EIR Science & Technology

X-ray laser: the full documentary record

Part 2 of Charles B. Stevens's report on the revelations contained in recently declassified materials, confirming the importance EIR's *reportage has attached to this technology.*

In last week's *EIR*, (No. 35), we demonstrated from top secret material now being declassified with the release of the Government Accounting Office (GAO) report, *Strategic Defense Initiative Program: Accuracy of Statements Concerning DOE's X-Ray Laser Research Program*, that *EIR*, from 1982 to the present, was alone in correctly projecting the potential for a missile defense based on the H-bomb-powered x-ray laser. Essentially, *EIR* repeated publicly what Dr. Edward Teller and other leading defense scientists were telling the government secretly: It is possible to realize a device such that "a single x-ray laser module the size of an executive desk which applied this technology could potentially shoot down the entire Soviet land-based missile force," and that the Soviet Union is "several—perhaps even seven—years ahead of us in at least the unclassified aspects of x-ray laser work."

Beginning with this issue, *EIR* now presents the full documentary record. First, we present the declassified versions of Dr. Teller's secret Dec. 22, 1983 letter to Presidential Science Adviser George Keyworth, and his Dec. 28, 1984 letters to Ambassador Paul Nitze, Chief Arms Control Negotiator, and Robert McFarlane, National Security Adviser to the President.

We then present two draft letters and one transmitted letter, declassified versions with deletions, by Roy Woodruff, a leading critic of Dr. Teller. Ironically, these letters, supposedly criticizing Dr. Teller's letters, actually, for the most part, support and expand on the most crucial aspects of the projections made by Dr. Teller and *EIR*. This was also the conclusion arrived at by the GAO based on the more general, secret record. *EIR* will publish a full copy of the GAO report in a forthcoming issue.

In presenting the Teller and Woodruff letters, this author will attempt to fill in many of the deletions. This will be accomplished in two ways. First, the essential content of the deletions can be determined from other parts of the letters and GAO report. For example, Woodruff's funding projections and milestone time estimates are sometimes deleted and sometimes not. Based on the full record, it is generally possible to reconstruct many of the deletions. Second, based on scientific analysis and reference to other published materials, it is sometimes possible to make an informed guess. Explanatory material, guesses, and interpolations will be given in footnotes marked with [#].

Brightness

Throughout the letters, reference is made to brightness. Some elementary discussion of this concept and its use in the laser context will be useful to the non-technical reader. In the most general terms, brightness is simply the measure of the rate of energy generation by some source. For example, a 100-watt light bulb is twice as bright as a 50-watt bulb. That is, the 100-watt bulb puts out 100 joules per second of light energy, while the 50-watt one puts out 50 joules per second. (Note, for the case of pulsed sources, that both the total energy and time duration are needed to determine the brightness. For example, a flash bulb which puts out 1,000 joules in one-tenth of a second would be a 10,000-watt source and be 100 times brighter than a 100-watt bulb.)

A source brightness can be significantly increased in a specific direction if the total output is somehow focused. That is, instead of just letting the light from the bulb propagate in every direction—an "isotropic radiator"—we could use mirrors to capture the light output and focus it onto a single spot. To compare the isotropic, spherical case—that is, in all directions—with the focused, directed one, it is useful to represent the focused case as a cone. That is, we place a cone with its apex at the center of a sphere. The center of the sphere represents the center of the energy source. At any given radius, the comparison between the isotropic and the focused cases is made by comparing the total area of the sphere with the area that the cone intersects on the spherical surface.

Now, let us say that the cone, which represents our focusing of the source output, intersects one-tenth of the area of the sphere. This means that the focused output is 10 times greater at a given radius than the isotropic case. This is the same result that would occur if we were to increase the brightness of an isotropic source tenfold.

In the simplest terms, chemical explosive weapons have maximum yields of several billion joules (about a ton of TNT), which is the energy that is released within about one-thousandth of a second. The first nuclear weapons generated thousands of times more energy in a time duration on the order of one-millionth of a second. This means that nuclear weapons are roughly a million times brighter than chemical ones.

The divergence angle of a laser—that is, the cone in which it can be focused—is determined by the square of the ratio of the wavelength of the laser light and the size of the "mirror"—its diameter. That is, the shorter the wavelength or the bigger the focusing mirror, the smaller the divergence angle, and therefore, the smaller portion of the sphere which is covered.

The effective range of a weapon falls off with the inverse square of the distance. This means that if a weapon is 10,000 times brighter, it would have an effective range of 100 times greater.

The Teller letter to Keyworth

SECRET December 22, 1983

The Honorable George A. Keyworth
Science Advisor to the President
Old Executive Office Building
Washington, D.C. 20503

Dear Jay: Merry Christmas!

This may be the first classified Christmas greeting you have received. Our Christmas present is a quantitative proof of the

DELETED [1]

measurements

DELETED [2]

There is no other theory except that of the laser which could explain these results.

I am dreaming of the time when the national need will not be quite so pressing, and when we can try to get an x-ray hologram of a gene containing thousands of atoms in one of these experiments.

In the middle of January 1983 you made a promise, heard by hundreds of people, concerning money at the right time. I agree that science cannot be sped up by throwing money at it. But we are now entering the engineering phase of x-ray lasers where the situation is all. . . . We have also developed the diagnostics by which to judge every step of engineering progress. A supplemental appropriation of $50 million for 1984 and a budget increase of $100 million in 1985 would triple our program in this area

DELETED CG-SS-1 Chapter 8
DELETED

What our results may mean is not that we are geniuses at Livermore, but that too many people may have overestimated the difficulty of the job. Since there is evidence that the Soviets have started sooner and in fact may have anticipated the President's speech of March 23 by a few years, it seems to me that we are facing a potentially dangerous situation.

Some of us feel that reliance on retaliation has been for some time politically bankrupt. It may turn out that it soon may be (and conceivably already is) technically bankrupt as well.

I do not believe that the x-ray laser is clearly the only means, the best means, or even the most urgent means for defense. It is clear, however, that it is in this field that the first clear-cut scientific breakthrough has occurred. It is necessary to draw all the possible consequences from this fact and, together with a few others, I am working on this point.

At the same time, I think this progress may serve as encouragement to other defensive projects, very particularly to those being pursued in Los Alamos.

I just am back from two days in Washington and was quite unhappy to have missed you there. I talked with quite a number of people about these questions, but I believe that your specific support would be truly crucial.

I started by saying Merry Christmas. I would like to continue and say Happy New Year also. Unfortunately, the next year will be 1984. With your help, by January 1, 1985 we may be in a better position to hope for a happy new year. The immediate future looks to me unusually critical.

Your wonderful talk to the JASONs is one of my strong reasons for hope, and I have heard many good and positive responses on that. In the specific case of the x-ray laser, we are now in the stage where money talks.

Looking forward to seeing you at the next WHSC meeting, if not sooner.

With best wishes and high hopes,

Edward Teller

The Teller letter to McFarlane

SECRET December 28, 1984

Mr. Robert C. McFarlane
National Security Advisor to the President
The White House
Washington, D.C. 20500

Dear Mr. McFarlane:

Please excuse me for disturbing you again. I am doing so at the urging of my good friend Richard Staar. Furthermore, the topic is of urgent importance. It relates to the forthcoming negotiations in Geneva concerning strategic defense. The Lawrence Livermore National Laboratory has worked for a few years with limited funds and disproportionate success on nuclear bomb pumped x-ray lasers. In fact, I had an opportunity to talk briefly with the President about the subject a little more than two years ago.

In the meantime, it has become highly probable that this instrument can destroy sharply defined objects at a distance of the order of 1,000 miles and possibly more. This was accomplished by sharply directed beams which locally enhance the brightness and effectiveness of the nuclear bomb effects a millionfold.

While this progress has by now some solid experimental foundation,

DELETED Topic 4 [3]

Assuming even moderate support, together with considerable luck, this might be accomplished in principle in as little time as three years.

I have written in slightly greater detail about this issue to my good friend, Paul Nitze. My classified letters to you and to him will be carried to Washington and delivered on Wednesday, Jan. 2, by Dr. Lowell Wood from the Livermore Laboratory, who is primarily responsible for these developments.

DELETED CG-SS-1 Chapter 8 [4]

My purpose in taking these actions is to try to prevent the inadvertent appearance in any possible forthcoming agreement with the Soviets of limitations that might impede our work, though they could be secretly violated by the Soviets.

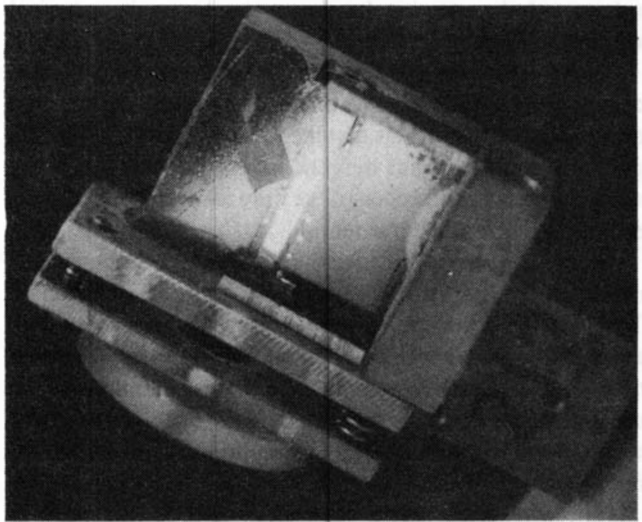
Lowell Wood, the carrier of this letter, will be available to you to answer any questions that you might have on the 2nd of January or if need be on the 3rd of January.

I am grateful for your indirect response which I received from you on the civil defense issue. I hope that I do not interfere too much by inviting your attention to this particularly important issue concerning the forthcoming meeting.

With many thanks,

Edward Teller

FIGURE 1
A laboratory x-ray laser



Given that nuclear explosive x-ray laser research is top secret, no photographs or diagrams of this process are available in the public literature. But Lawrence Livermore National Laboratory has simultaneously been carrying on an unclassified program for the perfection of laboratory scale x-ray lasers. This is one such laboratory x-ray laser. Most of the figure consists of an anvil to hold a thin sheet of metal, which will become an x-ray laser—the shiny streak between the two gold-colored pieces of the anvil. Overall, the anvil is about the size of a postage stamp. In the laboratory x-ray laser, the thin sheet of metal is irradiated with an intense pulse of optical laser light. This converts the metal into a plasma, which then produces a coherent x-ray pulse which travels down its length.

The Teller letter to Nitze

SECRET 28 December 1984

Ambassador Paul Nitze
U.S. Department of State
Washington, D.C. 20520

Dear Paul:

I certainly enjoyed talking to you today by phone. I'm sorry that the conversation had to be so elliptical. I really appreciate your receiving my friend Lowell Wood, who has carried this letter to you, and your considering the matters which I touch upon below.

For many years, people at this Laboratory have studied how the enormous energy of a thermonuclear explosion might be directed into beams, so that military targets, particularly targets in space, might be effectively attacked at much greater distances than the lethal radius of the explosion itself. A second advantage deriving from such a capability would usually be striking the target without warning, even in principle, with beams which would travel at the speed of light.

DELETED Topic 354.1 [5]

The technology employed in this demonstration appeared to be capable of generating a beam of x-rays which, at great distances, would be as much DELETED topic 421.1 [6]

bright as the bomb itself. One example of its utility would be the ability to kill a target at a distance of 10,000 km which would not be killed unless it were no more than 10 km from the bomb itself; another would be the ability to kill 100 such targets at distances of 1,000 km. This advance is thus comparable in magnitude to that involved in moving from chemical to nuclear explosives.

We expect to be able to realize this advance in this decade even though our pace is severely resource-limited and we have received meager additional funding to pursue it.

The Soviets led the x-ray laser field in essentially all respects until 1977, when their huge effort (comparable in magnitude to that of the rest of the world) quite abruptly ceased publishing. None of the lead personnel have apparently been assigned to other work, and none of them went to Siberia; they just haven't been publishing whatever work they have been doing. Curiously enough, their cessation of publication coincided with their experimental success in attaining laser action in the very far ultraviolet portion of the spectrum, an accomplishment which was not successfully duplicated in the West until our success this past summer at this laboratory. The inference is strong that they are several—perhaps even seven—years ahead of us in at least the unclassified aspects of x-ray laser work.

All this you may have heard of. All of it is significant in your present responsibilities, but I probably would not have invited your attention to it in so urgent a manner, had there not been a final consideration which is very little known in Washington.

As a result of work done by Lowell's team during the past two years, there appears to be a real prospect of increasing the brightness—and thus the potential military utility

DELETED Topic 4 (supp) [7] The overall military effectiveness of x-ray lasers relative to the hydrogen bombs which energize them may thus be as large as a trillion, when directed against sharply defined targets.

This is an exceedingly large gain, and even if it cannot be fully realized, this approach seems likely to make x-ray lasers a really telling strategic defense technology. For instance, a single x-ray laser module the size of an executive desk which applied this technology could potentially shoot down the entire Soviet land-based missile force, if it were to be launched into the module's field-of-view. Such a module might be pre-emplaced in space, popped-up in an attack-suppressing mode, or popped-up as the Soviet attack commenced. A handful of such modules could similarly suppress or shoot down the entire Soviet submarine-based missile force, if it were to be salvo-launched.

Employed differently in some details, this technology might be devastatingly effective in the mid-course and terminal phases of strategic defense, as it might be possible to generate as many as 100,000 independently aimable beams from a single x-ray laser module, each of which could be quite lethal even to a distant hardened object in flight. The beams from such x-ray lasers would also be useful in striking targets deep in the atmosphere, down to altitudes of perhaps 30 kilometers.

I felt that you should be aware of the possibilities of such striking advances, both the ones already in hand and the even more impressive ones in reasonably near-term prospect, before you go to Geneva. You may wish to reflect on not only what they could mean to the United States, but of what significance they could have for the Soviet Union, particularly when the Soviet half-decade lead is taken into account.

Thanks very much for your consideration of these matters. Lowell will answer any question on them which you may have. I hope to see you soon.

With warmest regards,
Edward

The Woodruff letter to Keyworth

Draft Letter

Bldg. 111 Room 701 L-38 3-0800
December 28, 1983

George Keyworth

Dear Jay:

I have just become aware of a letter dated December 22, that Edward Teller wrote to you concerning DELETED [8] x-ray laser research at Livermore. As the leader of that research, I wish to "set the record straight" and mitigate some of what I perceive to be premature conclusions arrived at by Edward. I have not discussed the letter in any detail with Edward and thus, cannot claim to know exactly what he meant. . . . "essentially quantitative agreement" with. . . . [I am] hesitant to claim quantitative agreement at this time. The status can be most accurately stated as:

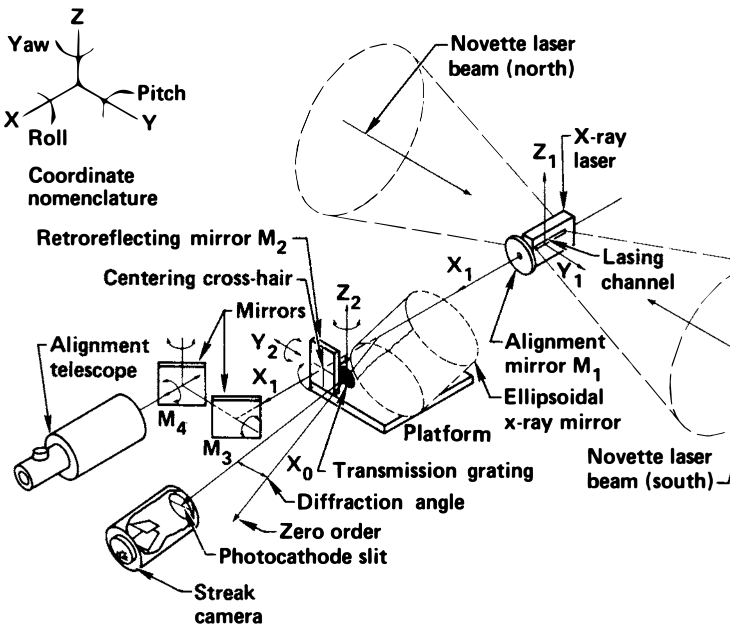
—DELETED [9]

—Spectral, temporal, spatial, and intensity characteristics of the laser output were measured and are in solid qualitative agreement with predictions.

—Much data were collected but many physics questions remain. We still do not have a solid predictive ability based on current models and codes.

—The DELETED data, in spite of clearly demonstrating strong lasing, do not establish that these systems can be scaled to the range needed for military applications.

FIGURE 2
Schematic of x-ray laser diagnostics



Shown is the arrangement of the scientific diagnostics utilized to measure the output of the Livermore Laboratory x-ray laser. The two beams of the Novette optical laser are shown irradiating the thin sheet of metal, which is transformed into a plasma and generates the x-ray laser pulse along its length. On the front of the x-ray laser is an alignment mirror, M1, which is used to align the x-ray laser with the diagnostics. Various mirrors and the alignment telescope are shown for this system. One set of diagnostics shown consists of a transmission grating, which diffracts the x-ray laser pulse, an ellipsoidal x-ray mirror which permits the comparison of an undiffracted portion of the x-ray laser pulse with the diffracted portion when both arrive at the streak camera.

With respect to Edward's comments that the x-ray laser research is entering the engineering phase and that additional funding should be applied, I only partially concur. The x-ray laser is nowhere near the engineering phase at this time. As we have stated so often in presenting our work, critical physics characterization and scaling experiments must be carried out before we can attempt to assess the weapon feasibility of this concept. Only then will we possibly be at the beginning of the engineering phase.

However, I must agree that additional funding is not only prudent, but critical to the program at this stage. Under present funding estimates, we can only hope to reach the milestone of assessing weapon feasibility by DELETED [10]. However, with additional funding of $ DELETED [11] in FY84, DELETED [12] in FY85, and continued supplements in the out years, we could move that milestone forward to DELETED [13].

Let me close by assuring you that we have unequivocally demonstrated an x-ray laser on DELETED [14] and our enthusiasm, as well as the need for accelerating this research, continues to grow. Let me also caution, however, that it is premature to extrapolate present successes to the conclusion that a viable weapons system is possible in the near term.

Roy D. Woodruff
Associate Director,
Nuclear Design

The Woodruff letter to Nitze

The Honorable Paul Nitze, Ambassador
U.S. Department of State
Washington, D.C. 20520

Dear Ambassador Nitze:

The letter from Edward Teller (dated December 28, 1984) concerning our progress on the x-ray laser which was delivered to you by Lowell Wood has just recently come to my attention. While I am sure you recall my enthusiasm for both the science and the potential military applications of x-ray lasers when we discussed the project here at Livermore last January, I am concerned that the balance set both in Edward's letter and in any additional discussions that may have taken place with Lowell is overly optimistic. While I would never object to either Edward or Lowell giving their personal opinion about the status and future possibilities for the x-ray laser, I believe I have a responsibility as leader of the program to convey to you my views of both the current status and future possibilities for the x-ray laser as a military weapon.

Let me begin by summarizing the experimental data relevant to the x-ray laser. As I am sure you recall, the laser is excited (or pumped) by the output of a specially designed hydrogen bomb. The x-rays emitted by this "source" irradiate the laser DELETED [15] and excite the lasant atoms. Lasing occurs in a similar fashion to more normal (visible light) lasers, only the output is in the DELETED [16] x-ray spectrum. We have successfully completed DELETED x-ray laser experiments at the Nevada Test Site,

DELETED

My summary of the results and experience gained DELETED includes:

- Intense output in the x-ray energy regime DELETED was observed DELETED
- This intensity was observed to increase nonlinearly with length and has divergence characteristics that are unmistakably from lasing action
- Analysis of one of the lasers DELETED indicates the gain is substantially lower than expected.

DELETED

These facts make clear a number of points about the present state of development and understanding of the x-ray laser. They are: 1) the production of strong x-ray energy beams that are unmistakably from lasing action is now within our capability; 2) the experimental measurement of these x-ray lasers are at the frontier of our capabilities and require great care and skill in both execution and evaluation; 3) the physics models, computer codes, and data base presently available are only capable of guiding our endeavors in a qualitative manner and large advances will be necessary before we can expect to be successful with quantitative predictions.

The above points represent a restatement of the view I presented to you during your previous visit to the Laboratory and can be summarized as follows: Important physics characterization and scaling experiments must be carried out before we can fully assess the weaponization potential of the x-ray laser concept. I fully expect these characterizations and scaling experiments will establish that the x-ray laser could be an effective weapon, but until the experiments do show this, the issue remains a matter of speculation.

DELETED

With the successful completion of the research program outlined above, the development of a full x-ray laser weapon system would require an additional 5-10 years and would cost several billion dollars, depending on the number of weapons required. Of course, this schedule could be accelerated if in parallel to the x-ray laser research one were to execute a weapon engineering development program.

Given the success of both the x-ray laser research and the engineering development programs, one would have a weapon with characteristics similar to those outlined in the third paragraph of Edward's letter—the brightness enhancement of a beam of x-rays from such a weapon would be DELETED [17] over an isotropic radiator. The possibilities for using such a weapon would include the engagement of single satellites to distances greater than 10,000 km and the exoatmospheric intercept of tens of objects (such as boosters and reentry vehicles) at distances from 100 km to 1,000 km, depending on target hardness. While such a device might prove to be important in Ballistic Missile Defense, I believe it is more likely to be useful in a category of technology which is often referred to as space superiority weapons. Based on the Earth, (and thus potentially as survivable as any of our current strategic assets including SLBMs [submarine-launched ballistic missiles]) such a weapon could engage satellites at distances out to geosychronous orbit within minutes after the decision to launch was made.

DELETED

All of the preceding material is consistent with the briefing you heard on January 12, 1984.

DELETED [18] Since the brightness of the beam depends inversely on the square of the beam width, decreasing the divergence of the beam really pays off rapidly.

DELETED While I share Edward's and Lowell's enthusiasm for the research and agree it may be possible DELETED [19] to even further enhance the output of a x-ray laser weapon beyond our DELETED [20] baseline goal, I am concerned that certain views expressed by Edward's letter may be interpreted with too much optimism. The statement, "For instance, a single x-ray laser module the size of an executive desk which applied this technology could potentially shoot down the entire Soviet land-based missile force, if it were to be launched into the module's field-of-view," while technically correct insofar as the realm of possibility is concerned, does not convey the difficulty of such a weapon achievement. As Edward points out, this particular weapon requires a DELETED enhancement in beam brightness. In struggling to express the probability of such a development, I can only say that it is my opinion we do not have sufficient understanding nor data to be quantitative about the possibility of achieving these results.

DELETED

Will we ever develop a weapon close to the characteristics described in the above quote? Not impossible, but very unlikely.

There are many good points in Edward's letter and I hope this note will help draw them out and place them in an appropriate perspective. In particular, I, too, am concerned about where the Soviets might be in the development of either an x-ray laser or some other nuclear directed-energy weapon. Their nuclear weapons programs seem to be supported at a level considerably above those of the U.S.,

DELETED

In addition, you may recall from your last visit to the Laboratory that we are working on several other methods for directing the energy of a nuclear explosion

DELETED [21] I believe it is only prudent to assume the Soviets also are actively pursuing other methods for directing the energy of a nuclear weapon and it could be very dangerous if they are successful first.

I very much appreciate this opportunity to express my views on these issues. Should you find more information would be useful I would be happy to discuss them further at your convenience.

Regards,
Roy D. Woodruff
Associate Director for
Lawrence Livermore National Laboratory Bldg. 111
Room 415 L-20 3-6806

The Woodruff letter to General Withers

Major General G. Kenneth Withers, Director
Office of Military Applications
U.S. Department of Energy
Germantown, MD 20585

Dear General Withers:

Having reflected on our telephone conversations of the past week, I would like to try to clarify some of the confusion regarding the baseline goal of the x-ray laser program, the milestone schedules for achieving that goal which are currently under discussion in the DOE and DOD, and how these schedules relate to today's budget reality at LLNL.

Let me begin by summarizing the technical goal of the program. We have described baseline performance for Excalibur,

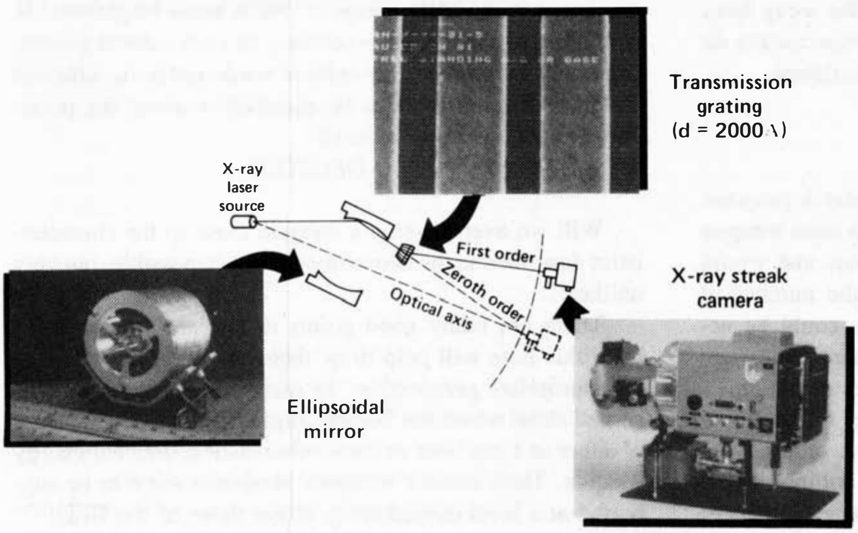
DELETED

This can be thought of as enhancement in brightness over a "conventional" nuclear explosive such as the Spartan warhead of the early 1970s. It is our belief that it will take DELETED tests at the Nevada Site to demonstrate this performance. However, the demonstrated complexity and significant cost of these x-ray laser experiments make the date by which we can achieve the technical goal highly dependent on the level of funding available during the next decade.

The schedule currently supported by the DOD Strategic Defense Initiative Office (SDIO) assumes achievement of the technical goal in the 1991-1992 timeframe. The ability to meet this milestone was predicated on LLNL, and LLNL Nevada, receiving a minimum of 5% real growth in [research, development, and testing] RD&T funding for the next seven fiscal years. (For your information, I have attached a background paper which provides a brief history of the program, and describes how the SDIO-supported milestone evolved.) The DOE Strategic Defense Research (SDR) plan establishes 1995 as the milestone for accomplishment of the same technical goal. In theory, the SDR schedule does not require increments in funding to begin until FY 1987.

As you know, we are currently spending DELETED on x-ray laser development. All of this funding has come from within our already tight resource envelope during the past

FIGURE 3
Pictures of ellipsoidal x-ray mirror, x-ray streak camera, and transmission grating



This particular set of diagnostics permits scientists to compare a diffracted portion of the direct x-ray laser output with an off-axis x-ray laser output signal. The data output is shown in the next figure.

several years. The incremental funding we have indicated as necessary to meet the SDIO/SDR schedules through FY 1990 is as follows:

DELETED

The funding increments identified relate to LLNL only; additional support is also required for LLNL Nevada. Also, these estimates assume that all else "remains equal," namely, that the base budget continues to provide for all ongoing/planned activities and keeps pace with inflation.

This latter point is important in understanding the situation which the Laboratory finds itself in today. A cursory review of the funding increments shown above would indicate that the DOE's SDR schedule can be met with no additional funds in FY 1986. However, the base assumption has not held firm. Indeed, the reality we face in FY 1986 is that:

- LLNL will receive an increase in operating expenditures of 6.8%, an amount which is essentially equal to inflation and which provides no real growth.
- The potential decision to allocate the [inertial confinement fusion] ICF budget on the basis of "Lab balance" rather than "program merit" will require us to reallocate as much as $12 million of WRD&T funds to the ICF Program to maintain operational capability of the just-completed NOVA facility.
- All signs indicate that the FY 1986 budget will not come back from Congress unscathed, and indeed, that the reductions sustained could be considerable.

The combined effect of these factors is to put pressure on the FY 1986 budget which was not anticipated when the SDIO/SDR milestones and related funding scenarios were established. Thus, even in the SDR case, incremental funding may be required in FY 1986 to maintain the pace necessary to meet the 1995 milestone.

In summary, there are two key questions which must be addressed as quickly as possible. The first of these is to reconcile the SDIO and SDR schedules. I believe this is a key issue which should be addressed by the SDI Steering Group in its meeting next week. Once the schedules are reconciled, the second issue is to identify the incremental funds required to meet the milestones agreed upon.

As I have discussed with you, I do not believe it prudent to identify these incremental funds from within the LLNL core weapons program. The redirection of funds to nuclear directed energy weapons efforts, which has taken place during the last several years, has already caused an imbalance within the program which is at the bound of tolerance. Further redirection of funds to the x-ray laser program, especially at the level of DELETED would have effects of major proportion:

- All nuclear directed-energy weapons concepts other than the x-ray laser would be terminated, including the potentially high-leverage DELETED [21].
- At least two tests would be eliminated from the schedule, with significantly reduced diagnostic measurements on those which remain.
- Most advanced weapons design projects would be cancelled, including work on the earth penetrator, advanced primary and secondary design, and high explosives development.
- Several weapons assembly and diagnostics facilities here and at Site 300 would be shut down.

The long-term consequences of such actions are, in my view, life threatening to this institution. A significant number of our key scientists would no doubt move to other programs, or more likely out of the Laboratory entirely. Once this rare talent and experience is lost to the nation's weapons program, it cannot be restored for at least a decade. The concept of maintaining two strong design laboratories—a concept which has served us so well for 30 years—would be permanently altered.

I am sure that it is difficult to see the potential magnitude and seriousness of these efforts from your vantage point. But, I am also confident that your concern for the vitality of this institution is strong. Thus, I look forward to discussing this matter in depth with you during the coming weeks.

Sincerely,

R.D. Woodruff
Associate Director for Defense Systems

Appendix
A brief history of nuclear pumped x-ray laser

Goals and Milestones: The general x-ray Laser Program goals have not changed since the beginning of the research effort five or six years ago:

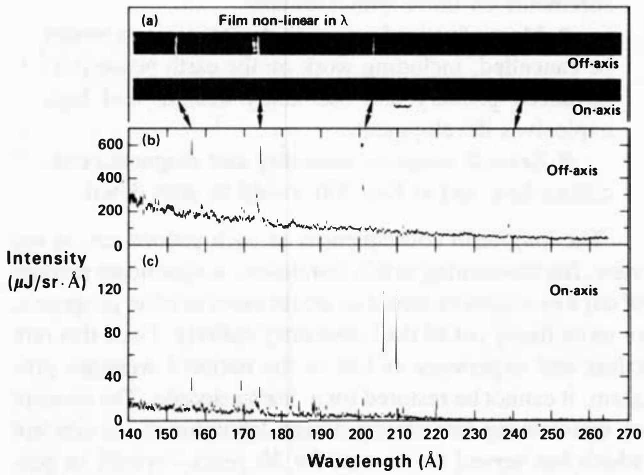
- To gain understanding of the physics of x-ray lasers for both military and scientific applications
- To use this understanding to guide the development of an engineering and material science base that will allow us to proceed as rapidly as possible toward a militarily useful weapon.

Enhancement in brightness DELETED over an isotropic source was not a program goal until mid to late 1983, but simply a step along the way toward developing the brightest and/or most efficient laser possible. We made estimates of the key physics parameters for the simplest of x-ray lasers (conceptually speaking) and DELETED enhancement became a near-term manifestation of these estimates.

The critical parameters which determine the brightness of a self-initialized, geometric divergence x-ray laser are:

FIGURE 4

Spectral data recorded from laboratory x-ray laser experiments



The actual streak camera film data is shown at the top of this diagram (a). (b) is a graphic representation of the data for the topmost streak film. (c) is the graphic representation of the data for the bottom film. (b) is data taken "off-axis," that is, along a line other than the line defined by the x-ray laser beam. (c) is the data taken when the camera is receiving the signal along the line defined by the x-ray laser beam. Note that there are two very large lines at 206 and 209 angstroms. This is indicative of a laser which has two output wavelengths. If laser action were not taking place, then there should not be such a large difference between on-axis and off-axis measurements. These x-ray laser diagnostics represent systems that are on the frontiers of scientific theory and technological capabilities. The diagnostics make measurements on a spatial scale of angstroms—less than atomic radii—and time spans measured in picoseconds (trillionths of a second). These measurement resolutions also define the required tolerances for the manufacture of these diagnostics.

- Pump Strength (yield, spectral composition, and length DELETED—all are important)
- DELETED
- Laser efficiency

Many individuals, organizations, and review committees have done back-of-the-envelope calculations to estimate these parameters—some of which have even appeared in the open literature. Most get the "right" answer and these results are summarized in the following table:

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Just how reasonable the DELETED intermediate step is has been the topic of at least three Jason reviews and several DOE/DARPA [Defense Advanced Research Projects Agency] workshops. So far no one has identified any show stoppers, and we are proceeding as rapidly as data and theory will permit to find the actual limits. A point on nomenclature: the reasonable line in the table is often referred to as either Excalibur or baseline and the physics limits line is known as Excalibur(+) or baseline physics limit. Insofar as a conceptual design of a weapon is concerned, the Excalibur device (which might have a brightness enhancement of DELETED over an isotropic radiator) was designed on paper by Livermore scientists and further developed into a model for our vault by the Rocky Flats shop in 1980.

Many technical people who should know better seem to regard the above table as the end game. It is not! Even A. Carter seems to have missed that the simple self-initialized laser represented by this table is by no means the end of the line for x-ray laser potential.

DELETED least a lot more difficult DELETED

- Intense output in the x-ray energy regime of DELETED was observed DELETED
- The intensity was observed to increase nonlinearly with length and had a measured divergence that was in close agreement with predictions. These data lead to the conclusion that the signals are unmistakably from lasing action.

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These facts make clear a number of points about the present state of development and understanding of bomb-pumped x-ray lasers and our capabilities to further develop them as potential weapons.

1. The production of strong x-ray energy beams that are unmistakably the result of lasing action is an accomplished fact.

2. The experimental measurements of these x-ray lasers are at the frontier of our capabilities and require great care and skill in both execution and evaluation.

3. The physics models, computer codes and data base presently available are only capable of guiding our endeavors in a qualitative manner, and large advances will be necessary before we can expect to be successful with quantitative predictions.

DELETED If all goes well, we will have for the first time some fundamental atomic physics including an estimate of the ionic species in the laser during its operation. Traditional nuclear weapons design practice might be summarized as lacking the absolute or first principle basis to predict device performance but having a fair-to-good predictive capability with regard to the derivative of the device operation as a function of some parameter change. This is what we are currently missing in the x-ray laser program. One very optimistic outcome from DELETED experiment might be a measure of the progress in this area. DELETED

While quite crude compared to what we believe is necessary for a weapon, they may provide useful results, and even if they do not, we will have learned a lot about how to do it better next time.

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Some of these notions were presented to the summer study chaired by J. Fletcher (known as the DTS). The major differences are that we did not have the DELETED so J. Fletcher was doubtful we actually had demonstrated lasing DELETED

Two general conclusions about x-ray laser weapons came out of that study:

- An Excalibur(+) system DELETED was the only [directed-energy weapon] DEW that had a clear potential for engaging a massive salvo attack in the boost phase. This is because the x-ray laser (and most other nuclear directed energy weapons) are capable of multiple intercepts (parallel kill). The more traditional DEW concepts are only capable of engaging one target at a time (serial kill);

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The milestone for demonstrating the feasibility of an Excalibur level of brightness naturally fell out of all this debate. The date of the early 90s was recommended because we (LLNL) said this was the earliest we could complete DELETED development tests in Nevada and it was compatible with DTS or now SDIO desires for some technology sorting around that time frame.

This milestone was also picked up by various policy people in the DOD and is still pushed by those people today. The reasons are many: They also believe DELETED increase in effects is revolutionary, there is no other nuclear option that was really pushed by the DTS, and perhaps because of this is one of the better possibilities for motivating the DOE budget. For whatever the reasons, the DOD has continued to support the demonstration of DELETED and has started what they call a "Phase B" with DOE and the Army.

Notes

1. Laser action with various types of diagnostics.
2. Reference to the actual measurements.
3. Apparently referring to Excalibur levels of operation with an x-ray laser—a source millions of times brighter than a hydrogen bomb.
4. Apparently referring to the new development of plasma optics for focusing x-ray lasers (the Super Excalibur), which were demonstrated in the spring 1985 Cottage tests in Nevada and which would make the x-ray laser trillions of times brighter than the hydrogen bomb.
5. The simple x-ray laser (Excalibur) would have a brightness millions of times greater than the hydrogen bomb and therefore increase the lethal range against soft targets such as satellites and boost-phase missiles a thousandfold, from 10 kilometers to 10,000 kilometers.
6. Millions of times.
7. See Note 4; To a level trillions of times greater than the hydrogen bomb.
8. See Notes 1 and 2; recent, unequivocal demonstration of x-ray lasing based on demonstration of advanced diagnostic techniques.
9. References advanced diagnostic measurements, probably having to do with coherence length.
10. 1991; See later Woodruff letter.
11. About $50 million; see Teller letter.
12. About $100 million; see Teller letter.
13. 1987 ("several years" in GAO report, three years in Teller letter). In general, Woodruff notes that it will take several billion dollars and five to ten years to actually develop a full-scale weapon once the full-scale scientific demonstration has been completed. But Woodruff also notes that this need not be sequential, but could be done much quicker with a parallel weapon engineering program.
14. Most recent Nevada test.
15. Rod.
16. Ultraviolet to soft.
17. Million times.
18. Background on plasma lens for focusing x-ray laser beams.
19. Plasma lens.
20. A millionfold increase over the baseline Excalibur, which is itself millions of times brighter than an H-bomb.
21. While this could refer to a host of alternative nuclear directed energy weapons (NDEW), it is most likely referring to the system in which the bomb energy is converted to a high-current, low-voltage electrical pulse which is then in turn used to accelerate plasmas to thousands of kilometers per second. Once in space, the plasma expands and cools, and thus forms a dust cloud moving at thousands of kilometers per second. And even though the dust cloud covers hundreds of square kilometers, each dust particle has sufficient energy to destroy a missile. This plasma accelerator NDEW is therefore like a shotgun and has a high "leverage."