RECORD

Scientific Adversary Procedure:
The Technical Aspects of
the Strategic Defense Initiative

Scientist Advocates:

Richard Garwin

Edward Gerry

Dartmouth College

May 24, 1985

GERRY -- GARWIN
SCIENTIFIC ADVERSARY PROCEDURE
MAY 23-24, 1985

To press 6 June 1985

SCIENTIFIC ADVERSARY PROCEDURE

STRATEGIC DEFENSE INITIATIVE:
WILL IT WORK?

MAY 23-24

Thursday, May 23

5:30PM Dinner for Participants (Faculty Club)

7:00PM Definition of Accepted and Challenged Propositions
(Ruebhausen Room, Rockefeller Center)

Scientist Advocates:
Edward Gerry, President, W. J. Schafer Associates
Richard Garwin, IBM Fellow

Friday, May 24

8:00AM Definition of Accepted and Challenged Propositions
(continued from the previous evening)

1:00PM Treatment of the Challenged Propositions
(Cook Auditorium)

Introduction and Welcome:
Agnar Pytte, Provost of Dartmouth College

The Concept of Scientific Adversary Procedures:
Prof. Roger Masters, Department of Government

Introduction of the Scientist Advocates:
Prof. Arthur Kantrowitz, Thayer School of Engineering

Scientist Advocates:
Edward Gerry and Richard Garwin

Reviewers:
Prof. Bengt U. O. Sonnerup, Department of Engineering
Prof. Walter Stockmayer, Department of Chemistry
Prof. John Strohbehn, Department of Engineering

Procedure Analysts:
Prof. Allan Mazur, Syracuse University
Ambassador Robert Barry, Dickey Fellow

Garwin's Goal:

The goal of continued avoidance of nuclear war is better achieved within the ABM treaty (which prohibits significant defense against strategic ballistic missiles) and does not require ever-increasing forces. It could be accomplished stably with 2000 warheads on each side if:

--both sides abandon the goal of destroying the strategic retaliatory force of the other side, and

--as is the purpose of the ABM Treaty, both sides abandon defense against the strategic retaliatory force of the other side.

Statement:

The question of countermeasure effectiveness will not be further debated here because

Garwin's Statement:

There has been no study within the government as to <u>whether</u> the US should pursue the research toward the goal expressed in the President's speech -- to "replace deterrence by threat of retaliation" by means that are defensive; to "render nuclear weapons impotent and obsolete." (GARWIN)

<u>Gerry's Statement:</u>

The goal of the SDI program is to determine whether it is feasible to improve the security of the US and its allies, while reducing the number and power of offensive nuclear weapons via a transition to defensive systems as the primary basis for continued deterrence of nuclear war. (GERRY)

Gerry feels that official secrecy precludes his participation. Further, Garwin states that countermeasures will defeat high performance systems while Gerry believes that solutions can be developed.

AGREED PROPOSITIONS

1. No system has been publicly presented which satisfies the twin requirements of the administration as presented by Paul Nitze 02/20/85 -- to be survivable, and to be cost effective. (AGREED)

2. No viable defensive system can allow space mines to be placed within lethal range of space assets. (AGREED)

3. The utility of pop-up for boost phase intercept can be negated by fast-burn boosters. (AGREED)

4. If rail guns are to be used for ballistic missile defense, they must propel homing kill vehicles. (AGREED)

5. Energy efficiency considerations favor chemically propelled homing kill vehicles over rail guns up to an added velocity given by the following equation:

ΔV WHERE CHEMICAL PROPULSION EFFICIENCY EQUALS RAIL GUN EFFICIENCY GIVEN BY SOLUTION OF FOLLOWING EQUATION

$$\Delta V = (I_{sp} g)\left[\lambda_p \eta_{ELEC} \eta_{RG} \left\{\left(\frac{\lambda_p e^{\frac{\Delta V}{N I_{sp} g}}}{1-(1-\lambda_p) e^{\frac{\Delta V}{N I_{sp} g}}}\right)^N - 1\right\}\right]^{1/2}$$

I_{sp} = SPECIFIC IMPULSE (SECONDS)
g = ACCEL OF GRAVITY
λ_p = STAGE MASS FRACTION (fuel and payload)
N = NUMBER OF STAGES (ΔV/STAGE = $\frac{\Delta V}{N}$)
ΔV = TOTAL VELOCITY INCREMENT

η_{ELEC} = EFF FOR CONVERSION OF CHEMICAL ENERGY TO ELECTRICITY
η_{RG} = RAIL GUN EFF (ELEC → KINETIC

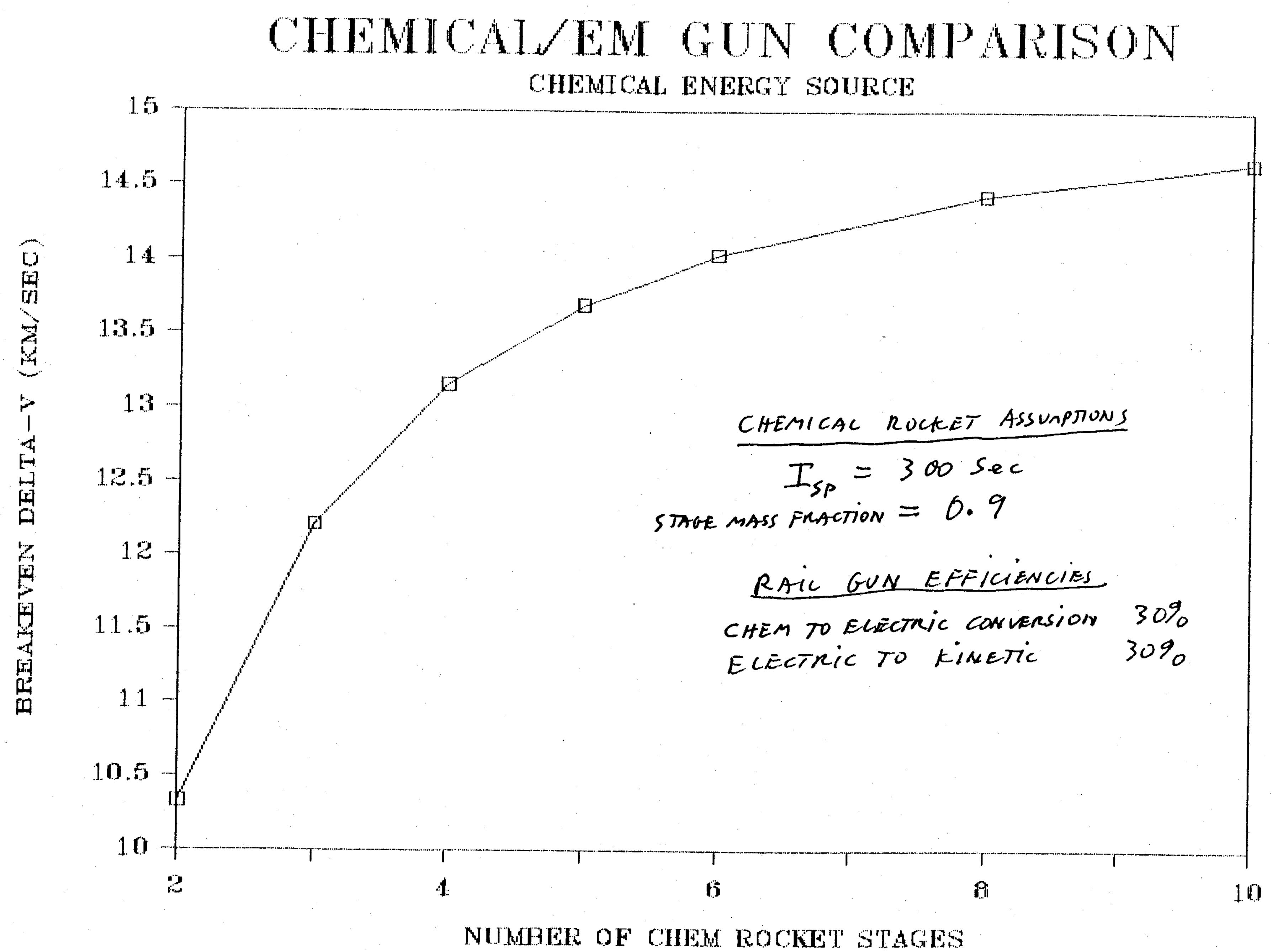
Under assumptions of an electrical generation efficiency of 30%, rail gun efficiency of 30%, chemical rocket specific impulse of 300 seconds and stage-mass fraction of 90%, and reasonable number of stages, this velocity is approximately 14km/sec. (see following table and calculations) (AGREED)

ISP (SEC)	ISP	300	RAIL GUN EFF	ETAG	0.3
STAGE MASS FRAC.	F	0.9	ELEC CONV EFF	ETAE	0.3
DELTA - V (KM/SEC)	V	14.03			
GRAVITY (KM/SEC)	G	0.0098			
STAGE VEL FACTOR	SVF	0.8			
NUMBER OF STAGES	N	6			

NO STAGES	MASS RATIO	FUEL MASS	CHEM EFF	ELEC EFF
6	282.1482	253.0334	9.00%	9.00%

PLOT — ITERATION SOLUTION

DELTAV1	N	EXP	DELTAV2	FACTOR	DELTAV3
10.327	2	5.790927	0.836738	12.34193	10.327
12.211	3	3.992697	0.836738	14.59577	12.213
13.155	4	3.060635	0.836738	15.72505	13.158
13.691	5	2.537959	0.836738	16.36306	13.692
14.030	6	2.215219	0.836738	16.76747	14.030
14.430	8	1.846921	0.836738	17.24841	14.432
14.654	10	1.646143	0.836738	17.51497	14.655
15.194	30	1.187995	0.836738	18.15860	15.194
15.363	100	1.053644	0.836738	18.36030	15.363
15.425	1000	1.005260	0.836738	18.43330	15.424


CHEMICAL/EM GUN COMPARISON
CHEMICAL ENERGY SOURCE
BREAKEVEN DELTA-V (KM/SEC)
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
2
4
6
8
10
NUMBER OF CHEM ROCKET STAGES
CHEMICAL ROCKET ASSUMPTIONS
I_{sp} = 300 Sec
STAGE MASS FRACTION = 0.9
RAIL GUN EFFICIENCIES
CHEM TO ELECTRIC CONVERSION 30%
ELECTRIC TO KINETIC 30%

6. Close-spaced decoys multiply greatly the number of HKVs needed for mid-course intercept unless they can be discriminated and designated. (AGREED)

7. Space-based kinetic energy weapons are fundamentally limited in effective range by their velocity and the time available for flyout to the target after launch. (AGREED but trivial)

8. In the context of an effective surveillance, acquisition, tracking, and designating system, HKVs would be effective in boost phase against the current class and deployment of Soviet ICBMs and SLBMs, and would have continuing effectiveness against re-entry vehicles in mid-course, and in defense of

space-based assets, providing the space-based systems can survive, and Soviet countermeasures aren't effective. (Gerry believes that the system can survive and be effective against countermeasures, Garwin dissents.)

9. In the continuing context of deterrence of nuclear war by threat of retaliation, technologies already exist to solve the problem of strategic force vulnerability sooner and at lower cost than via layered defense with space components. (AGREED)

10. Within the context of continuing deterrence of nuclear war by threat of retaliation, existing technology involving nuclear intercepts in space could be employed to handle a few rogue-nation ICBMs. A

cooperative system could handle accidental launch of one or a few Soviet ICBMs. (AGREED)

11. Equation 13 of "How Many Orbiting Lasers for Boost Phase Intercept?" (Garwin) provides a good estimate of the number of laser battle stations of a given brightness and retarget time to counter a prescribed threat. The following table provides results of this calculation for various assumptions. (AGREED)

NUMBER OF BOOSTERS	BOOSTER HARDNESS (KJ/CM^2)	BOOSTER BURN TIME (SEC)	LASER BRIGHTNESS Watts/Sterrad	NUMBER OF SATELLITES RETARGET TIME 0.1 SEC	1.0 SEC
1400	20	200	2.69E+20	94	146
1400	20	100	2.69E+20	188	291
1400	20	40	2.69E+20	470	728
3000	20	100	2.69E+20	403	624
3000	20	60	2.69E+20	672	1039
3000	20	40	2.69E+20	1008	1559
1400	20	100	2.69E+21	29	54
1400	20	40	2.69E+21	73	135
3000	20	100	2.69E+21	63	116
3000	20	40	2.69E+21	156	290

12. There is no known fundamental limit to laser power or brightness that can be achieved other than cost. (AGREED)

Disputed Propositions:

1/ Boosters have a very large infrared radiation which cannot be decoyed in a cost-effective way. (Gerry)

2/ A gradual reduction of the probability of war can lead to a finite hazard of nuclear war to eternity. E.g. if there is 1% probability of deterrence failing this year, 1% x a next year; 1% x a^2 the year after:

with a=0.8

1% of 0.8% 0.64% 0.51% ....

Sum (n=1 to infinity) of Pn = Po/(1-a)

which becomes 5% to all time.

13. Countermeasures are a fundamental problem to the success of a high-performance strategic defense. (AGREED)

14. The SDI program is exploring possible solutions to all of the countermeasures issues which have been raised publicly and more. (AGREED)

15. So long as the Soviets can reliably deliver by <u>any</u> means (e.g., aircraft, cruise missiles, suitcase bombs) numbers of nuclear weapons causing catastrophic national damage, capability for nuclear retaliation against the Soviets will still be required for deterrence. (AGREED)

Garwin's comment: The President's SDI-speech goal of eliminating offensive nuclear weapons will not then have been achieved.

SCIENTIFIC ADVERSARY PROCEDURES:

An Experimental Approach to Provide Scientific Information for Policy Makers

Jonathan Brownell

Adjunct Professor of Policy Studies

Arthur Kantrowitz

Professor of Engineering

Roger D. Masters

Professor of Government

Douglas Yates

Chair, Policy Studies Program

Dartmouth College

Spring 1985

DEVELOPMENTAL PROGRAM FOR SCIENTIFIC ADVERSARY PROCEDURES: SPRING 1985

ORGANIZATION

These procedures constitute an initial step at Dartmouth in the development of improved communication between the scientific community and the making of public policy. They will be conducted in connection with an advanced graduate Engineering course (ENG 200 Kantrowitz) and a senior level Policy Studies course (P.S. 50, Yates and Brownell). We plan three procedures dealing with various aspects of President Reagan's Strategic Defense Initiative. This issue was chosen as a striking example of policy making in the presence of vigorous controversy in the scientific community. We have invited three pairs of scientists prominent in the public debates to spend a day at Dartmouth carrying out the procedures outlined below.

These procedures are supported by grants from the Rockefeller Center Program Fund and the Mellon Grant to Dartmouth College. This program will be managed by a Faculty committee consisting of Jonathan Brownell, Arthur Kantrowitz, Roger Masters, and Douglas Yates.

PROCEDURES

We will structure these sessions around specific scientific statements (propostions) e.g. how fast can a mirror be slewed? or: Can a booster be profitably decoyed? These will be statements of great importance to the feasibility

These will be statements of great importance to the feasibility of SDI, accept- able to one of the scientist-advocates but which might be questioned by his adversary. We will search for informative propositions in 3 or more ways.

1. Groups of students in Eng 200 will be assigned to study the published statements of each participant and to identify those scientific and technical propositions that are essential to his argument. The list of propositions concerning each participant's position will then be sent to him; any propostion he refuses to defend will be deleted and any additional statements he wishes to add will be added.

2. After each scientist-advocate has approved the list based on his writings, it will be sent to his opponent and to other participants.

3. The scientist-advocates will be encouraged to offer statements which they are prepared to defend publicly in response to propositions offered by their adversary. Again, A might choose to suggest modifications or limitations to B's proposition so to approach a mutually acceptable proposition. Alternatively it might be more informative to exhibit differences which would then be treated in an evening adversary session.

Propositions selected in these ways will be exchanged between the scientist-advocates to establish areas of agreement and areas of disagreement. During morning and afternoon sessions of each procedure, with the faculty committee and members of the participating classes present, an attempt will be made to widen the areas of agreement.

A list of agreed propositions will be prepared and made public at the evening session. An effort will be made to phrase these propositions so that they can be understood by as large an audience as possible.

It is anticipated that areas of essential disagreement will remain. During the daytime sessions we will also make another attempt to sharpen these areas of disagreement. We will seek two of the most important of these "challenged propositions", one advanced by each side, to be dealt with in a public adversary session in the evening at Rockefeller Center. In phrasing these challenged propositions an effort will be made to avoid areas where classified information is essential.

The rules of the "adversary session" will be those those of a scientific meeting, not those of a court of law. Thus no ad hominem remarks will be tolerated. The scientist-advocates will be expected to answer each others scientific questions. Other procedural rules and details of the evening program (e.g. time to state the propositions and time for questions by adversaries and referees etc.) will be worked out during the day.

These rules will be enforced by the moderator whose role will be similar to that of the chair at a scientific meeting.

REVIEWERS

Reviewers whose function will be similar to that of peer review as practiced in scientific journals will observe and participate in the evening sessions. For this function, it is hoped to find members of the Dartmouth Engineering and Science faculty who have not taken a position on the Strategic Defense Initiative, and who are acceptable to the scientist-advocates.

After the procedures have been completed, the reviewers will be asked to write a short statement summarizing areas of agreement and disagreement. These reviewers statements will be given to the scientist-advocates for comment and will be made public. It is intended to advertise these sessions and to videotape them for a permanent record which will be distributed to the participants and will remain open to the public.

The output of the procedure will be the agreed propositions and the reviewers opinions on the challenged propositions after the evening sessions.

It is also planned to edit the videotape of the public sessions into an hour-long program on the technological issues arising from the SDI, but only with the approval of the scientist-advocates. This tape will then be made public.

ANALYSIS OF THE PROCEDURE

Two anticipated educational impacts of these procedures should be assessed. First we expect to increase the awareness of the Dartmouth community and the public of what is known and what is not known concerning Pres. Reagan's Strategic Defense Initiative. Perhaps more importantly we intend to shed some light on the nature of the current dialog between science and society. These impacts will be assessed by the professors and the students of the engineering and the policy studies courses.

We also aim at the development of Scientific Adversary Procedures to provide a more credible source of scientific information for public policy making when there is controversy or apparent controversy in the scientific community. To aid this development we will try to provide a record of the procedure which can be used to correct the weaknesses which become evident.

At the end of each procedure, an effort to obtain suggestions for improvement will be sought from all participants. A formal evaluation will be commissioned from a scholar who has studied the role of scientific and technical information in the making of public policy.

04/16/85

BACKGROUND ON SCIENTIFIC ADVERSARY PROCEDURES

Arthur Kantrowitz and Roger Masters

INTRODUCTION

It is remarkable that in recent decades, characterized by strident rhetoric in conflicts involving apparent disagreements over scientific facts, no powerful constituency for the development of improved processes have yet appeared. We have seen a proliferation of organizations who claim credibility because of who they are rather than how they proceed. Philip Handler, past president of the National Academy of Sciences, was quoted (Ref.1) as saying:

"...and if what we have to say is credible, the credibility rests on the the distinction and prestige of the members."

The Office of Technology Assessment is to be believed because it is an independent agency of the U.S. Congress. "Public interest" groups and regulatory agencies are to be believed because they exist only to protect the public interest. Industry is to be believed because of its expertise, etc.

Handler, in addressing The National Academy Bicentennial Symposium, reported the results as follows:

"But establishing truth with respect to technical controversy relevant to matters of public policy, and to do so in full public view, has proved to be a surprisingly difficult challenge to the scientific community. To our simple code must be added one more canon: When describing technological risks to the non-scientific public, the scientist must be as honest, objective, and dispassionate as he knows he must be in the more conventional, time-honored self-policing scientific endeavor. This additional canon has not always been observed. Witness the chaos that has come with challenges to the use of nuclear power in several countries. Witness, in this country, the cacophony of charge and counter-charge concerning the safety of diverse food additives, pesticides and drugs. We have learned that the scientist-advocate, on either side of such a debate, is likely to be more advocate than scientist and this has unfavorably altered the public view of both the nature of the scientific endeavor and the personal attributes of scientists. In turn, that has given yet a greater sense of urgency to the public demand for assurance that the risks attendant upon the uses of technology be appraised and minimized. And what a huge task that is!"

To begin this "huge task" the "Science Court" was proposed as an experimental means of approaching the problem of achieving higher credibility in the communication between the scientific community and the public. The credibility of its output would not depend entirely on the people involved but would lean on the credibility of a structure incorporating some of society's wisdom in dealing with controversy. To paraphrase Handler, the intention was to create a structure in which the "scientist-advocate" would be more scientist than advocate.

COMMUNICATION IN THE FACE OF CONTROVERSY

Communication between the scientific community and society is based on the myth of the "unprejudiced expert". Since real expertise requires years of commitment to a field, scientists usually have an unshakeable conviction that their discipline is beneficial to humanity.

This practice is to be contrasted with procedures in the scientific community where (ideally at least) it is what a person says, not who says it, that is important. The examination of factual scientific statements for logical consistency or for correspondence with observations of nature avoids the bankruptcy of appeals to authority, but it requires much more expertise and more time than the public and lay officials can devote to mainly scientific matters. When statements of scientific fact that are needed for making reasonable public policy are apparently disputed, it is the duty of the scientific community to provide some kind of due process for stating what is known, what the uncertainties are and what is currently unknown.

The scientific community has its traditions, which provide a kind of due process within each established discipline. What is needed is to extend the procedures normally accepted within scientific disciplines in order to provide information to the public in a way that both the policy-maker and the scientist, not to mention the average citizen, will find credible. To achieve this end, we propose the following ethical principle to be enforced by the scientific community:

ANY SCIENTIST WHO ADDRESSES THE PUBLIC OR LAY OFFICIALS ON SCIENTIFIC FACTS BEARING ON PUBLIC POLICY MATTERS SHOULD STAND READY TO PUBLICLY ANSWER QUESTIONS NOT ONLY FROM THE PUBLIC, BUT FROM EXPERT ADVERSARIES IN THE SCIENTIFIC COMMUNITY.

Over a decade ago, the science court was proposed as an experimental first step in the implementation of this ethical principle (refs. 2-4). The Scientific Adversary Procedures proposed here are a development of this idea, retaining the notion of open public cross-examination by differing scientific or technical experts, but now adapted to an academic setting. The function of the scientific adversary procedure is not to make the decision or even to recommend a decision. Its only function is to find some of the scientific facts which bear on the decision. Whereas the name "Science Court" falsely conjured images of a verdict carrying legal authority, the new name "Scientific Adversary Procedures" is designed to emphasize its role as an educational and informational process.

Reviewers, themselves with scientific or technical training -- who have been accepted by both scientist-advocates as unbiased -- will observe and participate in the public hearings. After the session, their task will be to identify the propositions for which the scientist-advocate had provided scientifically convincing evidence as well as those which have been effectively falsified. Where possible, it is hoped that the scientist-advocates will agree to stipulate those propositions which are not scientifically at issue. But in specifying the current bounds of knowledge (and their uncertainties), the reviewers would not be limited to those matters receiving the consent of the opposed experts; like the reviewers of manuscripts for scientific journals, those responsible for drafting the conclusions of a Scientific Adversary Procedure will be expected to weigh the evidence according to the best standards of scientific procedure.

To be legitimate in the eyes of the public, a procedure permitting scientific experts to question their peers about controversial issues must depend heavily on the groups who are committed on opposite sides of the policy debate. For example, a Scientific Adversary Procedure on issues related to acid rain would require some contact with groups like the Sierra Club or Nature Conservency as well as the Electric Power Research Institute. We will therefore consult with the representatives of opposed interest groups in naming Advocates. Once the public hearing phase has been completed, the publication of the findings of a Scientific Adversary Procedure would therefore have a claim to clarify public controversy without directly proposing public policies. If succesful, such a statement of scientific findings should be newsworthy in itself. But it is our hope that, if the Scientific Adversary Procedures spread, it will be possible to develop specific outlets for publishing the findings of such hearings at numerous Colleges and Universities. Hence, over the long run, one could hope that this mode of addressing scientific controversy would become institutionalized as a basic component of our educational system.

PAST EXPERIENCE WITH THE SCIENCE COURT

The "science court" described here was formulated in 1976 by a task force of a committee advisory to President Ford (Ref. 2). It was suggested by the Task Force that a public meeting be held where opinions pro and con the Science Court Experiment could be aired. This meeting was held 19-21 September 1976 in Leesburg,Virginia, sponsored by the U.S. Department of Commerce, The National Science Foundation and the American Association for the Advancement of Science. At this meeting the Task Force position was set forth by Richard Simpson, former Chairman of the U.S. Consumer Products Safety Commission, and anthropologist Margaret Mead agreed to present what was intended to be an opposition view. It turned out that by the time she got to the meeting Dr. Mead's views were certainly not opposed to the notion and in her typical colorful manner she expressed the need for a new institution.

"We need a new institution. There isn't any doubt about that. The institutions we have are totally unsatisfactory. In many cases they are not only unsatisfactory, they involve a prostitution of science and a prostitution of the decision making process."

Margaret Mead's misgivings about the science court were consistent with an observation she made about social innovation generally - that eventually all social innovations are corrupted and she pointed out that it would be essential that the science court be carefully protected from early corruption.

The science court was supported by numerous distinguished people and a transcript of the proceedings is available from the U.S. Department of Commerce, National Technical Information Service, Washington, D.C., Document No. PB-261 305.

During the 1976 Presidential campaign development of a "Science Court" procedure was endorsed by both President Ford and candidate Carter. It has received numerous other endorsements among them the endorsement of the Committee of Scientific Society Presidents which includes twenty-eight of the leading scientific societies of the United States. During the 1980 Presidential campaign candidate Reagan promised (Ref. 3):

> "In addition, I will explore the feasibility of a 'Science Court', to help arrange public discussions of controversial scientific issues. This will help guide the public, the Congress, and the executive branch. The purpose would be public exposure, not decision making."

Despite these testimonies of support, however, the concept has never been widely adopted in practice. Perhaps part of the reason for this failure is the opposition of the scientific community to the image of political interference symbolized by the concept of a "Court" in which experts are judged. The transformation of this approach into Science Adversary Procedures, to be held in academic settings, should thus meet the major objections while preserving the essential contribution of an open dialogue between opposed experts, based on canons of scientific evidence rather that on political expediency.

The development of the Scientific Adversary Procedure to a point of general utility is a substantial undertaking and thus far only tentative beginnings in this direction have been undertaken. Several examples of such tentative beginnings have come to our attention:

1. One interesting case was called to our attention by Dr. John C. Bailar then of the National Cancer Institute in Bethesda. Bailar had been conducting a campaign to reduce the use of x-ray mass screening for detection of breast cancer. He reported that some of the relevant medical organizations had refused to consider the possibility that this procedure was doing more harm than good. He let it be known that he intended to pursue a science court procedure to bring out the facts in this matter and he reports:

"...the very possibility of a science court may have a beneficial effect on the resolution of technical disagreement."

The matter was settled, at least temporarily, and guidelines restricting the mass screening of women under 50 have been issued.

2. The claim has been made that low frequency electromagnetic fields have deleterious physiological effects on plants, animals and humans. These effects have been advanced as reasons for opposing powerful, extremely low frequency, radio transmitters and more recently long distance power transmission lines. A controversy arose in Minnesota concerning the impact of a transmission line with a group of farmers resorting to vigorous civil disobedience to prevent its construction. Minnesota Governor Perpich offered to form a "Science Court" to provide factual scientific information which might be helpful in resolving the dispute. He attempted to use the prestige of his office to persuade both the farmers and the utility companies to accept a resolution by a "Science Court" of the problems of health and safety. The farmers insisted on two alterations of the procedure, both of which were intended to politicize the process. First, they insisted that questions of need for the power line be brought up before a "Science Court" as well as health and safety issues. These questions of need obviously would make the disentangling of facts and values more difficult. Second, the farmers' representatives proposed that Governor Perpich himself should sit in judgment rather than any panel of scientists. This would again obviously politicize the determination of scientific facts and we think was properly

opposed by the Governor.

In connection with the power line dispute Professor Allan Mazur (Ref. 4) has made an attempt to:

"...promote an exchange in the dispute over possible harmful effects from the electromagnetic fields of high voltage transmission lines, using the science court mechanism..."

Specifically, in cooperation with the leading scientific advocates of the deleterious effects of electromagnetic fields, Andrew Marino and Robert Becker, he made an attempt to phrase their scientific claims in language which would be acceptable as falsifiable statements suitable for use as claims in a science court proceeding. This effort was remarkably successful.

However, Mazur's efforts to induce proponents of the power line, who did not believe in the importance of the claims of Becker and Marino, to participate were unsuccessful. Obviously he lacked the authority to require a confrontation. However, Mazur's work indicates very clearly the feasibility of the translation of highly partisan statements into clear statements of fact.

3. The third case which has been brought to our attention is an effort by the Division of Magnetic Fusion Energy of ERDA (now the Department of Energy) to evaluate a series of magnetic fusion geometries other than their two principal

directions (Tokamaks and Mirror Machines). They said that

"An adversary or science court-like procedure was used for arriving at judgments on the criteria for each concept."

They reported that the procedure was efficient and useful (Ref. 5).

These three cases provide a little added insight into what needs to be done before the development of science court-like procedures can be undertaken in earnest. The Minnesota case illustrated the need for enough authority to bring the adversaries to present and substantiate their cases in the presence of opposition as is required in the science court procedure. It became apparent that Governor Perpich was unable to bring about this confrontation. However, in the later history of the dispute, it was noted that the discussions of health and safety issues were muted and the opposition of the farmers was stated much more simply in that they did not want the power lines to cross their lands for esthetic and practical reasons.

In the breast cancer case it was clear that Dr. John Bailar as Editor in Chief of the Journal of the National Cancer Institute had sufficient authority so that his proposal to set up a science court procedure had to be taken seriously by his opponents. The result was creation of "concensus" procedures by the National Institutes of Health.

In the magnetic fusion energy case a funding agency obviously had power to require the confrontation. In the power line controversy it was perfectly clear that while authority was lacking to force a scientific confrontation the very threat of such a confrontation may have been instrumental in simplifying that dispute.

DIFFICULTIES IN APPLYING THE SCIENCE COURT TO REAL CONTROVERSIES

Experience has exhibited a number of difficulties most of which will have to be faced in any attempt to improve communication between the scientific community and the public:

1) There are an array of interests vested in the present "flexible" system including politicians and industrialists who utilize confusion about the state of scientific knowledge in defending their policies, scientists whose positions depend on their willingness to be cooperative in disregarding the norms of scientific discourse in supporting partisan policies, and institutions financially supported by doing "studies" for sponsors comfortable with their previous output.

2) Distinguished scientists who are quite prepared to answer pointed questions from their expert adversaries in scientific meetings are sometimes unwilling to publicly answer the questions of their expert adversaries when they make scientific statements relevant to public policy matters. This unwillingness was responsible for the dilution of the science court procedures begun by Bailor at the National Institutes of Health to the present "Concensus Procedures". Perhaps this

unwillingness is related to the generally low esteem for the treatment of scientific matters by the legal courts. In the Scientific Adversary Procedure it will be necessary to exhibit that ad hominem attacks will not be tolerated and that rules of procedure similar to those at a scientific meeting will be enforced.

3) Perhaps the most important difficulty in implementing the Science Court is exhibited by the frequent observation that the procedure will be welcomed by partisans who see themselves as underdogs. Partisans who see themselves winning with procedures as they are will resist the introduction of new procedures whose outcome is unpredictable. The impetus for improvement in communication between the scientific community and the public will have to come from those who are persuaded that procedural improvements are needed to manage our very powerful technology adequately.

4) It must be recognized that before the Scientific Adversary Procedure can attain its full utility a considerable development would be required. Thus it will be necessaryto develop procedures which arenot only acceptable to allparties but will be perceived asleadingto a full statement of the current knowledge. It will also be necessary to develop the profession of scientific-advocate with adequate protection for those who defend viewpoints unpopular with powerful interest groups.

THE SCIENTIFIC ADVERSARY EXPERIMENTS AT BERKELEY

During the winter quarter of 1983, Arthur Kantrowitz conducted a work-shop seminar at the Interdisciplinary Studies Center of the College of Engineering at the University of California, Berkeley. Threeexperimental" Science Courts" characterized by progressively increasing realism were conducted. The first concerned nuclear waste disposal and the last two concerned the health hazards at Love Canal. The most striking result was the demonstration that in the Berkeley community it was possible to find scientists whose public statements had been diametrically opposed and who were emotionally involved in the Love Canal issue but who nevertheless were willing to answer publicly the questions of their expert adversary and to participate in a science court procedure.

The Scientist-Advocates for the third proceeding were:

Dr. Beverly Paigen, a geneticist who is the chief scientific advisor to the Love Canal homeowners, who asserted that her results and the results of other studies "suggest" that health hazards still exist at Love Canal.

Dr. William Havender, a biochemist who has written articles on Love Canal for the American Spectator, who wrote that these researches were "unrelievedly abyssmal" and that no defensible conclusions could be drawn from this work.

Arthur Kantrowitz acted as chair and the enrolled (graduate) students acted as reviewers.

During the weeks which preceeded the public meeting, Paigen and Havender determined their areas of agreement and disagreement in the course of many long meetings. They disagreed about the significance of Paigen's surveys of birth defects and about the significance of Dr. Picciano's studies of chromosome damage. These areas were dealt with in the public cross examination session on Feb. 24, 1983. During the session seven new extensions of their areas of agreement were identified but complete agreement could not be reached. The enrolled students in the course acting as reviewers wrote opinions on the remaining disputed points.

THE SCIENTIFIC ADVERSARY PROCEDURE AND THE UNIVERSITY

It is interesting to compare the difficulties which were experienced in the many attempts to implement the "Science Court" under government auspices with the encouraging results which were obtained in the first serious attempt to conduct what we would now call Scientific Adversary Proceedings in a university setting. Taking the points enumerated under " DIFFICULTIES..." one by one, we can see that in the university setting:

1) The interests vested in the status quo in the science/politics apparatus were not engaged and in any case were not in a good position to interfere.

2) The participants could expect that they would not be subjected to ad hominem attacks.

3) In the academic environment even politicized scientists who see themselves as "winning" with current procedures will feel some need to exhibit a willingness to publicly answer the scientific questions of their expert adversaries.

4) The facts that Scientific Adversary Procedures need further development and thatdevelopment of the profession of responsible scientific advocacy is needed are not handicaps in the university setting, they present important opportunities.

It is imperative that the actual conduct of the Scientific Adversary Procedures be insulated from politicization insofar as this is possible. It isto be expected,of course, that the opposed scientist-advocates will have political views as well as scientific or technical positions. But the PROCESS in which the exchange of views is presented need not be itself a political one. To this end, it is important that Scientific Adversary Procedures take place under "private" auspices, if possible away from Washington. With hindsight it is clear that conducting the procedure in a university setting would be much more successful.

For the university, Scientific Adversary Procedures provide the following educational and research opportunities:

A. To educate the university community in the vital relationship between expertise and the making of public policy.

B. To pioneer in improving that relationship.

C. To inform the university community and the public on the scientific information available, its uncertainties and areas of ignorance in specific controversies.

Perhaps the most important contribution of the Scientific Adversary Procedures will be to exhibit once again how little we know and how frequently we, no less than past generations,

> "Make words (our) safeguard, so that (we) ascend
> to certainty's high temple in the end."
> (Mephistopheles in Goethe's Faust)

REFERENCES

1. Interview, EPRI Journal, April 1980, pg. 33

2. "The Science Court Experiment: An Interim Report," SCIENCE. 193 (August 20, 1976): pp. 653-656.

3. "Presidential Candidates Answer Science Policy Questions," PHYSICS TODAY (October 1980): p. 50.

4. A. Mazur, A. Marino, and R. Becker, "Airing Technical Disputes: A Case Study," presented at the Annual Meeting of the AAAS, Washington, DC, February 13, 1977. Also Washington, DC: Communication Press, 1981.

5. "An Evaluation of Alternate Magnetic Fusion Concepts," Division of Magnetic Fusion Energy, ERDA, 1977.

Brief Biography of Richard L. Garwin
August 29, 1983

Richard L. Garwin was born in Cleveland, Ohio, in 1928. He received the B.S. in Physics from Case Institute of Technology, Cleveland, in 1947, and the Ph.D. in Physics from the University of Chicago in 1949.

After three years on the faculty of the University of Chicago, he joined IBM Corporation in 1952, and is at present IBM Fellow at the Thomas J. Watson Research Center, Yorktown Heights, New York; Adjunct Research Fellow in the Kennedy School of Government, Harvard University; Andrew D. White Professor-at-Large, Cornell University; and Adjunct Professor of Physics at Columbia University. In addition, he is a consultant to the U.S. government on matters of military technology, arms control, etc. He has been Director of the IBM Watson Laboratory, Director of Applied Research at the IBM Thomas J. Watson Research Center, and a member of the IBM Corporate Technical Committee. He has also been Professor of Public Policy in the Kennedy School of Government, Harvard University.

He has made contributions in the design of nuclear weapons, in instruments and electronics for research in nuclear and low-temperature physics, in the establishment of the nonconservation of parity and the demonstration of some of its striking consequences, in computer elements and systems including superconducting devices, in communication systems, in the behavior of solid helium, in the detection of gravitational radiation, and in military technology. He has published about 100 papers and been granted 27 U.S. patents. He has testified to many Congressional committees on matters involving national security, transportation, energy policy and technology, and the like. He is coauthor of the books Nuclear Weapons and World Politics (1977), Nuclear Power Issues and Choices (1977), Energy: The Next Twenty Years (1979), and Science Advice to the President (1980).

He was a member of the President's Science Advisory Committee 1962-65 and 1969-72, and of the Defense Science Board 1966-69. He is a Fellow of the American Physical Society and of the American Academy of Arts and Sciences; and a member of the National Academy of Sciences, the Institute of Medicine, the National Academy of Engineering, the Council on Foreign Relations, and the American Philosophical Society. The citation accompanying his 1978 election to the U.S. National Academy of Engineering reads "Contributions applying the latest scientific discoveries to innovative practical engineering applications contributing to national security and economic growth." He was awarded the 1983 Wright Prize for interdisciplinary scientific achievement.

DR. EDWARD T. GERRY

EXPERIENCE

Since 1975 Dr. Gerry has served as President of W. J. Schafer Associates, Inc., responsible for the overall operational management and development of the company. He has been deeply involved in all aspects of the DoD high energy laser program since its inception in the mid-sixties. In addition, he has extensive experience in optical systems design, inertial confinement fusion, and chemical kinetics.

Dr. Gerry has continued to participate directly in the technical activities associated with WJSA contracts. His most recent technical involvement has been in the areas of free electron lasers, inertial confinement fusion, and advanced methods of isotope separation. In addition, he has actively participated in or chaired several national level review panels.

During the summer of 1983 Dr. Gerry served as chairman, Boost Phase System Concepts, for the Defensive Technologies Study Team (DTST) which, under the chairmanship of Dr. James Fletcher, developed technology and system options for multitier ballistic missile defense in response to President Reagans March 23, 1983 initiative.

Before joining WJSA, Dr. Gerry served in the Strategic Technology Office of the Defense Advanced Research Projects Agency (DARPA) where, as Assistant Director for Technology he was responsible for DARPA's activities in space object surveillance and identification, advanced space-based surveillance optics and sensors, and high energy laser technology. Earlier, as Chief of the Laser Technology Division, he was responsible for the technical management and programming of DARPA's research and exploratory development activities in high power laser devices, materials and components, and the evaluation of laser systems application concepts.

Prior to joining DARPA, Dr. Gerry served in several positions at the AVCO Everett Research Laboratory beginning in 1959. His early activities were in the field of plasma physics and dynamics. Later he played a major role in initiating the High Energy Laser Program and became its Director in 1965.

EDUCATION

Ph.D. - Nuclear Engineering, M.I.T. - 1965
M.S. - Engineering Physics, Cornell University - 1962
B.S. - Physics, William and Mary - 1959

Richard L. Garwin
IBM Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598
(914) 945-2555

January 18, 1985

Professor Arthur Kantrowitz
Thayer School
Dartmouth College
Hanover, NH 03755

Dear Arthur,

Thanks for the telephone call 01/18/85 regarding my coming to Dartmouth and talking in the afternoon and evening to a group of graduate students and perhaps a broader audience about some of the technical aspects of the Strategic Defense Initiative.. As you know, I favor doing such things, but it has to have some impact. There are lots of small groups all over the country which would like me (and Canavan or Gerry) to visit them so that they can be informed. Your idea of having a videotape is a good one, and I think it should be an unedited videotape. It won't be very polished, but then at least we will be responsible for what we say. So I favor this in principle.

I am glad that you have read The Fallacy of Star Wars, which takes a middle ground in presenting this material to people with some interest but who are not specialists. Enclosed is a recent minor technical contribution, in which I calculate how many laser-bearing satellites are required for what seems to me to be the most realistic case-- that in which the Soviet Union would respond to such a capable defense by deploying a rather large number of small missiles within a region the size of the state of Ohio. The last line in the Table shows that even with rather aggressive states in the ability of mankind to slew satellites, every two such small missiles deployed would provoke the deployment of one laser satellite, with the satellite in optimum orbit as to inclination and altitude.

Since I have leaving for an airplane, I just attach without comment a number of other items of interest to you.

Finally, in case you don't remember it word for word, I enclose the 1968 paper on ABM that Hans Bethe and I published in Scientific American.

So you will call me after I return. Thank you.

Sincerely yours,

Richard L. Garwin
Forwarded in his absence

Encl:
12/30/84 "Missile-killing Potential of Satellite Constellations," Draft3 for Correction. (123084MPSC)
01/03/85 Letter written with H.A. Bethe, K. Gottfried, H.W. Kendall, C. Sagan, and V.F. Weisskopf to the Editor of Commentary Magazine rebutting Robert Jastrow's of 12/00/84. (010385.ECM)
12/00/84 "The War Against 'Star Wars,' by Robert Jastrow in Commentary. (120084..RJ)
01/02/85 Published Letter to the Editor of the Wall Street Journal, with H.A. Bethe, K. Gottfried, H.W. Kendall, C. Sagan and V. Weisskopf, entitled "'Star Wars' Seen as Unworkable and Dangerous," in response to "Politicized Science," editorial of 12/10/84. (010285EWSJ)
12/10/84 "Politicized Science," editorial from the Wall Street Journal. (121084.WSJ)
10/12/84 "Star Wars-- Shield or Threat?" a paper for the Second International Scientific Congress: "Earth and Space: How to Defend Them," Rome, ITALY. (101284SWST)
04/24/84 "The President's Strategic Defense Initiative," testimony for the Senate Armed Services Committee. (042484TEST)
04/09/84 "Verification and Limits on ASAT," written testimony for the Senate Armed Services Committee on ASATs held April 12, 1984. (040984TEST)
05/02/84 "Antisatellite Weapons" manuscript of speech presented at ELECTRO-CULTURE 1984 Annual Meeting of the IEEE Society on Social Implications of Technology. (050284..AW)
02/06/84 "ASAT Treaty Verification," presented at MIT Conference on Technical Means of Verification of Compliance with Arms-control Agreements." (020684.ATV)
03/00/68 "Anti-Ballistic-Missile Systems," Scientific American 218, 3, pp. 21-31, (with Hans A. Bethe). (030068.ABM)

RLG:rsa:018|AK:011885..AK

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April 26, 1985

Professor Arthur Kantrowitz
Thayer School
Dartmouth College
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Dear Arthur,

Thanks very much for your "Dear Richard" letter (undated) received in my office 04/24/85. I find the "Sample Propositions taken from my paper 'Star Wars: Shield or Threat?'" dull and indecisive. In some cases undecidable. I don't disagree with any of them, but I don't want to waste my time supporting them.

I would rather replace them with the following stronger propositions:

1. No system has been publicly presented by SDIPO and analyzed to satisfy the twin requirements of the administration as presented by Paul Nitze 02/20/85-- to be survivable, and to be cost effective at the margin.

2. Especially since President Reagan is committed to sharing or giving defensive technology to the Soviet Union, we must consider comparable technology on the two sides. The problem then is certainly countermeasures-- especially space mines against costly battle stations (e.g. chemical lasers). No viable solution has been proposed to the vulnerability of (e.g.) laser battle stations to small space mines accompanying them from day one, within lethal range.

3. Pop-up interceptors for boost-phase intercept become cost-ineffective against even moderately fast-burn boosters, and can do nothing against 50-second fast-burn boosters because of earth curvature. See my calculation in the Ash Carter/David Schwartz book "Ballistic Missile Defense" of January, 1984.

4. Figure 1 of "How Many Orbiting Lasers for Boost Phase Intercept?" and Equation 13 provide a good calculation of the minimum number of laser battle

stations to counter a prescribed fast-burn-booster threat, including retarget time of 3, 0.5, and 0.1 sec, for the assumed hardness and laser characteristics.

5. For homing-kill vehicles (HKV) doing mid-course intercept (MCI) or boost-phase intercept (BPI), rocket-propelled HKV dominate railguns for added velocities up to 20 km/s.

6. Close-space objects multiply greatly the number of HKVs needed for mid-course intercept.

7. Technologies already exist to solve the problem of strategic force vulnerability sooner and at lower cost than via SDI. Ditto for accidental launch of one or a few Soviet ICBMs or rouge-nation ICBMs.

8. Deterrence by threat of retaliation does <u>not</u> require ever-increasing forces. It could be accomplished stably with 2000 warheads on each side if

--one abandons the goal of destroying the strategic retaliatory force of the other side, and

--as is the purpose of the ABM Treaty, one abandons defense against the strategic retaliatory force of the other side.

9. The SDI Program Office staff have engaged in character assassination and <u>ad hominem</u> arguments, concealing unclassified information which could be used to evaluate the program.

10. The space-based system proposed by Brzezinski, Jastrow, and Kampelman in their <u>New York Times Magazine</u> article of 01/27/85 is totally vulnerable to the existing Galosh nuclear-armed BMD interceptor as described in the enclosed Letter to the editor of <u>The New York Times.</u>

Arthur, if Ed Gerry wants to maintain the negation of the propositions you've cited from "Star Wars: Shield or Threat?", I would be glad to take him on.

You might be interested also in my testimony to the Senate Appropriations Committee of 04/22/85.

At this point, I would like to have a detailed schedule of the activities at Dartmouth of 05/20-21. It is my impression that it will be mostly I and Ed Gerry talking to one another and answering brief questions from the court. Would you please give me a schedule and cast of characters?

Thank you.

Sincerely yours,

Richard L. Garwin rsa

Richard L. Garwin
Forwarded in his absence

Encl:

- 02/22/85 "How Many Orbiting Lasers for Boost-phase Intercept?" Draft 10 of 03/14/85 to be published by Nature. (022285HMOL)
- 03/07/85 Letter to the Editor of The New York Times, entitled "Shrouded Galoshes Beat 'Space Trucks'." (030785ENYT)
- 04/22/85 Testimony on the Strategic Defense Initiative for the Defense Subcommittee of the Senate Appropriation's Committee. (042285TEST)

RLG:rsa:116|AK:042685..AK

2 May, 1985

Dr. Arthur Kantrowitz
Thayer School
Dartmouth College
Hanover, NH, 03755

Dear Arthur,

Listed below are my thoughts on possible propositions for discussion between Dick Garwin and myself. I hope they are of a useful form.

1) Before the U.S. undertakes deployment of a ballistic missile defense system, it is essential that two conditions be met:

   a) The defense system functions must be sufficiently survivable so that system effectiveness can not be removed as a precursor to an attack.
   b) Enhancement of the defense system to respond to offense force proliferation must be less costly (by some appropriate measure) than proliferation of the offense.

2) The present level of technical knowledge and understanding of the phenomenology is insufficient to allow any technically trained person to provide assurances that the conditions in proposition 1 ultimately can be met. It is equally true that there is no basis for asserting that these conditions ultimately can not be met.

3) There is no fundamental limit to the laser power that can be achieved other than cost.

4) There is no fundamental limit to the brightness of a laser that can be achieved other than cost.

5) Space based components can be made harder to laser irradiation than ICBM boosters.

6) Space based kinetic energy weapons are fundamentally limited in effective range by their velocity and the time available for flyout to the target after launch. They can be effective against the current class and deployment of Soviet ICBMs and SLBMs and will be effective against re-entry vehicles in midcourse and in defense of space-based assets.

7) While the survivability of any particular space element can not be guaranteed, guaranteeing the functional survivability of the system is a matter of cost.

8) The phenomenon of "nuclear winter" could reinforce a deterrent based on defensive systems if the defense planners of both superpowers become convinced that the phenomenon is real and will occur at some finite (if uncertain) number of nuclear detonations.

9) Boosters have very large infrared signatures which can not be decoyed in a practical way.

10) In the event that deterrence failed, a robust defensive system would greatly reduce the number of civilian fatalities.

Very truly yours,

Ed Gerry

Edward T. Gerry

April 22, 1985

Professor Arthur Kantrowitz
Thayer School of Engineering
Dartmouth College
Hanover, NH 03755

Dear Arthur,

I have made arrangements to fly into Lebanon about 4:30 the afternoon of Sunday, May 5, and will join you at the Faculty Club at 7:30 that evening. I will leave on Tuesday, May 7.

I have not written on S.D.I. The short biography you requested follows, and a full vitae is enclosed as a reference.

Allan Mazur is both a sociologist and a technologist. He earned a B.S. in Physics from IIT (1961), an M.S. in Engineering from UCLA (1964), and a Ph.D. in Sociology from Johns Hopkins (1969). He worked as an engineer for North American Aviation (1961-4) and Lockheed Missile and Space Corporation (1967-8). He has taught as a sociologist in the Political Science Department at MIT (1966-7), the Sociology Department at Stanford (1968-71), and is currently a professor in the Maxwell School of Syracuse University. His primary research interests are the social aspects of technology, and biosociology.

I'm glad to see that Roger Masters is involved in the project. He and I share an interest in a wholly different area--the biology of social behavior, and I look forward to knowing him better.

Regards,

[signature]

Allan Mazur

THE CONCEPT OF SCIENTIFIC ADVERSARY PROCEDURES

Professor Roger Masters
Department of Government

The problem: politicization of science and technology

Undermines sound public policy and confidence in science

<u>Science Adversary Procedures</u>: experimental contribution

Experts cross-examined by experts (not by laymen): use the model of scientific discourse (instead of politics)

What we are not doing: no pretense of recommending a policy

Feasibility independent of desireability

SDI -- feasible but undesireable

<u>not</u> feasible but desireable

What we are doing: separation of areas of technical consensus

Distinction between what science knows, what science doesn't know and what science cannot know

Placing the process in an educational setting: adversary procedures not "courts"

Roles: Presiding officer: Chair at Scientific Meeting

Reviewers: educated judgment of agreement arising from cross-examination

Scientist Advocates: Known Specialists with Policy Views

Procedure Analyst

SCADPRO2

INTRODUCTION BY MODERATOR (KZ) FOLLOWING WELCOME BY PROVOST PYTTE AND EXPLANATION OF THE CONCEPT BY ROGER MASTERS

5/24/85 COOK AUDITORIUM

THIS AFTERNOON WE WILL IMPLEMENT TWO NORMS ESSENTIAL TO DEMOCRATIC CONTROL OF TECHNOLOGY.

1. ANY SCIENTIST, WHO ADDRESSES THE PUBLIC OR LAY OFFICIALS ON SCIENTIFIC FACTS BEARING ON PUBLIC POLICY MATTERS, SHOULD STAND READY TO PUBLICLY ANSWER QUESTIONS NOT ONLY FROM THE PUBLIC BUT FROM EXPERT ADVERSARIES.

2. THERE WILL BE NO AD HOMINEM ATTACKS.

THE RULES OF THIS PROCEDURE WILL BE THOSE OF A SCIENTIFIC MEETING, NOT THOSE OF A COURT OF LAW.

OUR PRIMARY AIM WILL BE TO DEVELOP PROCEDURE WHICH, IF EXTENDED, COULD PROVIDE A MORE CREDIBLE FACTUAL BASIS FOR MAKING DECISIONS SUCH AS A DECISION ON THE GREAT TOPIC WE WILL BE DEALING WITH THIS AFTERNOON. I AM SURE THAT EVERYONE WILL UNDERSTAND THAT WHAT WE WILL DO THIS AFTERNOON, AND WHAT WE DID IN THE FIRST PROCEDURE HELD ON 5/2, WILL DEAL WITH ONLY A SMALL FRACTION

OF THE HOST OF SCIENTIFIC QUESTIONS RAISED BY REAGAN'S 3/83 SPEECH PROPOSING THAT WE SET OUT ON THE LONG ROAD FROM MUTUAL ASSURED DESTRUCTION TOWARD THE GOAL OF MAKING NUCLEAR WEAPONS "IMPOTENT AND OBSOLETE."

THE SCIENTIFIC ADVERSARY PROCEDURE AND ITS PREDECESSOR THE "SCIENCE COURT" ARE BASED ON "SCIENTIST-ADVOCATES" WHO, COMING TO THIS PROCEDURE WITH OPPOSED VIEWPOINTS, HAVE AGREED TO ABIDE BY THE NORMS SET FORTH ABOVE AND TO HELP US FIND OUT WHAT SCIENCE KNOWS AND WHAT IT DOESN'T KNOW

THE SCIENTIST ADVOCATES WE HAVE HERE THIS AFTERNOON ARE TWO OF THE MOST IMPORTANT PEOPLE IN THE DEFENSE OF THE U.S. I HAVE BEEN PRIVILEDGED TO KNOW AND TO WORK WITH EACH OF THEM FOR MORE THAN A QUARTER CENTURY. THEY ARE RENOWNED FOR THEIR CONTRIBUTIONS TO DEFENSE TECHNOLOGY, AND FOR THEIR CONTRIBUTIONS TO THE NATIONAL DEBATE WHICH HAS BEEN RAGING ON HOW BEST TO GOVERN THAT TECHNOLOGY.

RICHARD GARWIN IS AMERICAS LEADING SCIENTIFIC CRITIC OF THE DEFENSE AND ARMS CONTROL POLICY OF THE REAGAN ADMINISTRATION. TWO DECADES AGO HE LED THE SUCCESSFUL SCIENTIFIC CRUSADE AGAINST FEDERAL FUNDING OF THE SUPERSONIC TRANSPORT. HE HAS MADE MANY IMPORTANT TECHNICAL CONTRIBUTIONS TO THE TECHNOLOGY OF DEFENSE.

EDWARD GERRY WAS THE PRIME MOVER OF A SMALL GROUP OF ENTHUSIATIC YOUNG SCIENTISTS WHO FIRST DISCOVERED HOW TO MAKE HIGH ENERGY LASERS TWENTY YEARS AGO. HE WAS A MEMBER OF THE FLETCHER COMMISION APPOINTED BY THE PRESIDENT TO STUDY AND

REPORT ON THE FEASIBILITY OF THE STRATEGIC DEFENSE INITIATIVE. GERRY LED THE PANEL ON BOOST PHASE DEFENSE. HE IS PRESIDENT OF A CONSULTING FIRM WHICH IS PLAYING A LARGE ROLE IN PLANNING FOR THE SDI.

AGREED PROPOSITIONS, WITH CORRECTIONS FROM

SC1.ADVS.

DISPUTED PROP.

REVIEWERS

PROF BENGT U. O. SONNERUP, Department of Engineering

PROF. WALTER STOCKMEYER, Department fo Chemistry

PROF. JOHN STROBEHN, Department of Engineering

PROCEDURE ANALYSTS

AMBASSADOR ROBERT BARRY, Dickey Fellow

PROF. ALLAN MAZUR, Syracuse University

RESUME

BENGT ULF ÖSTEN SONNERUP
Professor of Engineering
Thayer School of Engineering
Dartmouth College
Hanover, New Hampshire 03755

Born: 7/7/31, Malmo, Sweden
Immigration Status: Swedish citizen but permanent resident of the U.S. since September, 1964

Education:
- B. Mech. Eng'g. — Chalmers Institute of Technology, Gothenburg, Sweden, 1953
- M. Aero Eng'g. — Cornell University, 1960
- Ph.D. (Aero Eng'g) — Cornell University, 1961 (Minors: Physics and Appl. Math)

Teaching: Fluid Dynamics, Electromagnetics, Distributed Systems and Fields, Applied Mathematics. Developed unified course on Distributed Systems and Fields which has been taught as part of the undergraduate Engineering Science Core Curriculum at Dartmouth since 1969 (complete lecture notes, ~800 pages, developed for this course). Developed Dartmouth Off-Campus program in Environmental Studies at Lund University, Sweden (1974).

College Committees: Executive Committee Faculty of Arts and Sciences (Sec'y one year). Committee Advisory to the President. Committee on Off-Campus Activities (Chairman). Numerous departmental committees.

Research: Magnetohydrodynamics and Plasma Physics of the Solar System

Professional Committees:
- Assoc. Editor, J. Geophys. Res. (1972-1974)
- National Academy of Sciences, Subpanel on Solar System Plasma Processes (1976-1978)
- COSPAR Subcommission on "Energy Redistribution in Planetary Magnetospheres" (1980-)
- Editor, J. Geophys. Res. (1982-1986)

Memberships:
- American Institute of Aeronautics and Astronautics
- American Geophysical Union
- American Association for the Advancement of Science

Invited Lectures: U. New Hampshire, U. Minnesota, U. Michigan, U. Texas (Dallas), U. Cal (Berkeley), Princeton U., MIT, Goddard Space Flight Center, U. Tel Aviv, Ruhr U. Bochum, Danish Space Research Inst., Various national and international conferences and workshops on space physics and astrophysics.

Current Consulting: NASA (Headquarters); Los Alamos National Laboratory

THAYER SCHOOL OF ENGINEERING

MEMORANDUM

To: Arthur Kantrowitz
From: Bengt Sonnerup
Date: May 27, 1985

Dear Arthur:

You asked me for a statement of my position on SDI. Here it is:

While I agree that there are important and difficult technical problems associated with SDI about which we would like to be as well informed as possible, I also believe that the question of whether to develop and deplay SDI has even more important dimensions in the political and social sciences and in the humanities. Indeed, these issues outside of the scientific and technological arena are in my view the dominant ones and they have led me to conclude that the proposed crash program to develop and deplay SDI is sheer lunacy. Not only will the taxpayers money be unwisely used and in many cases completely wasted but, much more importantly, I do not believe the international political situation will become more stable. This is simply another escalation of the arms race and I am ashamed that the initiative for it comes from the U.S.

On the other hand, I do believe that it is prudent for the U.S. to devote modest resources to the study of critical technical problems as well as to the study of policy implications of SDI. Such studies have been going on for many years and I have nothing against this kind of a low-level low-profile effort, or at least, I am willing to live with it.

Bengt Sonnerup

BUOS:lhg

DARTMOUTH COLLEGE HANOVER, NH 03755 603 646-2230

THAYER SCHOOL OF ENGINEERING

MEMORANDUM

To: Arthur Kantrowitz
From: Bengt Sonnerup
Date: May 27, 1985

My evaluation of the two propositions is:

1) Whether Gerry's proposition concerning cost-effective decaying of boosters is correct or not depends on what is meant by cost effective. I do not find that Gerry proved his point in a convincing way but I also do not think that Garwin disproved it. In other words, it seems clear to me that decaying of boosters is going to be difficult and fairly expensive. Whether it will be too expensive, I could not conclude from the debate.

2) This proposition, while correct within its assumptions, is unlikely to be relevant to the real-world situation. Furthermore, if a=0.9 instead of 0.8 then P_n=10% which is the same as for 10 years without reduction followed by a perfect system. And for a>0.90 the latter alternative becomes better. However, no one knows what "a" is so the argument is largely irrelevant.

Bengt Sonnerup

BUOS:lhg

May 20, 1985

Professor Arthur Kantrowitz
Thayer School

Dear Arthur:

This is the statement you requested regarding my possible participation as a referee in this coming Friday's (May 24) Scientific Adversary Session on S.D.I. with Garwin and Gerry as the debaters.

I am not an expert on weapons or arms control or lasers. I have generally taken and supported positions very close to those of the Federation of American Scientists and the Union of Concerned Scientists, to both of which organizations I belong (give or take a few careless lapses of dues). However, I consider that this does not disqualify me from acting as a fair referee in the debating sense. If you think otherwise, I am of course able to understand and step down without protest.

I will telephone you on Wednesday to be sure you have received this.

Sincerely,

Walter Stockmayer

Walter Stockmayer

P.S. A CV from Amer. Men & Women of Science is attached.

STOCKMAYER, WALTER HUGO, b Rutherford, NJ, Apr 7, 14; m 38; c 2. PHYSICAL CHEMISTRY. *Educ:* Mass. Inst. Technol, SB, 35, PhD(chem), 40; Oxford Univ, BSc, 37. *Hon Degrees:* Dr, Univ Louis Pasteur, 72; LHD Dartmouth, 83. *Prof Exp:* Instr. chem, Mass. Inst. Technol, 39-41 & Columbia Univ, 41-43; asst prof, Mass Inst Technol, 43-46, from assoc prof to prof phys chem, 46-61; Chmn Dept. 63-67 & 73-76, prof. 61-79, EMER PROF CHEM, DARTMOUTH COL, 79-*Concurrent Pos:* Consult, EI du Pont de Nemours & Co. Inc. 45-; Guggenheim fel, 54-55; trustee, Gordon Res Conf, 63-66; fel, Jesus Col, Oxford, 76. *Honors & Awards:* College Chem. Teacher Award, Mfg Chem Asn, 60; Polymer Chem Award, Am Chem Soc, 66, Peter Debye Award phyPhys Chem, 74, High Polymer Physics Prize, 75. *Mem:* Nat Acad Sci; Am Chem Soc; fel Am Acad Arts & Sci. *Res:* High polymers; applied statistical mechanics; dynamics and statistical mechanics of macromolecules. *Mailing Add:* Dept of Chem Dartmouth Col Hanover NH 03755.

Dartmouth College HANOVER · NEW HAMPSHIRE · 03755
Department of Chemistry · TELEPHONE: (603) 646-2501

29 May 1985

Professor Arthur Kantrowitz
Thayer School of Engineering
Hinman Box 8000

Dear Arthur:

Enclosed please find my (short) review of last week's Scientific Adversary Procedure. I found it truly informative in the desired technical sense, even though I find that it did not lead to a favorable "peer review."

Sincerely,

Walter H. Stockmayer
Albert W. Smith Professor
of Chemistry Emeritus

WHS/tmb

Enclosure

Review of Scientific Adversary Procedure, May 23-24, 1985:
"Strategic Defense Initiative: Will It Work?"

On purely technical questions, the two adversaries more often than not had substantially similar points of view, as is evident from the very large number of statements (no less than fifteen!) on which they reached agreement before the formal procedure was begun. Several of the fifteen statements seem especially important to this reviewer, and it seems worth repeating them here:

(1) No system has been publicly presented which satisfies the twin requirements of the administration -- survivability and cost-effectiveness.

(2) So long as the Soviets can reliably deliver by <u>any</u> means (e.g., aircraft, cruise missiles, suitcase bombs) numbers of nuclear weapons causing catastrophic national damage, capability for nuclear retaliation against the Soviets will still be required for deterrence.

The two formal propositions chosen for the public adversary procedure must, in contrast to the above, be regarded as disappointing and intrinsically incapable of firm resolution. Thus, Gerry's assertion that "rocket boosters have a very large infrared radiation which cannot be decoyed in a cost-effective way" was not accepted by Garwin, who remarked that "anti-simulation" procedures could reduce the detectable differences between boosters and decoys. Gerry, on the other hand, was constrained by official secrecy from discussing decoy countermeasures. In the ensuing discussion, there seemed to be some agreement with the notion that if decoys were too expensive they would be abandoned in favor of an equal investment in additional boosters with warheads. In either case, in the opinion of Garwin, defense is monstrously difficult and expensive.

The second proposition, by Garwin, that "a gradual reduction of the probability of war could lead to a finite hazard of nuclear war to eternity," is narrowly demonstrable with a carefully chosen (and necessarily highly imaginative) scenario. But the probability of <u>achieving</u> the "gradual reduction" was not discussed! The simple calculation presented was neither convincing in its assumed conditions (e.g., 20% annual reduction in the risk of nuclear war) nor in its probability calculus, which can be demonstrated to have been faulty, probably because the example was constructed in haste. And one is inclined to suggest that the proposition itself is not of the "hard science" type upon which the scientific adversary procedure should concentrate.

This reviewer concludes that in a formal sense neither debated proposition can receive a favorable "peer review as practiced in scientific journals," for neither one was demonstrated. Yet the whole procedure was certainly of great value to those who observed any or all of it. The whole SDI question remains a political one, and the publication of the proceeding of this session should be acclaimed by serious citizens. Drs. Garwin and Gerry performed a signal service to the Dartmouth community.

Walter H. Stockmayer
Department of Chemistry
Hinman Box 6128

WHS/tmb

THAYER SCHOOL OF ENGINEERING
DARTMOUTH COLLEGE • HANOVER • NEW HAMPSHIRE 03755

April 19, 1985

Professor Arthur Kantrowitz
HB 8000

Dear Arthur:

This is in response to your letter concerning the May 21st Scientific Adversary Procedure. Enclosed you will find a short biography. Since I have not written any papers on S.D.I., it would be helpful to me if you would send a biographical list of any books or articles that you have recommended to the students in this area so that I might become better aware of the literature in this field. I will try to attend some of the daytime sessions and the cocktails and dinner at the Faculty Club on May 20th.

Thank you for including me in this Procedure. It seems like a valuable effort and the fact that you are involving our graduate students offers them a unique opportunity.

Sincerely,

John

John W. Strohbehn

JWS:pap

THAYER SCHOOL OF ENGINEERING
DARTMOUTH COLLEGE • HANOVER • NEW HAMPSHIRE 03755

MEMORANDUM

TO: Arthur Kantrowitz

FROM: John Strohbehn JWS

SUBJECT: Review of the Strategic Defense Initiative Scientific Adversary Proceedings

DATE: June 7, 1985

In order to put these comments in perspective, I did not attend the initial sessions between Dr. Gerry and Dr. Garwin where they agreed to a set of statements which were presented at the beginning of the public session.

In my opinion, perhaps the most important part of the public session was the reading of the agreed upon statements. As an individual who is not an expert on the Strategic Defense Initiative and many of the issues pertaining thereto, I found these agreed upon statements were interesting because they spelled out more clearly what some of the issues were, some of the technologies involved, and the areas of agreement between the two scientific adversaries. From the point of view of the audience listening to the public presentation, and assuming they have not attended the previous sessions, I feel this part of the presentation could be substantially strengthened because it presents some of the most useful information to the audience.

Let me suggest consideration of the following format. First, I believe that some individual, perhaps the moderator, should briefly sketch an overview of the technology that is of interest in the debate and the issues that are under consideration. I would like to see a format tried where the agreed upon statements are presented alternatively by each of the adversaries, with some discussion of its implication and impact on the general issues. After one individual has presented their discussion, the adversary might have a chance to make a few comments before presenting the next point. My interest in this approach is a belief there may be much more information in the agreed upon statements, and their implications, and some of the issues important in coming to agreement than the actual debate over the disagreed upon statements.

Dr. Gerry defending the proposition "Boosters have a very large infrared radiation which can not be decoyed in a cost-effective way." In my opinion, this is a reasonable statement for disagreement in that I felt neither participant could conclusively convince me that the statement was either true or false. Dr. Gerry presented some reasonable evidence that it would be difficult to decoy a booster, and his arguments concerning the cost of trying to develop such a decoy certainly had merit. However, I believe that it is very difficult on a scientific basis to argue that new technology cannot be developed to accomplish an objective unless one can prove that technology would

BIOGRAPHY - John W. Strohbehn

John W. Strohbehn received the B.S., M.S., and Ph.D. degrees in electrical engineering from Stanford University, Stanford, CA, in 1958, 1959, and 1964, respectively.

He joined the faculty at the Thayer School of Engineering, Dartmouth College, Hanover, N.H. in 1963, where he presently holds a position as Sherman Fairchild Professor of Engineering and Adjunct Professor of Medicine. Presently, his research efforts are in the development and evaluation of electromagnetic devices used in the cure and control of cancer, and in image processing for echocardiography and neurosurgery. Other research efforts of his have been in the fields of radiophysics including microwave and optical propagation through the atmosphere.

Dr. Strohbehn is a Fellow of the Optical Society of America, and a member of the following associations: American Association of Physicists in Medicine, North American Hyperthermia Group, Radiation Research Society, Bioelectromagnetics Society, American Association for the Advancement of Science, Institute of Electrical and Electronics Engineers, and the URSI Commission II. He was a National Academy Exchange Scientist to the Soviet Union in 1964, and Associate Editor of the IEEE Transactions on Antennas and Propagation from 1969 to 1971, and is presently Associate Editor of the IEEE Transactions on Biomedical Engineering and is a member of the editorial board for the International Journal of Hyperthermia. He was a Visiting Research Scientist at Stanford University Medical School in 1981-1982.

violate some fundamental physical law. Dr. Gerry admitted that he knew of no such law such decoys would violate, and the trust of his argument was on the difficulty and hence relatively high cost of such an approach. History, of course, is filled with instances where science and technology has been able to accomplish objectives which at the outset looked very difficult, and hence, while a rational argument on difficulty and cost is certainly convincing, it does leave the issue open. Similarly, Dr. Garwin, when discussing this issue, did not come up with any system for producing a decoy, or hiding the boosters (for example carbon dust) that were necessarily foolproof either. Therefore I concur that this is a legitimate issue on which at this time I cannot see any complete resolution. In my opinion it would be an area like much of military defense, where there would be countermeasure, and counter-counter measures, with no final resolution.

Dr. Garwin had a proposition with which I had a great deal of difficulty. He states that a gradual reduction of the probability of war can lead to a finite hazard of nuclear war to eternity, and such an approach is better than 10 years without a reduction and a perfect system following. First of all, this is not a scientific proposition, while he does use some obvious probability theory to produce some numbers, since these numbers have nothing to do with actual probabilities concerning nuclear war, nor do I see any means by which such probabilities could be ascertained, the argument seems to be based on a set of false premises.

In my opinion, this proposition is not appropriate for the scientific adversary procedure as I understand it, and I felt it detracted from the proceedings. It was the opinion of this observer that Dr. Garwin was using this proposition to make a political statement and was not using it to clarify the technical issues that I had understood were the point of the discussion and the scientific adversary procedures.

Draft Press Release

Ambassador First Dickey Fellow at Dartmouth

At the invitation of President David McLaughlin, Ambassador Robert L. Barry will be spending the 1984-1985 academic year at Dartmouth as the first resident fellow of the John Sloane Dickey Endowment for International Understanding. Barry, who was Ambassador to Bulgaria from 1981 to 1984, has been designated a Foreign Affairs Fellow by the U.S. Department of State.

While at Dartmouth, Ambassador Barry will assist the Dickey Endowment's director, Leonard Rieser, in arranging international conferences and bringing guest speakers to Hanover. He will also be available to advise students and ~~assist~~ [illegible] in courses. His main interests are East-West relations and arms control where he will be doing some writing and may organize an informal discussion group.

Before being appointed Ambassador to Bulgaria by President Reagan, Barry was Deputy Assistant Secretary of State for Soviet and East European Affairs. He served two tours in the Soviet Union and also was stationed in Yugoslavia. In Washington he directed the Voice of America's broadcasts to the USSR and later served as Deputy Director of Soviet Affairs in the State Department. He also spent some years working on United Nations affairs with tours at the US Mission to the United Nations in New York and as Deputy Assistant Secretary of State for International Organizations.

Barry graduated summa cum laude from Dartmouth in 1956, then did graduate work at Columbia and Oxford. A member of the NROTC, he spent three years serving on Atlantic fleet destroyers.

Ambassador Barry and his wife, Peggy, live in Hanover Center. Their daughter, Ellen, has entered eighth grade at the Frances B. Richmond School. Sons John and Peter are at Amherst and Yale [illegible]

Barry's office is 203 Rockefeller Center.

May 27, 1985

To: Arthur Kantrowicz
From: Bob Barry
Subject: Scientific Adversary Procedure

Thank you for including me in the second session of the SAP. It was an excellent discussion and I learned a lot from it. But let me fulfill my goal of being critical of the procedure itself from the point of view of the policy maker.

CLASSIFICATION

Obviously ther problem of classification inhibited the discussion. What is more serious, I suggest that it will seriously inhibit the use of the technique in general, even if the policy-makers in attendance have all the necessary clearances.

The problem is that for the most part those scientists who have the necessary clearances are those who are working on a given project and therefore support it. Those who disagree with the project probably lack the clearances and cannot answer critics who claim that if they knew all there was to know, they would not oppose the program.

The more sensitive and highly classified a project is, the less likely it is that a Scientific Adversary Procedure will be useful to policy makers because of this key assymetry. As to the case in point I had great sympathy with Ed Gerry; knowing all the classified details of a program makes it very difficult to discuss on an unclassified basis. At the same time I felt we had not really discussed a very essential part of SDI; the decoy problem.

Short of declassifying science, I can think of no way of solving this problem.

ORGANIZATION

A less serious problem involved the way the sessions were set up. To me, as a "generalist" with a limited knowledge of SDI the sessions leading to the agreed propositions were by far the most illuminating. A policy maker who attended only the public session would not have understood the significance of the agreed propositions, I think. And because the public session focussed on debate of a couple of minor provisions I think it was misleading.

The trouble with building the SAP around the preliminary sessions is that policy-makers would never have time to sit through them. So the problem is to structure the second session in a more meaningful way. I think that in addition to distilling agreed propositions there should be more stress on producing meaningful statements underlining the areas where there is disagreement on issues of science.

One this has been done it seems to me that the policy-maker should play a larger role in the discussion (they will anyhow, whether you want them to or not). While a scientist ought to be co-moderator so as to try to keep the other scientists on the straight and narrow path of the scientific method, a policy-maker ought to try to guide the discussion as well to focus it on policy-relevant issues.

Science and Politics

I would estimate that about 50% of the two-day discussion covered policy, not science. Keeping Dick Garwin out of the policy side of things is clearly impossible, barring some kind of Pavlovian system of electric shocks not usually used at scientific panels. But the discussion would have done more for the image of the SAP as a new kind of policy tool if the ground rules had been better observed by the participants. I would suggest a big sign with the ten commandments of SAP or something of the kind, plus a very mean moderator. It is not that the byways which the discussion took were uninteresting, only that their frequency made the procedure too like the usual kind of debate between scientists at a Congressional hearing. Dick Garwin's bag of slides etc should be excluded from future such procedures.

Contradictory Evidence

I thought the agreed conclusions on the rail gun were among the most interesting to come out of the SAP, but that very day the NYT carried a reoprt citing General Abrahamson to the opposite effect; that is, that the biggest surpise to come out of SDI research to date was the potential of the rail gun. What is the poor policy maker to believe? Yes, the two advocates here agreed on a straightforward scientific proposition which would seem to relegate the rail gun to the technological trash heap of history. But is Abrahamson then lying?

The problem may be that Ed Gerry, as a laser man, is wedded to a laser-based solution and does not know much about new engineering developments which make rail guns useful as accelerators. In any event if I had been a real-world policy maker I would have had to convene another panel to explore this contradiction. Like political issues, I guess scientific issues are never "finally" resolved.

Conclusion

I think the SAP has real possibilities as a policy tool and a device for informing the public. Perhaps as a first step, having the acronym problem in mind, is to think of another new name for it that can be abbreviated as WISE, not SAP.

Other than this cosmetic problem, it seems to me that the major obstacle is the classification one; all the others I have alluded to here can be "fixed" by format changes and by enforcing a stronger discipline on participants.

An important consideration is the end product. What do you plan to do to follow up a meeting like this one (I mean in terms of highlighting the issues, not improving the forum.) It seems to me that this is a job for the scientific moderator and the policy advisor; that is that they should jointly draw up a report stressing the scientific and policy relevance of the conclusions of the panel, and recommend new lines of inquiry opened up by this procedure

Once again thanks for intoducing me to this concept, and good luck with its further refining.

April 22, 1985

Professor Arthur Kantrowitz
Thayer School of Engineering
Dartmouth College
Hanover, NH 03755

Dear Arthur,

I have made arrangements to fly into Lebanon about 4:30 the afternoon of Sunday, May 5, and will join you at the Faculty Club at 7:30 that evening. I will leave on Tuesday, May 7.

I have not written on S.D.I. The short biography you requested follows, and a full vitae is enclosed as a reference.

Allan Mazur is both a sociologist and a technologist. He earned a B.S. in Physics from IIT (1961), an M.S. in Engineering from UCLA (1964), and a Ph.D. in Sociology from Johns Hopkins (1969). He worked as an engineer for North American Aviation (1961-4) and Lockheed Missile and Space Corporation (1967-8). He has taught as a sociologist in the Political Science Department at MIT (1966-7), the Sociology Department at Stanford (1968-71), and is currently a professor in the Maxwell School of Syracuse University. His primary research interests are the social aspects of technology, and biosociology.

I'm glad to see that Roger Masters is involved in the project. He and I share an interest in a wholly different area--the biology of social behavior, and I look forward to knowing him better.

Regards,

Allan Mazur

Allan Carl Mazur
246 Scottholm Terrace
Syracuse, New York 13224

Current Date: January 2, 1985
Born: Chicago - March 20, 1939
Phone: (315) 445-1970

EDUCATION

Ph.D., Social Relations, Johns Hopkins University, 1969.
M.S., Engineering, UCLA, Los Angeles, 1964.
B.S., Physics, IIT, Chicago, 1961.

PROFESSIONAL EXPERIENCE

Professor (from Associate Professor) of Sociology, Syracuse University, 1971-present.
Assistant Professor of Sociology, Stanford University, 1968-71.
Operations Research Analyst, Sr., Lockheed Missile and Space Corporation, Sunnyvale, California, 1967-68.
Instructor of Political Science, MIT, 1966-67.
Research Engineer, North American Aviation, Downey, California, 1961-64.

MAJOR AREAS OF INTEREST

Sociology of technology, biosociology, research methods.

The Dynamics of Technical Controversy, Communications Press.

COMMENTS ON THE SCIENTIFIC ADVERSARY PROCEDURE INVOLVING GARWIN AND GERRY OVER "STAR WARS"

Allan Mazur
Maxwell School
Syracuse University

At the outset of this critique, I should identify my own biases, as they no doubt influenced my perceptions of the procedure and its participants. First, I have a personal stake in the formulation of an adversary procedure, having worked with Arthur Kantrowitz on this for several years, and therefore my interpretations are bound to be charitable to its possibilities. On the substantive matter of "Star Wars," I side with Garwin against it. On the purely personal level, I found Gerry the more friendly and likeable of the adversaries. The reader will want to factor these biases out of the following comments.

The Procedure consisted of two separate parts. In Part I, extending from Thursday afternoon to Friday lunch, Garwin and Gerry met with a small group of observers (including me), with Kantrowitz as mediator, and attempted to specify points of agreement and of disagreement. Part II, on Friday afternoon, was a large public presentation at which the points of agreement were announced, and two points of disagreement were debated before the audience.

To me, Part II-- the public debate-- was completely anticlimactic, after the intensity and productivity of the first part. It accomplished little of substance, which was not surprising considering that our group had to grasp at the last minute for issues that Garwin and Gerry could debate. Of these, Garwin's comparison of the likelihoods of deterrence failing under offensive versus defensive means was totally gratuitous, being nothing more than a mathematical exercise that had no basis in the real world. The debate over booster decoys had more substance but not much more. I think we could have dispensed with Part II and suffered little substantive loss.

Contrary to my own initial belief that the main value of adversary proceedings was an airing of differences, so that impartial judges can reach conclusions about which (if either) adversary is correct, I think this exercise illustrated that more of value comes from isolating (and articulating) points of agreement from points of disagreement, even if the disagreements are never aired for judgement. I now believe that it is sufficient to produce a list of points of agreement and points of disagreement. Judging from this and prior exercises, it seems that the points of disagreement are fewer than one usually expects a priori, and that they cannot often be settled anyway.

Thus, one could pretty well eliminate the whole need for judges-- and the red herring that they would be dictating Truth-- by simply dropping any attempt to have disagreements resolved.

Perhaps adversaries would be more willing to participate in such proceedings, then they have sometimes been in the past, if they did not have to face each other and be judged in public debate.

This is the most important lesson for me. If I were setting up such a procedure in the future, I would limit the goal to having adversaries-- with the help of mediators (who seem essential)-- specify lists of agreements and lists of disagreements. I would drop the whole notion of debating their differences in front of judges. Once the disagreements are specified, they could be left to be settled (or not) by other means. It is enough of a contribution to pinpoint them, in a well articulated manner.

The academic format worked well, with a few qualifications which I will discuss shortly. I especially liked the use of the Macintosh-TV display (with its excellent operator), which was great for letting the adversaries try different formulations of statements, finally settling on a version that was mutually acceptable.

It was imperative to allow a break between the initial formulation of points and a second round of agreements. Gerry especially was tired and not well prepared on the first day, and Garwin carried a lot of influence in selecting the points that would be considered, and in their wording, which was often value loaded. For example, in the comparison of rockets and rail guns, Gerry was not prepared and yet Garwin was pressing him for agreement. I was impressed by how many changes in wording were introduced the next morning, when people were rested and had some chance to think about what they had said the night before. I suspect there would have been even more changes if we had allowed more time for consideration and preparation, so I am wary about rushing the procedure. Ideally, Gerry and Garwin should come back in a couple of weeks to reconsider what they did. Certainly, the process should never be compressed into a single sitting. As a practical matter, the two sessions-- separated by a night of sleep-- offered a good compromise. Still, I would prefer a procedure which allows people to come together a few times, usually weeks apart, so that they are not rushed into judgements and have time to check their points, their data, and their calculations.

In discussions of the "science court," which is ancestor to the current Procedure, there was a strict distinction between questions of fact and questions of policy. I regard this as an important distinction worth maintaining, because technical experts are well qualified to address questions of fact but they have no special wisdom nor mandate for addressing questions of policy. It is easier to maintain this distinction when scientific facts-- in principle empirically testable-- are at issue. We had a different situation here. We were not so much concerned with facts of nature but with questions about engineering design: Can one construct a system within certain (ill specified) costs and other constraints that would accomplish certain (ill specified) goals? This is a much more slippery problem than making claims about nature as it exists. And here lies my greatest dissatisfaction with the outcome.

The list of agreed upon statements runs the range from trivial facts (#7) to substantively interesting facts, to claims about engineering feasibility to assertions of national policy. The most disturbing item to me is #2: "No viable defensive system can allow space mines to be placed within lethal range of space assets. (AGREED)" I <u>insist</u> that this is a policy statement and not a substantive factual claim. Certainly one <u>could</u> allow space mines to be placed nearby. There is no fact of nature that precludes that as an action that could be taken if, for example, the President insisted that it be taken. One could argue that it would be a <u>foolish</u> action since facts clearly show that a space asset with a mine nearby would be vulnerable to instant destruction, but in doing so one is introducing value claims about policy. It is not the special province of the technical expert to decide whether national policy is foolish or wise. (One might conceivably assert that #2 is a technical-- not a policy-- statement because of the words "viable" and "lethal". Thus, if you allowed space mines within "lethal" range than the system would <u>in fact</u> not be "viable". To make such as assertion, however, is playing word games of the worst kind. After all, in that sense the statement is a simple tautology with no substantive meaning.)

Not only is this a policy claim, it is an important one, for it implies that the deployment of an SDI requires some sort of sovereignty claims over regions of space-- a bombshell of a claim in the international community. I would have been happier with a statement like, "No cost-effective means is currently known to defend satellites from space mines." This stays out of the policy question of whether or not we can "allow" mines in space.

Statement #15 is also a policy statement. Clearly, one could maintain some kind of <u>nonnuclear</u> deterrence, whether with conventional weapons, biological agents, or by holding Gorbachev's wife hostage. Whether these are wiser than nuclear deterrence or not is beside the point. That is a policy judgement, not a technical fact.

On the positive side, I think some of the technical agreements that appear on the list are striking. I also like the clear statement that the fundamental <u>technical</u> disagreement concerns countermeasures and whether they will always defeat high performance systems. This is, I think, a great achievement for a 24-hour effort.

I do wish we could cleanse the list of trivial points like #7, and #6 and #13 seem obvious too. Perhaps Gerry and Garwin were jockeying for propaganda value here (as they were in their "goals"), thinking that these statements, while technically obvious, "sounded good" from the perspective of one or the other policy position. Statement #15 is a particularly good illustration of this jockeying for position. Garwin's insistence on the claim that "The President's SDI-speech goal of eliminating offensive weapons will not then have been achieved," was probably motivated more by Garwin's desire to debunk the President's ridiculous rhetoric than to seriously discuss technical matters. Perhaps it would be good to let each adversary preface the list with an individual policy statement of 500 words or so, and then disallow this sort of thing within the list.

In this exercise, as in others, we see adversaries come to the Procedure with agendas of their own, which may be inconsistent with the definition of the Procedure. Garwin especially wanted to depart from the ground rule of avoiding policy statements, even threatening to leave if he could not advocate a policy position. In the end, he stuck pretty much to the ground rules but was still able to insert some policy claims into the proceedings, in the guise of technical statements. In particular, as I mentioned above, he successfully injected into the output the claims that Reagan's stated goal for SDI cannot be achieved, and that space mines cannot be allowed near SDI components in space. Gerry was no match for Garwin in this regard.

Garwin dominated the proceedings. His combination of celebrity and expertise makes an impressive figure. This was apparent from the outset, at an introductory dinner at the Dartmouth Faculty Club, where he was the focus of attention and directed most of the conversation. Garwin was very influential during Part I, when he and Gerry discussed points of agreement and disagreement, especially so since Gerry appeared tired and unprepared. Garwin was able to shift or hold the agenda, apparently at will, placing most of his points on the first evening's list and shaping the wording pretty much as he wanted it. Whereas Gerry was frequently in the position of having to acquiesce to statements that he was not completely happy about, Garwin never did. In my own research I study verbal and nonverbal means of exerting social influence, so I am sensitive to such behaviors. Garwin was effective in his use of these communication techniques for asserting control (perhaps not consciously), even using intimidation a couple of times, as when he threatened to leave, or when he spoke angrily to Roger Masters without apparent provocation. He vividly illlustrated how one adversary's personality can alter the outcome, and I think it required the occasional coalescence of other participants against him to mitigate his influence. One wonders how the list of agreed upon points would look if Garwin and Gerry switched policy positions.

This leads to the inevitable question of the robustness of the result. If a similar procedure were held between two other adversaries, how similar would their list be to the one that was obtained here? It would certainly be worth trying it again, with other principals, to compare the outcomes. I am sorry that we did not videotape Part I. We could then have shown the video to other experts, checking their reactions to the discussion and seeing whether they agreed or disagreed with the points on the list, and whether they had new arguments to raise. (It might have made a good classroom exercise.) As it is, I think it will be important to publicize the list and see how other experts respond to it. Do they accept the points of agreement, or do they dispute them?

The exercise was a fascinating experience that looks-- in the short run-- like it produced a valuable list of points of agreement and disagreement. I believe it failed in its aim to treat questions of fact separately from questions of policy. We must wait to see how it plays out in the longer run-- whether the results are ignored, accepted, or refuted-- before we can say much more.

HOW MANY ORBITING LASERS FOR BOOST-PHASE INTERCEPT?

by

Richard L. Garwin

IBM Thomas J. Watson Research Center
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February 19, 1985

ABSTRACT. An elementary analysis is provided for the boost-phase intercept capability of constellations of satellites bearing powerful chemical lasers. The time T_s required for slewing to a new target is explicitly included, and results tabulated. Cases treated include a concentrated distribution of boosters as well as distributions uniform over a very large region below many satellites. For example, lasers giving 25 MW of 2.7-micron light, with perfect 10-m diameter optics (so brightness 2.69×10^{20} W/steradian), might be faced with 3000 fast-burn boosters of 20 kJ/cm^2 hardness and 40-sec engagement time based in a region of diameter 1000 km or less. Such a fleet would require some 1340 satellites in optimum 60° orbits with a retarget time of 0.5 sec, or 2260 for T_s of 3 sec. Deployed in substantial numbers in a concentrated region hundreds of kilometers in diameter, two such 40-sec boosters would counter each additional laser battle station of 0.5 sec retarget time. Existing ICBM launchers are not spread over a sufficient area for local targeting of lasers against boosters to be a sensible strategy, but even under that approximation of infinitely widespread booster density opposed by satellites of fixed brightness and retarget time, the required number of satellites is nearly proportional to the density of boosters and not to the square root of booster density as has been claimed.

President Reagan's "Strategic Defense Initiative" for countering Soviet nuclear-armed intercontinental-range ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs) puts great stress on intercept of the missiles in boost phase.[1] The feasibility of a Star Wars defense will stand or fall on the relative ease of countering the system, but it is of some interest to know how many satellites of given characteristics would be required to destroy boosters of numbers and characteristics which might be available by the time such a defense could be mounted.[2]

In this note, both for the case of boosters concentrated in a region as well as for an enormously widespread uniform distribution, we consider a constellation of satellites assumed to provide over the region of ICBM silos an areal density s (number of satellites per unit area) adequate to destroy all the ICBMs, assumed launched simultaneously and burning out in time T_o. The number S of satellites required worldwide is then obtained by multiplying s by the surface area of the earth $4\pi E^2$ and dividing by a concentration factor y which takes into account the placement of satellites on orbits of optimum inclination to provide maximum satellite density over the ICBM silos. We calculate[3] $y \le 3.1$, and use that concentration factor in our examples. Thus we multiply required satellite densities by 164 $(Mm)^2$, confident that the number of satellites required will always exceed that thus estimated.

We assume a steady or rapidly pulsed laser on each satellite, provided with an optically perfect diffraction-limited mirror of diameter D which is refocussed at the range of the booster which is the target of the moment. The laser is assumed to have a steady output power P and wavelength λ. For a uniformly illuminated output aperture of area $A = \pi D^2/4$, the

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maximum possible power density at any point in the focal spot at range r is obtained from the brightness B of the laser (power per steradian of solid angle) as $p = B/r^2$. B in turn is given precisely[4] by $B = PA/\lambda^2$. In the numerical examples,[5] we thus take $B = 2.69 \times 10^{20}$ watts per steradian. At r = 3000 km or 3 Mm, the power density is thus 30 MW/m^2, and for an assumed booster hardness[6] J = 200 MJ/m^2, the time $t(r) = Jr^2/B$ required to deliver the assumed lethal heat is 6.7 seconds. Such calculations assume that the satellites can see the boosters sufficiently clearly and can point sufficiently accurately and stably that the power density at the peak within the 1-m diameter spot (at 3-Mm range) is not diminished by spot wander of more than a few tens of cm during the 40 km or so travel of the booster during the 7 sec engagement.

As one considers countering missiles with boost times ranging from the 300 sec or so of the Soviet SS-18 to the 180 sec of the U.S. MX missile, to the 40 sec of a fast-burn ICBM, one needs more numerous satellites or satellites at closer range. Furthermore, particularly for powerful satellites or for close-range engagements, the time T_s required for the laser satellite to retarget-- to slew and settle the beam to the necessary accuracy of 0.1 microradian or better-- plays an important role in the sizing of the constellation.

Our program of calculation is first to calculate for a flat earth and a planar satellite constellation above it at altitude h, the number of missiles launched from a region which could be killed by a constellation of assumed laser characteristics and satellite density. We then extend that calculation to the more realistic case of a spherical earth, obtaining a reasonably accurate closed-form expression; the results are graphed in Fig. 1. Next we calculate the missile-killing potential of

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an assumed satellite constellation density above a uniform areal dis-tribution of boosters, for which each satellite is assigned the boosters within its circle of responsibility, graphed in Fig. 2. This would be a reasonable assignment strategy for boosters covering the entire earth at uniform density, but it was introduced[7] as justifying "square-root scaling" of satellite numbers vs. booster numbers for boosters deployed over 10 $(Mm)^2$, asserted as the deployment area of the 1400 current Soviet ICBMs. The results are tabulated in Table I and discussed for some cases of interest.

Although there seem to be no published results on laser constellation size for finite retarget time, our calculations show the great importance of this time required to move the beam from one booster to the next.

Clustered launch-- flat earth, zero retarget time.

We now turn to the problem of relating local satellite density to number of boosters to be destroyed. Assume that M_o boosters are all launched simultaneously from a point, and that a satellite constellation of local density s and brightness B, deployed at altitude h, is assigned to kill the boosters. Assume a continuous distribution of satellites and an obliquity factor of unity (the beam always normal to the booster surface). Since the time to kill a booster at distance r is Jr^2/B, a satellite at distance r can kill $m(r) \equiv T_o/t(r) = (BT_o/Jr^2)$ boosters in the available boost time T_o. The missile-killing potential of the constellation against clustered launch is then obtained by integrating m(r) over all satellites from those directly above the launch site (r = h) to some maximum r. We cut off the integral at r = U such that a satellite can no longer kill

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even one booster-- $m(U) = 1$, i.e., $U^2 = BT_o/J$. Thus we optimistically take credit for fractional kills above unity. Each satellite closer than U is assigned a different booster and heats it for the required time before being assigned and moving instantly to heat a new booster. M boosters can be killed:

$$M = \int s m(r) 2\pi\rho d\rho = (BT_o/J)\int_{\rho=o}^{\rho=max} 2\pi s\rho d\rho/(h^2 + \rho^2), \qquad \text{I-1}$$

where the coordinate system is fixed at the booster launch point and the integration runs over the various satellites. Here ρ is the radius from the origin to a sub-satellite point. With $a \equiv r^2 = h^2 + \rho^2$,

$$M = \pi s(BT_o/J)\int_{a=h^2}^{a=U^2} da/a = \pi s(BT_o/J)\ln(U^2/h^2) \qquad \text{I-2}$$

$$M = \pi s(BT_o/J)\ln(BT_o/Jh^2) \qquad \text{I-3}$$

For the 25-Mw, 10-m diam HF laser described earlier, we have $B = 269$ Mw-(Mm)^2/m^2, $J = 200$ MJ/m^2, and for $T_o = 100$ s, $U = 11.6$ Mm. For $h = 500$ km (0.5 Mm), the logarithm is about 6 and only slowly varying with h. A planar constellation of 1 satellite per square megameter and zero retarget time (some 164 satellites in optimum orbit for covering only Soviet ICBM sites) could thus destroy about 2500 missiles of the assumed characteristics. As shown in the next section, the recognition of satellite retarget time of 0.1, 0.5, or 3.0 seconds reduces this capability to 1230, 917, and 603 boosters respectively. Alternatively, these 2500 missiles would require 333, 447, or 680 satellites respectively. Our imposition of horizon limitations will then further reduce constellation capability.

Constellation capability for clustered boosters-- flat earth and non-zero retarget time.

A 10-m diameter mirror cannot move instantly from tracking one target to heating another. The Hubble space telescope has a settling time of 3 sec for the smallest motion within a beam width (about 0.2 μradian), and several minutes for moving to a new target. Because of the large laser power at the mirrors, tricks often used in optical systems for compensating errors in surface or orientation of large elements by deformation or motion of small elements are not applicable to these laser satellites. A typical target might require a slew of 6-10°. One might manage to achieve T_s = 3 sec to retarget our 10-m diameter mirror to a stabiity of 0.1 microradian or less; we shall consider T_s = 3, 0.5, and 0.1 s. Kill time Jr^2/B in (I-1) becomes $T_s + Jr^2/B$, equivalent to replacing r^2 by $(r^2 + BT_s/J)$; We now have instead of (I-2) (now with $a \equiv h^2 + \rho^2 + BT_s/J$);

$$M = \pi s(BT_o/J)\int_{a=h^2+BT_s/J}^{a=U^2+BT_s/J} da/a \qquad \text{I-4}$$

$$M = \pi s(BT_o/J)\ \ln[(U^2+BT_s/J)/(h^2+BT_s/J)] \qquad \text{I-5}$$

...Round Earth.

The horizon (tangent plane to the earth at the booster launch location) intersects the satellite constellation sphere at a distance

$$H = [(E + h)^2 - E^2]^{1/2}. \qquad \text{I-6}$$

Satellites beyond that distance are below the horizon and shielded from the booster at low altitude. For example, H = 1.94 Mm for h = 300 km, far less than the upper limit of the flat-earth integral of (I-4), for which U exceeds 11 Mm. Aside from small effects relating to the somewhat reduced range to a satellite on the basing sphere at ρ, the spherical distribution of satellites can be taken into account by replacing U by a U' in the upper limit of (I-4) such that

$$U' \equiv \min [(U),(H)]. \qquad \text{I-7}$$

(I-5) then becomes

$$M = (\pi s B T_o/J) \ln [(U'^2 + BT_s/J)/(h^2 + BT_s/J)], \qquad \text{I-8}$$

or for the normal horizon-limited case,

$$M = (\pi s B T_o/J) \ln [1 + 2hE/(h^2 + BT_s/J)], \qquad \text{I-9}$$

In order to use the satellites to best advantage, we maximize M with respect to h. The logarithm is maximum when the argument is maximum, which for the horizon-limited case is when

$$0 = d/dh\ [(E + h)^2 - E^2 + BT_s/J]/[h^2 + BT_s/J], \text{ or} \quad \text{I-10}$$

$$h^2 = BT_s/J, \quad \text{I-11}$$

for the constellation altitude h which maximizes intercept capability.[8] So (I-9) becomes

$$M = (\pi s B T_o/J)\ \ln \{(BT_s/J)+[E+(BT_s/J)^{1/2}]^2 - E^2)/((BT_s/J)+(BT_s/J)\}, \quad \text{I-12}$$

$$\text{or} \quad M = (\pi s B T_o/J)\ \ln\ [1 + E(BT_s/J)^{-1/2}] \quad \text{I-13}$$

valid so long as $H^2 < U^2$,

$$\text{i.e., so long as} \quad 2E(BT_s/J)^{1/2} + (BT_s/J) < U^2 \quad \text{I-14}$$

For B = 269, J = 200, (I-14) is satisfied up to T_s = 9.8 sec for T_o = 40 and T_s = 17.5 sec for T_o = 100. The results of (I-13) are plotted in Fig. 1.

Distributed boosters-- non-zero retarget time.

The purpose of this section is to explore the validity and applicability of a claimed "square-root scaling" of satellite density as the density of boosters is increased. The calculation of constellation density required to destroy boosters distributed uniformly (density b) over a plane assumes satellites on a regular triangular (hexagonal close-packed) lattice at altitude h, with nearest-neighbor satellite spacing 2R. If each satellite is assigned the task of destroying every booster in its own circle of responsibility[9] of radius R, the capability of each satellite is exhausted when the sum of the times taken to kill each booster (including retarget time) exceeds the available engagement time T_o. For

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a given booster areal density b we calculate the time required for a satellite to kill <u>its</u> boosters, i.e., $T(b,J,h,R,B,T_s)$. Assuming the laser parameters B and T_s fixed, we maximize constellation capability vs. h for a given satellite density $s \equiv 1/\pi R^2$ and thus determine b-- giving a point on the b-s curve relating booster density and satellite density (or numbers). If t(r) is the time to kill a booster at distance r, and ρ is now the radial coordinate on the <u>ground,</u> with origin at the sub-satellite point, the time required to kill all boosters is

$$T \equiv \int_{\rho=0}^{\rho=R} t(r) b 2\pi\rho d\rho \qquad \text{I-15}$$

The integral extends over all the <u>boosters</u> within radius R of an individual satellite.

$$\text{With } t(r) = T_s + Jr^2/B, \text{ and } a \equiv r^2 + (BT_s/J) \qquad \text{I-16}$$

I-15 becomes

$$T = (2\pi Jb/B) \int_{a=h^2+(BT_s/J)}^{R^2+h^2+(BT_s/J)} ada/2 \qquad \text{I-17}$$

$$T = (2\pi Jb/B)\ (1/4)\ a^2 \Big|_{a=h^2+(BT_s/J)}^{a=R^2+h^2+(BT_s/J)} \qquad \text{I-18}$$

$$T_{min(h)} = (2\pi Jb/B)(R^4/4)[1 + (2/R^2)(BT_s/J + h^2)] \qquad \text{I-19}$$

which is minimum at h = 0.

$$T_{min(h)} = (2\pi Jb/B)(R^4/4)(1 + 2BT_s/JR^2) \qquad \text{I-20}$$

$$T_o = (Jb/B)(\pi R^2)^2\ (2/4\pi)(1 + 2BT_s/JR^2) \qquad \text{I-21}$$

$$s^2 = (Jb/BT_o)(1/2\pi)[1 + (2\pi T_s B/J)s] \qquad \text{I-22}$$

Satellites cannot be in orbit at zero altitude, so that s obtained from (I-22) will be <u>less</u> than the number of satellites really required. Eq.

(I-22) relates booster density b to satellite density s adequate to cope with an infinitely extended booster distribution. A more flexible assignment of lasers to targets would require fewer lasers, but we accept this restrictive assignment scheme as a prerequisite (but not a sufficient condition) for a claimed square-root scaling, in order to explore the actual scaling law. Solving,

$$s^2 - sb\, T_s/T_o - Jb/2\pi BT_o = 0 \quad \text{I-23}$$

$$s = (T_s/T_o)(b/2)\{1+[1+(1/b)(2/\pi)(T_oJ/BT_s{}^2)]^{1/2}\} \quad \text{I-24}$$

If $b \gg b^* \equiv (2/\pi)(T_o/T_s)(J/BT_s)$, then $S \approx bT_s/T_o$ and is linear in booster density. For the parameters assumed, this $b^* = 5.3/(\text{Mm})^2$ is far below the existing 140 per square megameter density of Soviet ICBMs, and the number of satellites required is linear in the number of boosters deployed.

In terms of satellite density, $(2\pi T_sB/J)$ is 25.36 for satellite retarget time $T_s = 3$ s. Thus the second term in (I-22) dominates the first for $s > 0.04$ satellites per square megameter. Much weaker satellites, or shorter retarget time, or tougher boosters will be required to obtain "square-root scaling," even for infinite distributions of boosters and satellites.[7]

Eqs. (I-22) and (I-24) teach us that "square-root scaling" can enter only at low satellite density or low booster density, respectively. But a stronger inference can be drawn from (I-24) regarding the scaling of numbers of satellites of given characteristics vs. numbers of boosters of infinite extent. Clearly, the asymptotic behavior for large numbers of boosters is $s = bT_s/T_o$ -- each local satellite destroying a booster each retarget time, for the entire burn or engagement time. But (I-24) tells us that satellite numbers are always greater than that given by the asymptotic formula, and in the linear range this residue of square-root scaling requires an additional satellite density $s_+ = J/2\pi BT_s$. Thus we know that even on the assumption of widely deployed boosters, the required local density of satellites is <u>at least</u> the local density of boosters multiplied by T_s/T_o, and the ratio of the <u>cost</u> of the satellite constellation to the cost of the booster constellation exceeds

$$(C_s/C_b)x(T_s/T_o)x(4\pi E^2/yA), \quad \text{I-25}$$

where C_s is the cost of a satellite, C_b the cost of a booster, and A the area over which the boosters are deployed. Adopting the proposed[7] assignment strategy that satellites should be restricted to shoot within their circles of responsibility (as required for square-root scaling), and assuming the deployment area to be 10 square megameters and a satellite concentration factor y = 3.1 from optimum orbits, satellite numbers are $16T_s/T_o$ times the number of boosters. With 3-sec retarget time and 100-sec engagement time, one satellite must be deployed for every two boosters, and the defense would be overcome by a cheaper offensive deployment if a booster cost less than half the price of a laser battle station.

Since the laser must have been launched into orbit by a rocket, and weighs far more than the ICBM payload, and because lasers must be deployed over an area very much larger than the booster deployment area (to which <u>active</u> lasers are limited by the assignment strategy needed for square-root scaling), boost-phase intercept can hardly be achieved cost-effectively by satellites armed with powerful lasers. Furthermore, for non-zero retarget time, satellite numbers are proportional to booster density even for infinitely extended booster deployment, for reasonable satellite and booster characteristics. Because satellites are assumed to shoot only at <u>local</u>[10] boosters in the distributed launch case, there appears to be little difference between the planar constellation and round-earth results for distributed launch, although the smaller values of S' in

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Table 1 would be increase by recognition of horizon limitations which impose $h>0$.

Results and discussion.

Table 1. Required satellite densities s and numbers S.

M boosters	J MJ $/m^2$	T_o sec	T_s sec.	s' Sats. $/(Mm)^2$	S' Sats.	s'' Sats. $/(Mm)^2$	S'' Sats.
1400	200	100	3	4.24	697	2.32	381
1400	200	40	3	10.54	1732	5.80	953
3000	200	40	3	22.5	3699	12.43	2044
1400	200	100	0.5	0.89	146	1.53	251
1400	200	40	0.5	1.96	322	3.82	628
3000	200	40	0.5	3.97	653	8.18	1344
3000	200	100	0.5	1.71	281	3.27	537
1400	200	100	0.1	0.48	79	1.14	187
1400	200	40	0.1	0.84	138	2.85	468
3000	200	100	0.1	0.76	126	2.44	401
3000	200	40	0.1	1.39	228	6.10	1003

Boosters distributed over 10 $(Mm)^2$ (solution of I-22):-
(Lasers assigned local areas of responsibilty)
(flat earth, satellite numbers will be greater than shown)

Concentrated boosters with horizon cutoff on satellite effectiveness:
(round earth, solution of (I-13), optimum altitude $h^2 = (BT_s/J)$)
For Ts = 3, 0.5, 0.1 sec, h is 2010, 820, or 370 km, respectively.
The point-launch approximation holds for $G \le h$, where G is the diameter of the launch field.

The last two columns in the Table present the satellite density and numbers required to handle the indicated booster threat for launch of boosters from an area some hundreds of km diameter. We assume 25 MW of 2.7 micrometer laser light; 10-m diameter perfect optics; retarget time T_s of 0.1, 0.5, or 3.0 sec as indicated; engagement duration T_o. For concentrated launch, the required number of satellites is proportional to the number of boosters.

With the simplistic assignment of satellites to kill widely distributed boosters in the immediate vicinity, (I-22) shows a number of satellites linear in booster density except for near-zero retarget time, and then only for satellite altitude zero or scaled with satellite separation, and also only for low booster densities. According to (I-24), large booster density, short burn time, reduced booster hardness, enforce linear scaling; while poor laser brightness and short retarget time are conducive to square-root scaling. Fig. 2 and Table 1 demonstrate near-linear scaling for many cases of interest with distributed boosters.

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FOOTNOTES.

FOOTNOTE 1

To destroy most of the ICBMs while the rocket booster is still burning is widely stated by SDI supporters as essential even to partial defense, because the missile in boost phase is more visible and more vulnerable than later when the reentry vehicles and any decoys may have been deployed, and there are fewer targets to be destroyed.

Because the Soviet silos are deep within the Soviet Union, two basing modes have been suggested for boost-phase intercept-- large numbers of low-earth orbit satellites carrying powerful lasers or homing rockets, so that there will always be enough within range of any silo to destroy the ICBM once launched; or pop-up interceptors based on submarines near the Soviet Union, launched on information that a massive ICBM launch has taken place, and which destroy the missiles in boost phase with x-ray lasers powered by nuclear explosions. If the x-ray laser is assumed feasible and effective, the necessity to bring it above the curve of the earth during the duration of boost of the ICBM requires an interceptor mass far larger than the payload mass itself. For instance, (see R.L. Garwin, p. 399, in "Ballistic Missile Defense," A.B. Carter and D.N. Schwartz, Eds., The Brookings Institution, 1984) an interceptor based 7400 km from the silo, required to climb in 120 sec to an altitude giving a line of sight with 185-km earth-limb clearance to a booster which has climbed to 370 km altitude, would need an initial mass of 660 tons to lift an x-ray laser payload of 1 ton. This assumes no structural mass needed for the rocket, a specific impulse of 300 sec (exhaust velocity of 3 km/s), and instant burn of the interceptor rocket propellant. To reach the same altitude in 60 seconds would require twice the speed and an initial mass of 430,000 tons.

Furthermore, it is essential to consider whether there are cost-effective counters to the assumed defenses; e.g., the evolution of the Soviet ICBM force to small, single-warhead missiles (equipped with fast-burn boosters burning out in 50 seconds at an altitude of 80 km) would doubly negate the pop-up interceptor, which could not climb to line-of-sight within 50 seconds, and also because the soft x rays cannot penetrate to 80-km altitude within the atmosphere. Studies made for the U.S. Government in July, 1983 by McDonnell-Douglas and Martin-Marietta Corps. indicate that such fast-burn boosters with MIRVs and penetration aids could be built at a cost some 10-15% more than optimized (normal-burn) boosters. In an era in which computers and sensors are assumed to be highly capable and cheap, the cost of the missile guidance system will be much reduced; a silo-based single-warhead ICBM could even be cheaper per warhead than a new MIRVed large missile because of economies of scale in production, and the much cheaper development and test program.

Basing the defense on satellites in low earth orbit provides continuous visibility from some satellite to each booster, but fast-burn missiles still negate the capability of both x-ray lasers and neutral particle beams (hydrogen-atom beams of 100-MeV energy) because of the screening of the atmosphere. Homing interceptors have little time to reach the boosters, and the atmosphere at 80-km altitude interferes with their infra-red homing. Satellites carrying powerful continuous-wave or repetitively pulsed infrared lasers at some wavelengths can see down to the clouds and might have significant capability against individual missiles, even fast-burn boosters; we assume that a 50-sec-burn booster could be engaged for 40 sec by this satellite fleet. Such large satellites would need to be protected against Soviet antisatellite weapons, such ASAT weapons would include space mines with nuclear or conventional warheads accompanying the defensive satellites in peacetime, always within lethal range.

FOOTNOTE 2
The best available technical introduction to the technology and systems aspects of SDI is probably
Carter, Ashton B., 1984, "Directed Energy Missile Defense in Space," (99 pages), Background Paper of the Office of Technology Assessment, Congress of the United States (April, 1984).

FOOTNOTE 3
To derive the overall number of satellites from the required local areal density s requires a calculation of s as a function of orbit parameters. Satellites in a mixture of orbits giving uniform density everywhere will occupy $4\pi E^2 = 509\ (\mathrm{Mm})^2$ of area. Then S = 509 s. Launch sites clustered at the North pole could be attacked most effectively with polar-orbit satellites, which have a much larger latitude-band-averaged density at $\lambda = \pm 90°$ than elsewhere. Silos limited to the equator could be addressed by equatorial low-earth-orbiting satellites with great efficiency. In general, there will be an optimum orbit to attack boosters launched from silos spread uniformly from λ_1 to λ_2. If we assume satellites uniformly phased in orbits of optimum inclination i, the band-averaged satellite density

$$<n>(\lambda_1,\lambda_2) \equiv \left[\int_{\lambda_1}^{\lambda_2} n(\lambda)\cos\lambda\, d\lambda\right] / \int_{\lambda_1}^{\lambda_2} \cos\lambda\, d\lambda, \qquad \text{I-26}$$

where $n(\lambda)$ is the satellite density averaged by earth rotation for each latitude λ. This is an optimistic measure; for satellites of very short range the constellation capability is limited by $\min(n(\lambda))$ over $\lambda_1<\lambda<\lambda_2$, and for long-range satellites those outside the latitude range will have been considered, which will reduce the average density below that calculated here. Thus the concentration factor y will be less than that derived here. Furthermore, the granular satellite density is assumed uniform.

For N satellites on any orbits of inclination i, the longitude-averaged

$$n(\lambda) = (N/2\pi^2)/(\sin^2 i - \sin^2\lambda)^{1/2} \qquad \text{I-27}$$

for $\lambda<i$, and $n(\lambda) = 0$ for $\lambda>i$.
Averaging over a band from λ_1 to λ_2, we have for such orbits

$$<n>(\lambda_1,\lambda_2) = (N/2\pi^2)\frac{[(\sin^{-1}(\sin\lambda_2/\sin i) - \sin^{-1}(\sin\lambda_1/\sin i)]}{(\sin\lambda_2 - \sin\lambda_1)}, \qquad \text{I-28}$$

(for $\lambda_1<\lambda_2<i$, and with obvious modifications for $\lambda_2>i$). For silos spread uniformly between 50° and 60°, the maximum concentration factor y is reached with orbital inclination i = 60°, and is y = 3.1, which we have

FOOTNOTE 4
By integrating over the radiating aperture to obtain the electric field a short distance away, and comparing with the electric field when the entire aperture is phased to provide a focus at distance r.

FOOTNOTE 5
The Hubble Space Telescope will have D = 2.4 m; demonstration of even megawatt diffraction-limited chemical lasers is several years away in the SDI program.

FOOTNOTE 6
A layer of carbon 3-mm thick could be evaporated by this energy density--generally taken as a hardness which can be achieved without much penalty.

FOOTNOTE 7
Cited in <u>military</u> <u>SPACE,</u> Feb. 4, 1985, p. 4.; derived in G.H. Canavan, "Comments on the OTA Paper on Directed Energy Missile Defense in Space," Los Alamos National Laboratory document P/AC:84:43 (May 4, 1984), especially Appendix A; also in G.H. Canavan, "Simple Estimates of Satellite Constellation Sizing," Los Alamos document 0903B (August 6, 1984)

FOOTNOTE 8
M. Lecar (private communication Feb. 23, 1985) obtains for the spherical shell of satellites, without approximation by a tangent plane, a missile-killing potential of exactly the same form as (I-9), multiplied by a factor E/(E + h). We continue to use (I-9), for which the optimum altitude can be derived analytically. Lecar's derivation shows that more satellites are required than calculated in (I-13), but by no more than 10-20%.

FOOTNOTE 9
The "circle" is really a hexagon, of area 10.3% larger than the inscribed circle. The area of the circle which circumscribes the hexagon is 4/3 that of the inscribed circle. Although the precise number of satellites to cover the hexagonal area compared with the inscribed circle depends on details of the problem, a 10% increase in satellite number (5% decrease in spacing) will provide coverage of the tiling hexagons.

FOOTNOTE 10
This rather primitive assignment of satellite resources is far from optimum in some of the cases considered here, and since a defensive system will be two decades or more in evolution, it is realistic to consider the satellite numbers required to overcome a more responsive threat-- the clustered launch of smaller missiles, for which the required number of satellites is <u>linear</u> in booster numbers (see (I-13) and Fig. 1).

CAPTIONS.

Table I:
Orbiting satellites carrying 25-MW lasers of 2.7 μm wavelength and with 10-m diameter perfect mirrors (brightness $B = 2.69 \times 10^{20}$ W/steradian) are placed in near-optimum 60° inclination orbits for boost-phase intercept of ICBMs near 55° latitude. The last two columns present the local satellite density s'' to destroy the indicated number of missiles of boost time (engagement time) T_o, with satellites of retarget time T_s, assuming the missiles concentrated in a region not much bigger than the altitude of the satellites. Total number of satellites needed is obtained by multiplying s'' by the surface area of the earth-- 509 $(Mm)^2$-- divided by a concentration factor of 3.1. For this concentrated launch, optimum orbit altitude (Eq. 11) is 2010, 820, or 370 km respectively for retarget times of 3, 0.5, or 0.1 sec.

The columns s' and S' are an improved analysis of an assumed distribution of boosters clearly inapplicable to the parameters discussed here-- as if boosters were deployed at constant density everywhere, with satellites constrained not to shoot at a booster if there is a satellite closer to that booster.[7] Taking this model seriously, we would clearly require more satellites than if an optimum assignment were used, as in calculating the density s'' against clustered launch. Equally clearly and primitively, distributed boosters should be an easier task for the defense-- a correct intuition contradicted by the comparison of 697 satellites and 381 satellites in the first row of the Table. The assumed model[7] is inappropriate.

Figure 1:
The number S'' of our standard laser satellites is plotted vs. assumed laser retarget time for two assumed booster numbers and 3 assumed engagement times during boost phase. Against the clustered launch of 3000 boosters of 40-sec engagement time, 1344 satellites of 0.5-sec retarget time in optimum orbit are required, working perfectly reliably, to dispatch the boosters.

Figure 2:
Perfect satellites as in Fig. 1 are uniformly distributed at optimum (near-zero) altitude above a distributed booster density of b and are constrained to shoot within their tiling hexagons. Soviet missiles are said[7] to number 1400 and be distributed over an area of 10 $(Mm)^2$; thus $b = 140$. With a 5-sec laser retarget time and 100-sec engagement time, some 10 satellites per $(Mm)^2$ are needed-- or 1640 in optimum orbit world-wide.

Figure 3:
Shorter retarget times T_s than in Fig. 2 are modelled here. Note that the "square-root scaling"[7] is confined to low booster density and is replaced by a linear relationship at high booster density. Satellite density s' exceeds the greater of bT_s/T_o and $(Jb/2\pi BT_o)^{1/2}$. Thus a model which is inapplicable because of geographic distribution also fails to give favorable square-root scaling at large threats when finite retarget time is considered.

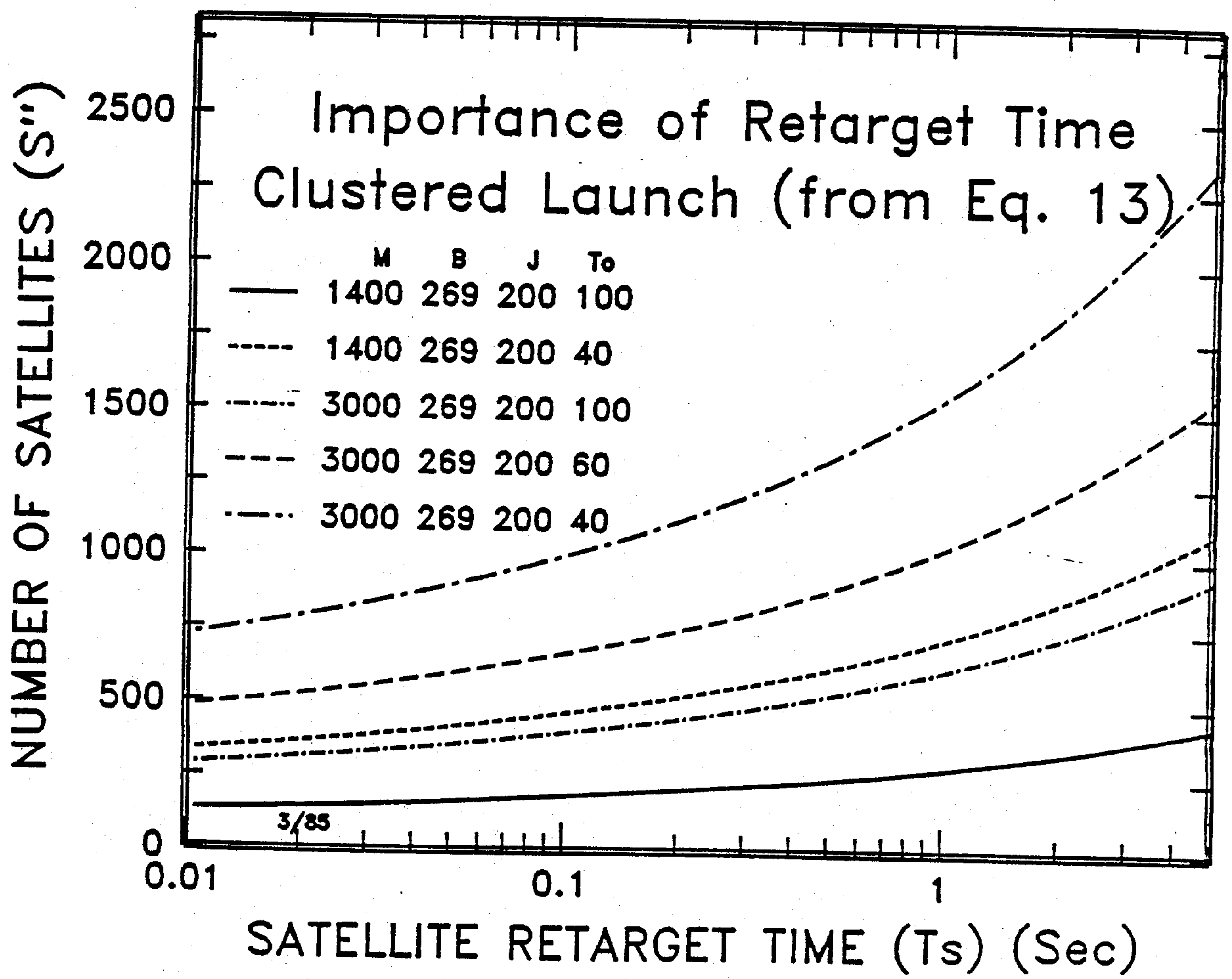

FIGURE 1

End of Job -- YOGI Version 3.45 Scale Factor 1.000

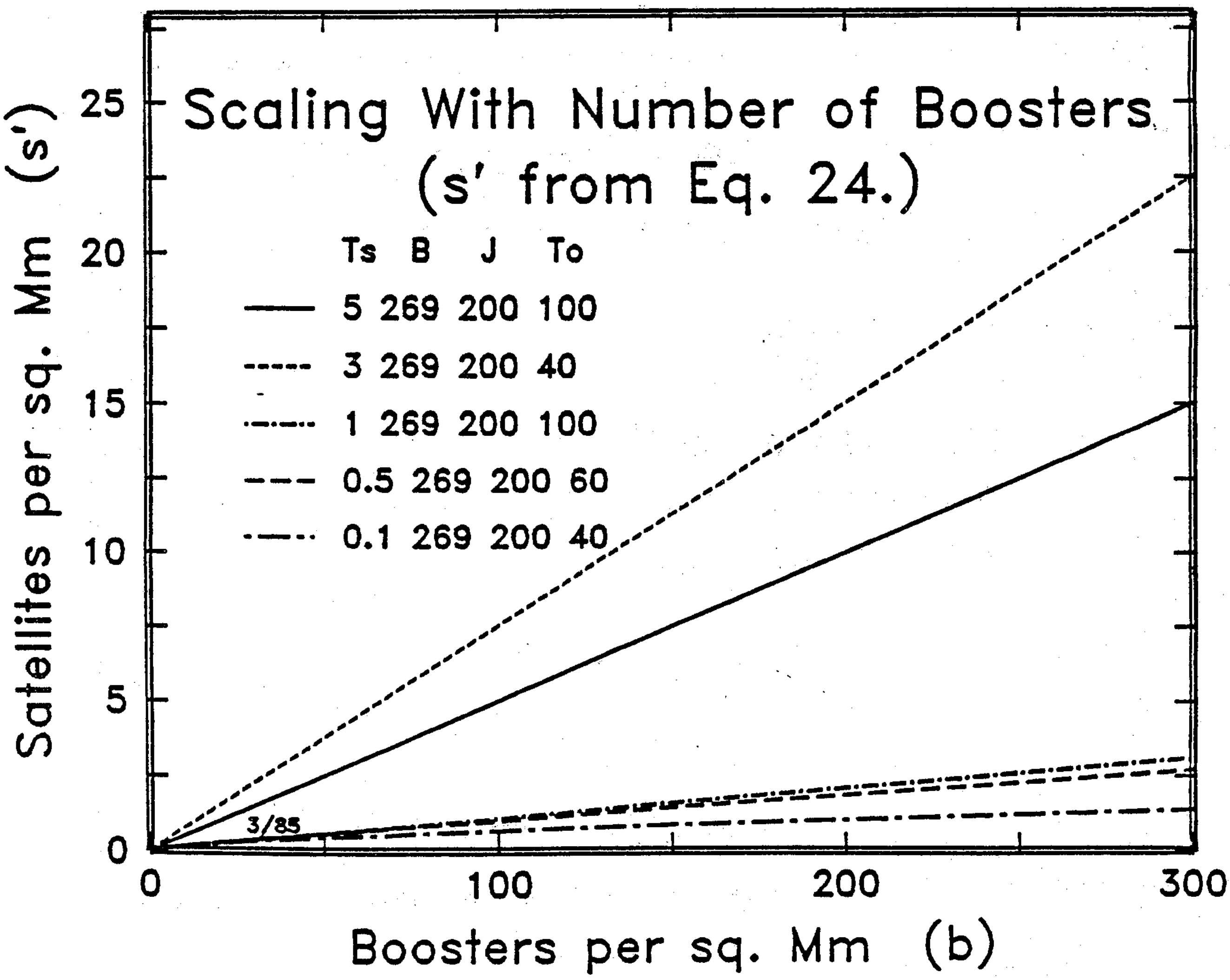

FIGURE 2

End of Job -- YOGI Version 3.45 Scale Factor 1.000

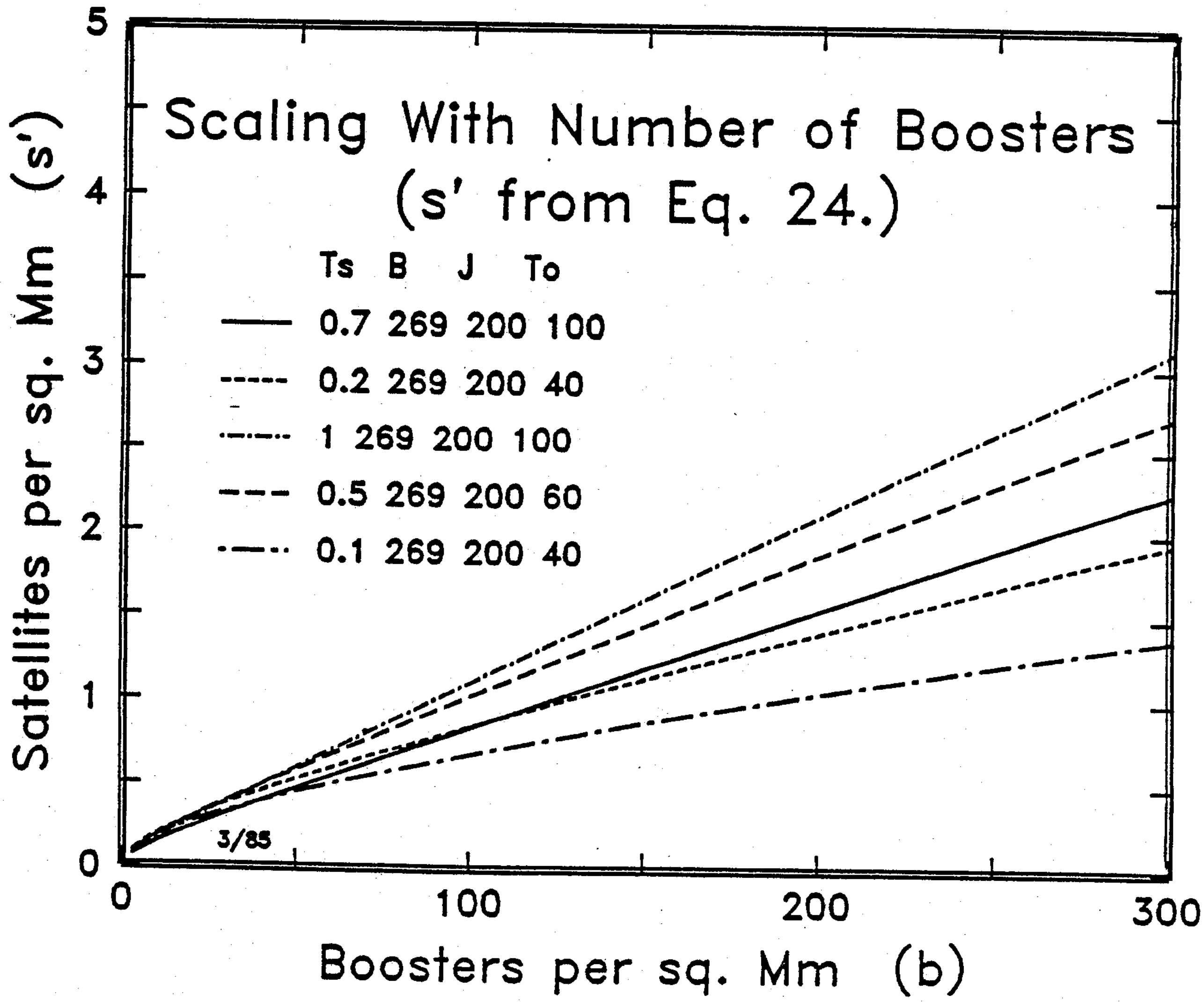

FIGURE 3

End of Job -- YOGI Version 3.45 Scale Factor 1.000

TESTIMONY ON THE STRATEGIC DEFENSE INITIATIVE

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Testimony Before
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of the Senate Appropriations Committee

April 22, 1985

(042285TEST)

Brief Biography of Richard L. Garwin
August 29, 1983

Richard L. Garwin was born in Cleveland, Ohio, in 1928. He received the B.S. in Physics from Case Institute of Technology, Cleveland, in 1947, and the Ph.D. in Physics from the University of Chicago in 1949.

After three years on the faculty of the University of Chicago, he joined IBM Corporation in 1952, and is at present IBM Fellow at the Thomas J. Watson Research Center, Yorktown Heights, New York; Adjunct Research Fellow in the Kennedy School of Government, Harvard University; Andrew D. White Professor-at-Large, Cornell University; and Adjunct Professor of Physics at Columbia University. In addition, he is a consultant to the U.S. government on matters of military technology, arms control, etc. He has been Director of the IBM Watson Laboratory, Director of Applied Research at the IBM Thomas J. Watson Research Center, and a member of the IBM Corporate Technical Committee. He has also been Professor of Public Policy in the Kennedy School of Government, Harvard University.

He has made contributions in the design of nuclear weapons, in instruments and electronics for research in nuclear and low-temperature physics, in the establishment of the nonconservation of parity and the demonstration of some of its striking consequences, in computer elements and systems including superconducting devices, in communication systems, in the behavior of solid helium, in the detection of gravitational radiation, and in military technology. He has published about 100 papers and been granted 27 U.S. patents. He has testified to many Congressional committees on matters involving national security, transportation, energy policy and technology, and the like. He is coauthor of the books Nuclear Weapons and World Politics (1977), Nuclear Power Issues and Choices (1977), Energy: The Next Twenty Years (1979), and Science Advice to the President (1980).

He was a member of the President's Science Advisory Committee 1962-65 and 1969-72, and of the Defense Science Board 1966-69. He is a Fellow of the American Physical Society and of the American Academy of Arts and Sciences; and a member of the National Academy of Sciences, the Institute of Medicine, the National Academy of Engineering, the Council on Foreign Relations, and the American Philosophical Society. The citation accompanying his 1978 election to the U.S. National Academy of Engineering reads "Contributions applying the latest scientific discoveries to innovative practical engineering applications contributing to national security and economic growth." He was awarded the 1983 Wright Prize for interdisciplinary scientific achievement.

He is a member of the Council of the Institute for Strategic Studies (London), and during 1978 was Chairman of the Panel on Public Affairs of the American Physical Society. He is a member of the Council of the National Academy of Sciences.

His work for the government has included studies on antisubmarine warfare, new technologies in health care, sensor systems, military and civil aircraft, and satellite and strategic systems, from the point of view of improving such systems as well as assessing existing capabilities.

FN:BIOG

Mr. Chairman, I am grateful for the opportunity to present my views on the Strategic Defense Initiative, and I look forward to responding to your questions. Of course, I speak for myself alone and not for any organization or group. As a consultant for various elements of the United States government, and as a member of the Advisory Committee to the Office of Technology Assessment, with others of varying views advisory to the OTA Staff preparing a report on the SDI, I have had the opportunity to come to an informed judgment on this program. In addition, as indicated in the enclosed brief biography, I have long been involved in national security and weapons programs for the US government and have contributed to many of them, including the hydrogen bomb, the air-launched cruise missile, and many military space activities, up to the present time.

In his speech of March 23, 1983, President Reagan noted that deterrence of nuclear war by threat of retaliation worked and would continue to work. He asked, though, whether the American people could live secure by <u>substituting</u> defense for deterrence, and he expressed confidence that our scientists could find the means to render nuclear weapons "impotent and obsolete," intercepting strategic ballistic missiles before they touched our soil or that of our allies. Because of potential countermeasures which could be taken by the other side, it is generally agreed that we cannot plan for a defense so competent that it could eliminate the ability of the Soviet Union to destroy US society, and therefore we shall have to retain our offensive forces indefinitely, taking also the measures to ensure that they can penetrate any defenses which the Soviets might construct independently, or which could evolve on their side from the findings of <u>our</u> program of SDI. Testimony of Administration witnesses has indicated that there is nothing in the SDI program which will support this goal of replacing deterrence of nuclear war, except possibly that 5% which is to be reserved for far-out ideas, unforeseeable at present.

Of course, the SDI is characterized as a "research program," of perhaps 10 years duration, for which more than $20 Billion is requested for this first five years, with perhaps $50 Billion for the next five years. According to the Fletcher Committee, at that time we should know enough to decide whether we want to make the investment in real development of the hardware and software, deployment and operation of a strategic defense system against ballistic missiles. But whether one takes the first step on a journey to China depends on whether one wants to go to China, and on the odds of success. A one-year step of $3.7 B is a significant fraction of defense research, and of the scarce talent in our nation and allied nations available for improving our security. It behooves us to look carefully at the desirability of the outcome and the likelihood of success.

The SDI is now presented as a program of investigation toward the goal of <u>strengthening</u> deterrence rather than replacing deterrence. It could strengthen deterrence by reducing the vulnerability of our land-based forces-- Minuteman or MX in vulnerable Minuteman silos. It is reputed to be able to strengthen deterrence not only by <u>strengthening</u> the retaliatory forces in this way, but also by "denying the Soviet Union confidence in the achievement of limited military goals," so they won't even try to achieve those goals. And some supporters of the SDI hold it absolutely essential because it is needed to counter accidental launch of one or a few Soviet missiles, or to nullify one or a few ICBMs in the hands of a "rogue nation." Every one of these partial goals can be achieved sooner and at less cost and less risk outside the context of SDI than within. Let me explain. As for accidental launch, we do not have to wait 10 or 15 years to be protected by a Star Wars system. The nightmare is that the Soviet Union will call up to say "We're very sorry, but one of our ICBMs has just been released by accident. It will impact in the United States in 30 minutes, and there is nothing you or we can do to stop it." Each one of our own ICBMs or SLBMs in test is fitted with a "command destruct link," which allows the range safety officer to destroy the missile if it heads off range. This small device has a secure (SECRET) message for each particular missile, which when transmitted to that missile will destroy it. To counter accidental launch as soon and as cheaply as possible, we should begin to equip our operational weapons with this command-destruct link, and encourage the Soviet Union to do likewise. This is a field in which the two sides should certainly be willing to cooperate, since, by definition, neither wants to destroy the other side "accidentally."

We could counter possession of an ICBM by a rogue nation, by covert action-- for which purpose it would be thoroughly justified. We could also very quickly arrange to reprogram one of our Minuteman-II missiles with its single nuclear warhead, which may have a usual target (a silo or other point a quarter world away) which it can strike with an accuracy much better than a kilometer and within a very short time-uncertainty. That same ICBM could intercept with its nuclear warhead the rogue-nation ICBM on its way to the United States, at a safe distance of 1000 km or more from our shores. Such a capability could surely be available within a year, as contrasted with a decade or more for any of the satellite-based technologies.

The defense of Minuteman silos has long been feasible, by intercepting the reentry vehicles within the atmosphere as they approach the silos. A Star Wars system of intercept in boost phase deep within the Soviet Union, or in midcourse, attempts to gain leverage over terminal defense of cities, but it gives up the enormous leverage which accrues to a terminal defense of hardened silos. An adequate number of silos can be made to survive by any one of a number of terminal defenses-- buried nuclear explosives 1 km north of each silo, triggered as the RV approaches that silo; SWARMJET rockets launched by the many thousands from a rocket launcher right at the Minuteman silo; or the nuclear-armed LoADS of the Ballistic Missile Defense Program Office. But we should not lose sight of the recommendations of the Scowcroft Commission, in its final report of March 1984, when asked to review the SDI in the context of the overall US strategic program. The Scowcroft Commission did not advocate any role for defense, but maintained that our future security needs would be met by the development of a small, single-warhead ICBM to follow the MX and the other MIRVed land-based missiles. They advocated also a small strategic submarine to carry fewer warheads than the present TRIDENT or Poseidon submarines. I thoroughly support these recommendations and urge that Midgetman development be speeded and a commitment made to deployment of 450

Midgetmen in the Minuteman-II silos, in addition to whatever mobile deployment appears necessary. Furthermore, we should have a program for developing means for a rapid and inexpensive deployment of small silos of modest hardness, so that we will be prepared, if necessary, to run a warhead race with the Soviet Union, deploying as many single-warhead Midgetmen in silos as the Soviet Union builds additional accurate warheads. Obtaining that kind of information threatens no one and is a prudent hedge.

The small strategic submarine is long overdue. Dr. Drell and I proposed in the late 1970s the use of small submarines for survivable deployment of the MX missile, and it is an even easier task to prepare ourselves for the prospect of major reductions in offensive weapons, by the actual development of submarines suitable for the economical basing of perhaps 8 warheads. And I have long advocated the development of the buried-explosives and the SWARMJET (or clustered SWARMJET) silo defensive schemes, again as a hedge against the need to defend the ICBMs, and to expand the choices available to us.

There seems to be some confusion as to the place of silo defense in the SDI. The President's Science Adviser, Dr. George A. Keyworth, says that silo defense would be "funded out of the strategic modernization program" and is not part of SDI. Yet according to Principal Deputy Assistant Secretary of the Army, Dr. A. Hoeber, all the work of the Army Ballistic Missile Defense Program Office (BMDPO) falls within the SDI program.

But as the Scowcroft Commission emphasized, it is not necessary that every portion of the strategic retaliatory force be invulnerable-- indeed it is unachievable. Note that the 40% of our strategic submarines in port at any time are totally vulnerable to destruction. Yet the force is sized so that the surviving 60% is adequate for our needs. The caution of the Scowcroft Commission toward strategic defense of Minuteman arises from their reluctance (and mine) to deploy a defense beyond that allowed by the ABM Treaty, which would then permit the Soviet Union to build an unconstrained defense of nuclear-armed interceptors across their vast country, to which we would have to respond with augmentation and modification of our offensive force, as well as, very likely, with a broad (and useless) defense of our own. It is this fruitless and dangerous offense-defense race which was stopped by the ABM Treaty of 1972, and as regards the desirability of silo defense, nothing has changed since then. Incidentally, because of the likelihood of "salvage fuzing," the use of non-nuclear-armed interceptors for terminal defense does not eliminate the problems the defense will have in operating in the presence of large fireballs from attacking nuclear weapons-- a far more serious problem than the small fireballs from the nuclear-armed interceptors themselves.

The problem with strategic defensive systems is not primarily technology, nor even, in itself, costs. The problem is countermeasures. This has been recognized by Paul Nitze in his February 20 speech, in which he states that no defense could be deployed which was not "survivable," and "cost-effective at the margin." This latter means that it must cost less to augment the defense to nullify an increment of offense, than to build that additional offense designed to counter the defense.

Those who suggest that the Soviet Union will not try as hard and effectively as it can to counter a defense which in effect disarms it are not referring to that same Soviet Union which has spent $10 Billion annually on an operating air defense system-- still ineffective in denying access to Soviet targets even by our old B-52 bombers. They are not describing a Soviet Union which has spent vast sums on hardened silos to prevent our acquiring a capability for disarming strike. These countermeasures can be characterized as "active," "passive," or "threatening." The active countermeasures are those which attack the defense-- by destroying it, blinding it, or otherwise disabling it. Passive countermeasures include hardening of the boosters, hiding, and the like. Threatening countermeasures include the augmentation of the strategic offensive force, or its retargeting to cover redundantly the more valuable targets, in the expectation that some of the weapons will be lost to the defense. It is, of course, very important for the United States to have a full stock of knowledge about countermeasures to potential Soviet defenses, and I strongly support such a program on "penetration aids," broadly construed.

I have time for only one example of an active countermeasure, and one of a threatening countermeasure. The active countermeasure is one which would be used against the near-term space-based BMD system proposed by Brzezinski, Jastrow, and Kampelman in their <u>New York Times Magazine</u> article of January 27. The space-based element of that system is to be

100 satellites, each carrying 150 rockets for boost-phase intercept, with each rocket weighing 500 pounds and carrying a 10-pound homing warhead. If the system worked perfectly and were not countered by space mines in orbit to destroy the defensive satellites, or by other means, it would be designed to have enough satellites within 2000-km reach of the Soviet ICBM fields at the moment of firing the ICBMs, so that the individual rockets could seek out and destroy Soviet ICBM boosters in boost phase above the atmosphere. But the countermeasures to this system already exist in the form of the nuclear-armed Galosh ballistic missile defense interceptor which the Soviets have deployed around Moscow for more than 15 years. The Galosh burns out in some 30 seconds, too short a time to be reached by any of the satellite-based rockets. Its warhead would emerge from the atmosphere, protected by a shroud, and would float into space, up to 10 km or so from the satellite it is to destroy. It would be invisible to satellite or rocket sensors designed for the brilliant flame of boost phase, and even if seen, it could not be attacked by the rocket if it had tethered to it a number of balloon decoys of a distance of 10 meters or so. Thus a system which we would not have for at least 6 or 8 years and $60 Billion investment (according to the authors) would be vulnerable the day it was deployed to countermeasures which the Soviet Union would have had in being for more than 20 years. This is only one example of the vulnerability of space-based defenses-- a vulnerability so severe that Edward Teller (otherwise a strong supporter of strategic defense) has said repeatedly that we cannot base a defense in space because "satellites are costly to put up and cheap to shoot down."

Now consider a much more advanced BMD system which one might hope to deploy in 20 or 30 years. This would consist of large satellites, each carrying a 25-megawatt laser, with a beam focused on the target via a mirror on the satellite of diameter 10 meters-- about as big as this room. Of course, the Soviet response to such orbiting battle stations would be to place next to each a small space mine, but let us ignore that for the moment. The Soviet Union has shown itself willing to make substantial expenditures in the past in order to maintain the viability of its strategic offensive force. It would not be averse to augmenting its strategic force by the deployment of 3000 single-warhead Midgetman missiles (or ones with 3 warheads), based in such a way as to require as many of these satellites as possible to handle the ICBM force. Unfortunately for the defense, satellites have the characteristic of being elsewhere in the world most of the time, except those at a distance of some 40,000 km in geosynchronous orbit. These laser battle stations must be in low earth orbit in order to be close enough to destroy boosters by overheating them. The figure on the next page shows the number of satellites

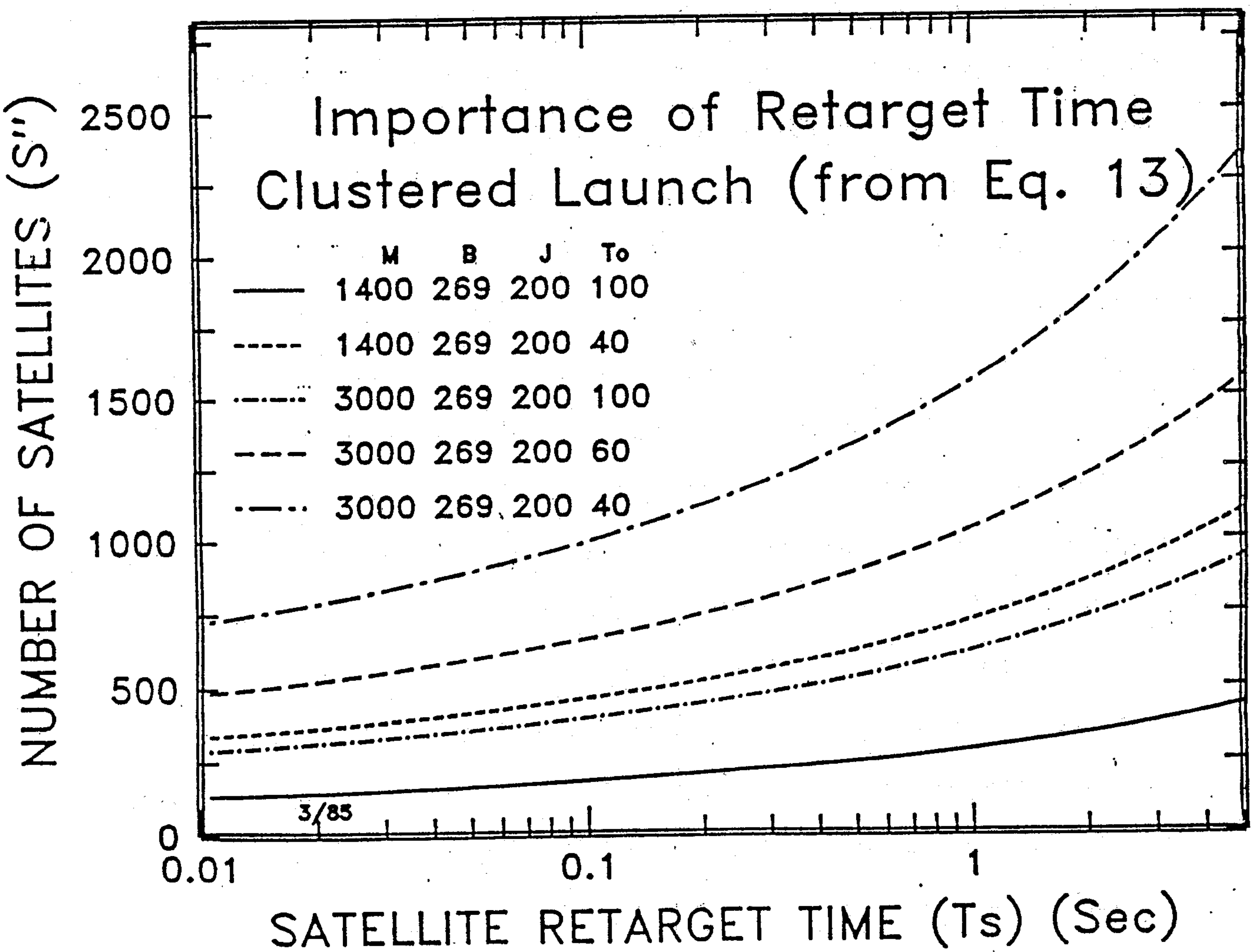

FIGURE 1

End of Job -- YOGI Version 3.45 Scale Factor 1.000

which would be required to counter 1400 or 3000 of these Midgetman missiles based in a region the size of Ohio, with various assumptions for missile boost time (40-100 seconds), and satellite retarget time. Note that more than 2000 satellites would be required to handle a force of 3000 missiles of nominal hardness 200 megajoules per square meter, for this standard (but of course not yet demonstrated) laser, if the missile booster time is designed to be 50 seconds (40-second engagement time), and if the satellite can point with exquisite accuracy in 5 seconds. The accuracy required is about that of the Hubble space telescope, which would take about 5 minutes for the same job. The goal (actually, hope) of the SDI Program Office is a 0.1 second retarget time, and from the figure you can see that it would take more than 1000 satellites if the SDI Program Office achieves its very ambitious goal. It is wrong to imagine that the United States is an infinitely rich country and the Soviet Union an infinitely poor country. Hence the criterion that the defensive system be "cost effective at the margin." In his presentation of August 9, 1984 to the House Republican Study Committee, Dr. Robert Jastrow wrote "Every laser-equipped satellite will cost about as much as a Trident submarine-- several billion dollars." The fast-burn Midgetman, according to studies done for the Fletcher Committee by Martin-Marietta and McDonnell Douglas Corporation, would cost perhaps 15% more than a missile built without fast-burn characteristics in mind. Procurement and 10-year operation of a fast-burn Midgetman might cost $10 M. Requiring one satellite for every three such Midgetmen is an egregious violation of the cost-effectiveness criterion.

The leverage of countermeasures can be seen from the following Table, taken from a forthcoming report:

Table 1. Required satellite densities s and numbers S.

M boosters	J MJ $/m^2$	T_o sec	T_s sec.	s' Sats. $/(Mm)^2$	S' Sats.	s'' Sats. $/(Mm)^2$	S'' Sats.
1400	200	100	3	4.24	697	2.32	381
1400	200	40	3	10.54	1732	5.80	953
3000	200	40	3	22.5	3699	12.43	2044
1400	200	100	0.5	0.89	146	1.53	251
1400	200	40	0.5	1.96	322	3.82	628
3000	200	40	0.5	3.97	653	8.18	1344
3000	200	100	0.5	1.71	281	3.27	537
1400	200	100	0.1	0.48	79	1.14	187
1400	200	40	0.1	0.84	138	2.85	468
3000	200	100	0.1	0.76	126	2.44	401
3000	200	40	0.1	1.39	228	6.10	1003

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Boosters distributed over 10 $(Mm)^2$ (solution of I-22):-| |------|
(Lasers assigned local areas of responsibilty) | |------|
(flat earth, satellite numbers will be greater than shown) |

Concentrated boosters with horizon cutoff on satellite effectiveness:|
(round earth, solution of (I-13), optimum altitude $h^2 = (BT_s/J)$)
For Ts = 3, 0.5, 0.1 sec, h is 2010, 820, or 370 km, respectively.
The point-launch approximation holds for G ≤ h, where G is the diameter of the launch field.

Since the Soviet Union is unlikely to want to make our defensive job easy, the satellite numbers in the final column are far more relevant than the approximate calculation for "distributed boosters."

As for the President's goal and the differing goal of the SDI Program, I quote the words of Dr. William J. Perry, former Undersecretary of Defense for Research and Engineering-- "What is desirable is not feasible;: what is feasible is not desirable."

Our security would be improved by a program in ballistic missile defense research which emphasizes penetration aids, and awareness of what the Soviet-Union might be able to build, rather than a program for developing and demonstrating such abilities ourselves. The President was serene about the effectiveness of deterrence. Recent arguments that the SDI is needed because the Soviets have one too, that our deterrent force cannot remain effective, so we must change to defense, are misguided and incorrect. They are the kind of background music that accompanies every request for funds. We who live in the glass house of deterrence should not throw stones. Nor should we demonstrate improved ways of throwing stones.

During the many decades over which we will have to rely on deterrence of nuclear war by threat of retaliation, our security and that of our allies will be best maintained by strict adherence of the Soviet Union (and ourselves) to the ABM Treaty of 1972, by effective use of the Standing Consultative Commission (SCC) of that Treaty to ensure the limitation of the new technologies which are indeed strongly limited by the Treaty. That treaty regime must be reinforced by a ban on anti-satellite weapons tests and on space weapons, so that neither side can perform the early stages of a BMD technology program in the guise of ASAT tests. That this is an urgent matter is indeed supported by the suggestion of Dr. Keyworth that the Soviets "would put two and two together" from observations of an ASAT capability that he advocates from ground-based lasers against satellites in geosynchronous orbit, and would realize that we were well on our way to a BMD capability using the same technologies.

An ASAT test ban would reduce the peacetime threat to our satellites, and its absence is likely to lead to a confrontation of weapons themselves in space-- as satellites acquire antagonistic space mines, and means are taken to counter those space mines-- an explosive combination of weapons in the same place at the same time, ready to destroy one another at a moment's notice.

I urge you to hold the SDI Program to the current level of $1.4 billion, emphasizing those aspects presented in the Workshop report by Dr. Drell. I urge you to support a moratorium on tests of ASAT weapons, so long as the Soviet Union abides by its self-proclaimed moratorium. I ask you to support the urgent negotiation of a ban on ASAT tests and on space weapons, to buttress the constraints against the erosion of our retaliatory capability, on which we will have to depend for a long, long time. Thank you for your courtesy.

THE NEW YORK TIMES, THURSDAY, MARCH 7, 1985

Shrouded Galoshes Beat 'Space Trucks'

To the Editor:

Robert Jastrow, in "Why Our Star Wars Beats Their Galoshes" (letter, Feb. 23), asserts that our Op-Ed article of Feb. 12 describes a fatally flawed scheme for nullifying a near-term space defense proposed by Mr. Jastrow in an article written with Zbigniew Brzezinski and Max Kampelman. That is not so. Mr. Jastrow appears not to know how in space launches we routinely protect the payload from heating or disturbance by the atmosphere.

We pointed out that some 10 to 20 Soviet Galoshlike interceptors, with their large nuclear warheads, could punch a big hole in the fleet of orbiting "space trucks" posited by Mr. Jastrow et al., a hole through which Soviet ICBM's could then be launched as if there were no space defense.

In his letter, Mr. Jastrow says that his space trucks could track the Galosh even after its booster engine burned out because air friction would have made it glowing hot. According to Mr. Jastrow, the heat-seeking homing projectiles launched by his space truck could therefore destroy the Galosh.

But like every delicate satellite and every multiple-warhead ICBM, the Galosh warhead would be protected by a shroud against wind and heat. The shroud would be discarded above the atmosphere just as one removes a mitten aflame on its outside. As we said, by the time any of Mr. Jastrow's homing projectiles could reach it, the Galosh would be too cool to be found, and to boot, indistinguishable from decoys it could eject.

Our point is that all the "Star Wars" schemes envisioned can be defeated by relatively inexpensive countermeasures — in this case a shroud. The Galosh demonstrates one way that an orbiting battle station is vulnerable, whether it houses lasers, particle beams or Mr. Jastrow's homing projectiles.

RICHARD L. GARWIN
KURT GOTTFRIED
Yorktown Heights, N.Y., Feb. 26, 1985

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Other Garwin Papers on Related Subjects

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Garwin, Richard L. with H.A. Bethe, K. Gottfried, H.W. Kendall, C. Sagan, and V. Weisskopf. Letter to the Editor of COMMENTARY rebutting Robert Jastrow's 12/84 article. (G)

Garwin, Richard L. with H. A. Bethe, K. Gottfried, H.W.Kendall, C. Sagan, and V. Weisskopf. "'Star Wars' Seen as Unworkable and Dangerous." WALL STREET JOURNAL, 01/02/85. (G)

THE STRATEGIC DEFENSE INITIATIVE

presented by

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to

Conference on
Nuclear Deterrence -- New Risks, New Opportunities

5 September 1984

University of Maryland
College Park

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The Strategic Defense Initiative

by

Edward T. Gerry

BACKGROUND

The development of politically and technically supportable alternatives for continued stable deterrence of nuclear conflict into the next century is long overdue. In addition, it is important that approaches are sought which can provide the basis for true nuclear offense force reduction. The thesis of this paper is that the President's Strategic Defense Initiative goes a long way toward providing the basis for the development of those alternatives.

POLICY FRAMEWORK

The primary goal of the Strategic Defense Initiative is to explore a new path for maintaining stable deterrence of nuclear war into the next century through the potential introduction of and increasing dependence on defensive systems as the basis for that deterrence. While a balance of offensive forces has worked so far, the growing numbers and sophistication of ICBM weapons are moving us toward what could be an increasingly less stable situation with advantages to the side that attacks first. Arms control negotiations have not led to sufficient limitations on offensive forces for a number of reasons -- political, strategic, and technical. Further, there is a second and increasing fundamental problem with the fact that we have no defenses against an irrational or accidental act by the Soviets or an Nth country. Defensive systems, properly configured, can provide real protection against the accidental or irrational attack, can be stabilizing against a first strike and can provide for offensive-force arms reduction opportunities that may not otherwise present themselves.

While it is clear that no system made up of technologies that we know about today can guarantee a perfectly leakproof defense, it is extremely important to understand that defensive deterrence does not require a leakproof defense. Defensive deterrence requires only that the defense operate well enough to deny an adversary any confidence that any useful military objective can be achieved through the use of its ballistic missile force. Adequate levels of defense can remove any incentive to a rational adversary for a first strike thereby stabilizing the deterrent balance. Defensive deterrence is equally effective for the defense of Europe as for the United States since, properly configured, systems designed for the defense of the U.S. against ICBM's and SLBM's can be technically quite capable against IRBM's and TBM's in Europe. Defensive deterrence that is stabilizing has two further requirements: 1) The defensive systems must be sufficiently survivable that they cannot be functionally removed as a precursor to an attack, and 2) Defensive system responses to offense force proliferation must be less costly (by some appropriate measure) than the proliferation of the offense.

The phenomenon of "nuclear winter,"[1] could strongly reinforce a deterrent posture based on defensive systems if the defense planners of both superpowers become convinced that the phenomenon is real and will occur at some finite (if uncertain) number of nuclear detonations. At the very least, it makes a proliferation response to a defensive deterrent even less rational. Also, it may further deter any decision by an attack planner to initiate a first strike. An attack plan aimed at a defended military target set must include an estimate of the defense effectiveness in order to determine the number and targeting of nuclear weapons to be launched to achieve the desired result. If the planner underestimates the effectiveness of the defense, then the attack is not militarily effective. If he overestimates the defense effectiveness, then more nuclear weapons arrive than necessary to achieve the objective and he runs the risk of initiating nuclear winter. The more

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[1]R.P. Turco, O.B. Toon, T.P. Ackerman, J.B. Pollack, C. Sagan, "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," Science, Vol. 222, pp 1283-1292, 23 December 1983.

capable the defense, the more weapons he must launch to achieve the same objective, and the smaller the margin for error in the calculation, making it increasingly unlikely that the attack would be attempted in the first place.

If deterrence of nuclear war by whatever means is successful, then the population is 100% protected. The previous paragraphs were directed toward making the argument that the addition of defensive options to the policy choices available to future Presidents could provide for more stable deterrence into the next century and could offer a better opportunity for negotiation of meaningful offensive arms limitations. With sufficient defense, the military utility of nuclear weapons could be reduced to the point where they are, in effect, "obsolete." Active pursuit of arms control agreements, in parallel with development of defensive systems, could very likely hasten the era of "obsolescence."

One additional point must be considered, namely, what happens if deterrence fails. Deterrence based on opposing offensive-only forces cannot tolerate any serious error. If deterrence should fail through miscalculation or accident, a robust defensive system would greatly reduce the number of civilian deaths. Against small or accidental attacks, it may actually reduce the leakage to zero. Against a massive attack some leakage would likely occur but, although the arrival and detonation of 10 nuclear warheads would be a human tragedy of monumental proportions, there is an enormous difference between 10 and 10,000 arriving warheads. With 10, the institutions and fabric of free-world society would likely survive.

It has been argued by most of those opposed to the strategic defense initiative that any defenses are fundamentally destabilizing.[2-5] Such arguments must be based on strict doctrinal application of mutually assured destruction as the basis for stability, because there appear to be strong arguments that would support the opposite conclusion.[6,7] It seems clear that modest defenses which remove the military advantage of first strike to either side (but do not preclude unacceptable population and economic disruption in a massive exchange) are in fact highly stabilizing. It seems clear that modest defenses which also protect against accidents or irrational acts are highly stabilizing for that reason as well.

It is also interesting to note that there is at least one attractive future which requires defenses for its stability. Jonathan Schell in his recent book "The Abolition"[8] sees defenses as an essential stabilizing mechanism for a world disarmed of nuclear weapons. They provide the insurance against clandestine rebuilding or clandestine caches of nuclear arms. He also argues that defenses in the near-term are likely to be destabilizing, (for the same "mad" doctrinal reasons used by the program detractors) but he does see an essential role in the long term. So, we have a situation where modest defenses, which we can have without resorting to exotic technology, provide stabilization of the current offense force balance and the possibility of a future world void of nuclear weapons stabilized by future defenses. There are

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[2] Ashton Carter, "Directed Energy Missile Defense in Space- A Background Paper," U.S. Congress, Office of Technology Assessment, OTA-BP-ISC-26, Washington, D.C., April 1984.

[3] Drell and Panofsky, Issues in Science and Technology 1, (Fall, 1984), pp. 45-65.

[4] Drell, Farley, and Holloway, The Reagan Strategic Defense Initiative: A Technical, Political, and Arms Control Assessment. A Special Report of the Center for International Security and Arms Control, Stanford University, July, 1984.

[5] Bethe, Garwin, Gottfried, and Kendall, Scientific American 251, October, 1984, pp. 39-49.

[6] Payne and Grey, Foreign Affairs 62, (Spring, 1984), pp. 838-842.

[7] Ben Bova, Assured Survival, Houghton Mifflin Co., Boston, 1984.

[8] Johathan Schell, The Abolition, Alfred A. Knopf, New York, 1984.

likely other futures, stabilized by defenses, which may also be attractive. A national effort with imagination, flexibility and perserverence must be able to find a stable path from here to there. It appears to be worth considerable effort to work to find and pursue those steps which, with each step, provide increased stability and move us toward a world where nuclear weapons have become "obsolete" as instruments of national policy. The solution must ultimately be political, but pursuit of programs supporting a defensive transition may provide the framework where both superpowers will find it in their own best interest to agree to substantial reductions of offensive arms.

TECHNOLOGY FRAMEWORK

Summary DTS* Findings

The technological options for implementing an effective defense have become more numerous in recent years and technology advances over the last 20 years may have made feasible several of those options that seemed beyond reach a decade ago. The Fletcher panel[9] (DTS), on which I served, evaluated a wide variety of existing and emerging technologies in the context of a multi-layered defense, recognizing that a layered defense makes the best use of imperfect technologies toward the objective of very low leakage. The DTS identified several combinations of technologies that in a layered deployment would provide low leakage, not only for the current Soviet threat, but for a threat designed to stress the defensive systems. Further, system functional survivability appeared achievable against a variety of attacks, and the possibility appeared real for cost exchange ratios in favor of the defense.

These assessments have held up through further analysis since the conclusion of the DTS, and provide the basis for the Strategic Defense Initiative (SDI) technology development program. This program supports the policy goal by determining and demonstrating the most suitable technologies to allow an informed decision, as early as possible, on

*DTS - Defensive Technologies Study, Summer-Fall 1983, Chaired by Dr. James Fletcher.

[9] J. Fletcher, Issues in Science and Technology 1, (Fall, 1984), pp. 15-29

whether to proceed with time phased development and deployment of systems which could evolve in time into a robust multi-tiered defensive system.

Discussion of DTS Findings

The DTS was asked to define a long term R&D program aimed at the ultimate goal of defending the U.S. and its allies against ballistic missile attack. All technically credible approaches were to be evaluated in a layered defense-in-depth approach toward the goal of very low leakage. The emphasis was to be on effectiveness rather than early deployment. The basis for performance comparison was to be a responsive threat designed to stress the defensive components to the maximum extent possible. The R&D program defined was intended to be a technology limited one that did not involve undue risk at the prototype demonstration stage. Technology validation demonstrations were to be included in the recommended program to provide concrete evidence of progress.

The approach taken by the DTS systems concepts group in evaluating the various technological options started from the recognition that a completely leakproof defense is certainly impractical if not impossible, (and not necessary to achieve the desired policy objectives), and that a layered defense makes the best use of imperfect systems. Three 90% effective systems in sequence provide a more resilient and believable approach to a 0.1% leakage than one system claimed to be 99.9% effective. The group also recognized that some of the new technologies might allow an effective boost phase layer and that such a layer could provide great leverage to the overall system performance.

The boost phase contains the minimum number of targets and negation of a MIRVed booster removes multiple RVs from the attack. Boosters have very large signatures which are impractical to decoy so there is no foreseeable discrimination problem. Further, kill of a booster before it has attained ICBM velocity removes targets and debris from the battle space to be dealt with by the subsequent layers. One of the major difficulties faced by some of the early ballistic missile defense concepts which were based on late midcourse and terminal defenses was the structured attack, where nuclear weapons were brought in in a precise sequence to defeat the defenses. The existence of a random killer in the boost or early midcourse phases precludes highly structured attack doctrines and, therefore, provides more than a multiplicative improvement in the overall system effectiveness.

Since boost phase defenses can provide important leverage to a layered ballistic missile defense system it is important to understand some of the principal characteristics of such a system. A boost phase defense system must operate on a very short timeline (the booster burn time) which occurs at the very beginning of the attack with the targets (ICBM's) located interior to the launching country (presumably the USSR). In almost all cases, this requires that the kill function of the boost phase system be forward based in space. The fact that the boost phase must operate at the very beginning of an attack to be effective also requires automatic initiation of the defense function based on exceeding a preset, but adjustable, attack size and characteristic. There is no time for man in the loop.* There is always a penalty to space-based systems in that some portion of the constellation of satellites is not accessible at any particular time. This is termed absenteeism and the only way to minimize this penalty is to have a long action range to the boost phase weapon system, typically a few thousand kilometers, to get the penalty down to a factor of three or less. The combination of requirements for a long action range together with the short timeline for boost phase intercept is the reason why the prime candidates for boost phase intercept involve directed energy technologies or very high speed kinetic energy weapons.

*Automatic initiation of the defense function has brought horrified reaction from many of the program detractors but in reality it is hardly a traumatic event. We are talking about a non-nuclear defensive system which is incapable of inflicting damage to anyone or anything on earth. It is only capable of shooting boosters rising above the atmosphere and it can only do that if boosters are really there.

The DTS evaluated a wide array of technology for the boost phase layer ranging from chemically and electromagnetically-propelled kinetic kill vehicles, through various kinds of pulsed and CW lasers to particle beam systems. The potential performance of each of these systems against a reactive threat designed to stress that system was examined and it was found that the reactive threat strongly influenced the perspective on suitable long term technologies for boost phase utilization.

To be effective against fast burn and hardened boosters, thermal kill (CW and rep-pulsed) laser systems must have substantially higher brightness than previously assumed, must be capable of retargeting rapidly, and must be able to propagate down into the atmosphere, ideally down to the cloud tops. Pulsed lasers also must be capable of operating down into the atmosphere; however, specific requirements await better understanding of pulsed interaction mechanisms and practical target hardening limits. Particle beam systems are limited by their lack of ability to propagate within the atmosphere and may be limited to operating only against post-boost vehicles (PBVs) and re-entry vehicles (RVs) in the fully responsive threat case.

The coverage of kinetic energy weapons is fundamentally limited by the flyout velocity. For the current Soviet booster and PBV burn times, reasonable size constellations are possible for achievable chemically-propelled kill vehicle flyout velocities of 5-8 km/sec, and provide a potentially attractive near term option. However, as booster burn time is shortened in a responsive threat, the required constellation quickly grows to unacceptable sizes. Electromagnetic launched projectiles may be a solution, but, in order to keep the electric energy invested in each kill vehicle reasonable, very lightweight homing vehicles weighing significantly less than 1 kilogram will be required.

In summary, while the responsive threat drives the requirements for boost phase systems, there is a progression of technologies which can provide both near term capability and growth potential to a robust boost phase layer capable of handling a responsive threat.

Midcourse defense, as it has been from the early days of BMD, is still driven by issues of discrimination. The midcourse phase extends from the termination of post-boost vehicle (PBV) operations until re-entry, typically up to 30 minutes for ICBM's, and provides the largest amount of time for defensive systems operations. However, this portion of the trajectory is not powered and occurs in the vacuum of space, so all manner of lightweight decoys and penetration aids are possible. Because the defensive system concept used in DTS includes space-based elements, new discrimination approaches are possible using those assets. The space- based sensors have access to the ICBM's and the objects released from them throughout their entire flight so that birth to death tracking and cataloging of all significant objects is possible. This provides the opportunity to observe the release of objects from the PBV which appears to limit the offense to sophisticated (i.e. heavy) decoys. Birth to death tracking also removes the need for rediscrimination of credible targets during intercept allowing the possibility of inexpensive mobile non-nuclear hit-to-kill interceptors with designation of the target to the interceptor by the space-based platform. Space-based platforms of the boost phase layer may be able to assist in the discrimination process as well. It is also important to note that the long timeline allows ground basing of the midcourse interceptors as the flyout footprint is substantially larger than the United States. Thus there are no absentees. The entire inventory of midcourse interceptors is available to the battle.

The terminal tier was designed as an independent tier in that it can operate autonomously with only a "heads-up" from the earlier layers, but it can also use whatever information is available from previous layers in assigning target priorities. The keepout altitude was set consistent with the requirement for soft target defense. The system consists of two key elements, an airborne optical platform and a mobile non-nuclear endoatmospheric interceptor. The airborne optical platform provides a wide area footprint for detection and discrimination, so that relatively few platforms are required to provide continuous coverage over the United States. It discriminates by measurements of high altitude atmospheric slowdown and designates the targets to the interceptors. In its early implementation, the airborne platform may be assisted by a ground-based radar for ranging information. The mobile non-nuclear endoatmospheric interceptor is a high acceleration high burn-out velocity missile (like Sprint or HIBEX). However, because of the very short timeline for flyout, the defended footprint is quite small and large numbers of missile batteries would be required for continuous coverage. Since the system is potentially completely mobile, a periodic redeployment reactive defense strategy is possible with the deployment of interceptors driven by changing perceptions of defense priorities.

DTS Conclusions and Recommendations

In summary, the DTS concluded that a robust multi-tiered BMD system could eventually be made to work with building blocks of the type outlined above. It was recognized that the ultimate utility, effectiveness, cost, etc., depended on how successful the various technology development programs were in achieving their objectives and on how the Soviets responded to our developments. It was also recognized that the proper strategy for beginning an evolutionary shift toward defense was driven by policy and technological issues yet to be resolved. Nevertheless, the DTS urged a vigorous broadly based R&D program aimed at producing the data necessary for a decision in the early 90's as to which technologies are suitable for engineering validation and whether to proceed to this phase of development. This leads to an option for a deployed capability after the turn of the century. It was also recognized that there were options for earlier deployments against constrained threats which could be derived from those technologies which are already further along in the development cycle. For example, chemically propelled kill vehicles based in space can provide a substantial boost and PBV phase capability against current Soviet operational and developmental ICBM's and SLBM's. The DTS did not address aircraft and cruise missile threats but recognized the need for a similar study to define defense system approaches for defense against these threats. Most importantly, the DTS recommended that success in carrying forward this difficult technological endeavor required the establishment of some form of special management, where the program manager reports at a high level and has the responsibility to get the job done, the authority to make and implement the necessary decisions, and control of the funds appropriated for the job. This recommendation has apparently been fulfilled with the appointment of LtGen Abrahamson as director of the Strategic Defense Initiative Office reporting directly to the Secretary of Defense.

Public Technical Criticism of the Strategic Defense Initiative

The Union of Concerned Scientists and the U.S. Congressional Office of Technology Assessment have both published documents[2,10] which, in addition to the usual policy objections, raise technical objections on the basis of example calculations. In addition to some technical errors in the method of calculation, the negative conclusions reached in the two papers mentioned above appear to be based primarily on poor choice of technology level, which of course yields poor performance.

The DTS found that specifying the correct technology goals was critically important to defining a system that was robust to countermeasures and potentially affordable in the long run. For example, designing a homing rocket vehicle for either midcourse RV intercept or boost-phase intercept with too heavy a homing head drives the size, weight, and cost of the system to the point of impracticality. However, modern microelectronics coupled with space-based sensors and

[10] "Space-Based Missile Defense," A report by the Union of Concerned Scientists, Cambridge, Mass., March 1984.

designators allow the possibility of a very small, low cost interceptor which might radically change the traditional cost exchange between offense and defense. Similarly, a laser boost-phase system designed at too low a technology level may be vulnerable to retrofit hardening of the ICBM targets, while one designed at the other extreme may be too costly for the extra performance achieved.

In the recent public discussion of the President's Strategic Defense Initiative, far too much emphasis, in my opinion, has been placed on the exotic directed energy technologies. The technologies that can play a role in the 90's likely do not include lasers or other directed energy devices, except in an information transfer, radar, or designator role. Directed energy technologies do, however, provide the growth potential to give long term robustness to the President's initiative well into the next century.

Technical Implications for European Defense

Several of the elements of the Strategic Defense Initiative can have substantial impact on European strategic and theater defense. The boost-phase systems have global coverage, and, with the proper C^3 and battle-management systems, are directly effective against IRBM's and tactical ballistic missiles (TBM's). The terminal defense layer, configured as a completely transportable system, is also applicable to terminal defense against IRBM's and TBM's. Because the re-entry velocities of these missiles are somewhat lower, the defended footprint of a terminal interceptor is larger and the system is somewhat more capable. Because penetration aids are more difficult to implement on shorter range ballistic missiles, the terminal layer can be augmented by mid-course exo-interceptors commanded by the same airborne optical platform.

Conclusion

It is important to remember that the current Strategic Defense Initiative program is not aimed at developing or deploying a new BMD system. It is, in fact, a focused technology program which will allow an informed, technologically sound decision on whether a change of strategy for deterrence to include defensive elements is possible and affordable. This information, coupled with parallel policy evaluations will determine whether such a change is desirable and the best approach for implementing it. Given the apparent near- and long-term advantages of beginning a defensive transition, I believe that the President's initiative may well prove to be of historic importance. Our future leaders must be given sound technological, political, and military alternatives for responding to strategic initiatives by our adversaries, alternatives that offer more choices than continued improvements in and proliferation of our offensive nuclear forces. The Strategic Defense Initiative deserves the strong support of the American people and in particular deserves support, imagination, and diligence from our scientific and engineering community.

'Star Wars' Adversaries Find Many Points To Agree On

By DAVID WHEELER
Valley News Staff Writer

HANOVER — A debate over President Ronald Reagan's proposed strategic defense initiative, commonly known as "Star Wars" weapons, produced a surpising amount of agreement yesterday.

"I am absolutely flabbergasted at the amount of agreement we could achieve, considering we started out with leaders of two opposite poles," said Professor Arthur Kantrowitz, an engineering professor who helped frame the rules of the debate held at Dartmouth College.

The debate format attempted to provide for the kind of expert cross-examination that occurs in scientific meetings, instead of letting scientists' statements go unchallenged as they often are in public forums or at congressional hearings.

In a morning session before the public debate in the afternoon, Edward Gerry, a member of the Defense Technologies Study Team advising President Reagan, and Richard Garwin, a physicist who is one of the most prominent critics of Star Wars, agreed on 15 statements and could probably have agreed on more with more time.

One of the agreements was that no space defense system that would work could let space mines be placed nearby. For example, a space mine, an explosive device designed for use in space, could not be allowed near a satellite designed to shoot down nuclear weapons with a laser.

If space mines were allowed, either because no treaty prevented them or because of a failure of a satellite's defenses, they could easily dismantle a space-based anti-missile system.

In a preamble to yesterday's debate, government Professor Roger Masters noted that while the adversary procedures devised at Dartmouth are not designed to make policy recommendations, establishing areas of scientific consensus could ultimately change public policy.

That is perhaps best illustrated by an agreement reached in a similar debate earlier this month over whether computing technology could be devised for a Star Wars system. Herbert Lin of the Massachusetts Institute of Technology and Charles Hutchinson, Dean of Dartmouth's Thayer School, agreed that some

Valley News — Stephanie Wolff

Edward Gerry, left, and Richard Garwin debated 'Star Wars'.

computer program for a Star Wars system. Given a shared set of assumptions, both agreed that a program about 50 million lines long would be needed to run a Star Wars system.

Yesterday's experts agreed that using ground-based defense systems to try to shoot down nuclear weapons while they are being propelled upward could be made impossible by missiles with booster rockets that burned very quickly. The heat given off by the booster rockets is usually suggested as a means of attracting the nuclear missiles with homing devices while they are still being propelled upwards.

Shooting down the weapons while they are being propelled upwards is considered important because once the weapons are in space, they can multiply into many projectiles carrying nuclear warheads — known as re-entry vehicles — toward the target nation.

Shooting down one missile is easier than shooting down many re-entry vehicles.

Quick-burning boosters would give homing devices less time to find missiles and, combined with the blocking effect of the earth's curvature, would make ground-based interception impossible, the two experts agreed.

In a written summary statement, Garwin asserted that there has been no study of whether the United States should pursue research toward President Reagan's goals of rendering nuclear weapons obsolete of retaliation with a defensive system.

Garwin said later that if people are technologically optimistic that a Star Wars system could be built, then they should also be optimistic that a system could be devised to penetrate or counter it.

In his summary, Gerry said that the goal of the current strategic defense initiative program is to determine whether the security of the U.S. and its allies can be improved while at the same time reducing the number and power of offensive nuclear weapons.

In the afternoon debate, Gerry suggested that building decoy missiles would not be cost-effective compared to the advantage of having additional missiles with warheads that would stand a chance of penetrating a defense system. Gerry suggested that the Soviets would not try to build decoy boosters because the risk of the United States developing a system of discriminating between decoys and missiles carrying warheads would be too great.

The two also differed over the potential damage that a satellite-based laser system would do to the earth if the lasers missed the missiles they were aimed at.

Garwin said that any good satellite-based laser would need to be able to shoot down a lot of boosters in a very short time. Assuming a satellite-based laser could shoot down 1,000 boosters in 100 seconds, and that the laser could penetrate the atmosphere, such a weapon