NUCLEAR PUMPED GAS LASER RESEARCH

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A nuclear-pumped gas laser is excited by the interactions of energetic particles from nuclear reactions with a laser gas. Such nuclear reactions can be of various natures, such as fission in a nuclear chain reaction, or radioactive decay resulting in fast particles, for example, from polonium 210. For practical reasons, I confine my discussion to the nuclear pumping of lasers by fission-fragments from nuclear chain reactions, because this mechanism promises to result in the highest laser power level. The NASA work on the nuclear pumped laser has evolved as a sideline of plasma core nuclear reactor research, in the course of which it was realized that a fissioning gaseous medium should emit em radiation in a nonequilibrium spectral power distribution and, hence, provide the basic conditions for lasing.

In principle, the conversion of fission-fragment kinetic energy into laser light is the direct conversion of nuclear energy into work in a controlled fashion. It is a breakthrough in the usage of nuclear energy, avoiding thermalization and the employment of a thermodynamic cycle with all its limitation of efficiency and temperature tolerances.

Nuclear pumped lasers are only a few months old. On 2 October 1974, NASA announced a nuclear pumped helium-xenon laser (ref. 1) and the Sandia Corporation announced a nuclear pumped carbon monoxide laser on 11 October 1974 (ref. 2). The efficiency in both of these experiments is quite low, if one relates the laser power with the power of the nuclear reactor that provides the neutron fluxes needed to induce the nuclear pumping. However, when one envisions nuclear power stations in space, that beam their power via laser beams to customers at various locations – to other spacecraft for propulsion or onboard power, to lunar bases for industrial processing, and, perhaps, back to Earth for utilization of power without pollution and hazards – a direct-pumped nuclear laser system need not be very efficient to be competitive with laser systems that involve more conventional pumping methods, and whose power is derived from the conventional conversion of nuclear heat into electricity. One can easily see that an efficiency of a few percent would already establish a quite attractive system, in addition to the potential of significant savings of mass and cost.

A schematic of the NASA experiment (ref. 3) is shown in figure 1. The Sandia experiment is somewhat different in the geometrical configuration, but very similar in its functional components.

In figure 1, one sees basically an arrangement in which fission fragments are produced and are made to interact with a gas for studying optical radiation. Fission reactions occur in a foil of enriched uranium by neutron capture and a good part of the fission fragments can escape from the foil and penetrate into the gas inside a laser tube. In the NASA experiment, a mixture of 1 part xenon in 20 parts of helium at 300 torr pressure lased at a wavelength of 3.5 μ, during a pulse of about 0.1 msec. The integrated energy at these first experiments was about 10 mJ, measured by means of a gold-doped germanium detector, 10 m away from the laser. The laser beam was bent three times by 90° in order to locate the detector behind heavy shielding against nuclear radiation from the reactor.

Left in the figure is the Los Alamos "Godiva" fast burst reactor, the origin of the neutrons that cause the fissions in the uranium coating in the laser tube. In this device, two half-critical masses of enriched uranium 235 are pneumatically shot into each other, whereupon the machine becomes supercritical and starts a chain reaction, running up to 10,000 MW of power. The system expands immediately by heat, thus slightly increasing its surface. In that moment, enough neutrons can escape to interrupt the chain reaction and shut down the reactor. Only a very small fraction of the nuclear fuel is burned, but nevertheless about a megajoule of energy is released – which makes the fraction of a joule of laser light that comes out of the laser tube, indeed, appear to be a very poor effect.

Figure 2 shows the Godiva reactor as a handsome little research machine, which it is, as long as one stays far away from it at operation. Also seen is a little laser tube, wrapped in a polyethelene moderator.

Looking back at figure 1, one recognizes immediately the reason for the very low efficiency of this arrangement. Only the neutrons of the reactor are used for the nuclear pumped laser experiment, and those neutrons, particularly when moderated, carry practically no power. What is needed, apparently, is to combine the laser tube and the reactor into one unit, that is, to make the laser tube nuclear critical, or, in other words, to make a gaseous core reactor that lases.

If everyone would be entirely biased and perfectly objective, and if he thus could see things as I do, he would immediately join us in the research on nuclear-pumped lasers and the related gaseous fueled reactors!

Gaseous core reactor research is well underway under a NASA interagency agreement with the Los Alamos Scientific Laboratory.

As mentioned before, the nuclear-pumped laser research is closely connected with this gaseous core reactor work. In the following, only our experimental program on nuclear lasers will be discussed. We plan to test a high pressure xenon laser for nuclear pumping with the Godiva. Before we achieved lasing with the helium-xenon mixture, numerous luminosity measurements were conducted which indicated that the generation of light by fission-fragment, gas-atom interactions increases with shorter wavelength. Because of insufficient instrumentation, we could not yet make measurements in the uv spectrum. However, we suspect that most of the conversion of fission-fragment energies into light occurs in the ultraviolet. Colleagues of the JPL will hopefully soon be ready to join our friends at the LASL in conducting nuclear-pumped, high pressure xenon experiments.

When increasing the pressure, the fission-fragment stopping distance will eventually become smaller than the diameter of the laser tube diameter. In that case, the technique of using an uranium foil inside the laser tube becomes less effective. Instead of a surface source of energetic nuclear particles, a volume source must be used (ref. 5). One possibility is an admixture to the laser gas of He^3, which upon the capture of a neutron undergoes the reaction He^3 (n T)p, where the triton and proton carry about 700 keV energy. From other laser systems it is known that helium will not quench lasing in certain systems. Another option for a volume source of energetic nuclear particles would be enriched uranium hexafluoride that undergoes fission in a neutron bath.

UF_6 may quench laser action, because of its many degrees of internal freedom; perhaps it does not do so, however, and instead may offer many lasing opportunities. This is a subject of forthcoming research.

For the research involving enriched UF_6 and He^3, we have shipped our ballistic piston compressor from the University of Florida to Los Alamos. This compressor and the Godiva reactor seem to be an ideal match to produce, for a fraction of a millisecond, all conditions that one possibly could desire for nuclear-pumped laser research: the cannon will compress gas mixtures to almost any degree of needed density and temperature. A schematic of this cannon is shown in figure 3. Very fortunately the free flying piston in this device, an old 50 mm Navy gun barrel, is driven by compressed air and not by gun-powder; had the latter been the case, the reactor people of LASL would have let the gun not come near the Godiva! Sometime in the near future we will compress enriched UF_6 or He^3 in the cannon and expose it to the high neutron flux from the Godiva reactor. The high neutron fluence combined with the large uranium particle density should give us an estimated 1000 joules of fission energy generated in the gun!

A good faction of this energy could be converted into laser light. Or that part of this energy could be used to recharge the air compressor – such that the machine would run like a Nuclear Otto Engine!

REFERENCES

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2. Sandia Laboratories News Release, 11 Oct. 1974.

3. Helmick, H. H.; Fuller, J. L.; and Schneider, R. T.: Direct Nuclear Pumping of a Helium-Xenon Laser. Appl. Phys. Lett., Vol. 26, no. 6, 15 Mar. 1975, p. 327-328.

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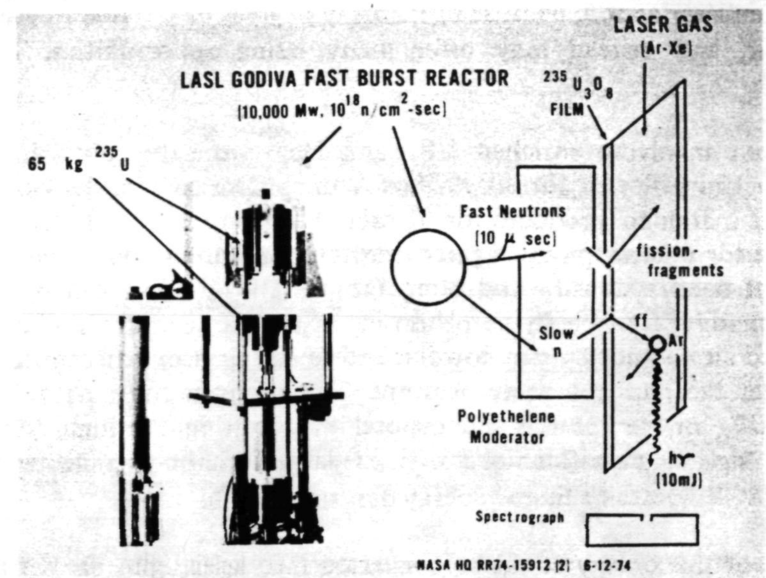

Figure 1.– Nuclear pumped laser research.

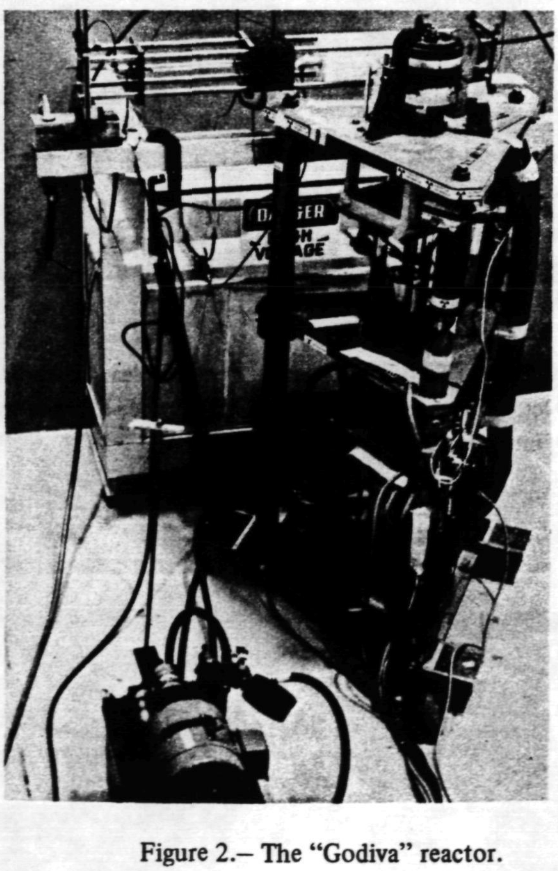

Figure 2.– The "Godiva" reactor.

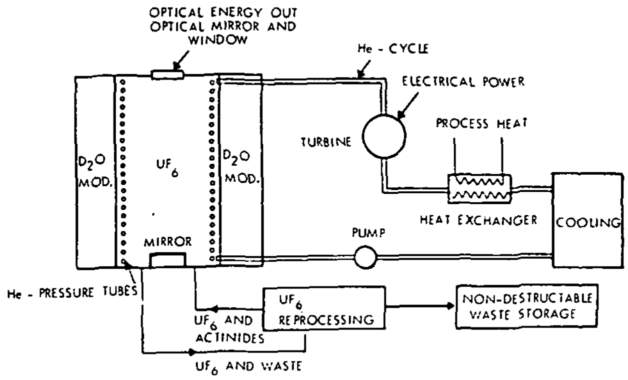

Figure 3.– Nonequilibrium nuclear reactor system.

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DISCUSSION

Abe Hertzberg, University of Washington – Karl, even though I'm very impressed with the success of these experiments, all those nuclear radiation signs on the apparatus tend to keep me at arms length!

Stuart Bowen, Stanford University – Are the pumping requirements of this device in any way compatible with the usage of reactor nuclear waste material? That is, can the waste actinides, etc., be used for this?

Answer: No, we wouldn't pump with it – we would hope to put it back into the reactor and burn it. The trans-uranium actinides, of course, are fissionable.

Abe Hertzberg, University of Washington – But that's not really connected with your laser. What you're indicating, of course, is that if you could build a UF_6 gas core reactor, you could recycle some of these wastes?

Answer: Yes.

Dick Stirn, J. P. L. – What is your feeling about the materials problems of mirrors, etc., at these high radiation levels?

Answer: It may be a big problem. Of course we might use aerodynamic windows and there are other ways of promoting self-anealing of materials. Such work at United Aircraft showed that some radiation damage can be self-anealed by heat. There are various possibilities.

Abe Hertzberg, University of Washington – What mixture did the group at Sandia use?

Answer: They used carbon monoxide. We believe we have to go to high pressure xenon to get better efficiency and shorter wavelength.

Abe Hertzberg, University of Washington – Have you made any calculations of what are the possible efficiencies of such a system?

Answer: Many attempts have been made. However, the problem is that the real cross sections involved are not known. Our approach will be to measure some of these and then use them to assist the theory.