Nuclear Analysis of 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. The main mysteries of the Shroud are how the images were formed, why the Shroud carbon dated to 1260-1390 AD, and why the blood which would have dried on the body is now on the cloth, since dry blood is not absorbed into fabric. By following the scientific evidence where it leads, the Vertically Collimated Radiation Burst (VCRB) hypothesis was developed to explain these mysteries. According to this hypothesis, an extremely brief radiation burst from the body included charged particles, probably protons, which deposited their charge onto the cloth producing electrical currents in the fibers. This caused localized heating of the fibers which discolored them, producing the images of a crucified man. Deuterium nuclei requires the least energy to fission, which would release protons to form the images and neutrons that could explain the 1988 carbon dating of the Shroud including: 1) an average date of 1260-1390, 2) a change in the carbon date as a function of the distance from the short edge of the cloth of about 36 years per cm, 3) the range and distribution of the 12 subsample dates, and 4) the carbon dating of the Sudarium of Oviedo, believed to be Jesus' face cloth, to about 700 AD. Nuclear analysis computer calculations indicate these four results can be explained by neutrons emitted from the body. A small fraction of the neutrons would have been absorbed in the trace amount of N-14 in the fibers which produced new C-14 atoms in the fibers by the [N^{14}+neutron→C^{14}+proton] reaction. This shifted the measured carbon date forward from the true date. If the radiation burst were sufficiently brief and intense, it could possibly have forced the blood off the body onto the cloth. This opens the possibility that the Shroud of Turin could be the authentic burial cloth of Jesus Christ. Every effort should be made to conduct further testing of this unique cloth.

1. Introduction

The Shroud of Turin is one of the most mysterious and potentially significant items in human possession. There are many papers, books, and websites that discuss it [1]. The Shroud is a long piece of linen cloth which inspired paintings, drawings, and images on coins starting in the sixth and seventh centuries in the Byzantine Empire. It was exhibited as Jesus' burial cloth in Lirey, France in about 1355, and has been in Turin, Italy since 1578. The unique aspect about the cloth is 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 the Shroud of Turin is Jesus' burial cloth. It appears the scientific evidence substantiates this view. The three main mysteries [2] regarding the Shroud are: 1) how the images were formed, 2) why the corner of the Shroud was carbon dated to the range of 1260 to 1390 AD, and 3) why the blood that would have dried on the body is now on the cloth, since dry blood does not soak into fabric. By following the scientific evidence where it leads, the

Vertically Collimated Radiation Burst (VCRB) hypothesis was developed to explain these mysteries.

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 after he died on the cross would then have been removed 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 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 a low-quality linen cloth about 84 by 54 cm, which is 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 believed to now be in the cathedral in Turin or Torino, 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.

The Shroud of Turin can be researched based on history and science. The most recent book in English on the history of the Shroud is titled "The Hidden History of the Shroud of Turin" by Jack Markwardt. 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.

In 1988, the Shroud was carbon dated to the range of 1290-1390, but there are many indicators discussed below that contradict this date range. This is confirmed by Professor Christopher Ramsey, a member (as C. R. Bronk) of the original team that did the carbon dating, when he said (https://c14.arch.ox.ac.uk/shroud.html) "There is a lot of other evidence that suggests to many that the Shroud is older than the radiocarbon dates allow and so further research is certainly needed. It is important that we continue to test the accuracy of the original radiocarbon tests as we are already doing. It is equally important that experts assess and reinterpret some of the other evidence. Only by doing this will people be able to arrive at a coherent history of the Shroud which takes into account and explains all of the available scientific and historical information."

2. Scientific Testing of the Shroud

It is often said that the Shroud of Turin is the most researched ancient artifact in existence. There certainly has been an immense amount of study on the Shroud as indicated by the number of papers that have been written on the Shroud that are available on www.shroud.com. 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 body of a crucified man that was wrapped in the Shroud. This is indicated primarily by the nature of the blood on the Shroud.

2. 1975 to 1987: 3D information is discovered to be encoded into the 2D images on the Shroud. This led to formation of the Shroud of Turin Research Project (STURP) which was invited in 1978 to send about 26 researchers to Turin to perform non-destructive experimentation on the Shroud over a five-day period, 24 hours a day.
3. 1988 to 2016: In 1988, the Shroud was carbon dated to a range of 1260-1390 AD, with a claimed 95% probability that the true date is within this range. They concluded that "The results provide conclusive evidence that the linen of the Shroud of Turin is mediaeval." This supposedly proved the Shroud could not be the authentic burial cloth of Jesus.
4. 2017 to 2022: Details of the 1988 carbon dating measurements and data analysis were finally released by the British Museum in 2017. Statistical analysis of the data proved the samples were 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.

3. Mystery 1: Formation of the Images

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 that if the prediction is tested and proven to be false, it will prove the hypothesis to be 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 testing of multiple predictions that are proven to be true before a hypothesis is generally accepted as true beyond a reasonable doubt.

Based on the STURP experiments in 1978 and subsequent analysis, an image formation hypothesis, to be true, 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.
2. STURP concluded the images were also not caused by a scorch from a hot object, any liquid, or by a photographic process.
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.
4. STURP also detected no body decay products on the cloth.
5. The images are formed by some of the flax fibers in the linen threads being discolored.
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.
7. The image of the face is a normal width for a human face.

8. The front image is a vertical projection upward from the body. The back image is 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.
10. The front and dorsal images have a good resolution, perhaps in the few mm range.
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.
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.
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.
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.
15. The discoloration on all the discolored fibers has approximately the same color, usually called a straw-yellow or light sepia color.
16. A flax fiber has a diameter of about 15 microns or micrometers (μm = 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 μm, 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 μm diameter, the inside 14.6 μm of the fiber diameter would not be discolored.
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.
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.
19. The images are negative images, i.e. with dark and light areas reversed.
20. The front and dorsal images have about the same quality, as though they were both made by the same process.
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.
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.
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 under thread.
24. There are multiple "hot spots" on the mustache that are more discolored than the rest of the mustache.
25. The images were not affected by heat in the 1532 fire or by subsequent water thrown onto the Shroud after the fire.

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.
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.

Analysis of these 27 evidences to develop a hypothesis for image formation [3] resulted in the Vertically Collimated Radiation Burst (VCRB) hypothesis. This hypothesis proposes that an extremely brief intense burst of radiation emitted in the body formed the images. When low-energy charged particles, probably protons, deposited their charge on the cloth it caused corona discharges between the body and the cloth which produced alternating currents in the fibers. This produced extremely localized heating which produced the fiber discoloration which made the front and dorsal images of a crucified man on the cloth. The VCRB hypothesis will be discussed further in section 9.

4. Mystery 2. Carbon Dating of the Shroud

The process of carbon dating an object is performed by first taking one or more small samples from the object, because the material to be carbon dated must be burned. After the samples have been burned to reduce them to carbon, the ratio of C-14 to C-12 in the carbon is measured. A standard equation is then used to calculate the date based on the measured C^{14}/C^{12} ratio. This equation assumes that the C^{14}/C^{12} ratio could only change due to the decay of the C-14, which has a half-life of 5730 years. Based on the analysis below, it is believed that new C-14 was produced on the Shroud, so the assumption that the C^{14}/C^{12} ratio could only change due to the decay of the C-14 is not valid. Thus, if new C-14 was produced on the Shroud, then this equation is not valid for calculating the date for the Shroud from the measured C^{14}/C^{12} ratio.

In 1988, a thin strip was cut from the corner of the Shroud for dating (Figure 1). Samples were cut from this strip and sent to three carbon dating laboratories: Tucson in Arizona, Zurich in Switzerland, and Oxford in England (Figure 2). These laboratories cut their samples into smaller pieces so that ultimately 12 subsamples were carbon dated with each of the twelve dates having an uncertainty based on counting statistics and other considerations. The dates and uncertainties obtained for these 12 subsamples were reported by Damon, et al. in the British journal *Nature* in 1989 [4]. This paper concluded that the Shroud dates to 1260 to 1390 AD, though most Shroud researchers believe this date should be rejected, i.e., given no credibility [5, 6], because: 1) they did not have the technology to produce the images in 1260-1390, 2) there are many other date indicators that contradict the carbon dating to 1260-1390 AD [7, 16], and 3) because of the statistical analysis of the measurement data discussed below.

Table 2 shows the dates and uncertainties for the 12 subsamples from Damon [4] in black. These value are uncorrected values, i.e., not corrected for the changing concentration of C-14 in the atmosphere. They are also dates AD, whereas the dates in Damon [4] are Years Before Present (YBP), where the present is defined as 1950. Thus, the dates AD in Table 2 equals 1950 minus

the date (YBP) given in Damon. In Table 2, the values in red are the author's calculated values starting from Damon's reported values. The values in red display one additional digit to the right of the decimal point to prevent propagating a round-off error to the next step. The weighted average or mean value of these three laboratory weighted mean values is in red at 1277.8 ± 12.6 AD. Instead of this value, Damon [4] chose to report an unweighted mean of 1260 ± 31, which was then corrected for the changing C-14 concentration in the atmosphere to produce a range of 1260 to 1390 AD for the date of the Shroud. It was claimed in Damon [4] that the true value had a 95% probability of being within this range of 1260 to 1390 AD. The average of the 1260-1390 range is 1325 AD, so it is often assumed that carbon dating proved the Shroud dates to the Middle Ages. However, the calculation of this 1260-1390 range and the 95% probability that the true value falls within this range assumed that the uncorrected mean value of 1260 ± 31 was known with certainty. Subsequent statistical analysis of the subsample data in Damon has indicated that this 1260 ± 31 value should be rejected, i.e., given no credibility (see below).

5. Analysis of the Data from Carbon Dating

The difference between the Arizona date (1303.6 ± 17.1) and the Oxford date (1200.8 ± 30.7) is 102.8 ± 35.1 years (square root of $17.1^2 + 30.7^2 = 35.1$), which means that the dates from Arizona and Oxford are different by 2.93 standard deviations (102.8 / 35.1 = 2.93). This is greater than the usually allowed two standard deviations so it should be concluded these laboratories obtained statistically different dates. This should not be the case since all samples were cut from the same cloth and next to each other. The average dates from the three laboratories can also be correlated to the positions of their samples relative to each other. From left to right on the strip cut from the Shroud (Figure 2), the samples were sent to Oxford, Zurich, and Arizona (Arizona did not date sample A2), but in this same sequence the carbon dates are increasing. This spatial dependence of the measured carbon date is plotted in Figure 3 with the three laboratories, Oxford, Zurich, and Arizona plotted from left to right. The vertical bars indicate the one standard deviation range. The y-axis is the carbon date AD and the x-axis is the distance of the center of the sample from the left edge of the Shroud when it is displayed horizontally as in Figures 1 and 2. This plot shows that the uncorrected average value of 1260 AD claimed in Damon [4], represented by the horizontal black dashed line in Figure 3 only goes through the date from Zurich but not the dates from Oxford or Arizona. The best fit to the three laboratory average values is the red dashed line, which has a slope of about 36 years per cm, which is about 91 years per inch. This is very significant because if the sample point were moved 25.4 cm (10 inches) further from the short edge of the cloth and thus closer to the center of the body, then at this rate (36 years per cm) the measured carbon date would increase by about 910 years from 1260 AD to 2170 AD, which is a date to the future. This data indicates that an unknown factor appears to be causing the measured carbon date to be a function of the distance from the short edge of the cloth. This is equivalent to stating it to be a function of the distance from the center of the body.

Further analysis of the data can be done using a Chi-squared statistical analysis technique to determine whether the 12 subsample dates and their uncertainties for the Shroud are consistent with each other, as they should be. This statistical analysis on the data obtained from the Shroud is in Table 1, which is a copy of Table 5 in [8]. In this table, the Shroud samples are called

material one on the top row and the three standards are called materials 2, 3, and 4 on the top row. The three standards discussed in Damon [4] are pieces of fabric taken from sources with known historical dates. They were carbon dated at the same time as the subsamples from the Shroud to confirm the accuracy of the carbon dating equipment and procedures. The result of this analysis is shown on the bottom row in Table 1 which gives the significance level for each of the four materials. This calculated significance level is the probability, in percent, of obtaining the magnitude of the scatter in the data that would have been obtained by random measurement errors alone. The usual criterion is a significance level of 5%, so if the significance level is 5% or above then the scatter in the data is normally accepted to be the result of random measurement errors alone, whereas if the significance level is below 5% then the magnitude of the scatter of the data is unlikely to be explained by random measurement errors alone so that a systematic measurement error is also likely present. As shown in the bottom row of this table, the significance levels for the three standards (materials 2, 3, and 4 in Table 1) are 90.1%, 28.0% and 13.9% which are all greater than 5% so the scatter in the data for the three standards is likely due to random measurement errors alone. However, the significance level for the subsamples from the Shroud, which is material 1 in Table 1, is only 1.4% and thus less than the criterion of 5%. This means that a systematic error was also likely affecting the measurements. Since it is not possible to determine the magnitude of this systematic measurement error, the only option is to reject the data, i.e., give no credibility to the measured carbon dates of the 12 subsamples or the alleged carbon date range of 1260 to 1390. This result is confirmed by four recent papers in peer-reviewed journals [9, 10, 11, and 12] which concluded that the subsamples from the Shroud are heterogeneous – fundamentally different from each other, so it is not correct to calculate an average value by adding the individual values and dividing by the number of values. Thus, it is not correct to arrive at a range of 1260 to 1390 AD. This conclusion is consistent with previous statistical analyses of the measurement data [8, 13].

The carbon dating of the corner of the Shroud produces three types of data: 1) the average value is about 1325, which is the midpoint of the range of 1260-1390 AD, 2) the change in the measured carbon date as a function of the distance from the short side of the cloth is about 36 years per cm, and 3) the measured carbon dates and uncertainties for the twelve subsamples are specified in Damon [4]. There is one additional evidence: 4) the carbon date for the Sudarium of Oviedo, which is believed to be Jesus' face cloth, was measured to be about 700 AD. This 700 AD date for the Sudarium is significant for the study of the Shroud because Jesus' face cloth (Sudarium) is closely related to Jesus' body cloth, which is believed to be the Shroud of Turin. For a hypothesis to be correct in explaining the carbon dating of the Shroud, it must be consistent with these four evidences. To assume that the Shroud was made in 1260-1390 is only consistent with the first of these four evidences, so this assumption should be rejected.

6. Explanations for the Carbon Dating

The concepts that have been proposed to explain the measured carbon date of 1260-1390 are the following, in their approximate order of being proposed:

1. The neutron absorption hypothesis was proposed in 1989 by particle physicist Dr. Tom Phillips [14] in the same edition of *Nature* that contained the paper [4] by Damon, et al. Phillips proposed that neutrons absorbed in the Shroud would produce new C-14 on the

fibers that would shift the carbon date measurement forward from the true date. No further work was done on this concept until nuclear analysis computer calculations were performed by the author in 2014.

2. Contamination due to handling of the Shroud during exhibitions.
3. Contamination due to intentionally putting materials such as wax or talc onto the Shroud to strengthen it.
4. Bioplastic film left on the fibers due to the normal action of bacteria. Concepts 2, 3, and 4 are not commonly advocated now because these forms of contamination would have to be over 65% of the mass of the samples to produce a measured carbon date of 1260-1390, and because visual inspection indicates these sources of contamination are not present in anywhere near this amount.
5. The invisible reweave hypothesis was proposed by Joe Marino [15] in 2000. In this hypothesis, French "invisible" reweave technology was used in the early 1500s, i.e., probably about 1520, to repair the corner of the Shroud where in 1988 the samples were cut from the Shroud for carbon dating. This involved weaving dyed cotton into the original linen fabric at the corner in such a careful manner that the resulting reweave cannot be seen. Thus, the samples that were carbon dated consisted of a mixture of new (about 1520 AD) and old (about 33 AD) material, resulting in the 1260-1390 carbon date. This hypothesis is currently the most common explanation for the 1260-1390 carbon date.
6. Carbon monoxide absorption hypothesis proposed by Dr. John Jackson. This hypothesis has largely been dropped due to lack of evidence for this mechanism, and other fabrics not being affected by it.

Since the measured carbon dates for the three standards were determined with reasonable accuracy, it should be accepted that the C^{14}/C^{12} ratio measurements for the twelve Shroud subsamples were likely correct. As a result, the spatial dependence of the carbon dates for the Shroud must result, not from an error in the measurements of the C^{14}/C^{12} ratio, but from something that altered the C^{14}/C^{12} ratios in the twelve subsamples as a function of the distance from the short side of the cloth. As discussed above, of the above six proposed options for explaining the carbon dating of the Shroud, only the neutron absorption hypothesis (#1) and the invisible reweave hypothesis (#5) are now considered to be viable options by Shroud researchers. Probably most Shroud researchers now believe an "invisible" reweave occurred in the early 1500s when new cotton thread and cloth was dyed and interwoven into the older linen cloth of the Shroud [6, 15] using French "invisible" reweaving technology, but there are multiple objections against this hypothesis as discussed in section 10 of [17]. Due to these objections, the neutron absorption hypothesis (#1) deserves further consideration.

7. Nuclear Analysis Computer Calculations

Due to his extensive experience in calculating neutron distributions in nuclear reactors, the author recognized that the spatial dependence of the carbon date measurements for the Shroud (Figure 3) is similar to the neutron distribution that would occur if neutrons were emitted from the body. If neutrons were emitted from the body, a small fraction of these neutrons would have been absorbed in the trace amount of N-14 in the linen. When a N-14 nucleus absorbs a neutron,

it ejects a proton, thus becoming a new C-14 atom [N^{14} + neutron → C^{14} + proton]. This production of new C-14 atoms in the samples will shift the measured carbon date to the future relative to the true date. For example, if the C-14 concentration were increased by 16.9%, it would shift the carbon date from 33 AD to 1325 AD.

To determine whether this could be the explanation for the carbon dates obtained in 1988, nuclear analysis computer calculations were performed using the MCNP computer code. 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 by a team of people. It is considered by US government agencies to be fully verified and validated for general nuclear calculations based on comparison of MCNP calculations with thousands of experiments in nuclear facilities.

In these MCNP calculations, for simplicity, a human body was modeled using simple geometrical volumes. The body was then surrounded by thin linen in the shape of a rectangular box to represent his burial cloth. Both were modeled with the head to the right on the back bench in a limestone tomb as it probably would have been designed in first century Jerusalem with a back bench and left and right-side benches (Figure 4). It was assumed that the neutrons were emitted homogeneously (uniformly) from within the body. Uncertainties in the assumptions had to be investigated using over 400 MCNP calculations run over a five-month period in 2014. To obtain good statistics, each MCNP calculation usually followed 30 million neutrons one at a time, which took between six and thirteen hours on a desktop computer. One set of assumptions had to be chosen from among these many calculations to facilitate communication of the results. For this set of assumptions, Figure 5 shows the MCNP predicted carbon date along the centerline of the body, i.e., along the backbone, on the section of the cloth that would have been under the body, where the dorsal image is now located. The output from MCNP is normalized to one neutron produced in the entire model. To make the calculated neutron distribution useful, it had to be renormalized to the only experimental data available, i.e., to the average experimental value obtained by the three laboratories for the location where the samples were cut from the Shroud. For convenience, it was also assumed that the area on the Shroud from which the samples were cut was folded under the feet so that the sample area was assumed to be on the centerline of the body just under the section of the cloth that was under the body. Thus, the carbon date distribution in Figure 5 was normalized to a total neutron emission from the body of about 2×10^{18} neutrons so that the second point from the left in Figure 5 would have a carbon date of 1260 AD, which is the uncorrected average value from the three laboratories. The question then is whether this hypothesis to explain the carbon dating of the Shroud is consistent with the above four evidences which it must be consistent with to be true.

1. Is the average date at the sample location 1260 to 1390? The answer is yes, but this is the result of the normalization process that forced the second point from the left to be the uncorrected average value of 1260 AD. The merit to this normalization is that it tells us how many neutrons would have to be emitted from the body, about 2×10^{18} neutrons, to produce the average carbon date at the sample location. This number is about one neutron for every ten billion neutrons that would have been in the body.
2. Is the change of the carbon date, as a function of the distance from the short edge of the cloth, about 36 years per cm? The answer is yes, the slope across the second point from the left in Figure 5, in comparison to the first and third points from the left, is close to a

slope of 36 years per cm. Nothing was input to MCNP to force this slope to be correct. The MCNP computer code calculates this slope (about 36 years per cm) to be consistent with the experimental measurements of the three laboratories based on two assumptions: 1) the neutrons were emitted homogeneously within the body, and 2) the modeling of the limestone tomb was close enough to reality.

3. Is the distribution and range of the calculated carbon dates for the twelve subsamples consistent with the measured carbon dates and their uncertainties listed in Table 2? To answer this question, acceleration techniques must be added to the previous MCNP calculations to improve the spatial resolution so that calculated carbon dates can be obtained for areas on the cloth as small as the subsamples that were submitted for carbon dating. These calculations will be done in the future.
4. Is the carbon date for the Sudarium of Oviedo, Jesus' face cloth, about 700 AD? We have no direct evidence of where the Sudarium was placed in the tomb other than the statement in John 20:7 that it was "folded up in a place by itself", but the most likely location for the Sudarium can be predicted based on normal human behavior. It is unlikely the Sudarium would have been placed on the back bench where Jesus' body and burial cloth were located, or dropped on the floor of the pit area, or placed on the walls or ceiling of the tomb. The only remaining areas are the left and right-side benches. Most people are right-handed, so the face cloth probably would have been dropped on the right-side bench. The person doing the burial would have been standing at the front of the pit or stand-up area in the tomb facing the body that he was working on, so he probably would have dropped the face cloth next to his own body onto the right-side bench in front of the back bench, i.e., in the direction of the entrance into the tomb. Based on this, it was predicted that the Sudarium was most likely located on the right bench about 35 to 45 cm (14 to 18 inches) in front of the back bench. MCNP was then rerun to include locations on the left and right benches. For the predicted location on the right bench, MCNP calculated a date of 700 ± 50 AD, in excellent agreement with the experimental results. The carbon date for the Sudarium would have been shifted less (from about 33 AD to 700 AD) than for the Shroud (from about 33 AD to 1260 AD) because the Sudarium was further from the body where a lower neutron density would have created fewer new C-14 atoms in the fabric.

The above indicates that the neutron absorption hypothesis is in good agreement with evidence related to the slope of the carbon date, i.e., the increase in the carbon date as the distance increases from the short edge of the Shroud, and the carbon date for the Sudarium, but that additional MCNP calculations should be performed to determine the agreement with the dates and uncertainties from the twelve subsamples. Due to problems with other explanations for the 1988 carbon dating of the Shroud to 1260-1390, it appears that the neutron absorption hypothesis [17] is the best explanation. The neutron absorption hypothesis proposes that if about 2×10^{18} neutrons were emitted homogeneously within the body, then a small fraction of them would have created enough new C-14 atoms in the linen fibers (a 16.9% increase in the C-14 density is required) at the 1988 sample location to shift the measured carbon date from 33 AD to about 1325 AD, which is the mid-point of the range of 1260-1390. About 96% of the new C-14 atoms would have been produced by a [N^{14} + neutron → C^{14} + proton] reaction. The other 4% of the new C-14 atoms would have been produced by two other reactions: C^{13} + neutron → C^{14} + gamma, and O^{17} + neutron → C^{14} + alpha (He^4). The man that was wrapped in the Shroud has

been estimated to weigh about 78 kg (170 to 175 pounds). A person of this weight would have about 2×10^{28} neutrons in his body, so emission of 2×10^{18} neutrons is only one neutron for every ten billion neutrons in the body. The results of the MCNP calculations have also received significant confirmation from the position dependence of the fluorescence on the Shroud [18] based on photos taken by STURP in 1978. This is indicated in Table 3, which is from section 13 of [17].

The credibility of a hypothesis is not only determined by its consistency with the current evidence but also by testing its predictions. Predictions made by the neutron absorption hypothesis are testable, falsifiable, and unique, including: 1) Every location on the Shroud will date differently as determined by nuclear analysis computer calculations. 2) Using the usual equation for calculating a date from a measured C^{14}/C^{12} ratio, about 75% of the area of the Shroud will date to the future relative to today, since it will contain a higher C^{14}/C^{12} ratio than in our environment today. 3) Neutron absorption in Cl-35 in the Shroud and in the Sudarium will produce new Cl-36. Neutron absorption in Ca-40 in the limestone of the tomb will produce new Ca-41. There are naturally only trace amounts of Cl-36 and Ca-41 present in these materials, so a significant ratio of Cl-36/Cl-35 or Ca-41/Ca-40 should be easily measurable. The half-life of Cl-36 is about 301,000 years and the half-life of Ca-41 is about 99,400 years, so if Cl-36 or Ca-41 were formed by neutron absorption, they should still be present and measurable. Distributions of these isotopes can be predicted by nuclear analysis computer calculations.

8. Mystery 3#: Blood

The third mystery is related to the blood that is on the Shroud. About a dozen tests have been performed on the blood that is on the Shroud. Results of these tests proved that what appears to be blood is blood. All results are also consistent with it being human blood, though further testing is needed to exclude other possible options. Blood could have drained from the body onto the cloth where there were open wounds in the scalp, wrists, side, and feet. However, the problem is regarding the blood that would have dried on the skin before the body was wrapped in the cloth. Examples are the blood that drained from the wrist wounds and ran down the arms, and the blood from the scourging.

Since dried blood does not absorb into cloth, why is the blood that would have dried on the body now on the cloth? The hypothesis of an extremely brief intense burst of radiation emitted in the body offers a possible explanation. If the vertically collimated radiation burst within the body were sufficiently brief and sufficiently intense, it might have forced the wet or dried blood vertically 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. If wet or dry blood is hit by particles in a sufficiently brief burst of radiation, then the blood will be hit with particles within this extremely brief time interval. If this time interval is brief enough, then the cohesive forces that normally hold the wet or dry blood together perhaps could continue to hold the blood together as it is accelerated, both vertically up and vertically down, away from the body toward the cloth. In this concept, the blood must not be excessively heated, so that 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. This is based on the different equations for momentum and kinetic energy of particles compared to photons of electromagnetic energy. An example of particles accelerating an object is a man being hit by bird-shot from a shotgun. His body will continue to hold together as it is accelerated away from the shotgun. 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 of particles forcing the blood off the body onto the cloth should be considered to be a possibility, and results in predictions that should be tested.

9. The Vertically Collimated Radiation Burst (VCRB) Hypothesis

The author's effort to solve the mysteries of the Shroud started with a scientific analysis of the 1988 carbon dating of the Shroud, as discussed in sections 4 to 7. The conclusions of this analysis is that: 1) the stated average carbon date of 1260 to 1390 is to be rejected, i.e. given no credibility, due to the presence of a systematic measurement error that caused the twelve subsample dates to be heterogeneous, as though they were not related to one another, and 2) the best explanation for the carbon dating of the Shroud is that neutrons were emitted from the body, with a small fraction of them being absorbed in N-14 to produce new C-14 atoms [N^{14} + neutron $\rightarrow$ C^{14} + proton] on the cloth that shifted the measured carbon date forward from the true date to the range of 1260-1390. This production of new C-14 atoms on the cloth by neutron absorption caused the systematic measurement error that is evident in the measurement data from carbon dating. This explanation is called the neutron absorption hypothesis. This explanation is the only hypothesis that could be consistent with the four things we know to be true about carbon dating related to the Shroud: 1) the average carbon date of 1260-1390 AD, 2) the change in the carbon date as a function of the distance from the short edge of the Shroud is about 36 years per cm, 3) the distribution and range (1155 to 1410 AD) of the measured carbon dates for the twelve subsamples, and 4) the measured carbon date for the Sudarium of Oviedo, which is believed to be Jesus' face cloth, of about 700 AD. The neutron absorption hypothesis is consistent with #1, #2, and #4 above, but additional MCNP calculations will be needed to prove it is consistent with #3. The invisible reweave hypothesis is consistent with #1 above, can be consistent with #2 under the right assumptions, is unlikely to be consistent with #3, and cannot explain #4.

Scientific evidence related to how the images of a crucified man were formed on the Shroud is discussed in section 3 based on [3]. The process was to follow the scientific evidence where it led. The conclusion of this analysis is that the images could probably have been formed by an extremely brief intense burst of vertically collimated low energy charged particles, probably protons, which were emitted in the body. These charged particles, when absorbed on the cloth, caused electrical currents in the fibers which produced extremely localized electrical heating which produced extremely localized discoloration of the fibers which caused the images. These charged particles could also have formed ozone in the air that could have chemically altered the thin circumferential region of the fibers. This charged particle radiation had to carry the information from the body to the cloth that was required to discolor the correct fibers to form the images of a crucified man. This information, in the form of the number of particles , was deposited on the cloth when the radiation was absorbed on the cloth. The basis for believing this

hypothesis could be true is its consistency with the scientific evidence related to the nature of the images.

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. The Shroud 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 that the charged particle emission that caused the images and the neutron emission that shifted the measured 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.

The VCRB hypothesis proposes that radiation was emitted from within the body in an extremely brief intense burst of low energy radiation. Charged particles such as protons in this radiation produced the images whereas neutrons in this radiation shifted the measured carbon date in the forward direction. For the protons to form good resolution images of the front and dorsal images without images of the sides of the body, they had to be vertically collimated. The protons and neutrons were probably emitted in the body by nuclei in the body that released their component parts by fission or splitting. The isotope that requires the least energy to fission and is thus the most likely to fission is deuterium, also called heavy hydrogen because it not only contains a proton in its nucleus but also a neutron, thus making it about twice as heavy as a normal hydrogen atom.

The discolored outer layer less than 0.2 micrometers thick around the outer circumference of the fiber was probably produced by a "skin-effect" of a high frequency alternating current in the fibers, which was most likely produced by proton emission that oscillated between vertically up and vertically down directions. Due to conservation of momentum, when a deuterium nucleus emitted a proton vertically up, the neutron would have been emitted vertically down. And when a deuterium nucleus emitted a proton vertically down, the neutron would have been emitted vertically up. Perhaps this process could have been produced by a vertical oscillation of nuclei in the body that caused about 0.0004% of the deuterium nuclei to split. This 0.0004% value is obtained from the requirement that about 2×10^{18} neutrons be emitted from the body to shift the measured carbon date for the corner of the Shroud from about 33 AD to 1325 AD.

To understand what could have caused such a vertical oscillation of the deuterium nuclei will probably require considerations in advanced modern physics such as particle physics, quantum field theory (QCD, QED, QFD, and EWT), super symmetry, and string theory. Many questions would arise in such considerations. For example, could the deuterium nuclei fission due to vertically oriented fluctuations in one of the quantum fields that permeates space-time, such as the quark field that gives rise to the up and down quarks that compose protons and neutrons, or the gluon field by which protons and neutrons are held together in the nucleus? In the standard model of modern physics consisting of 12 particle fields, four force fields, and the Higgs field, why would a gluon field fluctuate in the direction of the gradient in the gravity field? Could these vertical fluctuations be related to the alternate dimensions hypothesized by the various string theories? And could this be related to transfer of matter between dimensions, as suggested

by the Biblical evidence for the disappearance of Jesus' body from within his burial cloth [19, John 20:8-9]. Progress in better understanding this radiation process can hopefully be made by these considerations and future testing of the Shroud.

The VCRB hypothesis has the qualities of a very good hypothesis: 1) It can be consistent with the scientific evidence related to image formation and carbon dating since 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. Scientists are generally more attracted to a hypothesis that could explain multiple mysteries of a phenomenon. No other hypothesis attempts to explain more than one mystery of the Shroud. Predictions of the VCRB hypothesis include the following:

Image Formation:

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

Carbon dating:

- Every location on the Shroud will carbon date differently as determined by nuclear analysis computer calculations, as in Figure 14 of [20].
- Using the usual equation for calculating a date from a measured C^{14}/C^{12} ratio, about 75% of the area of the Shroud will carbon date to the future relative to today, since it will contain a higher C^{14}/C^{12} ratio than in our environment today.
- Neutron absorption in Cl-35 on the Shroud and in Ca-40 in the limestone of the tomb will produce Cl-36 and Ca-41. These isotopes have half-lives of 300 thousand years and 99 thousand years, so if they were formed by neutron absorption, they will still be present and should be measurable.
- The distribution of neutrons hitting the Shroud calculated by MCNP will cause measurable differences in the fluorescence from the Shroud. This was tested by McAvoy [18] and found to be true.

Blood on the Shroud:

- If a radiation burst is sufficiently brief and intense, it will force wet or dry blood off a surface such as skin onto another surface such as linen.

10. Future Testing of the Shroud

The Shroud was owned by the Savoy family in Italy starting about 1453, but in 1983 the Shroud was willed to the reigning pope so he will make the final decision regarding future testing of the Shroud. The last extensive testing was performed in 1978 immediately after an exhibition of the Shroud in Turin. Future testing of the Shroud should take advantage of the significant advances in nondestructive testing (NDT) technology since the last extensive testing in 1978. Predictions of the VCRB hypothesis that should be tested are discussed in the previous section. The following are some of the questions that should guide future testing of the Shroud.

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

Dating:
- Carbon dates for other locations? [21]
- Other long-lived isotopes produced by neutron absorption, such as Cl^{36} and Ca^{41}, on the Shroud, on the Sudarium, or in the tomb?
- Evidence of an invisible reweave at the 1988 sample location? [6, 15]
- Other dating methods: reflectance, tensile strength, etc.?

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

History:
- Pollen?
- Limestone chips, dust, debris?
- Side piece and stitch?

The following have been suggested for future testing of the Shroud.

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

11. Conclusion

The main mysteries of the Shroud are image formation, carbon dating, and the blood that 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 and make predictions that are testable and falsifiable, and when tested the predictions are found to be true.

Consideration of the scientific evidence related to the images indicates that 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 these particles were absorbed on the cloth, they caused electrical currents in the fibers that produced extremely localized heating which produced extremely localized discoloration of the fibers that made the front and dorsal images. The charged particle emission from the body could have also produced ozone in the air that chemically altered the thin discolored region around the circumference of the fibers. Consideration of evidence related to the carbon dating indicates that about 2×10^{18} neutrons were probably emitted in the body that produced new C-14 atoms on the Shroud primarily by a [N^{14} + neutron $\rightarrow$ C^{14} + proton] reaction. These new C-14 atoms would have shifted the measured 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. When these two explanations are combined, the result is the Vertically Collimated Radiation Burst (VCRB) hypothesis. The VCRB hypothesis proposes that an extremely brief intense burst of vertically collimated low energy particles were emitted in the body, with protons causing the images and neutrons shifting the carbon date forward from the true date. The source for these protons and neutrons could possibly have been the splitting of 0.0004% of the deuterium nuclei in the body. What would cause deuterium nuclei to split is not currently understood but might be investigated by future testing of the Shroud and by various considerations in modern physics. If this burst of radiation from the body were sufficiently brief and sufficiently intense, it could possibly have thrust wet or dry blood off the body onto the cloth.

The VCRB hypothesis has the qualities of a very good hypothesis: 1) Since the VCRB hypothesis was derived from the scientific evidence, it is possible for it to be consistent with the scientific evidence related to image formation and carbon dating, 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. For there to be a general consensus among Shroud researchers that the VCRB hypothesis is probably true will require: : 1) time to build a consensus that the VCRB hypothesis is consistent with the evidence from the Shroud, and 2) time to test the predictions in section 9 to determine whether they are true. 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 measured 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.

There is no known example of a human body producing an image of itself on a piece of cloth, except for the Shroud of Turin. This unique encoding event appears to require a unique mechanism that is beyond our current understanding of physics. There has been extensive progress in testing procedures since the last systematic testing of the Shroud in 1978. Testing should again be allowed on the Shroud to further mankind's understanding of reality.

12. References

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Author’s Biography

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. His videos are on YouTube.com.

Table 1. Analysis of Data from Damon, et al.

	Material 1	**Material 2**	**Material 3**	**Material 4**
Source of material:	Shroud of Turin	Linen from tomb at Qasr Ibrim, Egypt	Mummy of Cleopatra from Thebes, Egypt	Cope of St. Louis d'Anjou of France
Expected date:		11^{th} to 12^{th} Century AD	110 BC to 75 AD	1290 to 1310 AD
Laboratory	**Individual Measurements of C^{14} Date, Years Before Present (YBP, Present = 1950)**			
Tucson, Arizona	591 ± 30	922 ± 48	1838 ± 47	724 ± 42
	690 ± 35	986 ± 56	2041 ± 43	778 ± 88
	606 ± 41	829 ± 50	1960 ± 55	764 ± 45
	701 ± 33	996 ± 38	1983 ± 37	602 ± 38
		894 ± 37	2137 ± 46	825 ± 44
Zurich, Switzerland	733 ± 61	890 ± 59	1984 ± 50	739 ± 63
	722 ± 56	1036 ± 63	1886 ± 48	676 ± 60
	635 ± 57	923 ± 47	1954 ± 50	760 ± 66
	639 ± 45	980 ± 50		646 ± 49
	679 ± 51	904 ± 46		660 ± 46
Oxford, England	795 ± 65	980 ± 55	1955 ± 70	785 ± 50
	730 ± 45	915 ± 55	1975 ± 55	710 ± 40
	745 ± 55	925 ± 45	1990 ± 50	790 ± 45
Laboratory	**Weighted Mean C^{14} Dates (YBP) Based on Above Values**			
Tucson, Arizona	646.44 ± 17.05	927.44 ± 19.70	1995.23 ± 19.89	721.67 ± 20.42
Zurich, Switzerland	676.14 ± 23.74	940.60 ± 23.16	1939.81 ± 28.47	685.16 ± 24.63
Oxford, England	749.17 ± 30.70	937.88 ± 29.43	1977.05 ± 32.71	755.76 ± 25.66
	Analysis of Interlaboratory Scatter			
Unweighted mean of the unweighted means (YBP)	695.09 ± 32.37	937.33 ± 6.26	1968.82 ± 14.74	732.16 ± 19.17
Unweighted mean of the weighted means (YBP)	690.59 ± 30.52	935.30 ± 4.01	1970.70 ± 16.31	720.86 ± 20.39
Weighted mean of the weighted means (YBP)	**672.21 ± 12.62**	**933.98 ± 13.37**	**1977.05 ± 14.59**	**720.16 ± 13.40**
χ^2 for weighted mean (2 degrees of freedom)	8.60	0.210	2.55	3.95
Significance level* (%)	**1.40**	**90.1**	**28.0**	**13.9**

* - The significance level is the probability that random measurement errors alone would produce a scatter among the three laboratory weighted means as high as that observed. This analysis assumes the uncertainties in Damon, et al. [4], include all sources of variation.

Table 2. Uncorrected Dates (AD) from ~~Results of~~ the Carbon Dating of the Shroud ~~(AD)~~

Oxford	Zurich	Arizona
1155 ± 65	1217 ± 61	1249 ± 33
1205 ± 55	1228 ± 56	1260 ± 35
1220 ± 45	1271 ± 51	1344 ± 41
	1311 ± 45	1359 ± 30
	1315 ± 57	
1200.8±30.7	1273.9±23.7	1303.6 ±17.1

1277.8±12.6 (1260±31→1260-1390)

Table 3. MCNP Predicted Neutron Densities vs. Measured Intensity of the Fluorescence

MCNP Predictions	Intensity of the Fluorescence
1. The maximum neutron density is near the center of mass of the body	1. Ultraviolet fluorescence is highest in the mid-section of the image on the Shroud
2. The neutron density is greater on the dorsal side than the frontal side due to neutrons reflecting from limestone that would have been under the body.	2. The dorsal side of the Shroud fluoresces more than the frontal side
3. The neutron density decreases toward the head and toward the feet	3. Fluorescence decreases slightly toward the head and significantly toward the feet
4. The neutron density is greatest on the centreline and decreases to the left & right	4. Fluorescence decreases to the left and the right of the centreline
5. The neutron density is greater on the right side of the body image due to neutrons reflecting from the limestone wall that would have been to the right of the body as the body was modelled in MCNP.	5. The fabric to the right of the body image fluoresces more than fabric to the left

Figure 1. Location of Samples for C^{14} Dating

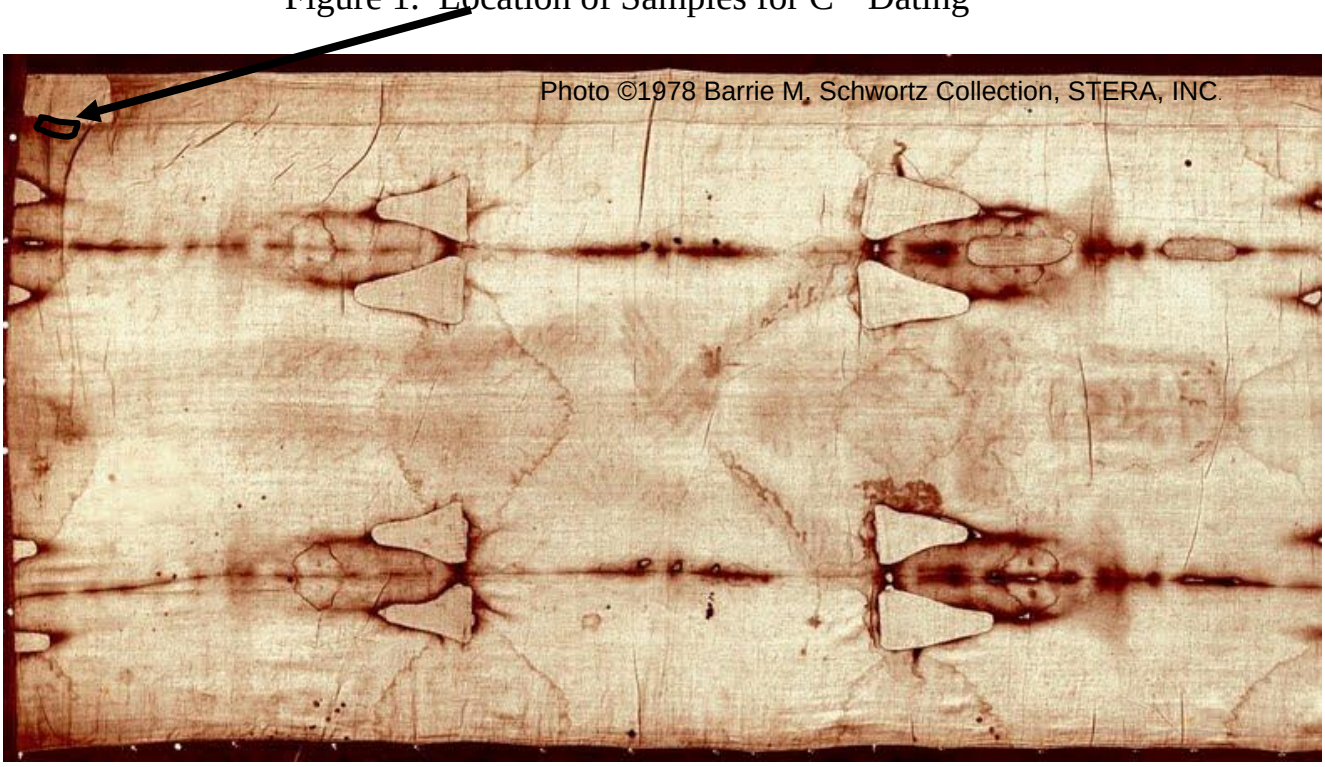

Figure 2. Location of Samples Cut from the Shroud in 1988

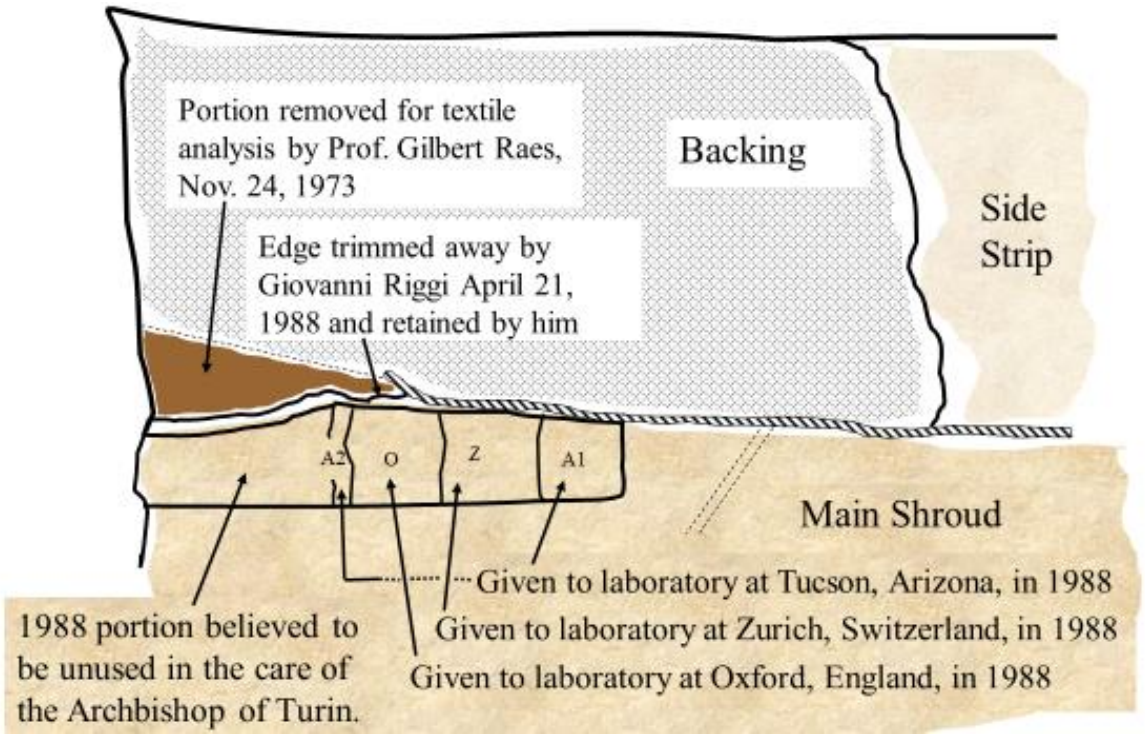

Figure 3. Measured Dates are a Function of Sample Location

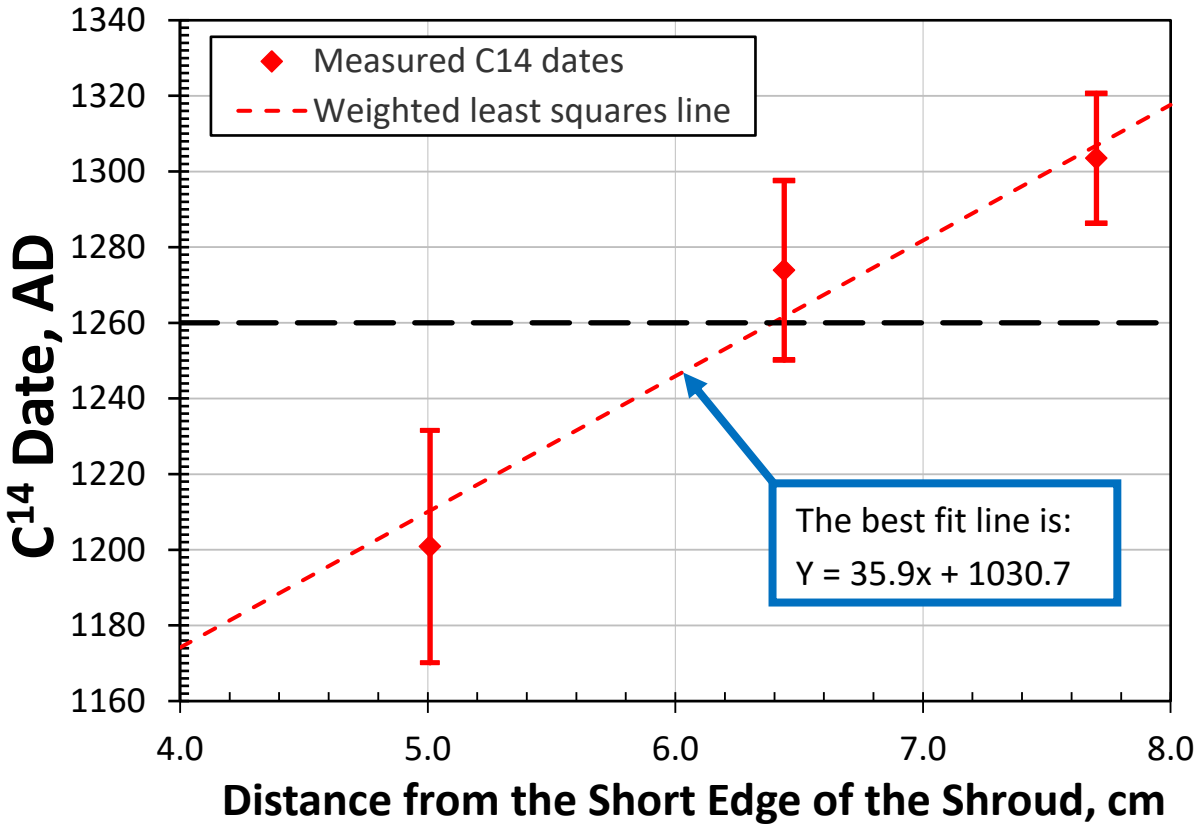

Figure 4. Diagram of Tomb Used in MCNP

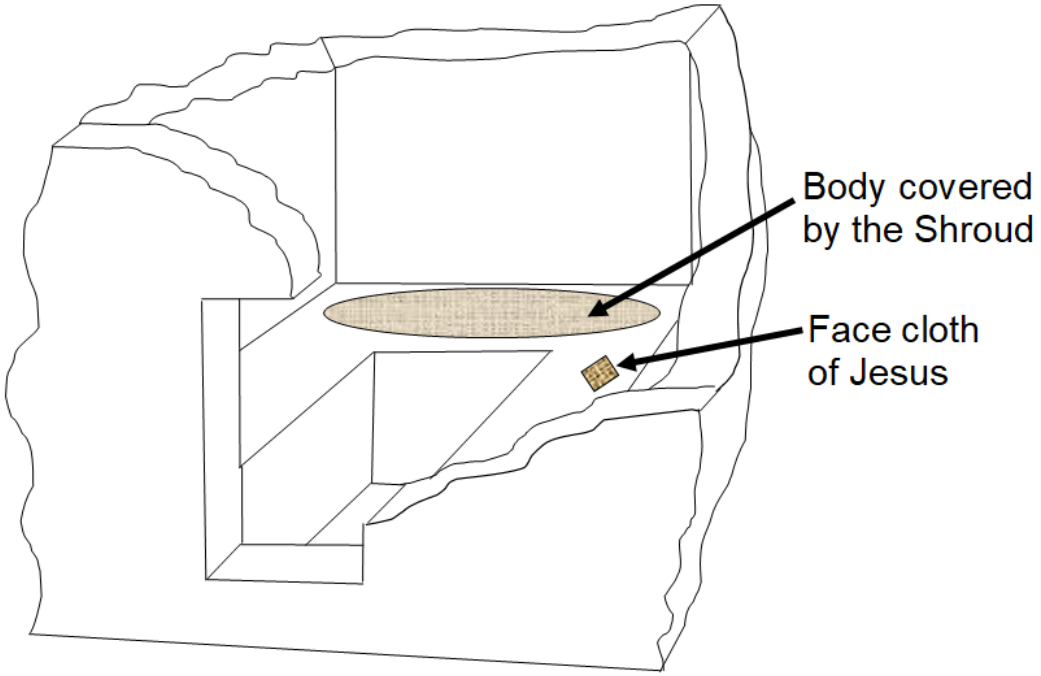

Figure 5. C^{14} Date on Shroud Under the Body