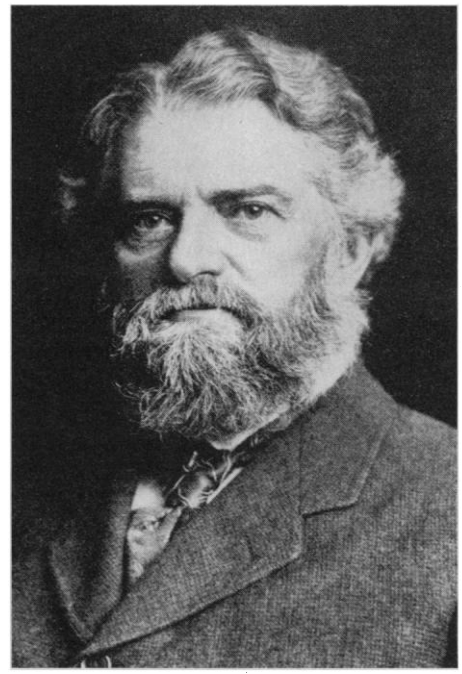
A Matter of Time

Bowing to celestial time, the world's timekeepers will slow their atomic clocks with a "leap second" at the New Year



Simon Newcomb, *an astronomer whose work in 1895 defined the exact length of the solar second.*

IF 1987 seems more substantial than 1986, perhaps that's because it is: by official reckoning, it contains exactly one more second.

At midnight (Universal Time) on 31 December, timekeepers around the world will add a "leap second" to their 250 master clocks, holding the New Year still for an instant, jarring a rigorously precise tally of 78,969,600 seconds that has been kept since midnight on 30 June 1985, when the last adjustment was made. The message will go out by radio, telephone, and telex, and it will be broadcast around the globe on a flock of satellites. After the moment has passed, the world will have a new Universal Time (Coordinated) or UTC.

Gernot Winkler, who since 1966 has directed the Timekeeping Service at the U.S. Naval Observatory in Washington, D.C., will be at his computer's side for the occasion. The Naval Observatory is the largest contributor to Universal Time with 24 participating clocks. Winkler will also be ready to greet the television crews that usually turn out on New Year's Eve if, as Winkler says, "the Iranians aren't making an attack" and upstaging the calendar. "Actually," he adds, thinking ahead to the show he will put on, "it's childish." The computers were programmed weeks ago to add the leap second by themselves, and they would gladly do so, except that people like to see a fallible human hand in the event.

The ceremony has nothing to do with human fallibility, of course. The adjustment is necessary because man-made clocks—which run on frenetic oscillations of the atom—are superior to the ancient timekeeper, the earth, which is running down. The earth wobbles, lurches, and continuously slows down on its axial spin, demanding a leap second's rest every so often to catch up with atomic time.

From mankind's earliest awareness of time until the 1950s, the universal measure of time was the solar day—one full rotation of the earth on its axis from noon to noon. In the 19th century, faster travel and more powerful means of communication made society aware of the odd fact that time changes with one's location. For convenience, astronomers and civil timekeepers got together and agreed to divide the globe into 24 local time zones. Each would keep its own unique time, but all would try to stay in step with a universal frame of reference. It was settled that in the universal frame, the noonday sun would always shine on Greenwich, England. The royal observatory there, commissioned by King Charles II in 1676, pioneered the use of exact time for sea navigation and thus held priority.

The definition of clock time gained some clarity in 1895 when Simon Newcomb, scientific director at the U.S. Naval Observatory, published tables of the actual duration of the earth's rotation as observed by astronomers. (The rate of spin is affected by proximity to the sun, lunar pull, wind and ocean currents, shifts in the earth's molten core, and other forces.) He analyzed data from the previous 200 years in which astronomers clocked the passage of stars. His work made it possible to smooth out seasonal and other variations and to come up with a definition of the proper duration of the "mean solar day" and its 86,400th part, the mean second. The next step was to install this abstraction in clocks and coordinate the clocks with the rotation of the earth, setting everything ticking on roughly the same scale, all pegged to noon at Greenwich. Thus began Greenwich Mean Time.

As clocks improved, the distinction between clock time and celestial time grew more noticeable. The big break came between 1948 and 1955 when researchers at the U.S. National Bureau of Standards built two very precise atomic clocks. One used as its "pendulum" an energy shift in the ammonia molecule; the second and better clock used a shift in the cesium-133 atom. Oddly, the Bureau of Standards was not the first to put this invention to practical use. That was done by the National Physical Laboratory in Britain, which in 1955 used a cesium oscillator to calibrate other clocks.

The cesium clock is basically a microwave amplifier (maser) combined with a cycle counter. In a maser, cesium can be made to hop in discrete jumps between two energy levels, cycling at exactly 9,192,631,770 ticks per second. Because of this breathtakingly rapid pulse, the cesium clock proved to have excellent precision in measuring the 1-second interval. It was also stable, running for months with little change in pace.

The Naval Observatory bought a cesium clock from the Hewlett-Packard Company in 1958 and began using it for timekeeping. That decision, as Winkler writes, appears to have led to "a triumph of watchmaking over astronomy." In 1967, timekeepers from around the world met at the Bureau Internationale de l'Heure in France and agreed to make the atomic second as the primary time standard. The earth, sun, moon, and stars are now held to account for their movements according to the atom. The earth, in particular, has shown itself sadly deficient, losing about one millisecond (a thousandth of a second) per day.

Industrial nations now orient their work according to two master timing systems: the high-frequency throb of the atomic clock and the less precise cyclical movement of the earth through space. This creates a dilemma. Winkler, who was born and educated in Austria, likes to quote Seneca on this point: "I cannot give the exact hour; [for] it is easier to get philosophers than clocks to agree." It is proven that, if allowed to run, two clocks inevitably will show different times. The only remedy is compromise, another term Winkler likes. In this case, the official time must defer to the sluggish behavior of the earth, for otherwise, daylight would creep back into the wee hours of the morning, and soon people would have to rise at midnight for breakfast. Leap seconds are essential to avoid that. They are also necessary because, even today, thousands of vessels steer by the stars. (It is cheaper than buying radio navigation gear.) If official time were to disagree with star time by a few seconds, a celestial navigator might wander miles off course.

Thirteen leap seconds have been added to atomic time since 1972, after a startup adjustment of 10 seconds. The earth was slowing down more rapidly in the early 1980s than at present, and it has not been necessary to add time as frequently since then. So many variables affect the earth's rotation that it is not known exactly why the speed shifts from year to year.

The decision on whether or not to add a second is made by the 33 nations belonging to the time section of the International Earth Orientation Service in Sèvres, France (formerly the Bureau Internationale de l'Heure). As agreed upon in a formula, the decision is automatic, coming whenever the earth's rotation changes enough to put celestial time more than 0.9 second out of sync with atomic time. The rules call for the leap second to be added preferably at the end of June or December. This means that someone must predict the earth's spin rate, a task performed for the international agency by the Naval Observatory and the U.S. National Geodetic Survey. They essentially make time forecasts, running 3 months or more into the future.

The product of all this negotiation is UTC, a compromise endorsed by the non-Soviet world. In some places (mainly Britain) it is still known by its old name, Greenwich Mean Time, a term that officially went out of use in 1975. France has led the campaign to banish Greenwich from the terminology. Recently, the British government gave up timekeeping at Greenwich and put the old castle up for sale. Instead, says Winkler with an air of distaste, the observatory leapt into advanced astrophysics. A hotel is planned on the old site.

Before the use of radio, timekeepers at Greenwich provided exact time to the public by means of a system of "time balls," the first of which was built on the roof of the Greenwich castle. It consisted of a large ball that slid down a pole when released by a galvanic pulse at noon from a clock in the observatory. Anyone who could see the castle could set time precisely every day. In 1861 there were at least four time balls in England controlled by the Greenwich clock, including two in London. The Naval Observatory used the same technique in Washington, D.C.. The ball that drops on New Year's Eve in Times Square, New York, is a relic of this era.

Precise time, because of its importance for navigation, has always had a military flavor. Perhaps for this reason the Soviet Union has never become overtly dependent on the Universal Time set by agreement in France. But it is no coincidence that the Soviets independently keep the same time. The fact that the Soviets do march in step with the West was displayed on a grand scale during a recent trip to the U.S.S.R. by David Allan of the Time and Frequency Division of the U.S. National Bureau of Standards.

Allan wears a quartz watch that he keeps in step with UTC. One night in Leningrad, he watched a fireworks display for 10 minutes as roll after roll of synchronized rocket flares went up from a small island, each barrage launched just on the tick of the UTC second at the minute or half-minute mark. "It was impressive," he says.

With radio and cable links, it is possible not only to keep precise time but to coordinate it over a large area. Western nations now keep their master clocks within about 5 microseconds (millionths of a second) of UTC. The Bureau of Standards, which provides time to the civil sector in the same way that the Naval Observatory provides time to the military, has installed an algorithm in its computer that keeps its clock "within a few nanoseconds" (billionths of a second) of UTC. The Naval Observatory's master clock has been running about 5 microseconds at odds with UTC. But recently the Naval Observatory has tightened its step, Allan says, by "steering" its clock ever so slightly toward the UTC standard.

What Winkler calls "crude time"—UTC with an accuracy of about one-tenth of a second—is available to anyone by telephoning the Bureau of Standards in Boulder Colorado (303-499-7111), or the Naval Observatory (202-653-1800), or by tuning in to one of its radio transmissions. More exact time is available through a telephone computer connection, and precise time can be obtained from any of several navigation systems that have grown up since World War II, all tied to the Naval Observatory master clock or the Bureau of Standards.

The oldest signal generators are OMEGA and LORAN-C, radio systems managed by the Coast Guard. Although primarily used for water and air navigation, they are also important for distributing precise time, down to an accuracy of 2 microseconds per day for OMEGA and 100 nanoseconds for LORAN. Two older satellite systems, GOES and TRANSIT, give time with an accuracy of 10 to 50 microseconds. These aging devices are slated to be replaced by the Global Position System (GPS), an expensive constellation of 18 satellites whose deployment has been held in check by the shuttle accident. The four operating GPS satellites now provide 10-nanosecond accuracy. With a proper receiver one can use GPS to determine a position to within 30 meters or less. The government hopes to save money by closing down older systems as it deploys GPS, but may find this politically difficult. Thousands of civilian users have receivers that use the old military beacons and will not want to replace them.

The progress in time measurement in the last few decades has been tremendous, so much so that some physicists argue that

USNO photo

Time begins here, *at the U.S. Naval Observatory in Washington, D.C., for most navigational systems in the non-Soviet world.*

understanding time has been the central obsession of the 20th century. As Allan says, it is remarkable that this abstract entity is more accurately measured than anything else in the world—with an uncertainty of about eight parts in ten to the 14th power, or roughly 1 second in 300,000 years. Winkler describes it another way: it is akin to measuring the distance between the earth and the sun with an uncertainty of 1.5 millimeters. Time standards are now so precise that the universal definition of the meter was established in 1983 as the length of a path traveled by light (in a vacuum) during 1/299,792,458th of a second.

Meanwhile, the cesium atomic clock, upon which the recent progress was built, has found some rivals. They include the hydrogen maser and the mercury trapped-ion clock. The latter, which has been running on a test basis at the Naval Observatory since July 1986, appears ready to push the standard a step higher, into the realm of ten to the fifteenth power. At the Bureau of Standards, work has already begun on a laser-cooled clock that is expected to leap three steps further, into the eighteenth power of ten. Allan says it "may take 20 years to get this clock to a place where you can buy it," but he expects that day will come.

There are many uses for precise time. As it becomes more accessible, more will be found. The most common application—aside from navigation—may be as a tuning standard for commercial TV and radio signals. The oldest and most interesting use is as a tool in astronomy. Allan points with excitement to a recent example, the discovery of a radio-emitting neutron star (or pulsar) whose emissions keep time with at least as much stability as the best atomic clocks (*Science*, 6 November, p. 761). This particular pulsar, one of four known to "tick" out radio waves at millisecond intervals, has only been observed steadily over a 6-month period. Over a longer period, Allan says, it might prove to be the best clock in the universe. Allan and others hope to use it to "look at all kinds of astronometry" in the solar system, to test theories of gravity waves, and to conduct experiments in relativity. None of this could be done without very precise control clocks on the earth.

Despite the tremendous improvements in the timekeeper's skill, the nature of the thing being measured remains confusing. Winkler has written, "Time is the abstract measure of change, an abstractum of an abstract notion." After reviewing some philosophers' definitions in a recent essay, he concedes that time has "no more substance than other notions as virtue or vice," but notes that it is "vastly more applicable." ■

ELIOT MARSHALL

Maxwell May Back Gallo

Several months ago, Robert Maxwell, the British publisher and entrepreneur whose holdings include Pergamon Press and valuable real estate in the center of London, approached Robert C. Gallo of the National Institutes of Health with an offer to support a new institute for AIDS research. Maxwell's philanthropic interest apparently came out of the blue, but it provided new impetus to Gallo's own long-standing desire to expand his laboratory beyond what NIH is readily able to support.

Since the 1970s, Gallo's lab has pioneered research on retroviruses, which includes the AIDS virus. Indeed, it has been said that it was this expertise that enabled Gallo and his colleagues to move quickly on AIDS. When the AIDS crisis hit about 5 years ago, Gallo's lab had about 35 people. Today, the number is the same. Efforts to expand have been frustrated by federal personnel ceilings that apply as much to NIH as to any other government agency. Salary limitations of $73,000 for a Ph.D. and $84,000 for an M.D., coupled with government restrictions on outside income, also stand in the way of attracting new people. It is these obstacles, rather than any desire for increased personal wealth, that lie behind Gallo's much publicized thoughts about leaving NIH after 22 years.

NIH officials, who are anxious to keep a number of first-rate scientists who are receiving attractive offers to leave, have been struggling to find ways to creatively manipulate the federal bureaucracy so that Gallo could lead some sort of consortium of scientists without leaving NIH itself. One proposal is to create a laboratory under what is called a "cooperative research and development agreement (CRADA)." In such an arrangement, Gallo would remain an NIH employee, as head of a newly created laboratory. University faculty could work in the new laboratory. However, according to an NIH memo, they could not be paid with government (e.g., NIH) funds. But they could be paid with money donated by Maxwell. In a CRADA deal, industry scientists could also work in the Gallo laboratory with money from their company. A complex set of rules governing who can supervise who, and who can and cannot share in royalties would be in force. Were this idea or some modification of it to be adopted, this university-industry-government triumverate would have to find lab space somewhere. Maxwell has already anticipated that by buying a good-sized research building not far from the NIH campus, where a collaborative program could he housed.

From time to time during the past four or five years, Gallo has entertained the idea of moving to Duke, where he already has research collaborators. Since Maxwell entered the scene, talks with Duke have picked up.

Shortly thereafter, Gallo also had preliminary talks with Johns Hopkins University when he was approached by David and Isaac Blech, two businessmen and Hopkins supporters who wanted to raise venture capital from the health insurance industry in order to fund an AIDS institute in Baltimore. The Hopkins deal, which apparently was never more than tentative, fell apart when Gallo refused to sign a contract that he interpreted as tying him too closely to the potential products and profits that might come from his research (*Science*, 4 December, p. 1349). Hopkins, which had plans for a new AIDS center even before they had talks with Gallo, will go ahead anyway.

During the course of the summer, Yale also entered the picture as a possible academic home to Gallo and an AIDS center that would be developed with a major philanthropic gift from Maxwell to the university. Maxwell has been to Yale to talk with university officials and faculty. Medical school dean Leon E. Rosenberg is attracted to the idea of a major new AIDS research program which, he says, is being seriously considered. However, he cautions, the discussions are only in preliminary stages.

Gallo, who declines to talk in detail about the Duke or Yale negotiations, says that if either comes to fruition it would have to be for research dedicated to virology and immunology, not just AIDS, in order to be of long-term scientific value. And it would have to be "fully integrated into the university, with appointments made according to university rules, under the dean," in order to function productively. "If I leave NIH I want to be part of a university, not a profit center," he says. ■ BARBARA J. CULLITON