ments made at Los Alamos National Laboratory and elsewhere have thus far shown that the electron neutrino falls short of the mark. Attention has begun to focus on the others.

There is no shortage of new and hitherto undiscovered particles predicted by speculative theories that reach beyond the Standard Model. Some of them are massive and interact weakly with normal matter, making them likely candidates for dark matter. One of these is the *axion,* a light particle predicted by U.S. physicists in the late 1970's to explain why the strong force obeys CP conservation. Although thought to be less than a *billionth* as massive as the electron, there can be far more of them in the universe than even photons or neutrinos. And because they would move at speeds far slower than that of light, axions could collect around galaxies and lead to their apparent "halos" of dark matter.

Other possible dark-matter particles arise in grand unified theories with a property known as *supersymmetry*. For every particle in the Standard Model, these theories require there be a so-called supersymmetric partner—a *squark* for every quark, a *slepton* for every lepton, a *photino* for the photon, etc. What's more, at least one of these exotic particles has to be stable and indestructible, with the current favorite being the photino. Massive, neutral, slow-moving, and interacting very feebly, it is an ideal candidate for the dark matter in galaxy halos.

Searches for axions, photinos, massive neutrinos, and other possible dark-matter particles are now under way at laboratories around the globe. Particle accelerators and colliders have been used to look for photinos, for example, which are thought to be far more massive than the proton. So far they have not turned up, but searches for them remain high on the list of objectives for physicists working on the SLC and Tevatron, which can both produce conditions resembling those that occurred when the universe was a trillionth of a second old.

Dark-matter searches can also be made by small teams of physicists working in their own laboratories. New detection methods, often involving superconducting materials, may soon enable one of these groups to record the extremely faint signal that would occur if a dark-matter particle originating in the halo of our own Milky Way dislodged a proton or neutron. Another promising method uses a superconducting magnet surrounding a copper cavity to try to convert axions from our galactic halo into detectable microwave photons.

The underground detectors originally built to search for proton decay (see Chapter 8) are finding increasing use in dark-matter research. They are particularly useful when neutrinos are involved, because these are the only known particles that can penetrate to such depths. If a photino encountered its antiparticle near the earth—inside the sun, for example—two high-energy neutrinos could emerge after they annihilated. One of these neutrinos might be detected in the underground detectors. So far no high-energy neutrinos attributable to photinos have been observed, but the search continues.

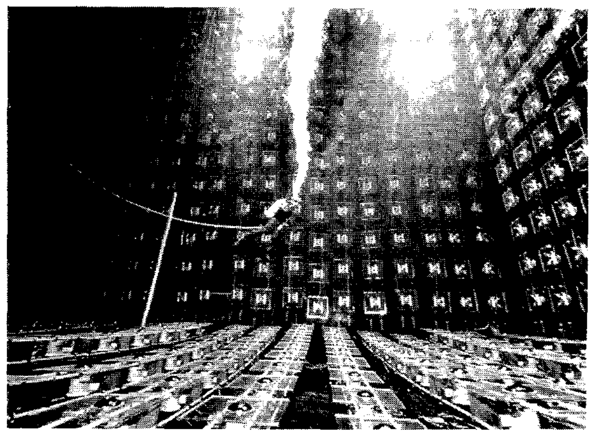

Figure 23. A skin diver checking phototubes inside the IMB underground detector.

The IMB detector near Cleveland did, however, witness a burst of low-energy neutrinos emanating from the 1987 supernova in the Large Magellanic Cloud—as did another underground detector in Japan. This was the first time that neutrinos from a supernova had been recorded. Of the many trillions of neutrinos that swept through these two enormous tanks of water during this 10 second burst, only 20 or so interacted, but this scant few revealed plenty. Because neutrinos are produced copiously in the core of a collapsing star, and most escape without interacting, they provide a unique "window" on one of the most violent processes occurring in the universe today.

From the duration of the neutrino burst as it reached earth, physicists concluded that the electron neutrino must have a mass-energy less than 20 eV—or about 0.004 percent of the electron's mass. This limit is almost as good as what has been obtained after years of painstaking research in terrestrial laboratories.