Understanding the 1988 Carbon Dating of the Shroud

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Abstract

Scientists cut samples from the corner of the Shroud of Turin for carbon dating in 1988. Carbon dating is done by measuring the C^{14}/C^{12} ratio of the samples. The average date obtained by the three laboratories was 1260 ± 31, which produced a range of 1260 to 1390 when corrected for the changing concentration of C^{14} in the atmosphere. But analysis indicates there are problems in the data: 1) two of the three laboratories obtained statistically different dates, 2) the carbon date is different for different locations on the cloth. The date increases about 91 years for every inch (about 36 years for every cm) that the sample location is moved further from the bottom of the cloth, and 3) if the carbon date is assumed to be the same for every location on the Shroud, then 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% (Table 6 in Ref. 3 and Table 4 in Ref. 16). This value is below the usual acceptance criteria of 5.0% so the possibility that the carbon date is the same at every location should be rejected. Thus, to explain the variation of the measured dates requires there to have very likely been an unidentified factor that altered the measured dates from the true date for the Shroud. The amount this unidentified factor altered the measured dates is unknown. This means that the 1260-1390 date from Damon, et. al. should be rejected, that is, given no credibility. According to the neutron absorption hypothesis, this unidentified factor is neutron absorption that would have created new C^{14} on the cloth. According to this hypothesis, neutrons were included in the burst of radiation from the body that formed the image of the crucified man that can be seen on the Shroud. 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. Simplified Explanation

This section attempts to explain in simple terms how the 1988 carbon dating of the samples produced a date that, in the opinion of many Shroud researchers, should not be accepted as the true date. The main objective of the 1988 effort (Ref. 1) 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 the correct date. Two basic assumptions were apparent: 1) the Shroud likely originated in the 13th or 14th century since the majority opinion in 1988 was 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 date of the samples. This means that the possibility that the Shroud could have wrapped the dead body of Jesus in His resurrection, and thus encountered unique phenomena, was assumed to not be 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" (pages 183 and 185 of Ref. 23). As a result of this assumption, when the variation of the measured dates was determined not to be consistent with the measurement uncertainties, no apparent consideration was given to the possibility that unique phenomena had altered the C^{14}/C^{12} ratios of the samples. Rather, it was assumed that the measurement uncertainties were underpredicted, so they could be ignored. However, the evidence is against this assumption because the measurement uncertainties 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 the measured values for the standards.

To assure the proper understanding of measurement data, a statistical analysis of the data is always necessary to prove that an unidentified factor has not affected the measured values, 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. Since this was not done, it means the 1988 carbon date for the Shroud to 1260-1390 AD should be rejected. If the measurement uncertainties are not assumed away but instead are used to analyze whether the measured dates are consistent with the measurement uncertainties, as in Ref. 3 and Ref. 6 to 16, the conclusion is that they are not, which indicates an unidentified factor had very likely altered the measured dates. 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).

It is proposed that this unidentified factor is neutron absorption primarily in the trace amount of N^{14} in the Shroud to create new C^{14} in the Shroud by the [N^{14} + neutron $\rightarrow$ C^{14} + proton] reaction. This new C^{14} could shift the carbon date forward by thousands of years, depending on the location on the Shroud. The neutron absorption hypothesis is consistent with the four things we know about carbon dating as it applies to the Shroud: the date, slope, and variation of the data for the Shroud and the 700 AD date for the Sudarium of Oviedo.

2. Introduction

Slide 1: My name is Robert Rucker. I earned an MS degree in nuclear engineering at the University of Michigan graduating in 1971 and spent the next 38 years in the nuclear industry performing computer calculations related to nuclear reactor design, criticality safety, and statistical analysis of measurements. This experience has been applied to the study of the Shroud since 2014. This includes running nuclear analysis computer calculations related to the carbon dating of the Shroud, organization of the International Conference on the Shroud of Turin (ICST-2017) held in July 2017 in Pasco, Washington, organizing the Shroud Research Network, and writing papers that are available on the research page of the website www.shroudresearch.net.

Slide 2: 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, people should always be open to review the process and conclusions of science, and full information should be made available for such a review.

To solve the mysteries of the Shroud, it 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, but in 1988 samples were cut from the Shroud and carbon dated at three laboratories to an uncorrected average value of 1260 ± 31. When corrected for variations in the carbon-14 (C^{14}) in the atmosphere, a range of 1260 to 1390 AD was obtained, with a supposed 95% probability that the true value falls within this range (Ref. 1). In subsequent years, Shroud researchers gradually came to believe the 1260-1390 value could not be the true date. People need to understand why the 1988 carbon date to 1260-1390 should be rejected. This presentation will explain this using the outline on slide 2. The basic principles of measurement analysis will first be explained followed by two examples involving measurements and analysis. Details of the 1988 carbon dating of the Shroud and objections to this dating will then be discussed, followed by evidence for the neutron absorption hypothesis and the conclusions. For background information on Shroud research and the 1988 carbon dating, please go to the research page on www.shroudresearch.net to download Ref. 2 to 5.

Slide 3: The mysteries of the Shroud relate to the image, the date, and the blood. This presentation will focus on understanding the 1988 carbon dating of the Shroud.

Slide 4: For further background on information to be presented here, please go to the research page on www.shroudresearch.net to download Ref. 2 to 5.

3. Analysis of Measurement Data

Slide 5: 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 the value that it inherently is, 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. This allows their cumulative effect to be included in the measurement uncertainty that is reported with each measured value. 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 so that 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, voltage, location, 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 is not known, as is usually the case, then the only option is to reject the measured values because they could be in error by an unknown amount.

Slide 6: 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 the measured values are consistent with (are explained by) their measurement uncertainties, whereas samples are called heterogeneous (non-homogeneous) when the variation or distribution of the measured values are not consistent with (are not explained by) their measurement uncertainties. For heterogeneous samples, the fact that the variation of the measured values exceeds that expected from the measurement uncertainties implies that an unidentified factor has likely altered the measured values. This unidentified 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 were altered. This alteration of the measured value from the true value by an unidentified factor is the systematic error discussed above. Thus, if analysis of the measured values compared to the measurement uncertainties indicates that an unidentified factor is likely causing a systematic error, then there are two options: determine how much the measured values have been changed from the true value, or reject the measured values. 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 measured values, i.e. give them no credibility. This means that the crucial item in determining whether measured values should be accepted or rejected is whether the variation of the measured values is consistent with the measurement uncertainties. To summarize: 1) if the variation of the measured values are consistent with the measurement uncertainties, then the samples are called "homogeneous" and the measured values should be accepted, but 2) if the variation of the measured values are not consistent with the measurement uncertainties, then the samples are called “heterogeneous” or “nonhomogeneous” and the measured values should be rejected. Many statistical analyses (Ref. 3 and 6 to 16) of the 1988 carbon dating have concluded that the dates are “heterogeneous” or “nonhomogeneous” which means that the 1260-1390 date for the Shroud should be rejected.

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 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 the measured values could have been altered by an unknown amount from the true value. If this is the case, then the measured values should be rejected.

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 (Ref. 1). Doing this could easily hide the presence of a systematic error that could have significantly changed 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, which allowed them to be ignored, caused those doing the analysis to not recognize the evidence in the data that a systematic error caused by an unidentified factor had probably altered the measured values. The latest statistical analysis by Walsh and Schwalbe (Ref. 16) considers two factors that could have altered the measured values. The abstract of Ref. 16 identifies these as:

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:

1. 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 (Ref. 16) 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. The three laboratories used multiple types of cleaning that were progressively more severe, with measurements between the steps in the cleaning process (Ref. 1). 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, et. al., 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 (slide 42). 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 (Ref. 17).

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

Thus, it is more likely that the measured dates have been altered by the first option of "a variation in the carbon isotopic compositions" 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

Slide 7: 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 in a field. 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, 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. The process of trying to put the 0" end 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 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? The only thing that should be done is to reject the results because they don’t make sense.

Slide 8: 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. 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 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 unidentified factor, beyond the measurement uncertainties, that had changed the measured values of the samples. This unidentified factor would have produced a systematic error in the measurements. Since it was not known how much the measured values were changed by this unidentified factor, the only option should have been to reject the measured values. 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 been rejected.

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 in the field. It is believed the problem with the 1988 carbon dating is that the samples had been altered. The next example corrects this inconsistency because its problem is in the samples.

5. Example 2. Measurements in a Tank

Slide 9: 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 would 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.

Slide 10. 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 slide 10. 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 in this slide is divided into standard deviations, which is a technical term in statistical analysis. In simple terms, 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 slide 10, 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 to characterize the width of the distribution. In this case, because an average value is being reported, the one-sigma range indicates a 68% probability that the true value will fall within this range. Both the maximum of the distribution and the width of the distribution are calculated from the measured values of the subsamples.

Slide 11. This slide shows the values reported by the three laboratories, including the average or mean value of the uranium concentration and the one-sigma value to characterize the width of the distribution. This slide 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.

Slide 12: With a closer look at the reported results, you notice the laboratories don't 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 criterion is 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?

Slide 13: As indicated in slide 11, 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 slide 13. 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 slide 10, with the distribution vertically oriented from each circle. Two lines are also plotted in slide 13. 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 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.

Slide 14: To help us decide which line is more appropriate, the red or the black line, we need to consider the width of the probability distribution for each data point. For this consideration, slide 14 plots the one-sigma uncertainties for each sample from the data in slide11. 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 measurement uncertainties.

Slide 15: If the uncertainties for each sample were one third as large, as in this slide, 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.

Slide 16: But if the uncertainties for each sample were three times as large, as in this slide, 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 a function of (depends on) the vertical location in the tank.

Slide 17. If we go back to consider the measured values and their reported uncertainties, as shown in this slide, 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 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 is consistent with the measurement uncertainties. If the variation is not consistent with 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.

Slide 18. 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 distance of the Shroud samples from the bottom of the cloth.

Slide 19. 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 related to the date 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 cannot be explained in terms of 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.

6. Carbon Dating of the Shroud

Slide 20: To understand carbon dating, it is first necessary to understand some things about the carbon atom, as shown in slide 20. 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 that contain 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 1/4th 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.

Slide 21: New C^{14} atoms are produced primarily in the upper atmosphere by cosmic rays from outer space but are also produced 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 the slide by the horizontal black line to the left of the zero age on the x-axis. The zero age 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} is being brought into the flax fibers 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, with the assumption 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 three standards were run at the same time as the Shroud samples and these standards were dated with reasonable accuracy (Table 1 of Ref. 3), it is reasonable 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 from the Shroud. This requires the C^{14}/C^{12} ratios for the samples to have been altered. For the carbon date to shift from about 30 to 1260 AD, the amount of C^{14} in the sample would only have to be increased by 16%. This is too large of a change for it to be the result of normal contamination (Ref. 18). The first suggested cause for this 16% increase was neutron absorption (Ref. 19). According to the neutron absorption hypothesis (Ref. 4), neutrons were included in the burst of radiation emitted from the body that produced the image. Some 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 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 (Ref. 1) was 1260. This date is 728 years before 1988, but all the dates reported in Ref. 1 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 as time progresses, 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 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.

Slide 22: A strip of linen about 1.2 x 8 cm was cut from the cloth by Giovanni Riggi on April 21, 1988. This strip was 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 date is faulty and 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 discussed below.

Slide 23: This strip was cut from the bottom corner of the cloth next to the front image.

Slide 24: It was cut off parallel to the seam that attaches the 3.5-inch wide side strip to the main Shroud cloth, 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. First, a sample, designated A1, was 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 cut in sequence along the linen strip. 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. The laboratories cut subsamples from the samples sent to 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.

Slide 25: 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 and measurement uncertainties, and the analysis of the data for the Shroud subsamples and the standards were reported in the British journal *Nature* in 1989 (Ref. 1). 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 Table 1 of Ref. 3.

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 calculates a date for the sample based on 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, et. al., 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, et. al. 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 from the British Museum in 2017 (Ref. 15), it was learned one of the peer reviewers of this paper (Professor Anthos Bray) recommended this concluding statement be removed from the paper, perhaps because it was not justified by the analysis of the data. However, *Nature* published this paper without removing this concluding statement, thus ignoring the recommendation of Professor Bray.

Slide 26: The dates obtained by each laboratory are given in this slide. The three values obtained by the Oxford laboratory and the five values obtained by the Zurich laboratory are from Table 1 of Damon, et. al. The eight values obtained by the laboratory in Tucson, Arizona, are from Table 4 of Ref. 3, which are based on Ref. 8 and 9. Table 1 of the 2019 paper by Casabianca, et al (Ref. 15) lists two changes in the measurement uncertainties: 676 ± 40 instead of 676 ± 59, and 540 ± 37 instead of 540 ± 57. 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, et. al., without revealing there were originally eight measurements. This reduction from the eight original values to the four values in Damon, et. al. 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 there is likely to be an unidentified factor causing a systematic error that could alter the measured values by an unknown amount.

7. Objections to the Carbon Dating of the Shroud

Slide 27: 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.

Slide 28: A summary of the objections to the 1260-1390 date for the Shroud is the following:

- 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 a first-century date and contradict the 1260-1390 date.
- Two of the three laboratories that did the 1988 carbon dating obtained statistically different dates, and the three average dates from the laboratories show an increase of about 91 years per inch (36 years per cm) of distance from the bottom of the cloth. This means that the dates are a function of (depend on) the location on the cloth.

- An analysis of the data using a chi-squared statistical analysis technique indicates an unidentified factor likely altered the measured dates from the true date. This unidentified factor could have caused the measured values 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.

Slide 29: 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 and suggests it might be caused by radiation causing an electrical discharge (Ref. 20). 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 less than 0.4 microns thick around the circumference of the fiber, which is about 15 microns in diameter, with the inside of the fiber not discolored. The cause of the discoloration in a fiber is also difficult to explain. It is due to some of the carbon atoms in the cellulose in the flax fibers 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 and does not exist today.

Slide 30: The date indicators for the Shroud are discussed in section 6C of Ref. 21. The following summary (this slide and slide 34) 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 (Ref. 22). 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 diagram of 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.
- 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.
- Paintings based on the image from the Shroud date back to about 550 AD.

Slide 31: This is a photo of the front and back of a typical Byzantine coin. 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 the carbon date of 1260-1390 for the Shroud. Coins containing this image go back to about 675 AD.

Slide 32: The Sudarium of Oviedo is mentioned above. It is currently located in the Cathedral of San Salvador in Oviedo, Spain. According to tradition, it is believed to be 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 33 by 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 700 AD, which is consistent with the neutron absorption hypothesis as discussed relative to slide 45.

Slide 33: This 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. 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.

Slide 34: This slide lists other date indicators.

- 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 3.5 inches wide is attached along one side of the Shroud. This strip is attached by a seam with stitching that is unique. The most 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 (Ref. 16).

- 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.

Slide 35: 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 Ref. 3, 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, which exceeds the normal acceptance level of 2.0 sigma. This indicates the carbon dates were statistically different for the samples sent to Arizona and Oxford. This shouldn't be true since both samples were cut from the same cloth very close to one another. This likely indicates an unidentified factor has altered the C^{14}/C^{12} ratios of the samples.

Slide 36: The average dates from each laboratory (Oxford on the left, Zurich in the middle, and Tucson on the right) and the measurement uncertainties are shown in this slide. 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 as shown in slides 23 and 24. The red circle 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 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 slide 10, this probability distribution is called a normal or Gaussian distribution. It is often also called a bell curve. Each date plotted on slide 36 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 probability of about 68% that the true value falls within the range of the vertical red bars. The question is whether the constant value at 1260 AD (horizontal black dashed line at 1260) assumed in Damon, et. al. 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 line only goes through the one-sigma uncertainty of one date (Zurich) but the red line goes through the one-sigma uncertainty of all three dates.

If the black 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 slide 36. 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 slide 36, then it would be easily recognized that the horizontal black line at

1260 would not be an appropriate fit to the data, so the red line would be the excepted 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 it would be recognized that some unidentified factor is causing the slope to the data in slide 36. This unidentified factor would cause a systematic error in the measurements. This could cause the measured value 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.

In the statistical analysis of the data in Damon, et. al., a decision was made to assume that the measurement uncertainties were underpredicted and thus could be ignored. But in ignoring the measurement uncertainties, they ignored the crucial item in the decision process as to whether the 1260 ± 31 AD date should be accepted or rejected. This was probably done because there were problems in the statistical analysis that should have caused them to question the 1260 date for the Shroud and because their main goal was to validate the accuracy of their small sample dating technique. Dating the Shroud was merely a means to that end. But when they ignored the measurement uncertainties in Damon, et. al., they could no longer perform a statistical analysis to prove the variation of the measurements for the 16 subsamples was consistent with the measurement uncertainties without the presence of some unidentified factor that had significantly altered the measurement results. Thus, they could not assure that no unidentified factor had altered the measurement process or the samples. As previously discussed, it is believed the C^{14}/C^{12} ratios of the samples were accurately measured within the stated measurement uncertainties in Damon, et. al., 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.

Slide 37: A chi-squared statistical analysis technique was used to calculate the probability that the black line at 1260 in Figure 14 is an acceptable fit for the measured dates with their measurement uncertainties. If the carbon date is assumed to be the same for every location on the Shroud, then this chi-squared statistical analysis indicates that the probability of obtaining a variation in the dates for the three samples at least as large as was obtained is only 1.4% (Table 6 in Ref. 3 and Table 4 in Ref. 16). This value is below the usual acceptance criteria of 5.0% so the possibility that the carbon date is the same at every location should be rejected. Thus, to explain the variation of the measured dates requires there to have very likely been an unidentified factor that altered the measured dates from the true date for the Shroud. This 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.

Slide 38: The proposed explanation for the 1988 carbon date of 1260 ± 31 AD is the neutron absorption hypothesis (Ref. 4), first proposed in 1989 by Dr. Thomas Phillips (Ref. 19) then of the Harvard Laboratory. This hypothesis is the following. If neutrons were included in the burst of radiation 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 forward by thousands of years depending on the location on the cloth, thus explaining the 1988 carbon dating.

Slide 39: 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 line could be used for dating. When they measured that the C^{14}/C^{12} ratio had decreased from 100% of its value while alive to only 92%, they would have moved horizontally from 92% on the y-axis over to the black line 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. 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. 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 unidentified factor could have altered the measured values. But if the Shroud had wrapped Jesus' body and if Jesus' resurrection were a true historical event, then we would have no idea of 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).

8. Nuclear Analysis Computer Calculations

Slide 40 Based on the neutron absorption hypothesis, nuclear analysis computer calculations were performed using the MCNP (Monte Carlo N-Particle) nuclear analysis computer code. MCNP 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.

Slide 41: To understand the 1988 carbon dating of the Shroud, MCNP was used to model a human body using simple geometrical volumes surrounded by a linen cloth on the back bench in a limestone tomb as it would have been constructed in first-century Jerusalem (Ref. 4). This model assumed neutrons were included in the burst of radiation that was emitted in the body that had formed the image (Ref. 20). It was also assumed these neutrons were emitted uniformly (homogeneously) in the body. MCNP was used to calculate the distribution of neutron absorption in the trace amount of N^{14} in the cloth, which would have produced new C^{14} in the Shroud, which would have shifted the carbon date forward. This is because carbon dating is based on a measurement of the ratio of C^{14} to C^{12}. If new C^{14} were produced in the threads of the Shroud, then the carbon date would have been shifted forward.

Slide 42: The distribution of the carbon dates calculated by MCNP is shown in this slide. 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. This 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, based on use of the usual equations for determining a date from a measured C^{14}/C^{12} ratio. About 80% 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 very 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 dates is about the same as the slope measured by the three laboratories shown in slide 36. This agreement between the calculated slope (this slide) and the slope experimentally determined by the three laboratories (slide 36) supports the validity of the neutron absorption hypothesis. The carbon dates also fall off in the direction perpendicular to the direction in this slide. This is discussed on pages 18 and 19 of Ref. 3.

Slide 43: According to the neutron absorption hypothesis, the neutron distribution in the tomb (slide 42) 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 this slide 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, which caused an increase in the carbon date of about 91 years per inch (36 years/cm, slide 36) of distance from the bottom of the cloth. According to the neutron absorption hypothesis, this changed the carbon date from about 30 AD to 1260 AD.

According to the neutron absorption hypothesis, the neutron distribution in the tomb (slide 42) 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. As shown in this slide 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, resulting in the slope in the carbon dates of about 36 years per cm (slide 36). According to the neutron absorption hypothesis, this is the cause of the systematic error that altered the carbon dates from about 30 to 1260 AD.

Slide 44: Data from the MCNP calculations were 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 this slide. Carbon dates were determined for linen on the left and right benches, and on the back bench in the tomb. The linen that covered the body on the back bench was modeled in a rectangle around the body, so the carbon dates were calculated for linen resting 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, as shown in this slide.

Slide 45: The carbon dates calculated by MCNP are shown in this slide based on the regions in the previous slide. 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 700 AD, in excellent agreement with the date distribution calculated in MCNP, as shown in this slide. 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. According to the neutron absorption hypothesis, the source of neutrons in the tomb was the body.

9. Evidence for the Neutron Absorption Hypothesis

Slide 46: The first step in the scientific method to explain a phenomenon is to develop a hypothesis consistent with what is known to be true about the phenomenon. We know four things about carbon dating as it relates to the Shroud:

1. In 1988, samples from the corner of the cloth were dated to an average of 1260 ± 31 AD, uncorrected.
2. The slope of the average values from the three laboratories is about 91 years per inch (36 years per cm), as indicated in slide 36.
3. The range of dates for the 16 subsamples is 1155 to 1410 AD (Table 6 of Ref. 3).
4. The Sudarium of Oviedo, which is believed to be Jesus' face or head cloth (John 20:7), was carbon dated to 700 AD.

The neutron absorption hypothesis is consistent with all four of these criteria. A hypothesis cannot be true if it contradicts any of these criteria. 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 #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. The invisible reweave hypothesis appears to be contrary to criteria #3. This is because cutting the subsamples from the samples provided to the three laboratories probably would have been a random process. This means at least some and most likely four of the 16 subsamples should have dated only old material, which should date to about 30 AD, and at least some and most likely four of the 16 subsamples should have dated only new material, which should date to about 1530 or so. Yet none of the subsamples were dated to about 30 or 1530 AD. Also, regarding #4, an invisible reweave on the

Shroud would not have altered the carbon dating of the Sudarium. Eight objections to the invisible reweave hypothesis are listed in section 2 of Ref. 4.

Slide 47: 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 this slide. 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.

Slide 48: 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 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. The fully carbonized linen from near the elbows is still available in these sample jars for carbon dating.

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. 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 very difficult to explain except by the neutron absorption hypothesis. Nuclear analysis computer calculations have not yet been used to calculate the distribution of these long half-life isotopes in the tomb, but this will be done in the future.

Slide 49: For further information, go to the research page of www.shroudresearch.net . Thank you.

10. Conclusion

The statistical analysis of the 1988 carbon dating of the Shroud (Damon, et. al., Ref. 1) contains multiple anomalies. This raises the question of whether the resulting date of 1260-1390 AD should be accepted as the true date for the Shroud. Measurements can be different than the true value due to random errors or systematic errors. Each scientific measurement can produce two values, the measured value itself and the measurement's uncertainty, which results from the random errors in the measurement. The effect of these random errors can be easily minimized by taking many measurements. But the effect of a systematic error can cause the measured values to all be significantly different than the true value and is not minimized by taking many measurements. Thus, for us to accept the average measured date (1260 ± 31, uncorrected) to be the best estimate of the true date, a proper statistical analysis must prove that the random measurement errors alone can account for the variation of the measured dates so that the presence of a systematic error is not required. This must be done to prove the measurements were not altered by one or more unidentified factors which could have created a significant systematic error in the measurements. If the statistical analysis of the data indicates that a systematic error was likely to have altered the measurements, and if the magnitude of the systematic error is not known, as is usually the case, then the measured dates may differ from the true date by an unknown amount. In this situation, the only option is to recognize that the measured dates are not the true date.

The statistical analysis of the 1988 carbon dating of the Shroud in Damon, et. al. (Ref. 1) failed to meet this requirement, i.e. it failed to prove an unidentified factor had not significantly changed the measured dates from the true date. A proper statistical analysis of the data was entirely avoided by assuming, without evidence or valid argument, that the measurement uncertainties which result from the random measurement errors, were underpredicted. This assumption is entirely unjustified since the measurement uncertainties would have been obtained from the same measurement process as produced the measured dates, and the measurement uncertainties for the three standards that were run at the same time as the Shroud samples were reasonably consistent with the measured dates for the standards. Assuming all the measurement uncertainties to be underpredicted allowed them to be ignored. Since each measurement of the C^{14}/C^{12} ratio would produce two values, the measured value and the measurement uncertainty, this means that half the data, i.e. all the measurement uncertainties, was ignored. Since no statistical analysis proved that a systematic error had not affected the measurements, the conclusion from the 1988 carbon dating of the Shroud (1260-1390 AD) should be rejected, i.e. given no credibility.

Carbon dating is done by measuring the ratio of C^{14}/C^{12} in samples. It is believed that the C^{14}/C^{12} ratios were accurately determined for the samples, but that the samples had been altered, thus causing a systematic error in the measured values. Analysis of the carbon dates reported by the three laboratories yields three pieces of evidence that a systematic error had altered the measured dates: 1) two of the three laboratories obtained different dates, with the difference being statistically significant at the 2.9-sigma level, 2) 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 91 years per inch (36 years/cm), and 3) if the carbon date is assumed to be the same for every location on the Shroud, then a chi-squared statistical analysis indicates the probability of obtaining a variation of the dates in the 1988 Shroud samples at least as large as was obtained is only 1.4% (Table 6 in Ref. 3 and Table 4 in Ref. 16). This value is below the usual acceptance criteria of 5.0% so the possibility that the carbon date is the same at every location should be rejected. Thus, to explain the variation of the measured dates requires there to have very likely been an unidentified factor that altered the measured dates from the true date for the Shroud. The amount this unidentified factor altered the measured dates is unknown.

Therefore, the conclusion in Damon, et. al., that the Shroud dates to 1260-1390 AD should be rejected., i.e., given no credibility.

According to the neutron absorption hypothesis, the unidentified factor that caused the systematic error is neutron absorption. If neutrons were included in the burst of radiation that formed the image on the Shroud, then neutron absorption 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 thousands of years. To shift the carbon date from 30 to 1260 AD requires only a 16% increase in the C^{14} concentration. This would require 2×10^{18} neutrons be emitted from the body, which is only one neutron in every ten billion (1×10^{10}) that are in the body (Ref. 4).

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