The Carbon Dating of the Shroud is Explained by Neutron Absorption

Robert A. Rucker, August 21, 2020

Abstract

The carbon dating of the Shroud in 1988 concluded that it dates from 1260 to 1390 AD. This paper explains why this conclusion should be rejected. Two types of errors, random errors and systematic errors, can alter the results of every measurement by altering either the measurement process or the samples. Analysis of the values obtained in the 1988 carbon dating indicates a number of problems: 1) two of the three laboratories obtained statistically different dates, 2) the carbon date is different for different locations on the cloth increasing about 36 years per cm (91 years per inch) as the sample location moves further from the bottom of the cloth, and 3) the probability of obtaining a variation of the dates for the 1988 Shroud samples at least as large as was obtained is only 1.4%, which is below the usual acceptance criteria of 5.0%. To explain the variation of the measured dates most likely requires an unexpected factor to have altered the samples, thus causing a systematic error in all the measurements. According to the neutron absorption hypothesis, this unexpected factor is neutron absorption which would have created new C^{14} on the cloth by the [N^{14} + neutron $\rightarrow$ C^{14} + proton] reaction. These neutrons were evidently included in the burst of radiation from the body that formed the image of the crucified man on the Shroud, so the two effects, image formation and the shift in the carbon date, are related. To change the carbon date from the time of Jesus' death, about 30 AD, to 1260 AD requires neutron absorption to increase the amount of C^{14} on the samples by only 16%. This paper is an abridgment of a 37-page paper titled "Understanding the 1988 Carbon Dating of the Shroud of Turin", available at http://www.shroudresearch.net/research.html.

1. Introduction and Nontechnical Explanation

To determine the best explanations for the Shroud's mysteries, including its image, date, and blood, the Shroud has been researched more than any other ancient artifact. Scientific data collected in 1978 by the Shroud of Turin Research Project (STURP) led many to believe it was likely the burial cloth of Jesus, which led many to desire its carbon dating. Carbon dating is done by measuring the ratio of carbon-14 to carbon-12 (C^{14}/C^{12}) in samples removed from the material of interest. The date is then calculated by assuming this ratio has only changed by decay of the C^{14}, which has a half-life of about 5730 years. Like sand running down in an hourglass, with the amount of sand in the top half decreasing with time, the amount of C^{14} remaining in the sample indicates how long ago the plant was cut down to make the linen cloth. In 1988, samples were cut from the corner of the Shroud and carbon dated at three laboratories in Tucson, Zurich, and Oxford. This resulted in an uncorrected average value of 1260 ± 31 AD. (In statistical analysis terminology, an average value is called a mean value.) This value, when corrected for variations in the C^{14} in the atmosphere, produced a range of 1260 to 1390 AD with a 95% probability that the true date falls within this range[1]. But multiple issues have convinced most Shroud researchers that this conclusion (1260-1390 AD) should be rejected, i.e. given no credibility.

1. P.E. Damon, and 20 others, "Radiocarbon Dating of the Shroud of Turin", *Nature*, February 16, 1989.

The main objective of the 1988 effort was not the correct dating of the Shroud but was the validation of the small-sample dating technique for Accelerator Mass Spectroscopy (AMS). This was expected to be a significant and lucrative improvement over the older dating technique. Dating the Shroud was probably chosen as the means toward validation of the AMS small-sample dating technique because many people were very interested in the Shroud so that its dating should produce much publicity.

To validate the small sample dating technique, the Shroud had to be dated to what was believed to be the correct date. Two basic assumptions are apparent: 1) the Shroud likely originated in the 13th or 14th century since many argued that it was first shown in Lirey, France, about 1355, and therefore 2) the Shroud was an ordinary piece of linen cloth that could be carbon dated as any other piece of cloth, so nothing unusual could have altered the C^{14}/C^{12} ratio of the samples. This means that the possibility that the Shroud could have encountered unique phenomena as it wrapped the dead body of Jesus at the time of his resurrection was assumed to be not credible. This is a common assumption for scientists, i.e. an event cannot have happened if it is contrary to our current understanding of science. For example, Harry Gove, one of the leaders in the 1988 carbon dating of the Shroud, rejected this possibility calling it "fanciful" in the range of "highly improbable to the ludicrous" [2]. As a result of this assumption, when the variation of the measured dates was recognized as probably inconsistent with the original measurement uncertainties stated in Damon, the possibility that a unique phenomenon had altered the C^{14}/C^{12} ratio of the samples was not seriously considered. Rather, to avoid this inconsistency, it was assumed that the original measurement uncertainties in Damon, resulting from the usual measurement and calculation sequence for the C^{14}/C^{12} ratio measurement process, were under-predicted, i.e. less than the true measurement uncertainties. However, the evidence is against this assumption because the variation of the measured dates for the three standards (three samples of cloth other than the Shroud) that were run at the same time as the Shroud samples were in good agreement with their measurement uncertainties, with these uncertainties also determined from the usual measurement and calculation sequence for the C^{14}/C^{12} ratio measurement process. Why should the usual methodology for determining the measurement uncertainties work for the three standards but not for the Shroud samples? Thus, it is believed that a wrong assumption (the Shroud is an ordinary piece of linen cloth) produced a wrong conclusion (the Shroud dates to 1260-1390 AD).

To assure the accuracy of measurement data, a statistical analysis of the data is always necessary to prove that an unexpected factor has not affected the measured values by either affecting the measurement process or by affecting the samples. This is because such a factor could alter the measured values by an unknown amount. The above assumption that the measurement uncertainties were underpredicted allowed them to proceed without performing this aspect of the statistical analysis. But if the measurement uncertainties are not assumed away but instead are used to analyze whether the measured dates are consistent with their uncertainties[3],

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2. Harry E. Gove, "From Hiroshima to the Iceman, The Development and Applications of Accelerator Mass Spectrometry", 1999, Institute of Physics Publishing, Bristol and Philadelphia, ISBN 0 7503 0558 4, pages 183-185
3. Robert A. Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 2: Statistical Analysis", August 7, 2018, T. Casabianca, E. Marinelli, G. Pernagallo, and B. Torrisi, "Radiocarbon Dating of the Turin Shroud: New Evidence from Raw Data", (2019), *Archaeometry,* 61(5), 1223-1231, and Bryan Walsh and Larry Schwalbe, "An Instructive Inter-Laboratory Comparison: The 1988 Radiocarbon Dating of the Shroud of Turin", *Journal of Archaeological Science: Reports,* Volume 29, February 2020.

the conclusion is that they are likely not consistent. This indicates an unexpected factor had likely altered the measured dates.

The dates could have been altered in two general ways based on carbon dating being a two-step process. In step 1, the C^{14}/C^{12} ratios of the samples are measured. In step 2, these measured C^{14}/C^{12} ratios are used to calculate the date assuming the C^{14}/C^{12} ratios have only changed due to the decay of C^{14}. It is believed that the C^{14}/C^{12} ratios were measured accurately but that something other than the decay of C^{14} had altered the C^{14}/C^{12} ratios of the samples. Evidence indicates that a burst of radiation from the body formed the image[4]. The neutron absorption hypothesis assumes neutrons were included in this radiation, though they were not involved in forming the image. Absorption of these neutrons in the trace amount of N^{14} in the fabric would produce new C^{14} in the threads[5] which could shift the carbon date forward by thousands of years, depending on the location on the Shroud. To shift the carbon date from about 30 to 1260 AD requires the C^{14} in the samples to be increased by only 16%.

2. Analysis of Measurement Data

An important concept in the analysis of measurement data is the difference between random errors and systematic errors. Due to these errors, the measured value of a quantity is usually different than the true value. The "true" value of a quantity is its inherent value, even though we may not be able to know the true value by use of measurements. The difference between a measured value and the true value is called an error or bias. These errors can be either random or systematic. The term "random error" means that the measured value can be a little higher than the true value one time and a little lower than the true value another time. Since random measurement errors can cause the measured values to be randomly higher or lower than the true value, the effect of these random errors can be minimized by taking many measurements. This is because the randomly positive or negative changes from the true value will tend to cancel each other.

Measurements may sometimes also be affected by a systematic error, which is often called a systematic bias. A systematic error is the opposite of a random error because it can, and usually does, change the measured value from the true value in only one direction. Thus, an equation for the measured value can be written as follows:

$$\text{The measured value} = \text{the true value} \pm \text{the random error} + \text{the systematic error}$$

A systematic error is not random because it is a function of (depends on) something such as temperature, pressure, humidity, voltage, materials, gravity, electrical field, magnetic field, etc. As a result, a systematic error can cause a measured value to be in error in only a positive direction or only a negative direction. This means the effect of a systematic error cannot be minimized by taking many measurements. A systematic error in the measured value of a sample can result from a problem in the measurement process or because the sample has been altered in some way. If measurements are affected by a systematic error, and if the magnitude of this error cannot be determined, as is usually the case, then the only option is to reject the measured values from necessarily being the true value because they could be in error by an unknown amount.

4. Robert A. Rucker, "Holistic Solution to the Mysteries of the Shroud of Turin", July 16, 2020, and "Image Formation on the Shroud of Turin", July 14, 2019.
5. A. C. Lind, "Production of Radiocarbon by Neutron Radiation on Linen", available at https://www.testtheshroud.org/articles

It should never be assumed that the measurement uncertainties are under-predicted to allow them to be ignored, as was done in the statistical analysis of the 1988 carbon dating. Doing this could easily hide the presence of a systematic error that could significantly change the measured values from the true value. This is the root cause of why the 1988 carbon dating of the Shroud produced a date (1260-1390 AD) that is inconsistent with so much other information about the Shroud. Assuming the measurement uncertainties to be under-predicted allowed them to be ignored. This caused those doing the analysis to avoid the evidence within the measured values that a systematic error, caused by an unexpected factor, had probably altered the measured values.

3. The 1988 Carbon Dating of the Shroud

An erroneous carbon date could either be caused by a problem with the measurement procedure or a problem with the samples. Since the 1988 carbon dating utilized three different laboratories, and three standards were run at the same time as the Shroud samples and these standards were dated with reasonable accuracy, it is appropriate to believe that the accelerator mass spectroscopy (AMS) procedure, including the equipment, personnel, procedures, materials, and standards, would have accurately measured the C^{14}/C^{12} ratios for the Shroud samples within the stated measurement uncertainties. The only other option for the 1260-1390 date to not be the true date for the Shroud, as is generally believed by Shroud researchers, is for there to be a problem with the samples. This requires the C^{14}/C^{12} ratios for the samples to have been altered by something other than decay of C^{14}. For the carbon date to be shifted from about 30 to 1260 AD, the amount of C^{14} in the sample would have to be increased by 16%. This change is too large for it to be the result of normal contamination[6]. The first documented hypothesis to explain why the Shroud could have dated incorrectly was neutron absorption[7]. According to the neutron absorption hypothesis[8], neutrons were included in the burst of radiation emitted from the body that is believed to have produced the image. A small fraction of these neutrons would have been absorbed in the trace amount of N^{14} in the threads to produce new C^{14} by the [N^{14} + neutron $\rightarrow$ C^{14} + proton] reaction. New C^{14} would have been produced in various amounts across the entire Shroud, including the samples cut from the cloth in 1988. This new C^{14} would have shifted the carbon date in the forward direction by up to thousands of years depending on the location on the Shroud.

A strip of linen about 1.2 x 8 cm was cut from the cloth by Giovanni Riggi on April 21, 1988. This strip was cut from the bottom corner of the cloth next to the front image. Samples for three laboratories were cut from this 1.2 x 8 cm linen strip as shown in Figure 1. To assure proper measurement results, three standards were also dated at the same time as the Shroud samples. These standards were cloth samples taken from cloth of known dates based on their history. The measured dates, the measurement uncertainties, and the analysis of data from both the Shroud subsamples and the standards were reported in the British journal *Nature* in 1989.

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6. Robert A. Rucker, "Carbon Dating of the Shroud of Turin to 1260-1390 AD is not Explained by Normal Contamination", August 9, 2019
7. Thomas J. Phillips, "Shroud Irradiated with Neutrons?", Nature, Vol. 337, No. 6208, page 594, February 16, 1989, published in the same edition of *Nature* as Damon.
8. Robert A. Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 3: The Neutron Absorption Hypothesis", July 7, 2018

The title is "Radiocarbon Dating of the Shroud of Turin".[1] Twenty-one authors are listed for this paper with the first author being P. E. Damon, so this paper is commonly called "Damon".

Carbon dating of a sample does not measure the date directly. It measures the ratio of C^{14} to C^{12} in the sample and then a date is calculated from this ratio for the sample. This calculation assumes that the C^{14}/C^{12} ratio has only changed due to the C^{14} atoms in the sample decaying with a half-life of 5730 years whereas C^{12} atoms do not decay. According to Damon, the average date for the Shroud samples from the three laboratories (Tucson, Zurich, and Oxford) was determined to be 1260 ± 31 AD. This is the raw or uncorrected value. When this value was corrected for the changing concentration of C^{14} in the atmosphere, a date range of 1260 to 1390 was obtained. This is claimed to be a two sigma or 95% range. This means there should be a 95% probability the true date for the Shroud is between 1260 and 1390 AD. Based on this, Damon states in both the abstract and the conclusion that, "These results provide conclusive evidence that the linen of the Shroud of Turin is mediaeval." When the raw data for the 1988 carbon dating was finally obtained[9] from the British Museum in 2017, it was learned that one of the peer reviewers of this paper (Professor Anthos Bray) recommended this concluding statement be removed from the paper, presumably because it was not justified by the analysis of the data. However, *Nature* published this paper without removing this concluding statement, thus ignoring the recommendation of Professor Bray.

The dates obtained by each laboratory are given in Table 1. The three values obtained by the Oxford laboratory and the five values obtained by the Zurich laboratory are from Damon. The eight values obtained by the laboratory in Tucson, Arizona, are from Casabianca, et al.

4. Objections to the 1260-1390 AD Date for the Shroud

The main objections to a date of 1260-1390 AD for the Shroud are summarized below:

- The characteristics of the image are so unique (image not formed by pigment, only the top two or three layers of fibers are discolored, only the outer thin layer in a fiber is discolored, discoloration is due to single electron bonds that were changed to double electron bonds) it seems impossible for the image to have been made in 1260-1390 because the technology to make the image did not exist, and still does not exist.
- There are at least 14 other date indicators that are consistent with the first century and contradict the 1260-1390 date[10].
- Two of the laboratories that did the 1988 carbon dating obtained statistically different dates. The difference between the dates from Arizona (1303.5 ± 17.2) and Oxford (1200.8 ± 30.7) is 1303.5 – 1200.8 = 102.7 years. The uncertainty of this difference is obtained from the square root of the sum of the squares of the individual uncertainties = square root of (17.2 squared + 30.7 squared) = 35.2. The difference between the dates from Arizona and Oxford is thus 102.7 ± 35.2. But 102.7/35.2 = 2.9, which means the dates from Arizona and Oxford are statistically different at the 2.9-sigma level because 2.9 exceeds the normal acceptance level of less than or equal to 2.0 sigma. This indicates the carbon dates were statistically different for the samples sent to Arizona and Oxford, as though the samples came from different pieces of cloth. This should not be true since

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9. T. Casabianca, E. Marinelli, G. Pernagallo, and B. Torrisi, "Radiocarbon Dating of the Turin Shroud: New Evidence from Raw Data", (2019), *Archaeometry*, 61(5), 1223-1231.
10. Section 4 of "Date of the Shroud of Turin" by Robert A. Rucker, July 16, 2020

both samples were cut from the same cloth close to one another. This suggests that an unexpected factor had altered the C^{14}/C^{12} ratios of the samples.

- The average dates from the three laboratories show an increase of about 36 years per cm (91 years per inch) of distance from the bottom of the cloth (Figure 2). This means that the dates are a function of (depend on) the location on the cloth. This slope or gradient in the experimental results agree with the results of nuclear analysis computer calculations that were based on the neutron absorption hypothesis (Figure 3).
- The statistical analysis in Damon used a chi-squared (χ^2) statistical test to determine whether the variation in the dates exceeded the variation allowed by the measurement uncertainties. This process found that for the three standards (labelled samples 2, 3, and 4 in Damon), the variation in the dates were reasonably consistent with their uncertainties (significance level $p = 0.9$, 0.5, and 0.3), but this was not true for the samples from the Shroud (labelled sample 1 in Damon). Why would this be? In paragraph 23 of Damon, which begins, "More quantitatively", it is stated that since "it is unlikely that the errors quoted by the laboratories for sample 1 fully reflect the overall scatter" they decided to use "the scatter of results" to estimate the uncertainties. This is the key mistake in the analysis of the data because it fails to allow for the possibility that the measured dates had been affected by an unexpected factor that produced a systematic error in the evaluation. When the original measurement uncertainties produced by the normal experimental and calculational process are used, instead of those calculated from the scatter of results, the chi-squared statistical analysis indicates that the variation in the measured dates likely exceeds the variation allowed by the measurement uncertainties. There is only a 1.4% chance they are consistent[11], if the analysis is performed using a chi-squared statistical analysis as in Damon for the three standards that were run at the same time as the Shroud samples. The 1.4% is below the usual acceptance level of 5.0%, and thus indicates an unexpected factor probably caused the measured dates to be different than the true date, which in statistical analysis terminology is called a systematic error. Since the magnitude of this systematic error cannot be known, the credibility of the 1260-1390 date range should be rejected.

In other words, in the statistical analysis of the data in Damon, a decision was made to assume that the original measurement uncertainties were underpredicted, i.e. less than the true values, and thus could be ignored. But in ignoring the original measurement uncertainties, they ignored the crucial item in the decision process as to whether the 1260 ± 31 AD date should be accepted or rejected. This was probably done because there were problems in the statistical analysis that should have caused them to question the 1260 date for the Shroud and because their main goal was to validate the accuracy of their small sample dating technique. Dating the Shroud was merely a means to that end. But when they ignored the original measurement uncertainties in Damon, they could no longer perform a statistical analysis to prove the variation in the measured dates was within that allowed by the measurement uncertainties, without the presence of some unexpected factor that had significantly altered the measurement results. Thus, they could not assure that no unexpected factor had altered the measurement process or had altered the samples. It is believed the C^{14}/C^{12} ratios of the samples were accurately measured

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11. Significance level $p = 0.014$ in Table 6 in Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 2: Statistical Analysis" and Table 4 in Walsh and Schwalbe, "An Instructive Inter-Laboratory Comparison: The 1988 Radiocarbon Dating of the Shroud of Turin".

within the stated measurement uncertainties in Damon, but the dates calculated from these C^{14}/C^{12} ratios could have been very different from the true date for the Shroud because something had altered the C^{14}/C^{12} ratios in the samples, such as neutron absorption creating new C^{14} in the samples.

5. Should All the Data in Damon be Rejected?

In summary, the conclusion in Damon (1260-1390 AD) should not be trusted for dating the Shroud. This is because an unexpected factor, which is believed to be neutron absorption, likely caused a systematic error in the measurement values. This is proven by the data being heterogeneous (statistically different from each other), based on the calculated significance level ($p = 0.014$) being below the 5.0% acceptance limit. But in rejecting the 1260 to 1390 date for the Shroud, it is important to understand what should be rejected and what should not.

It is important to realize that carbon dating does not produce a date directly but is a two-step process. Step 1 is to measure the C^{14}/C^{12} ratio of the samples. Step 2 is to use this measured C^{14}/C^{12} ratio to calculate the date assuming that the C^{14}/C^{12} ratio has only changed due to decay of C^{14}. This means there are two types of errors. A type 1 error occurs if the C^{14}/C^{12} ratios of the samples are measured incorrectly. A type 2 error occurs if the C^{14}/C^{12} ratios in the samples are altered by something other than C^{14} decay. Regarding a type 1 error; sources of error in the C^{14}/C^{12} ratio measurements are carefully monitored in the measurement process so that the uncertainty of each measurement can be determined with reasonable accuracy. This accuracy is confirmed by running standards in the measurement process. This means that measurement of the C^{14}/C^{12} ratios should be accurate within the stated measurement uncertainty. Thus, for the Shroud, it is most reasonable to believe that the C^{14}/C^{12} ratios were measured accurately within their stated uncertainties, so that both the C^{14}/C^{12} ratio measurements and their uncertainties should be regarded as accurate. This allows a statistical analysis to be performed on the data in Damon for the Shroud. The resulting significance level $p = 1.4\%$ indicates that the measured dates are heterogeneous (nonhomogeneous) due to the likely presence of an unexpected factor which altered the C^{14}/C^{12} ratios in the samples, so that the 1260-1390 date for the Shroud should be rejected. But since the C^{14}/C^{12} ratios were accurately measured, the dates stated in Damon for the samples and the subsamples should not be totally ignored but should be used to better understand the nature of the unexpected factor that altered the C^{14}/C^{12} ratios in the samples to cause the systematic error in the measurements. These considerations lead to four requirements that should be met for a hypothesis to explain the results of the 1988 carbon dating of the Shroud.

1. To be true, the hypothesis should explain why a date of 1260 ± 31 was obtained for the 1988 sample location. It is believed that this value was produced by correct measurements of the C^{14}/C^{12} ratios for the samples, but that the C^{14}/C^{12} ratios had been altered, so this is not the true date of the Shroud. But this value is important to help us understand what altered the C^{14}/C^{12} ratios of the samples.
2. To be true, the hypothesis should explain why there was a slope or gradient of about 36 years per cm as the sample location is moved away from the bottom of the cloth. This slope in the experimental data in Figure 2 is consistent with the slope in the results of nuclear analysis computer calculations at the second point from the left in Figure 3.
3. To be true, the hypothesis should explain why the variation or distribution of the subsample dates that were obtained in the 1988 carbon dating of the Shroud exceeded the variation

allowed by the measurement uncertainties. The variation of the subsample dates obtained in the 1988 experiments is consistent with the nuclear analysis computer calculations that were based on the neutron absorption hypothesis.

4. To be true, the hypothesis should explain why the Sudarium of Oviedo carbon dated to 700 AD, since it is believed to be related to the Shroud. This date is also consistent with nuclear analysis computer calculations based on the neutron absorption hypothesis, assuming that the Sudarium was placed at a reasonable location on the side bench in the tomb.

6. Nuclear Analysis Computer Calculations

Evidence indicates that the image on the Shroud was formed by a burst of radiation from the body[4]. The neutron absorption hypothesis assumes that neutrons were included in this burst of radiation. Based on this hypothesis, nuclear analysis computer calculations[7] were performed to understand the 1988 carbon dating of the Shroud. The MCNP (Monte Carlo N-Particle) software, developed over many decades at the Los Alamos National Laboratory (LANL), was used to model a human body with simple geometrical volumes. The body was surrounded by a linen cloth on the back bench in a limestone tomb as it would have been constructed in first-century Jerusalem. MCNP was used to calculate the distribution of neutron absorption in the trace amount of N^{14} in the Shroud, which would have produced new C^{14} in the fibers of the Shroud by the [N^{14} + neutron $\rightarrow$ C^{14} + proton] reaction. This new C^{14} would have shifted the carbon date forward. This is because carbon dating is based on a measurement of the C^{14} to C^{12} ratio. If the C^{14} concentration in the threads of the Shroud was increased by only 16% by this process, then the carbon date would have been shifted forward from 30 to 1260 AD.

The distribution of the carbon dates calculated by MCNP is shown in Figure 3. This curve is for locations on the dorsal (back) image along the centerline of the body, i.e. along the backbone, from the feet at the left to the head at the right. On the x-axis, the zero point is at the mid-height of the body. This curve is normalized to the laboratory's average value of 1260 AD at the second point from the left. The curve shows that according to the hypothesis of neutrons being emitted homogeneously in the body, the calculated carbon dates are predicted to be quite variable by position with a maximum value of about 8500 AD on the back image below the center of the body mass. About 75% of locations on the cloth are predicted to date to the future. Such dates to the future result when the usual equations are used to calculate a date from the C^{14}/C^{12} ratio and there is more C^{14} present in the sample than ought to be present in a living plant. The most important point is that MCNP predicts a significant slope in the carbon date at the second point from the left, which is about where the samples were removed from the cloth in 1988. This MCNP calculated slope in the carbon date is about the same as the slope measured by the three laboratories shown in Figure 2. This agreement between the calculated slope (Figure 3) and the slope experimentally determined by the three laboratories (Figure 2) supports the validity of the neutron absorption hypothesis. The carbon date also slopes in the direction perpendicular to the direction in Figure 3.

According to the neutron absorption hypothesis, the neutron distribution in the tomb calculated by MCNP at the 1988 sample location caused different amounts of new C^{14} to be produced on each of the samples sent to the three laboratories. These different increases in the C^{14} content caused the different carbon dates to be obtained by the three laboratories. Thus, it was the neutron distribution in the tomb that caused the carbon date at the 1988 sample location to increase by about 36 years per cm (91 years per inch) of distance from the bottom of the cloth.

7. Evidence for the Neutron Absorption Hypothesis

In using the scientific method to explain a phenomenon, the first step is to develop a hypothesis that is consistent with what is known to be true about the phenomenon. As discussed above, there are four things that are true for carbon dating as it relates to the Shroud:

1. For the 1988 sample location, the uncorrected average date is calculated to be 1260 ± 31, based on what is believed to be correct measurements of the C^{14}/C^{12} ratios in the samples, though this is not the true date due to the C^{14}/C^{12} ratio in the samples being altered by the addition of C^{14}.
2. For the 1988 sample location, the carbon date increases by about 36 years per cm (Figure 2) as the sample location is moved away from the bottom of the cloth.
3. For the 1988 sample location, the variation in the subsample dates result in a range of 1155 to 1410 AD[12].
4. For the Sudarium of Oviedo, the carbon date was measured to be 700 AD.

A hypothesis to explain the carbon dating of the Shroud must be consistent with these four requirements to be true. The neutron absorption hypothesis is consistent with all four of these requirements. The invisible reweave hypothesis could be consistent with requirements #1 and #2 if it is assumed to have the correct ratio of new to old fabric as a function of location on the Shroud, but it appears to be inconsistent with requirement #3. This is because cutting the subsamples from the samples provided to the three laboratories probably would have been a random process. This means some of the 16 subsamples should have dated primarily if not only old material, which should date to about 30 AD, and some of the 16 subsamples should have dated only new material. According to the main proponents of the invisible reweave hypothesis, this new material should probably have dated to the early 1500s. Yet none of the subsamples were dated to about 30 AD or to the early 1500s. Also, regarding requirement #4, an invisible reweave on the Shroud would not have altered the carbon dating of the Sudarium. There are also several other common objections to the invisible reweave hypothesis[13].

There are two ways to test the neutron absorption hypothesis: the predicted distribution of carbon dates on the cloth and the predicted production of long half-life isotopes in the Shroud and limestone of the tomb.

8. Conclusion

Carbon dating is performed by measuring the ratio of C^{14}/C^{12} in samples, from which the date is calculated assuming that the C^{14}/C^{12} ratio has only changed due to decay of the C^{14}. It is believed the C^{14}/C^{12} ratios of the Shroud samples were accurately measured, but the C^{14}/C^{12} ratio for each sample had been altered by neutron absorption, which caused a systematic error in the measured dates. There are four reasons why the 1988 carbon dating of the Shroud to 1260-1390 AD should be rejected, i.e. given no credibility:

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12. Table 6 of Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 2: Statistical Analysis".
13. Section 2 of Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 3: The Neutron Absorption Hypothesis" and Chapter 9 of Mark Antonacci, "Test the Shroud', 2015, LE Press, LLC, ISBN 978-0-9964300-1-2

1. In the 1988 carbon dating of the Shroud, each measurement produced two values: 1) the measured C^{14}/C^{12} ratio from which the date was calculated, and 2) the uncertainty in the measured C^{14}/C^{12} ratio. But in the original statistical analysis of the data in Damon, when it was realized that the variation in the measured values exceeded what was allowed by the measurement uncertainties, it was assumed that the measurement uncertainties were underpredicted, i.e. smaller than their true values. This assumption is unjustified because the measurement uncertainties would have been obtained from the same measurement process as produced the dates. Also, the variation in the measured dates for the three standards that were run at the same time as the Shroud samples were within the variation allowed by their uncertainties. Assuming all the measurement uncertainties to be underpredicted allowed them to be ignored. Since each measurement produced two values, the value itself and its uncertainty, this means that half the data, i.e. all the measurement uncertainties, was ignored. Thus, the 1260-1390 AD date for the Shroud should be rejected because it is based on only half the data.
2. By assuming that the measurement uncertainties were under predicted, the statistical analysis of the 1988 carbon dating in Damon failed to prove that the random measurement errors alone could account for the variation of the measured values without the presence of a systematic error. If a systematic error were present in the measurements, it could change the measured values by an unknown amount. Since they did not prove that a systematic error could not be present, the conclusion of the carbon dating for the Shroud (1260-1390 AD) cannot be claimed to be true.
3. There are various anomalies in the results of the 1988 carbon dating of the Shroud. These anomalies indicate that the 1260-1390 date is not reliable.
   - Two of the three laboratories obtained different dates, with the difference (102.7 ± 35.2) being statistically significant at the 102.7/35.2 = 2.9 sigma level. This exceeds the normal acceptance level of 2.0 sigma.
   - The average dates from the three laboratories indicate the carbon date is a function of (depends on) the distance from the bottom of the cloth with a change of about 36 years per cm (91 years per inch). This slope or gradient in the experimental data is consistent with the results of nuclear analysis computer calculations (Figure 3) based on the neutron absorption hypothesis.
4. A chi-squared statistical analysis of the 1988 measurement values and uncertainties indicates the probability of obtaining a variation of the dates at least as large as was obtained is only 1.4%, if the analysis is conducted as in Damon for the three standards that were run at the same time as the Shroud samples. This value is below the usual acceptance limit of 5.0%, so the possibility that the carbon date is the same at every location on the Shroud should be rejected. This implies the probable presence of a systematic error in the dates, which indicates that the 1260-1390 AD date probably differs from the true date by an unknown amount. The presence of a systematic error would cause the measured dates to be heterogeneous (statistically different from each other) rather than homogeneous (statistically the same). The most recent statistical analysis by Casabianca and by Walsh and Schwalbe[3] concluded that the three samples were heterogeneous, i.e. nonhomogeneous. This means that an unexpected factor had likely caused a systematic error in the measurements so that the conclusion in Damon that the Shroud dates to 1260-1390 AD should be given no credibility.

According to the neutron absorption hypothesis, the unexpected factor that caused the systematic error in the measured dates is neutron absorption. If the burst of radiation from the body that is believed to have formed the image[4] also included neutrons, then capture of a small fraction of these neutrons in the trace amount of N^{14} in the linen would have produced new C^{14} on the samples that were cut from the cloth in 1988. This new C^{14} would cause a systematic error in the carbon date measurements since carbon dating is based on measurement of the C^{14}/C^{12} ratio in the samples. This could have shifted the measured date forward by up to thousands of years, depending on the location on the Shroud. To shift the carbon date from 30 to 1260 AD requires only a 16% increase in the C^{14} concentration. Based on MCNP nuclear analysis computer calculations[11], to cause this date shift at the 1988 sample location would require 2×10^{18} neutrons be emitted from the body. This is a very small fraction, only one in ten billion, compared to the number of neutrons in an average human body (2×10^{28}). For example, the required number of neutrons (2×10^{18}) would be emitted if the neutrons and protons were to separate in only 0.0004% of the deuterium (also called heavy hydrogen, H^2, which has one proton and one neutron in the nucleus of each atom) nuclei in the body. Deuterium is of special interest because it requires the least amount of energy to split the nucleus. At 2.23 Mev (million electron volts) per nuclei, the total energy required to split 2×10^{18} deuterium nuclei is 7.2×10^5 Joules = 7.2×10^5 watt-seconds = two minutes operation of a 100-watt bulb. According to Einstein's equation $E=mc^2$, this amount of energy would be released if 0.00000000801 (8.01×10^{-9}) grams of matter were converted into energy (https://www.omnicalculator.com/physics/emc2).

Table 1. Carbon Dates (AD) from Each Laboratory

Subsample	**Oxford**	**Zurich**	**Arizona**
1	1155 ± 65	1217 ± 61	1344 ± 41
2	1205 ± 55	1228 ± 56	1376 ± 45
3	1220 ± 45	1315 ± 57	1197 ± 51
4		1311 ± 45	1318 ± 49
5		1271 ± 51	1274 ± 40
6			1410 ± 37
7			1249 ± 47
8			1249 ± 47
Weighted Mean	1200.8 ± 30.7	1273.9 ± 23.7	1303.5 ± 17.2

Figure 1. Location of Samples

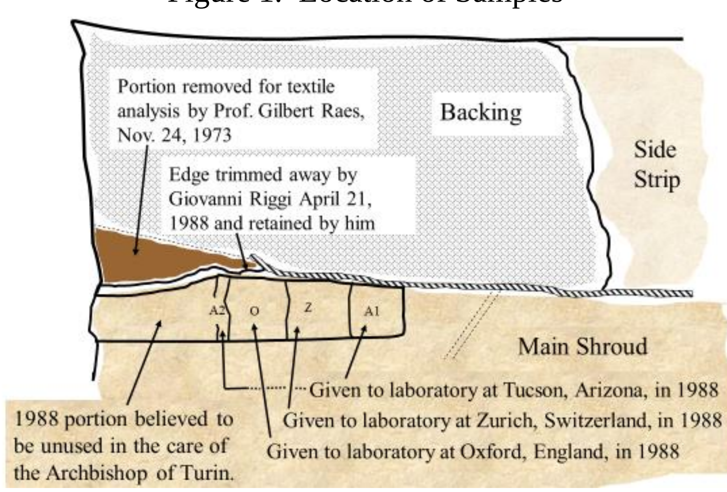


Figure 2. Dates are a Function of Sample Location

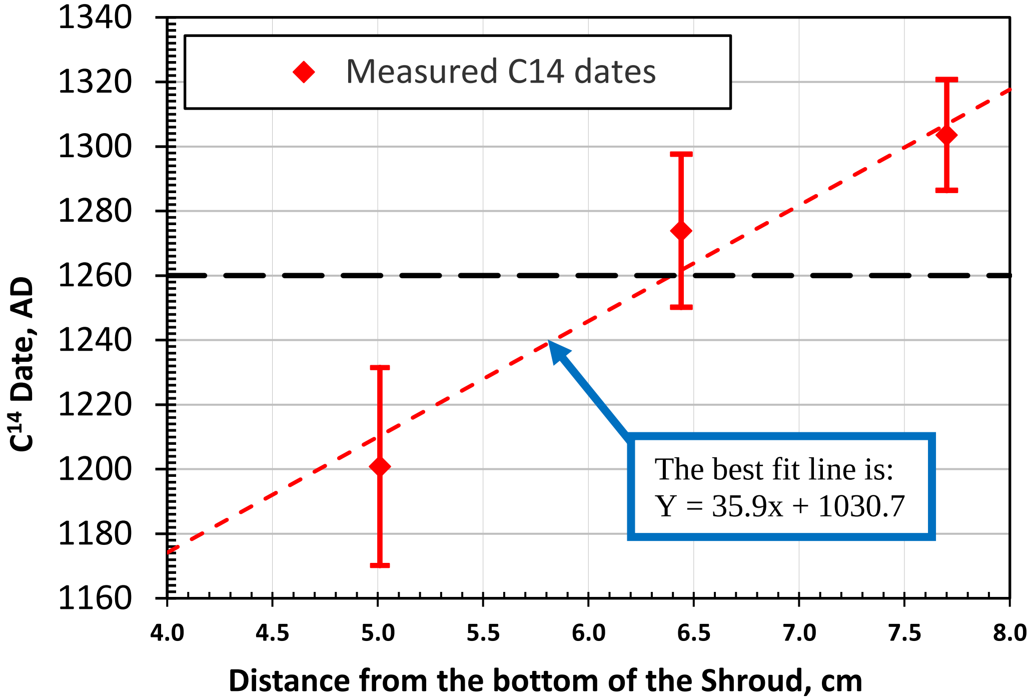
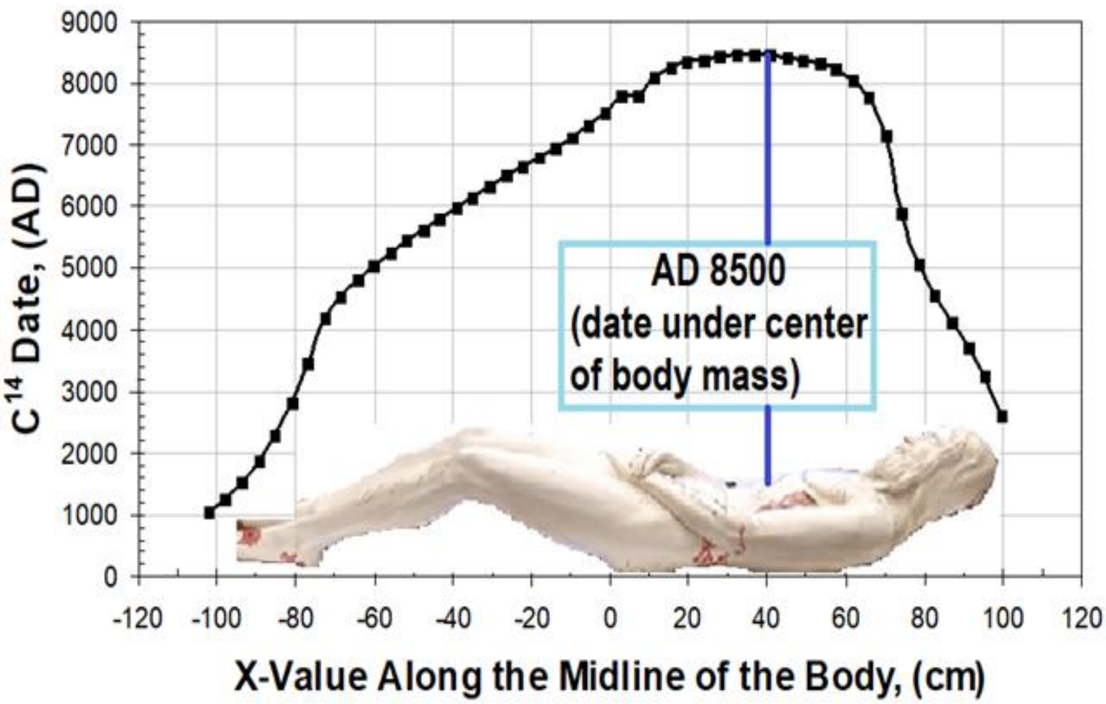


Figure 3. C^{14} Date in the Shroud Below the Body



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