Micro

Director of Central Intelligence

8 MAY 1984

~~Secret~~ S

[redacted]

Soviet Laser Weapons Technology: A Collection Guide [redacted]

Scientific and Technical Intelligence Committee

~~Secret~~

[redacted]

December 1983

Copy 286

4

52

National Security Information

Unauthorized Disclosure Subject to Criminal Sanctions

[redacted]

Classified by 0064777
Declassify: OADR
Derived from multiple sources

National Security
Information

Unauthorized Disclosure
Subject to Criminal Sanctions

[redacted]

Classified by 0604777
Declassify: OADR
Derived from multiple sources

Director of
Central
Intelligence

Secret

Soviet Laser Weapons Technology: A Collection Guide [redacted]

Secret
[redacted]
December 1983

Note

[redacted]

Preface

[redacted]

blankpg

Contents

[redacted]

Soviet Laser Weapons Technology: A Collection Guide (U)

Introduction

Laser weapons constitute a major new form of weapon system capable of delivering sufficient energy to destroy a variety of targets of military significance. The applications of such weapons could be as broad as those of missiles or guns. The five major characteristics of laser weapons that combine to define their promise are the near instantaneous delivery of energy, the potential for a large magazine, a wide field of fire within which the laser can switch rapidly from target to target, rapid growth of kill margin as the range to the target decreases, and a potential for selectively delivering energy at the optimum location on the target. These characteristics combined to make laser weapon systems highly responsive. Major disadvantages are atmospheric propagation problems and the requirements for extremely accurate pointing and tracking and line of sight to the target. [redacted]

Because even low-power lasers are highly intense compared with natural-light levels with which sensors operate, lasers have tremendous potential for a number of countermeasure applications. Lasers can disturb the aiming accuracy of threat weapon systems by temporarily saturating or permanently damaging or destroying electro-optics and human eyes or by creating false guidance signals or false targets for laser guided weapons. The application of lasers in space makes even greater use of the five characteristics cited above. [redacted]

Lasers which are effectively fielded as weapons systems will have the potential in a high-density threat environment, to methodically move from target to target over their all-azimuth coverage, focus their beam on the target, hold the selected aim point despite the target's speed and maneuverability, and to destroy a vital component or the structural integrity of the target or to igniting the fuel or warhead in seconds or less. [redacted]

A laser weapon system is comprised of a lasing source, the optics that perform the focusing, beam control, pointing and tracking, and all the other associated electronics which assist in the proper functioning of the system. This guide will focus primarily on these laser types and their associated component technologies. Some insight will be provided as to how the technologies come together for various weapons applications, and finally, collection targets, facilities, personalities and key questions will be addressed. [redacted]

blank pg

Laser Technologies

General

Laser devices are generally categorized by the lasing medium (for example, carbon dioxide (CO_2), iodine (I), hydrogen fluoride (HF), deuterium fluoride (DF), and so forth) and pumping technique (for example, gasdynamic, chemical, electric discharge, photoionization/dissociation, and so forth) used to achieve an excited state. Release of the stored energy through stimulated emission produces an intense, well-collimated, monochromatic beam of light. The Soviets sometimes call these devices optical quantum generators (OKGs) since they operate because of the discrete energy levels associated with quantum mechanics. Table 1 lists laser devices with several associated general parameters. [redacted]

In general, a laser device can be divided into two subsystems, the gain generator and the optical resonator, each performing unique functions. The gain generator is primarily the material that has been pumped to an excited state. When the gain generator is enclosed in an optical resonator assembly, which consists of parallel mirrors, randomly emitted photons are reflected back and forth stimulating the emission of additional photons and the amplitude of the light beam increases. There are two basic configurations for optical resonators: stable and unstable. Stable resonators are most applicable to devices with small gain regions and unstable resonators are most applicable to laser devices with large gain regions. The stable resonator employs a partially transparent mirror to split the beam allowing part of the beam to exit the resonator. Unstable devices employ spatially separated mirrors that allow fully reflective optics to be used with the beam being reflected out of the optical resonator. Because the unstable resonator allows fully reflective optics, it is most applicable to high-energy lasers (HEL). [redacted]

[redacted]

[redacted]

Gasdynamic Lasers (GDL)

The GDL was the first high-energy HEL developed capable of producing a multimegawatt power output. The device itself is composed of three subsystems; combustion or electrical heating chamber, nozzles, and optical cavity (see figure 1). The chamber produces a hot flowing gas with molecules generally occupying an excited energy state. The excited gas then passes through a set of expansion nozzles expanding and cooling the gas resulting in a population inversion of the lasing medium. As the gas flows past the optical resonator, photons are reflected back and forth between the parallel mirrors resulting in the laser beam. The diffuser then allows the exhaust gas to decrease in kinetic energy (velocity) and increase in potential energy (pressure) to be exhausted (open-cycle operation) or cooled, compressed, and reinjected into

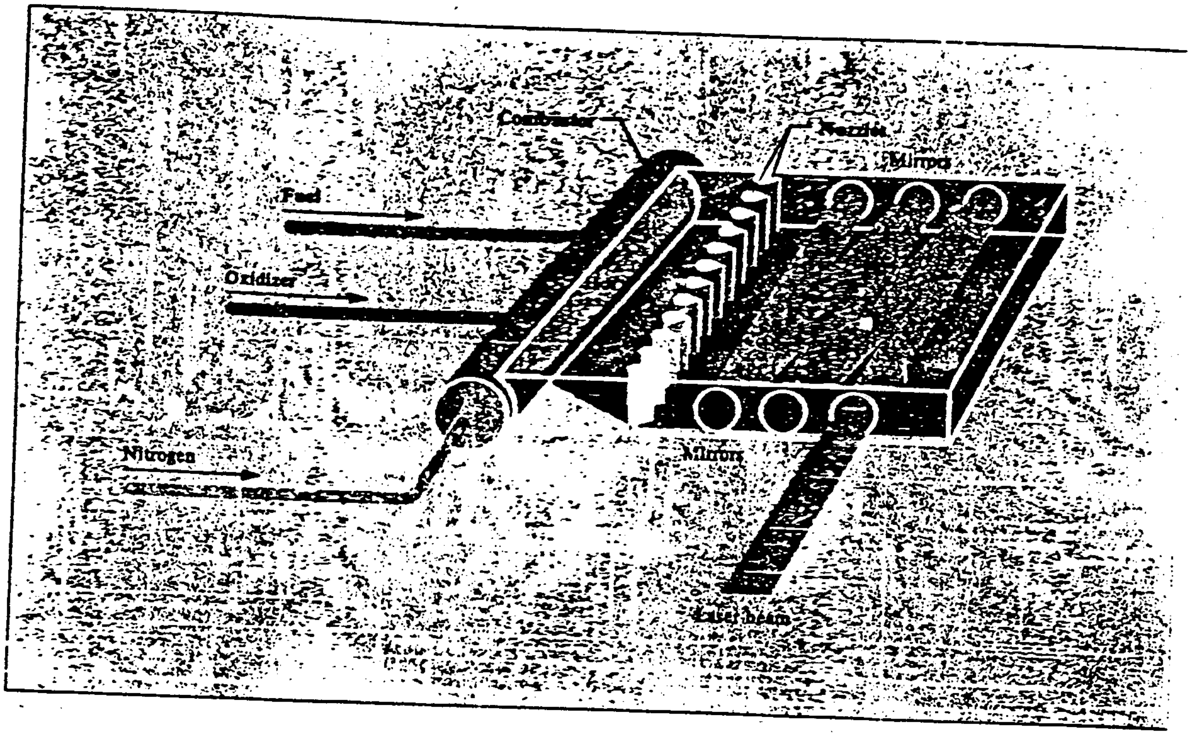
[redacted]

the heating chamber (closed-cycle operation). The most common GDL employs CO_2 as a lasant medium combined with nitrogen in a combustion chamber to excite the gas, which then flows through the supersonic nozzles creating the population inversion and resulting in lasing. The resulting beam is in the 10.6 μm wavelength and normally is operated in the continuous wave mode. [redacted]

Key Intelligence Questions:

1. The most important parameters for a GDL are the beam quality, weight, size, type of fuel (solid or liquid), fuel-mixture ratios, flow rate as a function of output power, and the types and design (including materials used) of supersonic flow nozzles.

Figure 1
Gasdynamic Laser Device



[redacted]

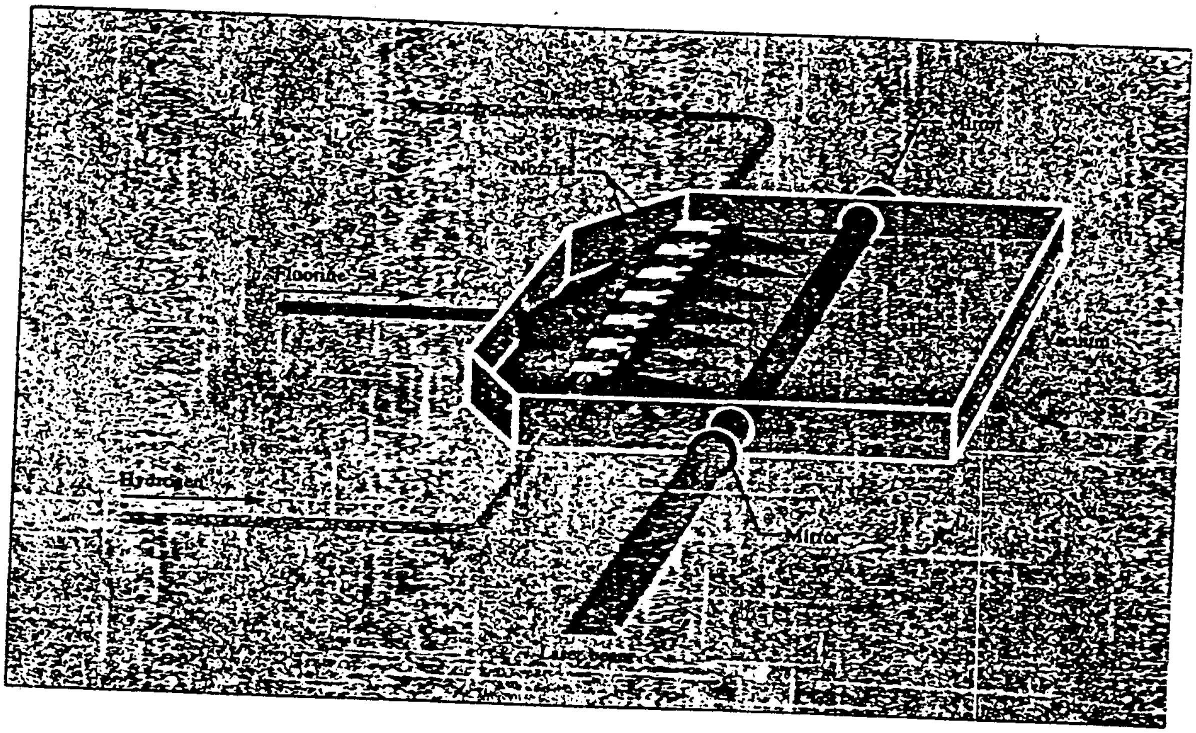
2. For combustion-driven GDLs it is important to know fuel types and mixture ratios.

3. For electrically driven GDLs it is important to know electrical efficiency. [redacted]

Chemical Lasers
In chemical lasers, as the name implies, two or more chemicals are combined in the cavity of the laser device to form excited molecules of a new compound. This continuously operating device is similar in operation to the gasdynamic laser with the addition of injector nozzles in the cavity to permit the introduction and mixing of the second chemical into the rapidly flowing medium. In general, the device consists of four primary regions: precombustion chamber (dissociation chamber), nozzles, cavity region, and diffuser. There are a number of variations of this general design, some employing subsonic flow within the laser cavity (therefore the absence of supersonic nozzles) and different methods used to create the initial dissociation of the reactant chemical species for the production of active chemical centers. [redacted]

POOR QUALITY PAGE

Figure 2
HF Chemical Laser



[redacted]

Hydrogen fluoride (HF) lasers (see figure 2) represent the most advanced technology being pursued in the United States today that is capable of producing the multimegawatt power outputs necessary for weaponization. The device itself operates by combining free atoms of fluorine with hydrogen molecules or atoms resulting in vibrationally excited molecules of HF. [redacted]

Two unique aspects of HF laser operations are the toxicity of the lasing medium and the requirement for water-free coatings in the optical resonator. HF is toxic in concentrations of only three parts per million, thus large devices require scrubber systems to prevent environment damage. HF attacks most materials and can critically degrade an unprotected surface. Most hydrogen fluoride laser emission lines are strongly absorbed by water. Thus, water trapped in optical coatings will absorb HF emission and destroy the coatings and even the optical components as well as decrease the laser beam quality and power flux. [redacted]

The HF laser emits at a number of infrared wavelengths between 2.5 and 3 μm which is in a region of the spectrum that is subject to strong atmospheric

POOR QUALITY PAGE

absorption. Deuterium fluoride (DF) lasers emit at a spectral region of 3.5 to 4.2 μm, which is more readily transmitted through the earth's atmosphere. [redacted]

The iodine chemical (I) laser emits a beam at the 1.315 μm wavelength, which means that levels of about four and nine times the brightness of HF and DF lasers respectively can be achieved with equivalent apertures and equal power devices. In addition, it is expected that iodine lasers will achieve similar mass flow efficiencies as HF and DF devices allowing trade-offs in aperture size, in-orbit weight, and lethality to be made for space-based applications. [redacted]

An attractive aspect of iodine lasing is that, unlike DF lasers which exhibit multiline lasing, the iodine laser can be made to lase at a single narrow band at 1.315 μm. As a result, laser transition fluctuations, which can affect beam quality and beam control system problems associated with multiple wavelength propagation, are avoided. [redacted]

[redacted]

Argon-Ion Lasers

For over a decade, researchers at the Novosibirsk Science City have been experimentally and theoretically investigating and developing argon-ion lasers. Their goal has been to develop high-power argon-ion lasers with a long life. Their investigations have included laser-mode control and emission spectra of ionic lasants in an accelerating field. Their developments have centered on special cathodes and optical systems for these lasers. Outputs from these lasers are the visible spectrum (Ar II, 488 nm) and in the 100- to 1,000-watt range. New investigations and developments have been on an argon-ion laser with supersonic flow. [redacted]

Two prototype argon-ion lasers have been built: MIL-1 and MIL-1-01. The former is a 300-W laser with a service life of 1,000 hours. Its dimensions (including power supply) are 40 x 110 x 310 cm. The latter operates in the single-frequency regime via mode selection. [redacted]

Applications of these lasers have included nonlinear effects, dye laser pumping, photochemical reactions, and single-crystal semiconductor restoration. [redacted]

Key Intelligence Questions:

1. What are the new increases in service life, power outputs, and mode selection?

[redacted]

Metal Vapor Lasers

A metal vapor laser uses a metal ion in vapor form as the medium for the lasing action. The metal ion is excited by an external source such as another laser. The Soviets continue to dominate in the literature published on metal vapor lasers. In the last year, the previous list of 150 authors was increased by 50 percent. [redacted]

The Soviets are concentrating on the following techniques for the development of powerful metal vapor lasers:

- Transverse discharges.
- Extremely powerful pumping circuits.
- High-pulse repetition rates.

- Multiple-laser output summing.
- Oscillator-amplifier configurations.
- Metal particles in a high-pressure buffer gas. [redacted]

[redacted]

Ruby Lasers

Ruby (Al_2O_3, Cr^{3+}), emits laser energy in the visible (red) region. The Soviets continue to use ruby lasers in the field for military-related applications. For example, the Soviets have been ranging cooperative satellites (corner-reflector equipped) since 1970. In addition, Soviet laser rangefinders employed by field artillery forward observers, appear to use a ruby laser. Ruby lasers also might be used in other military application such as blinding and sensor degradation. [redacted]

Soviet equipment described in open source literature is primarily for educational, scientific, or industrial applications. As far back as the mid-to-late 1960s, several units were described as having performance ratings suitable for military applications, (for example, against people) but these units were not miniaturized and packaged for field use. [redacted]

Key Intelligence Questions:

1. What is the status of R&D in ruby lasers? What are current applications? Describe dimensions observed in packaging.
2. What specific military applications use ruby lasers? [redacted]

Doubled Neodymium Lasers

The output of neodymium lasers (where either glass or YAG is the lasing medium) can be frequency doubled, and, as a result, the output is converted to the visible (0.53 μm) wavelength. Soviet research groups commonly use this technique and the nonlinear optical materials required are readily available. [redacted]

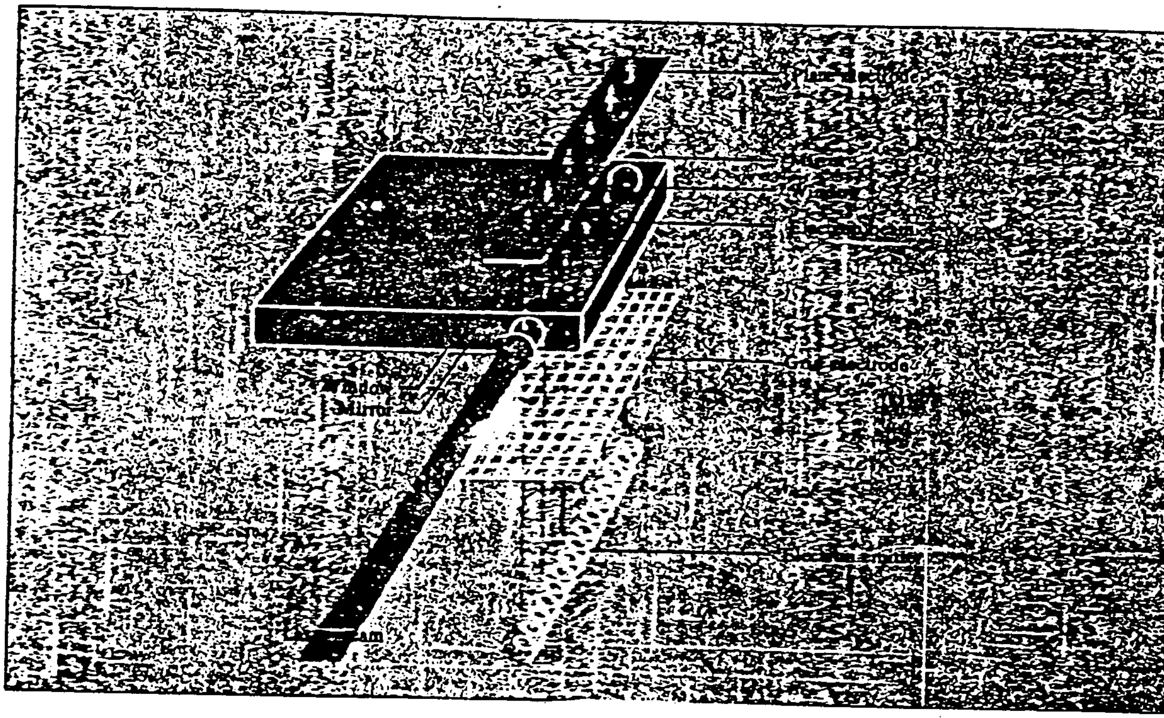
[redacted]

Electric-Discharge Lasers

Carbon dioxide (CO_2) electric-discharge lasers (EDL) operate at the 10.6-μm wavelength, which falls into one of the atmosphere's high-transparency windows. Energy is transferred either directly to the CO_2 medium by a UV preionizer, an electron gun, or through an intermediary gas (usually nitrogen) and diluent. The device structure parallels that described in the gas dynamic section with little variation from the general device description (see figure 3). [redacted]

Carbon monoxide (CO) EDLs operate at a number of wavelengths near 5 μm. Carbon monoxide continues to be of strong interest for development of endoatmospheric laser weapons, especially if operation can be restricted to wavelengths under 5 μm. CO lasers may also form the basis for near-term airborne or space-based weapon systems. CO_2 lasers have achieved efficiencies as high as 60 percent for pulsed operation and 50 percent in continuous-wave operation out of a theoretical maximum of 80-percent efficiency. [redacted]

Figure 3
Electric Discharge Laser



[redacted]

[redacted]

The principal concept that has contributed to scaling EDLs to high-average power outputs is that of the non-self-sustained electric discharge. In this type of discharge, an external source of ionizing radiation (proton and neutron beams, electron beams, UV radiation) generates an electron concentration in the laser cavity. [redacted]

The advantage of using an external source of ionizing radiation allows the independent control of both the concentration and energy of the electrons in the discharge. This makes possible the generation of stable volume discharges suitable for pumping various lasants, such as CO_2 and CO. These lasers are called combined pumped electric-discharge lasers (CPEDL) in reference to the combined action of the ionizing radiation and the electric discharge. [redacted]

Personnel associated with one of the Soviet EDL efforts published first on combined discharges in 1966. Further, the Soviets were the first to publish on the three principal combined pumped schemes: proton-neutron beams as ionizing radiation (1968), electron beams as ionizing radiation (1969), and UV radiation (photons) as ionizing radiation (1969). [redacted]

[redacted]

The weaponization of CO_2 and CO CPEDLs developed in the early and mid-1970s is believed to be in the hands of the designers at classified defense industrial design bureaus. These designers publish unclassified aspects of their research in open literature. A special effort should be exerted to collect less readily available literature, such as preprints, reprints, and proceedings of institutes and internal institute publications. [redacted]

Soviet interest in atmospheric pressure CO_2 combined pumped electric-discharge lasers (CPEDLs) was strongly evident as early as 1968. By the early 1970s Soviet literature for the most part discussed quasi-CW (100-1,000 μs pulse lengths) and CW outputs. Further, the combined discharges were discussed as useful for pumping large volumes at high pressures at energy-density deposition rates of 1 to 4 kW/cm (1 MW per liter). Various fast-flow (subsonic) gas-discharge studies relative to lasers were conducted as early as 1970. [redacted]

[redacted]

[redacted]

Key Intelligence Questions:

1. Provide details on the following criteria associated with the design and operating parameters of the electric-discharge lasers' cavity: its discharge arcing, cavity-clearing time, turbulence management, boundary-layer control, gas mixing and flow conditioning, high-voltage connectors, acoustic attenuation, beam quality, and resonator design.

2. What military applications are evident using EDLs?

3. What types of external sources are being used to produce the ionization radiation used to excite the laser cavity? [redacted]

Excimer Lasers

An excimer laser is one that uses a rare gas halide as the lasing medium and that is then pumped by one of several types of excitation sources. (See table 2.) Since the mid-1970s the Soviets have frequently published results of theoretical and experimental work on rare gas halide lasers. Half of the eight pumping sources listed in table 2 have received most of the attention: electron-beam pumped, photo-preionized discharges, electron-beam-stabilized discharge, and electric photoionization. [redacted]

The large number of groups working on rare gas halide lasers will continue to be supported because of the diverse requirements for the numerous possible applications for these lasers. The amount of experimental work reported will probably be considerable and detailed. Emphasis will continue on engineering data relative to these types of lasers. The interest in these lasers shown by ministerial facilities is indicative of engineering development in response to both industrial and military customer interest. [redacted]

Table 2
Soviet Rare Gas Halide Laser Pumping Schemes

	XeF	KrF	ArF	XeCl	XeBr	KrBr	KrCl
Electron-beam pumped	X	X	X	X	X		X
Optically pumped	X	X		X		X	
Self-sustained discharge	X	X	X	X			
Electrically preionized discharge	X	X	X				
Photopreionized discharge	X	X		X			
Electron-beam-stabilized discharge	X			X	X		
Capacitive discharge	X						
Electric photoionization (self-laser-radiation-sustained discharge)				X			

[redacted]

Key Intelligence Questions:

1. What rare gas halides are receiving special emphasis in the excimer laser programs? Provide wavelengths, output levels, and beam quality.
2. What applications are evidenced in the excimer laser R&D programs?
3. What design bureaus are involved in the work? [redacted]

Nuclear Pumped Lasers

Direct nuclear pumping of the lasing medium has been proposed for a number of different media including argon, argon-helium-3, and carbon monoxide (CO). Devices employing CO as the lasant medium have received the most attention because of the relatively long lifetime (30 millisec to several seconds) of excited carbon monoxide. While nuclear pumping of lasers is expensive, in applications involving large power requirements (for example, tens of megawatts), nuclear reactors do have potential advantages because of the ability to reduce reactant storage requirements and therefore total system weight. [redacted]

Nuclear reactors excite the molecules of the lasing medium in two ways. First, as the molecules of the lasing medium flow through the reactor they are bombarded by fission fragments causing the gas molecules to release secondary electrons during the ionization process. Thus, energy is transferred to the molecules of the lasing medium raising the vibration states of the molecules in a similar manner as the EDL. This is the predominant transfer mechanism in most nuclear pumped lasers, however, some nuclear pumped lasers rely on a secondary mechanism for energy transfer. [redacted]

The secondary mechanism, dominant in nuclear pumped carbon monoxide lasers, relies on indirect transfer of vibrational energy to the CO medium through other excited CO species produced by fission fragments. This is an extremely complex transfer mechanism, as well as a very unusual mechanism for nuclear pumped lasers, and very little is known about the kinetics of this transfer mechanism. [redacted]

The device itself has three primary subsystems; fluid supply system, gain generator, and optical resonator. The fluid-supply system functions as the primary system for maintaining and storing the coolant and lasant. It maintains cryogenic storage (when required) of the lasing medium and reactor coolant and converts them to gases before entering the gain generator. [redacted]

[redacted]

[redacted]

X-Ray Lasers

Five main approaches to X-ray lasers are being considered by the Soviets in the literature: electron collisional excitation, electron attachment, photoabsorption, Compton scattering, and relativistic charged particle channeling. Most of the Soviet effort, as indicated in the open literature, is concentrated in only two of the general approaches, those of electron attachment and stimulated emission from relativistic beams in a crystal. However, the effort in the photoabsorption approach may be larger than it appears because development of a laser plasma X-ray source could be directed toward providing the pump source for an X-ray laser based on photoabsorption. The use of nuclear explosions has been proposed as a method of creating conditions for X-ray lasers. There is a sizable laser plasma X-ray program in the USSR. [redacted]

[redacted]

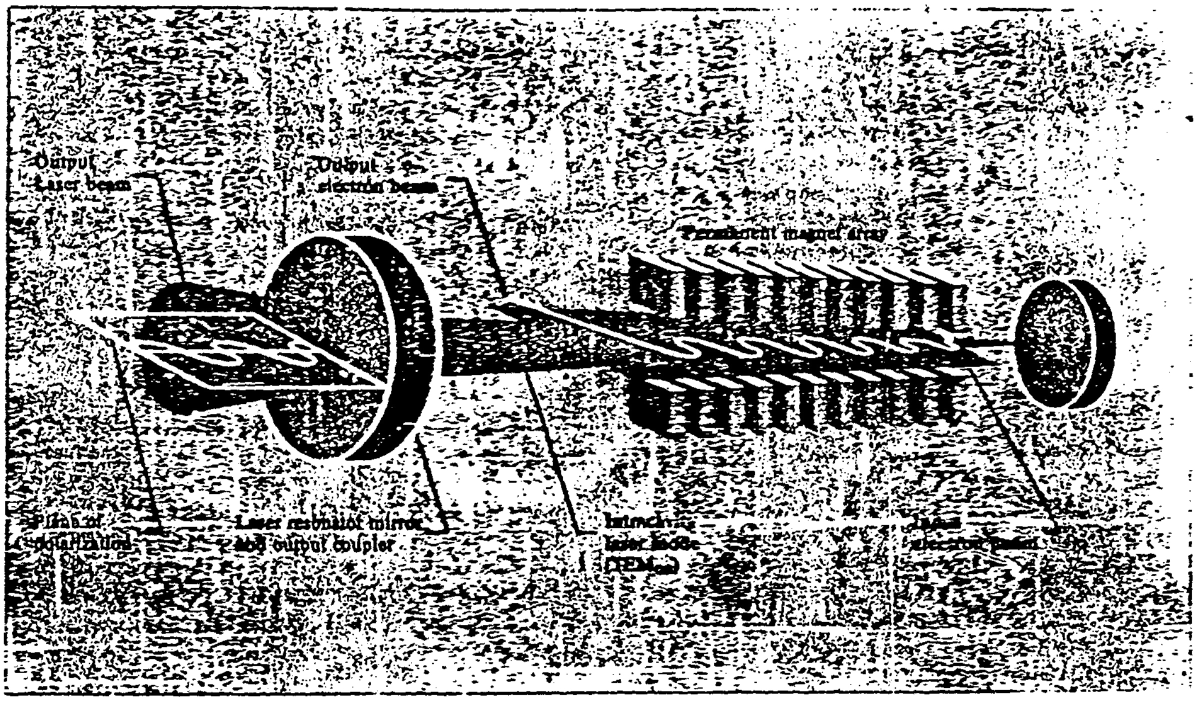
Free-Electron Lasers

Free-electron lasers (FEL) operate on the principle of free electrons radiating in a periodic magnetic field rather than on induced transitions between quantum states of bound electrons (for example, population inversions). The primary principle behind its operation is that a laser beam can be extracted from a beam of free electrons passing through a spatially varying magnetic field by placing mirrors at each end. The physics of the device operation is based on stimulated Compton scattering. A unique aspect of its operation is that it can be tuned to operate from the millimeter-wave region to the ultraviolet region of the spectrum. Laser beam wavelength is dependent on electron-beam energy (for example, high-energy short-wavelength, low-energy long-wavelength) and magnetic field period (spatial variation) used in the FEL. [redacted]

The device operates similar to a radiofrequency linear accelerator (rf linac) except that the electron beam gives up energy to the electromagnetic field and the rf cavities are replaced by a static magnetic field. The primary electron beam is generated by an accelerator and steered into the laser cavity where it traverses the periodic magnetic field (see figure 4) generating and amplifying the laser beam. The electrons can be forced to radiate coherently (all in phase) at a predetermined wavelength by controlling the relative phases of the electrons and the laser pump field. [redacted]

[redacted]

Figure 4
Free Electron Laser



[redacted]

[redacted]

Transfer Chemical Lasers

The laser medium pumping mechanism of transfer chemical laser (TCL) depends on the transfer of stored chemical energy from the products of an exothermic chemical reaction to some molecule that subsequently lases. The most common TCLs use transfer of vibrational-rotational energy from diatomic molecules like HF or DF to CO_2. [redacted]

The TCL can operate in a repetitively pulsed mode, monopulsed mode, or a continuous wave mode (CW).

POOR QUALITY PAGE

The hardware required closely parallels that required for HF/DF chemical lasers. The iodine laser discussed previously has been considered a TCL. [redacted]

Key Intelligence Question:
- Provide all information on the status of and technical parameters of this work. [redacted]

Plasma Recombination Lasers
The main attraction for development of these lasers is the potential for generating short wavelength laser radiation (X-ray). The principle of this laser is the combining of an electron deficient plasma (H+) with an electron beam (e−). The resulting reaction (H+) + e− produces photons which provide laser radiation. [redacted]

Key Intelligence Question:
- What is the status of this work?

Photodissociation Lasers
Photodissociation lasers are based on the development of an energy population inversion produced by the photodissociation of some molecular species. The oldest and best developed photodissociation laser is the atomic iodine photodissociation laser. The development and improvement of high energy photodissociation lasers is intimately tied to the development of high intensity light sources emitting in specific spectral regions. [redacted]

Key Intelligence Question:
- What is the status of this work? [redacted]

Explosively Pumped Lasers
Explosive pumping can involve exploding wires, exploding thin metal foils, explosively pumped optical sources, or direct pumping of the laser medium by high explosives or by using an explosive laser mixture. Explosively pumped lasers are of interest because the explosion provides a large amount of energy in a very short time to pump an HEL weapon. [redacted]

Key Intelligence Question:
- What is the current status of this work?

[redacted]

Key Intelligence Question:
- What is the status of this work? [redacted]

Dye Lasers
The laser medium for dye lasers is an organic dye dissolved in a solvent, vaporized, or embedded in a solid (for example, plastic). The pumping mechanism is usually a flashlamp or another laser, and the output is tunable over a number of wavelength regions between 0.2 and 1.2 μm. The tunability of such devices makes them potentially useful as rangefinders or target designator with a counter-countermeasure capability. The greatest disadvantage of dyes as laser sources is their lifetime. [redacted]

Key Intelligence Question:
- Provide information on which organic dye is being used, the kind of solvent, the pumping mechanism, the wavelength tunability region, and the energy density required for dye breakdown. [redacted]

Related Technologies

Optics

Generation of the beam by the laser device is only the first step in delivering the required fluence on the target. To maximize the amount of energy delivered to the target, the beam must be undistorted and focused on the target. Therefore, deformable mirrors may be used to help correct phase aberrations. As the beam exits the optical resonator it is steered toward the telescope by a series of steering mirrors. [redacted]

At the telescope, usually a Cassegrain (figure 5), the beam strikes the secondary mirror and is expanded to fill the primary mirror area. The primary mirror then focuses the beam to the desired spot size at the target plane. The larger the mirror, the smaller the spot size and the higher the energy density on the target. Several types of apparatus can be used to point the beam at the target. One method involves a coelostat (figure 6), which is a fixed telescope pointed at a large flat mirror, fixed about two or more axes, used to reflect the beam toward the target. Another method of pointing the beam at the target uses a gimbal mounted telescope, which is physically pointed at the target. Each method has unique advantages and limitations; the selection of one method over another depends upon the mission of the laser. [redacted]

Beam Control

To describe the beam control system, a generic model will be identified, which outlines the general subsystem. Although there are a number of variations possible, this generic system identifies most of the major functions involved in beam control. The beam control system can be envisioned as a series of feedback loops that function simultaneously. These include the device cleanup loop and the beam train loop. [redacted]

The cleanup loop corrects phase errors which arise in the HEL beam during beam generation by the laser device. [redacted]

Laser beam wavefront sensors are used to control the amount of correction applied by the feedback loops. The bandwidths of these sensors must be in the 200- to 500-Hz range. [redacted]

Mirror Technology

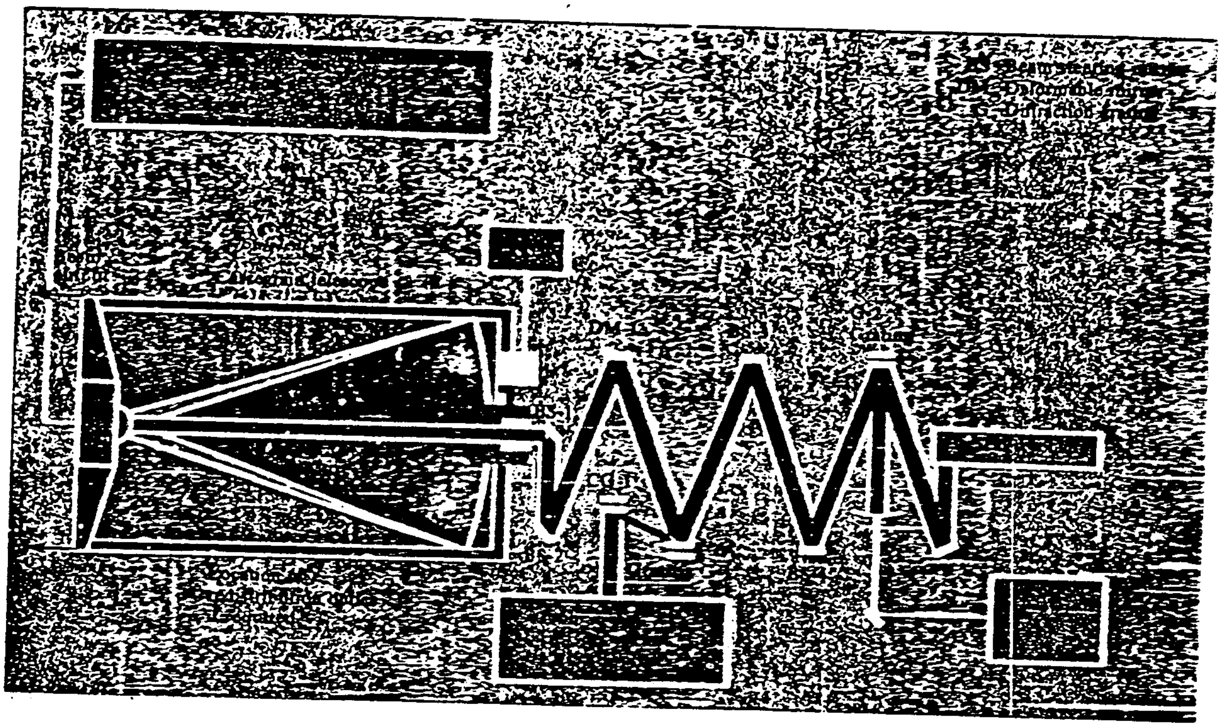
The basic types of mirrors used in HEL beam control systems include primary mirrors, secondary mirrors, and steering mirrors, usually the primary and secondary mirrors are concave but the steering mirrors are usually flat (planar). Other mirrors are necessarily used within the laser device to form a resonator. [redacted]

Highly reflective, accurate mirrors are important components of the beam control system. The mirrors for laser weapons must survive high radiation density for long periods while retaining their high reflectivity and shape. To sustain the high flux density, the mirrors must have reflectivities greater than 99 percent and have very accurate, smooth surfaces. It is in the area of mirror technology that a great uncertainty exists concerning the feasibility of developing high-power laser systems. [redacted]

The highly reflective mirror blanks may be produced by highly accurate application of coatings to the mirror's surface. Two different types of coatings are used: metallic coatings and dielectric coatings. Selection of a coating material depends upon the operating wavelength of the laser; a coating may be highly reflective at one wavelength (λ) but poorly reflective at another. Aluminum, couper, beryllium, stainless steel, silicon, and molybdenum are proved metallic coating materials. Dielectric coatings could be the most reflective—over 99.99 percent—but require a higher technology than the metallic coatings. Dielectric coatings consist of alternating layers of materials that have high and low indices of refraction. Coatings of either type rely on very-high-purity materials; materials containing impurities cause damage or sometimes complete destruction of mirrors when they are exposed to HEL radiation. [redacted]

To establish a high-quality laser beam, the shape of the mirror and the surface roughness of the mirror must be within fractions of a wavelength of a theoretical limit. A root-mean-square (RMS) surface figure—which is a figure of merit of a mirror—is usually

Figure 5
Typical Beam Control Subsystem Schematic



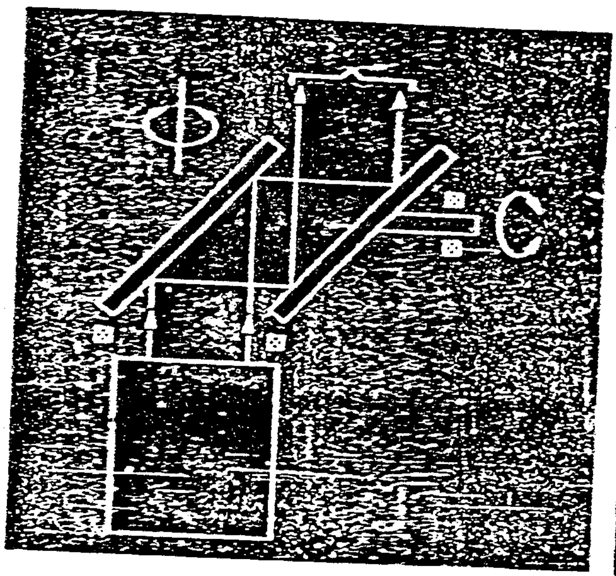
[redacted]
301760 2-84

given as a fraction of the wavelength. Proceeding beyond λ/15 or λ/20 is very costly and provides only slight gains in beam quality, but some projected requirements (US) lie in the λ/100 regime. The actual surface quality seems to vary as a function of laser wavelength; for example, the actual surface for a carbon dioxide laser mirror can be 10 times "as bad" as one for a neodymium YAG laser and still maintain the same beam quality.[redacted]

One of the major effects that detracts from optical quality is thermally induced expansion of the mirror resulting from irradiance by the beam. Large thermal gradients may cause destruction of a mirror substrate or its coatings. Two techniques are used to compensate for this: cooled mirrors and deformable mirrors. Cooled mirrors have cooling channels within the mirror blank through which circulates coolant to dissipate the mirror's heat. Deformable mirrors have actuators behind the mirror faceplate that physically deform the mirror—usually by fractions of a wavelength—to compensate for phase errors of the beam and thermal expansion of the mirror surface.[redacted]

POOR QUALITY PAGE

Figure 6
Coelostat



[redacted]

301770 2-84

[redacted]

Reflectivity and surface figures are the major considerations for the secondary mirror which is used to expand the beam into the primary mirror. A concern is that turbulent coolant flow can cause mirror surfaces to vibrate, which in turn causes wavefront distortion or jitter. [redacted]

The heart of the beam control system involves steering mirrors to spatially stabilize and correct phase errors in the beam. These mirrors must possess the same reflectivity and surface figure as the primary and secondary mirrors. In addition, their control systems must possess high bandwidth and provide large mirror displacement while remaining vibration free. One problem associated with the mirrors is achieving the needed large-angle, low-frequency corrections and small-angle, high-frequency corrections from the same assembly. This problem is compounded by the large size of typical steering mirrors. [redacted]

[redacted]

POOR QUALITY PAGE

[redacted]

The development of HELs has caused the development of new manufacturing and test methods so that the stringent requirements posed by HELs can be met. For example, materials have been developed for mirror substrates that have high thermal stability as well as a high degree of mechanical stiffness. Coating materials have been developed—especially dielectric coatings—that allow very high reflectance mirrors to be produced. Diamond cutting and grinding technology has been highly developed so mirror surfaces could be formed by using optical lathes having unprecedented accuracy. Techniques and equipment for testing mirror shapes, surface roughness, and reflectivity were developed to new levels of precision—usually through laser interferometry. To coat the surfaces of mirrors, large vacuum chambers are required. Deposition techniques based on E-beam evaporation and sputtering were developed to provide reflective coatings that adhere tightly to the mirror surface. [redacted]

Considering the requirements of deployed HEL weapons and supporting optical systems, the production requirements of a large quantity of precision mirrors would almost certainly currently exceed the present capability of any nation. [redacted]

Acquisition, Tracking, and Pointing

The acquisition, tracking, and pointing (ATP) system includes the on-board target detection sensors, precision tracking sensors, and pointer assembly of the high-energy laser. These systems combined provide the necessary targeting and beam control functions needed to identify and kill the targets selected. [redacted]

Once targets are identified by the surveillance sensors (either on board or off board), their location and state vector are handed over to the acquisition sensor. Upon receiving the handover signal, the acquisition sensor slews to the indicated target position and identifies (detects) the target within the sensor field of view. Once the target is identified, its track is established and maintained until handover to the precision track sensor. [redacted]

The precision sensor accepts handover from the coarse tracker and provides pointing error information and image resolution sufficient for aimpoint selection and boresight error determination. In addition, the fine track sensor provides spatial and spectral information to the fire-control system for kill assessment. [redacted]

The pointing subsystem receives the pointing error information from the tracking subsystem and slews the HEL telescope to the desired position. In addition, boresight error, between the precision track sensor and HEL beam, is received from the precision track sensor and corrected by the pointing subsystem. Furthermore, the pointing system must maintain the selected aimpoint based on inputs from the precision tracker. Specific requirements for each of the subsystems are identified in the following sections. [redacted]

Acquisition Technology. The acquisition sensor is presumed to be, in most systems, a passive optical system that receives the target coordinate and state vector from a surveillance sensor. The surveillance sensor could be passive optical or laser radar but probably it will be a radar system. The acquisition sensor must have a total field of view that is consistent with the target location uncertainty of the surveillance sensor. The acquisition sensor must have detectors and optics that provide the sensitivity necessary for timely handoff of the target to the precision tracker. The acquisition sensor must have sufficient spatial resolution and signal processing to assure a high probability of detection and target identification, but with an extremely low false alarm rate. (U)

The nature and capability of the acquisition system necessarily depends to a great extent on the location of the weapon system and the engagement scenarios for which the weapon is intended. For example, an acquisition sensor for a ground-based HEL weapon may need to provide a hemisphere of coverage against aircraft or satellites; a spaceborne system may need to provide complete coverage—spherical coverage—against a variety of other satellites. (U)

[redacted]

Tracking Technology. The precision tracking subsystem provides pointing information to the pointing subsystem, target imaging for aimpoint selection and maintenance, boresight error detection, and kill assessment for the fire-control subsystem. The precision tracker receives handover from the acquisition sensor. The precision tracker necessarily is an imaging system that images the target with sufficient signal-to-noise-ratio (SNR) to perform the above functions and uses suitable tracking algorithms. [redacted]

The most important parameter for the precision tracker is the angle equivalent SNR, which is a function of target range, background, target signature across the spectral band, detectivity of the sensors, and collector aperture. Because of the various target parameters present in different missions, the precision tracking system probably will employ multiple tracking sensors to achieve the required SNR for all missions. The two primary sensors that probably will be used in a dual tracking mode are passive IR and active visible tracking. Dual tracking allows some redundancy and is less susceptible to countermeasures. [redacted]

Pointing Technology. The pointing system is used for pointing and focusing the laser beam at targets and the maintenance of the laser beam spot. To achieve the necessary accuracy, the pointing system uses a number of complex and interrelated subsystems. These include beam expander/telescope, boresight alignment and stabilization system, and beam control system. The complex interaction of these systems may be envisioned by outlining the operations that occur in pointing the laser beam. The precision tracking system tracks the target and drives the pointer's gimbals so that the high-energy laser beam is placed on the selected aimpoint of the target. The precision tracker generates error signals (based on the difference between telescope line-of-sight and desired aimpoint) that are used to drive the laser beam to the desired aimpoint. A wavefront sensor detects beam displacement errors in the optical train and causes the beam steering mirrors to correct the beam misalignment. The telescope gimbals operate in a follow-up mode to correct the tilt in the steering mirrors. As the telescope is guided toward the desired aimpoint, the magnitude of the error signal becomes increasingly smaller until the desired aimpoint is achieved. The process should be seen as a feedback loop in that continuous error inputs are produced by the precision tracker until the desired aimpoint accuracy is achieved. [redacted]

As can be seen by the generic pointing discussion, the operation of all three subsystems is critical to the overall pointing accuracy. The limitations of each individual subsystem degrade the overall performance of the pointing system. For example, the primary contributor to pointing error from the beam expander/telescope is jitter. [redacted]

Jitter in the telescope results from device operation, mirror cooling, and servomechanism response. The operation of the laser device and the resulting multimegawatt beam can cause vibrations in the beam expander optics and supporting structure that produces beam jitter. Jitter is also introduced into the beam by turbulent coolant flow through mirrors. A third source of beam jitter results from rapidly slewing the beam pointing telescope ensuring target acquisition or retargeting. [redacted]

Once the platform is stabilized, the inertial beam must be stabilized relative to the platform itself, through the steering mirrors of the beam control system. Thus, beam control integration into the pointing system is the final critical task in achieving the desired pointing accuracy. [redacted]

Key Intelligence Question:

- Provide the following parametric data: the pointing jitter (usually expressed in microradians), the inertial reference unit (IRU) performance (in microradians), the retarget time including slew velocity (degrees/seconds) and settle time, and the boresight error (in microradians). [redacted]

Nozzles, Ejectors, Scrubbers, Diffusers, Mixing, and Flow

Chemical and gas-dynamic lasers require large flow rates of the lasant medium to establish and sustain the high laser power output over the time for which the laser must operate. The gas flow system will provide for feeding the gaseous components of the lasant into a combustor (or reactor) where the conditions are established to produce laser energy. The flow processes involved in creating the inverted population of excited particles for lasing, in creating the necessary laser cavity conditions, and in providing steady flow through the system (sometimes for a very short time) are established with nozzles, diffusers, and jet ejectors. For lasers that operate in a closed loop, a compressor is necessary to provide the pressure required to establish and maintain circulation. An open-loop type of laser system receives its gaseous components from pressure tanks or bottles and exhausts the used medium to the atmosphere or into a large vacuum tank or tank farm. [redacted]

Nozzles. Mixing of gaseous components is important to the operation of all flowing gas lasers. Since large mass flow quantities are involved, the conditions for mixing are usually established by accelerating the gases to high velocity in nozzles arranged to provide maximum interactive contact of the gases. This is necessary to keep the apparatus small and minimize the distance required for complete and uniform mixing. [redacted]

In addition to mixing gases, the nozzle provides for expansion of a high-pressure medium with very low velocity to a low pressure and substantially higher velocity. The high velocity is required for two reasons in high-power lasers. To produce a high power output, a lot of lasant must pass through the laser cavity quickly. The other reason applies to the pumping of GDLs. [redacted]

Diffusers. A diffuser is used to reduce the velocity of a gas in such a way that the gas pressure in increased. It is applied in cases where an increase of pressure is needed such as for a laser with cavity pressure less than the ambient pressure. Diffuser design varies depending on whether cavity and ambient pressure are very low as for space-based lasers or whether cavity pressure is high and ambient pressure is atmospheric as with ground-based lasers. [redacted]

Ejector. An ejector pump uses a high-velocity primary gas flow to induce a secondary flow (the laser exhaust products). The two flow streams are allowed to mix and, as a result, the discharge pressure can be substantially higher than the pressure where the secondary flow enters. Ejectors can pump a relatively large quantity of secondary flow with a small increase in pressure. However, when a large pressure ratio for the secondary flow is required (as often is the case for a laser application), the primary flow required can be several times the mass flow rate of the secondary. which is being pumped. Mechanical pumps have also been used to perform this function. [redacted]

Chemical Scrubber. In laser applications for which the exhaust products are toxic, a scrubber is used to remove the toxic substance by washing with a liquid that absorbs that substance. The liquid with dissolved toxic material may be collected in a holding facility and disposed of appropriately. Scrubbing can also be achieved by using solid material that absorbs or reacts with the toxic effluents. [redacted]

blank pg

[redacted]

Air Defense

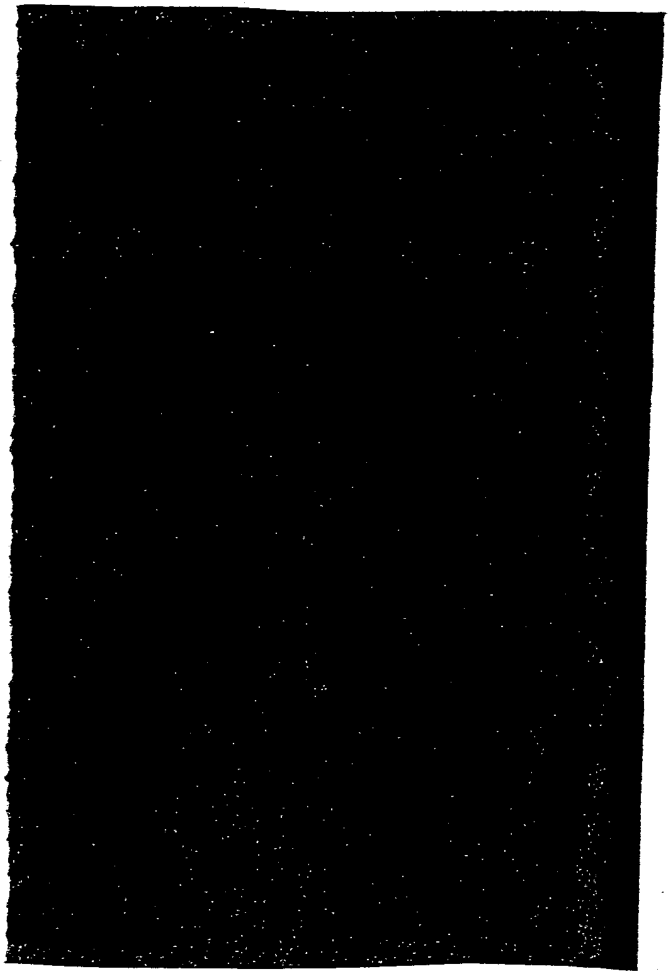
[redacted]

The obvious naval warfare applications of high-energy lasers is in response to the antiship missile (ASM) threat. Ship-based escort/self-defense lasers could provide part of a defense where a mix of ship- and aircraft-based missiles and lasers are employed in roles that maximize their individual capabilities. Laser weapons on amphibious ships could be used to attack ground targets. [redacted]

HEL weapons may be employed in an air-to-air engagement. In one-on-many encounters, a fighter aircraft could instantaneously attack the enemy fighters at the edge of visual range (about 7 to 10 km). Proceeding rapidly from target to target, the laser-equipped fighter could attack before air-to-air missiles are launched or attack any missiles the enemy fighters were able to launch. Furthermore, airborne laser weapons permit attacks at large angles off the nose of the aircraft, a major potential advantage in dog fighting. [redacted]

Space-based laser weapons could be employed to suppress or shoot down enemy bombers or AWACS.

[redacted]



Targets for Laser Weapon Collection

Institutions and Production Plants

This section gives a general overview of the Soviet weapon development cycle along with the specific institutes, individuals, design bureaus, and test facilities that might be part of a HEL development program. [redacted]

There are essentially three stages in the Soviet weapon development cycle:

- Scientific research.
- Experimental design/prototype fabrication/ development test.
- Production. [redacted]

The production stage is outside the scope of this collection guide and will not be addressed. Scientific research (NIR) is the research and development phase and has the following goals:

- Demonstration of the feasibility of a proposed weapon concept.
- Design and construction of devices to prove that the required level of technology may be accomplished.
- Testing a variety of devices to determine their advantages and disadvantages.
- Development of a preliminary design with major subsystem trade-offs. [redacted]

During the latter phases of NIR, the military customer sets forth specifications for the proposed weapon system in a document known as a Tactical Technical Requirement (TTT) for experimental design. The TTT is approved by the Military Industrial Commission (VPK). At this point a national-level commitment to develop a weapon is made. The VPK coordinates scheduling, support, funding, and assigns a system integration design bureau (KB) or scientific production association (NPO) to oversee experimental design (OKR). The OKR is normally performed by an independent KB, which is subordinate to one of the defense industrial ministries, but NPO or research institutes may also be involved. Depending upon the scale and complexity of the weapon system, there may be a KB for individual subsystems or components.

Each step of OKR is reviewed by committee and approved or disapproved. The latter may mean termination of the program or a return to the KB with instructions for additional work. The integrating KB is also responsible for the fabrication of a prototype weapon system and the demonstration of its capabilities at a test facility. The initial phases of NIR, dealing with fundamental research, are concentrated in Academy of Sciences (AN) facilities, whereas exploratory research is performed mostly within institutes of the higher educational and industrial sectors. Table 3 lists those organizations, facilities, and personalities likely to be involved in the research and development of laser weapons. [redacted]

Pages: 26 - 34

Exemptions: (b)(1) (b)(3)

Appendix A

Technological Intelligence Indicators

This appendix describes those technological areas that are likely to be investigated as part of a Soviet laser weapon program. [redacted]

Prime power requirements for a laser weapon may range from a few kilowatts of average power (for tactical systems) to several gigawatts (for a strategic system). For the space-based HEL, a lightweight and compact power source is important. Prime power and power conditioning indicators would therefore include development of:

- Large conventional power sources (turbogenerators, fuel cells, batteries, and fossile fuel or fission power plants).
- Large magnetohydrodynamic or magnetocumulative generators.
- Gaseous-core or high-temperature solid-core nuclear reactors (with MHD for conversion to electric power).
- Large (10-MJ) capacitive, inductive, or rotational energy stores.
- Switching equipment (high-power opening switches, or in general high repetition rate, high-power fast-rise time switches).
- Scrubbers, steam injectors. [redacted]

Target vulnerability studies is another major area providing technological indicators of a laser weapon program. This would include:

- Investigation of material responses to laser irradiation.
- Exploration of possible countermeasures to laser effects.
- Determination of deposition levels needed for soft/hard kills. [redacted]

Acquisition, pointing and tracking systems development also provides indicators of a HEL program. For the laser system to be an effective weapon, it must be capable of rapidly acquiring and disposing of its intended target (fire control). Supporting R&D could include:

- Investigation of radar acquisition systems for laser weapons.
- Passive electro-optic target acquisition.
- Possible development of high-speed, compact, specialized computers. [redacted]

Large optical mirrors capable of withstanding the deposition of energy from a HEL cavity for a sustained period without thermal failure and cooled mirrors are other technological indicators of an HEL weapons program. [redacted]

This list of laser-related technologies is not intended to be inclusive; however, it is expected that the most visible aspects of any laser weapon effort in the USSR would be among these areas. [redacted]

blank pg

Pages: 37- 42

Exemptions: (b)(1) (b) (3)

Appendix E

Glossary

ALMAZ	Design Bureau
AMP	Amperè
km	Kilometer
m	Meter
CO2	Carbon dioxide
CO	Carbon monoxide
HF	Hydrogen fluoride
DF	Deuterium fluoride
I	Iodine
µm	Micrometer
GDL	Gasdynamic laser
CL	Chemical laser
Kg/s	Kilogram per second
W/cm2	Watts per square centimeter
W	Watts
kg	Kilogram
s	Second
nm	Nanometer
MOPA	Master Oscillator Power Amplifier
YAG	Ytterium Aluminum Garnet
EDL	Electric Discharge Laser
CPEDL	Combined Pumped Electric Discharge Laser
UV	Ultraviolet
PRF	Pulse Repition Frequency
us	Microsecond
MW	Megawatt
kW	Kilowatt
KB	Design Bureau
NPO	Scientific Production Association
OKR	Experimental Design Work
AN	Academy of Sciences
MVL	Metal Vapor Laser
NPL	Nuclear Pumped Laser
SAM	Surface-to-Air Missile
MTC	Missile Test Center
GOT	State Optical Institute
IAEh	Institute of Atomic Energy
LOMO	Leningrad Optical Mechanical Association
LFTI	Leningrad Physico Technical Institute
IVTAN	Institute of High Temperatures
ITMP	Institute of Heat and Mass Transfer
IKhF	Institute of Chemical Physics
TAO	Institute of Atmospheric Optics
TsNIRTI	Central Scientific Research of Radio-technical Research
VNIIOFI	All-Union Scientific Research Institute of Optical-Physical Measurements
TsNIIMASH	Central Scientific Research Institute of Machine Building

VNIM	All-Union Scientific Research Institute of Monocrystals, Scintillating Materials and Ultrapure Chemicals
NITsTLAN	Scientific Research Center for Industrial Lasers of the Academy of Sciences
KrF	Krypton Fluoride
FEL	Free Electron Laser
MeV	Million Electron Volt
RF	Radio Frequency
TCL	Transfer Chemical Laser
LTNAC	Linear Accelerator
CW	Continuous Wave
Hz	Hertz Wavelength
RMS	Root Mean Square
ATP	Acquisition, Tracking, Pointing
HEL	High Energy Laser
SNR	Signal-to-Noise-Ratio
IR	Infrared
IRU	Inertial Reference Unit
μRAD	Microradian
deg/s	Degree Per Second
m/s	Meters Per Second
BMD	Ballistic Missile Defense
ASAT	Antisatellite
ASM	Antiship Missile
FEBA	Forward Edge of the Battle Area
RV	Reentry Vehicle
NIR	Scientific Research Work
TTT	Tactical Technical Requirement
VPK	Military Industrial Commission
ASTROFIZIKA	Design Bureau
KOMETA	Design Bureau
LUCh	Design Bureau
OPTICA	Design Bureau
RADUGA	Design Bureau
FIAEh	Branch of the Institute of Atomic Energy
MNIIP	Moscow Scientific Research Institute of Instrument Building
SAROVA	Nuclear Weapons Test and Development Center
NIIFKh	Scientific Research Institute of Physico Chemistry
MFTI	Moscow Physical Technical Institute
FIAN	Physics Institute of the Academy of Sciences
MVTU	Moscow Higher Technical SchoolMGU
Moscow State University	
ISEh SOAN	Institute of Powerful Electronics of the Siberian Department of Academy of Sciences
IPFAN	Institute of Applied Physics of the Academy of Sciences
IAEh	Institute of Atomic Energy
C^3	Command, Control, and Communications
LASINT	Laser Intelligence
SIGINT	Signals Intelligence
MHD	Magnetohydrodynamic
VNIIELEKTROMASH	All Union Scientific Research Institute of Electrical Machine Building
NIIPOLYUS	Scientific Research Institute "POLYUS"

[redacted]