nique did he permit the test to go forward.

So intense are people's feelings about the Shroud, however, that even that decision provoked controversy. There are currently seven laboratories in the world equipped to do this kind of measurement. And when representatives from each one met last year to design protocols for the Shroud experiment, they agreed to an elaborate double-blind setup with multiple control samples, and with testing by all seven sites. Yet Cardinal Ballestrero and his science adviser, Luigi Gonella, refused once again on the grounds that seven pieces of the Shroud—even seven small pieces—was too much. In October 1987 they therefore decreed that the radiocarbon tests would be conducted by just three laboratories: Arizona, Oxford, and Zurich. These were the three that had specialized in dating with carbon-14, as opposed to other isotopes, and that had acquired the most experience in working with archeological material.

The protests from the rejected laboratories were predictably loud: Harry Gove of the University of Rochester and Garmon Harbottle of the Brookhaven National Laboratory even held a press conference to protest. But Ballestrero and Gonella were not to be moved. And indeed, now that the results are in and passions have cooled, there seems to be general agreement that things have gone satisfactorily. "Scientifically, there is absolutely no problem in getting a good final result," says Michael S. Tite, director of research at the British Museum, who is coordinating the project in collaboration with the Pontifical Academy of Sciences.

To eliminate any possibility of fraudulent substitution, for example, all three samples were removed from the Shroud by a qualified textile expert working under the supervision of Tite and Cardinal Ballestrero. Each sample weighed 40 milligrams, and each was taken from a single site on the Shroud away from any patches or charred areas. (The Shroud was damaged by a fire in 1532.) The samples were then weighed, wrapped in aluminum foil, and sealed in numbered stainless steel containers. At the same time, 40-milligram control samples of known age from the British Museum collection were packaged in the same way. Immediately thereafter, representatives of each of the three laboratories were provided with three containers apiece: the Shroud and two controls. The whole proceeding was recorded by videotape and still photography.

The testing sites, for their part, saw to it that there was always at least one observer watching every step of the dating process: chemically cleaning the sample to remove any contaminants—a drastic step that essentially reduces the cloth to pure cellulose; burning the residue for conversion into graphite; compressing the graphite into tiny pellets; and then bombarding the pellets with cesium atoms in vacuum to supply a steady stream of ionized carbon for the accelerator. Each 40-milligram sample provided enough material for multiple runs. "This all would have been routine for us, except for the public attention," says Damon.

As a final step, the three laboratories sent their data to Tite, who correlated them all into a final result in conjunction with the Institute of Metrology in Turin. (Apparently, all the control samples were dated correctly.) After sending his answer back to the laboratories for concurrence, he then forwarded it to Cardinal Ballestrero to release at his discretion.

For all the care taken with the experimental protocol, however, it was less than pristine in one respect: the tests were not blind. The linen of the Shroud has a very distinctive herringbone weave, and, as Damon admits, "We *were* able to tell which piece it was."

The researchers cannot help but be a little defensive about this. And indeed, someone—whether skeptic or believer—will certainly wind up condemning the experimental results because of it. But the decision not to have a blind test was a deliberate one. Even if all the samples had been shredded, says Tite, factors such as color would still have allowed the laboratories to distinguish the Shroud. And as Oxford's Hedges points out, to have asked a third party to grind up the fibers any further would have greatly increased the risk of contamination. So the samples were delivered whole.

And in truth, one does have to wonder whether a hard-nosed double-blind protocol would have made any real difference in this case. From all reports, the data required very little in the way of subjective interpretation. "I was invited to Arizona to watch," says Rochester's Gove. "And on the first sample, they knew from the first minute what the answer was."

■ **M. MITCHELL WALDROP**

ADDITIONAL READING

B. J. Culliton, "The mystery of the Shroud of Turin challenges 20th-century science," *Science* **201**, 235 (1978).

Science Achievement in Schools Called "Distressingly Low"

U.S. science education brought home another disappointing report card last week. This time, one expert said, the grade was at best a C− or D.

A report prepared by the Educational Testing Service (ETS) using 1986 data shows that only about 7% of 17-year-olds are adequately prepared for college-level science courses. Even worse, the report says that more than half the nation's 17-year-olds have so little scientific understanding that they cannot hold down jobs that require technical skills, benefit from specialized on-the-job training, or make informed decisions as citizens. Science achievement for 17-year-olds overall in 1986 was well below 1969.

Younger students fare only a little better. Achievement for 13-year-olds remains below that of 1970 and 9-year-olds are achieving at roughly the same level as in 1970. Only half of 13-year-olds, for example, can apply basic scientific information to answer questions such as: "Which of the following diseases is not directly transmitted among people in contact with each other: herpes, influenza, tuberculosis, diabetes."

The data come from the Science Report Card, a federally mandated study that monitors student performance in a wide variety of subjects. The study collects data from 9-, 13-, and 17-year-olds across the country.

ETS president Gregory Anrig, who gave science education the low grade, also gave grades to writing (D), mathematics (C+), and reading (B or B−).

The report confirms the sex and race gaps that previous studies have found in science achievement. Whereas black and Hispanic students have made some gains in the past 4 years, 13- and 17-year-olds remain at least 4 years behind their white peers in science proficiency. Only about 15% of black and Hispanic 17-year-olds show the ability to analyze scientific procedures and data, while nearly half their white peers can do so. For example, few know that a drop in barometric pressure is the best indication of an approaching storm.

In introducing the report, education officials called on astrophysicist Carl Sagan of Cornell University, Bassam Shakhashiri of the National Science Foundation, and Philip and Phylis Morrison of MIT to voice their concern. No specific policy proposals were forthcoming, but Sagan suggested that attitudes on the part of national leaders have gone awry. "Excellent grades on future national report cards in science are more central to our national security than half a dozen strategic weapons systems," Sagan said. "The present mediocre grades should sound an alarm." ■ **GREGORY BYRNE**