enhanced by the presence of protein in vivo, presumably for this same reason.

The emerging commonalities between these three different types of intron are strengthened by the further discovery, reported by A. C. Arnberg and colleagues in the same issue of *Cell*, that a group I intron in a ribosomal RNA precursor in yeast mitochondria is excised as a lariat, not a circle. Chances are, therefore, that all these introns have a rather close evolutionary relationship.

It is perhaps appropriate that the *Tetrahymena* intron, which was the first to show self-splicing in vitro, should also be the first RNA molecule to show true biosynthetic activity. Once the intron has excised itself from the precursor, it nibbles off the first 19 nucleotides from its 5′ end, employing the same chemistry that effects the original cleavage and ligation. The reaction then stops. Cech and his colleagues decided to see if this foreshortened molecule still had catalytic activity, by adding a short RNA (five cytidylic acids joined together) to the reaction mixture.

Sure enough, the intron continued to perform the splicing-type reactions, which resulted in the shortening of some of the poly C molecules and the lengthening of others, some of which reached 30 nucleotides in length. The reaction involves the binding of the poly C substrate to a conserved sequence in the intron, which, in the splicing reaction, recognizes the 5′ splice site. This sequence acts as an internal template for the polymerization reaction. Cech and his colleagues speculate on the biosynthetic possibilities that might emerge if the sequence of the internal template is modified or is even separated from the catalytic molecule entirely.

Not only can one see how primordial RNA could have acted as a replicase, making copies of itself and other RNA species, in the complete absence of protein enzymes, but it is also tempting to consider the utility of suitably engineered RNA molecules in modern biotechnology. Cech points out that, although there are batteries of protein enzymes for manipulating DNA, there are very few for RNA. RNA enzymes may, therefore, fill this gap. ■ ROGER LEWIN

ADDITIONAL READING

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A. Van der Veen *et al.*, "Excised group II introns in yeast mitochondria are lariats and can be formed by self-splicing in vitro," *ibid.*, p. 225.

A. C. Arnberg *et al.*, "Formation of lariats and circles in self-splicing of the precursor to the large ribosomal RNA of yeast mitochondria," *ibid.*, p. 235.

A. J. Zaug and T. R. Cech, "The intervening sequence RNA of *Tetrahymena* is an enzyme," *Science* 231, 470 (1986).

Wisconsin Storage Ring Reaches 120 Milliamps

After long delays, the "1-GeV ring" now generates respectable VUV-XUV intensities, but continued funding is uncertain

EARLY last month, accelerator physicists at the University of Wisconsin's Synchrotron Radiation Center (SRC) in Stoughton for the first time were able to store and accelerate to full energy a beam current in excess of 100 milliamperes in its "1-GeV ring." The latest breakthrough caps a year of steady progress in commissioning the problem-plagued machine, once known as Aladdin and designed to be a high-brightness source of vacuum-ultraviolet and soft x-ray radiation for users throughout the United States.

While the recently achieved beam current can generate more than enough light to keep a flock of waiting users happy, the success may have come too late. Despite signs of progress evident last June, after years of delays and disturbed by studies concluding that even the expenditure of some $25 million for a proposed upgrade project could not ensure that the machine would meet its specs, the National Science Foundation pulled the plug on Aladdin. NSF continues to support the operation of Tantalus, an older, smaller, lower energy, but highly reliable VUV synchrotron source at SRC.

The university then took the bold step of spending its own money to operate Aladdin for a maximum of 9 months, beginning last October. The machine's performance had already improved enough by then to make it superior to Tantalus in light output and spectral range. Moreover, Tantalus was oversubscribed with about twice as many hours of beam time requested as could be accommodated. Since Aladdin is physically larger, it has room for more beam lines and consequently can service more experimenters. The hope was that the upward climb in light output would convince NSF or some other federal agency to fund the new machine as an alternative to the older one, even if the current remained well below the original design specification of several hundred milliamperes.

Last September, the university submitted a proposal requesting the switch to NSF, which is in the process of assembling a reviewing team to make a recommendation. According to SRC director David Huber, the proposal comes to about $3.5 million per year for 3 years, a little more than twice what it costs to operate Tantalus. During this period, six of the eight beam lines from the older machine would be moved over and several new ones added. Together with the ones that are in place now and taking data, these would make a total of 17 at the new facility.

One notable feature of the proposal is the total absence of the name Aladdin, now called simply the 1-GeV ring. As far as NSF is concerned, Aladdin was a project that aimed at an electron storage ring with a beam current of at least 500 milliamperes and did not succeed.

Particular concerns of the NSF reviewing team, according to Lewis Nosanow, director of NSF's materials research division, will include documentation of the need for the 1-GeV ring and assurance that no major extra expenditures are waiting in the wings. Although Nosanow mentioned no specific alternative, moving some experimenters into the rapidly saturating National Synchrotron Light Source at Brookhaven National Laboratory might relieve the pressure for a while. Then the third-generation Advanced Light Source proposed by the Lawrence Berkeley Laboratory, if approved, could be ready in about 5 years.

As for the 1-GeV ring, no formal decision to proceed can be expected from NSF until this May because the amount of money requested requires National Science Board concurrence. A negative decision would force Wisconsin to approach other agencies, such as the Departments of Energy or Defense, says Huber.

Until now, the main technical problem with Aladdin has been the inability to accumulate a large beam current. A small accelerator called a racetrack microtron was to boost pulses of electrons to 0.1 GeV and then squirt them into Aladdin, where, after enough pulses had been accumulated, the electrons were to be accelerated to the final operating energy. Although the first beam was stored in November 1981, by the fall of 1984 the largest current that could be accelerated was only 2.8 milliamperes. Not only was the current low, but there was no sign of improvement. "We were up against a brick wall. Nothing we did raised the current, and we didn't know why," recalls Ednor Rowe, who designed Aladdin and oversaw its construction.

By this time, panels of outside accelerator physicists had scrutinized the machine in detail. They found no fundamental flaws in its design, but concluded that somehow the low injection energy was the difficulty. The only sure way to raise the current to 100 milliamperes or more was a new injector accelerator, an electron synchrotron of energy 0.8 GeV. Another study team that included accelerator experts from several national laboratories was assembled in December 1984 to work out the details. By the next April, the team had put together the $25-million, 3-year upgrade plan that included the new synchrotron and other improvements. Frustrated users, who had been making do with Tantalus, supported the upgrade but wondered if they would ever see any light.

In the meantime, an experiment at Tantalus provided the first clue as to how to breach the brick wall blocking the way to higher currents. Although it was dedicated to the production of synchrotron radiation in the late 1960's, Tantalus had been built as a testbed for concepts relating to high-current accelerators and equipped accordingly. In particular, it had devices called clearing electrodes whose function was to extract positively charged ions from the circulating electron beam by means of a direct-current voltage and thereby prevent the ions from disrupting the beam.

When Tantalus was new, its current was low and the clearing electrodes had little effect. However, they proved to be a convenient means of monitoring the current and were routinely left on for this purpose. Later, as the current grew with operating experience, no one made any connection between their presence and the improved performance.

Rowe says that by December 1984 he suspected, but could not prove, that ion trapping was preventing the accumulation of a large beam current in Aladdin. In brief, the negative charge of the electron beam attracts the ions, raising the effective gas pressure near the beam. One effect is to shorten the beam lifetime by scattering electrons out of their orbits. If the lifetime were short enough, electrons would be lost as fast as they were injected, and no current build-up could occur. Whatever the actual mechanism, the SRC physicists remembered the clearing electrodes in Tantalus, tried turning them off, and saw the beam disrupted.

Accelerators are individuals; no two behave alike. Hence, the Tantalus result did not prove that ion trapping was the cause of Aladdin's problem, and the new machine did not have clearing electrodes, anyway. However, it did have a few striplines, another kind of beam-monitoring device that could be made to have a clearing-electrode effect. In a test, the beam current that could be accelerated to 0.8 GeV increased to 5 milliamperes almost immediately, motivating the installation of clearing electrodes.

The machine responded; by the end of January 1985, the stored current at injection jumped to 15 milliamperes. As it became clear that the electrodes would have to cover as much of the ring as possible, they were gradually added. The injected current reached 40 milliamperes in May, when 40 percent of the ring was equipped. By last December, clearing electrodes blanketed all but an inaccessible 20 percent of the ring, and 75 milliamperes could be accumulated. Some current is lost during acceleration, so that, for example, at 0.8 GeV the beam was a little over 60 milliamperes.

Clearing electrodes alone were not enough to get over 100 milliamperes, however. Because they do not remove all the ions, the use of the electrodes only raises the current threshold at which ion trapping once again exerts its limiting influence. A way to remove more of the troublesome particles was suggested by the SRC's Dornis Morin, who realized that the ions actually oscillate perpendicularly to the orbit of the electron beam at a characteristic frequency that depends on their mass. An alternating-current voltage at that frequency would increase the amplitude of the oscillation and perhaps drive the ions away altogether.

During this period, the SRC accelerator staff was also able to increase the energy of the racetrack microtron injector slightly to 0.108 GeV. However, the beam lifetime varies as the inverse of the energy to the third power. The resulting 25 percent increase in beam lifetime further pushed up the current threshold for ion trapping. The strong dependence of lifetime on energy is why the accelerator experts had recommended a higher energy injector as the surest path to high beam currents.

Last month, all three ingredients came together to give the largest single increase in beam current in the machine's history. "For a while we were going up 10 milliamps a day," says Rowe. The maximum current achieved at injection was 138 milliamperes, of which 120 survived after acceleration to 0.8 GeV. The current at 0.8 rather than 1 GeV is used as the benchmark partly because anxious users had once agreed that the minimum useful performance was 10 milliamperes at 0.8 GeV. Currents up to 106 milliamperes have been accelerated to the full energy, however.

How high can the current go? There is no fundamental limit immediately in sight, as long as the ion clearing procedure can be made more efficient, according to Rowe. But, unless funding to operate the 1-GeV ring is forthcoming, no one, including the waiting users, is going to find out. ■

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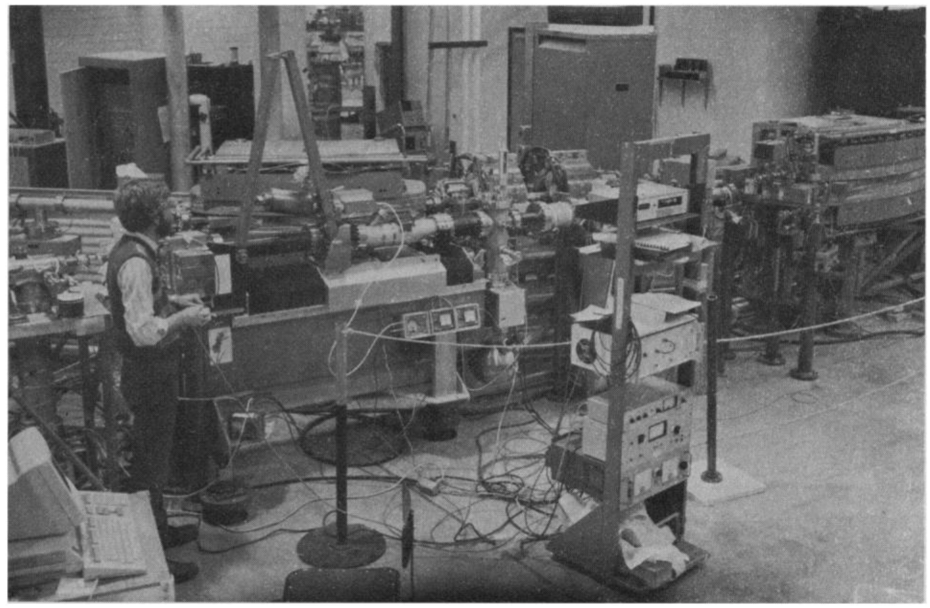

Synchrotron Radiation Center

Mark II beam line

Formerly installed on Tantalus, the beam line has been operating on the 1-GeV ring since November. Light emerges from the bending magnet on the right on its way to the experimental station in the center.