Russian progress on the nuclear laser

Soviet scientists discover breakthrough for gamma-ray laser and invite the U.S. to join in co-operative development.

Left: George C. Baldwin. Right: Laser pulses compress graser rod, causing microscopic fission reaction and release of gamma rays from isomer imbedded in the beryllium core.

by John H. Douglas

Packing the wallop of a miniature A-bomb and able to penetrate a wall several feet thick, the gamma-ray laser —or "graser"—could create a revolution in scientific research and weapon development. No serious work has been conducted in this country on gamma-ray lasers for almost a decade, but now word comes from the Soviet Union that Russian scientists appear ready for the final, concentrated research preceding actual development of the device. And they say they are eager to share the project with American colleagues.

That extraordinary message is being relayed to American scientists by George C. Baldwin, a nuclear engineering professor at Rensselaer Polytechnic Institute. Last June, Baldwin attended a conference on nonlinear optics (lasers and such) in Novosibirsk, where he was approached by several leading Soviet scientists in the field, all talking excitedly about the new breakthroughs in solving the seemingly insurmountable problems of making a graser and asking what the Americans could contribute. Deeply embarrassed, Baldwin replied that, so far as he knew, no one had worked on the problem in this country since he and a few colleagues gave up almost a decade ago for lack of support. Eagerly pursuing the initial tantalizing hints, he met privately with the Soviet scientists and emerged with a fascinating account of scientific persistence and a crucial technology that almost passed America by.

Optical lasers derive their extraordinary power and flexibility by stimulating electrons in individual atoms of a substance to radiate light all at once, at exactly the same frequency. Gamma rays originate in the nuclei of atoms, where changes in the motion of protons and neutrons create radiation of much greater energy and penetrating ability. How to stimulate individual nuclei to give off their gamma rays together at the same frequency—to "lase" —is the essential problem of making a nuclear laser.

At first, the problem looked so simple that Baldwin and some co-workers at the General Electric Company took out a patent on how to prepare materials for a nuclear laser a decade ago. Then came a dilemma. Nuclei must first be energetically excited—or "pumped" —before they can lase. But isotopes that were found to lase could not be pumped by any known method, while isotopes that were readily pumped just dribbled away their gamma rays without lasing. When a well-known expert then pronounced that nuclear lasing was impossible, everyone went off to tend to other business.

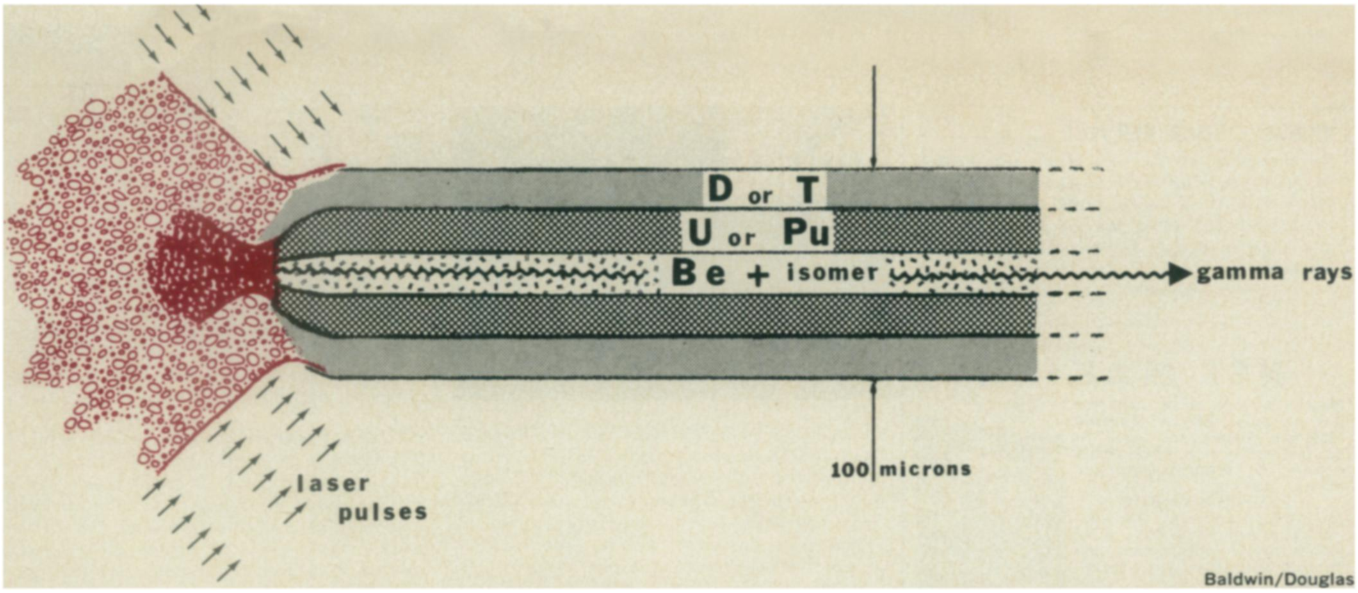
Except for the Russians. Working in multi-disciplinary groups, the Soviet scientists pursued the needed research along three lines: how to pump short-lived, easily lased isotopes; how to lase the sluggish, easily pumped isotopes, and how to combine the best features of both approaches. Apparently it was this interdisciplinary approach that paid off, for as Baldwin recalls, in the early American work there was "too much parochialism" and a lack of the necessary communication between nuclear and solid-state physicists.

To pump nuclei with short lifetimes (10^{-5} seconds) requires an extremely intense beam of neutrons. Baldwin spent an evening at the home of V. I. Goldanskii, the leading proponent of this approach to nuclear lasing, who described in some detail how the idea could work—but would not reveal how he intended to get such a powerful neutron beam. Then Baldwin noticed that Goldanskii had written a technical paper with V. A. Namiot, who in turn had written a paper on a novel way to produce enormous densities of neutrons by creating, in effect, a microscopic atom bomb.

Combining the two pieces of work with calculations of his own, Baldwin produced a hypothetical model of a graser. A long, slender filament of beryllium is impregnated with a carefully chosen isotope. The filament is covered with a layer of plutonium or uranium, which in turn is covered with a layer of deuterium or tritium. When a train of optical laser pulses bombard this "graser rod," the outer layers are compressed and heated, causing the uranium or plutonium to fission, releasing neutrons. The neutrons strike the isotope nuclei implanted in the beryllium filament which then lase. The outer layer of deuterium or tritium helps to reflect neutrons into the central filament and also undergoes a fusion reaction, releasing more neutrons.

The key to success of the operation is fissioning such a tiny amount of uranium or plutonium. Under normal circumstances, more than 10 kilograms of material in a volume about the size of a basketball is needed to start a fission chain reaction, but under high compression, the "critical mass" is a little over one milligram. The graser rod would thus start out at a diameter of about 0.1 mm and be compressed by the laser pulses to a fraction of that size. Baldwin calls this technique "microfission." Such compression techniques are already under investigation in laser-fusion research (SN: 5/20/72, p. 328) and development of the technology involved would itself have far reaching consequences.

Another problem that must be solved before this microfission approach to nuclear lasers can succeed is how to choose the proper isotope for lasing. Many isotopes have various forms, called isomers, which give off gamma rays or other radiation at very different time intervals. Unfortunately, the properties of many of these isomers have not been mapped out, which complicates the task of selecting just the right isomer to put into the beryllium rod. There is also some uncertainty about how such implantation should take place. Without being fitted into a crystal structure, such as beryllium, all the individual nuclei of the lasing isomer could not give off the same frequency of gamma rays, since they would re-



coil like a gun shooting forth a bullet. The energy and thus the frequency of the emitted gamma rays would vary from nucleus to nucleus according to the amount of recoil. Just as a hunter must make sure his gun rests firmly against his shoulder to assure the bullet's accuracy, a nucleus must be able to pass its recoil to a crystal lattice, a process called the "Mössbauer effect." More basic research on this effect must take place before it can be used in construction of a graser.

Controlling the frequency and direction of gamma rays coming out of nuclei with very long lifetimes (minutes to hours) is even more difficult, because the magnetic fields of neighboring atoms can upset the radiation pattern in spite of the Mössbauer effect. Again, with determination and ingenuity, the Russian scientists believe they can surmount this obstacle, using an external field to rotate the nuclei together and cancel random interactions—a process called nuclear magnetic resonance (NMR). The Soviet scientist leading this NMR research, R. V. Khokhlov, says he can reduce the interatomic magnetic effects by at least a factor of 10,000. Very long-lived isomers are so rare, however, that chemical separation to provide isomer enrichment would be necessary for this technique to work.

V. S. Letokhov hopes to get around the problem of chemical separation by working with isomers of intermediate (one second) lifetimes. Chemical separation, he says, could then be avoided by using carefully tuned laser beams to ionize the isomers involved, so that they could be separated electrically. The nuclei would presumably still need neutrons from a microfission apparatus to pump them.

If the Soviets have progressed so far alone, why should they now suddenly want to collaborate with Americans on these projects? Probably because they need some vital pieces of technology. The microfission graser rod, for example, would require a very precisely crystallized beryllium core. The United States leads the world in such materials technology. Similarly, Russian scientists are hampered in any sort of research requiring complex computer simulation; another area in which the United States is far and away the world leader. Finally, a measure of altruism could reasonably be expected from anyone stumbling onto such a fantastic discovery: the best way to avoid a "super death-ray" race between the United States and the U.S.S.R. is probably to have the nuclear laser developed as a joint, totally unclassified project.

A major international project might be able to demonstrate graser feasibility within two years, Baldwin estimates, but a more likely figure would be five to ten years. "Why, we could do all the basic research, except for the microfission, at RPI," he says.

Immediate applications of a nuclear laser could be spectacular. Because of their short wavelengths, gamma rays could, in theory, be used to form detailed, three dimensional pictures of molecules and genes in much the same way that optical lasers now make 3-D holograms of everyday objects. Present-day films could not be used for the task, however, and Baldwin warns that the problem of finding a way to record the gamma-ray information might be as difficult as developing the graser itself. The great penetration power of gamma rays might open new realms of radiotherapy, precision measurement and long-distance energy transmission, as for example, to a satellite in orbit. Also, any breakthrough in microfission technology could surely speed the development of fusion reactors, widely conceived to be the world's best hope for solving the long-term energy crisis.

Military applications would depend upon how powerful a graser could be made and how mobile it would be. Experiments with conventional laser weapons for antiaircraft use (code name "Eighth Card") have reportedly progressed to the point of setting wood afire at two miles and punching a hole in a playing card-sized object waving on a twenty-foot pole one mile away. That is a far cry from bringing down a highly reflective metal aircraft or missile, and conventional laser weapons seem, for the present, limited to guiding "smart" bombs accurately to their target and possibly antipersonnel use, through their capacity to blind an enemy. A gamma-ray laser, on the other hand, could easily penetrate the clouds that block optical lasers and, if powerful enough, could damage almost anything one wanted to damage.

Some microfission and laser fusion research is already classified because of its applicability to making hydrogen bombs. Graser technology might even revive prospects of developing a "neutron bomb"—a weapon giving off almost nothing but radiation that would destroy an urban population while leaving the buildings standing with very little radioactive residue. However, since relatively "clean," lightweight conventional hydrogen bombs reportedly can already be disguised as TV sets, the Pentagon is probably in no hurry to develop a neutron bomb.

Whatever potentials of the gamma-ray laser are ever developed, a stark lesson can be learned from the Soviet Union's open-mindedness and "can do" spirit in the matter. The developments documented here grew out of an exquisite marriage of long-term pure and applied research, conducted over a wide variety of fields at well-funded multidisciplinary laboratories. That they come at a time when the United States has cut back on its own long-range research, especially in pure science, and fostered a trend to narrow, short-term, pragmatically directed technological development, is hardly coincidental. The chances for developing a gamma-ray laser, Baldwin says, are as good now as the prospects for optical lasers were in 1955; what is needed, he says, is commitment to a program of broadly based research. ☐