ANTIPROTON ANNIHILATION'S ADVANTAGES FOR IMAGING

The fine review article by Felix Wehrli on the history and future of nuclear magnetic resonance imaging techniques (June 1992, page 34) conveys a dramatic sense of the multiple applications of those techniques. Perhaps some words of slight caution may be apropos regarding the very last paragraph of the article, which states that mri "is likely to emerge as the universal mode of medical imaging of the 21st century." One powerful competing technique with many merits of its own is not mentioned, but likely ought to be because of its potential generality.

This competing technique would use the phenomenologies of antiproton annihilation. Use of antiprotons might be felt to be a bit more exotic than some of the more usual approaches, but the possibilities are well understood. An excellent review article, prepared by a multidisciplinary group of physicists and practicing physicians, appears in the book *Antiproton Science and Technology* (B. Augenstein, B. Bonner, F. Mills, M. Nieto, eds., World Scientific, 1988, page 640).

The considerable range of biomedical uses for antiprotons includes very-high-resolution imaging; tumor therapy; means for greatly improving more conventional tumor therapies; mesic chemistry, or imaging elemental atoms *in vivo* and *in vitro*; and a variety of special possibilities, such as transmutation *in situ* of ^{16}O to ^{15}O for positron emission tomography.

For biomedical imaging uses, antiprotons would be injected (into a human body, say) via a tightly collimated beam. Antiprotons in the beam would be slowed down by passage through matter and would finally annihilate at rest with protons and neutrons. The chief annihilation products are charged and neutral pions, nuclear gamma rays and nuclear fragments. Some annihilation products would escape from the body; detecting and tracing back such products, especially charged pions, would locate the annihilation vertex with great precision (to within less than 1 mm). Simplified, the key direct imaging principle involved is that antiprotons travel farther in less dense materials, the density is directly inferred from the distance traveled, and the distance traveled is precisely known from the location of the final annihilation vertices.

Substantial numbers of simulations, detailed computer analyses (of effects of straggling, scattering and so on) and antiproton stopping experiments suggest the following brief comparisons of antiproton imaging with other techniques: Compared with x-ray CT scanners, antiprotons can give considerably better imaging resolution, or the same resolution with about two orders of magnitude less radiation exposure; have very attractive operational features; do not have the troubling artifacts and other complexities of x-ray tomography; and can image a desired volume without exposing other parts of the body to the significant radiation introduced by tomographic techniques. The resolution, speed and scope of imaging of all tissue elements via antiprotonic x rays and characteristic nuclear gamma rays are far superior to what positron emission tomography imaging provides and allow new, interesting complements to PET. Antiprotons significantly enhance many imaging characteristics (such as speed, resolution and determination of elements in the body) compared with mri techniques; for example, antiprotons image all elements at once, while mri principally images hydrogen.

Further, while imaging techniques such as mri and ultrasound are in principle nonionizing, antiprotons are also ideally suited for radiation therapy. Generally, heavy-particle therapies have significant advantages over x rays because the particles deposit energy preferentially at the end of their range. Such Bragg peak effects are enhanced with antiprotons by about a factor of two (largely because of nuclear fragments). Thus the ratio of the radiation exposure of diseased tissue to that of healthy tissue is substantially superior for antiprotons. Antiprotons also can uniquely combine *in situ* imaging with precision radiation delivery—of great importance in treating small tumors near sensitive organs. One can use antiprotons to guide other heavy-particle therapy beams, or one can use antiprotons for both purposes, simply turning up the beam flux for therapy once the tumor site is being precisely imaged.

Issues of producing antiprotons and storing them in small, fully transportable containers (so that, *inter alia*, many applications now possible only at large particle accelerator sites can become accessible at virtually any hospital or laboratory) are extensively discussed in the above-mentioned review article. For example, antiprotons at very low energy are being stored in transportable ion traps at the LEAR facility of CERN, and there are plans to expand such technical possibilities. Studies have also been made in detail of storing antiprotons at about 200 MeV in very small transportable rings; such energies would permit, for example, ranges of tens of centimeters in body tissue.

Basic current antiproton production levels are already adequate for a great many experimental biomedical uses. For example, very-high-resolution imaging of large volumes might take about 10^7 to 10^9 antiprotons (the current cost of producing a few 10^8 of antiprotons is roughly one dollar), while experimental tumor therapies might take about 10^9 to 10^{10} antiprotons per cubic centimeter of tissue. Today CERN and Fermilab can collect about 10^{14} to 10^{15} antiprotons per year. Brookhaven's Alternating Gradient Synchrotron facility is also applicable and could be enhanced. Planning work is well advanced at Brookhaven for tests of multielement targets useful for biomedical studies. Production and collection of increased numbers of antiprotons of appropriate energies for wide-scale operational biomedical use would be possible at several facilities for a relatively minor cost.

Further assessments of the biomedical possibilities of antiproton use would benefit from comparative evaluations by experts in other imaging and therapy techniques of the less widely known antiproton applications. It is not uncommon to hear those who have investigated antiproton applications express the belief that antiprotons can become the future's brightest choice for manifold biomedical purposes.

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The World Has Room for Two ϕ Factories

A news story in your July 1992 issue (page 54) discussed the report of the subpanel of DOE's High Energy Physics Advisory Panel that was charged with setting program priorities for high-energy physics. While it is clear that any Federally funded field requires an occasional priority review, it is also clear that such reviews can be very dangerous if they serve in place of, or pretend to be, peer reviews. The reason for this is that such panels do not have the time to analyze carefully any single project, let alone two dozen or more, as the HEPAP subpanel did. The panel's conclusions are also directly linked to the input it receives from the funding agency, and this can introduce a different bias into the study—that is, the agency may want to protect some projects.

Let me take the example of the proposed ϕ factory at the University of California at Los Angeles as a specific case. The subpanel simply commented that it didn't believe there was a reason for having two ϕ factories in the world. (The subpanel did not specifically reject the UCLA project.) In a previous peer review that lasted three days, chaired by Edward Temple, the reviewers, with full knowledge of the ϕ factory being built in Frascati, Italy, reached an opposite conclusion about the physics interest.

To my knowledge, the subpanel made no comparative review of the Frascati and UCLA ϕ factories. The proposed machine design and construction techniques are entirely different (UCLA would use a superconducting quasi-isochronous storage ring), and the UCLA group is emphasizing the search for *CPT* symmetry violations—for example, by looking for a tiny fractional mass difference between the K^0 and its antiparticle, on the order of 10^{-18} or 10^{-19}, which is the ratio of typical quark masses to the Planck mass. This is, in my opinion, an extremely important scientific goal that might be carried out at more than one place on Earth! There was no comment by the subpanel on this scientific goal, possibly because it is unfashionable.

The UCLA project also involves US industry, national laboratories and international collaboration (Novosibirsk and Milan). There is no evidence from the subpanel report that this was appreciated or even considered.

The history of similar panels over the past 20 years or so shows a noticeable trend: Innovative projects proposed by nonestablishment groups normally have a difficult time. One notable example is the rejection of the proposal by Carlo Rubbia, Peter McIntyre and myself in 1976 to convert Fermilab into a $\bar{p}p$ collider to discover the W and Z bosons. A direct consequence of that rejection was the discovery of the W and Z at CERN in 1983—the last major discovery in particle physics. Other examples could be cited to indicate this trend. I seriously doubt that Ernest Lawrence could have gotten the cyclotron approved in similar circumstances.

We believe the HEPAP subpanel judged our project unfairly. However, since it was not a real peer review, the conclusions of the subpanel are apparently not subject to any questions or alternative viewpoints. This is a dangerous precedent for our or any field of science!

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A Physics Center Grows in Ukraine

It is with great interest that I follow PHYSICS TODAY reports on physics developments abroad, especially in the former Soviet Union. In this respect, the article "Soviet Science in Danger," by Evgenii L. Feinberg (May 1992, page 30), is of signal importance. Feinberg suggests that the best path to large-scale collaboration of scientists from the FSU with Western scientists will be through international research centers based at the leading research institutes of the FSU.

Already in the late fall of 1991, steps were taken in Ukraine to establish one such center. It is called the International Center of Physics and is based at the Bogoliubov Institute for Theoretical Physics in Kiev. The primary aims of the new center closely parallel those envisioned by Feinberg. They are collaboration with other countries in programs of fundamental research; organization of advanced workshops, topical symposia and schools; sponsorship of a series of lectures by eminent physicists from Ukraine and from abroad; and assisting in the publication and dissemination of English translations of papers and monographs on some of the more significant physics research in Ukraine.

The first workshop held under the aegis of the newly established international center was on turbulence and nonlinear processes in plasma and took place in Kiev from 11 to 26 April 1992. It was attended by 40 participants from Ukraine, Sweden, France, Yugoslavia, Georgia and Russia. Three more international workshops were held in 1992: Current Problems in Quantum Field Theory, New Trends in Nuclear Physics, and Hadron Physics. An international congress of physics has been scheduled for 22–27 June 1993 at the center. The purpose of the congress will be to acquaint physicists from other countries with the outstanding work performed in Ukraine and to open avenues for future cooperation.

The center's advisory council has discussed the possibility of expanding the opportunity for foreign graduate students to pursue research leading to a PhD degree in physics in a very attractive program established in Kiev jointly by the University of Kiev and the Institute for Theoretical Physics.

The center will be supported financially by the Ukrainian Academy of Sciences, but for the foreseeable future this support will be in the form of the local, nonconvertible currency. Avenues for securing hard-currency support from Western foundations and other sources have been explored. Such support is particularly needed for participation in American and West European conferences and workshops, for journal subscriptions and books, and for electronic mail.

Members of the pool of physicists in Ukraine are ready and willing to join their Western and Japanese colleagues in collaborative efforts in fields not only of academic but also of industrial interest. One of the missions of the International Center of Physics in Kiev is to serve as a clearinghouse for such contacts. The center's address is International Center of Physics, Bogoliubov Institute for Theoretical Physics, 252130 Kiev, Ukraine; telephone: (044) 266-5362; fax: (044) 266-5998; e-mail: nmakovsky@glas.apc.org. or