Understanding the 1988 Carbon Dating of the Shroud

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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%.

1. Introduction

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.

Science should be an objective pursuit of the truth. However, science is done by human beings, and as such, the process can be affected by what might be called "the human element". This can include considerations of funding and deadlines on the schedule, desire for prestige, professional advancement, and money, as well as envy, bias, faulty assumptions, faulty reasoning, and ridicule. As a result, in our pursuit of the truth, scientists must be careful to follow the evidence where it leads, apart from personal motivations and presuppositions, either

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

religious or naturalistic. And people should always be open to review the process and conclusions of science, and full information should be made available for such a review.

2. Nontechnical Explanation

The carbon dating of the Shroud can be compared to the operation of an hourglass. An hourglass consists of an upper region and a lower region, both being fully enclosed in glass but with a small diameter tube connecting the two regions so that sand in the hourglass can run down from the upper region to the lower region. Assume that all the sand is initially in the lower region. When the hourglass is turned over, all the sand is then initially in the upper region and starts to flow from the upper region to the lower region through the connecting tube. The amount of time that has passed since the hourglass was turned over can be measured by the amount of sand in either region, with the amount of sand in the upper region decreasing and the amount of sand in the lower region increasing. Consider the upper region. The volume of sand in the upper region decreases as time increases, so the height of the sand in the upper region can be marked off on the glass in minutes, thus making a “clock” that gives the time since the hourglass was turned over. At least this is the normal expectation based on the assumption that the amount of sand in the hourglass remains constant. But what if, unknown to the observer, the upper region is not fully enclosed so that more sand can be added to the upper region. If at some point after the hourglass is turned over, additional sand is added to the upper region that the observer is not aware of, this additional sand would cause the time read from this “clock” to shift, i.e. the apparent time since the hourglass was turned over would be shorter than the true time.

This is similar to the carbon dating of the Shroud. The time since the flax plant was cut down, thus ending photosynthesis and the incorporation of new carbon-14 (C^{14}) into the plant, can be measured by the amount of C^{14} remaining in the plant as it gradually decays to N^{14}. But if, like sand being added to the top region in an hourglass, new C^{14} is added to the linen threads made from the flax, then this C^{14} “clock” is shifted to a more recent time reading. The addition of new C^{14} to the samples from the Shroud explains how a cloth from the first century can be carbon dated to 1260-1390 AD. According to the neutron absorption hypothesis, neutrons were evidently included in the burst of radiation from the body that caused the image. A small fraction of these neutrons would have been absorbed in the trace amount of N^{14} in the linen to form new C^{14} by the [N^{14} + neutron $\rightarrow$ C^{14} + proton] reaction. To shift the carbon date for the Shroud from 33 AD to 1260 AD requires absorption of neutrons to increase the C^{14} in the cloth by only 16%.

Several factors need further explanation. 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, the conclusion is that they are likely not consistent[3]. 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

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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.
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.

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%.

3. 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. This is typically caused by random changes in the measurements rather than in the item being measured, so these random errors are often called random measurement errors. These random measurement errors create an uncertainty in every measurement, but their effect can be carefully analyzed in the measurement process. The magnitude of the uncertainty of a measurement is specified as the one-sigma standard deviation of the variability of a measurement. This allows each measured value to have a measurement uncertainty associated with it. 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:

The measured value = the true value ± the random error + 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.

Another important concept in the analysis of measurements is homogeneous vs. heterogeneous. Homogeneous means "the same" whereas heterogeneous means "different". For a specific quantity being measured, samples are called homogeneous when the variation or distribution of their measured values are consistent with (can be explained by) their measurement uncertainties, whereas samples are called heterogeneous or non-homogeneous when the variation or distribution of their measured values exceed the variation allowed by their measurement

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[5] A. C. Lind, "Production of Radiocarbon by Neutron Radiation on Linen", available at https://www.testtheshroud.org/articles

uncertainties. For heterogeneous samples, the fact that the variation of the measured values exceeds that allowed by the measurement uncertainties implies that an unexpected factor has likely altered the measured values. This unexpected factor could have altered the measurement process, or it could have altered the samples that were measured. In this latter case, the measurements could obtain the correct values for the samples but result in measured values that are not the true value because the samples had been altered. This alteration of the measured value from the true value by an unexpected factor is the systematic error discussed above. Thus, if analysis of the measured values compared to the measurement uncertainties indicates that an unexpected factor likely caused a systematic error, then there are two options: determine how much the measured values have been changed from the true value, or recognize that the measured values are likely not the true value. Since it is usually not possible to determine how much the measured values have been altered from the true value, the only remaining option is to reject the conclusion of the measurement process, i.e. give it no credibility. This means that the crucial item in determining whether the conclusion of the measurement process should be accepted or rejected is whether the variation of the measured values is within the variation allowed by the measurement uncertainties. To summarize: 1) if the variation of the measured values is consistent with the measurement uncertainties, then the samples are called “homogeneous” and the measured values can be accepted as representative of the true value, but 2) if the variation of the measured values is not consistent with the measurement uncertainties, then the samples are called “heterogeneous” or “nonhomogeneous” and it should not be claimed that the measured values represent the true value.

Two things should be accomplished by a statistical analysis of the measurement data. The statistical analysis should:

- Average the measured values, possibly weighting them by the measurement uncertainties, to calculate the best estimate of the true value. This averaging should be done after outliers are identified and eliminated from consideration.
- Compare the variation or distribution of the measured values with the measurement uncertainties to determine whether a systematic error is likely to have altered the measured values. If it is likely, and if the magnitude of this error cannot be determined, as is usually the case, then it is not valid to use the average of the measured values as the best estimate of the true value.

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 ignore the evidence within the measured values that a systematic error, caused by an unexpected factor, had probably altered the measured values.

The latest statistical analysis by Walsh and Schwalbe[6] considers two factors that could have altered the measured values:

1. "An approximate linear dependence of the dates on the original sample locations suggests a variation in the carbon isotopic compositions."
2. "Differences in the cleaning protocols of the three laboratories may have given rise to differences in residual contamination."

It seems unlikely that the "cleaning protocols of the three laboratories" would have altered the measured dates for the Shroud because:

14. The various cleaning methods evidently did not alter the measured dates for the three pieces of other cloth run as standards along with the Shroud samples. This is based on comparison of the measured values with the measurement uncertainties for the three standards. This issue is addressed in paragraph 17 of Walsh and Schwalbe where "Sample #1" is the Shroud and "Samples #2, #3, and #4" are the standards that were run along with the Shroud samples:

    > "no statistical issues arise with Samples #2, #3, and #4, which indicates it likely that the cleaning procedures used were sufficient to substantially reduce any contamination that may have been present on the control samples. Whether they were sufficient for the level and types of contamination seen on Sample #1 is unclear."

2. According to Damon, the three laboratories used multiple types of cleaning that were progressively more severe, with measurements between the steps in the cleaning process. This should have indicated whether there was any issue with remaining contamination because the full array of cleaning methods should have removed any known contamination. This is recognized in paragraph 21 of Damon which says that from their data "it can be seen that, for each laboratory, there are no significant differences between the results obtained with the different cleaning procedures that each used."

3. It also seems unlikely that the "cleaning protocols of the three laboratories" would have altered the measured dates for the Shroud in a way that would have produced "an approximate linear dependence of the dates on the original sample locations on the Shroud" whereas this "linear dependence of the dates" is a prediction of the neutron absorption hypothesis (Figure 17). The probability that the neutron absorption hypothesis is true is increased because it is part of a larger radiation hypothesis that explains the characteristics of the image, the carbon dating, and the blood on the Shroud[7].

4. If it is assumed that the Shroud is from 1260 to 1390 AD and that the different cleaning methods used at the three laboratories caused "an approximate linear dependence of the dates on the original sample locations on the Shroud", then:

    A. Explanations must be given for how the 14 other date indicators discussed in section 7 can be consistent with a date of 1260-1390,

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[6] Bryan Walsh, 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.

[7] Robert A. Rucker, "Holistic Solution to the Mysteries of the Shroud of Turin", July 16, 2020

B. Explanations must be given for how the unique characteristics of the image and the blood on the Shroud were made in 1260-1390, and

C. An explanation must be given for why the Sudarium carbon dated to about 700 AD when its history and multiple characteristics are closely associated with the Shroud. For the neutron absorption hypothesis, a good explanation exists. The MCNP nuclear analysis code calculated that the Sudarium would carbon date to 700 AD, in agreement with the experimental value, if it were placed at a reasonable location on the side shelf in the tomb. The shift in the date for the Sudarium (30 to 700 AD) is less than for the Shroud (30 to 1260 AD) because it would have received less neutron irradiation at its larger distance from the body than the Shroud.

Thus, it is more likely that the measured dates have been altered by the first option above of "a variation in the carbon isotopic compositions" of the samples than the second option of "differences in the cleaning protocols of the three laboratories". According to the neutron absorption hypothesis, neutron absorption caused the above "variation in the carbon isotopic compositions" that caused a systematic error in the measurements. Absorption of neutrons in the trace amount of nitrogen-14 (N^{14}) in the threads would have created new C^{14} on the Shroud, including on the samples that were cut from the Shroud in 1988. If the C^{14}/C^{12} ratio in the samples was increased by only 16%, it would have shifted the carbon date from about 30 to 1260 AD. Thus, according to this hypothesis, the C^{14}/C^{12} ratio for the samples was correctly measured but the samples had their C^{14}/C^{12} ratios altered by neutron absorption.

4. Example 1: Distance Measured with a Ruler

Two examples of the above principles will be discussed. The first example involves the measurement of distance with a ruler. Assume you ask three friends to measure the distance between two points on a concrete sidewalk. You give each friend a 12-inch (12") ruler to measure the distance. You tell each friend how to do the measurement. He is to start by putting the 0" (zero inches) end of the ruler at one point on the sidewalk, then put his finger at the 12" end of the ruler, then move the ruler so the 0" end lines up with his finger, then repeat the process until he gets to the other point on the sidewalk. The process of trying to put the 0" end of the ruler exactly where the previous 12" end was located by using your finger creates a random error because each time it might be off in either a positive or negative direction. It is assumed for this example that previous testing indicated that if this process is done carefully, the uncertainty in the measurements due to this random error over the distance between the two points on the sidewalk is expected to be only 2 or 3 inches. When the measurements are completed, your three friends report their results to you: 95 feet 3 inches, 90 feet 1 inch, and 86 feet 2 inches (95'3", 90'1", and 86'2"). The problem is these three values are different, and the difference is much larger than would be expected just due to the expected random error of 2" to 3". The question is whether the significant difference between the three values should be ignored so that the three values can be averaged to 90 feet 6 inches. But if you don't know why the three values are different, how can you trust the average value (90'6") to be an accurate estimate of the true value? Without further investigation, the average value of 90'6" should be rejected because the variation in the values (95'3", 90'1", and 86'2") does not make sense.

With further investigation, the cause of this difference in the measurements might be discovered. In this example, the three rulers were not a standard 12 inches long, though each of them was marked off in 12 segments to give them the appearance of being the correct length. This created a systematic error in the measurements. If the three friends would have remeasured the distance many times with their same ruler, each of them would have obtained about the same values (95’3”, 90’1”, and 86’2”) because their rulers were the wrong lengths. We learn from this that repeating measurements does not reduce the error created by a systematic error. In this example, the true distance between the two points on the sidewalk was 100 feet, but the three rulers were too long by 5%, 11%, and 16%, which created the apparent average value of 90 feet 6 inches.

This example demonstrates the problem with the analysis of the 1988 carbon dating results. The dates from the three laboratories were different, and these differences were larger than should be expected from the measurement uncertainties created by random errors in the measurements. How could this happen? It is reasonable to conclude there was probably an unexpected factor beyond the measurement uncertainties that had changed the measured values of the samples. This unexpected factor would have produced a systematic error in the measurements. Since it was not known how much the measured values were changed by this unexpected factor, the only option should have been to reject use of the measured values to determine the true value. Instead, they assumed, without adequate justification, that the measurement uncertainties were underpredicted. This meant that the measurement uncertainties could be ignored, which allowed the values from the three laboratories to be averaged to produce the uncorrected date of 1260 AD. When corrected for the changing C^{14} concentration in the atmosphere, this date of 1260 became a range of 1260-1390 AD. But this corrected range of 1260-1390 should have no credibility because it was based on the uncorrected 1260 date, which should have had no credibility.

A measured value can be wrong either because there is a problem with the measurement process or because there is a problem with the items being measured. In example 1, the problem was with the measurement process due to the wrong lengths for the rulers. The problem was not in the item being measured, which was the distance between the two points on the concrete sidewalk. It is believed the problem with the 1988 carbon dating is that the samples were altered. To demonstrate this, in the next example, the samples are altered rather than there being a problem with the measurement process.

5. Example 2. Measurements of Uranium in a Tank

This second example involves a tank of unspecified liquid containing many types of compounds and many different elements including enriched uranium (U). Assume you work at the company where this tank is located and are assigned a very important task. You are told to determine how much uranium is in the tank to assure a nuclear criticality accident is not possible. Such an accident would result from too much enriched uranium in the tank. This could cause the number of fissions in uranium to rapidly increase, which would cause a large amount of energy to be released, which would cause water and other liquids in the tank to boil. The resulting pressure would cause the tank to rupture and spread radioactive material over a large area. People might be hurt or even killed. It would not cause a mushroom cloud as in the explosion of a nuclear weapon, but it might cost hundreds of millions or even billions of dollars to clean up, which might cause the company to go bankrupt and thousands of people to be laid off. On the other hand, if you tell your company that no more uranium should be placed into the tank, it could shut down operations, and if you told them the tank needs to be cleaned out, it would cost the company many millions of dollars to accomplish. You must do this assignment correctly.

The tank is 2.17 meters (about 7 feet 1 inch) high with a diameter of the same dimension. Your boss tells you to turn on the mixer in the tank and let it run for at least 24 hours to assure the materials in the tank are thoroughly mixed, i.e. homogeneous. He then tells you to take three samples from the tank. You are to send each of the samples to a different laboratory to measure the uranium concentration in micrograms of uranium per gram of sample. Three laboratories are used to assure the uranium concentration is measured correctly. You are then to analyze the results from these three laboratories to determine how much uranium is in the tank, and then recommend to the company's top management what should be done with the tank and its contents.

Each of the laboratories will take its sample and divide it into smaller volumes, called subsamples, so multiple measurements will be made on the sample sent to each laboratory. Each laboratory will then determine an average value from the measurements of their subsamples and report their average value back to you. Because each measured value on each subsample is expected to be slightly different due to normal random measurement uncertainties, the average value will be reported to you in terms of a distribution rather than a single value. Under normal conditions where variations in the measured values are only caused by random effects, the measurements should fall along the curve in Figure 1. This distribution is called a normal or Gaussian distribution, or a bell curve. It shows how much a measured value can change due to random variations in the measurements. The horizontal axis is divided into standard deviations, which is a technical term in statistical analysis. In simple terms, for a normal distribution and a large number of measurements, i.e. over about 30 measurements, a plus or minus variation of one standard deviation should include 68% of the measurements of a sample, if the variation in the measurements is only due to random effects. This is called a "one-sigma" range. As shown in Figure 1, for a large number of measurements, a two-sigma range will include 95% of the measurements, and a three-sigma range will include about 99.7% of the measurements. In our example, since each of the subsamples will be measured, each laboratory will report back to you the average of the values, which is the peak of the normal or Gaussian distribution, as well as the one-sigma value of the standard variation to characterize the width of the distribution. Both the maximum of the distribution and the width of the distribution are calculated from the measured values of the subsamples.

[Technical note: If there are not a large number of measurements, then it becomes more complex. In this situation, a Student's t-distribution is used to determine the number of standard deviations needed to include 68%, 95% or 99.7% of the measurements. Values for the Student's t-distribution are listed in the appendix of textbooks on statistical analysis, and involves a term called the degrees of freedom, which is equal to one less than the number of measurements. For example, if there are only five measurements, then there are four degrees of freedom. This value is used to look up the correct value in the table of the t-distribution. For only five measurements, this process results in a value of 2.776 standard deviations for 95% of the measurements in the possible population to be included, rather than 2.0 standard deviations if there are a large number of measurements, as discussed in the above paragraph.]

In this example of measuring uranium in a tank, Table 1 shows the values reported by the three laboratories, including the average or mean value of the uranium concentration and the one-sigma standard deviation to characterize the width of the distribution. Table 1 also includes the distance into the liquid at which each of the samples was taken. The question that must be resolved is what do the measured values mean and should the uranium concentrations reported by the three laboratories simply be averaged. If it is true that the mixer being on for 24 hours has produced a homogeneous mixture of materials in the tank, then, using the simplest methodology, the three measured values can be averaged to determine the uranium concentration in the tank:

(1200.8 + 1273.9 + 1303.5) / 3 = 1259.4 micro-gram (μg) of uranium per gram of material

A more correct but complex methodology would be to weight the three measured values by their one-sigma uncertainties (30.7, 23.7, and 17.2). This process increases the calculated average value to 1277.5 micro-gram (μg) of uranium per gram of material, but this value is only 1.4% higher than the simpler method.

This average concentration of uranium calculated to be in the tank could then be multiplied by the volume of the tank to obtain the total weight of uranium in the tank. It might be tempting to take this quick and easy approach, but this project is too important to the company to take the quick and easy approach. It must be done right.

With a closer look at the reported results, you notice the laboratories do not agree with each other. The average value reported by laboratory 3 minus the average value reported by laboratory 1 is 1303.5 – 1200.8 = 102.7. To determine whether this value is significant, you must determine the uncertainty in the 102.7 value. This is done by squaring the uncertainty reported by laboratory 3, adding it to the square of the uncertainty reported by laboratory 1, and then taking the square root:

The uncertainty of the 102.7 value is the square root of $(17.2^2 + 30.7^2) = 35.2$

Thus, the difference between the two laboratories is 102.7 ± 35.2, where 35.2 is the one-sigma uncertainty. But 102.7 / 35.2 = 2.9, so the difference (102.7) is 2.9 times the one-sigma uncertainty. The usual acceptance limit is less than or equal to 2.0 times the uncertainty. This means we should conclude there is a real difference between the values reported by the two laboratories, which means the samples sent to laboratories 1 and 3 were different in their uranium concentrations, which means there is something we don’t understand, at least at this point. Why don’t the laboratories agree with each other within the measurement uncertainties?

As indicated in Table 1, the samples were taken very close to the top of the tank, at 5.0, 6.4, and 7.7 cm into the 217 cm high tank. As we look at the measured uranium concentrations for samples 1, 2, and 3, the values increase with the depth of the sample location. This is plotted in Figure 2. The uranium concentration is on the y-axis and the distance of the sample location from the top of the tank is on the x-axis. The red circles plot the uranium concentration (μg of U per gram of sample) as a function of the distance from the top of the tank. It should be kept in mind that each red circle represents the peak value of a probability distribution as shown in Figure 1, with the distribution vertically oriented from each circle. Two lines are also plotted in Figure 2. The red dashed line is the best fit line (weighted least squares line) for the three data points. This line would be appropriate if the uranium concentration is a function of (depends on) the vertical location in the tank. The black dashed line would be appropriate if the uranium concentration were the same at every vertical location in the tank. The red dashed line would indicate there is much more uranium in the tank than would be indicated by the black dashed line.

To help us decide which line is more appropriate, the red or the black dashed line, we need to consider the width of the probability distribution for each data point. For this consideration, Figure 3 plots the one-sigma uncertainties (one-sigma standard deviation for each distribution) for each sample from the data in Table 1. The one-sigma uncertainty is represented by the vertical red bar extending through each circle. The red dashed line goes through the one-sigma bars of all three points, whereas the black dashed line only goes through the one-sigma uncertainty of one point. This shows that the red dashed line appears to be the better line through the data points, but the black dashed line may also be an acceptable line depending on the magnitude of the measurement uncertainties.

If the uncertainties for each sample were one third as large, as in Figure 4, then the uranium concentrations would very likely be a function of the vertical location in the tank, and the black dashed line for no vertical dependence would be very unlikely. But if the uncertainties for each sample were three times as large, as in Figure 5, then the uranium concentrations may or may not be a function of the vertical location in the tank, since either the red dashed line or the black dashed could be an acceptable fit to the data. The important point to remember is that the measurement uncertainties determine how the measured values ought to be interpreted, i.e. whether the uranium concentration is, or is not, a function of (depends on) the vertical location in the tank.

If we go back to consider the measured values and their reported uncertainties, as plotted in Figure 3, what conclusion should we make? We should conclude the data has a better fit to the red dashed line than to the black dashed line, so the uranium is probably a function of the vertical location in the tank. What would cause this? It is probably because the mixer was inadequate to produce a homogenous mixture of uranium in the tank. In this situation, we cannot simply average the three measured values from the top of the tank to get the average uranium concentration in the tank. The concentration of uranium is probably much higher in the bottom of the tank due to the uranium settling toward the bottom. If this is the case, then the measured values would have been affected by normal random measurement error but also by a systematic error caused by the uranium settling in the tank. This systematic error would have caused the variation of the measured values to be higher than would be expected due to random measurement errors alone. Thus, the presence of the systematic error could be detected by determining whether the variation of the measured values exceeds the variation allowed by the measurement uncertainties. If the variation in the measured values exceed that allowed by the measurement uncertainties, then the presence of a systematic error is needed to explain the variation of the measured values. If this systematic error had been ignored to allow the three measured values to be averaged, a wrong answer would have been obtained for the total amount of uranium in the tank, thus creating the possibility of a nuclear criticality accident. The conclusion is that the measured values from the three samples cannot be used to produce an accurate value for the weight of uranium in the tank. Many more samples would be needed for an accurate value, including samples taken all the way down to the bottom of the tank.

Example 2 for measurements of the uranium concentration in a tank was set up to simulate the 1988 carbon dating of the Shroud. The height of the tank was half the length of the Shroud, three samples were removed and sent to three laboratories in the example and in the carbon dating, and the distances of the sample locations from the top of the tank were the same as the distances of the Shroud samples from the bottom of the cloth.

The measured values and one-sigma uncertainties were also the same, except in example 2 the measured values were the uranium concentration in micrograms of uranium per gram of sample (µg/g) whereas in the 1988 carbon dating the results were the dates of the samples. A second difference is that in example 2, the failure of the mixer to produce a homogeneous mixture caused the samples to have uranium concentrations that were a function of their distance into the tank. This can be explained in terms of our current understanding of the laws of physics. But in the 1988 carbon dating, according to the neutron absorption hypothesis, the distribution of neutrons in the tomb caused the samples to have different C^{14}/C^{12} ratios that were a function of their distance from the bottom of the cloth. This is beyond or outside our current understanding of the laws of physics. There is no known mechanism by which a dead body can emit an intense burst of radiation to produce an image of itself on fabric, with enough neutrons included in this radiation to significantly alter the C^{14}/C^{12} ratio for samples as a function of their distance from the bottom of the cloth. Yet the presence of the image of a crucified man on the Shroud forces us to acknowledge that a unique event has happened that is outside or beyond our current understanding of the laws of physics. The relation between science and research on the Shroud is discussed elsewhere[8].

6. The 1988 Carbon Dating of the Shroud

To understand carbon dating, it is first necessary to understand some things about the carbon atom, as shown in Figure 6. Though all atoms of an element contain the same number of protons and electrons, they can contain different numbers of neutrons. These are called isotopes of the element. 99% of all carbon atoms are the C^{12} isotope, with 6 protons and 6 neutrons in the nucleus, thus making a total of 12 total protons + neutrons in the nucleus, which is why the superscript on C^{12} is a 12. 1% of all carbon atoms are the C^{13} isotope, with 6 protons and 7 neutrons in the nucleus. Only a very small fraction of carbon atoms is the C^{14} isotope with 6 protons and 8 neutrons in the nucleus of each atom. For most calculations, the fraction of C^{14} atoms in carbon at the surface of the earth is usually assumed to be 1.0×10^{-12} (one C^{14} atom per trillion carbon atoms). The C^{14} nucleus is not stable because its ratio of neutrons to protons ($8 / 6 = 1.33$) is higher than in C^{12} and C^{13} atoms. As a result, C^{14} atoms decay with approximately a 5730-year half-life. This means that for a sample of carbon, after 5730 years, only half of the initial number of C^{14} atoms would still exist, the rest having decayed. In another 5730 years, the number of C^{14} atoms would be reduced by half again, thus leaving only ¼th of the initial number of C^{14} atoms. A C^{14} atom decays by one of the neutrons emitting an electron thus changing into a proton ($C^{14} \rightarrow N^{14}$ + electron). This natural process of the decay of the C^{14} atoms in a material, such as the linen Shroud, is what allows the C^{14} dating methodology to work.

New C^{14} atoms are produced primarily in the upper atmosphere by cosmic rays from outer space but are also produced to a small extent in nuclear reactors and nuclear weapons testing. The new C^{14} atoms gradually diffuse throughout the atmosphere until a small fraction is taken in by growing plants during photosynthesis. While the flax plants used to make the Shroud were growing, the C^{14} already in the plants was decaying but this loss of C^{14} atoms was compensated by new C^{14} atoms being brought into the plant in the process of photosynthesis, so the C^{14}/C^{12} ratio in the plant would have been constant. This is shown in Figure 7 by the horizontal black line to the left of the zero age on the x-axis. The zero age in Figure 7 is assumed to be when the flax plant is cut down and made into the linen that was used to make the Shroud. The black line shows that the C^{14}/C^{12} ratio would have decreased in the flax fibers after the plant is cut down since after the death of the plant no new C^{14} was brought into the flax fibers

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[8] Robert A. Rucker, "Status of Research on the Shroud of Turin", July 16, 2020

by photosynthesis. The decay of the C^{14} atoms causes the C^{14}/C^{12} ratio to decrease with a 5730-year half-life. This allows the date of the linen to be determined by measurement of the C^{14}/C^{12} ratio, if it is true that the C^{14}/C^{12} ratio in the sample has only changed due to the decay of the C^{14} atoms.

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[9]. The first documented hypothesis to explain why the Shroud could have dated incorrectly was neutron absorption[10]. According to the neutron absorption hypothesis[11], 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 → 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.

The average uncorrected date obtained in the 1988 carbon dating of the Shroud was 1260. This date is 728 years before 1988, but all the dates reported in Damon were recalculated to be relative to 1950, which is the standard reference year used in the carbon dating industry. Thus, this 1260 AD date for the Shroud was reported as 690 YBP, where YBP is the Years Before Present, with the present defined as 1950. When the scientists measured the C^{14}/C^{12} ratio in the samples in 1988, they measured about 92% of the C^{14}/C^{12} ratio that would have been present when the flax plants were alive. Believing this ratio must be following the black decay curve in Figure 7 as time progressed, those doing the analysis of the carbon dating would have used the black decay curve to conclude the Shroud is about 690 years old (relative to 1950), as shown by the horizontal and vertical red dashed lines. As a result, they assigned an uncorrected date (not corrected for changes in C^{14} concentration in the atmosphere) of 1950 – 690 = 1260 AD to the Shroud. The validity of this approach is discussed below.

A strip of linen about 1.2 x 8 cm was cut from the cloth by Giovanni Riggi on April 21, 1988. The cutting of this strip is shown in Figure 8. This strip was used to produce samples that were sent to three laboratories in three different countries for carbon dating. The result of this process was a date range of 1260 to 1390 AD, with a 95% probability that the true date falls within this range. The consensus of Shroud researchers is this 1260-1390 date is faulty and

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[9] Robert A. Rucker, “Carbon Dating of the Shroud of Turin to 1260-1390 AD is not Explained by Normal Contamination”, Rev. 0, August 9, 2019

[10] 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.

[11] Robert A. Rucker, “The Carbon Dating Problem for the Shroud of Turin, Part 3: The Neutron Absorption Hypothesis”, July 7, 2018

should be rejected. How carbon dating could produce a date of 1260-1390 AD for a cloth that much other evidence indicates could not be from 1260-1390 is explained below.

This strip was cut from the bottom corner of the cloth next to the front image (Figure 9). It was cut off parallel to the seam that attaches the three inch wide side strip to the main Shroud cloth (Figure 10), and adjacent to one corner that had torn off or was possibly cut off at some point in the past, thus revealing only the backing cloth that was attached to the Shroud in 1534. Samples for three laboratories were cut from this 1.2 x 8 cm linen strip. Although there is some confusion regarding the process of cutting samples from this strip, it is generally believed that a sample, designated A1, was first cut from the right end of this linen strip. It was to be sent to the dating laboratory in Tucson, Arizona. Samples were then cut for dating laboratories in Zurich, Switzerland, and Oxford, England. These samples, designated "Z" and "O", were probably cut in sequence along the linen strip as shown in Figure 10. These cuts were intended to provide each of the laboratories with samples of at least 50 mg, but it was found that sample A1 was only about 40 mg whereas samples Z and O were slightly over 50 mg. As a result, it was decided to remove a second sample, designated A2, to also be sent to the laboratory in Tucson, Arizona. Sample A2 was probably cut from the remainder of the linen strip next to where sample O had been removed from the strip. When the laboratories received these samples, they cut subsamples from them for carbon dating, except the laboratory in Tucson did not cut subsamples from sample A2 but rather put it into a vault in Tucson where it is to this day.

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[1] in the British journal *Nature* in 1989. The title is "Radiocarbon Dating of the Shroud of Turin". Twenty-one authors are listed for this paper with the first author being P. E. Damon, so this paper is commonly called "Damon". The measured dates and uncertainties reported in Damon, et al., are summarized in Tables 1 and 2 of Rucker's statistical analysis[12].

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[13] 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*

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12. Robert A. Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 2: Statistical Analysis", August 7, 2018
13. 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.

published this paper without removing this concluding statement, thus ignoring the recommendation of Professor Bray.

The dates obtained by each laboratory are given in Tables 2 and 3. The three values obtained by the Oxford laboratory and the five values obtained by the Zurich laboratory are from Table 1 of Damon. The eight values obtained by the laboratory in Tucson, Arizona, are from Table 4 of Rucker[11], which are based on values from Remi Van Haelst[14]. Table 1 of the 2019 paper by Casabianca[12] lists two changes in the measurement uncertainties: 676 ± 40 instead of 676 ± 59, and 540 ± 37 instead of 540 ± 57, with the date given in years before present where present = 1950. Pairs of these eight values were somewhat "correlated" because each pair was run on the same day based on the same measurements of the standards. Because of this, those doing the statistical analysis decided to average the pairs of values, thus reducing the eight values down to the four values published in Damon without revealing there were originally eight measurements. This reduction from the eight original values to the four values in Damon eliminated the earliest and the most recent dates, thus reducing the range of the dates from 213 years to 110 years. This had the effect of bringing the range of the measured dates into better agreement with the measurement uncertainties, which is what determines whether an unexpected factor likely caused a systematic error that could alter the measured values by an unknown amount.

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

By the early 1980s, many were starting to recognize several lines of evidence that the Shroud was the authentic burial cloth of Jesus. Long-standing tradition claimed it to be authentic and historical research did not disprove this as a possibility. Many decades of research on the blood marks appeared to require that the blood came from the dead body of a man that was wrapped in the cloth. The STURP analysis in 1978 and the following years indicated the characteristics of the image were so unique they could not have been produced by an artist or forger. And some Shroud researchers were starting to suspect the best explanation for the image was radiation. But when samples were carbon dated in 1988, a 95% probability range of 1260 to 1390 was obtained, supposedly proving it could not be authentic.

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

- The characteristics of the image are so unique it seems impossible for the image to have been made in 1260-1390 because the technology 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[15].
- Two of the three laboratories that did the 1988 carbon dating obtained dates that were statistically different (difference = 102.7 ± 35.2) at the 2.9-sigma level.
- 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. This means that the dates are a function of (depend on) the location on the cloth. These experimental results agree

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[14] Remi Van Haelst, "Radiocarbon Dating the Shroud of Turin, A critical review of the Nature report (authored by Damon, et al.) with a complete unbiased statistical analysis", Oct. 2002, and "A critical review of the radiocarbon dating of the Shroud of Turin. ANOVA – a useful method to evaluate sets of high precision AMS radiocarbon measurements", June 1999

[15] Robert A. Rucker, "Summary of Scientific Research on the Shroud of Turin", Rev. 3, Nov. 14, 2018, Section 6C.

with the results of nuclear analysis computer calculations that were based on the neutron absorption hypothesis.

- An analysis of the data using a chi-squared statistical analysis technique 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. Thus, the credibility of the 1260-1390 date range should be rejected.

These objections are discussed more fully below.

The technology did not exist to make the image in 1260-1390. The STURP team that performed experiments on the Shroud in 1978 concluded that the image is not due to pigment, and has no carrier, no brush strokes, no capillarity (soaking up of a liquid), no stiffening of the fabric, and no cracking of the image along the fold lines. This means the image could not be due to paint, dye, stain, acid, or any organic or inorganic liquid. Lack of fluorescence under ultraviolet light proves the image was not made by a scorch from a hot object. The presence of 3D information in the image proves the image was not made by a photographic process. The extreme superficiality of the image is very difficult to explain but suggests it might have been caused by radiation which discolored the fibers by an electrical discharge from the tips of the fibers[16]. This superficiality includes: 1) only the top one or two layers of fibers in a thread are discolored, and 2) the discoloration in a fiber is only about 0.2 microns thick around the circumference of the fiber, which is about 15 microns in diameter, with the inside of the fiber not discolored. The very thin discolored layer in a fiber is caused by some of the carbon atoms in the cellulose having some of their single electron bonds changed into double electron bonds in a pattern to create the image of a naked crucified man. The technology to accomplish all these characteristics has never existed, even today.

The date indicators for the Shroud are discussed in section 4 of "Date of the Shroud of Turin" [17]. The following summary starts with the most recent date and then moves to earlier dates:

- The carbon dating gave a date of 1260 to 1390 AD.
- Coins were often rubbed onto the Shroud and jewelry such as rings would have often contacted the Shroud. This left micro-particles of gold and gold-alloy metals on the Shroud. The composition of these micro-particles has been analyzed and found to be consistent with the history of the composition of coins and jewelry during the Byzantine empire[18]. This probably indicates the Shroud existed before the fall of Constantinople in 1204 AD.
- The Hungarian Pray Codex or manuscript, which is dated to 1192-1195, contains a colored picture that includes the Shroud.
- Since the spinning wheel is believed to have been invented between 500 and 1000 AD in India, and the Shroud is made of hand-spun linen, it was probably made before the invention of the spinning wheel.

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16. Robert A. Rucker, "Image Formation on the Shroud of Turin", July 14, 2019.
17. Robert A. Rucker, "Date of the Shroud of Turin", July 16, 2020
18. Giulio Fanti, Claudio Furlan, "Do Gold Particles from the Shroud of Turin Indicate its Presence in the Middle East During the Byzantine Empire", *Journal of Cultural Heritage*, August 8, 2019, available on www.sciencedirect.com

- The size of the linen cloth is very close to 2 x 8 Assyrian cubits, with this unit of measurement being very ancient.
- Coins with the image of the face from the Shroud date back to about 675 AD.
- The historical link between the Shroud and the Sudarium of Oviedo, which is in Oviedo, Spain and is believed to be the face cloth of Jesus (John 20:7), would take the date for the Shroud back to at least 570 AD.
- Paintings based on the image from the Shroud date back to about 550 AD.
- Crucifixion was outlawed by Constantine possibly in 337 AD. Knowledge of the details of crucifixion would have gradually been lost after it was banned but the Shroud gets the details correct, in contrast to paintings from the 13th and 14th centuries.
- Ancient traditions indicate the burial cloth of Jesus was taken to Edessa, Turkey, in the first or second centuries.
- A strip of linen about eight cm (three inches) wide is attached along one side of the Shroud. This strip is attached by a seam with stitching that is unique. Similar stitching has only been found on a piece of cloth from Masada, which was destroyed in 73 to 74 AD. Thus, the stitching dates the Shroud to the first century.
- Tradition maintains the image is Jesus, which dates the cloth to about 30 to 33 AD.
- A possible coin over one eye has been identified as a Roman lepton minted by Pontius Pilate in 29 to 32 AD. This identification is uncertain due to the image enhancement used to obtain the image.
- Experimental testing of fibers from the Shroud regarding their reflectance and tensile strength, in comparison to linen of various known ages, indicates the Shroud is from about 90 AD ± 200 years[19].
- Natural background radiation causes radiation tracks of damage in flax fibers. Ray Rogers, who was a chemist at the Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico, claimed the Shroud has about the same density of radiation tracks in the fibers as the dead sea scrolls, which date to about 250 BC to 70 AD.

Figure 11 is a photo of the front and back of a Byzantine coin owned by the author. The many similarities between the face on the coin and the face on the Shroud indicate the face on the coin was copied from the face on the Shroud, proving the Shroud was in existence at the time this coin was minted. The face on the Shroud could not have been copied from the coin because the image of the face on the Shroud is not due to pigment, based on the STURP analysis. The identity of this person whose face is on the coin is indicated by the nimbus around his head and by the words in capital Greek on the back of the coin, “Jesus Christ King of Kings”. Jesus’ burial cloth was so well known and treasured in the Byzantine empire that they minted this coin with the image of the Shroud’s face rather than the image of the emperor’s face. According to coin experts, this coin is an authentic Byzantine coin minted under Constantine VIII from 1025 to 1028. Since the uncertainty in the uncorrected carbon date is 31 years (1260 ± 31), this coin is 7.5-sigma below the carbon date [(1260-1028)/31 = 7.5] so the measurement uncertainty cannot explain the difference between the 1260 and 1028 dates. The conclusion is this coin contradicts

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[19] Page 2 of Bryan Walsh, 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, quoted from G. Fanti, P. Malfi, F. Crosilla, “Mechanical and Olpto-Chemical Dating of the Turin Shroud”, 10.1051/matecconf/20153601001, with details in Giulio Fanti, Pierandrea Malfi, “The Shroud of Turin, First Century After Christ”, 2015, Pan Stanford Publishing, ISBN 978-981-4669-12-2

the carbon date of 1260-1390 for the Shroud. Coins containing this image go back to about 675 AD.

The Sudarium of Oviedo (Figure 12) is mentioned above. It is currently located in the Cathedral of San Salvador in Oviedo, Spain. According to tradition, it is Jesus' face cloth mentioned in John 20:7. Documents that arrived with it indicate that it left Jerusalem in 570 AD and came into Oviedo in 840 AD. It is a low-quality rectangular piece of linen cloth about 84 x 53 cm (33 x 21 inches) in dimension. It contains no image but contains blood in a pattern similar to the pattern of blood on the Shroud. It was carbon dated to about 700 AD, which is consistent with the neutron absorption hypothesis as discussed relative to Figure 20.

Figure 13 is a painting from St. Catherine's Monastery in the Sinai, and has been dated to about 550 AD. It is called the Christ Pantocrator. Due to the many similarities to the image on the Shroud, it should be concluded this painting is a copy from the image on the Shroud, so that the Shroud must have existed in 550 AD. The Shroud could not be a copy of the painting because the image on the Shroud is not caused by pigment, based on the STURP analysis.

Another objection to the 1988 carbon dating of the Shroud to 1260-1390 is that the laboratories don't agree with each other. Consider the results from Arizona and Oxford, whose samples were on either end of the sampled region. Taking data from Table 6 of Rucker's statistical analysis[11], 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 shouldn't be true since both samples were cut from the same cloth very close to one another. This suggests that an unexpected factor had altered the C^{14}/C^{12} ratios of the samples.

Figure 14 shows the average dates from each laboratory (Oxford on the left, Zurich in the middle, and Tucson on the right) and their measurement uncertainties. The y-axis is the carbon date calculated from the measured C^{14}/C^{12} ratio and the x-axis is the distance of the center of the sample from the bottom edge of the cloth, with the bottom edge of the cloth on the left side in Figures 9 and 10. The red diamond is the measured value, i.e. the date calculated from the measured C^{14}/C^{12} ratio of the sample, and the vertical bar through each measured date is the one-sigma standard deviation of the measurement, i.e. the measurement uncertainty of the date. The one sigma measurement uncertainty is a necessary consideration because each carbon date is not a single point but is a probability distribution caused by uncertainties in the measurements. As shown in Figure 1, this probability distribution is called a normal or Gaussian distribution. It is often also called a bell curve. Each date plotted on Figure 14 indicates the peak of the probability distribution and the vertical red bar through each date indicates the width of the probability distribution. The length of each red bar is the one-sigma width of the probability distribution, which means there is a good probability the true value falls within this range. The question is whether the constant value at 1260 AD (horizontal black dashed line at 1260 in Figure 14) assumed in Damon is an acceptable fit to the three measured dates with their associated uncertainties, or whether the red dashed line with a slope of about 36 years per centimeter (cm) ought to be used instead. It should be recognized that the black dashed line only goes through the one-sigma uncertainty of one date (Zurich) but the red dashed line goes through the one-sigma uncertainty of all three dates.

If the black dashed line is an acceptable fit to the three probability distributions, i.e. to the average dates with their associated uncertainties, then the measured dates are not necessarily a function of (depend on) the distance from the bottom of the cloth. This would be the case, for example, if the measurement uncertainties indicated by the vertical red bars were three times larger than shown in Figure 14. If this were the case, then the measured carbon date would not have to depend on the location on the Shroud, so the 1260 ± 31 AD uncorrected date could be a legitimate possibility. On the other hand, if the measurement uncertainties were one-third as large as shown in Figure 14, then it would be easily recognized that the horizontal black dashed line at 1260 would not be an appropriate fit to the data, so the red dashed line would be the better fit to the data. This would indicate that the measured carbon date depends on the distance from the bottom of the cloth. But if this is the case, then the slope to the data in Figure 14 was likely caused by an unexpected factor that caused a systematic error in the measurements. This could cause the measured values to differ from the true value by an unknown amount, so there would be no guarantee the measured dates represent the true date. If this were the case for the 1988 carbon dating, then the 1260 ± 31 AD carbon date should be rejected as the date for the Shroud. Thus, whether 1260 ± 31 AD should be accepted or rejected depends on the magnitude of the measurement uncertainties.

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[20], if the analysis is performed 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

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[20] 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”.

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 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.

8. Is the Data in Damon Heterogeneous?

If the Shroud is a normal piece of cloth, with nothing unusual ever happening to it, then it is reasonable to assume that every location on the cloth should carbon date to the same value. This assumption is the black dashed line in Figure 14. This is also the assumption, i.e. the null hypothesis, in the chi-squared statistical analysis technique. This analysis technique determines whether the variation of the measured dates is adequately explained by the random measurement errors. If it is not, it implies that a systematic error had likely affected the measured dates to a significant extent. When a chi-squared statistical analysis is applied to the measured dates and uncertainties obtained for the Shroud samples in 1988, it indicates that the probability of obtaining a variation in the measured dates at least as large as was obtained is only 1.4% (Table 6 in Rucker[11] and Table 4 in Walsh & Schwalbe[5]). In statistical analysis terminology, this value is called the significance level ($p = 0.014$). This calculated significance level of 1.4% 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. For this case where the significance level is below the 5.0% limit, to explain the variation of the measured dates requires there to have likely been an unexpected factor that altered the measured dates from the true date for the Shroud. This difference is the systematic error. This unexpected factor could have significantly altered the measured dates from the true dates, which is why the uncorrected date for the Shroud of 1260 ± 31 should be rejected. And if the 1260 ± 31 date should be rejected, then the range of 1260-1390 should also be rejected because it was obtained starting from the 1260 ± 31 date.

As discussed in section 3 regarding samples being homogeneous (essentially the same) or heterogeneous (essentially different) in the quantity being measured:

- If the variation of the measured values does not exceed the variation allowed by the random measurement uncertainties, i.e. if the calculated significance level is equal to or above the 5.0% limit, then the samples are called “homogeneous” and the measured values can be accepted as representative of the true value, but
- If the variation of the measured values exceeds the variation allowed by the measurement uncertainties, i.e. if the calculated significance level is less than the 5.0% limit, then the samples are called “heterogeneous” or “nonhomogeneous” and it should not be claimed that the measured values represent the true value.

Many statistical analyses[21] of the 1988 carbon dates have calculated the significance level to be less than the 5.0% limit and have thus concluded that the dates are "heterogeneous" or "nonhomogeneous", which means that the 1260-1390 date for the Shroud should be rejected, i.e. given no credibility. The two most recent journal articles on the statistical analysis of the data in Damon are examples of this. Casabianca[12] concluded that "the presence of serious incongruities among the raw measurements … strongly suggest that homogeneity is lacking in the data." Bryan Walsh and Larry Schwalbe[15] concluded "We find the Shroud data to be heterogeneous."

It has long been recognized by specialists in statistical analysis that the data published in Damon is heterogeneous so that the 1260-1390 date for the Shroud should be rejected. As previously mentioned, Professor Bray, who was one of the peer reviewers for the Damon paper, required that Damon's conclusion ("The results provide conclusive evidence that the linen of the Shroud of Turin is mediaeval.") be deleted[12]. Unfortunately, this requirement was rejected, and the above conclusion was included when Damon was published in *Nature*. Another example is the "Paris Scientific Symposium on the Shroud of Turin" that was held in Paris on September 7 and 8 of 1989, only seven months after Damon was published. Professional statisticians, including Bourcier de Carbon who was the symposium moderator, reported to the leadership of this symposium that they "had expressed strong reserves about the manner in which the results obtained by the three laboratories had been statistically analyzed" because a chi-squared analysis of the data in Damon led them to conclude that "the samples are not homogeneous in radiocarbon date" so that the "statistical estimates are devoid of value" [22].

The proposed explanation for the 1988 carbon date of 1260 ± 31 AD is the neutron absorption hypothesis[10], first proposed in 1989 by Dr. Thomas Phillips[9] then at the Harvard Laboratory. The modern version of this hypothesis[10] is the following. If neutrons were included in a burst of radiation from the body that caused the image, then a small fraction of the neutrons would have been absorbed in the trace amount of N^{14} in the cloth to produce new C^{14} atoms primarily by the [N^{14} + neutron $\rightarrow$ C^{14} + proton] reaction. This could shift the carbon date

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21. Robert A. Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 2: Statistical Analysis", August 7, 2018, Remi Van Haelst, "Radiocarbon Dating the Shroud, A Critical Statistical Analysis", 1997, "Radiocarbon Dating the Shroud of Turin, The Nature Report", June, 1999, "Radiocarbon Dating the Shroud of Turin, A critical review of the Nature report (authored by Damon, et al.) with a complete unbiased statistical analysis", Oct. 2002, "A critical review of the radiocarbon dating of the Shroud of Turin. ANOVA – a useful method to evaluate sets of high precision AMS radiocarbon measurements", June 1999, "The Validity of the 1988 Shroud Sampling", April 2001, Collegamento pro Sindone Internet, Bryan J. Walsh, "The 1988 Shroud of Turin Radiocarbon Tests Reconsidered, Part 2", 1999, "The 1988 Shroud of Turin Radiocarbon Tests Reconsidered, Part 1", 1999, Marco Riani, A. C. Atkinson, Giulio Fanti, Fabio Crosilla, "Carbon Dating of the Shroud of Turin: Partially Labelled Regressors and the Design of Experiments", May 4, 2010, "Regression Analysis with Partially Labelled Regressors: Carbon Dating of the Shroud of Turin", Journal of Statistical Computation and Simulation, 23:551-561, 2013, 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, 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.
22. "Declaration of the Scientific Committee of the Paris International Scientific Symposium", unanimously signed September 29, 1989 by the 10-member Scientific Committee for *The Paris Scientific Symposium on the Shroud of Turin* held in Paris September 7 to 8, 1989, Available in Shroud Spectrum International, Issue 32/33, September/December 1989, pages 33 to 35, https://www.shroud.com/pdfs/ssi3233part5.pdf

forward by thousands of years depending on the location on the cloth, thus explaining the 1988 carbon dating.

Those who carbon dated the samples in 1988 evidently assumed there was no reason to believe there could be anything unusual about this linen cloth, so the black dashed line in Figure 15 could be used for dating. When they measured that the C^{14}/C^{12} ratio had decreased from 100% of its value for a living plant to only 92%, they would have moved horizontally from 92% on the y-axis over to the black line in Figure 15 to conclude that the flax was cut down in about 1260 AD. But according to the neutron absorption hypothesis, neutron absorption increased the C^{14} at the sample location by about 16% in a small fraction of a second, as shown by the vertical section of the red line in Figure 15. As time passed, this red line would then have decreased with the usual 5730-year half-life as shown on the graph. According to the neutron absorption hypothesis, when they measured their 92% value, they should have moved horizontally over to the red line, which would have given them a date of about 30 AD, as shown in Figure 15. Thus, the root cause of their dating the Shroud to 1260 AD resulted from assuming nothing unusual had happened to the Shroud so that no unexpected factor could have altered the measured values. But if the Shroud had wrapped Jesus' body and if a unique event that was outside or beyond our current understanding of the laws of physics had happened to Jesus' body, then we would have no idea how the Shroud would have been altered by such an event. Thus, this is an example of how an assumption (the Shroud is an ordinary piece of linen) can predetermine the conclusion (the Shroud is not the burial cloth of Jesus).

9. 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. Regarding a type 2 error, the C^{14}/C^{12} ratio of the samples can occasionally be altered by processes other than decay of C^{14}. This is the explanation for the many examples in the literature where the carbon dates are very likely incorrect. These examples of bad results are probably not due to an error in the measurement of the C^{14}/C^{12} ratio in the samples but are probably due to something changing the C^{14}/C^{12} ratio in the sample other than decay of C^{14}. Thus, in these examples in the literature, it is probably not a measurement problem but is a sample problem. It is important to make this distinction when discussing the accuracy of carbon dating.

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. And if an unexpected factor altered the C^{14}/C^{12} ratios in the Shroud samples, then perhaps it also altered the C^{14}/C^{12} ratios in the samples from the Sudarium of Oviedo to produce a carbon date of 700 AD for an object that historically is probably the face cloth of Jesus (John 20:7). 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[23].
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[10], assuming that the Sudarium was placed at a reasonable location on the side bench in the tomb.

10. Nuclear Analysis Computer Calculations

If Jesus' body disappeared from the tomb as claimed in the New Testament, this disappearance was probably due to his body transitioning into an alternate dimensionality[24]. In this scenario, it is reasonable to assume that the process that caused this transition may have also caused the release of radiation. This radiation could explain how the image was encoded onto the Shroud by charged particles and/or electromagnetic radiation, how the carbon date was shifted from about 30 AD to 1260 AD by neutron capture, and explain the characteristics of the

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[23] Table 11 and 12 of Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 2: Statistical Analysis".

[24] Robert A. Rucker, "The Disappearance of Jesus' Body Part 2: Physical Considerations", Oct. 11, 2016

blood that is now on the Shroud[4]. Since the entire body made this transition, it is reasonable to assume that this radiation was homogeneously (uniformly) emitted from within the body. With this as a basis, computer calculations can be performed to model the emission of the radiation within the body.

The assumption that neutrons were included in the burst of radiation that formed the image is called the neutron absorption hypothesis[10]. Based on this hypothesis, nuclear analysis computer calculations were performed to understand the 1988 carbon dating of the Shroud. These calculations used the MCNP (Monte Carlo N-Particle) nuclear analysis software that was developed over many decades at the Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico. The accuracy of this computer code has been verified and validated for use on United States NRC (Nuclear Regulatory Commission) and DOD (Department of Defense) projects by comparison of thousands of nuclear experiments with MCNP calculations.

In these computer calculations, MCNP 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 (Figure 16) as it would have been constructed in first-century Jerusalem. Calculations with this model assumed neutrons were included in an extremely brief intense burst of radiation that is believed to have been emitted in the body, with this radiation forming the image[4]. 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 17. 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 14. This agreement between the calculated slope (Figure 17.) and the slope experimentally determined by the three laboratories (Figure 14) supports the validity of the neutron absorption hypothesis. The carbon date also slopes in the direction perpendicular to the direction in Figure 17. This is discussed on pages 18 and 19 of Rucker's statistical analysis[11].

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. This is shown in Figure 18 by the vertical line rising to different values for the three samples, based upon the measured dates: a 15.20% increase in the C^{14} content for the sample sent to the laboratory in Oxford, a 16.24%

increase for the sample sent to Zurich, and a 16.66% increase for sample A1 tested by Arizona. 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. According to the neutron absorption hypothesis, these neutrons changed the average carbon date of the 1988 sample locations from about 30 AD to 1260 AD.

Neutrons from this hypothesized burst of radiation emitted within the body would have scattered within and from the limestone walls of the tomb, resulting in neutrons throughout the tomb. The number of neutrons at any specific location in the tomb would have depended on the distance from the source of the neutrons, which was the body, with the number of neutrons decreasing as distance from the body increases. This distribution of neutrons in the tomb would have caused a distribution in how much the carbon date was shifted for linen anywhere in the tomb. Data from the MCNP calculations was used to determine the carbon dates for linen that would have been exposed to neutrons at various locations in the tomb. The regions for which the carbon dates were calculated are shown in Figure 19. This figure shows a top view of the left side bench, the back bench, and the right-side bench in the tomb. The body was modelled in MCNP on the back bench with the head facing to the right. The linen Shroud that covered the body on the back bench was modeled in a rectangle around the body, with the Shroud in thin flat regions below the body, to the right of the body, above the body, and to the left of the body. The MCNP calculations were used to calculate the carbon dates for the linen in these regions: on the back bench under the body, on the side of the rectangle next to the wall, on the top of the rectangle above the body, and on the side of the rectangle away from the wall. The sides of this rectangular cloth are unfolded in Figure 19 to allow display of the calculated results on the "Shroud below the body", the "Shroud to the right of the body", the "Shroud above the body", and the "Shroud to the left of the body". Carbon dates were also determined for linen on the left and right benches.

The carbon dates calculated by MCNP are shown in Figure 20 based on the patten in Figure 19. Of most significance is the yellow highlighted area on the right bench, which shows the region where a calculated carbon date of 700 ± 50 AD is obtained on the side bench according to the neutron absorption hypothesis. When the person doing the burial removed the face/head cloth from the body prior to covering the top of the body with the Shroud, if he was right-handed, the most likely place for him to have dropped it is at this location, beside his body, on the right-side bench. The Sudarium of Oviedo is believed by many to be the face cloth of Jesus. It has been carbon dated to about 700 AD, in excellent agreement with the date distribution calculated in MCNP, as shown in Figure 20. The shift in the carbon date for the Sudarium (700 – 30 = 670 years) is less than the shift in the carbon date for the Shroud (1260 – 30 = 1230 years) because the Sudarium was further from the neutron source in the tomb, which according to the neutron absorption hypothesis, was the body.

11. 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 14) 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[25].
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 hypothesis that the image on the Shroud was produced by an artist or forger in 1260-1390 could be consistent with #1, and with #2 and possibly #3 if these could be caused by different cleaning methods of the three laboratories, and with #4 if it is assumed the Sudarium of Oviedo was also produced by an artist or forger, but the unique characteristics of the image and the blood would still have to be explained. 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[26].

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. The MCNP nuclear analysis computer calculations predict different carbon dates for every location on the Shroud based on the calculated neutron distribution in the tomb. These predicted dates, and the change in the C^{14}/C^{12} ratio are shown in Figure 21. A positive change in the C^{14}/C^{12} ratio, when utilized in the normal equations for carbon dating, produce a predicted date to the future. The production of long half-life isotopes in the Shroud and limestone in the tomb have not yet been calculated.

As shown in Figure 21, the neutron absorption hypothesis predicts dates of about 4500 AD at the elbow next to the back wall of the tomb and about 3500 AD at the elbow on the side of the body away from the back wall of the tomb. The difference in the date (4500 vs 3500) is due to neutrons reflected from the back wall of the tomb, thus allowing them a second chance to be absorbed in the linen to create new C^{14}, which would shift the carbon date further forward. These two areas near the elbows could be carbon dated without removing any new material from

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[25] Table 6 of Rucker, "The Carbon Dating Problem for the Shroud of Turin, Part 2: Statistical Analysis".

[26] 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

the Shroud. This is because the patches on the Shroud were removed in 2002 when the Shroud was refurbished. Fully carbonized material found under these patches was broken off from the Shroud and placed into small sample jars which were placed into a vault in Turin. Though the fully carbonized linen from near the elbows is still available in these sample jars for carbon dating, it is uncertain that the location of this material in the sample jars has been adequately recorded.

A second way to test the neutron absorption hypothesis is to test materials from the prospective tombs for long half-life isotopes such as calcium-41, chlorine-36, and possibly other isotopes, though measurement sensitivity and uncertainties may prevent the accurate measurement of many isotopes. If neutrons were emitted from the body as it lay in the tomb, as predicted in the neutron absorption hypothesis, these neutrons would have been absorbed in the elements in the tomb. For example, calcium is a common element in limestone. If calcium-40 absorbs a neutron, it becomes calcium-41 (Ca^{41}) which is not naturally occurring and has a half-life of 99,400 years, so it would still be present today. If Ca^{41} is detected in limestone from a tomb, it would prove neutrons were emitted in the tomb. This would be difficult to explain except by the neutron absorption hypothesis. Nuclear analysis computer calculations will be used to calculate the distribution of these long half-life isotopes in the tomb.

12. 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:

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 17) 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 (significance level = 0.014, Table 6 in Rucker[11] and Table 4 in Walsh & Schwalbe[5]). 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[12] and by Walsh & Schwalbe[5] 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[10], 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 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. Measured Uranium Concentrations in Example 2

Sample	**U (µg/g)**	**One Sigma Uncertainty**	**Depth into the Tank**	
			cm	**inches**
1	1200.8	30.7	5.0	2.0
2	1273.9	23.7	6.4	2.5
3	1303.5	17.2	7.7	3.0

Table 2. Results for the 1988 Carbon Dating of the Shroud

Sample	**Date (AD)**	**One Sigma Uncertainty**	**Distance from the Bottom of the Cloth**	
			cm	**inches**
1	1200.8	30.7	5.0	2.0
2	1273.9	23.7	6.4	2.5
3	1303.5	17.2	7.7	3.0

Table 3. 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 ± 59
6			1410 ± 57
7			1249 ± 47
8			1249 ± 47
Weighted Mean	1200.8 ± 30.7	1273.9 ± 23.7	1303.5 ± 17.2

Figure 1. Normal or Gaussian Distribution

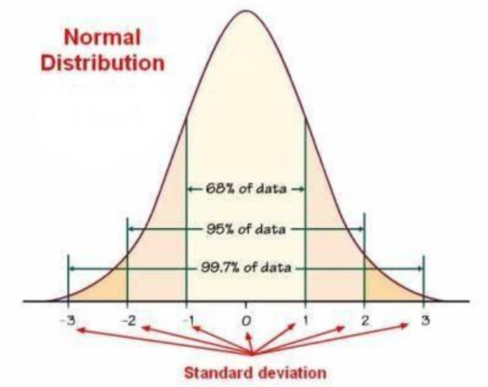


Figure 2. Measurements for Uranium in a Tank

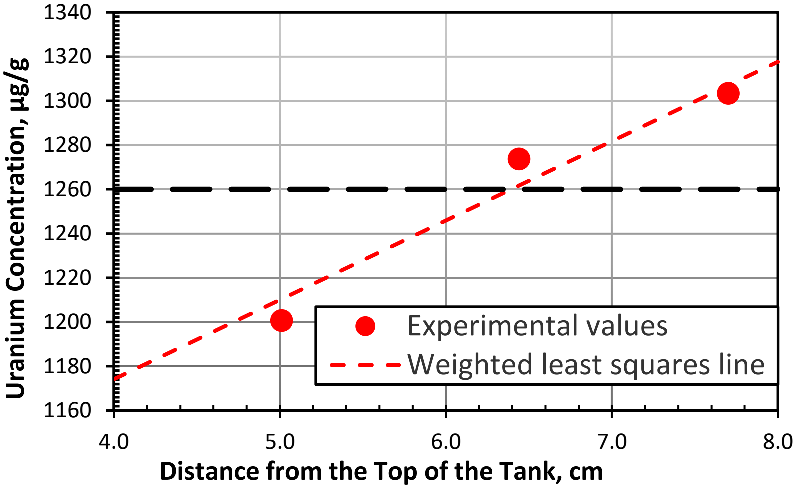


Figure 3. Measured Values with Measurement Uncertainties

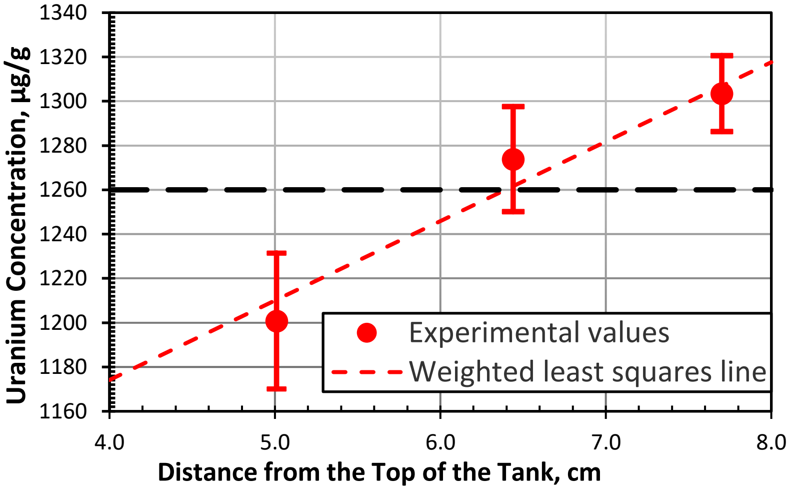


Figure 4. Measured Values with (1/3) x Measurement Uncertainties

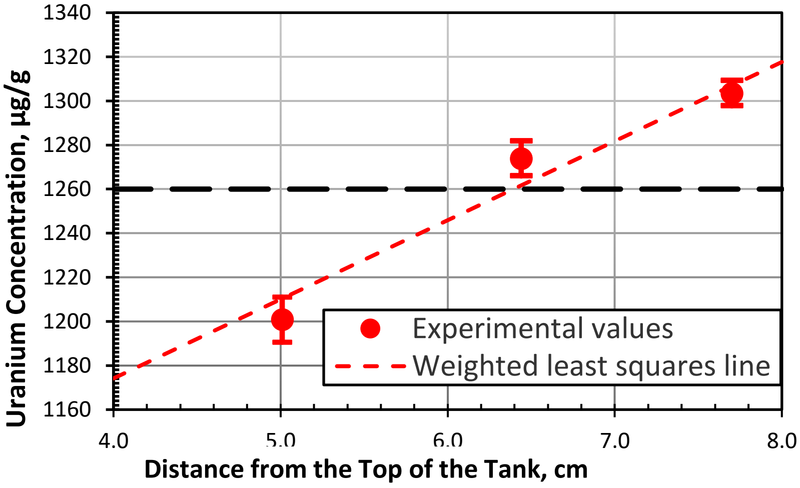


Figure 5. Measured Values with 3 x Measurement Uncertainties

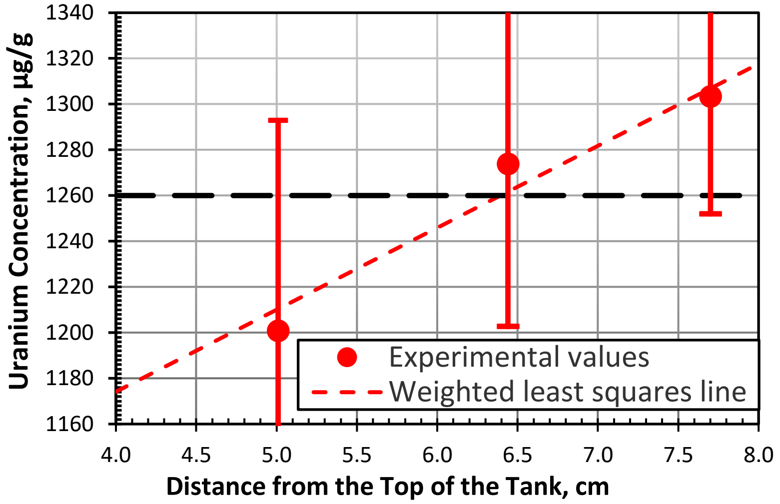
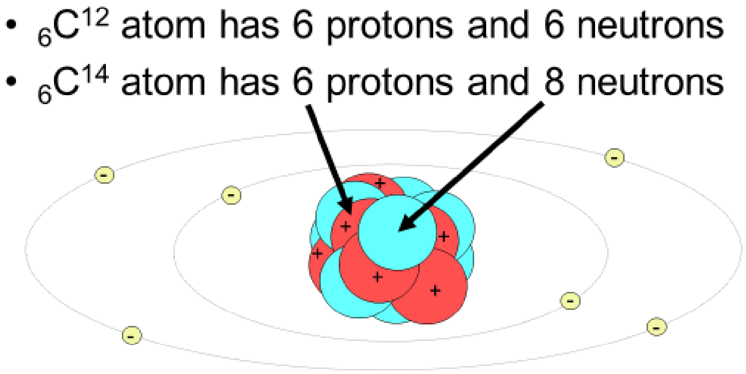


Figure 6. What is a Neutron?



- $_6C^{12}$ atom has 6 protons and 6 neutrons
- $_6C^{14}$ atom has 6 protons and 8 neutrons

Figure 7. Normal Decay of C^{14}

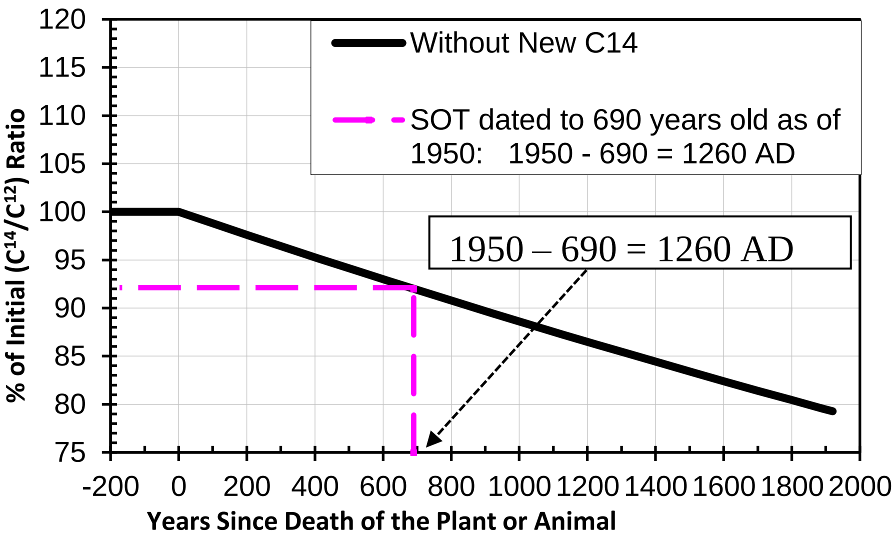


Figure 8. Cutting of the Samples in 1988

Figure 9. Locations of Samples for C^{14} Dating

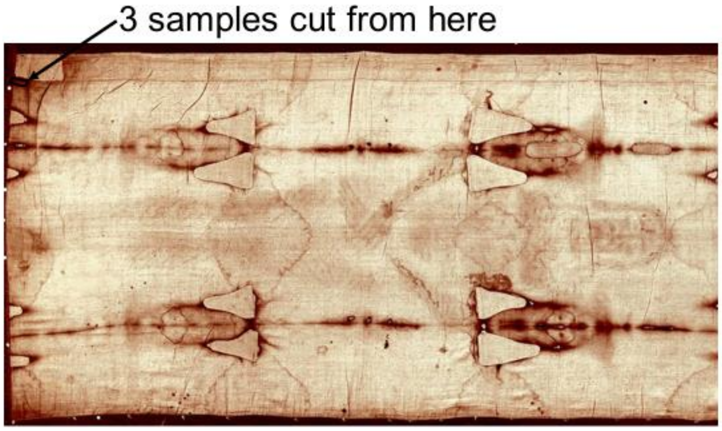


Figure 10. Location of Samples

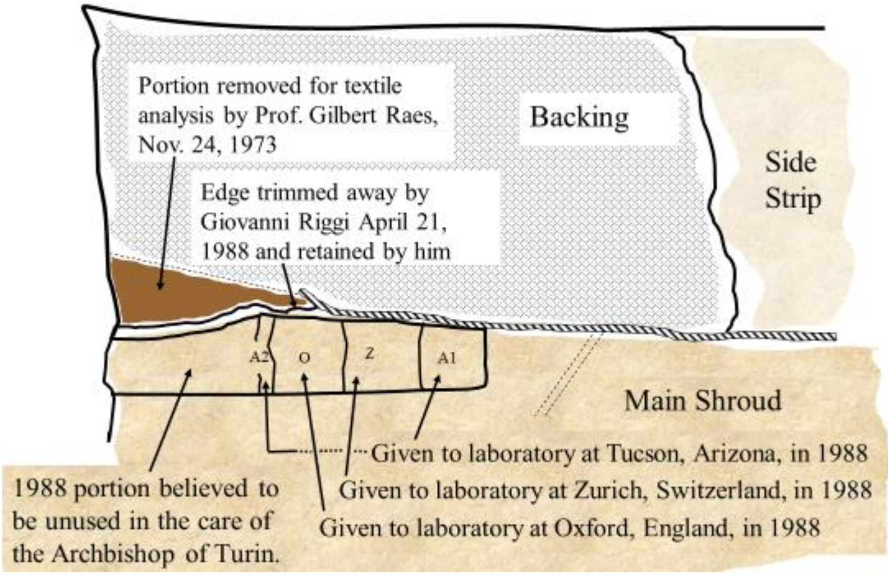


Figure 11. Byzantine Coin Dated to 1192-1195 AD

Figure 12. Sudarium of Oviedo, 84 x 53 cm (33 x 21 inches)

Figure 13. Christ Pantocrater, About 550 AD

Figure 14. Dates are a Function of Sample Location

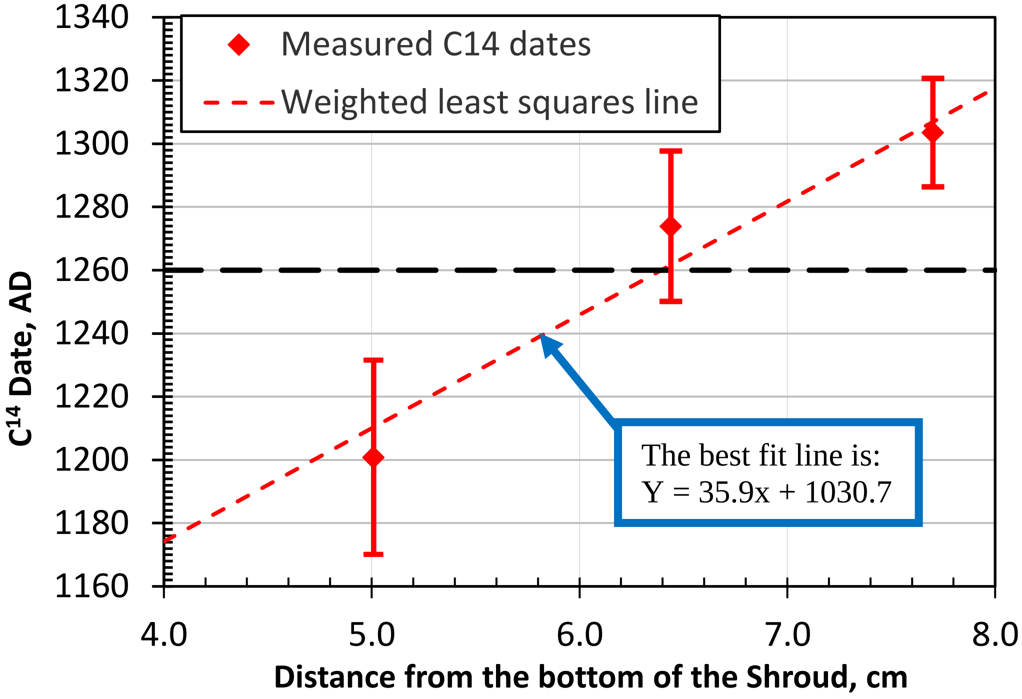


Figure 15. Effect of Producing New C^{14}

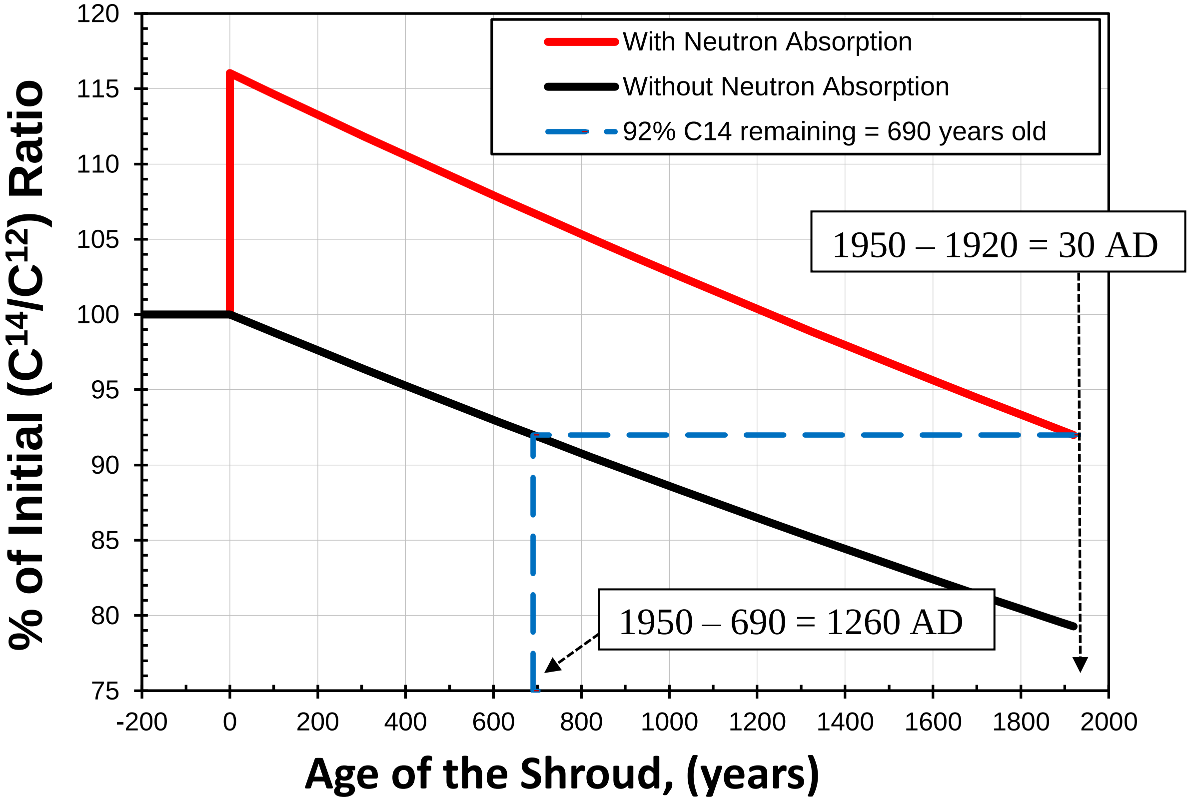


Figure 16. 3D View Inside the Tomb

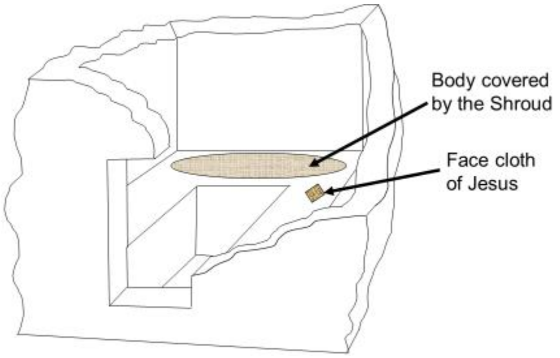


Figure 17. C^{14} Date in the Shroud Below the Body

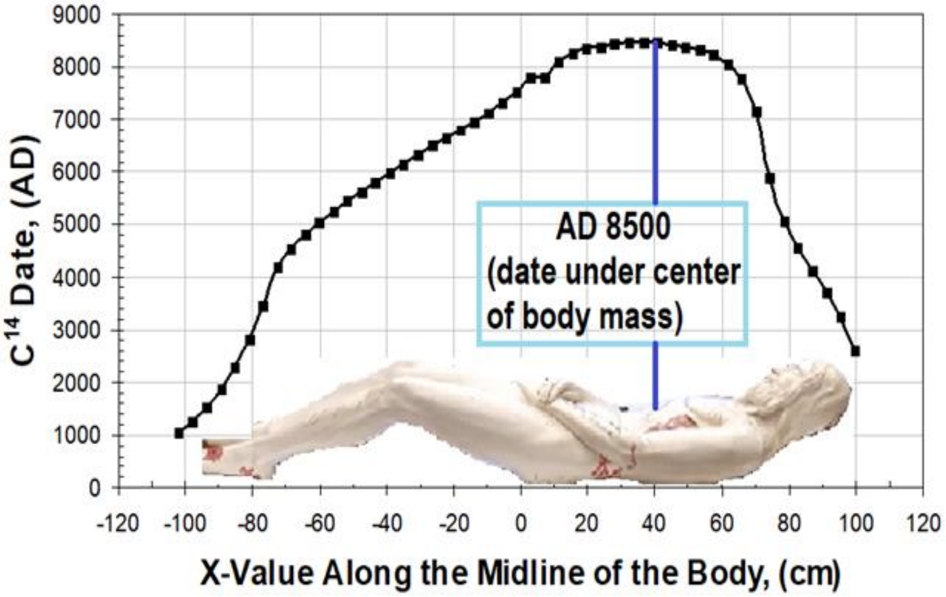


Figure 18. Different Increases in C^{14} for Each Sample Cause Different Dates

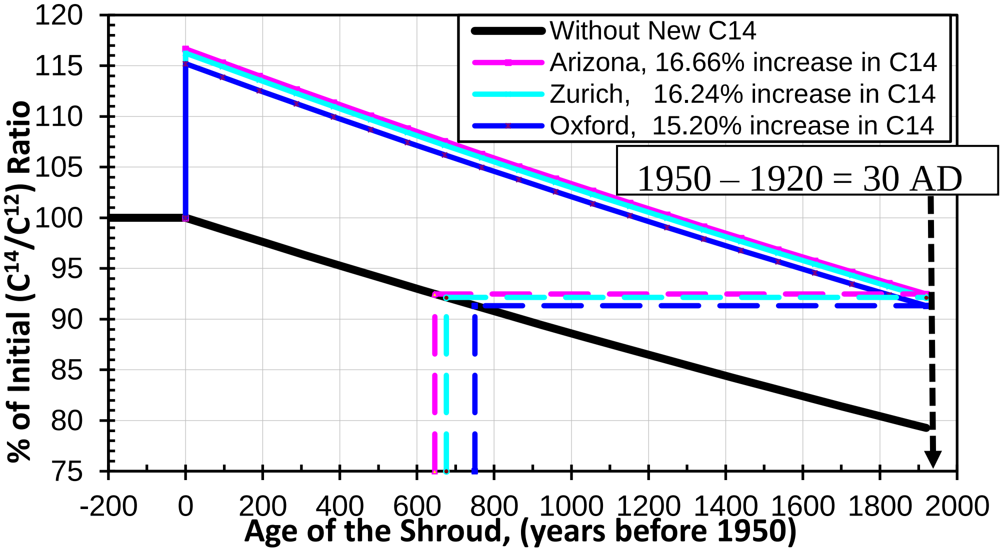


Figure 19. Large Tally Regions in the Tomb

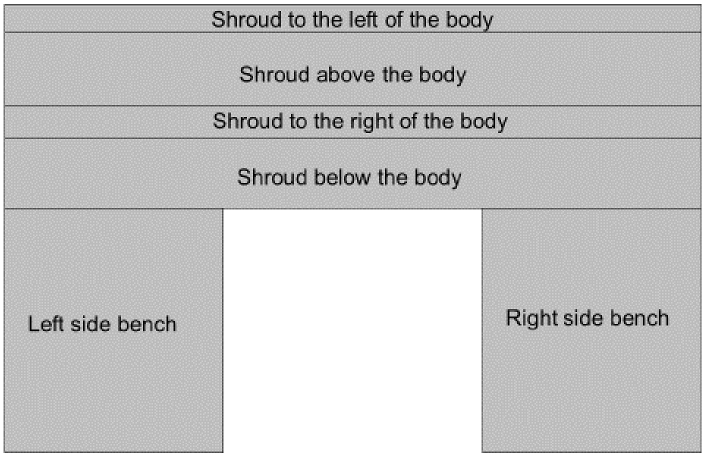
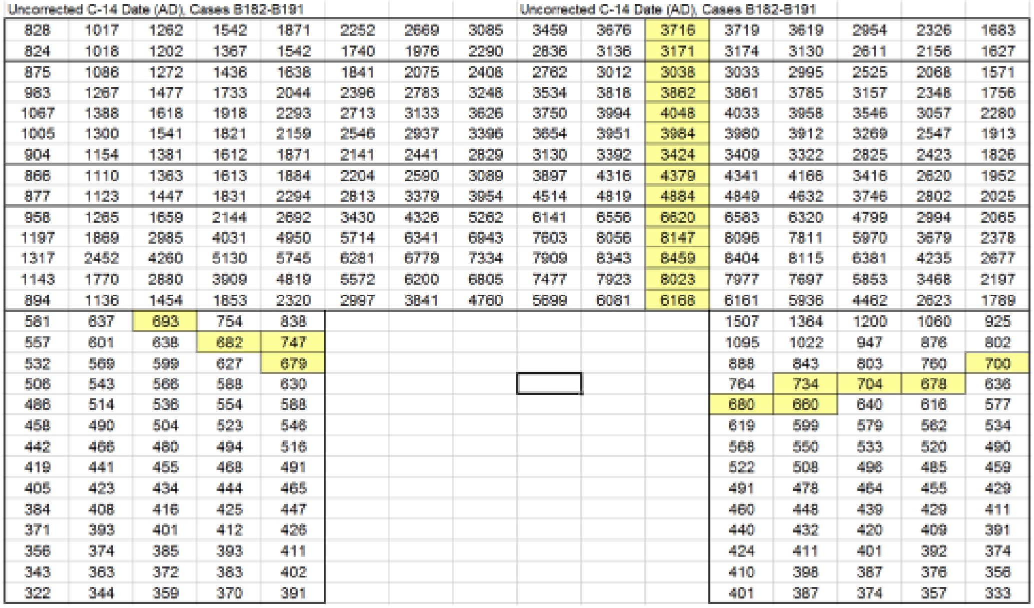


Figure 20. Predicted C^{14} Dates (AD)



Uncorrected C-14 Date (AD), Cases B182-B191								Uncorrected C-14 Date (AD), Cases B182-B191							
828	1017	1262	1542	1871	2252	2669	3085	3459	3676	3716	3719	3619	2954	2326	1683
824	1018	1202	1367	1542	1740	1976	2290	2836	3136	3171	3174	3130	2611	2156	1627
875	1086	1272	1436	1638	1841	2075	2408	2762	3012	3038	3033	2995	2525	2068	1571
983	1267	1477	1733	2044	2396	2783	3248	3534	3818	3862	3861	3785	3157	2348	1756
1067	1388	1618	1918	2293	2713	3133	3626	3750	3994	4048	4033	3958	3546	3057	2280
1005	1300	1541	1821	2159	2546	2937	3396	3654	3951	3984	3980	3912	3269	2547	1913
904	1154	1381	1612	1871	2141	2441	2829	3130	3392	3424	3409	3322	2825	2423	1826
866	1110	1363	1613	1884	2204	2590	3089	3897	4316	4379	4341	4166	3416	2620	1952
877	1123	1447	1831	2294	2813	3379	3954	4514	4819	4884	4849	4632	3746	2802	2025
958	1265	1659	2144	2692	3430	4326	5262	6141	6556	6620	6583	6320	4799	2994	2065
1197	1869	2985	4031	4950	5714	6341	6943	7603	8056	8147	8096	7811	5970	3679	2378
1317	2452	4260	5130	5745	6281	6779	7334	7909	8343	8459	8404	8115	6381	4235	2677
1143	1770	2880	3909	4819	5572	6200	6805	7477	7923	8023	7977	7697	5853	3468	2197
894	1136	1454	1853	2320	2997	3841	4760	5699	6081	6168	6161	5936	4462	2623	1789
581	637	693	754	838							1507	1364	1200	1060	925
557	601	638	682	747							1095	1022	947	876	802
532	569	599	627	679							888	843	803	760	700
506	543	566	588	630							764	734	704	678	636
486	514	536	554	588							680	660	640	616	577
458	490	504	523	546							619	599	579	562	534
442	466	480	494	516							568	550	533	520	490
419	441	455	468	491							522	508	496	485	459
405	423	434	444	465							491	478	464	455	429
384	408	416	425	447							460	448	439	429	411
371	393	401	412	426							440	432	420	409	391
356	374	385	393	411							424	411	401	392	374
343	363	372	383	402							410	398	387	376	356
322	344	359	370	391							401	387	374	357	333

Figure 21. Predicted Date (Change in C^{14})