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27 JAN 2016

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Mr. John Greenewald
[redacted]

Dear Mr. Greenewald

This is the Air Force Nuclear Weapons Center's supplemental response to your Freedom of Information Act (FOIA) request, Case No. 2014-05431-F, received by the FOIA Office, Kirtland AFB, on 28 July 2015 for a report dated September 1979, entitled "Vulnerability Assessment of Charged Particle Beam Weapons", no. AFAL-TR-79-1124. The responsive document is a Final Technical Report, originally classified as "SECRET" and later the majority declassified. It is being provided herein in redacted form, pursuant to the authorities cited below.

Exemption 1 of the Freedom of Information Act protects from disclosure information that has been deemed classified "under criteria established by an Executive order to be kept secret in the interest of national defense or foreign policy" and is "in fact properly classified pursuant to such Executive order. The current executive order in effect is Executive Order 13,526. It prohibits the disclosure of the development, production, or use of weapons of mass destruction, and military plans, weapons systems, or operations. Accordingly, the Air Force has determined that such information should retain its original "SECRET" classification category, and is being withheld. The authority for this exemption is the U.S. Code, Title 5, Section 552(b)(1) and Department of Defense (DoD) Regulation 5400.7-R_AFMAN 33-302, paragraph C3.2.1.1.

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Secretary of the Air Force
Thru: 377 MSG/SCOK (FOIA Manager)
2051 Wyoming Blvd SE
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Sincerely

LANCE K. KAWANE, Colonel, USAF
Vice Commander

Attachment:
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LEVEL II

VULNERABILITY ASSESSMENT OF CHARGED PARTICLE BEAM WEAPONS (U)

Richard D. Hunziker
Active Electronic Countermeasures Branch
Electronic Warfare Division

September 1979

TECHNICAL REPORT AFAL-TR-79-1124

Final Technical Report for the Period August 1978 to June 1979

Classified by Multiple Sources
Declassify on 1 December 1998

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This technical report has been reviewed and is approved for publication.

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Electronic Countermeasures
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Directed Energy Weapon Vulnerabilities

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

~~(S)~~ This report defines and provides a preliminary assessment of vulnerabilities that might exist in prospective Soviet Charged Particle Beam Weapon (CPBW) systems. Intelligence information indicates that the Soviets have been interested in this area since the early 1950s. The USAF presently has no countermeasure techniques for protection of their strategic weapon systems from Soviet CPBWs. This effort divided the CPBW into five major subsystems and/or technologies. A summary of the results is as follows:

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011670

a. ~~(C)~~ CPBW Device: No apparent realistic countermeasures exist.

b. ~~(S)~~ Pointing and Tracking Mechanism: No apparent realistic countermeasures exist.

c. ~~(S)~~ Fire Control System: Vulnerabilities to this subsystem do exist; however, it appears that tracking errors of 4 to 5 degrees will be required to effectively counter a CPBW system.

d. ~~(S)~~ Propagation: There exists the possibility of beam-bending or collapsing the channel in order to degrade the CPBW system.

e. (U) Target Interaction: Material hardening with conventional materials appears non-realistic; the AF Material Laboratory is investigating this aspect of the problem.

~~(S)~~ The information obtained during this in-house study will be utilized as background and the technology base for a contemplated FY-80 Charged Particle Beam Weapon Countermeasure effort under Project 2000, Task 32, Work Unit 34.

(S)

FOREWORD (U)

(U) This study was initiated by the Electronic Warfare Division of the Air Force Avionics Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson AFB, Ohio, under Project 2000, Task 32, Work Unit 33, entitled "Future Weapon Countermeasures." The study was conducted by the author, Mr. Richard D. Hunziker of the Electro-Optical Warfare Group, Active ECM Branch, Electronic Warfare Division, during the period of August 1978 through June 1979. The report was submitted by the author in June 1979.

(U) The author is grateful for the special cooperation and information obtained from Major H. Dogliani, Dr. D. Straw and Dr. W. Baker of the Air Force Weapons Laboratory and Colonel R. Roberds of the Air Force Avionics Laboratory.

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SECTION I

INTRODUCTION (U)

1. OBJECTIVE (U):

~~(S)~~ The objective of this analysis is to define and assess the vulnerabilities that might exist in prospective Soviet Charged Particle Beam Weapon (CPBW) systems. This analysis will then establish the technological base required before countermeasure efforts can be pursued to negate such new weapon systems. Of primary concern in this effort is the vulnerabilities of in-atmosphere Particle Beam Weapon systems; hence, only Charged Particle Beam Weapon systems will be addressed, not space-based Neutral Particle Beam Weapon systems.

~~(S)~~ A secondary objective of this effort is to provide US designers and builders of such weapon systems with an insight into vulnerabilities that might exist in our own systems--thereby to facilitate the incorporation of counter-countermeasures techniques in our systems to probably "hardened" them against attack from early generation Soviet CPBW countermeasures.

2. REQUIREMENT (U):

~~(S)~~ Evidence obtained from a variety of intelligence sources indicates the Soviet interests in Charged Particle Beam Weapons for antiaircraft and antiballistic missile applications since the early 1950's and that the Soviet understanding of a number of fundamentally new technologies applicable to CPBW's has reached an advanced level. The exact status and direction of the Soviet Research and Development in CPBW technology are uncertain; therefore, threat definitions and vulnerabilities must be "generic" in nature, and countermeasure concepts must be varied, possibly unconventional, and "all-encompassing." At the present time, the USAF has no countermeasures that will protect aircraft and/or cruise missiles from CPBW systems. The need for effective and practical countermeasure systems for strategic weapon systems will become urgent in the near future as these CPBW systems are deployed operationally.

Because of the lead time required to make design changes and to procure "add-on" protective measures for existing USAF weapon systems, it is now timely to evaluate and enhance the survivability of our strategic weapon systems against CPBW technology. Without these protective measures, our strategic weapon systems would be very vulnerable to CPBW systems; thus, gravely threatening USAF mission accomplishment capability.

~~(S)~~ The requirements for usable CPBW countermeasures are near critical. Such countermeasures should be effective against future CPBW systems as well as those presently being designed and considered. They should not be the type of countermeasure technique that can be easily negated by minor design changes and/or modifications of proposed CPBW systems. Typical counter-countermeasure techniques should be considered when investigating prospective countermeasure techniques. This analysis will set down the basic information required to establish, by the mid-to-late 1980's, effective countermeasure techniques that can be utilized by USAF aircraft and/or cruise missiles to negate Soviet threat CPBW systems.

3. TECHNICAL APPROACH (U):

~~(S)~~ For the purpose of this analysis, the CPBW system has been broken down to the following five subsystems:

a. (U) CPB Device
   - Power Generation
   - Accelerator
   - Switching

b. (U) Pointing and Tracking Mechanism
   - Beam Transport
   - Exit Ports
   - Steering Mechanisms

c. (U) Fire Control System
   - Target Detection and Identification
   - Target Tracking
   - Beam Control

d. ~~(S)~~ Propagation
Beam Propagation
Secondary Radiation

e. ~~(S)~~ Target Interaction
Material
Electronic
Human

(U) Vulnerabilities of each of these five systems were examined and are reported in Section III. A schematic of the CPBW system and appropriate countermeasures is depicted in Figure 1.

4. CONCLUSIONS AND RECOMMENDATIONS (U):

~~(S)~~ The conclusions and recommendations of the vulnerability assessment for each of the five technology areas outlined in Section I.3 are as follows:

a. ~~(S)~~ The CPB Device is invulnerable to conventional countermeasures; however, weapon (conventional or nuclear) could be employed against it.

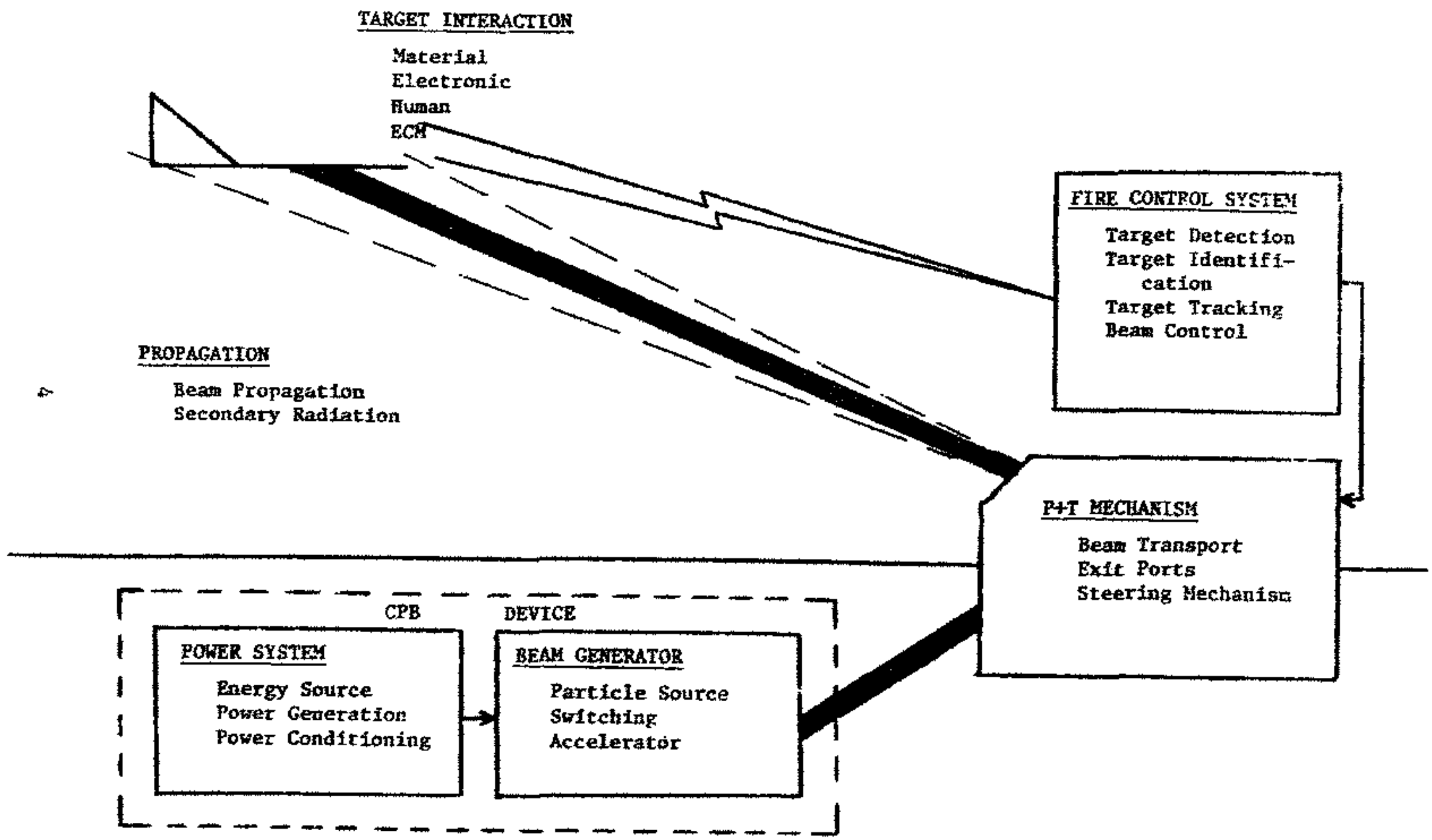
b. ~~(S)~~ The Pointing and Tracking Mechanism is invulnerable to conventional countermeasure techniques the same as Section I.4.a.

c. ~~(S)~~ The Fire Control System is probably the most vulnerable subsystem to countermeasures; however, errors of 4°-5° will have to be accomplished in order to protect strategic weapon systems from the secondary radiation effects caused by the Charge Particle Beam propagating through the atmosphere.

d. ~~(S)~~ The Propagation of the CPB has two interesting aspects: First, the probability of disturbing the actual propagation of the beam through the atmosphere does not appear to be feasible operationally or technologically. Secondly, there does exist a possibility of causing bending of the beam such that the beam could miss the target.

e. ~~(S)~~ The Target Interaction problems of the beam hitting the target appear to be numerous and very difficult to reduce.

FIGURE 1. (S) CPBW SYSTEM CONCEPT (U)



~~(S)~~ Based on the above synopsis, future efforts in the area of CPBW countermeasure should be directed toward degrading the fire control system and the propagation/beam-bending areas. Since the foregoing conclusions are based on countering a very "generic" CPBW system, as more information becomes available on approaches the Soviet Union is taking in this technology area becomes available, a reassessment of vulnerabilities of the other subsystems should be accomplished in a timely manner.

SECTION II

BACKGROUND (U)

1. HISTORY OF CPBW SYSTEMS (U):

~~(S)~~ Since the early 1950's, both the United States and Soviet Union have been engaged in efforts to investigate the technologies required in order to be able to field a prototype CPBW system. US programs that have been conducted to work toward this end include the following:

a. ~~(S)~~ (b)(1) - This program was conducted by Defense Advanced Research Project Agency (DARPA) from 1953 to 1972. (b)(1) (b)(1) placed emphasis on ground-based defense against nuclear re-entry vehicles. For this mission, proton or electron beams with gigaelectron-volt energies per particle and currents of kiloamperes were required for propagation (Reference 1).

b. ~~(S)~~ (b)(1) - Since 1972 the Naval Surface Weapons Center has been conducting this effort. (b)(1) is examining the potential use of a charged particle beam for tactical ship defense against conventional nonnuclear warheads. Electrons are again being emphasized, (b)(1) Recently DARPA has taken over this effort and has redirected it to mostly look at technology issues such as propagation (Reference 2).

(b)(1)

a. (b)(1)

b. (b)(1)

c. (b)(1)

~~(S)~~ At the same time that the United States was pursuing the foregoing programs, the Soviet Union was apparently conducting similar types of efforts. Along with accelerator technology, Soviets have conducted extensive work in other critical technology areas and are postulated to possess a capability equal to or greater than the US in the following areas:

- Magnetohydrodynamic Generators
- Magnetocumulative Generators
- Inductive Storage
- Capacitive Storage
- Energy Switching
- Externally Driven Accelerators
- Collective Accelerators
- Beam Transport
- Beam-Bending Systems
- Atmospheric Propagation Theory and Experiments
- Target Kill Assessment

(U) During the last several years there has been open controversy going on in the United States as to the capability of the Soviet Union in this area and whether or not CPBW systems are even feasible. On one side there have been published articles containing comments by retired Major General George Keegan (Reference 3 and 4) who has estimated that the Soviet Union is as much as ten years ahead of the US in this technological area and feels that by the early 1980's the Soviets will be able to field a prototype CPBW. At the time of some of General Keegan's announcements, others in the scientific community bitterly disagreed (Reference 4). In May of 1977, Defense Secretary Harold Brown stated to the National Press Club, "There's no evidence that we know how to solve that problem (steering a Charged Particle Beam through the atmosphere and the earth's magnetic field) or that the Soviets do . . . the laws of physics are the same in the US and in the Soviet Union. And in this particular case, I'm convinced that we and they can't expect to have such a weapons system in the forseeable future (Reference 5)." More recently a group of scientists at MIT published an article (Reference 6) on the impossibility of CPBW systems. They state that even if CPBW systems could be developed, they "could be easily countered." The foregoing statements show a heated debate ensuing as to whether or not CPBW can be developed, and if they can, when we or the Soviet Union will be able to deploy such weapon systems operationally.

~~(S)~~ The probability of such weapon systems existing in the next 8 to 15 years appears to be reasonable and; therefore, the United States should pursue countermeasure techniques now so that they will be available to USAF strategic weapon systems by the time the CPBW is developed. As stated in Section I.2, the techniques to be considered for countering this new and different threat must be "all-encompassing," varied and, in some cases, possibly unconventional. Since the threat is defined in only general terms (see Section I.3), the countermeasure techniques must be ones that are "usable" or "effective" against several types of possible CPBW system configurations. They can not be ones that rely on countering only one very critical component of a subsystem, since a redesign of the component may completely negate the effectiveness of the countermeasure. Typical counter-countermeasure techniques that one could employ with reasonable complexity and cost in a CPBW system should be considered when determining prospective countermeasure techniques and performing trade-off studies.

2. THREAT DEFINITION (U):

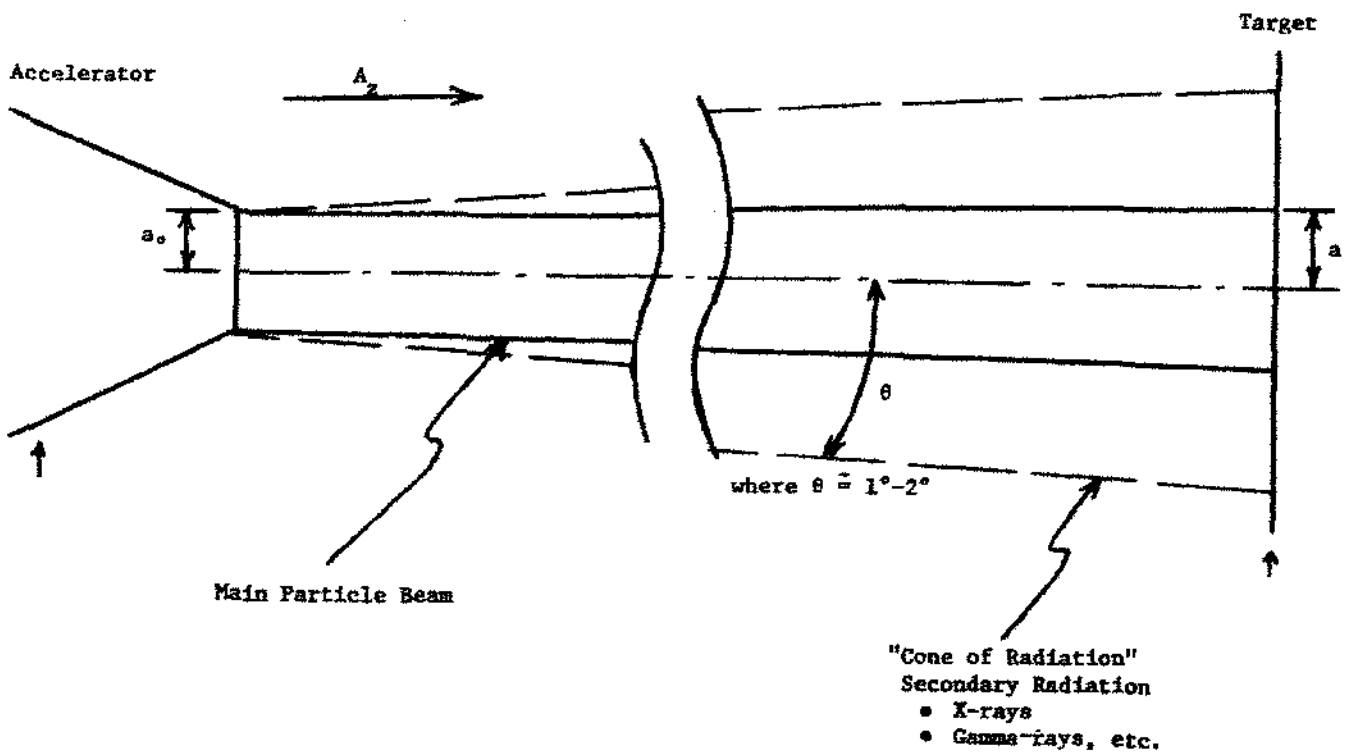
~~(S)~~ In this section the CPBW system will be described. Note that the detailed configuration is unknown at the present time and that only Charged Particle Beam devices will be included in the analysis. Table 1 shows the parameters that will be considered to exist in a generic CPBW system.

TABLE 1. ~~(S)~~ CPBW THREAT PARAMETERS (U)

Particle Type	Electron or Proton
Peak Power Output	$10^{12} - 10^{14}$ Watts
Particle Energy	.5 - 10 GeV
Pulse Current	20 KA
Pulse Energy	$1 - 10 \times 10^{6}$ j
Pulse Per Shot	30 - 40 Pulses
Pulse Width	15 - 20 nsec
Inter Pulse Period	30 - 100 μsec
Range	1 - 3 Km (possibly 5 Km)
Tracking Accuracy	5 - 25 μrad

~~(S)~~ Discussions with CPBW design people (References 2, 7, and 8), reveal that in the CPBW area there are probably two types of weapons that could exist. The first is the conventional CPBW, where the beam or "bolt" itself is the destructive device. The second is more of a "radiation weapon," which consists of the secondary radiations (i.e., X-ray, gamma-rays, neutrons, etc.,) that are produced as the beam propagates through the atmosphere. Preliminary analysis indicates that there exists a "cone of radiation" around the beam itself that propagates beyond the end of the beam. The "cone of radiation" is estimated to have a cone

FIGURE 2. ~~(S)~~ CPB PARAMETERS (U)



angle of about 1-2° and to propagate two to three times the range of the beam itself. An illustration of this is shown in Figure 2.

~~(S)~~ The spreading of the beam itself is given by the following formula:

$$a = a_0 \exp \frac{kA_z}{IE}$$

Where a = radius of beam at the target

a_0 = radius of beam at the output port

k = constant

A_z = range from the accelerator to the target

I = beam current

E = particle energy

~~(S)~~ As shown in Figure 2, the IE term is the dominating factor in this formula and must be in the $10^{12} - 10^{14}$ watt region in order for the beam to propagate a reasonable distance. As an example, the Chair Heritage system is designed to have a beam output energy of 10^{9}eV and 10 KA current; thus, an IE of 10^{13} watts.

~~(S)~~ As shown in Table 1, a CPBW "bullet" can be defined as a train of 30 - 40 pulses, each having a peak power of $10^{12} - 10^{14}$ watts, and being 15 - 20 ηsec in width with an interpulse period of 30 - 100 μsec. The minimum total time length of a "bullet" would be about 1.2 msec. When firing the CPBW, one must at a fixed point rather than slew and fire the beam at the same time, because each pulse does not, in itself, propagate the entire distance to the target but only a small portion of that distance. As the first pulse leaves the weapon, it progapates a distance through the atmosphere along its path which causes a channel of a partial vacuum. Before this channel collapses, the next pulse is fired; it travels down the first pulse's channel and propagates a little farther into the atmosphere. This process continues for each succeeding pulse until one of the pulses in the train, and each succeeding pulse thereafter, hits the target. If one were firing at a target going Mach 1.0 at sea level and desired to hit the target in a specific spot, the target would have to be lead by a linear dimension of about 1 to 2 feet because the "bullet" is about 1.2 msec long. CPBW design people (Reference 2 and 7) believe that all they would need on a target, such as an aircraft or cruise missile, would be one of the 30 to 40 pulses in order to affect a kill.

~~(U)~~ The damage mechanism from a "bolt" hitting a target appears to be complex and to involve many different disciplines. First, as the "bolt" hits the target there will be some mechanical shock to the material from the particles impinging on the target. Combined with surface effects is thermal shock: material heating, melting and/or vaporization of the material in the general area where the "bolt" hits the target. A hole slightly larger than the beam diameter at the target (i.e., several centimeters at a range of 2 or 3 Km) will probably be made. Electromagnetic pulses (EMP) and electro-static gradients will be formed throughout the target, possibly to the point where high explosives onboard may be detonated. The next effect, and possibly one of the most serious ones, is that of a creation of large doses of X-ray and gamma-rays that can degrade and/or destroy electronic equipment and crew members. Note that a weapon of this type will actually deposit more energy further into a material than it does at the surface (see the "Bragg peak" in Figure 3). The severity of a CPBW's beam impinging on a target appears to be much greater than that of an high-energy laser's (HEL) beam hitting the same target. The HEL only imparts thermal and/or mechanical shock energy at the surface (depending on whether it is a CW or a pulsed laser beam); however, the CPBW imparts the same type of thermal/mechanical shock energy plus secondary energies in the form of X-rays, gamma-rays, EMP, etc.

~~(U)~~ The aforementioned effects are true if the beam or "bolt" actually hits the target; however, if what has been described as the "cone of radiation" around the beam is also true, then damage of the target can also occur even if the target is not struck by the "bolt." The use of a CPBW as a radiation weapon should be seriously considered. As an example, if a CPBW has a range of 3-5 Km then the "cone of radiation" will have an effective range of 8-12 Km and the pointing and tracking requirement will be drastically reduced (i.e., from 5-25 μrad to 1°). Such a weapon system could be very potent and cost effective. Thus the "cone of radiation" should be considered as part of the kill effects when considering the evaluation of countermeasures against a CPBW system.

~~(S)~~ As the charged-particle beam propagates through the atmosphere, its particles (either electron or proton) collide with other particles/molecules in the atmosphere. This collision causes additional particles and/or radiations to be given off. Particles and radiations contained in the "secondary radiation" category include: neutrons, protons, electrons, mesons, X-rays and gamma-rays. Most of this "nuclear trash" is projected in a forward direction and appears to be a cone of 1°-2° in angle around the beam. Dose rates are unknown at the present time, but it appears that they could be in the Kilo-to Mega-Rad level. These dose rate levels would be sufficient to render crew personnel of an attacked aircraft useless, if not to kill them outright. [redacted] (b)(1) The author does not know what the hardening specifications are for aircraft or cruise missiles against such nuclear radiations. Such hardening may have already reduced some of the effects of the "cone of radiation."

~~(S)~~ Little information could be obtained on the type of fire control system that a CPBW system may employ. At the present time, the major concern of personnel in the CPBW development area is that of power generation, accelerator technology and propagation theory and experimentation. Certainly, when these very complicated technical problems are solved, the fire control problem will be addressed. Since little could be found in this area and since the pointing and tracking requirements of the CPBW could be similar to that of a HEL weapon system, similar types of fire control systems will apparently be used for the CPBW application.

~~(S)~~ The scenario or sequence of events required for a CPBW system (b)(1)

appear to be similar to that of the HEL weapon system. First, acquisition of the penetrating target will probably be accomplished by utilizing conventional radar techniques. Identification Friend or Foe (IFF) will then be accomplished by radar; however, if because of IFF jamming this is made impossible, it may be accomplished later in the scenario via optical means. The early warning radar will probably hand the target off to a tracking radar which, in turn, will hand the target off to an electro-optical tracker. The electro-optical tracker may be a TV or a Forward Looking Infrared (FLIR) system. Final tracking and identification of the target can then be made with these systems. At this point, an aim point on the target will be selected (this may not necessarily be required as per the discussion of the kill mechanisms of the beam and of the "cone of radiation"), a lead angle incorporated into the fire control algorithm with slewing of the weapon system stopped during the firing of the ≈1 msec bullet. In the case of the HEL, some form of beam control system is required to allow all of the energy of the laser beam to be deposited on the same spot of the target. It is not clear at this point whether such a system would be employed on an in-atmospheric CPBW system or even considered because of the required tunneling effect of the beam for propagation needed. When the target is attacked, some form of kill assessment will have to be accomplished. This probably would be accomplished via the TV or FLIR system and observing the actions/reactions of the target to the "bolt" or "cone of radiation." Once the kill can be confirmed, the CPBW is then available to attack the next highest priority target.

SECTION III

CPBW VULNERABILITY/SUSCEPTIBILITY ASSESSMENT (U)

~~(S)~~ This section includes an assessment of the vulnerabilities/susceptibilities that CPBW systems are anticipated to possess. The vulnerabilities/susceptibilities are enumerated as per each subsystem of an entire CPBW system that is affected; however, some of the vulnerabilities/susceptibilities and, therefore, the appropriate countermeasure systems required to exploit the respective vulnerabilities/susceptibilities may affect one or several of the subsystems. Note that the weapon system has been broken down into the following five general technical areas: (1) the CPB device itself, (2) the pointing and tracking mechanism, (3) the fire control system, (4) the beam propagating through the atmosphere, and (5) the interaction of the beam with the target. The discussion that follows will include some potential vulnerabilities/susceptibilities of CPBW systems that lend themselves to degradation by what is not normally considered <u>electronic</u> countermeasures. The two main examples are the use of: (a) weaponry (whether conventional or nuclear) which counters the CPBW system by destruction and (b) hardening of the target skin material to withstand the striking of the CPB "bolt." These two techniques are important in the overall scheme of enemy CPBW suppression and countermeasures; however, they are not within the charter nor responsibility of the Air Force Avionics Laboratory and, therefore, will only be mentioned in passing.

1. VULNERABILITIES/SUSCEPTIBILITIES OF THE CPB DEVICE (U):

(U) The following vulnerabilities/susceptibilities were determined to exist in the CPB device itself:

a. ~~(S)~~ Energy Source: CPBW systems will require large quantities of energy delivered in a short time period. Sources capable of supplying such energy needs will include chemical explosions, fission/fusion reactors or fission/fusion detonations. In all cases, these types of systems appear to be invulnerable to conventional electronic countermeasure techniques. The only technique that appears to have application against this area would be that of weaponry.

b. ~~(S)~~ Power Generation: Three types of power generation techniques appear to be applicable to this type of weapon. The first is beefed-up conventional electro-mechanical generators. The other two are explosively driven electrical generators: (a) magnetocumulative generator (MCG) which converts the stored energy of explosives into electrical energy through the explosive compression of a magnetic field and (b) magnetohydrodynamic generator (MHD) which generates a current by passing a conducting fluid through a magnetic field. Susceptibility of such devices to conventional countermeasures is the same as the energy source, nonexistent. These devices could even be put below ground; thus, further reducing their vulnerability to weaponry.

c. ~~(S)~~ Power Conditioning: Power conditioning systems will include energy storage techniques using capacitors, inductors or rotor systems. Switching of large energies will be included in this subsystem and is an important and difficult task which is required for the proper operation of the CPBW. Again, as in the preceeding systems, no susceptibilities to electronic countermeasures were found to exist in this area.

d. ~~(S)~~ Particle Source: The two main charged-particle choices for in-atmospheric weapons are electrons and protons. Electron source generation is usually done by high-current cathodes such as using a vacuum arc originating from a metallic surface, dielectric cathodes, liquid metal cathodes or multipoint cathodes. The type of sources used to produce protons or positive ions are plasma cathodes, reflex triodes or using the ionization front of the gas. None of these appear to be vulnerable to electronic countermeasures.

e. ~~(S)~~ Accelerator: The main component in a CPBW system will be the high-energy accelerator. There are several different types of accelerators that could be used for this application; however, they appear to fall into one of two general classes of accelerators: (a) externally driven systems (such as linear induction accelerators and radio frequency accelerators) and (b) beam-driven accelerators (such as the electron autoaccelerator and the collective ion accelerator which has the motive power required for the accelerating mechanism provided by a high-current electron beam). Consideration was given to the possibility of causing in the accelerator the analogy of a parasitic feedback in an high-energy laser device. If one could "pump energy" backwards through the accelerator in a manner similar to energy being pumped backwards in a laser, then one would have what is considered an effective countermeasure. Further study, however, showed that accelerators can not work in reverse like high-energy laser devices can. No other potential vulnerability was found to exist with the accelerator.

2. VULNERABILITIES/SUSCEPTIBILITIES OF THE POINTING AND TRACKING MECHANISM (U):

(U) The following vulnerabilities/susceptibilities were determined to exist in the CPB pointing and tracking mechanism:

a. ~~(S)~~ Beam Transport: As the high-energy CPB leaves the accelerator, it must be transported to the pointing and tracking system. For this study, the beam transport system will be considered as part of the pointing and tracking mechausim. There appears to be three techniques used for beam transport: (a) waveguides, (b) low-pressure gas, and (c) magnetic fields. Operational systems will probably utilize a combination of these techniques. The low-pressure gas utilized with either of the other two will be the most likely method. Such high-energy beam transport systems will require beam-focusing and beam-bending techniques. The low-pressure gas will probably be used for focusing. Beam-bending will probably be done via mirror-capturing techniques or using highly accurate traverse field magnets. The beam could be made susceptible to countermeasures if magnetic fields could be applied to the beam transport system. However, the system would most likely be shielded from such radiation because of its near proximity to the energy sources, power conditioning system and accelerator which could provide such magnetic fields to disturb the beam. No other susceptibilities were determined.

b. ~~(S)~~ Exit Port: A CPBW system will require an exit port which will probably have the mission of shaping the beam in order to improve beam quality and to bend the beam toward the target. Presumably, traverse field magnets will be used for producing a weapon quality beam before it enters the atmosphere. Some form of highly accurate, quick-reaction beam-bending technique will be required to put the beam on target and then move it quickly to another target. One possible method is the use of electromagnetic optics, which is similar to the electromagnetic coil used on the cathode ray tube in a TV to move the electron beam across the screen. In examining the possible countermeasure techniques that can be used against this subsystem, there appears to be no real vulnerability to conventional electronic countermeasures. The only possibility, and very slight at that, is to induce false current, via high-power electromagnetic energy, into the elctromagnetic mirror coil such that pointing errors would result. However, at the present time, this appears to be a very remote possibility because of a lack of high-energy electromagnetic systems.

3. VULNERABILITIES/SUSCEPTIBILITIES OF THE FIRE CONTROL SYSTEM (U):

(U) The following are the vulnerabilities/susceptibilities found to exist in the CPBW fire and control systems:

a. ~~(S)~~ Target Detection and Identification: It is assumed that a CPBW system will utilize conventional radar techniques for the detection and identification of incoming targets. Certainly these systems are vulnerable to countermeasures and the US has had, and continues to have, an agressive program in RF countermeasures. Since at this time it is impossible to predict the parameters of the specific radar(s) that will be used with a CPBW system, that no additional work should be conducted in this area and, as the threat becomes more mature, the RF countermeasure community should be surveyed for appropriate countermeasure techniques to negate such a radar net.

b. ~~(S)~~ Target Tracking: Once detection and identification of the target has been accomplished via radar devices, the tracking of such targets will be accomplished. At first, radar probably will be used for coarse-to-medium accuracy tracking. As stated in the preceding paragraph, conventional RF countermeasure techniques could be applied toward the RF tracking system. Note that since fine tracking accuracy (i.e., 5-25 μrad) will probably be required, additional tracking techniques will be needed. As with the case of HEL weapon systems, probably TV or FLIR devices will be used for this fine pointing and tracking of the target and for aim-point selection. The Army, Navy and Air Force have had several programs studying the vulnerability of TV and FLIR systems and performing countermeasure effectiveness evaluations. There is even an effort currently on-going by the AFAL to look at countering HEL fire and control sensors (Reference 9). There is no question that such systems are vulnerable to countermeasures and that any effort to investigate countermeasures against CPBW systems should include this area. However, note that in the HEL case if one cause fairly significant beam wander on the target (such as 25-50 μrad) or moves the beam off the target, the HEL is basically defeated. This may not be the case in the CPBW situation. First, the countermeasure may have to be effective enough to keep the beam from ever hitting the target. Secondly if the 1°-2° "cone of radiation" exists around the beam, then pointing and tracking errors of 4°-5° may have to be accomplished to assure survivability of the attacking penetrator. The requirements placed on a countermeasure system by a CPBW system certainly appear to be far more extensive than those placed on a HEL countermeasure system. As a result, additional work will have to be accomplished in this area to significantly upgrade countermeasure systems to meet these requirements.

c. (S) Beam Control: A beam control system would be used to make corrections in beam aiming such that the beam hits the point on the target aimed at by the fire control system. Feedback from the beam propagation through the atmosphere or from where the beam hits the target would be required for such a system. This system would be similar, in concept, to beam control systems utilized on HEL weapon systems such as a hot spot tracker. There is a question as to whether or not such a subsystem would even be required for a CPBW system. The AFAL has recently concluded a successful study on countering HEL hot spot tracking systems (Reference 10). In all cases covering this effort, the beam of the HEL device was allowed to hit the target. An examination of the CPBW system and its kill mechanisms must be made to determine if such a subsystem is required. If it turns out the the "cone of radiation" is significantly reduced from what is believed today and that it would take more than one or two pulses from the "bolt" on target to cause a kill, then countermeasure techniques against this type of subsystem should be considered further.

4. VULNERABILITIES/SUSCEPTIBILITIES OF ATMOSPHERIC PROPAGATION (U):

(U) The vulnerabilities/susceptibilities that were found to exist in the propagation of a CPB in the atmosphere are as follows:

a. (S) Atmospheric Beam Propagation: The area of beam propagation through the atmosphere is one of the more interesting, and yet difficult, technical aspects of the CPBW to understand and describe. However, it is also an area which holds promise for some "unconventional" countermeasure techniques. As described earlier in Section II.2, atmospheric propagation occurs via a technique called "hole boring." Physically, the beam would ionize the air, forming a plasma which would shield the electrostatic forces of replusion of the beam particles. As it propagates, the heating of the air causes expansion and rapid evacuation of a cylindrical core. The partial vacuum core decreases scattering and other losses. The two particles to be accelerated are either electrons or protons. Little theory is available on proton propagation; however, protons appear to have three possible advantages over electrons for weapon application: (1) less bending due to the Earth's magnetic field, (2) the potential to penetrate the atmosphere better, and (3) the prospects of enhanced nuclear damage at the target. The prospects of using countermeasures against the CPB as it propagates through the atmosphere falls into two categories: beam attenuation and beam-bending. For beam attenuation the prospects of using an aerosol, material particles or chaff to attenuate the beam does not appear feasible. The reason for this is as shown in Figure 3, where it takes 20 cm of aluminum to attenuate a 250 MEV beam, which is about one-fourth the energy of a postulated weapon beam such as Chair Heritage. The quantity of material that would have to be in the beam would be ponderous. Also, operational implementation of such a technique to protect all of a strategic weapon system just from attack from the lower hemisphere is not feasible. Another mechanism for increasing attenuation of the beam in the atmosphere would be via collapsing the tunnel that the beam is propagating down. This might be accomplished via detonation of a device near the beam path or by causing other severe atmospheric disturbances, such as by acoustical techniques. Operational deployment of such techniques do not appear to be reasonable at the present time.

(S) The second prospective countermeasure technique, that of beam-bending, may hold some promise. Note that countermeasure techniques that try to collapse the beam tunnel might also cause sufficient atmospheric disturbances to cause beam-bending. Also, if the target could employ some form of magnetic field, which would act on this beam containing charged particles, beam-bending could be accomplished. The closer to the CPBW the electromagnetic or magnetic field can intercept the beam the less would be the requirement for the degree of beam-bending. Such a system is not possible with today's state-of-the-art technology; however, this appears to be one area that needs to be

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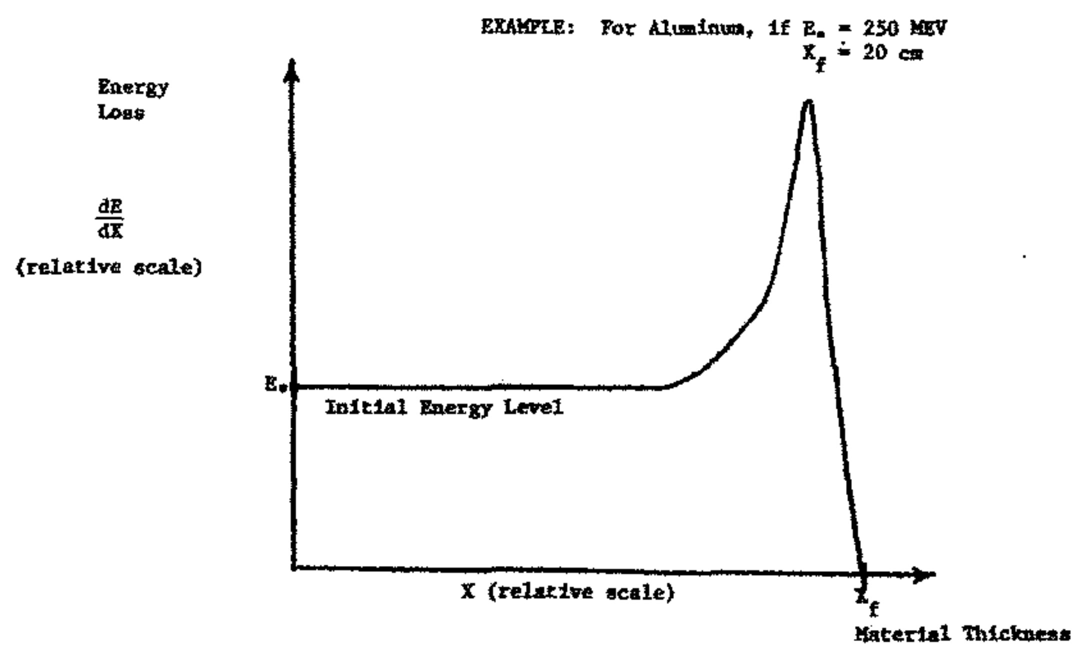

FIGURE 3. ~~(S)~~ BRAGG CURVE (U)

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thoroughly investigated in any future CPBW countermeasure programs.

b. ~~(S)~~ Secondary Radiation: If this "cone of radiation" of 1°-2° exists around the be   it will be imperative to protect the target from it as well as the beam itself. As stated earlier, it appears that tracking errors of 4°-5° or similar beam-bending effects will have to be accomplished in order to sufficiently reduce this type of radiation on the target. If these types of errors can not be obtained, then the only alternative that appears to exist for protecting the target are forms of nuclear hardening and shielding. Such techniques would have to be able to protect crew members, electronics, high explosives, fuels, etc., from radiation levels in the Kilo-to-Mega Rad level. Shielding/hardening work ought to commence in this area; however, note that these technical areas, except for hardening of electronics, do not fall within the AFAL charter but are the responsibilities of other organizations. No known method for collapsing or reducing this "cone of radiation" is known to exist; however, this may be an area for future investigation.

5. VULNERABILITY/SUSCEPTIBILITY OF THE CPB/TARGET INTERACTION (U):

(U) The vulnerabilities/susceptibilities found to exist in the area of the interaction between the CPB and target are as follows:

a. ~~(S)~~ Target Material: As shown in Figure 3, conventional materials such as aluminum (which requires a 20 cm thickness to attenuate a 250 MEV beam) do not appear to be usable or practical for material hardening. This is not to say that new materials and/or composites could not be developed that might meet the requirements of this mission. Other organizations that have expertise in materials and material hardening should examine such approaches. As stated in Section III.4.b, these materials should be effective against the "cone of radiation" as well as the beam itself.

b. ~~(S)~~ Electronic Protection: As shown in Table 2, electronics can be hardened against nuclear effects and such work should continue. Extra shielding/hardening will be required for avionic systems subjected to this new type of threat. Target skin hardening will help to reduce the total requirement for hardening of the electronics. Hardening levels must be established and electronic hardening techniques investigated.

c. ~~(S)~~ Crew Protection: Also as stated earlier, crew members of penetrating aircraft that encounter CPBW systems will probably be subjected to X-ray and gamma-ray radiation doses in the "Kilo" to "Mega" Rad level. This will probably be true whether the CPB hits the aircraft or has a near miss, because of the "cone of radiation." Depending on when in the mission the aircraft is attacked by a CPBW will determine the maximum dose rate crew members could be subjected to and still function well enough and long enough to complete their mission. Radiations in the hundreds of rads will probably be enough to incapacitate most crew members. Even at about 80 rads the blood pressure is sufficiently lowered that a G-load greater than one G will probably cause blackout. Certainly, investigation must be accomplished to provide protection for the crew of strategic weapon systems that will encounter CPBW system, since the crew appears to be the softest subsystem of the strategic weapon system against the aspect of the CPBW.

6. OTHER CONSIDERATIONS (U):

a. ~~(S)~~ Threat Warning: There is one other extremely important area that has not been addressed in the above discussion because it really does not fall under vulnerabilities/susceptibilities of the CPBW system, but is critical when considering countermeasures to a weapon system. That area is threat warning. The most obvious use of a warning receiver would be to use it for threat avoidance. If the penetrator can "fly around" the threat CPBW system, mission survivabilities is certainly increased significantly; however, there probably will be circumstances which, for one reason or another, the penetrator will not be able to avoid the threat. In this case a threat warning receiver, by alerting the crew or interfacing with a countermeasure activation control system, could make the difference between a successful or unsuccessful engagement. There are several potential techniques that a warning receiver might use for threat detection. In the 1971-73 time period, the AFAL conducted an investigation (Reference 1) to determine if a laser would give off precursor energy prior to the beam actually being fired. Such precursor energy was found to exist in a Nd:YAG laser. It is contemplated that such precursor energy may also be leaked out of a CPBW device prior to the beam firing because of the large quantities of energy stored in the system just prior to switching. EMI in the area of a weapon will probably be detectable. Detection of secondary radiation certainly seems plausible. Acousitical or optical detection of the beam itself is probably a viable approach. Any number of approaches probably exist for the detection and direction finding of CPBW systems that may pose a threat to a penetrator. Near-term future countermeasure efforts should include an investigation as to what the requirements of a threat warning receiver should be. Follow-on efforts should theu consider techniques for warning receivers and experiments to verify such techniques.

b. ~~(S)~~ Countermeasure Considerations: Prior to providing the recommendations and conclusions, a set of ground rules for prospective future CPBW countermeasure efforts should be put forth. The following are some technical items of consideration that should be kept in mind when conducting countermeasure efforts against this new threat:

(1) ~~(S)~~ Commonality: One of the most critical factors is to exploit the commonalities that exist between different prospective CPBW systems. This will ensure that one countermeasure system can be utilized against a variety of CPBW systems. In early countermeasure efforts, only generic CPBW configurations can be used.

(2) ~~(S)~~ Scenario: A surface-to-air CPBW threat will be considered the primary threat for first generation particle beam weapons. Second and third generation threats may include airborne systems. Countermeasures that can counter both kinds of threats should be given precedence over those that can only counter the ground threat.

(3) ~~(S)~~ Target Maneuvers: Where threat avoidance can be accomplished it will be used; however, times will exist when the penetrator will not be able to perform radical or drastic maneuvers and will have to penetrate the CPBW lethality zone (either the beam or "cone of radiation" or both) to accomplish its assigned mission. Therefore, countermeasure techniques which impose the minimum requirements for maneuvers on the penetrator should be given precedence.

(4) ~~(S)~~ CPBW Counter-Countermeasures: The Soviet Union will probably incorporate inexpensive, simple, effective counter-countermeasure fixes on first generation CPBW systems. Prospective countermeasures should be ones that are not easily negated by such first generation counter-countermeasure fixes.

(5) ~~(S)~~ Threat Detection: Threat detection and location may be required for some, if not all, countermeasure techniques. Countermeasure techniques that utilize less accuracy for target location should be given priority over those techniques that require higher accuracy for protective effectiveness.

(6) (U) General Considerations: Certainly consideration should be given to prospective countermeasures that conform to favorable costs, weight, power, drag, and reliability/maintainability parameters.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS (U)

1. CONCLUSIONS (U):

~~(S)~~ The first general conclusion arrived at under this effort is that technology will probably progress to the point that within the next 8-15 years CPBW systems could become feasible. Controversy abounds today as to when, and even if, such devices could be produced; however, there does appear to be enough evidence to favor the belief that such weapon systems will be accomplished.

~~(S)~~ Secondly, it became evident early in this study that no vulnerability/susceptibility analysis has really been done by the CPBW design organizations. This really did not come as a surprise since the emphasis, and rightly so, being put forth in the US by the appropriate organizations working on CPBW systems has been in the area of proving the theory of beam propagation, accelerator concepts, power generation techniques, etc. Certainly one cannot worry about counter-countermeasure employment until the weapon is designed and shown to be feasible in the first place.

~~(S)~~ The third general conclusion reached is that few vulnerabilities exist in this potent weapon system and that developing effective countermeasures will be difficult. Unconventional countermeasure thinking will have to be applied towards solving this problem.

~~(S)~~ Specific conclusion as to the vulnerabilities of the total CPBW system are shown in Table 3. It appears countermeasures will have to attack primarily the fire control system or cause beam-bending. The majority of the other areas do not show much promise as to their vulnerability/susceptibility to countermeasures.

2. RECOMMENDATIONS (U):

(U) The following recommendations are put forth for any near-term

(S) TABLE 3. CONCLUSIONS (U)

CPBW SUBSYSTEM	VULNERABILITY
CPB Device	None, accelerators do not work in reverse.
Pointing and Tracking Mechanism	None, extremely high electromagnetic energies would be required to get into electromagnetic optics.
Fire Control System	Yes, but need errors of 4°-5° to keep "cone of radiation" off of target.
Propagation	Maybe, probably cannot attenuate beam; beam-bending may be possible.
Target Interaction	No, quantities of conventional material to attenuate beam are too great (i.e., 20 cm of aluminum to attenuate 250 MEV beam).

CPBW countermeasure programs as a result of this small in-house analysis effort:

a. (U) That a "free spirit, blue sky" type of thinking be applied when considering prospective countermeasures which could negate a CPBW system. Do not limit prospective countermeasure techniques to those considered as "conventional" types.

b. ~~(S)~~ That emphasis should be placed on countermeasure techniques which attack the fire control subsystem. Pointing and tracking errors of at least 4°-5° should be obtained.

c. ~~(S)~~ That some further investigation should be put forth in the area of degrading the propagation of the beam through the atmosphere. The emphasis in this area should mostly be put toward bending of the beam.

d. (U) That, since this analysis was conducted under a limited amount of manpower and time, as the threat becomes better defined in the out years, this analysis should be redone, as required, to keep abreast with CPBW configurations.

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