The X-Ray Laser

President Reagan, in an historic March 23 speech, proposed to use a layered defense system to render intercontinental ballistic missiles "impotent and obsolete." Most strikingly, his proposal referred to a completely new technology—the X-ray laser—to solve the hardest problem of defense against intercontinental ballistic missiles (ICBMs).

In motivating his speech, Reagan summarized the most striking feature of the past decade's military balance: the development by the Soviet Union of a preemptive strike capability and the unilateral renunciation of defensive capabilities by the United States with a strategic military predicament in which its nuclear arsenal is irrelevant to international political power: too small to destroy Soviet silos, too vulnerable to be a deterrent; and too unreliable to be launched on warning.

As many of the President's advisors point out, a new generation of *offensive* weapons does not redress this vulnerability; it only intensifies the push toward a first-use, "use them or lose them" dilemma.

The only way out of this dilemma is a *defensive* capability that neutralizes these offensive weapons.

As it has been elaborated since the President's address to the nation, the Reagan proposal in its final deployment would consist of:

(1) a boost phase intercept capability using space-based lasers of short wavelength and very high power, such as the X-ray laser;

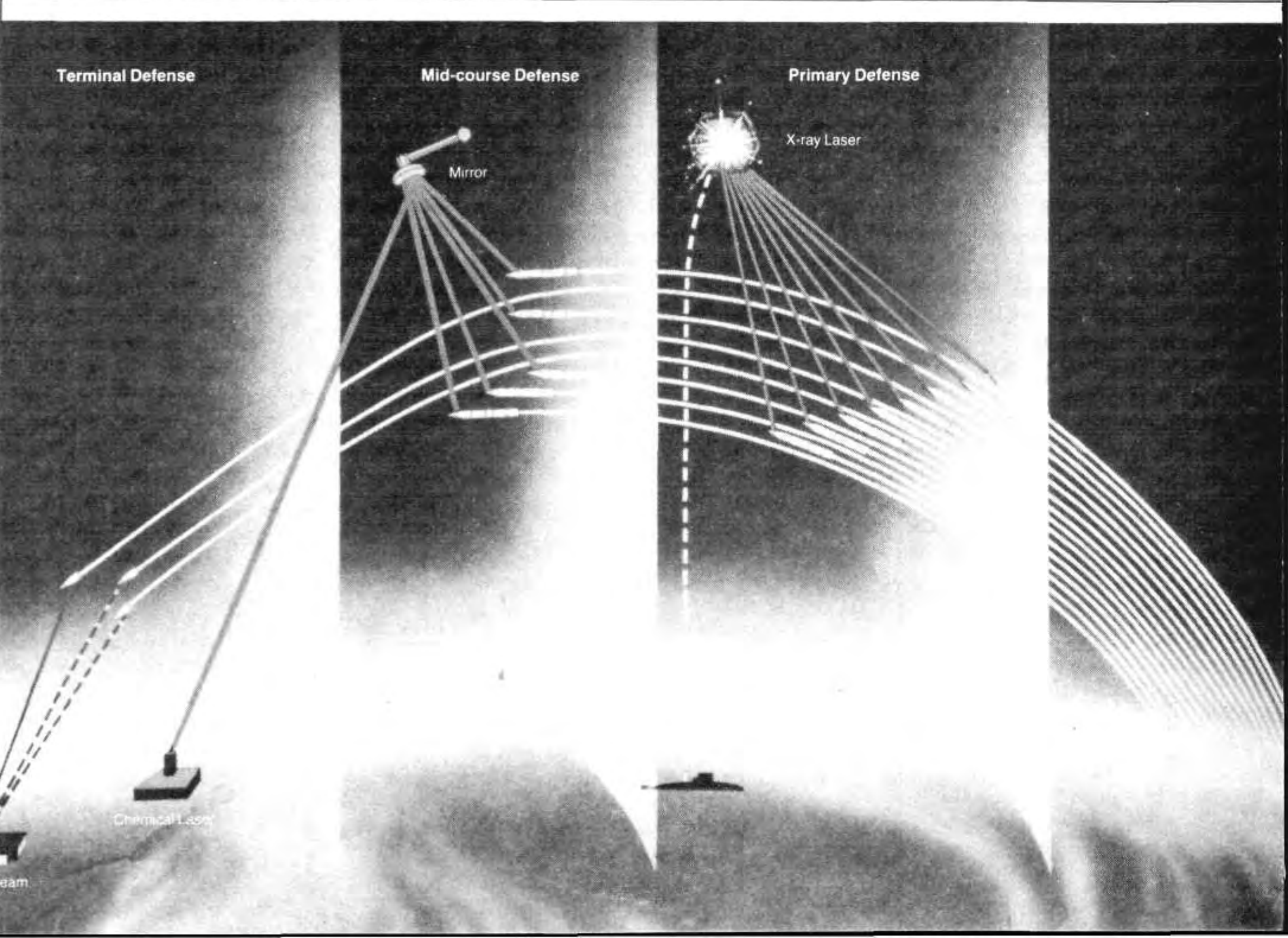
(2) a boost-phase or bus-phase intercept capability using space-based or hybrid (either space-based mirrors and land-based lasers, or space-based free-electron lasers) systems;

(3) a terminal system using particle or projectile beams.

Figure 1 shows this three-phase layered defense system and the table (page 36) summarizes the properties of these three layers.

The criteria that any such defense system must achieve are simultaneously ones of damage-limitation, offense-denial, and a psychological goal requiring the generation of sufficient uncertainty in the military calculation of one's adversary to prevent its deliberate offensive use of ICBMs. Together these criteria require a cumulative capability of destroying more than 99 percent of the adversary's *warheads* in an attack. This percentage would ensure protection of the vast majority of targets, as well as the creation of the objective result that a first-strike would be equivalent to self-disarmament.

It is unlikely that any single technology could be counted on to assure that defense. However, a set of complementary, qualitiatively different systems can achieve that rate of



by 1986!

by Dr. Steven Bardwell

destruction of nuclear weapons with maximum assurance, if each layer has a unique technology, deployment mode, and engagement strategy.

Boost-Phase Intercept

It is clear from the table that the objectively new ingredient in the problem of ballistic missile defense is the technology that makes boost-phase intercept possible—the ability to destroy a large fraction of the incoming missiles while they are still in the "boost" or powered flight stage of their trajectory. This phase, taking up about 5 minutes of the 30-minute flying time for an ICBM, is the missile's most vulnerable stage: It is slow moving, under great mechanical stress, and contains all its nuclear warheads.

An adequate defense against nuclear weapons is possible only when this boost phase intercept problem is solved. Thus, until the development of the beam weapon concept, there was no viable proposal for boost phase intercept of ICBMs: The beam weapon is designed to destroy ballistic missiles using a ray of energy generated on a space-based platform many thousands of miles from the missile's launch site and traveling at the speed of light, to incinerate the missile as it is launched. As little as three years ago, even the phrase "directed energy beam weapon" was classified by the U. S. government; today these technologies are widely recognized to be the centerpiece of ballistic missile defense.

Figure 1
TOTAL DEFENSE IN THREE STAGES

Experts agree that no single antimissile system can be 100 percent effective against ballistic missile bombardment. But, by combining three different systems, each with 90 or 95 percent effectiveness, a total system can be built that provides almost complete protection against ballistic missiles. The first layer must destroy 90 percent of the missiles as they are launched. This space-based system might be launched as soon as the missiles are detected (as shown in the figure) or might be permanently based in space. An X-ray laser station is shown here. The second stage has only to deal with the 10 percent of the remaining missiles, a more modest role of which a space-based mirror and ground-based optical laser would probably be capable. The third, terminal, stage of the system would be a ground-based particle or laser beam designed to intercept the warheads themselves, after they had been released from the ICBM. Because only 1 percent of the original targets would be left after the protection of the first two layers, the last stage can be more expensive and complex, as a particle beam would be.

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As long as the defense can only intercept reentry vehicles, only a very limited point defense is possible (of the sort contemplated in the original U.S. plans for the Safeguard antiballistic missile program, for example), and the arithmetic of one or two defending warheads for each offensive warhead is very disadvantageous to the defense. However, with the ability to destroy many (10 to 50) ICBMs with a single warhead (a nuclear-pumped X-ray laser satellite, for example), the arithmetic changes from 2 to 1 against the defense to 300 to 1 in favor of the defense. Ironically, with the development of beam weapons, the MIRV (multiple independently targetable reentry vehicle) tactic of putting many warheads on a single booster, which so effectively saturates terminal defense systems, now works against the offense, since the destruction of a single ICBM disables many warheads. The X-ray laser concept and its scientific proof-of-principle demonstration over the past two years is the central new feature of a ballistic missile defense system.

This X-ray laser technology combines small size and weight (a result of the inherent efficiency of nuclear pumping), with relatively low cost and a wide range of deployment modes. Current thinking is that the X-ray laser layer of the system would consist of one component (with perhaps 300 satellites) permanently based in low-Earth orbit. These satellites would be vulnerable to antisatellite destruction (although this danger is minimized by the small size and large number of the satellites).

This component would be complemented by a "pop-up" capability of another several hundred satellites, which would be based on submarines, on land near the Soviet Union, or in the continental United States, and would be launched into low-Earth orbit on warning.

How Soon?

In an interview in the *Washington Times* on June 14, Presidential science advisor George Keyworth commented on the ballistic missile defense system proposed by President Reagan: "These programs are a lot closer than people think. . . . All the components already exist—we simply have to assemble them."

This striking assessment is confirmed by a new analysis of X-ray laser technologies recently completed by the Fusion Energy Foundation. Based on extensive discussions with leaders in the American physics community and experimentalists in several foreign countries, FEF researchers have concluded that the "state of the art" in X-ray lasers is very far advanced, not only justifying Keyworth's statement, but making development and initial deployment of X-ray lasers possible within the next three years.

There are three independent indications pointing to the near-term feasibility of an X-ray laser antiballistic missile (ABM) system.

First, scientists at Lawrence Livermore National Laboratory in charge of the X-ray laser system have repeatedly hinted that the scientific and engineering progress has been so rapid that they expected to "present the next President" with a working system for ABM defense. In several conversations they have emphasized that chemical laser-mirror systems are *irrelevant* because the X-ray laser will be deployable *sooner* than a chemical laser system. Apparently, this confidence has been conveyed to Congress as well, because for the past two years, Congress has redirected the U.S. beam technologies research program increasingly toward "short wavelength" lasers—a code phrase for X-ray laser systems.

Second, three independent reports have circulated of very successful tests of different components of the X-ray laser. The first of these appeared in a February 1981 article in *Aviation Week & Space Technology* and was corroborated by a Soviet analysis of this material published in English.[1] This report is not a "leak" in the usual sense. It is known to have been based on detailed written experimental data from the U.S. Dauphin test, which demonstrated the scientific proof of principle of the X-ray laser. Reportedly, this test was so much more successful at producing a monochromatic, collimated beam of X-rays that the diagnostic equipment installed for the experiment was vaporized by the pulse of X-rays. There have been two subsequent reports of tests, one of the sensing and pointing system for an X-ray laser, and the second for other components of the system. One of the great virtues of the X-ray laser is that its small size makes possible separate testing of the sensing and power technologies.

A Layered Beam Weapon Defense System

Layer	Basing	Technology of Choice	Range (km)	Target Stage	Number of Targets
First	Near Earth	X-ray laser	3 to 5,000	Boost phase	5000
Second	Near Earth or hybrid	Chemical or free-electron laser	1,000	Boost or bus phase	300 to 500
Third	Terminal (point)	Particle or projectile beams	100	Reentry vehicles	500

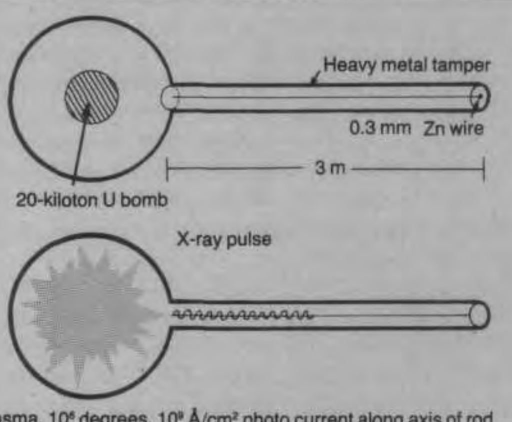

Figure 2
CONVENTIONAL X-RAY LASER DESIGN

In the public literature, an X-ray laser is envisioned to use an exploding atomic or uranium bomb to generate broad spectrum of high energy X-rays. This bomb, exploded in a spherical cavity, irradiates the ends of the lasing rods surrounding that cavity. When the X-rays from the bomb ionize the solid-state lasing medium, they produce a pulse of collimated, monochromatic X-rays that travels down the rod.

There are two obvious and well-known difficulties with this design. First, it is inherently inefficient because only a small part of the X-rays from the bomb actually intercepts the end of the rod. Second, the rods provide only geometrical focusing for the beam and so produce an X-ray pulse of large diversion.

Third, the significance of these tests has been misestimated by the scientific community not privy to classified data because of the obvious engineering problems of the published designs of a nuclear-pumped X-ray laser. These problems, noted by critics of the X-ray laser, are as follows:

Energy output efficiency. The reported pulse energy of the first experiment was 1 megajoule. For a workable near-term system, an increase in energy of two or three orders of magnitude would be necessary. The problem concerns the inherent inefficiency of the designs described in speculative reports on the device. These designs all showed that only a very small amount of the pumping energy released by the bomb energy could be used, which provided a geometrical limitation on the efficiency of the device that is the result of the small area that the lasing medium subtended at the active surface of the device. (See Figure 2.)

Beam divergence. Since the only known focusing mechanism for collimating the beam was the geometric one of having a very small diameter rod (really a wire) of several meters in length, increasing the area irradiation of the rod meant increasing the beam spread. There is a fatal tradeoff between these two requirements: A brightly focused beam would be of low power and a high power one would be spread over a large area.

Pointing. The pointing difficulty of the X-ray laser of pulse energy in the range of the first test is roughly the same as with a chemical laser system, a challenging task that itself would require about several years. However, if the power could be increased by 100 to 1,000 times, the pointing accuracies would be relaxed sufficiently that the pointing would become within *present* technological capabilities. That is, there is a similar tradeoff between pointing difficulty and energy. Low energy systems conceivable now require very severe pointing accuracies, but the high energies necessary to relax this accuracy seem unattainable with the design in Figure 2.

A Hypothetical Design

Based on discussions with a large number of physicists involved in weapons and inertial confinement fusion research work, the FEF has proposed a design for the X-ray laser that shows that each of the problems listed above can be solved with technologies well known in the weapons field. In fact, these technologies already form the basis for the current generation of "advanced" nuclear weapons.

Figure 3 shows a geometric configuration for the X-ray laser that uses present bomb technology to completely solve the inefficiency inherent in Figure 2. By using X-ray focusing mirrors as shown, the whole pump energy is focused on the lasing medium. These ellipsoidal cavities are a standard component of small, efficient nuclear weapons. This design also removes the tradeoff between accuracy and efficiency, using two physical principles to focus the beam, with reasonable rod dimensions. The result is a beam 20 microradians in divergence, giving dramatically lower requirements for pointing accuracies.

The configuration of lasing medium shown uses a hyperbolic horn at the inside surface of the rod, which focuses the X-rays reaching the rod into a one-dimensional flux of radiation. This radiation in turn produces a zinc plasma and an intense photocurrent. The combination of the photocurrent, its magnetic field, and the inertial effects of the heavy metal tamp, produce focusing beyond that provided by the geometric focusing of the lasing medium itself. Thus, a rod with larger diameter (hence more stable and able to contain more energy) can be used. The technologies involved in the construction of these focusing horns, the tailoring (or filtering) of X-radiation, and the use of intense photocurrents are all standard components of recent generations of nuclear weapons.

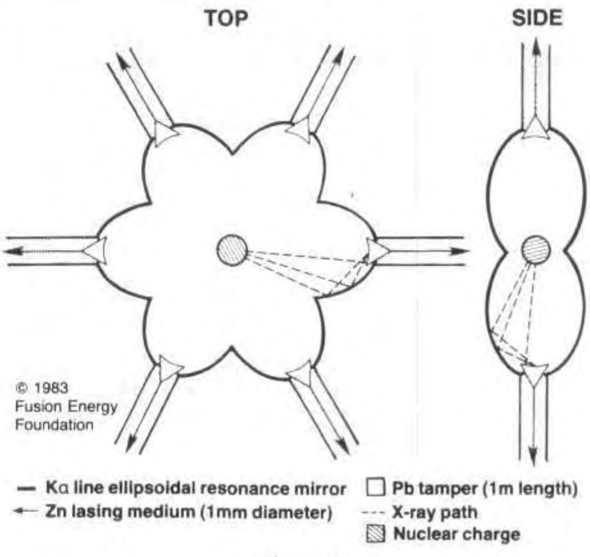

Figure 3
HYPOTHETICAL X-RAY LASER DESIGN

By combining several techniques well known in the construction of advanced nuclear weapons, it is possible to solve the problems of the inefficiency and large divergence of conventional X-ray laser designs. First, the X-rays from the bomb blast can be focused using a set of ellipsoidal cavities. These cavities, using multilayered K-alpha dielectric mirrors, focus all the X-rays from the spherically symmetric explosion on to the ends of the rod. These rods use a conical assembly of lasing material to further focus the plasma produced by the X-rays along the axis of the rod.

The lasing medium itself is embedded in a heavy metal tamper. This tamper provides mechanical stability as well as an inertial focusing of the lasing medium. In addition, a very intense photoelectric current generated by the X-rays in the lasing material confines and focuses the X-ray producing plasma. These techniques increase the efficiency of the conventional design by 2 to 3 orders of magnitude and decrease the divergence of the beam by perhaps a factor of 10.

This design shows that once the scientific principle of the lasing has been demonstrated (which it was two and a half years ago), it is only a question of known bomb technologies combined with communications and control capabilities that remains to be answered.

Two conclusions follow from these facts:

First, the United States is very close to the deployment of an X-ray laser. This is the significance of Keyworth's June 15 interview. The first deployment would seem to be possible within the next two to three years.

Second, the technologies required for this deployment are those in which the United States is well known to be ahead of the Soviet Union. This is true, for example, concerning the construction of small efficient nuclear weapons. In an ironic turn, the large heavy hydrogen weapons of the Soviet Union are inappropriate for generalization to X-ray laser pumping. The small efficient bombs that are the focus of U.S. R&D use precisely the focusing, filtering, and materials technologies required for X-ray lasers.

This is also true for the command and control demands on the X-ray laser, which require computer and communication capabilities in which the United States has excelled. The industrial base for the software and hardware required for these lasers is in advance here of that in the Soviet Union.

The dilemma facing the Soviet Union is not, of course, that it is impossible for them to develop an X-ray laser in space; with diversion of enough manpower, money, and capital goods, they might succeed on approximately the same time-scale as the United States. However, it is the case that U. S. development of the X-ray laser definitively reverses the present vulnerability and puts the initiative on the American side. The X-ray laser is American technological genius applied to America's greatest strategic asset: its ability to make dramatic, qualitative technological leaps. This is the basis for real national security.

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Notes

1. Clarence A. Robinson, Jr., "Advance Made on High-Energy Laser," *Aviation Week & Space Technology*, Feb. 23, 1981, p. 25. The Soviet report appeared in July 1981: F.V. Bunkin, et al., "Specifications for Pumping X-ray Lasers with Ionizing Radiation," *Soviet Journal of Quantum Electronics*, 11:7, p. 971.
2. The author gratefully acknowledges many valuable discussions with F. Winterberg, as well as his book, *The Physical Principles of Thermonuclear Devices* (New York: Fusion Energy Foundation, 1981).