tute of Technology and applied mathematician George Karniadakis of Brown University propose a novel approach that harnesses electromagnetic fields to nip the eddies in the bud. In computer simulations of turbulent ocean-water flows, their method cuts the drag force by almost 30%. If the simulations are borne out by upcoming experiments, says Richard Philips of the Naval Undersea Warfare Center in Newport, Rhode Island, it will be a tremendous advance in fluid dynamics.

Turbulence is more a process than a thing. As ocean water streams past a submarine's hull, for example, the flow splits up into pairs of fast- and slow-moving ribbons of current called "streaks." Loops, or eddies, of current circulate between the two halves of each streak. These loops grow rapidly until they burst, exerting a force that vibrates the hull and slows down the submarine's progress.

Turbulence is tough to counteract largely because a turbulent flow is very stable. "The flow does not want to be changed," explains Mohamed Gad-el-Hak, a mechanical and aerospace engineer at the University of Notre Dame in South Bend, Indiana. "Brute force does not work." Instead, Gad-el-Hak has been exploring the use of a kind of "smart surface" that senses the presence of turbulent eddies. A control system then activates many tiny, pistonlike actuators that morph the surface, pressing it against the fluid in a way that inhibits the developing turbulence. Computer simulations and laboratory-scale experiments show that this approach could work in the real world, but the actuator power must be carefully rationed, or else "the amount of energy needed is more than you save by suppressing the turbulence," says Gad-el-Hak.

Others have been trying to reduce drag by vibrating the surface at a specific frequency. This approach is called "predetermined control," because the frequency of the vibration does not respond to changing conditions in the fluid. Although it reduces turbulence, Karniadakis thinks the cure may be as bad as the disease. "Imagine that you are flying over the Atlantic, and the pilot turns on the 'shaker' to damp turbulence," he says. Either way will make nervous fliers jittery.

Instead of wiggling the walls to push the fluid around, Karniadakis and Du's method applies the force directly to the fluid. In their simulations, predetermined electromagnetic pulses from tiles on the surface of a submarine hull induce a force perpendicular to the direction of the streaming—and electrically conductive—salt water. They found that the additional force prevents "streaks" from forming along the hull, so the explosive current loops never have a chance to form. "We cut the legs off the turbulence," says Karniadakis.

Du and Karniadakis have demonstrated electromagnetic tiles in the lab but have yet to measure their effect on turbulent drag. "The proof of the pudding is if they can demonstrate this effect experimentally," says Philips. Karniadakis has recently received a grant to test both predetermined and reactive turbulence control. Gad-el-Hak, for one, is curious to see how it turns out. "In the past, predetermined control methods have not been very successful," he says, "but George is the best in his field; it may be that he has hit the jackpot." —**MARK SINCELL**

Mark Sincell is a science writer in Houston.

DNA COMPUTING

Hairpins Trigger an Automatic Solution

DNA, the alphabet of life, can also spell out the solutions to tough computations. Not only can its jumbo molecules store huge amounts of information, but, when mixed into a chemical soup, they react in so many ways at the same time that they can perform many calculations in parallel. Spurred by such promise, computer scientists and molecular biologists have already performed DNA- and RNA-based "molecular computations" to solve math and logic problems (*Science*, 17 October 1997, p. 446; 18 February, p. 1182).

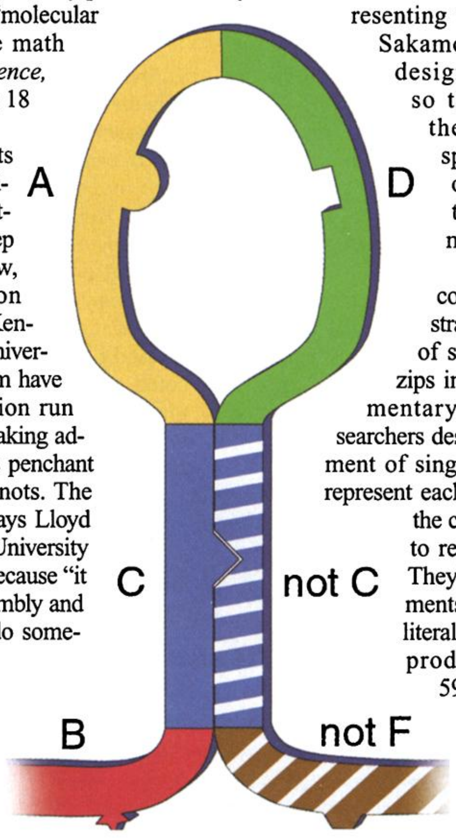
So far the experiments have required lots of old-fashioned, shake-the-test-tube lab work for each step in the calculation. Now, however, as reported on page 1223, biochemist Kensaku Sakamoto of the University of Tokyo and his team have made a DNA computation run more or less by itself by taking advantage of the molecule's penchant for twisting itself into knots. The new method is elegant, says Lloyd Smith, a chemist at the University of Wisconsin, Madison, because "it takes the idea of self-assembly and puts it under control to do something for you."

Sakamoto and colleagues tackled a version of the satisfiability problem in Boolean logic, a form of reasoning in which "literals"—statements and their opposites—are linked together with *or* and *and* to form complicated formulas. In the type of problem they considered, two or more literals link together with *or* to form a clause, and the clause is true if any one literal is true. Two or more clauses then link together with *and* to make the complete formula, which is true only if every clause is true. The problem is to find a string of literals that makes the entire formula true.

Any string that makes each clause true is a potential solution. But there's a catch: The string cannot contain both a statement and its negation. For example, consider the formula "(I exist *or* I sleep) *and* (I do not exist *or* I dream)." Even glum, distracted Prince Hamlet knew it was possible to sleep and (perchance) to dream, and the phrase "I sleep *and* I dream" satisfies the formula. On the other hand, it's logically impossible to be *and* not to be simultaneously. To solve their problem, a whopping formula of 10 clauses of three literals each, Sakamoto and colleagues set things up so that, of the tens of thousands of potential solutions, all but two dozen tied themselves into just such logical knots.

To translate the problem into molecules, the team began as other researchers have done, with a large assortment of DNA strands, one for each possible solution of the puzzle. But whereas others mixed in one enzyme after another to cut up the strands representing the wrong answers, Sakamoto and colleagues designed their strands so that, when cooled, the wrong answers spontaneously folded over and stuck to themselves to form molecular "hairpins."

DNA naturally comes in two matching strands, so every stretch of single-stranded DNA zips into a unique complementary strand. The researchers designed a 30-base segment of single-stranded DNA to represent each statement and used the complementary strand to represent its opposite. They then linked 10 segments, one representing a literal from each clause, to produce the more than 59,000 potential solutions to the formula. The problem was formulated so that each wrong-answer strand had to contain at least one statement and its negation, and hence one segment and its complement. Therefore, when the researchers lowered the temperature of their soup in just the right way, complementary sequences locked together,



Hairpin turn. Single-stranded DNA binds to itself when caught in a logical contradiction.

ILLUSTRATION: C. CAIN

causing all the wrong-answer strands to fold over and form hairpins. The researchers then either cut all the hairpins with a single dose of enzyme, or used a standard technique for copying DNA to reproduce just the remaining unfolded strands, which represented the right answer.

The new method obviates several laboratory procedures by exploiting DNA's knack for forming complicated structures, says team member Masami Hagiya, a computer scientist from the University of Tokyo. But the researchers pay a price to avoid the extra chemistry, Smith says. The logic problem reduces to finding one correct solution out of the 64 possible combinations of six statements and their opposites. In restating the problem so that wrong answer strings all have contradictory literals, however, the researchers make it much larger. As a consequence they wade through thousands of redundant wrong answers. The new technique also lets through many more wrong solutions, notes Laura Landweber, a biologist at Princeton University, in Princeton, New Jersey. "I remain intrigued but skeptical," she says, "until they can reduce the large proportion of errors."

–ADRIAN CHO

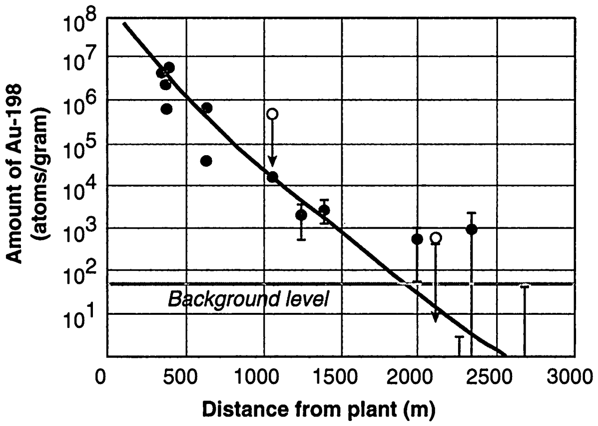
JAPAN

Exposure Levels Tracked Around Nuclear Accident

TOKYO—When workers at a nuclear fuel processing plant inadvertently set off a nuclear chain reaction last fall, more than 6 hours passed before the Japanese government set up radiation monitoring equipment at the scene. The time lag left a critical gap in the record of the amounts and types of radiation released in the accident 110 kilometers northeast of the capital (*Science*, 8 October 1999, p. 207).

That gap has now been filled by a group of Japanese university researchers, whose results appear this week in a special issue of the *Journal of Environmental Radioactivity* (vol. 50, no. 1-2, May 2000). In 21 reports, the team has reconstructed the aftermath of the accident by collecting over 400 samples of irradiated table salt, sugar, stainless steel cutlery, coins, and gold and silver jewelry. This approach, although not new, builds on the cooperation of company officials to offer the most detailed picture ever of the spread of radiation from a nuclear accident.

Ohtsura Niwa, director of Kyoto University's Radiation Biology Center, says the results are particularly important given ongoing controversies over the effects of neutron radiation, the primary type of radiation in the Tokaimura accident. Previous studies have yielded inconsistent results on the relation between distance from the source and radiation dose, and the possible health effects of exposure to neutron radiation. These questions make "this kind of study very necessary," he says.



Golden records. Gold isotopes in household jewelry help scientists measure radiation exposure around the accident site.

The 30 September incident at a nuclear fuel processing facility in Tokaimura was Japan's worst-ever nuclear-related accident. Dozens of residents close to the plant were evacuated, and hundreds of people in the surrounding area were warned to stay indoors for 18 hours after the event. Two employees of the Tokyo-based JCO Company Ltd., the plant operator, eventually died from complications arising from high radiation doses. Kazuhisa Komura, who heads the university group and is director of the Low Level Radioactivity Laboratory at Kanazawa University, says the study provides an independent check of the official governmental investigation and extends its scope.

The researchers use the fact that neutron radiation makes many substances, particularly metals, radioactive. Gold, for example, captures neutrons to produce the isotope Au-198, in proportion to the amount of radiation (see graph). After examining household items loaned by area residents, the group concludes that the level of accumulated radiation at the edge of the JCO property was about 100 millisieverts. A sievert is a measure of the total radioactive dose, factoring in each type of radiation and its energy. Normal background radiation results in an annual dose of about 1 millisievert, and doses of more than 5 sieverts have typically been fatal. The stricken workers suffered dosages of 17 and 10 sieverts, and 50 other people received up to 100 millisieverts.

Dose levels outside the plant were much lower, and the health implications for the general public are likely to be negligible, Komura says. Another group studying the biological effects of low-level neutron radiation has yet to publish its results.

The journal reports are consistent with previously released government studies, which stopped at the site boundaries. However, the university researchers also plan to study the level of radiation to buildings and other objects beyond the accident site in hope of understanding the shielding effect of various materials, natural and human-made. The results, says Murdoch Baxter, editor for the special edition of the journal and a former official with the International Atomic Energy Agency in Vienna, could even help scientists looking back at the atomic bombings of Hiroshima and Nagasaki.

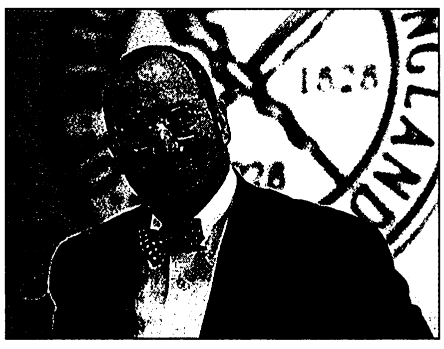
–DENNIS NORMILE

JOURNAL PUBLISHING

Harvard Researcher Named *NEJM* Editor

The New England Journal of Medicine (NEJM) has a new editor, its third in less than a year. Jeffrey Drazen, 53, a Harvard asthma researcher and associate chief for research in the Pulmonary Division at Boston's Children's Hospital, takes on the challenge of trying to set the 188-year-old journal on a smooth course following a year of controversy about both its internal policies and its outside activities.

Last summer, conflict over the journal's commercial activities led to the sacking of Editor-in-Chief Jerome Kassirer (*Science*, 30 July 1999, p. 648). Then early this year, *NEJM* confessed to violating its own conflict-of-interest policies (*Science*, 3 March, p. 1573). In its 24 February issue, the journal listed 19 papers in which one or more authors had accepted money from drug companies. Drazen was one of them: He co-



Hot spot. Pulmonary scientist Jeffrey Drazen becomes the third *NEJM* editor in 10 months.

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