms) added to the fibers, but rather is the result of a rearrangement of the atoms that were 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 and other materials being changed to double electron bonds. This causes the molecule to vibrate differently so it reflects light differently, so it appears discolored.

### 3. Hypotheses for Image Formation

Many Shroud researchers have spent much effort to determine how the images were formed [7, 8, 9]. This effort has been primarily based on how the fibers could have been discolored since it is the discoloration on the fibers that make the images. Multiple hypotheses should be welcome at this stage of Shroud research. Previous hypotheses to explain image formation include:

1. The Maillard reaction hypothesis promoted by Ray Rogers [10, 11] and updated by Kelly Kears [12],

2. The skin bacteria hypothesis promoted by Stephen J. Mattingly [13],
3. The cloth collapse hypothesis promoted by John Jackson [14, 15] and Mark Antonacci [16, 17],
4. The Holy fire / corona discharge hypothesis [18, 19] promoted by Giulio Fanti, and
5. The ultraviolet hypothesis promoted by Paolo Di Lazzaro [20 to 24].

These hypotheses appear to start with a concept that could have discolored the fibers, and then analyzed whether this hypothetical discoloration mechanism can explain the scientific evidence from the Shroud. This could be called a top-down approach. The Vertically Collimated Radiation Burst (VCRB) hypothesis discussed in this paper was developed by the reverse process. By following the evidence where it leads, the nature of the discoloration mechanism is deduced from 27 scientific evidences related to the images. This can be called a bottom-up approach.

It should be noted that the first two options (#1 and #2) propose naturalistic concepts, i.e., normal common processes that could explain the image formation on the Shroud. If the images on the Shroud were formed by such a common process, then why are there not hundreds or thousands or even millions of burial shrouds containing images of the bodies they wrapped? Why do we only have one burial cloth with an image of the person it covered, and why does this totally unique cloth show the front and dorsal images of a man crucified exactly like Jesus was crucified according to the New Testament? The uniqueness of this cloth indicates that the images were probably made by a unique process, a process so unique it may never have been investigated by science, and so may be outside or beyond our current understanding of physics. This expectation is consistent with radiation hypotheses for image formation such as the cloth collapse hypothesis (#3). This hypothesis proposes that when Jesus' body disappeared from within his burial cloth, gravity and air pressure difference would have caused the cloth to collapse into the volume previously occupied by the body where it encountered radiation that caused the images. Thus, the cloth collapse hypothesis (#3), the Holy fire/corona discharge hypothesis (#4), the ultraviolet hypothesis (#5), and the Vertically Collimated Radiation Burst (VCRB) hypothesis discussed in this paper all propose the images were formed by radiation, though the methodology differs. Many if not most Shroud researchers believe the images were probably formed in some way by radiation.

For an image formation hypothesis to be true, it must be consistent with all the evidence related to the front and dorsal images on the Shroud. For researchers to accept the hypothesis as true beyond a reasonable doubt, the hypothesis should make predictions that are testable and falsifiable, which means if the prediction is tested and proven to be false, it will prove the hypothesis is false, at least as stated. If the prediction is tested and proven to be true, it will increase the credibility of the hypothesis. Depending on the nature of the predictions and the testing, it may require multiple predictions to be tested and proven to be true before the hypothesis is generally accepted as true beyond a reasonable doubt.

#### 4. Following the Evidence Where it Leads

To be true, an image formation hypothesis must be consistent with the following 27 evidences related to the images.

1. According to experiments performed in 1978 over a five day period (120 hours) by about 26 researchers associated with the Shroud of Turin Research Project (STURP), these images have no pigment, no binder to carry the pigment, no clumping of fibers or threads, no stiffening of the cloth, no cracking along fold lines, no brush strokes, and no outline.

Comments: This proves the images on the Shroud were not produced by paint, dye, or stain.

2. STURP concluded the images were also not caused by a scorch from a hot object, any liquid, or by a photographic process.

Comments: Though the objective of the STURP researchers was to determine how the images were formed, they could only determine how the images were not formed, but this is still helpful. When pigment, scorch from a hot object, any liquid, and photography are excluded as possibilities, it becomes more likely that the images were not produced by an artist or forger, so it becomes more likely the images were formed in some way by the body that was wrapped in the cloth.

3. There is a smooth gradation of discoloration on the Shroud from points vertically closer to the body relative to points vertically further from the body.

Comments: An example of this is the smooth gradation of discoloration on the cloth starting from the tip of the nose down either nostril to the cheek. This indicates the image formation on the cloth was not due to contact between the cloth and the body. This argues against the skin bacteria hypothesis for image formation.

4. STURP also detected no body decay products on the cloth.

Comments: Based on the New Testament, people usually believe Jesus died about 3 pm on a Friday and his resurrection took place at the latest about 6 am on Sunday morning. This is a period of about 39 hours. Putrefaction of a dead body starts to occur sometime later than about 48 hours after death. This is consistent with STURP not finding any decay products on the cloth and is also consistent with the Biblical statements that Jesus' body did not decay ("You will not allow Your Holy One to undergo decay", Psalms 16:8-11, Acts 2:27, 13:37). Significant decay gases would only be available for release after about 48 hours, so Jesus' body would not have released significant decay gases by 39 hours after his death. This means significant decay gases would not have been available to drive a Maillard reaction to form the images. A Maillard reaction is being given special consideration because it is the primary alternative to a radiation hypothesis for image formation. For a Maillard reaction to form the images within the time the cloth was wrapped around the body, it would require a heat source to drive the reaction, but the body wrapped in the Shroud does not provide such a heat source. When you put a piece of bread into a toaster, a Maillard reaction produces the discoloration on the toast, but you do not see the image of a face on the toast, much less the image of Jesus' face. This is because production of an image requires information to control the process. If a Maillard reaction

formed the images on the Shroud, where did the required information come from and how did it control the Maillard reaction to form the front and dorsal images on the Shroud? If a common natural process such as a Maillard reaction formed the front and dorsal images of a crucified man on the Shroud, why are there not many other examples of a dead body producing an image of itself on cloth? These issues argue against a Maillard reaction forming the images on the Shroud.

5. The images are formed by some of the flax fibers in the linen threads being discolored.

Comments: Based on microscopic examination of the fibers, STURP concluded the front and dorsal images were formed by some of the fibers in the threads being discolored. But based on evidences 1 to 4, the fibers were not discolored by pigment, scorch from a hot object, any liquid, a photographic process, contact between the body and the cloth, or a Maillard reaction (see evidence 4).

6. The Shroud contains full size front and dorsal (back) images of a man who was scourged and crucified exactly like Jesus was scourged and crucified according to the New Testament.

Comments: Three things are needed to form the images: a mechanism to discolor the fibers in the images, 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. The role of information should be a key consideration in any image formation hypothesis. For example, we recognize a person in a photograph 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 front and dorsal 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 [25, 26]. 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 to the cloth, and be deposited on the cloth. Whatever carried or transported this information must have traveled from the body to the cloth across the air gap between the two. This excludes the possibility that the images were formed by a nearby earthquake or lightning strike that caused radiation to be emitted from the limestone because the information that defines the appearance of a crucified man was not in the limestone. This information was only inherent to the body that was wrapped in the cloth.

The question might arise whether radiation that was emitted in the limestone perhaps by an earthquake or close lightning strike have gone through the cloth, hit and interact with the body, and then be reflected or reemitted from the body to carry the required information from the body to the cloth. There are two problems with this. 1) The radiation going through the cloth first would cause radiation effects on the cloth that would overpower the reflected or reemitted radiation which would be much less intense. Only the reflected / reemitted radiation could carry the information related to the appearance of a crucified man, yet this information would be overwhelmed by the effects of the radiation from the limestone that first goes through the cloth. Because of this, the resolution and contrast

would significantly decrease so that the good resolution image on the Shroud could not be formed. 2) The reflected / reemitted radiation would be reflected / reemitted in all directions so that each point on the cloth would receive information from multiple points on the body so that a good resolution image could not be formed. The chaos of the information would result in a blur on the cloth instead of a good resolution image.

The question then becomes how could this information which is required to form the images be carried, transported, or communicated from the body to the cloth. There are six ways information can be transported from one location to another. This includes:

1. Radiation, including charged particles such as protons or electrons, and what is called electromagnetic radiation such as infrared, visible, and ultraviolet light.
2. Waves in a medium such as sound waves in air or water waves in the ocean.
3. Direct contact such as fingers on a keyboard.
4. Flow of charged particles through physical connections such as the flow of electrons through wires or the system of nerve cells in the body.
5. Diffusion of molecules such as the smell of a skunk or the taste of an orange.
6. Waves in a field such as an electrostatic or gravitational field.

The cloth was not in contact with the body at every point of the image, such as next to the tip of the nose, so direct contact (#3) can be ruled out as an option. Wires were not connecting every point of the body with every point on the image, so electron flow through wires (#4) can be ruled out. The image on the Shroud has good resolution (evidence 10), so the information had to be delivered to the cloth as focused information. Diffusion of molecules (#5) and waves in a medium (#2) or field (#6) spread out as they move through space so each point on the body would receive information from multiple points on the body. This would produce confusion of the information so could not produce a good resolution image on the cloth. This means diffusion of molecules (#5) and waves in a medium (#2) or field (#6) can be ruled out. The only remaining option is radiation [25]. Radiation, both charged particles and photons of electromagnetic radiation, are ideally suited to transport the information required to define an image. This is why radiation in the form of reflected photons transports all the information to our eyes that allows us to see the scene in front of us. The frequency or energy of radiation can communicate colors in the image, the intensity (number of particles) of the radiation can communicate the shades (light vs dark), and the direction of the radiation can communicate the location of each color and shade. It can be concluded that radiation is the only option to communicate the required information from the body to the cloth. It is also significant that in testing various mechanisms to reproduce the image of the face, the best image of the face was produced by radiation controlled by information [27].

7. The image of the face is a normal width for a human face.

Comments: If the cloth were wrapped around the head during the image formation, then when unwrapped, the image of the face would be much wider than a normal face. This indicates the cloth was not wrapped around the head at the time of the image formation, but rather was relatively flat above the face. Though the width of the face on the front image

indicates this is true, it is not clear why it is true. Two possibilities have been suggested: 1) bags of flowers might have been placed on either side of his head which supported the burial cloth so the cloth was relatively flat above his face, or 2) an electrical charge may have been deposited on the cloth that caused the section of the cloth above the body and the section of the cloth below the body to repel one another, resulting in the top cloth being relatively flat across the face. This concept may be related to the fibers being discolored by a corona discharge from the top fibers facing the body, which is the conclusion from evidence 12.

The cloth being flat above his face is not sufficient to explain the face image having a normal width. It is also necessary for the radiation that communicated the information from his body to the cloth be vertically oriented. This is discussed further under evidences 8, 9, and 10.

Some Shroud researchers also believe there is evidence the body was also levitated between the sections of the cloth that were above and below the body during the image formation. This might also be caused by a distribution of electric charge.

8. The front image is a vertical projection upward from the body. The back image is a vertical projection downward from the body.

Comments: Analysis of evidence 6 concluded the information had to be communicated from the body to the cloth by radiation. The correct width of the face in evidence 7 indicates the radiation was vertically oriented. In evidence 8, the front and dorsal images being vertical projections from the body also indicate the radiation was vertically oriented as it traveled from the body to the cloth. This means the radiation was going vertically up from the body to form the front image as a vertical projection upward from the body, and the radiation was going vertically down from the body to form the back image as a vertical projection downward from the body.

9. The Shroud does not include images of the sides of the body or the top of the head.

Comments: This indicates the radiation was not travelling at an angle to the vertical, which would be required to form images of the side of the body or the top of the head. This is discussed further under evidence 11.

10. The front and dorsal images have a good resolution, perhaps in the few mm range.

Comments: Many, if not most, Shroud researchers believe the images were probably formed by radiation. Only radiation emitted from the body can communicate to the Shroud the focused information that is required to form the images (analysis of evidence 6). This radiation must be strongly oriented in the vertical direction, both vertically up and vertically down, to produce the correct width of the face (evidence 7) with the images being vertical projections from the body (evidence 8), while not producing images of the sides of the body or the top of the head (evidence 9). This radiation being strongly oriented in the vertical direction is referred to as vertical collimation of the radiation. The vertical collimation of the radiation is also required to form the good resolution of the front and dorsal images (evidence 10). Vertically collimated radiation causes each point on the cloth to receive information from only one point on the body, the point vertically below it for the front image and the point vertically above it for the dorsal image. 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.

To the extent that the radiation is not vertically collimated, then from each point on the body, the radiation will go to many points on the cloth so it delivers the information to many points on the cloth. And conversely, each point on the cloth will be receiving radiation and thus information from many different points on the body. This leads to a confusion of the information deposited on each point on the cloth, which causes a significant loss of resolution in the image. The good resolution of the images on the Shroud indicates the radiation was essentially vertically collimated. If the radiation was emitted isotopically (equally in all directions) then to form a good resolution image on the Shroud would require innumerable lenses between the body and the cloth to focus the radiation on each fiber, but lenses were not between the body and the cloth. Thus, the only option to obtain a good resolution image on the cloth is for the radiation to be emitted vertically collimated. Examples of collimated radiation include photons from a laser and particles in a nuclear accelerator.

11. Based on the location of the blood on the Shroud, the front and dorsal images are on the side of the cloth that faced the body. There appears to be very dim indications of the face and the hands on the other side of the cloth, i.e., on the outside of the wrapped configuration, though this is disputed.

Comments: This indicates the radiation had to go from the body to the cloth to form the images on the inside of the wrapped configuration. It had to go upward from the front of the body to form the front image on the cloth above the body, and it had to downward from the back of the body to form the dorsal image on the cloth below the body. What does this mechanism to produce images on the inside of the wrapped configuration predict about producing an image on the outside of the wrapped configuration? Probably, it neither predicts nor precludes the possibility of much lighter images being produced on the outside of the wrapped configuration.

12. A typical linen thread contains a hundred or more flax fibers twisted together. The images on the Shroud are caused by fiber discoloration in only the top two or three layers of fibers in a thread, with those discolored fibers facing toward the body, on both the front as well as the dorsal image.

Comments: Only the top two or three layers of fibers that were facing the body are discolored in the images. This effect can be compared to a thunder cloud as it goes over irregular terrain that contains lightning rods. Lightning will occur when the electrical charge difference between the lightning rod and the cloud are sufficient to ionize the air between the cloud and the tip of a lightning rod. Lightning will then occur between the cloud and the tip of the lightning rod. This comparison suggests the top two or three layers of fibers are discolored because there was a corona discharge between the body and the top fibers that were facing the body, like lightning hits the tip of the lightning rod. Lightning is an example of a corona discharge. A corona discharge is an electrical discharge that occurs when the electric field around a conductor is strong enough to strip electrons off the surrounding air molecules. Electrons can then flow along the path of the ionized air molecules. A corona discharge can also be called a static, electrostatic, electrical or electron discharge.

13. The threads in the images are discolored in a mottled pattern, yet this mottled pattern forms the front and dorsal images of a crucified man.

Comments: When lightning occurs between a cloud and the tip of a lightning rod, it tends to discharge the cloud and the ground around where the lightning occurred, so lightning is unlikely to occur again in the same place. This results in a mottled pattern of lightning strikes from the cloud. This suggests the mottled pattern of discolored fibers that form the images also results from a corona discharge between the body and the top fibers facing the body. The area around this location is then reduced in electrical charge so a mottled pattern of corona discharge will result.

14. The density of ion tracks in the image fibers is about the same as the density of ion tracks in the non-image fibers.

Comments: When high energy photons or charged particles go through a flax fiber as in the Shroud, it will knock electrons out of the material thus causing a series of electrically charged molecules (ions) along the path of the radiation. This is called an ion track. It is sometimes claimed that since the image fibers and the non-image fibers have about the same ion track density, it proves the images were not formed by radiation, but this claim assumes the radiation is above the threshold energy required to form ion tracks. This evidence only proves that if the images were caused by radiation, then the energy of the radiation had to be relatively low, below the threshold energy required to form ions. Thus, since analysis of evidence 6 established that the images were formed by radiation, evidence 14 proves this radiation had to be low energy radiation.

15. The discoloration on all the discolored fibers has approximately the same color, usually called a straw-yellow or light sepia color.

Comments: This is the same color as is caused by a scorch, but STURP proved the images cannot be a scorch caused by contact of a hot object with the cloth because the images do not fluoresce under ultraviolet light. But a scorch color can be produced by processes other than contact with a hot object. This will be discussed under evidence 16.

Since the discoloration on all the fibers is about the same color, the various shades on the front and dorsal images are not produced primarily by different shades of discoloration on the fibers but are produced primarily by a greater or lesser number of discolored fibers per area. This is called a half-tone effect.

Ray Rogers claims his chemical experiments form the basis for a Maillard reaction being able to explain the images on the Shroud [11]. However, the discoloration Rogers obtained in his experiments is the wrong color. Figure 2 in [11] is a yellow with a greenish tint and Figure 3, according to Rogers, is “golden yellow similar to that on the shroud”. In acknowledging this color is only “similar to that on the shroud”, Rogers is acknowledging the color is not the same as the straw-yellow discoloration on the Shroud’s fibers. Thus, Rogers’ Maillard reaction cannot have caused the discoloration on the Shroud.

16. A flax fiber has a diameter of about 15 microns or micrometers ( $\mu\text{m}$  = one millionth of a meter), which is about one-fifth the diameter of a human hair. The discoloration on an image fiber has a thickness of less than 0.2  $\mu\text{m}$ , with the discoloration around the outer circumference of the fiber, with the inside of the flax fiber not discolored. Thus, in this

example of a flax fiber with a 15  $\mu\text{m}$  diameter, the inside 14.6  $\mu\text{m}$  of the fiber diameter would not be discolored.

Comments: The fiber discoloration makes the images. Thus, how the fibers in the images were discolored around their circumference to a thickness of less than 0.2  $\mu\text{m}$  must be explained. This thin discolored layer is one of the most difficult features for an image formation hypothesis to explain. A hypothesis that does not explain this cannot be true.

The discoloration of this thin layer around the circumference of the fiber could have been caused by something external to the fibers or by something internal to the fibers. A possible external cause is a chemical in the air around the fibers such as ozone, which could have been produced by a corona discharge from the fibers. Ozone could have discolored the fibers by chemically interacting with the material in the 0.2  $\mu\text{m}$  outer circumference region of the fibers, but it is not clear whether ozone would produce the sepia or straw-yellow color of a scorch. A possible internal cause of fiber discoloration is heat deposited in this very thin 0.2  $\mu\text{m}$  region. This heat could have raised the temperature in this region to the point it would have altered how the atoms were bound together, which is the mechanism of a scorch. The heat could have been deposited in this thin region by a high frequency alternating current in the fibers. The advantage of this explanation is that it would produce the same color as a scorch from contact with a hot object, because the color would be produced by a high temperature as in a scorch from a hot object.

Why would an alternating current deposit heat only near the outer circumference of a linen fiber? An alternating current in a conductor will cause oscillations in the magnetic and electrical fields in and around the conductor. These oscillating electrical and magnetic fields will force the electrons to flow primarily near the outer circumference of the conductor. This is called a "skin effect" of an alternating current. With the electrons flowing near the circumference of the conductor, they will collide with the atoms in this region of the conductor, which will produce heat in this region. As a result, the heat will be deposited in the thin region near the circumference of the conductor. The higher the frequency of the alternating current, the more the electrons will be forced to flow near the outer circumference of the conductor. If the frequency of the alternating current is high enough, the electrons would flow primarily in the outer 0.2  $\mu\text{m}$  region of a conductor. This will also apply to a flax fiber. If the frequency of an alternating current in a flax fiber is high enough, the electron flow and thus the heat deposition could be primarily in the thin 0.2  $\mu\text{m}$  outer circumference region of the fiber.

What could cause an alternating current in the flax fibers of the Shroud? Lightning should be considered as an example of this effect. Lightning occurs with multiple lightning bolts, usually between three and 30 in number, moving back-and-forth along the ionization path between the cloud and the tip of the lightning rod. These multiple back-and-forth lightning bolts will be in alternate directions, either toward or away from the cloud, and will occur so rapidly it will appear to be only one lightning bolt. During and between these multiple events, electrons will be flowing in the cloud and in the lightning rod and the ground. The electron flow in the ground and lightning rod will be toward or away from the tip of the lightning rod, depending on whether the electrons are flowing toward or away from the cloud. The electron flow in the cloud will be away from or toward the point where the ionization path connects to the cloud, again depending on whether the electrons are flowing toward or away from the cloud. The alternating directions of electron flow in the cloud and

in the lightning rod and ground will constitute a high frequency alternating current. For the Shroud, this effect could set up a high frequency alternating current in the top fibers facing the body as the corona discharge goes back-and-forth between the cloth and the body. This would deposit heat in these fibers that would discolor them.

What kind of radiation was involved? Both ozone production and the localized heat deposition from an alternating current could have been produced by a corona discharge from the top fibers facing the body, as in the analysis of evidences 12, 13, and 16. The radiation that caused this corona discharge was probably primarily charged particles rather than photons of electromagnetic radiation. This is because charged particles can create an alternating current in the fibers that could discolor the fibers entirely around the circumference of the fiber. Electromagnetic radiation would deposit its energy primarily on the side of the fiber toward the source of the radiation, which is the body. Also, if the radiation burst is brief enough and intense enough, the particles emitted from within the body might be able to thrust the blood off the body onto the cloth without excessively heating it. This cannot be accomplished by electromagnetic radiation. This is because the equations for momentum and energy for particles are different than the equations for electromagnetic radiation.

What was the duration of the radiation emission from the body? The radiation was emitted in an extremely brief burst is indicated by the thin (less than 0.2 micrometers) discoloration on the fibers when heat transfer from the 0.2  $\mu\text{m}$  region (inward by conduction and outward by convection) is considered. It might be possible to calculate the duration of this radiation burst and the frequency of the alternating current from heat transfer calculations and the equations related to the skin effect of an alternating current.

17. There appears to be images of bones on the Shroud. This includes bones near the surface of the body such as teeth, bones in the hands, and perhaps in the backbone.

Comments: This indicates the radiation that formed the images was emitted in the body.

18. The images are two-dimensional yet contain 3D or topographical information related to the vertical distance from the body to the cloth at each point.

Comments: This means the image on the Shroud is darkest where the cloth-to-body distance is a minimum, with the image lighter for greater cloth-to-body distances. This 3D or topographical information that is encoded into the images is not related to how we would see the body in reflected light. It is the information that specifies the vertical distance between the body and the cloth at each point [3, 4, 5]. This information had to be deposited on the cloth by radiation (evidence 6) that traveled vertically up to form the front image and vertically down to form the dorsal image. The radiation being vertical is consistent with the conclusions from evidences 7 to 10. Comments on evidence 16 concluded the radiation emitted from the body was probably charged particles rather than photons of electromagnetic radiation. As these charged particles traveled vertically through the air from the body to the cloth, they had to be altered in a way that effectively recorded the vertical distance they had traveled through the air, so this information could be deposited onto the cloth. Charged particles can communicate the vertical gap distance by their intensity (number of particles) being diminished by absorption and scattering in the air. Thus, it can be concluded the further the charged particles traveled vertically through the air between the body and the cloth, the more the intensity (number of charged particles)

would be reduced by absorption and scattering in the air. This allows the radiation to encode the vertical distance between the body and the cloth into the images on the cloth. This 3D information allows a statue to be derived from the 2D images on the Shroud. Normal paintings or photographs do not contain such 3D information.

19. The images are negative images, i.e. with dark and light areas reversed.

Comments: Based on the conclusions from evidence 18, with the intensity of the radiation being reduced due to absorption and scattering in the air, the images on the Shroud are darkest where the cloth-to-body distance is a minimum, with the image lighter for greater cloth-to-body distances. This means the tip of the nose where the cloth would have been in contact with the nose will be darkest, whereas the eyes which are under the eyebrows will be lighter. In viewing a person in normal light, the nose will be bright because it is out in front of the rest of the face where it readily reflects light, whereas the eyes will be darker because they are shielded from some of the surrounding light because they are under the eyebrows. Thus, the light and dark qualities of the nose and the eyes on the Shroud are opposite those of normal lighting. This explains the negative images.

20. The front and dorsal images have about the same quality, as though they were both made by the same process.

Comments: There are two options that could produce this evidence. Either the charged particles could have been emitted in the body (evidence 17) vertically up and vertically down simultaneously, or there could have been an oscillation between the up and down directions of the charged particle emission. It is suspected the latter option is more likely true, and that this oscillation between the up and down directions was very rapid. This would cause a very high frequency alternating current in the fibers to produce the thin discoloration layer less than 0.2  $\mu\text{m}$  thick around the outer circumference of the image fibers. This would be in addition to the cause discussed in evidence 16, and may be the dominant cause.

21. The discoloration on the image fibers is due to some of the single electron bonds of the carbon atoms being changed to double electron bonds.

Comments: A carbon atom has two electrons in the inner electron orbit closest to the nucleus and four electrons in the outer electron orbit. These four outer electrons can make bonds or connections to surrounding atoms. This allows a carbon atom to be connected to four surrounding atoms if each of the four outer electrons makes a single electron bond to each of the surrounding atoms. But if two of these four outer electrons make a double electron bond to one surrounding atom, then the carbon atom can only be connected to three surrounding atoms. This would cause the carbon atom to vibrate differently so it would emit light at a different frequency and energy. When many carbon atoms in a fabric are changed from all single electron bonds to at least one double electron bond per carbon atom, the emission of light at a different frequency from these carbon atoms would cause the fabric to appear discolored. The discoloration can also be said to be caused by an oxidation-dehydration chemical reaction at an elevated temperature, because this chemical reaction would alter the structure of the atoms in the molecules so some of the single electron bonds would be changed to double electron bonds. This is the mechanism that discolors a fabric in a scorch from a hot object. In chemistry, the result of this oxidation-dehydration chemical reaction is called a conjugated carbonyl compound.

22. The Shroud of Turin Research Project (STURP) concluded that the discoloration on the fibers is not caused by any material being added to the fibers.

Comments: STURP came to this conclusion based on the front and dorsal images not being visible in rear lighting. They evidently reasoned that if the images were caused by material, i.e. atoms, being added to the cloth, then the image would be visible in front as well as back lighting. Evidence 22 follows from evidence 21, with radiation causing a rearrangement of the atoms that were already in the fibers, so it is unnecessary for new atoms to have been added to the cloth to form the images.

23. The top threads facing the body create a non-discolored region on otherwise discolored threads that are beneath them, like a “shadow” of the top thread on the next thread.

Comments: This indicates there was a “straight line” interaction of some sort between the body and the top fibers facing the body with this interaction involved in discoloring the fibers. This is consistent with the discoloration of the fibers being formed by a corona discharge between the body and the top fibers facing the body because the top fibers tend to shield the fibers that were deeper in the thread from the charge difference between the fibers and the body.

24. There are multiple “hot spots” on the mustache that are more discolored than the rest of the mustache.

Comments: Some of the hairs on the mustache would have been acting as little lightning rods during the corona discharge between the body and the top fibers facing the body.

25. The images were not affected by heat in the 1532 fire or by subsequent water thrown onto the Shroud after the fire.

Comments: Water probably would not have affected the discoloration on the image fibers because the discoloration was caused by a change in the arrangement of the atoms in the molecules, as in evidence 21. If the discoloration on the image fibers was due to an organic chemical, then the heat from the 1532 fire should have affected the color, but it didn't.

26. Images of various parts of flowers were encoded on the side of the Shroud facing the body, as though flowers were placed between the section of the cloth that was below the body and the section of the cloth above the body.

Comments: The images of objects placed between the body and the cloth, such as flowers or coins over the eyes, could have been encoded onto the cloth by their effect on the corona discharge between the body and the top fibers on the cloth facing the body.

27. During the STURP experiments in 1978, many oxidizing and reducing agents were applied to image fibers to determine which agents would eliminate the fiber discoloration. None of them eliminated the discoloration except for diimite which eliminated the discoloration immediately when it was applied.

Comments: Diimite is a reducing agent which should have a strong effect on the double electron bonds in the image fibers, so this is consistent with evidence 21. Experiments could be performed with the other oxidizing and reducing agents to determine whether they could confirm or disconfirm other image formation hypotheses.

The primary alternative to radiation hypotheses for image formation is the Maillard reaction proposed by Ray Rogers [10, 11]. Multiple objections to the Maillard reaction have been discussed under evidences 4 and 15. Rogers' Maillard reaction is based on body decay gases moving from the body to the cloth by diffusion of molecules in the air. This involves each decay gas molecule following a "random walk" path through the air as each decay gas molecule randomly scatters off each air molecule. However, in this diffusion-of-molecules process: 1) Information required to control the discoloration process would have been lost in each random scattering event so a good resolution image could not be produced. 2) It is not possible for such a diffusion process to produce images of the front and back of the body but not the side of the body or the top of the head. 3) It is difficult to imagine how images of flowers and bones near the surface of the body were encoded into the images by a Maillard reaction. Also, there is no evidence a Maillard reaction could: 1) discolor only the top 2 or 3 layers of fibers in a thread, 2) discolor a thickness less than 0.2 micrometers all the way around the circumference of the linen fiber without discoloring the inside of the fiber, 3) produce a mottled pattern of discolored fibers to form the front and back images of a crucified man, or 4) produce an image that contains 3D or topographical information. Many of these objections would also apply to the skin bacteria hypothesis.

## 5. VCRB Hypothesis for Image Formation

The conclusion of the analysis in the previous section is the images could have been formed by an extremely brief intense burst of vertically collimated low energy charged particles, probably protons, which were emitted in the body. This charged particle radiation probably oscillated between vertically up and vertically down directions. This caused an alternating corona discharge between the body and the top fibers facing the body, which caused an alternating current in the fibers. Based on the "skin effect" of an alternating current, this would have produced extremely localized heating which produced extremely localized discoloration, less than 0.2 micrometers thick, on the image fibers. This discoloration would have been formed in a mottled pattern on the fabric, as in the previous example of a lightning strike discharging the surrounding ground and cloud. This mottled pattern of discoloration formed the front and dorsal images of a crucified man on the Shroud. These charged particles could also have formed ozone in the air that could have contributed to the discoloration on the image fibers. Thus, we can see the front and dorsal images on the Shroud because the information that specifies the vertical distance of the cloth from the front and back of a crucified man has been encoded by this process into the mottled pattern of discolored fibers on the cloth. The basis for believing this hypothesis could be true is its consistency with the above 27 evidences related to the nature of the images.

It might be asked why discoloration of the fibers caused by contact with a hot object fluoresces whereas the extremely localized discoloration on the fibers caused by the hypothesized alternating current apparently does not. The difference is caused by the depth of the discoloration. A fiber discolored by contact with a hot object would be discolored across its entire approximate 15 micrometer diameter whereas a fiber discolored by the extremely localized heating is only discolored to a depth of less than 0.2 micrometers. Also, contact with a hot object would cause more than the top two or three layers of fibers to be discolored. Probably all the fibers in the thread would be discolored. This larger volume of discolored material causes

enough fluorescence that it can be recognized and measured, whereas the very thin layer of discoloration, less than 0.2 micrometers thick, on only the top two or three layers of fibers would emit much less fluorescence.

Atoms in the body contain protons and neutrons in their nuclei. The source of the protons utilized in the above image formation hypothesis could have been released by the splitting of nuclei in the body. The isotope that requires the least amount of energy to split or fission is deuterium, which is also called heavy hydrogen because it contains a neutron as well as a proton in the nucleus. This makes it twice as heavy as a normal hydrogen nucleus. Splitting of deuterium nuclei would release the same number of neutrons as protons. A small fraction of these neutrons would have been absorbed in the trace amount of N-14 in the fibers to produce new C-14 in the fibers by the  $[N^{14} + \text{neutron} \rightarrow C^{14} + \text{proton}]$  reaction. This new C-14 would shift the carbon date to the future relative to the true date, which could explain why the Shroud was carbon dated to 1260-1390 AD [2].

These explanations for the image formation and the carbon dating both depend on particles being emitted from the dead body that was wrapped in the Shroud. Thus, both explanations are beyond or outside of our current understanding of the laws of physics, but this is consistent with the unique qualities of the Shroud. It is the only cloth in existence in which the dead body that was wrapped within it produced full-size front and dorsal images of itself on the cloth. In this situation, it is probably reasonable to assume the charged particle emission that caused the images and the neutron emission that shifted the carbon date forward are both part of the same event. When these two explanations are combined, the result is the Vertically Collimated Radiation Burst (VCRB) hypothesis. This hypothesis proposes radiation was emitted from within the body in an extremely brief intense burst of low energy radiation. Charge particles such as protons in this radiation produced the images by a corona discharge from the top fibers facing the body. Neutrons in this radiation produced new C-14 on the cloth which shifted the carbon date in the forward direction, thus explaining the carbon dating of the Shroud to 1260-1390 AD.

The VCRB hypothesis has the qualities of a very good hypothesis: 1) It is consistent with the scientific evidence related to image formation and carbon dating because it was derived from this evidence, 2) It makes predictions that are testable, falsifiable, and some of which are unique, and 3) It offers explanations for multiple mysteries of the Shroud related to image formation, carbon dating, and the blood on the Shroud. No other hypothesis attempts to explain more than one mystery of the Shroud. Predictions of the VCRB hypothesis related to image formation include the following:

- A very high frequency alternating current in a flax fiber can discolor the outer circumference of a fiber to a thickness of less than 0.2 micrometers.
- An extremely rapid alternating pulse of low energy charged particles such as protons hitting a linen cloth can produce a mottled pattern of discolored fibers only two or three layers deep in a thread like the fiber discoloration on the Shroud.
- If protons were emitted in a human body in an extremely brief burst, the number of protons could diminish due to scattering and absorption as they pass through the air between the body and the cloth, consistent with evidence from the Shroud. This effect is necessary to

explain the images on the Shroud being negative images with light and dark area reversed, and the presence of 3D or topographical information encoded into the images related to the vertical distance between the body and the cloth. Testing of this prediction will probably have to be done using computer calculations such as with the MCNP computer code.

- MCNP nuclear analysis computer calculations [2] have shown that about  $2 \times 10^{18}$  neutrons emitted in the body will shift the carbon date at the 1988 sample location at the corner of the Shroud from about 33 AD to 1325 AD, which is the midpoint of the range of 1260 to 1390 AD. This is only one neutron out of every ten billion neutrons that would have been in the body. If this number of neutrons were emitted by splitting of deuterium nuclei, then the same number of protons would also be emitted. Thus, about  $2 \times 10^{18}$  protons emitted vertically from the body are predicted to be able to cause the corona discharges from the top fibers facing the body, which caused the images on the Shroud. Splitting of about  $2 \times 10^{18}$  deuterium nuclei is about 0.0004% of the deuterium in the body.

## 6. Conclusion

The main mysteries of the Shroud are image formation, carbon dating, and why the blood that dried on the body is now on the cloth. Hypotheses to explain these mysteries should be developed by following the scientific evidence where it leads. This should be done with a neutral mindset that is not restricted by presuppositions. According to the scientific process, for such a hypothesis to be credible, it must be consistent with the evidence. It should also make predictions that are testable and falsifiable, and when tested the predictions are found to be true.

Consideration of the scientific evidence indicates the images appear to have been formed by an extremely brief intense burst of vertically collimated low energy charged particles such as protons emitted in the body. When absorbed on the cloth, the protons caused electrical currents in the fibers that produced extremely localized heating. This heat caused extremely localized discoloration of the fibers that formed the front and dorsal images of a crucified man. The charged particle emission from the body could have also produced ozone in the air that contributed to the fiber discoloration. Previous consideration [2] of evidence related to the carbon dating indicates about  $2 \times 10^{18}$  neutrons were probably emitted in the body that produced new C-14 atoms on the Shroud primarily by a  $[N^{14} + \text{neutron} \rightarrow C^{14} + \text{proton}]$  reaction. These new C-14 atoms would have shifted the carbon date forward relative to the true date. It is reasonable to conclude that the image formation and the carbon dating are related to each other since they are both the result of radiation emitted from the body, perhaps due to the splitting of deuterium nuclei. Vertical oscillations of the nuclei should be considered as a possible cause of the deuterium nuclei splitting.

When the two explanations for image formation and carbon dating are combined, the result is the Vertically Collimated Radiation Burst (VCRB) hypothesis. The VCRB hypothesis proposes an extremely brief intense burst of vertically collimated low energy particles was emitted in the body, with protons producing the images and neutrons shifting the carbon date forward from the true date. The complexity of this VCRB hypothesis results from the complexity of the evidence. If this burst of radiation from the body were sufficiently brief and sufficiently intense, perhaps it could have thrust wet or dry blood off the body onto the cloth. This concept is suggested by our

common experience of one object hitting another object causing the second object to accelerate away from the point of collision, as when one ball hits another ball on a pool table. Experimental evidence for blood being thrust off fabric by an extremely brief burst of particles would probably require use of a particle accelerator, but this experiment has not yet been done. However, this concept should be considered to be a possibility, and results in predictions that should be tested.

To the extent that the VCRB hypothesis is accepted as true, it leads to two criteria that can be used to determine whose image is on the Shroud of Turin: 1) He was crucified exactly as Jesus was crucified according to the New Testament, and 2) His dead body emitted an extremely brief intense burst of radiation that encoded an image of his body onto the Shroud and shifted the carbon date of the Shroud to the future relative to the true date. In all the historic documents available to humanity, the only person and event that satisfies these two criteria is Jesus in his resurrection.

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Robert A. Rucker (Bob) earned BS and MS degrees 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 computer calculations for design of advanced nuclear reactors, criticality safety calculations for nuclear fuel production and storage, and statistical analysis of measurement data. He published 41 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 organized a four-day international conference on the Shroud in 2017. His many papers on the Shroud are available on the research page of his website [www.shroudresearch.net](http://www.shroudresearch.net). His videos are on YouTube.com.

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