An Unexpected Consequence of Radiation Theories for the Holy Shroud of Turin Image Formation: A Possible Repositioning of the Burial Linens in the Tomb

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Introduction:

The various historical, archaeolgical and scientific methods of studying the Holy Shroud of Turin have produced an enormous body of data and evidence, both as to its authenticity and to its enduring, fundamental mystery. A principal exception to this has probably been the 1989 Report in *Nature* (1) on the carbon-14 tests. Recently available information on the sampling procedure used in these tests has now, however, made it possible to indepenently calculate the expected radiocarbon age of the Shroud samples, and to thereby redetermine the true age of the cloth. The results of this new approach are outlined below, while the more detailed discussion and numerical conclusions are presented in Appendix A.

Next, the radiation theory of image formation is analysed in some detail, and a new and quite unexpected consequence of radiation theories in general is examined.

The Carbon-14 Test Results Point To a First Century A.D. Origin for the Shroud

While a 1st century origin of the Shroud of Turin is today accepted by more and more of those studying it, for some there may still remain an obstacle to accepting its authenticity because of a 1989 Report in *Nature* (1) on the carbon-14 testing which asserted that it was of mediaeval origin. What is not widely realized yet, however, is that the carbon-14 test results actually point to a 1st century origin, and it is the mediaeval origin that is ruled out.

The essential element here is the matter of the contamination of the Shroud test samples. These were cut from a heavily handled corner of the cloth, which had accumulated layer upon layer of organic carbon over the centuries, so that the 50 milligram samples were heavily contaminated (clean linen weight per sample 17.9 milligrams and organic contamination 32.1 milligrams). The effect of this more modern carbon is to artificially shift the indicated radiocarbon age of the cloth from its actual 1st century origin into the mid thirteenth century.

This contamination was acknowledged implicitly by the authors of the *Nature* article, but, when they got a "radiocarbon age" of 724 years from their measurements, they unaccountably then ignored the contaminatiuon in their calculations. and simply declared that the Shroud was mediaeval. Examples of the effect of contamination on radiocarbon ages are given in Table 1. They show the effect on a cloth of 1A.D. origin when it is contamnated, first with 100% and then with 200% of modern carbon.

Then, when we make the radiocarbon calculations for the heavily soiled samples taken from a first century cloth like the Shroud, we get an expected "radiocarbon date" of 713 years. Since this calcuated value effectively matches the actual radiocarbon measurement for the Shroud made in 1988 of 724 years, we are obliged to conclude that the linen of the Shroud is of 1st century origin. (See full discussion and calculations in Appendix A).

Table 1

Effect of Contamination on Radiocarbon Age

Case	Contamination	Weights		Age		
		Cloth	Contamination	"t"	Radiocarbon*	Actual
Example 1	Clean	10 mg	Nil	1999 years	1A.D.	1A.D.
Example 2	100%	10 mg	10 mg	941 yrs	1059A.D.	1A.D.
Example 3	200%	10 mg	20 mg	616 yrs	1384A.D.	1A.D.
Shroud of Turin	**179%**	**17.9 mg**	**32.1 mg**	**713 yrs**	**1275A.D.**	**33A.D.**

* "t" is the measured or calculated radiocarbon elapsed time in years (see Appendix A). "Radiocarbon age" is test year (Shroud 1988; three examples each 2000 A.D.) minus "t".

We turn now to the radiation theory of image formation on the Shroud and an unexpected consequence which it entails.

The Energy Necessary for Image Formation

As a foundation for any image formation hypothesis, we require a knowledge of the energy necessary to form the image. This has been estimated (3 ,6) to be in the range of 2.86×10^6 to 1.43×10^7 Joules, depending on the amount of linen fibrils assumed to be chemically discolored to form the image. Clearly, then, the energy released from the dead body of The Man in the Shroud must be at least this amount ΔE , plus any energy lost in the air gap between the body and the cloth. (We say 'at least' because there is the possibility to be considered that not all of the energy reaching the linen is actually absorbed by it, leaving some to pass through the cloth unabsorbed).

Necessary Characteristics of Image Formation Radiation

The image on the Shroud is made up of a pattern of areas of slightly discolored or yellowed linen fibrils. This yellowing of the linen fibrils is spectrally similar to that which can be produced in linen by a slight heat scorch. Now the radiation cannot be uniform in intensity when it reaches the cloth, or else there would be no image-forming variation in density; so the radiation must be capable of being attenuated or absorbed somewhat by the air in the gap between the body and the cloth, and the amount of this attenuation must be proportional to the width x of the air gap from point to point across the body (7,8,9,10) (Fig. 1).

Attenuation of the Image forming Radiation

The attenuation of electromagnetic radiation in air follows the Lambert/Bouguer Law

$$I/I_0 = e^{-k x} \qquad (1)$$

where I_0 is the intensity of the radiation entering the absorbing air gap and I is the intensity value at any distance x into the air. The ratio I/I_0 is then the relative intensity (either a decimal fraction or a percentage value) of the intensity of the radiation at any distance x from the emitting point on the body. The constant k is called the absorption coefficient; its numerical value in air depends on the wavelength of the radiation (6).

As an illustrative example, Fig. 2 shows the attenuation curve for the I/I_0 observations from the 1977 U.S. Conference and from the 1977('82) STURP values (7,8,9,10). Both sets of data have been standardized to the same base.

Figure 2 shows a plot of relative intensity I/I_0 versus distance x across the air gap in centimeters. We see that the 37 data points give a clearly discernible trend line. At a distance into the air of 1 centimeter the intensity ratio I/I_0 has dropped to 0.5, which means that 50% of the emitted radiation has been absorbed by the air over a distance of only 1 centimeter. This is a much higher value for absorption or attenuation of the radiation than for most electromagnetic radiation in air at wavelengths likely to have formed the image, which are from 1 to 3 mm (i.e. microwave or far-infrared) (6).

A possible solution to this problem would be if the radiation were actually composed of two types, one being a weakly absorbed ordinary electromagnetic radiation (Curve B) , and the other a strongly absorbed type (Curve C), whose physical nature and origin are as yet unknown. The combined curve D then fits the observed data points quite well. Its equation would then be

$$I/I_0 = 0.13\ e^{-0.00023\ x} + 0.87\ e^{-0.855\ x} \qquad (2)$$

<u>An Unexpected Secondary Effect of Radiation Hypotheses</u>

We now note that, since the radiation energy ΔE acts chemically on the linen as a sort of heat scorch, then this radiation must also act on the air molecules through which it passes so that part of it is attenuated or absorbed. <u>So the air in the air gap must also be heated by the image formation radiation.</u> An unexpected consequence of this heating will now be explored.

We shall first estimate the amount of temperature rise ΔT in the air enveloped in the Shroud, caused by the absorption of a portion of the image formation energy as it travels across from the body to the cloth. The heat equation is

$$\Delta E = m_{air}\ \Delta T_{air}\ c_v \qquad (3)$$

where c_v is the specific heat of air and is numerically equal to 7.158×10^5 Joules.

Rearranging, we have $\Delta T = \Delta E/(m_{air}\ c_v)$ (3a)

The energy input values ΔE are given in Table 2. For the mass of air heated m_{air} ,we estimate a volume of about 0.15 cubic meters. Then, since 1 cubic meter of air weighs about 1 kilogram, we have $m_{air} = 0.15$ kg. Inserting these for ΔE and m_{air} into Eqn. 3a, we get the predicted temperature rise ΔT as follows:

Table 2

Temperature Rise (ΔT) in the Air Enclosed in the Shroud After Absorption of Radiation Energy (ΔE)

ΔE	ΔT ($= \Delta E / m_{air} c_v$)
2.86×10^6 Joules	27° C
5.72×10^6 "	53
1.14×10^7 "	106
1.43×10^7 "	133

These values, of course, are estimates, but they clearly are sufficient to establish that a very large and sudden increase in temperature (Δ T) would necessarily occur in the air enclosed in the Shroud because of the attenuation and absorption of a large fraction of the radiation energy involved in the image formation mechanism.

This large increase in temperature would in turn result in a large and sudden increase in the enclosed air's pressure (Δp). The temperature and pressure for air are related by the equation

$$p/p_0 = [\ T/T_0\ ]^{7/2} \qquad (4)$$

where p is the air pressure at the new and higher temperature T, p_0 is the original air pressure at the original ambient temperature T_0 in the Tomb , which is probably near 15°C.

Eqn. 4 is called the adiabatic relation of pressure and temperature for a compressible gas, which in our case is air. From it we can calculate the effect of the range of temperature rises ΔT on the pressure rise Δp. We arrive at the results in Table 3.

Table 3

Increase in Pressure of Air Enclosed in Shroud
Caused by Increase in Air Temperature from
Absorption of a Portion of the Image Forming Radiation

ΔT	T/T_0	p/p_0	Increase in Pressure Δp		
			%	Atms.	lbs./in^2
27° C	1.09	1.35	35	0.35	5.1
53	1.18	1.78	78	0.78	11.5
106	1.37	3.00	200	2.00	29.4
133	1.46	3.76	276	2.76	40.6

Notes: (1) To use Eqn. 4 we must express degrees Celsius in degrees Kelvin; if we take the undisturbed air temperature in the Tomb at 15°C , this is equal to 273 +15 = 288 °K.

(2) 1 atmosphere pressure = 14.7 lbs/in^2= 1.013 kilopascals.

(3) Note that the percentage increase in air pressure is larger than the percentage increase in temperature. For example, T/T_0 of 1.06 represents a 6 % rise in temperature but a 23% rise in air pressure.

Clearly, any radiation mechanism for Shroud image formation must also result in a sudden large increase of pressure of the air enclosed in the Shroud.

Motion of the Heated Air in the Tomb

With a presumed burial deposition in the Tomb depicted in Figures 3a and 3b, what would be the effect of a sudden, violent expansion of the heated air inside the folded Shroud?

First, from the magnitude of the pressure rise (Δp), it seems clear that the upper part of the Shroud which was folded over the body, and the *sudarium,* or "cloth which was over His head" (Jn: 20: 7) (12), would each have been thrown up towards the roof of the Tomb and then presumably would have been swept out by the air flow onto the floor. This effect could thus have caused a physical separation or repositioning of the Shroud and the *sudarium* as recounted in Jn: 20: 7-8. (The under layer of the Shroud, which had been beneath the body of The Man in The Shroud, would have been pressed more firmly downward onto the stone sepulchral couch by the air pressure) (Fig. 3c).

The usual type of air motion by which heat is distributed to reestablish a uniform temperature throughout is called turbulence or convection. These two processes give a disorganized, random eddying motion to the air flow and are relatively slow.

It is also conceivable that the heated, suddenly expanding air might go into the organized, circular, swirling notion which is called a vortex or whirlwind. The vortex wind speeds which could result from the sudden violent temperature and pressure increases can be calculated from the compressible energy flow equations (11) as follows:

Energy equation: $c^2 = c_0^2 - V^2/n;$

or, rearranging: $[c/c_0]^2 = [1- 1/n[V/c_0]^2]$

and, from the adiabatic relation $[c/c_0]^2 = T/T_0$

whence, we have $V = \sqrt{n}\, c_0 [1 - T/T_0]^{1/2}$ (5)

Equation 5 gives the relation between velocity V and temperature T which must be satisfied in any adiabatic process, such as the expansion of air in a vortex causing a drop in temperature from some previous undisturbed value T_0 . Therefore, if a vortex exists and additional heat and temperature rise ΔT are injected into the vortex, the rise in temperature at the point of injection of the heat will disturb the existing values of T and V which are required by Equation 5. To then restore the required smooth profile of V and T in the vortex, the injected air at temperature $T + \Delta T$ must be cooled by expansion of the air, and this in turn must cause the velocity V to increase to satisfy the relationship values of Eqn 5.

In Table 4 we have presented some velocities V which must result from a linear or helical expansion of the air when temperature rises ΔT are injected into a vortex whose initial temperature was T_0 .

Table 4

Wind Speed V Corresponding to a Temperature Rise ΔT

ΔT	T_0	T = (288 - ΔT)	Wind Speed V m/s	Wind Speed V mph
1°C	288°K	289°K	45	100
2	"	290	63	142
5		293	100	224
10		298	142	317

Note :We take the temperature of the undisturbed air in the Tomb as being 15°C = 288°K. so that $V = \sqrt{n}\, c_0 = [\,(288 - \Delta T)/288)]^{1/2}$. The value of n for air is 5, and the speed of sound c_0 at 15°C is equal to 340 m/s or 1115 ft/s.

Of course, physical processes are never one hundred percent efficent, and so the actual velocities reached would be considerably less than those indicated for V in the table. But it is clear that temperature rises (ΔT) as large as those in Table 3 could give momentary wind speeds V of 100 to 200 mph (160-322 kph).

Since the effect would be sudden, a shock wave would probably result, and this would set up a rotational effect which would lead instantly to a whirlwind or vortex motion. While this would last only a second or two, it would be enough to violently separate the burial linens and to twist them up (Fig. 3d), which could relate to a second observation in Jn: 20:8 that " this (i.e. the *sudarium*) was rolled up in a place by itself."

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Jn 20: 3-8 "So Peter set out with the other disciple to go to the tomb. They ran together, but the other disciple, running faster than Peter, reached the tomb first; he bent down and saw the linen cloths lying on the ground, but did not go in . Simon Peter who was following now came up, went right into the tomb, saw the linen cloths on the ground, and also the cloth that had been over his head; this was not with the linen cloths but rolled up in a place by itself."

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Appendix A

Radiocarbon Age

Carbon-14 is a form of carbon whose amount in any plant or organism is fixed at the moment the organism dies. Thereafter, the carbon-14 content in a sample from the plant, for example in a piece of linen cloth woven from flax plants , decays at a known rate. Therefore, if the carbon-14 amount remaining in a sample is measured, this can tell us the number of years that have elapsed since the plant from which the sample was made died, and so we can determine the date of the origin of the sample. How this is done can best be seen from some examples.

First, let us suppose we have a clean linen cloth that we are sure originated from the 1st century A.D., for example from the year 1 A.D. Let us then cut a tiny sample from this linen cloth 1 square centimeter in size. Let its weight be 10 milligrams. Now, suppose we test this sample in the year 2000 A.D. Then the radiocarbon calculations (see below) show that we should expect to get an instrumental reading of 1999 elapsed years (2000 minus 1 year = 1999 years) since the date when the linen sample was woven from the flax. So, in the case of a clean sample, the radiocarbon date and the real historical date of origin will be the same.

Second, let us take the same sample (weight 10 milligrams), but this time we suppose that, just as the technician is about to test it, he inadvertently drops it into olive oil so that it becomes contaminaed with 10 milligrams of the oil. The soiled sample now weighs a total of 20 milligrams, half of its weight being 10 milligrams of linen cloth and the other half being 10 milliigrams of contaminating olive oil. Then, let us further suppose that, to avoid exposing his clumsiness to his colleagues, the technician doesn't try to clean the olive oil off, but just goes ahead with the radiocarbon tests on the contaminated sample. What result does the radiocarbon method say he should expect to get from his instrument? Well, since the weights of sample and contaminating olive oil are equal, it is obviously going to be somewhere about half way between 1 A.D., the date of the cloth, and 2000 A.D., the date of the olive oil. In fact, the radiocarbon elapsed time "t" turns out to be 941 years or 1059 A.D. (2000 - 941 = 1059 A.D.) ,in spite of the fact that we know the true age of the cloth itself is 1A.D. (calculations below).

For a third example, let us assume that the olive oil contamination is now 20 milligrams. What value of t do we expect to get now? In this case, where the contamination is double (200%), we calculate that t is equal to 616 years, or an indicated historical date of 1384A.D. (2000 - 616 = 1384 A.D.), although once again we know that the true historical date for the cloth is 1 A.D..

Now, in the case of the Shroud, the radiocarbon testing done in 1988 gave an indicated instrumental measurement value for "t" of 724 years. Obviously , to now interpret this 724 year figure in terms of a true historical age of origin for the cloth, we must get answers to the following two key questions :

(1): Were the samples clean?, and (2) If they were contaminated, could they have been cleaned or not?

On this matter of contamination of samples, it is well known that organic contaminants on cloth are a good medium for bacterial growth. Even if the organic contaminaton is old, any bacteria present will quickly multiply, recycle the organic materials and thereby update the original carbon-14 content by taking in fresh, more modern carbon-14 from the surrounding air. Thus, a heavily handled linen cloth, such as the Shroud test sample, becomes increasingly contaminated with organic carbon of increasingly more modern carbon-14 age. Furthemore, if this contamination is not promptly removed by washing, it soon becomes so tightly chemically bound to the linen that it eventually becomes non-removable by any cleaning process.

Were the Shroud samples clean? Three small test samples were cut from a corner which had obviously been heavily handled by human hands during inspection and private and public viewing over many centuries. So the answer to the essential initial question is: "No, the Shroud samples were not clean, they were heavily contaminated." The scientific proof of this was certainly available to the *Nature* authors, since the weight of a clean sample of 1 sq. cm area taken from other parts of the Shroud well away from the heavily handled corner should be only about 23 milligrams (2,4). Adjusting for the loosening of the weave of the cloth at the corner from handling and the slight difference in size, we have an estimated weight for the clean linen sample of 17.9 milligrams (calculations below). Since the total sample weight was 50 milligrams, then the contamination weight is simply the difference, 32.1 milligrams (50 - 17.9 = 32.1). In percentage terms, the contamination was about 179 % (32.1 ÷17.9 = 1.793).

Therefore, before the tests were run in 1988, the researchers certainly should have been aware that the three Shroud samples were contaminated by around 179%. However, in the *Nature* Report there is no mention of this vital fact of contamination. Instead, the authors simply reported that they vigorously cleaned the samples, and then went ahead as though the samples were clean. In fact, the samples were <u>non</u> <u>cleanable</u>, that is to say, the more recent carbon contamination had over the years become so chemically bonded to the linen that it had become unremovable. This non-removability of contamination was implied in the *Nature* report where the authors vaguely stated that ".. <u>the samples showed no loss of weight on cleaning</u>", but did not make any mention of this essential fact that the samples were contaminated and could not be cleaned. (Obviously, if a contaminated sample (contamination 179%) shows no loss of weight after you have tried to clean it, then its 179% contamination was not removed by the cleaning). But, in spite of this, <u>the *Nature* Report just went ahead and intepreted the results as though the sample were now clean.</u>

The *Nature* authors , in fact, have never in over a decade provided any explanation whatever for their action, although one of the senior authors, Prof. Woelfli, is reported to have said " Nobody (among the authors) has seen this error. We were under pressure but this is not an excuse" (5). Just what error Prof. Woelfli was acknowledging is not explicit, so that we must draw our own conclusions.

So, in spite of this 179% non-removable modern carbon contamination, the authors of *Nature* simply took the *test results* of t = <u>724 years</u>, subtracted this value from 1988, the year of the tests, got an historical date of 1264 A.D.,(1988-724 = 1264 A.D.), and then, never mentioning the contamination, announced to the world that the Shroud was of mediaeval origin. (1260 A.D. to 1390 A.D. at the 95% confidence level).

To be quite clear, what is being stated here is not that the radiocarbon *test result* of 724 years is wrong, but rather that the *historical date interpetation* of the test result in the *Nature* Report- made on the hypothesis that the Shroud samples were clean- is false.

Let us turn to the observed fact that the test samples were heavily contaminated with non-removable carbon accumulated over the centuries intervening since the linen was woven. We must now, as in our examples above, calculate an expected value for the radiocarbon age "t", taking into acount the amount of this contamination, and then see if the calculated value for t matches the observed mass spectrometer *test results* for "t"of 724 years or not. <u>If it matches, then the Shroud linen is of ancient, not mediaeval origin.</u>

To repeat, and be quite precise this is what we are testing: : The Shroud of Turin is of 1st century origin (e.g. 33 A.D.), It is heavily contaminated at the sampled corner with 179% of more recent organic materials containing carbon-14 from centuries of human handling and the subsequent bacterial reworking and updating of the carbon-14 content until its last probable handiing by bare human hands in 1898 at a public exposition in Turin. We estimate that the carbon contamination content of the samples also has the same effective date of this last handling in 1898 A.D.

When we run the radiocarbon calculations (see below) we get an expected *test value* for t of 713 years. Since this matches closely the observed mass spectrometer measurement value of 724 years, we have to conclude that the linen of the Shroud is of 1st century origin.

Table 1

Effect of Contamination on Radiocarbon Age

Case	**Contamination**	**Weights**		**Age**		
		Cloth	**Contamination**	**"t"***	**Radiocarbon***	**Actual**
Example 1	Clean	10 mg``	Nil	1999 years	1A.D.	1A.D.
Example 2	100%	10 mg	10 mg	941 yrs	1059A.D.	1A.D.
Example 3	200%	10 mg	20 mg	616 yrs	1384A.D.	1A.D.
Shroud of Turin	**179%**	**17.9 mg**	**32.1 mg**	**713 yrs**	**1275A.D.**	**33A.D.**

*"t" is the calculated or measured radiocarbon elapsed time in years. "Radiocarbon Age" is the test year (Shroud 1988 A.D.; three examples each 2000 A.D.) minus the value of "t".

While there are a number of refinements in the radiocarbon calculations which can be introduced with interesting results, they will not alter our conclusion that the assertion of the N*ature* authors that the Shroud of Turin is of mediaeval origin is no longer tenable and that the radiocarbon tests instead indicate a 1st century origin for the Shroud.

Radiocarbon Age Calculations

1. Clean Sample:

The standard Carbon-14 radioactive decay equation is

$$N/N_0 = e^{-k\,t} = e^{-0.0001209\ t} \qquad [1]$$

where t is in years, and k is the numerical constant for carbon-14 whose value is 0.0001209.

The ratio N/N_0 gives the percentage (in decimal form) of the carbon-14 remaining in the sample after an elapsed time of t years since the origin of the sample.

The radiocarbon decay time t expected for the clean linen sample from the year 1A.D. to 2000 A.D. is 2000 - 1 = 1999 years. Then Eqn. I gives N/N_0 equal to 0.785, which means that by 2000A.D. a 1st century clean linen cloth would have only 78.5% of its original carbon-14 remaining. Or, putting it the other way round, it would have lost 21.5% of its carbon-14 in the 1999 years between 1 A.D. and the year 2000 A.D.

We see that in the case of a clean sample the radiocarbon age and the true historical age are in agreement.

2. Sample soiled 100%: by an equal weight of oil

The linen weighs 10 milligrams; the contamination by oil weighs 10 milligrams; the combined total weight of the test sample is then 20 milligrams.

The radiocarbon decay age for the clean linen (A) is 1999 years as in Example 1 (2000 -1 = 1999) and the value of $(N/N_0)_A$ is again 0.785.

The radiocarbon decay age for the contaminating (oil) portion (B) is 1 year (assuming the olive oil was pressed one year earlier than 2000 A.D.), so $(N/N_0)_B$ calculated from Eqn. 1 is 0.9999.

The combined decay ratio is then the N/N_0 value for the sum of the A and B portions, after each is weighted by the ratio of its weight (10 milligrams) to the total weight of the soiled sample (20 milligrams).

$$(N/N_0)_{combined} = (0.785 \text{ x } 10/20) + (0.9999 \text{ x } 10/20) = 0.8925$$

Inserting this valueof 0.8925 into Eqn.1 and solving for t, the combined sample's "indicated age", we get t = 941 years, which corresponds to an indicated radiocarbon historical age for the soiled cloth of 1059 A.D. (2000 - 941 = 1059). And so we see that the 100% olive oil contamination has shifted the indicated radiocarbon age forward by 1059 years from the true date of origin of the cloth sample in 1 A.D.

3. Sample soiled 200 % by double the weight of oil

In this case we have: linen weight 10 milligrams, contamination weight 20 milligrams, total test sample weight now 30 milligrams.

$$(N/N_0)_{combined} = (0.785 \text{ x } 10/30) + (0.9999 \text{ x } 20/30) = 0.9283$$

The indicated test age to be expected from the measurements calculated from Eqn. 1 becomes t = 616 years, which gives an indicated radiocarbon historical age of 2000 - 616 = 1384A.D. We see that a sample test cloth, which has become contaminated with 200 % of modern organic material, would shift the indicated age forward to show a " radiocarbon age" of 1384 A.D., while the cloth actually dated from 1 A.D.

4. The Shroud of Turin

There were three approximately equal samples tested. We first estimate the proportion of each sample's total weight (50 mg) which is clean linen and that which is due to the contamination. The clean linen weight can be calculated from the known value of 23 mg/sq. cm. for the Shroud as a whole, multiplied by the area of each sample, 1.167 sq. cm. So, allowing also for a one-third loosening of the weave at the heavily stretched and handled corner, relative to the weave closeness in the main body of the linen, we get (23 x 0.67) x1.167 = 17.9 mg. for the weight of the clean linen portion of each test sample. Since the total weight of each sample is 50 mg., the contamination weight per sample is simply the difference, namely (50 -17.9) = 32.1 mg. With these values we can now calculate the *test result* date t to be expected in the carbon-14 tests on the contaminated samples, as follows:

The contamination is either removable by cleaning, or it is not. So, we subject the samples to cleaning, and then, noting that there is no loss of weight, conclude that the contamination is non-removable. We deal with the non-removable contamination by calculating the *test result* date t which is to expected. The radiocarbon decay time t expected for the clean linen (A) is 1988 A.D.- 33 A.D. = 1955 years, whence Eqn. 1 gives the decay ratio

$$N/N_0)_A = e^{-k\,1955} = 0.789$$

The date expected for the contaminated portion (B) is 1988 - 1898 = 90 years, whence we have the decay ratio

$$(N/N_0)_B = e^{-k\,90} = 0.989$$

The combined decay ratio is then $(N/N_0)_{comb.} = (f_A\ 0.789) + (f_B\ 0.989)$,
where f_A and f_B are weighting factors which account for the proportional weights of clean linen and of contamination carbon, as follows:

$f_A = 17.9 \div 50 = 0.3578$, and $f_B = 32.1 \div 50 = 0.6422$

The value of $(N/N_0)_{combined}$,that is, the carbon-14 decay ratio for the contaminated samples, is then

$$(N/N_0)_{combined} = (0.3578 \times 0.789) + (0.6422 \times 0.989) = \underline{0.9174}$$

Inserting this value 0.9174 in Equation 1 and solving for the indicated decay time, we get <u>t = 713 years</u>. This gives us a corresponding Historical Date of 1988 A.D. - 713 = <u>1275 A.D.</u>

Since 713 years is so close to the value of 724 years found in the 1988 radiocarbon measurements we conclude that our hypothesis <u>that the clean linen has a 1st century A.D. date of origin is acceptable</u>, provided also that the carbon in the non-removable contamination on the samples has an effective, bacterially reworked date of 1898 A.D.

Puting it another way, the *Nature* report found a range of radiocarbon dates of 1260-A.D. to 1390 A.D. at the 95% confidence level. Therefore, since our radiocarbon calcluation for a clean llinen of 33 A.D. origin which has become contaminated by 179% of carbon updated to 1898 A.D. gives a predicted radiocarbon date of 713 years - only 11 years off the measured result of 724 years - we must conclude that the cloth of the Shroud is of first century origin, also at the 95% confidence level.

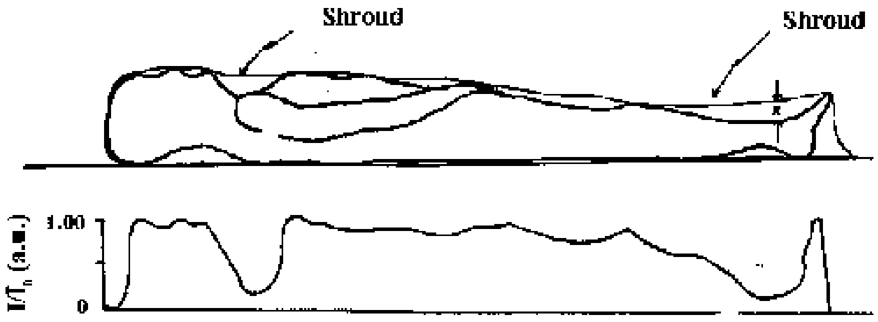

Figure 1: Shroud image intensity profile versus cloth-to-body distance (x)

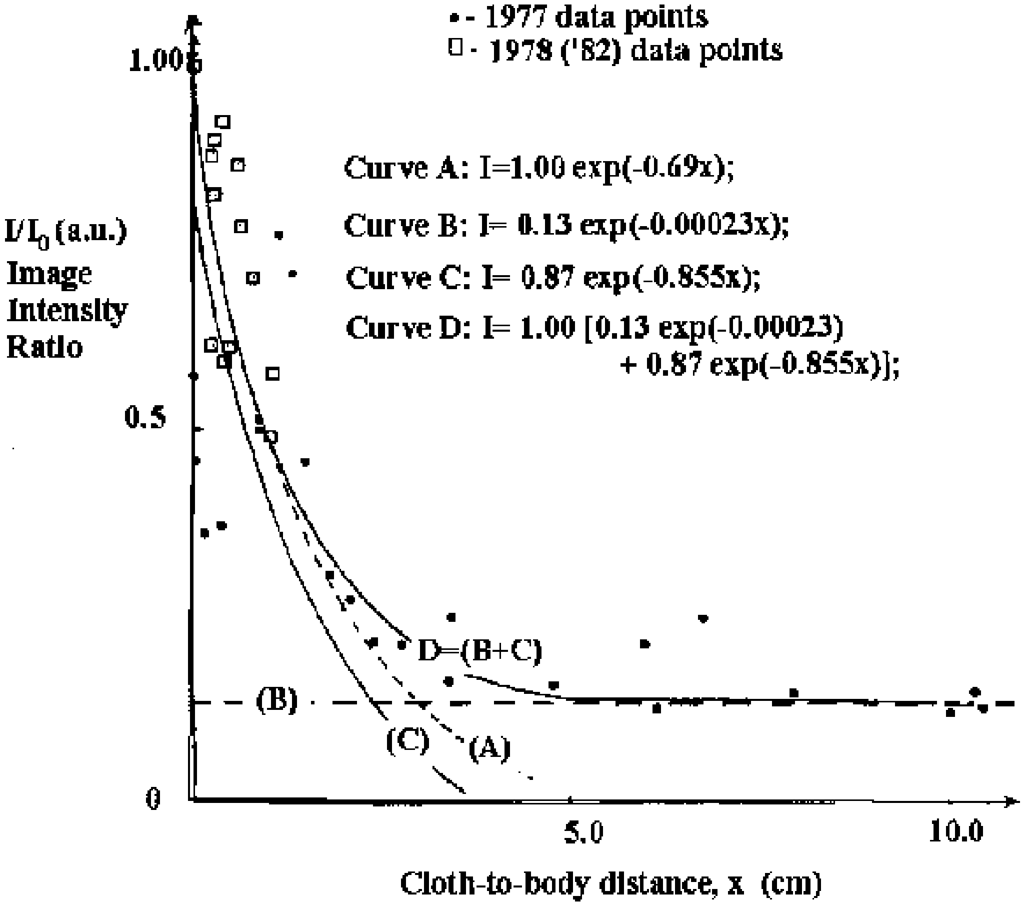

Figure 2: Shroud image intensity ratio versus cloth-to-body distance (x)

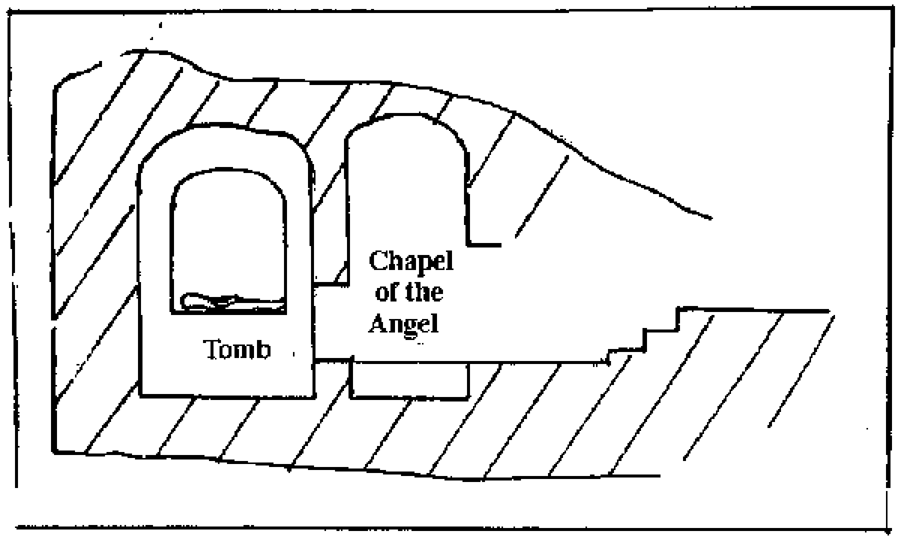

Figure 3a: Generalised cross-section of the Holy Sepulchre

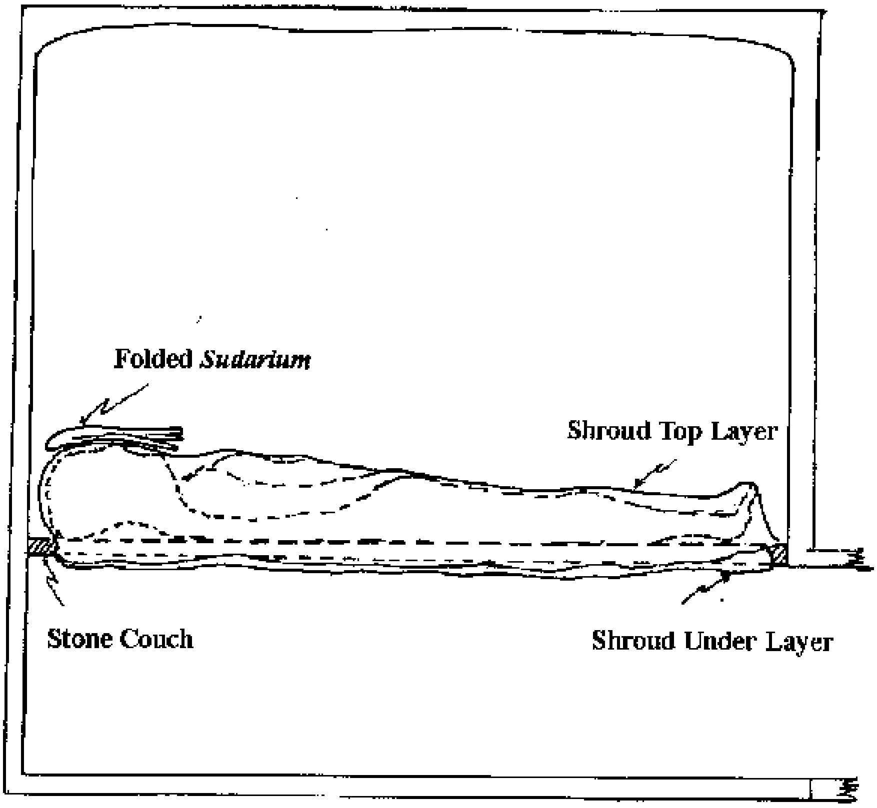

Figure 3b: Body enveloped in the shroud with the Sudarium 'over his head'

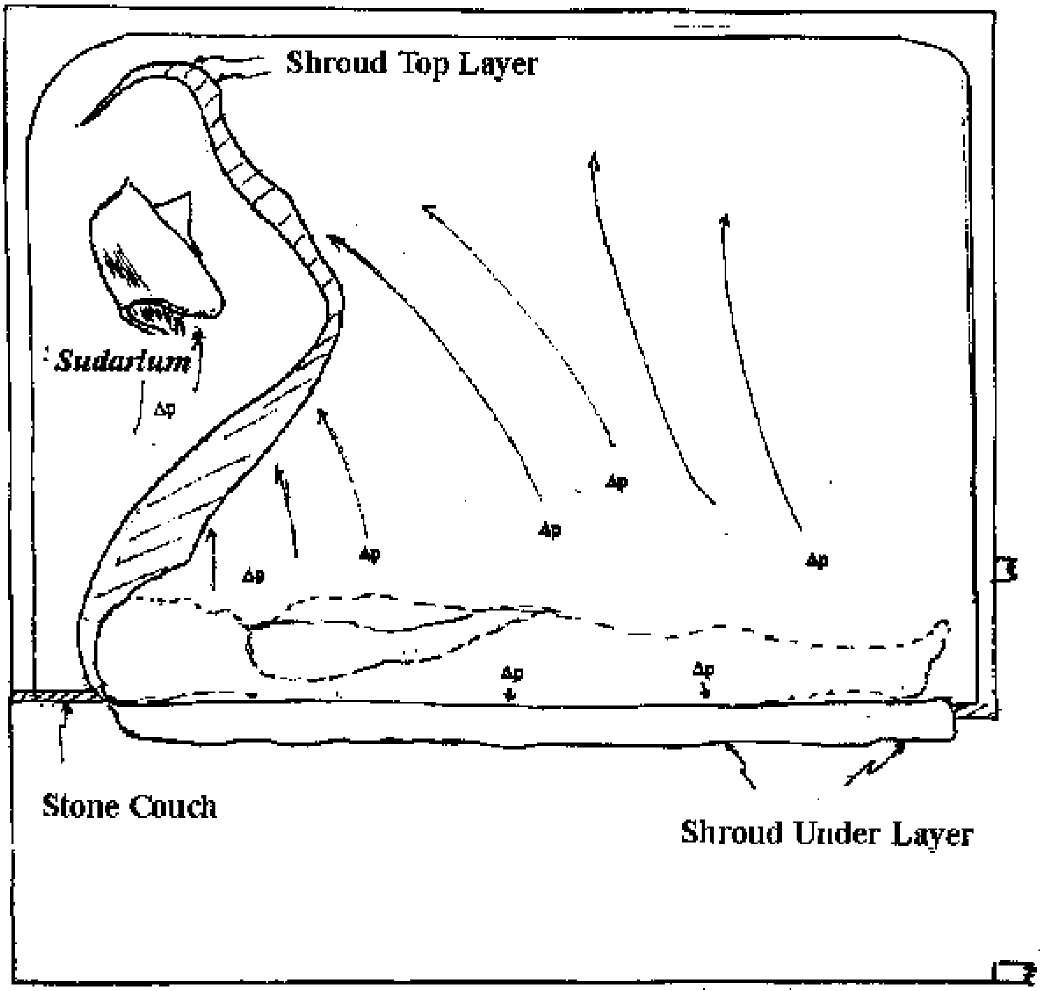

Figure 3c: Heat and pressure surge throws Shroud and Sudarium upwards towards the roof of the tomb, thereby separating them;

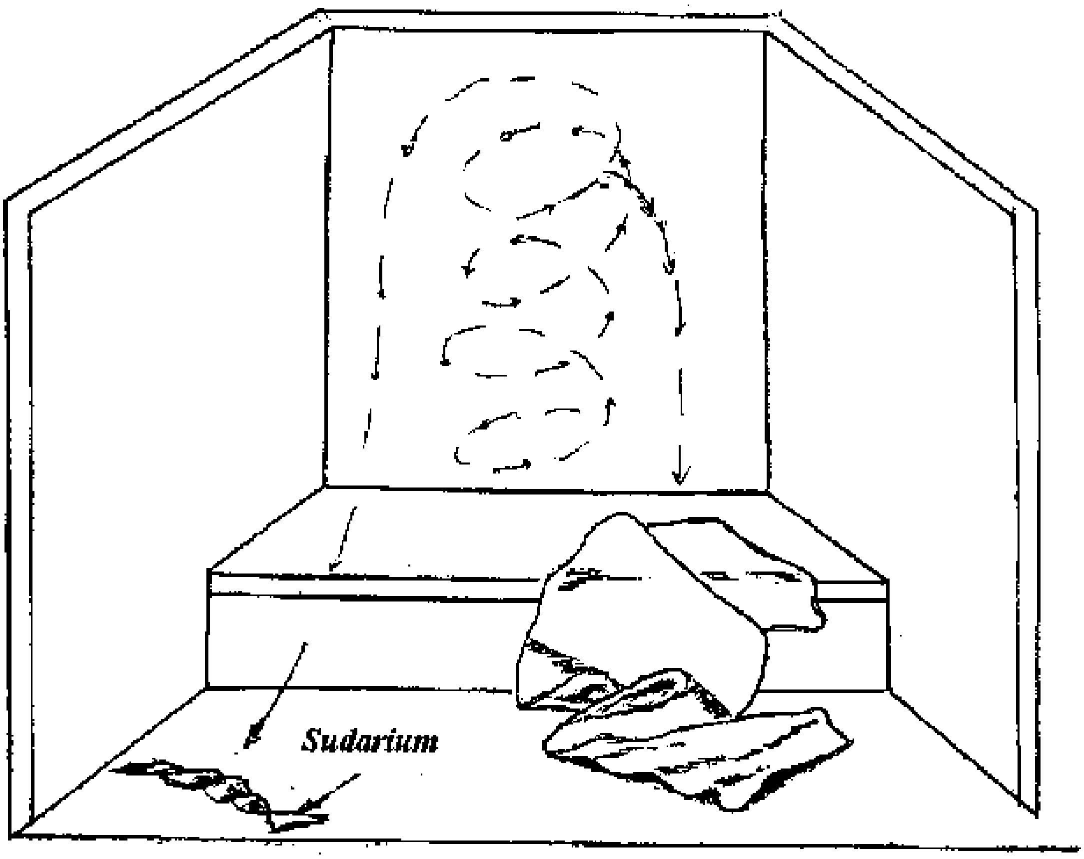

Figure 3d: Vortex throws the burial cloths onto the floor of the tomb and rolls up the Sudarium;

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