Neutrino Exploration of the Earth

The project we imagine is one of the most ambitious ever conceived by our species. We are thinking of a mobile, circular, submarine accelerator with a circumference of 100 miles. It rivals the construction of the pyramids, the cathedrals, and the manned space program . . . [Yet] it is a carefully honed tool for the purpose of studying our own planet. It will detect and survey conventional deposits of oil, gas, and other commercially important minerals. . . . It can also search for unconventional resources, like very deep deposits of natural gas . . . [It] represents a fusion of pure and applied research that will forever remain a landmark of scientific endeavor.—CERN physicists Alvaro De Rújula and Georges Charpak, Harvard theorist Sheldon L. Glashow, and Fermilab founding director Robert R. Wilson, writing in *Neutrino Exploration of the Earth* (Harvard preprint HUTP-83/A019, March 1983).

That pretty well captures the tone of the thing. But De Rújula and his colleagues mean it. "At the moment, no oil company in its right mind is going to lay out a few billion dollars for this thing," concedes Glashow. "But our attitude is, 'If not today, then tomorrow.' "

The GEOTRON, as they call their device, would scan the solid earth with neutrinos much as a physician scans the human body with x-rays. This is not exactly a new idea—physicists are fond of amazing laymen with the thought that neutrinos from the sun are streaming through the earth by the trillions—but to date it has not even been practical in principle. The earth is essentially transparent to low-energy solar neutrinos, and even to the neutrino beams produced at present-day accelerators. Interactions are so rare that the emergent flux offers no information about the interior.

A few years ago, however, De Rújula realized that this might not always be a problem. Even then, people were talking about building ultrahigh-energy accelerators in the 1990's that could reach energies of 10 to 20 trillion electron volts (TeV). (The talk is much more serious now; see *Science*, 20 May, p. 809.) Moreover, it happens that the probability of a neutrino interacting with ordinary matter rises linearly with energy, so that the average distance between collisions correspondingly falls. At 10 TeV, in fact, this interaction length is comparable to the diameter of the earth, which means that variations of density and composition along the path of a neutrino beam can begin to have an observable effect. De Rújula realized that it might be possible to do a kind of whole earth tomography with such a beam, analogous to the computerized tomography used in medicine. Indeed, it occurred to him that such an endeavor might be very lucrative: one obvious application was the search for oil, gas, and minerals. He recruited Charpak, Glashow, and Wilson, and—quietly—they began to develop the idea.

They found three complementary approaches that seemed viable:

- Geological Exploration by Neutrino-Induced Underground Sound (Project GENIUS) is designed to search for deposits of oil and gas at large distances from the accelerator. Millions of neutrino interactions along the beam path would produce a coherent sound signal that could be picked by sensors at the surface. Analysis of variations in the signal would then allow geologists to map the deep strata. The method is similar to conventional seismic prospecting, but it has the advantage of starting with a known signal at a known depth. On the other hand, the neutrino-induced sound would probably be very faint, and the natural seismic background could be a problem. More research is needed.
- Geological Exploration with Muons produced In Neutrino Interactions (Project GEMINI) is designed to search for distant ore deposits. It depends on the surface measurement of neutrino-induced muons produced in the last few kilometers of the neutrino's underground voyage.
- Project GEOSCAN, a purely scientific endeavor, would determine the vertical density profile of the earth, and especially its core. Essentially, the beam would be slowly swept through the planet while mobile detectors on the far side mapped its attenuation as a function of energy and angle.

The key to all this, of course, is the GEOTRON that will produce the 10-TeV neutrino beam. For definiteness, De Rújula and his colleagues envision a scaled-up version of the neutrino facilities at Fermilab and CERN. High-energy protons would be accelerated in a conventional (albeit huge) proton synchrotron some 30 kilometers across. They would then be directed at a target where collisions would produce an intense, highly collimated beam of mesons. These mesons would then be directed down a long evacuated tube where they would decay into a beam of neutrinos. It all sounds straightforward enough—except that in a 10-TeV GEOTRON, the combination of beam extractor, target, and decay tube (dubbed the "snout") would have to be several kilometers long and movable. In fact, for the GEOSCAN project, it would have to point straight down.

Thus, the group was led to resurrect an old, tongue-in-cheek idea of Wilson's: float the accelerator out to sea. (When Wilson presented the idea in 1972 he estimated the cost in pieces of eight.) For example, if the GEOTRON were moored above a coral atoll with deep water just offshore, the snout could be rotated from horizontal to 90 degrees quite easily.

By last February, however, the oil companies had disabused De Rújula and his co-workers of their hopes of selling the GEOTRON idea on its financial merits—its cost would be in the billions, and its advantage over conventional prospecting methods is far from clear—so Glashow took it public at a meeting of academics and oilmen at Texas A & M University. This was no accident, since Texas A & M was actively trying to court Glashow away from Harvard at the time, and since Texas has ambitions of being the site of the next big U.S. accelerator. The proposal was promptly nicknamed the "Oilatron."

The high energy physics community has been "hesitant and doubtful" about the scheme, says Glashow, and the oil companies are hardly less so—although if the physicists ever build a 10- or 20-TeV accelerator for themselves, the oilmen might want to use it for prototype studies. The earth scientists are more interested, he says, since the GEOTRON would get at some fundamental geophysics problems that would be hard to study in any other way.

And, he recently told *Science*, "I just got a letter from an Arab professor who thinks the GEOTRON would be a great idea for Saudi Arabia."—**M. Mitchell Waldrop**