millionth of a meter (0.5 microns). The team achieved this with a 115 million volt electron beam. This work demonstrates that the same high powers achieved by FELs at Los Alamos in producing longer-wavelength infrared radiation, can also be achieved in producing more lethal, shorter wavelength laser light.

Radiation of shorter wavelengths is more lethal because the intensity of action of electromagnetic radiation increases as it becomes more concentrated. But the future of the Stanford program has been uncertain since the budget cuts of October 1986. As one scientist put it, "Nobody knows where they stand."

Livermore made limited progress in amplifying an infrared laser beam from a carbon dioxide laser over the past year.

The Livermore Beam Research Group had predicted at the 1985 Particle Accelerator Conference in Vancouver, B.C. that they would be able to amplify a 1 million watt laser pulse by a factor of 30, with an efficiency of 2%, using a magnetic "wiggler" that is five meters long. But the July 1987 issue of the lab's *Energy and Technology Review* reported that so far, the device has only been able to amplify the input laser beam pulse by about 50%, one-sixtieth of what they had hoped. The efficiency beam is less than one-tenth of one percent.

The big effort for FEL scientists working on the radio frequency type of device, revolves around the Boeing project. If Boeing can achieve significant progress over the next six months, it will demonstrate the capability to build the engineering model at White Sands. Boeing turned on its machine for the first time last year. Recently, it reengineered its FEL to generate 0.63 micron radiation, a slightly longer wavelength than that which achieved lasing last summer.

Meanwhile, the FEL oscillator under development at Los Alamos is undergoing extensive modifications to enable the device to produce 160 to 200 million watts (megawatts) in peak *output* power of infrared laser radiation with an efficiency of 8 to 10%.

Los Alamos plans to combine such a radio frequency linear accelerator-driven FEL oscillator, which generates radiation, with a radio frequency linear accelerator-driven FEL amplifier, to amplify the output of the oscillator and achieve gigawatt power levels.

Los Alamos is funding another FEL laboratory at Stanford, headed by John Madey, to test the oscillator-amplifer concept on a laboratory scale with FEL hardware available there. After this work is completed, it is expected that Madey will leave Stanford, due to political problems at the university. His company, Sierra Lasers, is reportedly building a radio frequency FEL for Vanderbilt University for medical applications. The short picosecond pulses produced by a radio frequency FEL have been found to be preferable for treating tissue because their action is nonthermal.

Finally, SDI funding for development of radio frequency weapons has begun to pay off. Lawrence Livermore National Laboratory and the Air Force Weapons Laboratory at Kirtland Air Force Base have both produced pulses of radiation in the radio frequency spectrum with powers of billions of watts with a device called a "virtual cathode oscillator" (vircator). A photo of the vircator at Kirtland appeared in *Aviation Week and Space Technology* in December, and shows that the entire device can be housed in two or three large camper vehicles. This is only two to three times larger than prototype Russian radio frequency weapons, a nice accomplishment for a program that only started in 1984.

A good year for the Soviet space program

by Marsha Freeman

This past year the Soviet Union marked some important milestones in its space programs—both civilian and military. On the public side of space activities, the *glasnost* policy opened a window into previously quiet aspects of Soviet space plans and operations, including the first admission that the Soviets are developing a reusable space shuttle vehicle.

A multi-day extravaganza in Moscow at the beginning of October called Space Forum, for the 30th anniversary of Sputnik, gave the Soviets a captive audience of about 450 foreign scientists, many of whom had their expenses paid by the Soviet Academy of Sciences. At the meeting, the Soviets presented an unusually candid picture of their future unmanned science missions, new modules to be added to the Mir space station, and some of the new technology they are developing for the manned space program.

In order to procure U.S. government participation at the conference, and undoubtedly in step with pre-summit preparations, Soviet Space Institute head Roald Sagdeev promised that SDI-bashing would not be included on the agenda of the three-day space science conference. The Soviets have accelerated their drive to entice U.S. and European participation in their ambitious space science programs. They have gotten a sympathetic hearing, due to the dreary state of advanced planning for Western space missions.

On May 15 the Soviets surprised the world with the first test launch of its Energiya rocket. This booster, with a 220,000 pound payload capacity, was launched the day after Soviet leader Gorbachov visited the Baikonur Cosmodrome, along with the Soviet minister of defense. Energiya gives the Russians the ability to launch massive payloads into Earth orbit,

and there is no doubt that its extensive cost and development time was expended largely on behalf of the Soviet strategic defense effort.

Energiya represented the first use of liquid hydrogen fuel by the Russians, and though this was mastered by the United States 25 years ago, it represented a significant advance in capability for the Soviet program. Soviet space representatives stressed that the new rocket will be used to orbit heavier elements for manned space stations, larger interplanetary science spacecraft, and the Soviet shuttle.

At the Oct. 2-4 Space Forum Moscow conference, the Russians announced that the Energiya would have its second test launch before the end of this year. Though it is unlikely that this will take place, a few more tests will be required before the rocket is declared operational.

This dramatic new capability, which is additional to the eight other rockets that are in the Soviet's stable of operational boosters, left the United States in the dust, in terms of heavy-lift capability. At the current pace, it will be the mid-1990s before the U.S. can match the Energiya.

New capabilities in manned operations

During the early October celebrations on the 30th anniversary of the launch of the first spacecraft to orbit the Earth, Soviet cosmonaut Yuri Romanenko broke the previous Russian record for Earth-orbital long-duration flight, spending his 238th day in space. During the year, the Soviets announced that the crew to follow Romanenko's will try a one-year stay aboard the Mir space station.

The Soviets added their first scientific module, Kvant, to the Mir space station this year, and though there were docking problems which required challenging extra-vehicular activity, or space walk, by the resident cosmonauts to fix it, Kvant was the only sophisticated spacecraft in orbit to observe this year's supernova explosion.

The Kvant astrophysics laboratory, launched on March 31, has four x-ray spectrometers, which were designed by Eastern and Western European scientists. It also houses an ultraviolet telescope, and contains other experiments. The head of the Soviet Institute for Biomedical Problems, Oleg Gazenko, announced in November that the Medilab science laboratory module will be added to Mir in 1990.

This year, the Soviets admitted for the first time, that they are developing a reusable manned shuttle vehicle. Without releasing details on the size or capability of the projected vehicle, project head Stefan Bogadyazh did announce that all launches would be announced in advance. It was also announced that nine cosmonauts are in training to fly the future shuttle.

There remains a wide difference of opinion in the U.S. space community, as to when the first test flight of a full-scale shuttle vehicle might take place. There is little doubt that the shuttle will be boosted into Earth orbit on the back of an Energiya rocket.

1987 Soviet space milestones

March 31: Kvant astrophysics module launched to Mir space station.

April 12: Space walk by cosmonauts Romanenko and Laveikin sucessfully docks the Kvant to the Mir.

April 15: George Shultz and Soviet Foreign Minister Eduard Shevardnadze sign an agreement for space cooperation in Moscow, covering 16 general areas. The last agreement expired in 1982, and was not renewed by the United States, due to the declaration of martial law in Poland.

April 23: Unmanned Progress supply-ship docks with the Mir, marking the first time four space vehicles have ever been linked together in space.

May 15: Energiya superbooster launched; first Soviet liquid hydrogen rocket. The booster was successful, but the payload failed to orbit.

July 15—*Wall Street Journal* reports that Mir cosmonauts used a laser to target and track a Soviet-launched ICBM. This is repeated by *Time* magazine on Oct. 5, but is otherwise denied. The *Journal* says this is being kept secret because of preparations for the Reagan-Gorbachov summit.

July 18: Planetary Society conducts its satellite link, "Spacebridge," in Boulder, Colorado, with Soviet scientists in Moscow. The discussion centers on joint missions to Mars, and is led by Carl Sagan. It is aired on public television in October, in a one-hour show.

July 25: Cosmos 1870 is launched, and appears to be a massive, 15-20-ton radar remote sensing satellite, many times larger than any similar U.S. spacecraft. Ocean reconnaissance appears to be one important mission for Cosmos 1870. This is one of a series of "mysterious" spacecraft launched over the past two years, which had been "inert" in that they have appeared to not communicate with ground control.

Sept. 11: Reconnaissance satellite Cosmos 1810 is commanded to reenter the atmosphere after 259 days in orbit. This exceeded by 20 days the operation of any previous Soviet reconnaissance satellite, and reflects the Soviet effort to lengthen the lifetime of key military spacecraft.

Sept. 29: Biosat is launched, with two monkeys, rats, and other biological specimens. Participants include the U.S., France, Hungary, and East Germany.

Oct. 1: Cosmonaut Yuri Romanenko breaks the previous 237-day record for continuous time in space, set in 1984.

Oct. 2-4: International Space Forum conference in Moscow, with 450 foreign scientists.

Oct. 12: Biosat lands, 2,000 miles off-course, delaying scientists from immediate analysis of the effects of microgravity on the specimens.

Oct. 29: The 2,000th Soviet spacecraft is launched. The comparable U.S. total is 870.

Dec. 9: Soviet space head Sagdeev reports to a space forum in Washington, that during the Summit, General Secretary Gorbachov indicated that the next major area of U.S.-Soviet cooperation should be joint missions to Mars.