

SECTION VII

AFTERWORD



ARE WE A SPACEFARING SPECIES?
ACKNOWLEDGING OUR PHYSICAL FRAGILITY
AS A FIRST STEP TO TRANSCENDING IT

M. G. Lord

In a preface to *The Man Who Sold the Moon*, a 1950 collection of short stories, Robert Heinlein emphasized that science-fiction authors do not generate “prophecy.”¹ They write speculative fiction, a riff on the notion of “What if?” Often they invent alternative realities to critique aspects of the world in which they live. Yet our aspirations to become a spacefaring species—and our assumptions about our abilities to do so—were defined by science fiction, from the cannon-ball-shaped spaceship that blasted off in Jules Verne’s 1865 fantasy *From the Earth to the Moon* to the canonical stories and screenplays produced by various authors—Ray Bradbury, Isaac Asimov, Frank Herbert—during the Cold War.

What interests me is the disparity between who we are in our imaginations and who we are in real life. In fiction, we have mastered extraterrestrial flight; our technology enables us, to quote a classic split infinitive, “to boldly go” anywhere. In reality, however, we are fragile creatures that do not thrive outside Mother Earth’s atmosphere, gravity, and magnetic field. In the last 40 years, robotic scouts—many designed and flown by NASA’s Jet Propulsion Laboratory (JPL)—have sent home tantalizing glimpses of new worlds. In the next 40 years, we ourselves will strike out for these worlds—planets many times more distant than our Moon, worlds truly apart.

Engineers have demonstrated the know-how to build a craft that will transport a crew to, say, Mars. But there is a catch. In recent months, biomedical researchers working in relative obscurity have begun to raise a big unanswered question: Can the human body withstand a prolonged journey into deep space? The constraints imposed by our biology could have profound societal implications. What does it mean to our collective dreams if a major obstacle exists to realizing them? And how much risk—as well as financial expenditure—will society tolerate in their pursuit?

1. Heinlein, Robert, *The Man Who Sold the Moon* (New York: Signet, 1950), pp. v–vi.

Galactic cosmic rays are the “dragons” that lurk beyond Earth’s magnetic field, the biggest threat to human spaceflight. And they are not just of concern to a few Chicken Littles. They trouble, for example, Shannon Lucid, the plucky astronaut who spent 223 days, 2 hours, and 50 minutes in space, the longest stint of any American woman. “Radiation could be a showstopper,” she said.²

This is a far cry from the way radiation appeared in literature at the dawn of the space program. In *Americans into Orbit*, a 1962 book aimed at young readers, radiation was simply one more hurdle that a can-do astronaut could easily surmount.³ No air in space? We’ll take it with us. No gravity? We’ll spin the spacecraft and make some. And to reverse the decline of muscle and bone caused by weightlessness, we’ll lash ourselves to a treadmill and break a sweat.

In 1961, Marvel Comics writer Stan Lee and artist Jack Kirby actually cast radiation as benign, suggesting it could produce positive mutations. After exposure to a solar flare during the flight of an experimental spacecraft, the Fantastic Four—scientist Reed Richards and his fellow astronauts—morphed into crime-fighting superheroes: Mr. Fantastic, the Thing, the Human Torch, and Invisible Woman (who back then was called Invisible Girl).

Perhaps the fiction most responsible for the dream of safe, easy travel was Robert Heinlein’s *Rocket Ship Galileo*, a 1947 tale of two boys who, with the help of one boy’s scientist uncle, cobble together a rocket in their back yard and blast off for the Moon. Nearly every engineer I interviewed for *Astro Turf*, my recent book on JPL, recalled Heinlein’s impact, as did many of today’s space entrepreneurs: X-Prize founder Peter Diamandis, XCOR chief Jeff Greason, and even *SpaceShipOne* financier Paul Allen.

Heinlein was not unaware of radiation, and he knew it could cause mutations. But he, too, cast them as benign. His character Joe-Jim, for example, a two-headed beefcake who leads a mutant army in *Universe* (1951), is none the worse for his genetic anomaly. If anything, because Joe-Jim has the thinking power of two brains, he is better.

What exactly is a galactic cosmic ray and why does it pose a threat? It is a high-energy heavy ion that originates from an exploding supernova outside our galaxy. Such atoms travel very fast, about the speed of light, and they are said to be “ionized,” meaning that they have gained or lost electrons. As a consequence, they carry a positive or negative charge. They can be any element up to the atomic weight of iron. We don’t encounter them on Earth because our atmosphere protects us. Likewise, the Earth’s magnetic field, which extends beyond the atmosphere, functions as a shield—except for a small, quirky patch of orbit over Brazil known as the “South Atlantic anomaly,” where it does not.

2. Interview with Shannon Lucid, Johnson Space Center, 5 June 2005.

3. Gurney, Gene, *Americans Into Orbit: The Story of Project Mercury* (New York: Random House, 1962), p. 28.

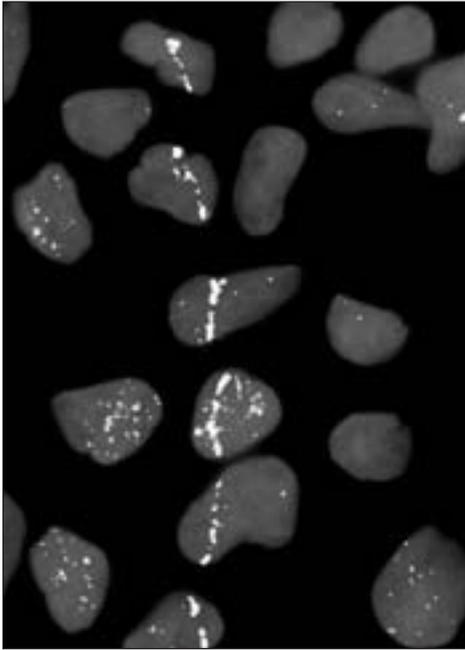


Figure 32.1—This image shows a “track” made by a heavy ion passing through a brain cell in vitro. (Image courtesy of Brookhaven National Laboratory.)

One might expect lead—that familiar prophylactic against dental x-rays—to provide shielding. But a lead “shield” actually compounds the problem. When a heavy ion strikes an atom of lead, it dislodges a cascade of charged particles that can cause destruction similar to that of the heavy ion.

Think of a cosmic ray as “a bullet flying around with speed and mass,” Marcelo Vazquez explained.⁴ He is a researcher at Brookhaven National Laboratory on Long Island who studies the effect of radiation on brain cells and other tissue. “When the rays go through

matter—it can be a rock, a body, or your brain—they produce so much energy and charge that they produce a kind of hole. But they also produce secondary particles, like a shower.” These secondary particles are called delta rays.

Hydrogen compounds offer the best protection against secondary particles because hydrogen atoms contain one electron for one proton. The current best solution for a Mars-bound ship is an aluminum or carbon-composite shell, with 2 to 4 inches (5 to 10 cm) of polyethylene (a hydrogen compound) around the crew compartment. Water is another efficient shield. But nothing—not even an artificial electromagnetic shield around the spacecraft—will block the rays entirely.

Shielding matters because cosmic rays kill brain cells (or, in any case, brain cells in vitro). In Vazquez’s laboratory experiments, cosmic rays induced what is called programmed cell death in neurons. The bombarded brain cell assesses its degree of damage and decides to die rather than try to fix itself. Moreover, as a heavy ion passes through a column of cells, it forms a “track,” which you can see in the microscopic image in figure 32.1. Dislodged particles career out from this track, inflicting yet more damage on adjacent tissues.

4. Interview with Marcelo Vazquez, Brookhaven National Laboratory, 10 November 2005. All Vazquez quotations are from this interview; some of Vazquez’s observations are cited in M. G. Lord, “Impossible Journey,” *Discover* (June 2006): 38–45.

Vazquez has written papers calculating the amount of brain cells that will be struck by cosmic rays on a two-and-a-half year voyage beyond the Earth's magnetic field—in other words, on a Mars trip as it is currently conceived by NASA planners.

Depending upon the size of the cell, we estimate that between 13 percent and 40 percent of brain cells will be hit once by cosmic rays We have billions and billions of cells in our brain. But 40 percent is a lot. Some areas are very tiny, but they play an important role in functioning. If you wipe out those cells, you don't need to worry about the hundreds of billions of cells. A few million—you're gone. [Alzheimer's patients lose about 5 percent of their brains annually.]⁵

Radiation, we know from studying atomic bomb survivors, put people at risk for long-latency soft-tissue tumors. But, Vazquez pointed out, leukemia can develop more quickly, in as few as two years, raising the possibility of a severely brain-damaged, fatally sick astronaut barely limping back to Earth.

Of course, what happens to cells *in vitro* does not always reflect what happens in the body, where optimists hope repair will be possible. "To go from Petri dishes to humans is a big jump," Vazquez said. But his experiments on animals do not bode well for astronauts. Rats exposed to cosmic rays, as well as rats exposed to conventional radiation, showed major impairment of motor skills, measured by their ability to move around in a box. Over a period of 11 months, the rats exposed to x-rays and gamma rays recovered some of their lost coordination, but the rats exposed to cosmic rays appeared never to recover.

On the bright side, NASA scientists believe they have solved one major radiation problem: solar particle events. These are sudden bursts of hot plasma that periodically spew out at high speeds from our Sun. When astronauts return to the Moon, they will most likely tour its surface in a vehicle equipped with a solar-particle shield. Or they will carry equipment for building a temporary storm shelter—a concept that will also work on Mars where, because the planet is farther away from the Sun, astronauts will have more time to secure refuge. The most acute problem remains chronic exposure to cosmic rays.

Not only does chronic radiation exposure hurt people, it also degrades the drugs used to treat them. The antibiotics NASA currently uses on Shuttle missions (Bactrim, Cipro, and Augmentin) lose their potency after about two weeks in space, according to Lakshmi Putcha, a pharmacotherapeutics researcher at the Johnson Space Center.⁶ If Mars-bound astronauts equipped with these drugs in their current formulations became ill, she said, "We would have no way of treating them."

5. Lord, "Impossible Journey."

6. Interview with Lakshmi Putcha, Johnson Space Center, 7 June 2005.

The problem of drug degradation, however, is not insoluble, and its resolution could come through chemical engineering—coating the active ingredients of a drug with a substance or material that will preserve its effectiveness. For example, lidocaine (an anesthetic used on the Space Shuttle) is suspended in water—a radio-resistant substance—so it tends not to degrade in flight. Dosage for astronauts is also a hit-and-miss affair, particularly for substances ingested orally. Gastrointestinal motility slows down in space and it takes longer for medications to be absorbed.

Space medicine is a long way from the ideal projected in *Star Trek: Voyager* where a holographic doctor, the Mark I Emergency Medical Hologram, performs nifty repairs without ever making a cut. Indeed, laparoscopic surgery, because it does not release buckets of blood, is well-suited to microgravity. Astronaut and medical doctor Dafydd Williams and Mehran Anvari, a Canadian scientist specializing in telerobotic surgery, have been experimenting with telerobotic medical techniques that might be used at, say, a Moon base.⁷ But because of the 20-minute lag for radio signals between Earth and Mars, telerobotics will not be of much use to a crew on Mars.

Space medicine must advance before a Mars flight because the human body—even one belonging to a robust astronaut—is extremely vulnerable in space. In a test on an early Shuttle mission, astronauts were pricked on the arm with various antigens, to which they showed diminished immune response. Latent viruses also express themselves in space. NASA microbiologist Duane Pierson has published several papers documenting the presence in astronaut saliva of various viruses, including Epstein-Barr, which has been linked to human mononucleosis.⁸ Other common latent viruses could be yet more uncomfortable if they reactivated on a long spaceflight—chicken pox, for example, which usually returns as shingles. And no data exist on whether antiviral drugs, such as acyclovir, work in flight.

The main issue, which NASA scientists have been unable from their current data to determine, is: Does the immune system remain severely depressed, or, in the words of NASA immunologist Clarence Sams, does it “adjust to a new normal?”⁹ Some researchers are optimistic that if they could collect data throughout the mission, instead of merely at takeoff and landing, their results might be different. But stress of the sort experienced by, say, researchers in Antarctica also degrades the immune system. And radiation is a big wild card, which may intensify the weakening. Vazquez was blunt in his assessment of a Mars mission: “No matter what you do, you put a guy in a can for six months and it’s a big stress.”

Skeptics often ask, Why bother to leave Earth? Science fiction answers that question with a bigger question, a question that has haunted human society since its first members looked skyward: Are we alone in the universe?

7. Interview with Dafydd Williams, Johnson Space Center, 6 June 2005.

8. Interview with Duane Pierson, Johnson Space Center, 7 June 2005.

9. Interview with Clarence Sams, Johnson Space Center, 7 June 2005.

In the 1980s, NASA began a ground-based program, the Microwave Observing Project, to address this question. It involved a systematic sweep of the heavens with radio telescopes. The project was of immense concern to scientists, artists, theologians—just about everyone but former Senator William Proxmire, who tarred it with his “Golden Fleece” award for wasting public money. In 1982, Congress cut the project’s funds, but the public’s yearning for an answer was more powerful than Proxmire’s scorn. Privately financed, the sweep continues.

Robots also seek evidence of life. At JPL, the mission architect’s mantra—“Follow the water”—is code for “Find clues linked to life.” In 1976, scientist Carl Sagan was involved with Project Viking, the Martian probe that some scientists hoped would detect traces of life. Such a wish, however, was never made explicit. Nor was it gratified, which may have led Sagan to fulfill it through science fiction. Nine years later he published *Contact*, a novel describing a fictive alien encounter.

Scientists approach the hunt for life with a mixture of hope and dread, their expectations molded by science fiction. Hope is inspired by the aliens who came in peace; dread, by those who waged war. The film *The Day the Earth Stood Still* (1951), directed by Robert Wise, is a hopeful classic; benevolent aliens try to stop us from destroying ourselves. They stand in sharp contrast to the weapon-toters who touched down in H. G. Wells’s *War of the Worlds* (1898). And I find it hard not to view Robert Heinlein’s *The Puppet Masters* (1951), about an invasion of parasitic extraterrestrial slugs, as a prescient book. In one scene, scientists view a map of this country. Its central states are designated “red”—indicating the residents’ brains have been taken over by alien slugs.¹⁰

The most interesting fantasy, however, involves the commingling of human DNA with that of a benign alien species—the subject of Octavia Butler’s Xenogenesis Trilogy, whose first volume, *Dawn*, appeared in 1987. Butler, an idiosyncratic loner, may not consciously have sought to comment on the zeitgeist, but her theme reflected the times. With the Cold War nearing an end, Americans were less paranoid about the alien, or—to strip away a metaphor—the communist “Other.”

In contrast, at the height of the Cold War, alien motives were highly suspect. Arthur C. Clarke’s *Childhood’s End* (1952) is a chilling fantasy of alien “Overlords” who dupe us into relinquishing our autonomous future. Perhaps the funniest—and the cruelest—comment on our eagerness to trust was a 1962 television episode of the *Twilight Zone* adapted by Rod Serling from a short story by Damon Knight. Titled “To Serve Man,” the show introduced an extraterrestrial race devoted to advancing human health and agriculture. All that human cryptographers know about this race is the title of what appears to be their bible: *To Serve Man*—which, as it turns out, is a cookbook.¹¹

10. Robert Heinlein, *The Puppet Masters* (New York: Ballantine, 1990), p. 151.

11. Marc Scott Zicree, *The Twilight Zone Companion* (Los Angeles: Silman-James Press, 1982), pp. 235–236.

Since the beginning of the Cold War, gender roles have also been rethought. No longer, for instance, is the idea of women astronauts ridiculed as it was in 1962, when scientist Wernher von Braun responded dismissively to a question about women in space. His boss at the Agency, he quipped, might allow room on a future mission for “110 pounds of recreational equipment.”¹²

Curiously, during the Cold War, when the private lives of American engineers were often rigidly sexist, the science fiction they consumed explored unconventional gender identities.¹³ Heinlein, for instance, was almost subversive in the way he proselytized for women as equals, anticipating the careers of astronauts such as Shannon Lucid. “Delilah and the Space Rigger,” his short story from 1949, featured a woman engineer who coeducates an all-male space station, transforming her misogynistic boss into a cautious feminist because her presence increases productivity.

But at odds with fiction is this troubling fact: Women are in certain ways less suited than men to long-duration space travel. Breasts and ovaries are vulnerable to radiation-linked cancers in ways the prostate, for example, isn’t.¹⁴ And women’s metabolisms are different. Promethazine, NASA’s motion sickness drug, takes longer to reach a level of effectiveness in women. Women also tend to show more orthostatic intolerance—light-headedness after getting up from bed or being in space.

Walter Sipes, a Johnson Space Center psychological researcher, believes a mixed-gender crew may have psychosocial advantages on a Mars trip.¹⁵ But women will have to ask themselves: Is this worth the risk?

In an e-mail sent in September 2006, Vazquez reminded me that solutions to the radiation problem will mostly likely not come exclusively through engineering. They will also be operational and medical, and they will always involve *minimizing* rather than eliminating risk.

Francis Cucinotta, chief scientist of NASA’s radiation program, explains his Agency’s goal: Limit an astronaut’s radiation exposure so that his or her likelihood of developing cancer will be no more than 3 percent greater than that of an average person.¹⁶ Astronauts, as a result, wear dosimeters to monitor the radiation they receive during flight. But the 3 percent is a murky number because data on soft-tissue cancer formation, gleaned largely from atom bomb survivors, are imprecise. Likewise, the dose rate, the type of radiation, and the differences between the populations exposed play a role in computing probability, as do individual dietary, environmental, and genetic factors.

12. Wernher von Braun quoted in Howard E. McCurdy, *Space and the American Imagination* (Washington, DC: The Smithsonian Institution, 1997), p. 224.

13. M. G. Lord, *Astro Turf: The Private Life of Rocket Science* (New York: Walker, 2004), pp. 185–187.

14. Vazquez talked about women’s cancer risks in the interview cited earlier.

15. Interview with Walter Sipes, Johnson Space Center, 7 June 2005.

16. Interview with Francis Cucinotta, Johnson Space Center, 9 June 2005.

These are some solutions that might make for a safer Mars trip:

1. Travel faster to reduce exposure. Power the spacecraft with a nuclear reactor placed far away from a well-shielded crew compartment.
2. Surround the spacecraft with an artificial magnetic field—an engineering solution that has not yet proven feasible.
3. Surround the crew quarters with a shield of water—currently impractical because of the expense of getting an immense weight, or mass, of water off the Earth.
4. Ingest foods or drugs that shield against radiation. The flavonoids in blueberries and strawberries have antioxidant properties. They don't yet protect the brain from radiation, but in 30 years there may be a breakthrough.¹⁷
5. Finally, send a bunch of aging space cowboys. If, after 10 years, astronauts in their seventies developed cancer, one could hardly say they were struck down in the prime of life. “My kids said that NASA should send me to Mars,” Shannon Lucid joked. “They said, if NASA would send you when you're 80, Mom, then you could live up there, do something, and they wouldn't even have to worry about bringing you back.” Of course, with the nearest emergency room 30 million miles away, NASA had better make progress on that holographic doctor.¹⁸

The most radical solution, and the one with the greatest societal impact, however, may involve genetic engineering. In defiance of the odds, some atom bomb survivors have not developed soft-tissue cancers. Scientists need to examine their genetic material to determine why. Resistance to radiation would be a strong asset to an astronaut on a long-duration mission. Because of concerns over the medical privacy of astronauts, it's currently illegal to screen a crew based on genetics, but this might change for a Mars mission. Or, in the more distant future, a private agency could grow radio-resistant astronauts through the miracles of genetic engineering—an idea with a science-fiction precedent.

Gattaca, a 1997 movie written and directed by Andrew Niccol, describes a space program in which astronauts are chosen based on genetic superiority. In the movie, this is a bad thing. The hero is a love child, not the product of a eugenics exercise. Yet the hero's short-term triumph—securing a spot on a desirable space mission—may seem less admirable if his weak genes expose him to a fatal illness. In the 1970s, in vitro fertilization procedures were uncommon as well as ethically suspect. Today they are performed frequently and not considered an ethical problem. Likewise, other eugenics procedures that are not approved today may become commonplace in the future.

17. Vazquez discussed flavonoids during his 2005 interview cited earlier.

18. A variety of solutions are discussed in Eugene N. Parker, “Shielding Space Travelers,” *Scientific American* (March 2006): 41–47; also Lord, “Impossible Journey.”

At an International Space Development Conference in Los Angeles in May 2006, I chatted informally with some people from the Space Frontier Foundation. We discussed space tourism—the fact that engineer Burt Rutan’s suborbital spaceship and Los Vegas entrepreneur Robert Bigelow’s orbiting hotel, things that science fiction writers had forecast, were hurtling toward reality.

When Heinlein’s 1955 novel *Tunnel in the Sky* came up, however, some space fans said things that disturbed me. In expressing their desire to emulate the novel’s characters, they failed to make a distinction between plausible reality and fantasy. Set in the future, the novel deals with a group of high school students taking a survival test who end up stranded on a hostile planet. One of the kids who weathers the ordeal returns to Earth but later goes back to the planet with other settlers to found a colony.

I understand the allure of space settlement and share a passion to achieve it. But there is no “tunnel in the sky”—a safe passage without radiation to distant worlds. On Mars, the preferred destination of today’s settlers, there is no magnetic field to shield people from cosmic rays. The most disturbing comment I heard in a space settlement workshop was “When are we going to see babies born in space?” Not soon, I hope, given the damage cosmic rays are known to cause to genetic material.

Robert Zubrin, the engineer-founder of the Mars Society who favors a trip to Mars with Apollo-era technology, has pooh-poohed the threat of radiation. In a 2003 letter responding to a *New York Times* article on space radiation, he pointed out that astronauts who spent months in Earth orbit have not been debilitated.¹⁹ Yet oddly, he did not adequately consider the fact that low-Earth orbit is within the Earth’s magnetic field, and Apollo astronauts never spent more than a couple of weeks outside it.

John Charles of the NASA Space Life Sciences Division seems to have a firmer grip on reality. “Lots of internal discussion is going on now about what level of risk is acceptable for trips like the Mars flight,” he told me, and added,

What is it going to mean in terms of real-world manifestations, including: What is the likelihood of losing a person—having somebody die on a trip to Mars? We may have a case where they only have so much morphine and so many antibiotics so if somebody’s really sick, do you just keep pumping them full of morphine that somebody else might need tomorrow? Or does something else have to happen? And what that something else is, we all dance around because nobody wants to talk about it We constantly remind each other that our examples

19. Robert Zubrin, “New York Times Misrepresents Mars Radiation Danger,” online at <http://www.marssociety.org/news/2003/1210.asp>, accessed September 2006.

would be people like those who settled the North American continent. [When they struck out for the West], they weren't planning on coming home. If they got sick along the way, somebody buried them.²⁰

Astronauts have a different relationship to risk than normal people. I got my first sense of this reading the Astronaut Ten Commandments on a Web site for Astronaut Hopefuls (or As Hos, as they call themselves). "Keep your weaknesses to yourself," says Commandment Three. "If you don't point them out to others they will never see them."²¹

This sense was confirmed when I raised cosmic-ray concerns at a recent dinner in Hollywood. An astronaut visiting the host rolled her eyes dismissively. "Doctors have been wrong in the past," she said. "They used to think you couldn't swallow in space." And here sat one astronaut, she assured me, who would leap for a spot on a one-way Mars mission.

Public perception, however, is another story. This has profound implications for society. Society must determine, through public discussion, how much risk it is willing to tolerate or, in any event, how much it is willing, through tax dollars, to underwrite. I'm not sure a federal agency should use public money to place civilian astronauts at high risk. Soldiers maybe, but not civilians. The burgeoning private space industry may best accommodate those who choose to place themselves in extreme jeopardy. According to Federal Aviation Administration guidelines, a tourist on a suborbital flight, for example, does not have the same assurance of safety as a passenger on a commercial airline. He or she understands and chooses the hazard. Likewise, explorers on a privately funded space mission could imperil themselves in any way they want, irrespective of society's disapproval.

This evaluation of risk reminds me of the way scientists discussed cosmic rays in the 1970s and of the unusual means by which a controversy about high-energy heavy ions was resolved. When a heavy ion passes through an astronaut's head, the astronaut sees a burst of light. This is called a retinal flash. Astronaut Buzz Aldrin first reported the phenomenon in 1969, when he returned from the Moon, but scientists studying cosmic rays had anticipated it. In the early 1950s, University of California at Berkeley biophysicist Cornelius Tobias posited a link between cosmic rays and such visual fireworks. In 1970 (a time when guidelines for experimenting on oneself were more lax than they are today), Tobias placed his own head in the path of a high-energy heavy ion. He wore a black hood when the beam sliced through him; ambient light, he feared, would distort his perception. Tobias believed

20. Interview with John Charles, Johnson Space Center, 6 June 2005. All Charles quotes are from this interview.

21. "Ascan Ten Commandments," online at http://www.ashos.org/astro_ten_commandments.html, accessed September 2006.



Figure 32.2—A high-energy heavy ion passes through the head of Cornelius Tobias (wearing a hood) at the Lawrence Berkeley Laboratory in 1970.

strongly that he would see a pyrotechnic streak, and what he saw would confirm his thesis. The experiment accomplished this and more: “It was as if I were looking into the universe itself,” he said.²²

I hope the optimists are right: that the human body can survive chronic exposure to cosmic rays. I hope our flesh does not forever curtail our dreams. But to prove this, the optimists might, in the manner of Cornelius Tobias, have to place themselves in the line of fire. And unless society becomes dramatically less risk-averse, they might have to do it on their own dime, without popular support.

22. Tobias’s experiment is discussed in “Cosmic Ray Questions: Studies at Lawrence Berkeley Laboratory’s Bevalac Will Help Resolve Uncertainties about Radiation Risks to Astronauts,” online at http://imglib.lbl.gov/LBNL_Revs/RR_online/91fu.html, accessed September 2006.

