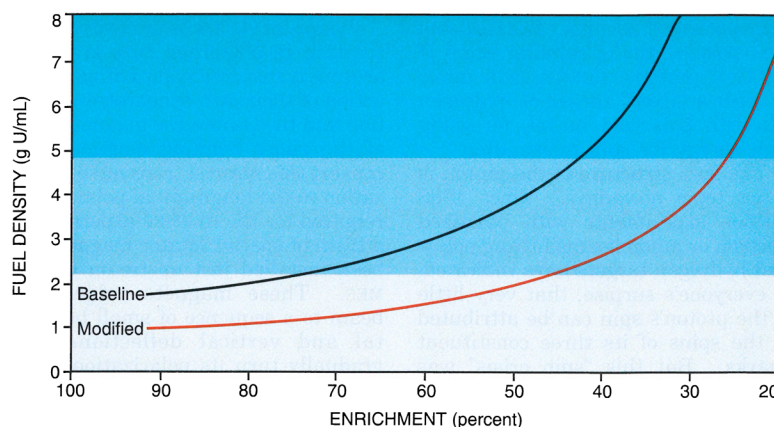


possible, to convert reactors already so fueled to low-enriched uranium, technically defined as containing 20% ^{235}U . To support this policy, the Reduced Enrichment for Research and Test Reactors program was started in 1978 at Argonne to develop, test and demonstrate a series of low-enriched uranium research reactor fuels, with significantly higher uranium densities to compensate for the lower enrichment. So far nine US research reactors and 15 overseas research reactors have been converted to low-enriched uranium. US policy does not specifically forbid the construction of a domestic reactor that uses highly enriched uranium, but building the ANS as designed, with 93% enriched uranium fuel, would be inconsistent with US policy and would establish a double standard for domestic and foreign research reactors.

Concern over this issue led Congress to request in its FY94 budget that the ANS designers address the enrichment level of its fuel. A team composed of researchers from Brookhaven National Laboratory, Argonne, Oak Ridge and the Idaho National Engineering Laboratory and led by Bari studied the trade-offs among enrichment level, flux, cost, safety and safeguards. There is a limit to increasing the fuel density of the uranium silicide fuel planned for the ANS: Frequently, denser fuels have lower thermal conductivity, leading to higher temperatures in the fuel.

In a draft report issued last January the study group led by Bari stated that one could operate the ANS at the same power level with a 35% enriched fuel but with 20% less flux and \$0.4 billion higher costs over the plant lifetime of 40 years. This configuration would require a larger core and higher fuel density (3 g/cc). The study group's overall conclusion was that "although it would be feasible to redesign the Advanced Neutron Source to operate with medium- or low-enriched uranium fuels, such designs would significantly reduce performance and increase cost."

Since the Bari study, Oak Ridge has come up with a design that would allow the ANS to operate at the same power and cost with a lower level of enrichment compared to the baseline design. The figure above shows the trade-off between enrichment level and fuel density for the baseline and for the modified design. In the modified design, which uses a larger core, the flux would be just over five times that of the ILL. The reactor might be fueled with 50% enriched fuel having a material density of 2.2 g/cc, or with 35% enriched fuel at 3.5 g/cc.



Trade-off between enrichment level and fuel density for the ANS. Below 2.2 g/cc, no fuel development is needed; regions of light, medium and dark shading indicate, respectively, small, moderate and high risk of failure. The baseline design features a two-element core. Going to the modified design, with a three-element core, enables one to lower the uranium enrichment level below the planned 93% without going above a fuel density of 3.5 g/cc. Not shown is the decrease in flux level at lower enrichment levels. (Courtesy of Oak Ridge.)

Researchers on nuclear fuels give the 2.2-g/cc density fuel nearly 100% chance of success and the 3.5 g/cc a 95% chance. The larger core gives reactor designers the option to operate at even lower levels of enrichment, perhaps with some reduction in flux, if higher density fuels are developed. It also gives operators a greater margin of safety because of the lower power density.

Switching from 93% to 50% or 35% enrichment lowers the danger of diversion of materials from the reactor, but it does not entirely avoid the conflict with US nonproliferation policy. Oak Ridge is awaiting comments from DOE on its proposed redesign. In the

meantime, the lab is proceeding to optimize the design.

—BARBARA GOSS LEVI

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HERA IS NOW RUNNING WITH LONGITUDINALLY POLARIZED POSITRONS

Recently there have been some interesting developments at HERA, the Hadron-Electron Ring Accelerator that winds its circular way for 6 kilometers beneath the streets and parks of Hamburg. Since the fall of 1992 this uniquely asymmetric pair of storage rings has been providing experimenters with collisions between 820-GeV protons and 30-GeV electrons. (See PHYSICS TODAY March 1992, page 21.) Since July, however, HERA has been running with positrons instead of electrons, and will continue to do so at least until the end of 1995. And more importantly, the circulating

HERA positron (or electron) beam can now be longitudinally polarized at will. That's an important first: No other electron storage ring has ever achieved longitudinal polarization.

HERMES and the spin crisis

The new HERMES detector, which will join the two original detectors in the beam line this month, will be the first to take advantage of HERA's new polarization capability. To investigate the spin structure of the proton, one wants to collide longitudinally polarized charged leptons (electrons, positrons or muons) with longitudi-

nally polarized protons. Because one can't polarize the circulating beam of 820-GeV protons, HERMES will make do with a "fixed" target of hydrogen gas with polarized nuclei, foregoing high energy for spin information.

The spin structure of the proton is a hot topic nowadays. Since 1988 various experiments with polarized electron or muon beams hitting polarized hydrogen targets have indicated, to everyone's surprise, that very little of the proton's spin can be attributed to the spins of its three constituent quarks. But this "spin crisis" was muddled by seeming discrepancies between the data coming from CERN and the Stanford Linear Accelerator Center. Within the last year, however, a happy convergence of the data and new, higher-order calculations have yielded a fairly precise but still puzzling result: The quark spins account for $32 \pm 4\%$ of the proton's spin.^{1,2} It's clear that the so-called naive quark model cannot, by itself, explain the spin of the proton or the neutron. That will require a more subtle exploitation of the full apparatus of quantum chromodynamics, the quantum field theory to which the naive quark model is a convenient heuristic approximation.

Neither the CERN nor the SLAC experiments that have been measuring the proton's spin structure functions over the years with longitudinally polarized lepton beams have used polarized storage-ring beams. The polarized electrons at SLAC are shot out of a 2-mile-long linear accelerator, and CERN's polarized muons come from the decay of high-energy pions. The principal advantage of a circulating storage-ring beam over these earlier arrangements is that the target sees a much larger beam flux, averaged over time. Therefore the target doesn't have to be as dense. Whereas HERMES can make do with a pure hydrogen gas target, the SLAC and CERN experiments require solid targets of frozen ammonia and butanol, respectively. With these solid molecular targets, it's hard to tell whether the lepton scattered off a polarized free proton, as intended, or off one of the bigger, unpolarized nuclei. This uncertainty adds significantly to the systematic errors in the SLAC and CERN measurements of the proton's spin structure.

HERMES will have yet another advantage. The older experiments measure the scattered lepton and little else. HERMES, by contrast, comes with a large hadron spectrometer that will let the experimenters see what becomes of the proton and what hadronic entourage after the collision.

Beams of electrons or positrons circulating in a storage ring gradually acquire transverse polarization by the action of their own synchrotron radiation and the transverse magnetic field of the ring's bending magnets. To convert this natural transverse polarization to the longitudinal polarization required for the HERMES experiments, a train of special rotator magnets has been installed just upstream of HERMES. These magnets subject the beam to a sequence of small horizontal and vertical deflections that gradually turn its polarization direction. A similar train of magnets just after the detector must then return the beam to its transverse polarization. That's essential for stability.

The percent longitudinal polarization cannot exceed the percent transverse polarization of the beam entering the rotator train. Although transverse polarization comes naturally in a storage ring, high-energy rings are particularly troubled by depolarizing resonances, which have to be laboriously sought out and cancelled. When HERA was under construction, it was decided that HERMES would not be built unless and until the electron beam could demonstrate at least 50% transverse polarization. Last winter, after the transverse polarization had reached 70%, the rotator magnets were installed in the electron beam line. In July the magnets were activated, quickly yielding 70% longitudinal polarization after surprisingly little fine-tuning.

Positrons

The decision to run HERA with positrons rather than electrons for the time being was taken because the electron beam was acting up. A well-behaved electron beam in a storage ring decays exponentially with time, with a characteristic lifetime of a few hours in a new machine that still has a lot of gas adsorbed in its vacuum walls. As the machine gets progressively cleaner with age, the beam lifetime can become as long as a half a day.

But from the very beginning, HERA's electron beam had not exhibited this nice textbook behavior. The beam decay rate would often change abruptly in midstream for no obvious reason, usually for the worse. The higher the injected beam current, the more frequent were these sudden glitches. So the problem was seriously slowing HERA's acquisition of physics data, both by limiting the electron beam current at which the collider could be run and by increasing the number of times a day one had to stop and refill the beam.

The precise origin of the electron

beam's troubles is still under investigation. But it is already fairly clear that the proximate culprits are microscopic grains of dust that occasionally wander into the beam. There they become positively ionized and, if it's an *electron* beam, they're trapped in its negative Coulomb potential well. As soon as the beam is turned off, they drop out of harm's way to the bottom of the beam pipe.

The obvious immediate remedy is to run with positrons instead of electrons. The Coulomb force of the circulating positrons *repels* the positively charged dust grains. "From the moment we switched over to positrons in July, the beam has been behaving with textbook perfection," says Gus Voss, director of the accelerator division at Hamburg's DESY laboratory. "Running at 30 milliamps [more than half the design current] we're already getting beam lifetimes of 7 or 8 hours."

HERA was designed to run with either electrons or positrons, with the same luminosity. (The circulating lepton current is limited by space charge effects long before positron shortage becomes an issue.) For most of the physics now being done at HERA, the sign of the lepton beam's charge doesn't matter. The scattering electron (or positron) is simply supplying the virtual photon that probes the proton's innards. But weak-interaction proton cross sections are, in fact, higher with electrons, and measuring the difference between cross sections with electrons and positrons can be instructive. Therefore one wants eventually to run HERA again with electrons. To that end it's important to figure out how best to keep the offending dust particles out of the electron beam pipe. Furthermore, it's likely that similar problems will confront the builders of the high-luminosity electron-positron collider rings that will be serving as "B-meson factories" before the end of the century.

It looks like the source of the dust particles is the "getter" pumps arrayed alongside the full length of the evacuated electron beam pipe for the purpose of trapping residual gas. (In view of this unintended extra role, some wags are calling them "putter" pumps.) The getter pumps, with slotted steel anodes at 5 kV sandwiched between titanium cathode plates, are designed to continuously produce fresh titanium surfaces, which adsorb residual gas from the adjacent beam pipe. But it appears that synchrotron radiation from the circulating electron beam occasionally instigates discharges between the anode and the beam-pipe wall. These discharges, it

seems, can catapult microscopic charged grains of metal into the path of the electron beam, where they become trapped and do their mischief. The greater the beam current, the worse the problem.

What can be done, beyond the temporary expedient of switching to positrons? As the machine gets older and cleaner, Voss told us, the getter pumps will have less residual gas to contend with. Therefore, he explained, one might be able to run them at lower voltage, thus minimizing the danger of discharges. He and his colleagues are also experimenting with non-evaporable getter pumps. These new NEG pumps have porous metal surfaces that can absorb enormous quantities of gas.

NEG pumps are being used at LEP, the very large 50-on-50-GeV electron-positron collider at CERN. There are plans at CERN eventually to have longitudinally polarized electrons and positrons in LEP. But in a storage ring of such size and beam energy, depolarizing resonances are likely to be more troublesome than they were at HERA.

—BERTRAM SCHWARZSCHILD

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IS THE NOISE OF OVERHEAD NEIGHBORS INESCAPABLE?

If you have ever lived in an apartment and had overhead neighbors, you have probably been annoyed by the noise they made just walking. This can be a problem even in luxury condominiums designed with acoustic privacy in mind. Now we know why.

A detailed study¹ of the problem by Warren Blazier Jr (president of Warren Blazier Associates Inc, of San Francisco, California) and Russell DuPree (Office of Noise Control, California Department of Health Services)

has revealed some startling facts about lightweight residential construction. Chief among these is that the peak energy in a footfall sound spectrum occurs at the fundamental natural frequency of the floor-ceiling system, typically between 15 and 35 Hz, not at the higher frequencies associated with, for example, clicking heels on a hardwood floor. Standard acoustic analyses of buildings, consistent with code requirements, ignore all frequencies below 100 Hz. The

lower limit of human hearing is frequently given as 16 Hz, but this varies with individuals. Furthermore it is less of a hard limit than a transition between sensing vibrations as aural effects and as tactile effects.

"What we're talking about here are the thuds and thumps of overhead foot traffic and their detection by the folks below," says Blazier, "who perceive it as noise." Adding carpeting or wearing cushioned track shoes may exacerbate the problem rather than alleviate it. "When you add such an element of resilience to the system, the rise time of the impact is

lengthened and more energy is coupled to the low frequencies," Blazier explains.

The usual methods for attenuating frequencies above 100 Hz—such as installing floating floors—simply don't work for these thuds and thumps. The most important ingredient turns out to be the structural factor kf_n , where f_n is the floor system's natural frequency and k is known as the static point stiffness of the floor system. Because the noise level depends logarithmically on the reciprocal of kf_n , only a significant increase in the floor's stiffness will help. For typical residential construction the following proportionality holds:

$$kf_n \propto \frac{(EI)^{1.5}}{w^{1/2} L^5}$$

where E is the modulus of elasticity (treated as constant), I is the moment of inertia of the structural system, w is the weight per unit length of the section used for computing I , and L is the length of span along the floor joist. For either wood or steel joist-framing systems, increasing I may require a significant increase in both the width and depth of the floor joists, while decreasing L implies adding more transverse framing. For economic reasons, however, builders are unlikely to pursue either of these options, because current building codes come nowhere close to requiring them. The practice of adding a poured concrete topping to the sub-floor doesn't help: The added mass lowers the natural frequency of the system slightly, and the two effects tend to offset each other. As a result the stiffness does not materially increase. On the other hand, the stiffness of residential construction that uses reinforced concrete for columns, beams and floor systems (as it often did 20 years ago, and still does in Europe) is at least an order of magnitude greater than the stiffness of wood or lightweight-steel joist construction; in such apartment buildings the amplitude of overhead low-frequency footfall noise is typically below the hearing threshold. Unfortunately for quiet-seekers, those reinforced-concrete residential buildings are a vanishing breed.

So what can apartment dwellers do about the bumps and thumps of the people upstairs? "Learn to live with it," advises Blazier.

—STEPHEN G. BENKA

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"Oh, hi! I'm Dwayne, your new upstairs neighbor!"