Special Feature

The Formation of the Shroud's Body Image

by
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*On 26 April 1995 Dr. Kitty Little, a retired nuclear physicist from the U.K.'s **Atomic Energy Research Establishment** at **Harwell**, gave a talk to the BSTS 'The Turin Shroud: How was the Image Formed?' She promised to prepare a publishable text of this, which she recently completed in a more developed form than in her talk, under the title 'The Application of Scientific Methods to a Study of the Turin Shroud'. The following is a key extract from this that includes description of her work irradiating fabrics during her time at Harwell:*

When the STURP team worked on the Shroud back in 1978 one of their problems was that they were unable to think up any mechanism that would account for the formation of the Shroud's image. This is a straw-yellow colour, on the surface of the fibres facing the body. Wherever a fibre crosses an underlying one the underlying fibre is unaffected. The fibrils from which the fibres were formed measure 15 microns in diameter. The colour of the image is confined to the surface fibrils. The colour change never affects more than one or two fibrils in depth, so that whatever caused the change can only have had very little depth of penetration. There are no obvious differences in the straw-yellow shade. It is merely the number of fibrils coloured that determine the intensity of the image. There are well-defined edges to the affected areas.

Another observation of considerable significance is that when blood was, or had been, present over the fibres, it also protected the underlying fibres from whatever caused the image. This means that the blood must have been in place before the image was formed.

Drs. Adler and Heller carried out exhaustive chemical tests, and found that the straw-yellow colour could be reproduced by "dehydrating acid oxidation" leading to the conjugated carbonyl groups that were responsible for the colour. But having got so far they were unable to find any "reasonable explanation as to how the image came to be on the cloth".

Now it seemed almost certain that the image must have been caused by some sort of radiation, but the various types of radiation that were suggested and tried did not produce the straw-yellow colour. However, there was one source of ionizing radiation that they did not try. The relevant experiments were carried out in 1950, but most of the results were not published until 1978 [Dr. Kitty Little, " Photographic Studies of Polymeric Materials ", Chapter 4, pp. 145-269, in *Photographic Techniques in Scientific Research*, vol. III, Academic Press, 1978].

One thing we can say is that the illumination for the formation of the image would seem to have come from the body. It had a limited range and was non- directional. The closer the material was to the surface of the body, the stronger the image. At a distance greater than about 2 inches or 4 centimetres, no image was produced. That is the range in air of alpha particles, mesons, and other products of nuclear disintegration. Further, these are particles whose range in solids is very small. If nuclear disintegration was the source of the illumination, then all the observations - including those recorded in the Gospels - would fall into place.

In 1950 (before I had heard of the existence of the Shroud) I irradiated a range of polymers and fibres, including several different cellulose fibres, in BEPO, a research reactor at the Atomic Energy Establishment at Harwell. At that time BEPO was being run at only 3.0 or 3.5 MW, so that the temperatures in the channels where most of the specimens were placed was in the range 70 C to 90 C. In a few instances the temperatures were as low as 40 C. That meant that radiation effects could be examined without the complication of heat degradation. The majority of specimens turned to varying shades of straw- yellow or yellowish-brown at high doses, and those that retained some molecular cohesion at very high doses turned to brown or dark brown shades. To obtain these high doses specimens were kept in the channels in the reactor for up to six weeks. The cellulose fibres turned to the straw-yellow colour that has been described for the image on the Shroud.

The linen of the Shroud is a cellulose, a polymeric material. That is, it contains long chain molecules, with repeating subunits, which pass through crystalline, partly crystalline and non-crystalline regions. There can be sample to sample variations when polymeric materials are irradiated, as a result of differences in the ordering of molecules as they pass through crystalline and non-crystalline regions. There could even be differences between one thread and another in the linen material.

The radiation doses to which the specimens placed in BEPO were subjected were far higher than those which would have been produced by ionizing radiation from other sources in an equivalent time. That radiation caused some chemical bonds within the molecules to be ruptured:

Some bonds are ruptured. Ends may remain apart, with the formation of nearby unsaturated bonds; bonds may reform; free ends may become attached to different free ends caused by rupture in other molecular chains; low molecular weight fragments may be lost; the fragments may tack onto the same or other molecular chains as side groups; reactions may occur with oxygen, water or other adsorbed materials. Altogether there are plenty of possibilities, but with very high radiation doses, of the order of 10,000,000 Mrad or more, one can expect either total degradation or the formation of a brittle glass-like material. At lower doses, up to 10,000 Mrad, the main interest is in changes that take place in the more flexible non-crystalline regions of the polymers and which affect their physical and mechanical properties . [Little, op.cit., p. 171].

Such changes, induced by the lower doses, may be beneficial, with toughness or resilience enhanced as a result of the redistribution of bonds, and can result in a greater resistance to solubility or chemical reactions.

The main products of a nuclear disintegration are the short-range high-energy particles, neutrons, gamma rays and heat. Observations in Hiroshima and Nagasaki after the two bombs in 1945 provided information about the heat flash. (Unfortunately most of the photographs have been destroyed, but I did have the opportunity to go through them not long afterwards). The heat flash was of very brief duration, so that only very inflammable materials caught fire. Most of the deaths in Hiroshima were due to burns, but those were ordinary burns. Flimsy buildings collapsed as a result of the blast, and were set on fire by the cooking fires - it was breakfast time.

An ordinary white material was sufficient to stop the heat flash without even being singed. This showed very clearly in the dresses some women were wearing, with a pattern of coloured flowers on a white background. The skin under the white areas was unharmed, while there were burns under the coloured flowers.

The conditions in BEPO when it was run at 3MW were such that heat was not a relevant factor. If the image on the Shroud was caused by a nuclear disintegration of the atoms in the body, we can say that the image was primarily due to the short range particles, and that any changes that took place in the main part of the Shroud were due to neutrons and gamma radiation.

The description given by the STURP team of the linen of the Shroud was that it was in remarkably good condition - "... it was supple, strong and felt almost like a new expensive tablecloth."

Neutrons and gamma rays have a comparatively long range, so that they would pass through the whole of the linen of the Shroud. As the neutrons passed through their main action would be to convert some of the hydrogen into tritium. This is radioactive, has a half-life of 12.26 years, and emits low energy beta radiation. This has only a short range, but would have the effect of inducing some virtually strain-free cross-linking of molecules in the non- crystalline regions. Given a high crystallinity, such as one would expect to find in good quality linen, more crystalline than an "ordinary" cotton, that would account for the description that was given of the material of the Shroud. (The usual practice was to put the bodies of Jewish crucifixion victims into common graves, and so it would be extremely improbable that any other crucifixion victim would be buried in an expensive shroud, as is indicated by the present properties of the linen).

This type of cross-linking also reduces solubility and susceptibility to oxygenation and other chemical reactions, which would account for the lack of degradation and "ageing" that might be expected in a material 2,000 years old, and that had been subjected to repeated handling and ill-treatment. Such a reduced chemical activity would also account for the fact that although the Shroud was reported to be covered with mildew spores there were no mildew reactions, so that the fabric was unharmed.

In the areas affected by the high-energy short-range particles the effect was quite different. With molecular chains shortened and ordered regions disrupted, the mechanical strength would be greatly reduced - that is, the material would become friable, something that Dr. Adler and Dr. Heller observed.

In the BEPO experiments an X-ray diffraction technique was used to give a qualitative assessment of the ordered, partially ordered or disordered regions. The cellulose with a structure nearest to linen that was investigated was cotton.

With massive radiation doses cotton remained a solid, but went to a fine powder. Its ordered regions broke up at about the same rate as its loss of strength. By 120,000 Mrad there was some loss of definition in the diffraction patterns, while by 680,000 Mrad they showed a mixture of a non-crystalline but partly ordered structure and completely amorphous . [Little, op.cit]

The effects of high doses of radiation on different bonds is different, and this becomes relevant in the formation of the conjugated double bonds that produce the yellow to brown colours. Even at comparatively low doses the factors that become of importance can be observed. **Dr. Dole** [M. Dole, 1959, J. Chem. Educ., vol. 36, no 353], using infra-red analysis, found that bond energies do not always correlate with radiation stability. For example, the C-H bond has a higher strength (4.08 ev) than the C-C bond (3.21 ev), yet it is the C-H bond that appears to be ruptured more easily, because the C-C bonds reform more rapidly and more effectively. Again, C-O bonds show little or no tendency to reform after rupture.

This means that some of the hydrogen is likely to diffuse away as hydrogen gas, while there will be a surplus of free carbon ends. Stability is restored by the formation of double bonds. With increasing radiation doses, and increasing loss of hydrogen, the number of conjugated double bond systems increases. So, also, the depth of colour increases with increasing radiation dose. With the passage of neutrons a certain number of tritium atoms would be formed. The soft beta radiation that they emitted would help to stabilize the structure.

There is a major difference between the formation of the friable regions in the Shroud and the formation of similar regions in materials irradiated in BEPO. The former happened in an instant, and so the oxygen in the air did not have time to induce the chemical changes. In BEPO the irradiation covered a period of days. Most specimens were therefore irradiated in air and also in an inert atmosphere. To produce a genuinely inert atmosphere it was found necessary to use pure argon. The specimens were "rinsed" several times with the pure argon, before being sealed in more argon in glass capsules. They were then irradiated. The radiation to which those specimens were subjected was a mixture of gamma radiation and neutrons. Some specimens were also irradiated under a Van de Graaf generator. There there could be heat problems, but a subjective impression was that it was the total dose rather than the particular source of radiation that was important. What was important was to avoid the complication from oxidation reactions.

Descriptions of the altered areas of the Shroud, when compared with observation of the materials irradiated in BEPO, suggest a very high radiation dose, more than 120,000

Mrad and less than 680,000 Mrad, but probably nearer the latter. In trying to assess the dose to which the Shroud was subjected by such a comparison one needs to bear in mind that in the early centuries artists used the Shroud as a model, and so must have been able to see the image clearly. At that time, therefore, it must have had a deeper shade of colour than it has at present. Either there has been a gradual fading of the image or, more likely, oxidation was accelerated at the time of the fire, so reducing the number of double bonds.

The appearance of the image and the properties of the linen of the Shroud can thus be explained if the cause was the nuclear disintegration of the atoms in the body. With such a disintegration - a minor nuclear explosion - light and energy would also be produced. In the body the main elements involved would be carbon, hydrogen, oxygen and nitrogen, together with smaller quantities of calcium, phosphorus and sulphur. These all have lower molecular weights, and a lower proportion of internal energy, so that the energy liberated would be far less than that from the disintegration of the heavy atoms in nuclear weapons. It would still be sufficient to move the stone at the entrance to the tomb, and to make the guards think that there had been an earthquake.

An instantaneous disintegration of the nuclei of the atoms in the body would account for the formation of the image, detail by detail, and the good state of preservation of the linen of the Shroud. It would seem to be the only mechanism whereby the straw-yellow colour could be produced - and the lemon-yellow colour of the serum deposits. It would have to be instantaneous to account for the well-defined image, in terms of the clarity of detail and the range of the radiation causing the image before any collapse of the linen cloth. The minor earthquake described in the Gospels is also explained. This gives the answer to the last remaining problem faced by the STURP scientists.