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Status of the x-ray laser: the exclusive real story

Charles B. Stevens pieces together the evidence from the redakted reports and correspondence of the top scientists on the most promising of SDI technologies. The first of two parts.

We undertake here a detailed technical analysis of the letters and reports released this past summer, in the wake of the latest controversy surrounding the hydrogen-bomb powered x-ray laser. These documents and the following analysis demonstrate that most of what has been publicly presented by others in the way of technical assessments of President Reagan's Strategic Defense Initiative (SDI) program, first announced on March 23, 1983, has been way off the mark.

Almost all of these so-called "technical" assessments have been off the mark by as much as a factor of one million! That is, they have been treating the technologies involved as if they were not the technologies they really are: For example, as if there were no difference between spears and guns, or between chemical explosives and atom bombs.

And, despite the recent release of an overwhelming amount of previously secret data and assessments, most scientific and technical journals are still publishing distorted reports, to the effect that the x-ray laser does not work, and that Dr. Edward Teller—the "godfather" of the SDI—is an emperor with no clothes. In this light, it is evident that these technical journals are, to a degree, deliberate in their misrepresentations, and to a degree, ideologically blind to this subject matter.

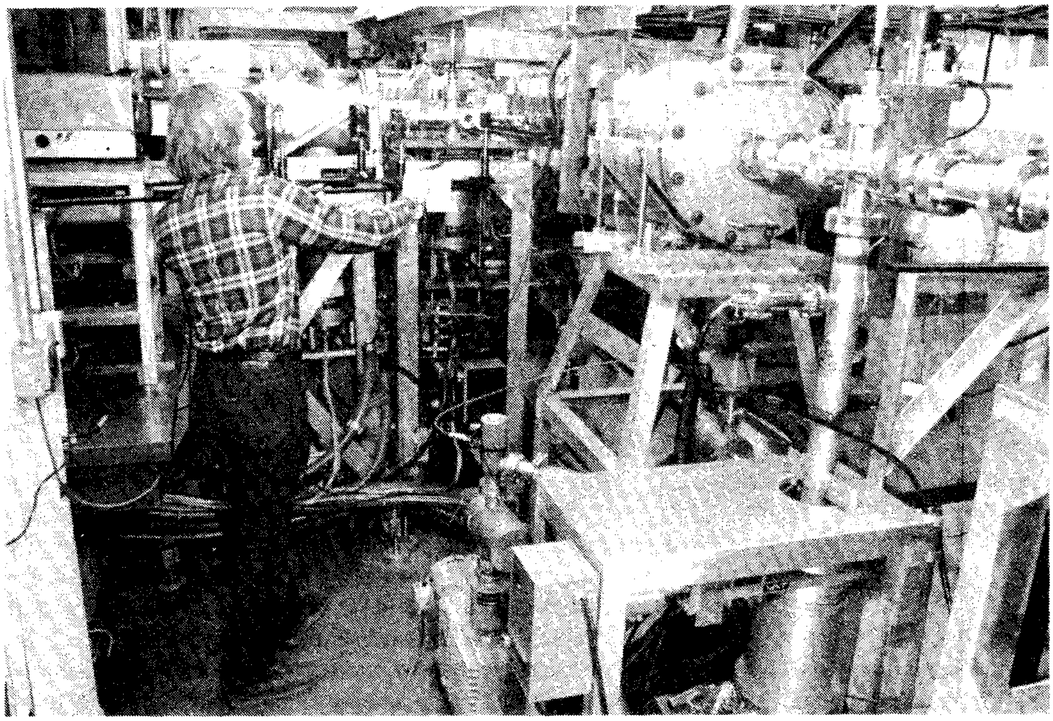
In any case, what is true is that the nuclear-powered x-ray laser has tremendous firepower potential—one module potentially capable of knocking out the entire ballistic missile fleet of the Soviet Union. In this, the x-ray laser categorically demonstrates the efficacy of Lyndon H. LaRouche, Jr.'s design of the SDI policy. And even so, as Edward Teller emphasizes, the x-ray laser is certainly not the only potential defensive weapon, and is possibly not even the best one.

Yet, it is sadly the case that the West has failed to actually adopt the policy required in regard to SDI. Therefore, the following technical assessments have an ominous ring, since the West has not launched a crash R&D program, according to all public reports, and the Soviets have had at least a seven-year lead on the West in the development of the nuclear-powered x-ray laser. (Obviously, one module can also knock out the entire U.S. missile fleet!)

Part two of this report, appearing in *EIR*'s next issue, contains two detailed designs for possible target-acquisition, pointing, and tracking systems for the x-ray laser. These system designs demonstrate that while the x-ray laser anti-missile capability does require further technical developments to be realized as an effective weapon, the advances required are far less than those needed for any other proposed system.

Analysis of the Teller-Woodruff letters

The Government Accounting Office recently released declassified letters of Edward Teller and Roy D. Woodruff concerning the x-ray laser. Analysis of these letters, plus a few conjectures, yields what can be considered highly probable estimates of key x-ray laser design parameters. These key design parameters are 1) the *yield* or energy output of the thermonuclear weapon driving the x-ray laser; 2) the *energy conversion efficiency* or the ratio of the energy of the x-ray laser beam to the energy of its nuclear weapon; 3) the *divergence angle* or spread of the x-ray laser beam; 4) the *kill fluences* or the energies per unit area the x-ray laser must



X-ray laser at Princeton University.

deliver to a booster or a reentry vehicle (RV) to obtain a sure kill; and 5) the *brightness* or intensity of the x-ray laser beam. (While RV refers to reentry vehicle, it is also used as a synonym for nuclear warhead, since the reentry vehicle carries the nuclear weapon to its target.)

The kill fluence of a target should not be confused with its *hardness*. The hardness of a target is the fluence level at which significant damage will likely occur, whereas kill fluence is typically 10 times this number. The kill fluence is the value of fluence for which a kill is virtually assured, since it compensates for any hardness uncertainties.

The brightness of an x-ray laser is a function of its energy conversion efficiency and its divergence angle; therefore, any two of these three parameters determines the third. Of the five key parameters, energy conversion efficiency and divergence angle are the most difficult to estimate, since the information in Teller's and Woodruff's letters is insufficient to compute unique values.

More explicit definitions of all the key parameters, as well as their relationships to one another, may be found in next week's report.

The key pieces of evidence establishing the high probability of accuracy for the parameter estimates are 1) comments in Woodruff's letter to Gen. G.K. Withers concerning a table of key x-ray laser parameters; 2) statements in Woodruff's letter to Paul Nitze concerning the range of x-ray lasers; 3) statements of x-ray laser brightness enhancement in Teller's letters to Robert McFarlane and Nitze; and 4) Teller's statements concerning the distance at which targets can be killed in the same letters.

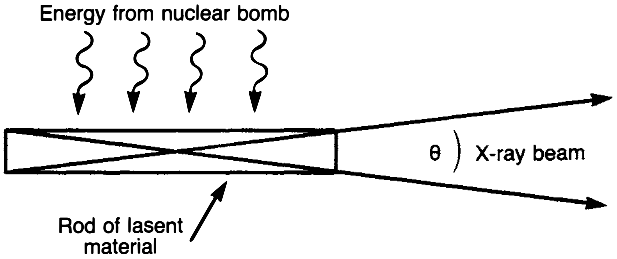
Woodruff's letters

After listing a few critical x-ray laser parameters by name, Woodruff says in his letter to Withers, "Many individuals, organizations and review committees have done back-of-the-envelope calculations to estimate these parameters—some of which even appear in the open literature. Most get the 'right' answer and these results are summarized in the following table." The table has been deleted in the declassification process, but a paragraph later, Woodruff says, "Many technical people who should know better seem to regard the above table as the end game. It is not! Even A. Carter [Ashton B. Carter, MIT physics professor and SDI adversary] seems to have missed that . . . the laser represented by this table is by no means the end of the line for x-ray laser potential."

Woodruff further states that the table presents two x-ray laser conceptual designs: the Excalibur or "baseline design," which was designed on paper in 1980, and the Excalibur(+) [sometimes called Super Excalibur] or "baseline physics limit." Woodruff refers to the Excalibur parameters as the "reasonable line in the table," and says Livermore is moving "as rapdily as data and theory will permit to find the actual [Super Excalibur] limits," as compared to the postulated values for Super Excalibur in the table. Woodruff also says that the planned steps proceeding to Super Excalibur have been the topic of at least three Jason reviews and several DOE/DARPA workshops and "so far no one has identified any show stoppers." DOE and DARPA are the Department of Energy and the Defense Advanced Research Projects Agency.

In light of Woodruff's comments about individuals and organizations getting the "right" answer, and the special at-

FIGURE 1



In an x-ray laser, a rod of lasant material is pumped to upper energy states by a nuclear bomb. Those cascades of downward transitions that travel lengthwise build up more energy than sideways-going cascades. As a result, most of the energy emerges from the ends of the rod into a cone with divergence angle equal to twice the rod width divided by its length.

Source: Ashton B. Carter

tention he gives to Ashton Carter, it seems highly reasonable to suspect that Ashton Carter's conceptual design of the x-ray laser published in "Directed Energy Missile Defense in Space" (Office of Technology Assessment, April 1984), provides good estimates of key x-ray laser parameters. Since the American Physical Society (APS) also presented an exemplary x-ray laser design in their July 1987 report on directed energy weapons ("Science and Technology of Directed Energy Weapons," *Reviews of Modern Physics,* Vol. 59, No. 3, Part II, July 1987), Carter's and the APS's numbers can be cross-checked for consistency. A consistent set of numbers from these independent sources would support the conjecture that Carter's numbers are credible estimates of key x-ray laser design parameters.

Both Carter and the APS authors base their key assumptions on publications in the open U.S. and Soviet literature. However, both also had access to classified aspects of the x-ray laser program prior to the completion of their reports. The APS authors were briefed on the results of x-ray laser underground tests conducted in 1985, results that were not available to Carter, or to Teller and Woodruff for that matter.

A key piece of evidence for validating Carter's numbers is also contained in Woodruff's letter to Paul Nitze. Talking about Excalibur (to be precise, Woodruff refers Nitze to a paragraph in Teller's letter, where Teller discusses a near-term x-ray laser; for reasons discussed below, this near-term device is Excalibur), Woodruff says, "The possibilities for using such a weapon would include the . . . exoatmospheric intercept of tens of objects (such as boosters and RVs) at distances from 100 km to 1,000 km depending on target hardness." Since RVs are harder—that is, they require more energy to be deposited on them to be destroyed—than boosters, and the energy deposited by an x-ray laser beam is inversely proportional to R^2 (proportional to $1/R^2$) where R is the distance to a target, we can conclude that RVs are about a factor of 10^2 (i.e., 100) times harder than boosters and that tens of boosters can be destroyed at 1,000 km and tens of RVs can be destroyed at 100 km.

Woodruff implies that Excalibur can have tens of independently aimable beams. If all of the beams are aimed at a single target, the total energy deposited on the target is simply the sum of the energy due to each beam. If we assume Excalibur has about 30 beams, then Woodruff is telling us that Excalibur can destroy a single booster at about 5,500 km and a single RV at about 550 km.

Teller's letters

Some of Carter's parameter values can also be directly compared to numbers given by Edward Teller in his letters. In Teller's 1984 letters cited above, he gives the brightness and lethal range for two x-ray laser conceptual designs—a near-term design expected to be realized in this decade, and a far-term design. According to Teller, the near-term design uses "sharply directed beams which locally enhance the brightness . . . of the nuclear bomb effects a million fold" and "can destroy sharply defined objects [e.g., boosters] at a distance on the order of 1,000 miles [1,600 km] and possibly more." "The overall military effectiveness of [far-term] x-ray lasers relative to the hydrogen bombs which energize them may . . . be as large as a trillion, when directed against sharply defined targets." With the far-term device 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 [e.g., an RV] in flight. The beams from such x-ray lasers could also be useful in striking targets deep in the atmosphere, down to altitudes of perhams 30 km."

Since Woodruff's letters were a response to Teller's letters, it can only be that Teller's near-term device is Woodruff's Excalibur, and Teller's far-term device is Woodruff's Super Excalibur. Thus we know that the Excalibur is about a million (10^6) times brighter than the nuclear bomb that powers it, and Super Excalibur is about 10^{12} times brighter than the nuclear bomb that powers it. We also know that "this is not the end game," according to Woodruff. We can also conclude that Excalibur can kill a single booster at roughly 4,000 km (this is based on Woodruff's letter suggesting roughly 5,500 km and Teller's comment suggesting 1,600 km or more), and that Super Excalibur could kill 100,000 "distant" RVs. The term "distant" can probably be interpreted as about 550 km (Woodruff) to 1,600 km (Teller), or about 1,000 km.

Estimating x-ray laser parameters

While Teller does not give the brightness of Excalibur and Super Excalibur, he does give their brightness enhancements, i.e., the ratio of the brightness of the x-ray laser to the brightness of the x-ray emissions of the nuclear bomb powering it. Thus, if we know the latter, we can compute the former. The x-ray brightness of a nuclear bomb can easily be estimated if we know its yield or energy release and the fraction of energy emitted as x-rays. Putting it all together, the x-ray laser brightness is simply the brightness ratio times the bomb yield times the fraction of energy released as x-rays divided by 4π (see next issue for details).

The brightness of an x-ray laser can also be determined if we know how much energy it deposits at a specified range. Since Teller and Woodruff give ranges at which targets can be destroyed by x-ray lasers, we can compute the brightness of the x-ray lasers if we know the kill fluence of the targets. The brightness is simply the kill fluence times the square of the lethal range.

To summarize, Teller's and Woodruff's numbers for the x-ray laser brightness ratios and x-ray laser lethal ranges provide two independent means to estimate x-ray laser brightness. One requires knowing the yield of the x-ray laser's nuclear bomb; the other requires knowing the kill fluence for boosters or RVs. It turns out that estimates of these two parameters (yield and kill fluence) to within an order of magnitude can be made fairly easily.

Carter and the APS authors perform back-of-the-envelope calculations for the x-ray laser energy level required to kill a booster. Carter computes an x-ray laser booster kill fluence of 20 kilojoules/cm^2, while the APS authors come up with 5 kilojoules/cm^2. Both of these numbers presume an impulse kill, i.e., the x-ray pulse (assumed by both studies to be "soft" x-rays with a wavelength of roughly 1 nanometer, or a photon energy of 1.24 keV) generated by the x-ray laser would be absorbed in a fraction of a millimeter of the skin of the target, which would explode (vaporize), sending a shockwave through the target. Since the APS analysis is more detailed than Carter's and had the benefit of an additional three years' worth of publications from which to draw, we shall give their result greater weight and assume the kill fluence of boosters is roughly 10 kilojoules/cm^2.

Woodruff's letter to Nitze suggests that RVs are 100 times harder than boosters. Therefore, we shall assume that the kill fluence of RVs is roughly 1,000 kilojoules/cm^2.

Based on the above kill fluences and assuming Excalibur has 30 beams, we find that the brightness of each beam is 5.3×10^{19} joules/steradian and the total brightness is 1.6×10^{21} joules/steradian. For Super Excalibur, we find that the brightness of each beam is 1.0×10^{22} joules/steradian and the total brightness is 1.0×10^{27} joules/steradian.

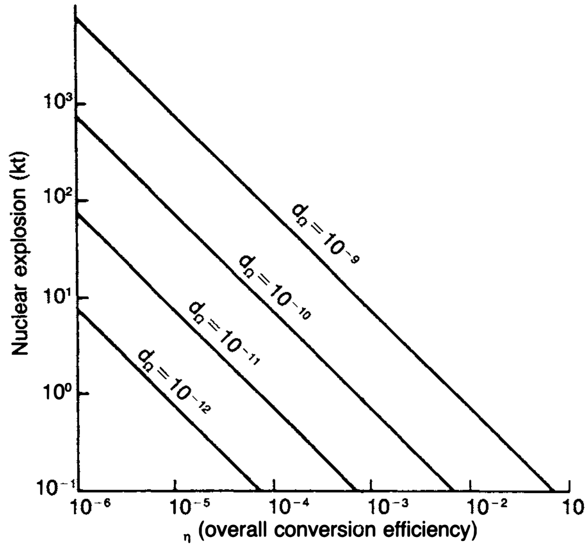
The above brightnesses can be cross-checked by independently estimating the yield of the nuclear bomb powering the Excalibur and Super Excalibur. In his exemplary x-ray laser calculations, Carter uses a nuclear bomb yield of 1 megaton. While such a number simplifies the arithmetic of his calculations, there is no rationale given for the selection of this number. It is known however, that the yield of RVs is of this order of magnitude. However, a rather strong argument can be made for a yield of roughly one tenth of this value.

If one believes the United States would not deploy an x-ray laser unless it was fully tested, then an upper limit for the yield of the nuclear bomb powering an x-ray laser can be set at 150 kiloton, given existing treaty specifications. Currently, the Threshold Test Ban Treaty between the United States and U.S.S.R. limits the yield of underground nuclear test devices to 150 kiloton (Ref. 1). Given that the theory, and therefore the scaling relationships, for x-ray lasers is not yet well understood, it seems doubtful that Teller and the Livermore Laboratory would base their claims for x-ray laser effectiveness on devices that could not be fully tested. Thus, we hypothesize that the numbers put forward for Excalibur and Super Excalibur are based on 150 kiloton nuclear bombs.

Assuming 150 kiloton nuclear bombs (1 kiloton is equivalent to 4.186×10^{12} joules) which release 70% of their energy in the form of x-rays (Ref. 1), and using Teller's brightness ratios, the brightnesses of Excalibur and Super Excalibur are 3.5×10^{19} joules/steradian and 3.5×10^{25} joules/steradian, respectively. These values are within a factor of 50 of those calculated using kill fluences. Thus, we can be quite confident our brightnesses are within an order of magnitude

FIGURE 2

Pump power needed for producing 3×10^7 j/ m^2 on a target at 1,000 km



Calculated nuclear explosion pump power needed for the delivery of a fluence of 3 kJ/cm^2 on a target at a range of 1,000 km as a function of the overall conversion efficiency. Variations are shown for a number of solid angles of x-ray laser emission.

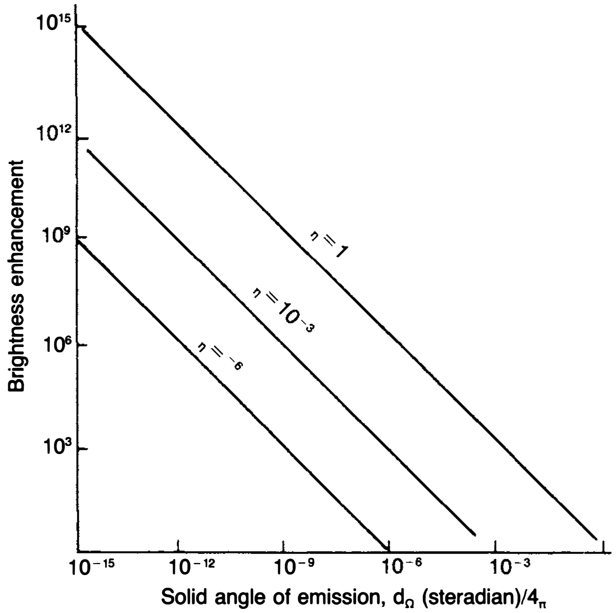
Source: APS Study: *Science and Technology of Directed Energy Weapons.*

of the actual values. Averaging our yield and kill fluence results to the nearest order of magnitude, our best estimates for the brightness of Excalibur and Super Excalibur are 10^{20} joules/steradian and 10^{26} joules/steradian, respectively. Recalling our original list of five key x-ray laser design parameters, only two have not yet been specified: energy conversion efficiency and divergence angle. As the next report will show, 16 times the energy conversion efficiency divided by the square of the divergence angle is equivalent to the brightness ratio. Thus, when the brightness ratio is known, specifying one of these two parameters determines the other. Both Carter and the APS authors use values for the energy conversion efficiency and divergence angle that yield a brightness ratio of roughly 10^9, which is "midway" between the Excalibur and Super Excalibur brightness ratios specified by Teller. Thus, we can assume that the Carter and APS values are in the ballpark.

Carter uses an energy conversion efficiency of 2.5% and a divergence angle of 20 microradians. The APS study presents the energy conversion efficiency parametrically, but centers its value at about 0.1%. The APS study gives special attention to a divergence angle of 1 microradian by using it in a numerical example.

FIGURE 3

X-ray laser brightness enhancement



Calculated brightness enhancement for a nuclear explosion pumped x-ray laser as a function of the solid angle of laser emission. Three typical variations are shown for the overall conversion efficiency of 1, 1^{-3}, and 10^{-6}.

Source: APS Study: *Science and Technology of Directed Energy Weapons.*

Carter claims his numbers are upper limits belonging to a "perfect" x-ray laser, i.e., the energy conversion efficiency cannot exceed about 2.5% and the divergence angle cannot be less than about 20 microradians. It is for these dogmatic claims that Woodruff chides Carter in his letter to Withers.

Clearly, one or both of Carter's numbers are not upper limits and can be improved upon, since his x-ray laser is not as bright as Super Excalibur. Based on the pumping efficiency of other lasers (e.g., excimer lasers), we concur with Carter's upper limit for the energy conversion efficiency. Thus, there must be room for improvement in his divergence angle. This is consistent with the APS authors' use of a smaller divergence angle in their exemplary calculation.

In fact, based on Carter's approach in analyzing the divergence angle, 20 microradians is probably closer to a nominal, near-term value. Carter presumes that collimation of the x-ray laser beam is solely due to a "mechanical" effect, analogous to placing a pure color (a single frequency) light bulb at the closed end of a long, narrow tube. Because the photons leaving the bulb are not in phase (the light is incoherent), the light leaves the bulb isotropically (equally in all directions). Since only light traveling down the axis of the tube can leave the tube's open end, the tube collimates the light. Collimation can be improved bu using longer, narrower tubes, but only up to the point that the light becomes diffraction limited. This point defines the optimum dimensions of the tube and the minimum divergence angle of the light. Using this approach, Carter derives his 20 microradians (see next week for details).

What Carter neglects is the nonlinear phenomenon of plasma focusing. When the lasant material is pumped by the nuclear bomb's x-rays, it is vaporized and forms a plasma. As the lasant plasma relaxes to a lower energy state, photons cascade down the length of the plasma and it lases x-rays. But the plasma's work is not over. It possesses optical properties that can focus the x-ray beam beyond the "mechanical limit" put forward by Carter. This focusing can be produced in two ways—by actual bending of the x-rays and by enhancing the coherence of the beam (i.e., putting all the individual x-ray photons "in step" or in phase). For a coherent beam, divergence of the beam is reduced by increasing the aperture through which the beam is emitted. Carter's use of long, narrow rods of lasant material is not required in this case, and would actually increase the divergence.

Since plasma focusing is an extremely complex phenomenon, it is likely that this effect would not be counted on for an initial prototype x-ray laser such as Excalibur. Thus, we consider Carter's 20 microradian divergence angle an upper limit for Excalibur, but not for Super Excalibur.

Now, presuming 1) the upper limit of energy conversion efficiency for Excalibur and Super Excalibur is on the order of 1% (cf. Carter); 2) the upper limit of Super Excalibur's divergence angle is unknown; and 3) the upper limit of Excalibur's divergence angle is 20 microradians, what can we

TABLE 1
Estimates and comparisons of x-ray laser parameters

	Teller & Woodruff				EIR	
	Excalibur	Super Excal	Carter	APS Study	Excalibur	Super Excal
1. Yield, *kilotons*	?	?	1000	?	150	150
2. Conversion efficiency	?	?	.025	.001	.001	.001
3. Divergence angle, *microradians*	?	?	20	1	100	.1
4. Brightness multiplier	10^6	10^{12}	10^9	10^9	10^6	10^{12}
5. Number of x-ray laser rods	1 to 20	10^5	?	?	1 to 100	10^5
6. Brightness, *joules/steradian,* using 1 & 4 above	?	?	10^{24}	?	10^{20}	10^{26} (10^{21} per rod)
7. Fluence at 1000 km, *kilojoules/cm*^{2} using 6	16F*	100F (each rod)	10^5	?	10	10^7 (100 per rod)
8. Range at booster kill fluence, *km*	4000	10,000 (each rod)	70,711	?	1000	3162 (each rod)
9. Range at RV kill fluence, *km*	400	1000	?	?	100	316 (each rod)
10. Booster kill fluence, *kilojoules/cm*^{2}	F	F	20	5	10	10
11. RV kill fluence, *kilojoules/cm*^{2}	100F	100F	?	?	1000	1000

* Where F is the average power per unit area, or Flux of radiant energy at a distance R from its source and is given by: $F = B/R^2$, where B has units of kilojoules per steradian and R is measured in centimeters.

say about the "practical" values of the energy conversion efficiency and divergence angle of Excalibur and Super Excalibur? If we adopt the rule of thumb that most physical processes operate within 10% to 100% of their upper limits or theoretical maxima, then the non-unique values of energy conversion efficiency and divergence angle that conform to our assumptions and also yield the brightness ratios of Excalibur and Super Excalibur are as follows. For Super Excalibur: 0.1% and 100 microradians, respectively; for Excalibur: 0.1% and 0.1 microradians, respectively. In light of the information available, these values appear to be reasonable estimates of the relevant parameters.

vant parameters.

Table 1 summarizes our best estimates of the Excalibur and Super Excalibur key design parameters, as well as the hard data provided by Teller, Woodruff, Carter, and the APS study. We utilize the variable F, the flux, to present the ratios discussed by Teller and Woodruff.

Reference

1) Taylor, Theodore S., "Third-Generation Nuclear Weapons," *Scientific American,* Vol. 256, No. 4, April 1987.