[H.A.S.C. No. 106-31]

ELECTROMAGNETIC PULSE THREATS TO U.S. MILITARY AND CIVILIAN INFRASTRUCTURE

HEARING

BEFORE THE

MILITARY RESEARCH AND DEVELOPMENT SUBCOMMITTEE

OF THE

COMMITTEE ON ARMED SERVICES
HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTH CONGRESS

FIRST SESSION

HEARING HELD
OCTOBER 7, 1999

U.S. GOVERNMENT PRINTING OFFICE
62-236 WASHINGTON : 2000

For sale by the U.S. Government Printing Office
Superintendent of Documents, Congressional Sales Office, Washington, DC 20402

ISBN 0-16-060500-8

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CONTENTS

ELECTROMAGNETIC PULSE THREATS TO U.S. MILITARY AND CIVILIAN INFRASTRUCTURE

HOUSE OF REPRESENTATIVES,
COMMITTEE ON ARMED SERVICES,
MILITARY RESEARCH AND DEVELOPMENT SUBCOMMITTEE,
Washington, DC, Thursday, October 7, 1999.

The subcommittee met, pursuant to call, at 10:30 a.m. in room 2118, Rayburn House Office Building, Hon. Curt Weldon (chairman of the subcommittee) presiding.

OPENING STATEMENT OF HON. CURT WELDON, A REPRESENTATIVE FROM PENNSYLVANIA, CHAIRMAN, MILITARY RESEARCH AND DEVELOPMENT SUBCOMMITTEE

Mr. WELDON. The subcommittee will come to order. This morning the Military Research and Development Subcommittee meets in open session to receive testimony on the potential of an electromagnetic pulse attack to disrupt the United States military and civilian electronic infrastructure. Our open hearing will be followed by a closed, classified briefing. The classified briefing will give our witnesses an opportunity to brief Members in greater depth and to respond to questions that may be too sensitive to fully answer in open session.

Before I go into the subject of today's hearing, I want to announce that we can now confirm that on October 26 we will have a very special hearing in this subcommittee. In fact, over the course of the last five years, I have had five witnesses appear before our subcommittee from Russia, including General Alexander Lebed. Twice I have had Dr. Alexander Yablokov. I have had Mr. Lunev, who is one of the highest ranking defectors from the GRU, and on October the 26th of this year, our committee will have Dr. Christopher Andrew, a noted Cambridge scholar, along with Russian—London Chief of Station of the KGB, Oleg Gordievsky, who will appear with Andrew, and they will discuss the recently released book entitled *KGB,* which documents approximately three decades of KGB files that were copied by Mitrokhin, who was the KGB archivist.

This book has received international attention. It is provocative in terms of what factual information is in here, and it will be the first time in America that Members of Congress will have a chance to see and ask questions of both an outstanding scholar on Russian intelligence, as well as a Russian individual who has, in fact, cooperated with us on some of the patterns that have occurred in the Russian Intelligence Community.

I would also like to announce at this time the release within a matter of several weeks of a new book entitled *War Scare.* This

book has been published by a very eminent author, who has documented five very real cases over the past several decades of Russia's movement toward a possible response in terms of their nuclear arsenal.

The author is sitting to my left and your right, Peter Pry, who is a staffer for our committee. We are extremely proud to have him on staff because of his expertise, his former tenure as an agent in the CIA, and this book is extremely provocative. I am also working on a way that we can give visibility to the author Peter Pry's comments, not the staffer Peter Pry's comments, because I think they are relative to the work that is outlined in the KGB book documenting the Mitrokhin archives by Christopher Andrew.

So those events will take place in October, later on, and they should be exciting, and they will be provocative.

Our hearing today, as I said earlier, focuses on electromagnetic pulse (EMP). We first held a hearing on this issue in 1997. To my knowledge, we were the first major committee in the Congress to devote any attention at all to this issue. It has been an ongoing concern of both my distinguished Ranking Member Owen Pickett and myself, and certainly has been at the key of the interests of Congressman Roscoe Bartlett, who, in fact, held kind of a mini-field hearing in his district on this issue at Johns Hopkins earlier this year.

Being a physiologist himself, Roscoe has a particular expertise here that has been very helpful to this committee in fully understanding the potential threat posed by electromagnetic pulses.

Part of our purpose today in holding an open hearing on EMP is to help educate the public on this still not widely understood threat. Electromagnetic pulse can be generated when a nuclear weapon is detonated at high altitude above the atmosphere. The EMP produced by such an explosion can potentially damage or destroy electronic systems along vast areas of Earth's surface.

Let me say at this point in time, for those who think and for those people who have testified that this could never happen to America, I led a delegation to Vienna on April 30th and May the 1st of this year to meet with a group of Russian Duma officials and leaders to work out the framework for a peaceful solution of the Kosovo crisis. In fact, Congressman Bartlett went on that delegation with me.

In our discussions with our Russian counterparts, all of whom are friends of mine, one of the leaders of that delegation, Vladimir Lukin, the former Soviet Ambassador to the U.S. here in Washington, made this statement, that America needs to understand that while Russia may be in a state of turmoil, Russia still has the capability to do significant harm to our people and our country.

He went on to further outline Russia's capability to conduct electromagnetic pulse laydown. He described it. He said that Russia has this capability, and that if our policies continued along the line that they were going, in that particular case in relation to Kosovo, that that could be the response that could be generated against America.

So for those who would say that this kind of a threat would never emerge, I can only tell you what came out of the mouth of the former Soviet Ambassador to the U.S. and current Chairman

of the International Affairs Committee for the Russian Parliament, the lower House, the state Duma.

The United States is involved in a technologically-dependent society with high potential vulnerability to EMP. The widespread paralysis of electronic computer systems, communications power grids and transportation systems would not be merely an inconvenience. Nor would an EMP attack have only commercial consequences. Our modern way of life and life itself depends upon the functioning of our electronic society.

How severe would the consequences of an EMP attack on the United States be? Some have argued that an EMP event could be like putting the United States in a giant time machine and in the blink of an eye transforming our high-tech society into a primitive preindustrial one, circa the 19th century. Others argue that while the consequences of an EMP attack would be serious, the effects are likely to be much less severe and much more manageable.

The EMP threat may have acquired new and urgent relevance as the proliferation of nuclear weapons and missile technology accelerates. North Korea, for example, is assessed as already having developed one or two atomic weapons and is on the verge of testing an Inter-Continental Ballistic Missiles (ICBM) capable of delivering a nuclear warhead to the United States. North Korea already has missiles capable of delivering a nuclear warhead against U.S. regional allies and U.S. forces based in Japan and South Korea.

Is it possible that given the small size of North Korea's nuclear arsenal, Pyongyang may consider an EMP attack the most efficient military option; the best way to inflict the maximum damage on the U.S. and its allies in the event of a conflict, or perhaps the best way to blackmail or deter the U.S. in the event of a crisis?

There are differences within the scientific community over just how damaging an EMP attack would be. There are differing opinions among experts over the likelihood that a rogue state armed with a small number of nuclear missiles would prefer to perform an EMP attack as opposed to blasting a city or a military base.

The main purpose of our hearing today is to air and explore these differences of opinion about the EMP threat by receiving testimony from two panels representing different points of view.

On our first panel representing the administration and the Joint Chiefs of Staff are Mr. Stanley Jakubiak, senior civilian for nuclear Command and Control and EMP policy from the Joint Chiefs of Staff; Dr. Michael Bernardin, provost for Theoretical Institute of Thermonuclear Studies, Los Alamos National Laboratory.

Our second panel is made up of Dr. William Graham, former science advisor to the President of the United States Ronald Reagan, and Rumsfeld Commissioner on the ballistic missile threat; and Dr. Lowell Wood, member of the director's technical staff at Lawrence Livermore National Laboratory.

We welcome you all and thank you all for being here. However, before I turn the floor over to you, I want to call upon Mr. Pickett, the Ranking Democrat on the R&D subcommittee, respectfully for his comments.

[The prepared statement of Hon. Curt Weldon can be found in the Appendix on page 45.]

Mr. WELDON. Mr. Pickett.

STATEMENT OF HON. OWEN PICKETT, A REPRESENTATIVE FROM VIRGINIA, RANKING MEMBER, MILITARY RESEARCH AND DEVELOPMENT SUBCOMMITTEE

Mr. PICKETT. Thank you, Mr. Chairman. I want to join you in welcoming our distinguished witnesses today, and also I applaud the fact that you are holding an open meeting here on this subject that I think will help inform the public about the seriousness of this threat.

Today's hearing is an excellent opportunity to learn more about the potential effects of an electromagnetic pulse, or EMP, attack. Based on history, there is certainly reason to be concerned. Both nuclear blast tests and simulated scenarios have allowed us to recognize many of the vulnerabilities of our military and civilian systems.

I am particularly interested in examining this issue more closely due to the military's growing reliance on commercial off-the-shelf technologies. While this is neither the time nor the place to dwell on our Nation's efforts to emphasize and rely on diplomacy, early warning capabilities and deterrence doctrine to prevent such attacks, I look forward to learning more from our witnesses today about how such EMP incidents may occur and the likelihood of their possible occurrence. Greater insight into the possibility of an EMP laydown should prove beneficial in our effort to design a more capable, robust and dependable military and national infrastructure and better inform our people about the potential of this particular threat.

Again, Mr. Chairman, I applaud you for calling this hearing, and I look forward to the testimony of our distinguished witnesses here today.

Mr. WELDON. I thank you, Mr. Pickett.

Mr. Pickett, would you be in agreement that perhaps before our witnesses speak we should go complete the journal vote?

Mr. PICKETT. Yes.

Mr. WELDON. Are there any other Members who would like to make opening statements before we go for the journal vote? If there are, that is fine. If not, we will go over and vote and come back and start our panel.

Mr. Bartlett.

Mr. BARTLETT. Just one quick moment. I am very appreciative of the fact that you have called this meeting. This is a discussion of an eventuality that could potentially bring us to our knees or worse. It is very important that the American people understand it and collectively decide what we need to do to prepare for such an eventuality.

Thank you very much for calling the meeting.

Mr. WELDON. Thank you, Mr. Bartlett, for your ongoing efforts in this area.

Mr. Reyes, any comments?

Mr. REYES. No.

Mr. WELDON. Mr. Hostettler?

Mr. HOSTETTLER. No.

Mr. WELDON. We will unfortunately have to temporarily adjourn. This is only one vote. We run very fast so we can be back here and

start hopefully within about six to eight minutes. So the hearing is temporarily adjourned.

[Recess.]

Mr. WELDON. The hearing now will reconvene, and we will now turn to our distinguished panel of witnesses. As I said before, we will start with Mr. Jakubiak and Dr. Bernardin, and then we will move right down the line to Dr. Graham and to Dr. Wood.

Mr. Jakubiak, your statement will be entered into the record without objection, and you are free to make whatever comments that you would like to make. Obviously, if we have questions that you feel are not appropriate for this forum, then they will have to wait until we get into the classified forum. I am sure you will know better than us as to when that line is reached. But we would like to keep as much as possible for the public to consume about this, because there are a lot of misconceptions and misinformation, and we are hoping to clear some of that up today. So the floor is yours.

STATEMENT OF STANLEY J. JAKUBIAK, SENIOR CIVILIAN FOR NUCLEAR COMMAND AND CONTROL AND HIGH ALTITUDE ELECTROMAGNETIC PULSE PROGRAMS AND POLICY, JOINT CHIEFS OF STAFF

Mr. JAKUBIAK. Mr. Chairman, Members of the committee, I am grateful—.

Mr. WELDON. Could you pull the mike a little closer to your mouth, please.

Mr. JAKUBIAK. Mr. Chairman, Members of the committee, I am grateful for the opportunity to address the committee on the electromagnetic pulse threat environment and to discuss the impact on commercial off-the-shelf or so-called COTS equipment used in military command and control systems.

As you know, the detonation of a nuclear weapon between 50 and several hundred kilometers above the Earth's surface will produce an electromagnetic pulse that can, under certain conditions, damage electronic equipment. We don't know exactly how much damage can be done to commercial equipment. The phenomenon is well-known, but the variances in electronic equipment design, commercial design, and the systems that they are incorporated in, do not provide us with sufficient information to allow us to accurately predict how widespread the damage or disruption will be.

Now, to counter the EMP attack, the military has in the past taken a simplistic approach. We have basically said and assumed that all commercial equipment would fail under an EMP pulse, and therefore we have designed protection into that equipment to withstand the EMP protection or the EMP environment.

Critical nuclear command and control nodes, critical military nodes that must operate through that EMP environment have been identified. The Chairman puts out policy to the services and also to the Commander in Chiefs (CINCs) identifying what nodes and what systems and what equipment should be protected. That is published in the Chairman of the Joint Chiefs of Staff instructions, which I am responsible for preparing. In fact, some of those selected systems are even provided backup power generators on the assumption that the commercial power grid would fail in an EMP environment.

However, to capitalize on leading-edge technologies, military systems are becoming more and more increasingly reliant on commercial off-the-shelf (COTS) equipment, which are not specifically designed to survive an EMP environment. To ensure that that equipment reliably operates in an EMP environment, what the services do is basically take that COTS equipment and test it in simulators to the projected threat. The failures are analyzed, and modifications are retrofitted to that equipment to ensure that the equipment does perform properly in an EMP environment.

In some cases that retrofitted fix is a very simple fix, costing less than $10 to make a piece of equipment that is off-the-shelf, commercial piece of equipment, in fact, perform in an EMP environment. However, when we talk about large sensor systems, that inexpensive $10 part can, in fact, quickly soar to a $50 million bill to protect that sensor.

The testing of COTS equipment has allowed us to make some observations regarding the vulnerability of COTS equipment to a range of EMP environments that may be of some use in assessing the impact on the commercial infrastructure.

If I could have that first view graph, please.

On this view graph, you can see that the EMP field strengths between 3 and 8 kilovolts per meter, that there can be some upset on commercial off-the-shelf equipment. When the field strengths get above 8 kilovolts per meter, the risk that there will be upset is more probable. In the range of 7 to 20 kilovolts per meter, there is a possibility that some equipment will be damaged. Above the 20-kilovolt-per-meter range, the damage is most likely probable, although some equipment will even perform above that level.

Results from some recent testing of COTS equipment—can I have the next view graph, please—appear to confirm these levels.

Now, the temporary upset reflected on this view graph indicates that the upset was self-correcting. The equipment, in fact, had an upset, and the equipment self-corrected without any operator intervention. The upset column shows that the equipment, in fact, required an operator to do something to the equipment to bring it back into operation. And then the damage levels are shown on this chart also.

The Office of the National Communications System (NCS) has also done some extensive testing of the commercial public switch network and have found that the public switch network infrastructure is inherently resistant to the effects of EMP. Their studies have shown that the probability of connection of a telephone call under an EMP environment is greater than 90 percent with normal loading, and greater than 70 percent when there is panic loading on that system.

The NCS results have also been confirmed by AT&T Bell Laboratories, who reported that their testing of the public switch network also showed that some upset could be expected, but that damage to the system in an EMP environment was not a concern.

In conclusion, due to the sensitivity of COTS equipment in various EMP field strengths, we have (the Joint Staff) over the past several years sponsored an effort at the national laboratory of Los Alamos to assess the potential field strengths that can be produced by nuclear weapons. When you receive Dr. Michael Bernardin's as-

sessment in closed session, keep in mind the COTS vulnerability levels that I have addressed in my presentation.

Mr. Chairman, Members of the committee, on behalf of the Chairman of the Joint Chiefs of Staff, I appreciate this opportunity to present the Joint Staff views on EMP environment, and I look forward to your questions.

Mr. WELDON. Thank you, Mr. Jakubiak.

[The prepared statement of Mr. Jakubiak can be found in the Appendix on page 52.]

Mr. WELDON. Dr. Bernardin.

STATEMENT OF DR. MICHAEL P. BERNARDIN, PROVOST FOR THE THEORETICAL INSTITUTE FOR THERMONUCLEAR AND NUCLEAR STUDIES, LOS ALAMOS NATIONAL LABORATORY

Dr. BERNARDIN. Mr. Chairman, thank you for the opportunity to provide testimony on this issue vital to national security. I speak as a weapons designer with specialized knowledge in electromagnetic pulse. Since 1996, I have been the provost for the Postgraduate Nuclear Weapon Design Institute within the laboratory chartered with training the next generation of nuclear weapon designers.

The issue to be addressed this morning is the impact of a high-altitude nuclear detonation over the United States to the civilian and military infrastructure. A high-altitude nuclear detonation would produce an electromagnetic pulse that would cover from one to several million square miles, depending on the height of burst, with electric fields larger than those typically associated with lightning.

In such an event, would military equipment deployed within the area of EMP exposure be seriously impaired? Would civilian communications, the power grid and equipment connected to the power grid catastrophically fail? The answers to these questions depend on three elements: One, the types of threat weapons deployed; two, the EMP produced by these weapons; and three, the effects that are caused by EMP.

The Defense Intelligence Agency (DIA) and the Central Intelligence Agency (CIA) identify current and projected nuclear weapon threats and provide inputs to the Department of Energy nuclear design labs, Los Alamos and Livermore National Laboratories, who model foreign nuclear weapons. The labs each have over 25 years of experience in performing this type of modeling. The weapon models serve as a basis for associated EMP threat assessments.

For the purpose of EMP assessment, it is convenient to group the threat weapons into the following five categories: One, single-stage fission weapons; two, single-stage boosted weapons; three, nominal two-stage thermonuclear weapons with yields up to a few megatons; four, two-stage thermonuclear weapons with yields over a few megatons; and five, special technology thermonuclear weapons.

The reason for this grouping and the threat weapons themselves will be discussed in closed session. The EMP produced by these weapons is also a topic delegated largely to closed session.

It is possible to discuss in an open forum the process by which high-altitude EMP is produced in the atmosphere, its propagation down to the ground, and some of the generic features of the result-

ant EMP. This information will be discussed briefly in my statement, and detailed information can be found in my written testimony.

I have brought three graphics along to help illustrate the production of EMP. May I have graphic one.

Shown in graphic one is an illustration of the area coverage of direct EMP exposure from a 200-kilometer height of burst over the United States. For this burst altitude, which might be appropriate for a hypothetical multimegaton weapon, the horizon is located at about 1,600 kilometers or 1,000 miles from a point on the ground directly beneath the burst.

For a 50-kilometer height of burst, which might be appropriate for a 10-kiloton fission weapon, the horizon is located at about half this distance, within the circle.

May I have graphic two.

Shown in graphic two is the spatial distribution of the peak EMP fields for a hypothetical weapon detonated over the United States. The directionality of the Earth's magnetic field causes the largest peak field region to occur to the south of the burst point. The large numbers on the plot are peak electric fuel values in thousands of volts per meter or kilovolts per meter, and the smaller numbers are distance increments in kilometers.

Note that the peak field ranges from 12 to about 25 kilovolts per meter. Other later time, lower-amplitude EMP components are generated by nuclear detonation. These are discussed in my written testimony.

May have I have graphic three. Graphic three illustrates details of some additional specifics of EMP generation, of the generation process, for the early time portion of the pulse. A high-altitude nuclear detonation produces gamma rays, X-rays, neutrons and debris. Some of the gamma rays propagate down into the Earth's atmosphere where they collide with air molecules and produce recoil electrons. The electrons are created with a velocity directed principally radially away from the burst. The electrons are turned by the Earth's magnetic field, which results in synchrotron radiation. The radiation adds coherently to form the electromagnetic pulse.

As the electrons traverse their trajectories, they collide with other electrons creating a sea of ionization. Ionization can be enhanced by atmospheric breakdown or avalanching due to the presence of the EMP electric field. The ionization shorts out the EMP, limiting its value to typically 30,000 volts per meter.

High-energy x-rays are also produced by the exploding weapon and can enhance the ionization in the high-altitude EMP source region. This source of ionization was largely ignored in EMP assessments until 1986. The inclusion of the X-rays lowered the assessed values of the peak field for many weapons.

Note in graphic three that the thermonuclear weapon consists of two stages, a primary stage, which is typically of relatively low yield and is used to drive the secondary stage, which produces a relatively large yield. Each weapons stage produces its own EMP signal, but the primary stage gamma rays, after they go out, leave behind an ionized atmosphere from their EMP generation that is present when the secondary stage gamma rays arrive a moment

later. Thus, the primary stage can degrade the EMP associated with the secondary stage.

[The graphics referred to can be found in the Appendix on page 91.]

You can take down the graphic now.

Given an understanding of the resultant EMP fields from a high-altitude nuclear detonation, the effects of those fields on military and commercial infrastructure must be determined. The effects cannot be quantified simply by drawing upon nuclear test experience. High-altitude EMP was produced on ten nuclear tests conducted in the United States in 1958 and in 1962, and damage or temporary glitches of electronics were noted on a number of the systems. However, these weapons are not truly representative of the foreign nuclear weapons in existence today. Nor are the electronics of 1962 representative of the modern era. Moreover, the U.S. atmospheric tests were conducted over large bodies of ocean, and thus the exposure of extended land line systems to EMP fields was quite limited.

A much more extensive set of vulnerability data has been accumulated over the years through EMP testing and laboratory simulators. Tested items include aircraft, tanks, automobiles, computers, telecommunication equipment, et cetera. Both upset and damage (information) have been obtained for some of the systems at certain field levels, and some of the systems experience no deleterious effects.

A limitation with this type of testing is if the simulators are a finite volume and are not able to expose electric lines of greater length than about 50 meters to EMP. Systems connected to power and communication lines are frequently tested with current injection, but even these tests are limited.

Electronic systems can be protected against EMP, and standard protection techniques include enclosing systems or subsystems in metal boxes and adding surge arresters to power lines, cables, et cetera. Simulator testing has shown that EMP protection is effective. There are costs and practical considerations associated with implementing EMP protection. This is an area of specialty of the military services and the Defense Threat Reduction Agency (DTRA) for military systems, and I suggest consulting them if more detail is desired.

To address the likelihood of catastrophic damage by EMP from a high-altitude nuclear detonation, one must begin with a model of a historical high-altitude detonation, say the Starfish event that was conducted in 1962, and demonstrate that the predicted EMP environments, the EMP coupling and the effects match observation. Then one must be able to establish that the model retains its fidelity when the warhead model is changed, when the burst location is moved over land and changed in elevation, when the electromagnet coupling pads change, when the vintage of electronics changes, and, with the incorporation of EMP test simulator data, that the results are reliable. While it is conceivable for a model to achieve all of this, any such model that is developed should be thoroughly peer-reviewed before its predictions are to be believed.

Thank you.

Mr. WELDON. Thank you.

[The prepared statement of Dr. Bernardin can be found in the Appendix on page 56.]

Mr. WELDON. Dr. Graham.

STATEMENT OF DR. WILLIAM R. GRAHAM, PRESIDENT AND CEO, NATIONAL SECURITY RESEARCH

Dr. GRAHAM. Thank you, Mr. Chairman, and distinguished Members of the Committee on Armed Services. I appreciate the opportunity to testify today on nuclear EMP, and I am also going to say a few things about nonnuclear electromagnetic effects, which I think are closely related.

I would like to begin by just mentioning a few examples of the circumstances in which another nation might wish to employ a nuclear-weapon-generated EMP effect against the United States and the benefits that might be sought through such use. The scenarios cover both political and military use and run from tactical to the strategic level.

By way of background, I have worked in EMPs since 1962, when I was a lieutenant at the Air Force weapons lab, handed a dataset taken from the last atmospheric and Pacific exoatmospheric nuclear test series, and asked to try to explain some very strange-looking phenomena that had been observed. Fortunately, we had the benefit of colleagues at Livermore, Los Alamos and other places in doing this, and the theory of high-altitude EMP, and, in fact, all EMP was developed over the next decade or so.

Interestingly, though, like many important scientific discoveries, the intense electromagnetic pulse produced by the exoatmospheric nuclear weapon explosion was discovered by accident. It was first observed both directly and by its effects on civilian systems during the exoatmospheric nuclear test series we had conducted, primarily the FISHBOWL series in the beginning of the 1960s. However, the theory that was being used at the time to predict the effect had been incorrectly derived by a Nobel laureate actually and caused all of the instrumentation on monitoring those exoatmospheric tests to be set at far too low a scale, far too sensitive a level, so that the data on the scope tended to look like vertical lines. We couldn't see the peak amplitudes that were being produced, and it was Conrad Longmeier of Los Alamos National Laboratory who, after looking at the data, figured out what was really happening.

One possible use of EMP against U.S. forces, just by way of a few brief examples, might be against forces stationed overseas; for example, on the Korean peninsula or in the Persian Gulf. Even if an adversary had only a very few nuclear weapons, by launching even as primitive a missile as a SCUD and exploding a nuclear weapon above the atmosphere, the ability of the U.S. and Allied Forces to make full use of their electronics systems, including communications, fire control, radar systems, missiles and certainly network systems envisioned for our 21st century forces could be degraded to some degree. Depending on the characteristics of the weapon as described here, such degradation—and, of course, the susceptibility of the equipment—such degradation could range from a nuisance to a major hindrance in the employment of electronic systems throughout the theater.

Another possible use of a nuclear weapon might be against U.S. space assets, particularly low-altitude assets, supporting military forces in a theater. The detonation of a nuclear explosion outside the atmosphere, even if it were a small nuclear weapon, perhaps a few tens of kilotons, could produce sufficient direct and delayed radiation to degrade or destroy satellites in line of sight of the burst, as well as a second effect; that is, producing EMP near the Earth's surface, which could interfere with, among other things, the satellite ground stations on the Earth.

Satellite assets, as you know, are a significant part of our overall military capability and, therefore, would be a desirable target.

Another possibility would be the use of EMP because the adversary does not have confidence in his ability to target precisely with a nuclear attack against forces or infrastructure, populations on the ground. For example, if an adversary is not able to pinpoint a carrier battle group or amphibious ready group, he could produce an EMP effect over the presumed operating area of the group, with only rough knowledge of where it is.

Another possibility might involve an adversary with a long-range but relatively inaccurate ballistic missile or a short-range missile launched from a platform that engenders some inaccuracy itself, such as a ship or a submarine, and have only a relatively low-yield nuclear weapon. In this case, the weapon could be more confidently used for an EMP attack than a direct attack, because the accuracy would not be required for the EMP attack.

And, of course, another reason would be basically a demonstration that a country may wish to make that it had a nuclear capability and could deliver it over our forces and allies. A by-product of that would be an EMP effect, but in addition, it would announce to the world that the country is nuclear-capable and prepared to use it, while at the same time not causing any loss of life among our forces, friends and allies, and, therefore, might impede the strong nuclear response by the U.S.

I would like to mention one particular effect of nuclear EMP that is, in fact, unique. While all electronics systems fail spontaneously for a myriad of reasons from time to time, in the case of reliable systems, as most military systems are, these failures occur infrequently, and then only at single points or nodes. Therefore, experience has been gained in dealing with single-point electromagnetic and electronic system failures during the normal operation of systems.

However, since the nuclear EMP, even from a single exoatmospheric detonation, covers a wide area of the ground and the atmosphere above it, nuclear EMP can produce electronic system failures at many widely distributed points simultaneously. Unless special nuclear EMP recovery preparation and training has been implemented, system operators will have no experience with recovering the system from simultaneous, widely distributed multifailures and would have to discover how to recover from such failures at the time they occur, which would be a highly stressful time.

I know of no training in U.S. commercial systems focused on multiple, widely spread, simultaneous failures of highly reliable equipment.

Let me turn now to nonnuclear electromagnetic weapons. These are typically high-powered, radio frequency or microwave devices for which there is a great deal of interest in the world today, and there is a substantial history of interest from the Soviet Union's technology and that of others.

These weapons as well, these nonnuclear electromagnetic weapons, have several characteristics that could make them attractive to an adversary of the U.S. On the other hand, they have the potential disadvantage of requiring closer proximity to their targets to be effective than do nuclear EMP weapons. For example, a small radio frequency device might have a range measured in feet, while a relatively large, again nonnuclear radio frequency weapon might produce upset or damage in electronic systems at ranges measured in hundreds of feet and, of course, through basically what we call electronic countermeasures could cause interference up to ranges of 100 miles.

Radio frequency weapons, however, are more suitable for covert use than are nuclear EMP weapons. A targeted asset might not realize that its problems are the result of a radio frequency or high-powered microwave attack, or even that a radio frequency weapon attack has taken place at all. And if such nonnuclear radio frequency weapons were used simultaneously against multiple sites, they could cause confusion and could slow restoration efforts because of a multipoint failure problem.

The ability of radio frequency (RF) weapons to be used selectively and intermittently as well as to be disguised as ordinary objects from briefcases to trucks could allow an adversary's covert operatives to interfere with U.S. or allied systems in a more controlled manner than a nuclear EMP attack.

And finally, RF weapons provide an opportunity for their users to escape detection, capture and potentially could be used repeatedly against U.S. assets. A truck-mounted RF weapon, for example, likely would be large enough to act from at least a few tens to 100 feet and mobile enough to have a reasonable chance of escaping before detection.

It should be noted, of course, that RF weapons, nonnuclear ones, are not as damaging over a large area as are nuclear EMP weapons. But in regard to a specific target against which they might be employed, both nuclear EMP and RF weapons can produce effects ranging from temporary interference, to the need to shut down and restart a system, to physical disablement of the targeted system by literally fusing or melting sensitive internal components. Especially due to the greater applicability of RF weapons for covert use within the United States, RF weapons, as well as nuclear EMPs, should be given serious consideration.

Let me describe a range of the type of effects that you can experience from both EMP and RF weapons, and then I will summarize, or I will conclude by describing examples of easy errors to make in doing EMP testing and analysis that I have seen in my experience with this field.

At the lowest levels of field strength, the complex world of electronic warfare involving nonnuclear generation and transmission of signals has been present for many years and, in fact, was a major theme in World War II. I won't address that particular aspect of

electromagnetic warfare today any further. As nonnuclear electromagnet field strengths increase, signal carrier and modulation effects, usually involving continuous wave or nearly continuous electromagnetic field interaction in ways not envisioned in the design of the target system, come into play. In addition to pickup on deliberate system antennas, the most likely coupling mechanisms of these signals and, for that matter, all those that I am going to describe from this point forward is the pickup on other conductors extending from the core of the system and acting like electromagnetic antennas.

Examples of these effects include the use of a conventional warfare (CW) carrier with an audio modulation picked up on telephone lines attached to a computer, rectified by the semiconductor devices in the computer and interpreted as a telephone control signal, thus resetting modems and other features of a computer; and another example, the penetration of a microwave electromagnetic signal into a missile, such as an air-to-air missile or an air-to-ground missile, where the signal is rectified and interpreted as a missile guidance signal and navigation command, causing the missile to go off target.

At still higher electromagnetic field levels, both nuclear and nonnuclear signals can be induced that are comparable in size to the normal signal levels in a digital system, the one bit versus the zero bit, for example, injecting anomalous bits, corrupting data and/or producing system upset. This injection of erroneous digital information into systems can be as benign as causing a flicker on the screen, or it can also cause a computer to lock up, which is a more typical response, and requires the computer to be restarted, rebooted, as they say. But in relatively autonomous systems like missiles or unmanned aircraft, particularly missiles in powered flight, which require active guidance to maintain their stability, not to mention their navigation, a lock-up of the computer is equivalent to the destruction of the system. There is no time to reset on a missile in flight.

At still higher electromagnetic fields than those that cause digital upset, signals induced on conductors that lead into semiconductor junctions can cause what is called a reverse breakdown of those junctions, and that, in turn, can then dump the power supply connected to the semiconductor through the junction in the wrong direction and cause the junction to fail permanently. This only occurs when the system is powered, but the effects can be catastrophic, and they can be apparent on power supplies, normally very rugged equipment, as well as on signal-processing electronics.

Then finally, at still higher electromagnetic field levels, just the direct EMP or RF weapon-induced signal can have sufficient power and energy to cause direct damage to semiconductor devices even when the system is turned off; and those are at the highest levels.

Let me summarize briefly by describing five common errors I have seen in doing testing and analysis of electromagnetic effects on military and other systems. There is some tendency to regard the item that is responding to the electromagnetic effect as the box rather than the box with all the conductors extending to it, even fiberoptic conductors, because those designed for outside use and designed to be pulled through conduits inevitably have steel or

other conductive wires protecting the fiberoptics. So the antennas are the dominant pickup mechanism for EMP, not the box itself, and even though I have designed simulators for use on things like missiles, which don't tend to have a lot of wires on them once they are launched, use of those simulators for things like telephone switching systems is really not appropriate unless electromagnetic pulsers are attached to the cables. It is not a box response. It is a box plus antennas response issue.

I have seen systems tested with power off, even though it is clear that having power on the system makes it much more susceptible than having it off, and power off versus power on is a major issue. Clearly, systems would be used with power on, and they should be tested with power on.

I have seen systems tested in a quiescent state where they are not functioning, where subsystems are not exchanging data from one to another, and, therefore, the prospect of corrupting that data is small; whereas if a system is actually functioning, the data exchanges are taking place, and they are more susceptible to EMP.

I have seen systems well-designed with shields, which are operated in the field with the shields open. This is particularly true with personnel access hatches, where you might have an excellent electromagnetic shielding door, but if the personnel find it more convenient to leave the door open, then much of the shielding has been lost, or if wires have been run through the open door, they act as antennas directly into the electronics.

Finally, I have seen the issue of when a failure occurs, confuse EMP analyses, the most likely components to fail are first those near the outside world, near these EMP antennas, the conductors going into a system, and the components most likely to fail first are the weakest ones. I have seen tests where several components failed, and when they were replaced and tested again, they didn't fail, and people would say, well, this must have been a test anomaly. In fact, what they were doing was weeding out the weakest components near the interface and replacing them with statistically stronger components. Now, that is fine if all the operational systems you deploy in the field have also gone through this EMP trial and you have been able to weed out the weakest components as well, but generally that is not done, and, therefore, the weak components are left in the systems that are deployed in the field and will fail at the first high-level pulse.

So even when tests and analyses have been run on systems, one has to look at the results very skeptically and with the benefit of experience that we have gained in testing systems over many years.

I guess I would finally like to say that I have seen major military systems fail as low as in order of magnitude below the level that Mr. Jakubiak showed there, and not failed at all at the highest levels we could produce, depending on whether they had been hardened or not. Thank you.

Mr. WELDON. Thank you, Dr. Graham.

[The prepared statement of Dr. Graham can be found in the Appendix on page 63.]

Mr. WELDON. Dr. Wood.

STATEMENT OF DR. LOWELL WOOD, MEMBER OF DIRECTOR'S TECHNICAL STAFF, LAWRENCE LIVERMORE NATIONAL LABORATORY AND HOOVER INSTITUTION

Dr. WOOD. Thank you, Mr. Chairman and distinguished Members. I am grateful for the invitation to appear today. Like Dr. Graham, my esteemed senior colleague, I also commenced EMP studies in 1962, as my graduate advisor Willard Libby had recently retired from a long term of service as the Commissioner of the Atomic Energy Commission, and he assigned me EMP analysis problems kind of as exercises for the students, as he was then very keenly concerned by them.

Indeed, electromagnetic pulses, EMP, generated by high-altitude nuclear explosions have riveted the attention of the military nuclear technical community for more than three and a half decades since the first comparatively modest one very unexpectedly and abruptly turned off the lights over a few million square miles of the mid-Pacific. This EMP also shut down radio stations and street-lighting systems, turned off cars, burned out telephone systems and wreaked other technical mischief throughout the Hawaiian Islands nearly 1,000 miles distant from ground zero.

The potential for even a single high-altitude nuclear explosion of a more deliberate nature to impose continental-scale devastation of much of the equipment of modern civilization and of modern warfare soon became clear. EMP became a technological substrate of the black humor, "Suppose they gave a war and nobody came.".

It was EMP-imposed wreckage, at least as much as that due to blast, fire and fallout, which sobered detailed studies of a postnuclear attack recovery process, the PONAST studies of the 1970s. When essentially nothing electrical or electronic could be relied upon to work even in rural areas far from nuclear blasts, it was surpassingly difficult to bootstrap national recovery, and postattack America in these studies remained stuck in the very earliest 20th century until electrical equipment and electronic components began to trickle into a Jeffersonian America from abroad.

For obvious reasons, the entire topic of EMP was highly classified, and congressional oversight was generally circumspect and conducted in closed session. Indeed, this is only the third even partly open session of congressional oversight devoted to the EMP topic of which I am aware, and I congratulate you and your colleagues, Mr. Chairman, for the extraordinary vision and dedication to bedrock, albeit less fashionable, aspects of the Nation's security which are evidenced by this morning's hearing, as well as for the exceptional expertise of your staff on this subject embodied by Dr. Peter Pry.

The third decade following the high-altitude tests of the early 1960s saw the expenditure of roughly five billion present-day dollars by the Defense Special Weapons Agency, now part of the Defense Threat Reduction Agency, and its predecessors, the Defense Atomic Support Agency and the Defense Nuclear Agency, to develop a detailed working-level understanding of EMP and related nuclear effects phenomena and the consequences for both our own and our adversaries' military hardware systems. Substantially larger sums than this $5 billion were expended by other components of DOD in order to express this understanding as force in being,

primarily to defend especially vital military equipment against EMPs' destructive effects. Regrettably these defensive efforts directed towards strategic military capabilities were not perfectly fruitful.

To be sure, there were some outstanding success stories. However, a number of important military systems were quite incompletely defended, and some were defended only on paper. Even more regrettable was the fact that much military hardware and systems, especially those not considered vital to the conduct of strategic war, weren't hardened against EMP very much at all.

I strongly concur with the remark that my colleague Dr. Graham just made, that I know of major military systems, some very important to the Nation's warfighting capabilities, which were documented to have failed at EMP levels in order of magnitude and more below those which Mr. Jakubiak represented to you.

As a result, at the present time our national profile of vulnerability to EMP attack is highly uneven, with large parts of our military machine and virtually all of the equipment undergirding modern American civilization being EMP-vulnerable.

Through the end of the Cold War, our national posture, though unfortunate, arguably could be tolerated. Only one nation, the Soviet Union, could mount EMP attacks on the U.S. and likely only as the first punch of a fight to the death conducted with EMP-hardened means. Indicated responses to any EMP attack then were clear.

To be sure, as you noted at the outset, Mr. Chairman, the maximum Soviet capability to impose such attacks still exist today in the strategic forces of the Russian Federation, and I unhesitatingly predict that it will continue to exist for many decades to come.

Today we also watch the ongoing diffusion by purchase and perhaps by illicit routes, at least as much as by indigenous development; as the Rumsfeld Commission documented in the case of ballistic missile proliferation, we see the ongoing diffusion of nuclear weapons technologies throughout the Third World. Just last week, for instance, former Secretary Perry told the Nobel Institute that he expected to see nuclear weapons in the hands of the Iraqis, the Iranians and the Syrians, in addition to those who already have them.

At the same time, we are compelled to acknowledge the unique opportunities for defeating both advanced U.S. forces abroad and the American Nation itself which are offered to our adversaries by EMP-centered attacks. You have heard a great deal about the revolution in military affairs and the promise which it extends for far greater effectiveness of a postrevolutionary American military. You have likely heard far less about the classic Achilles heel which EMP poses to any information-intensive military force completely dependent for its electronic data flows on EMP fragile integrated circuits.

There arises the regrettably real prospect that EMP weaponry, assuredly if nuclear and perhaps, as my colleague Dr. Graham just highlighted for you, even if it is nonnuclear, could abruptly transform a future Desert Storm type of operation from another historic victory to a memorable American defeat.

Such EMP weaponry could also be deployed with only slightly more advanced means from space to rip up the electrical and electronic infrastructure of the American homeland. Thus, the de facto national policy of nakedness to all of our potentially EMP-armed enemies takes on ever more of the character of national scale masochism. It is perverse and irrational, and it is assuredly not necessary or foreordained.

Relative to the two years since I last testified before you on this subject, it is useful to ask what has changed and what has not. The natural laws governing EMP haven't changed an iota, nor has the EMP-oriented Russian strategic war machine. American preparedness against EMP attacks hasn't improved. Rather, the operation of Moore's Law continues to endow our national infrastructure with ever more intrinsically fragile electronics.

Notably, Third World nuclear weaponry capabilities and long-range rocketry both continue to advance rapidly, as the Rumsfeld Commission reported. Specifically, North Korea, a nation which has elected to lose an appallingly large fraction of its population to starvation over the past few years, and which is still formally at war with the United Nations and with the United States, nonetheless has been allowed to gain nuclear weapons capabilities and is just now on the threshold of ICBM ownership. In short, our previously poor national position vis-a-vis EMP attacks has deteriorated markedly over the past two years, and it is no exaggeration to forecast future major peril.

It is therefore heartening to see the Congress continue to engage the EMP threat, for too much of the DOD has seemingly resigned itself or, worse by far, is actively deluding itself regarding the nature and severity of EMP.

That said, I must commend those dedicated and competent DOD components and staff, both civilian and military, who continue to labor to harden with respect to EMP crucial national warfighting capabilities, strategic and tactical. While those belittling the magnitude of the consequences of EMP threats should be judged harshly by the Congress, the more so when the shakiness of their technical premise becomes manifest, the many DOD people and organizations of integrity and fidelity to the enduring national interests vis-a-vis EMP are most deserving of praise.

For the sake of America's future in a nuclear multipolar world, I appeal most earnestly to you and your colleagues, Mr. Chairman, to remain seized of this vital issue, for it is one of the few which in and of itself carries the potential of military victory or defeat; perhaps even of national well-being or devastation.

Thank you, Mr. Chairman. I will be grateful if my prepared statement can be included in the record. I also ask your attention to the fact that I am here today as a private individual, not necessarily representing any opinions other than my own. I have verified, however, the viewpoints I have expressed and will express in subsequent testimony seem congruent with the community consensus as represented in documentation in the pertinent files of the Defense Threat Reduction Agency. Thank you, sir.

Mr. WELDON. Thank you, Dr. Wood.

[The prepared statement of Dr. Wood can be found in the Appendix on page 72.]

Mr. WELDON. I thank all four of you, and your statement will be entered in the record as will all the statements. We appreciate the testimony, and as we had hoped and wanted, and as we have seen and observed, there is a significant amount of difference in the assessment of what the impact would be of an EMP laydown or the EMP threat, and I think also the preparation of response, and I would hope that during our time of questioning, our colleagues would explore those significant differences.

Let me start out by asking the question, is it not true that in the past both the strategic doctrine of the U.S. and the Soviet Union had an EMP laydown at the beginning of a nuclear attack on the other country? Hasn't that been a part of the strategic doctrine of both nations?

Dr. WOOD. Yes, Mr. Chairman, it has been. In all of the war games in which I have been present and all the ones which I have studied when I have not been present, the attack, the red attack, always begins with an EMP laydown on blue, that is to say a Soviet laydown on the continental United States by multiple multimegaton high-altitude bursts.

Mr. WELDON. Mr. Jakubiak, would you agree with that?

Mr. JAKUBIAK. I agree with that.

Mr. WELDON. Dr. Bernardin?

Dr. BERNARDIN. I cannot speak to that subject.

Mr. WELDON. Dr. Graham, do you concur with that?

Dr. GRAHAM. I don't have current information on that, Mr. Chairman.

Mr. WELDON. How about in the past, did your experience indicate that that, in fact, was the case?

Dr. GRAHAM. Yes.

Mr. WELDON. That being said, Mr. Jakubiak, maybe I misread your statement, but it seemed to me as though there was some question as to whether or not EMP was an effective tool.

I guess I would ask the question, why would both major superpowers have an EMP laydown as the key start of a nuclear confrontation if, in fact, there was not a degree of certainty that, in fact, this was a good tool?

Mr. JAKUBIAK. In my statement, sir, I basically indicated that, in fact, the U.S. military has assumed that, in fact, unless the equipment is protected against an EMP, it would fail under an EMP environment, and therefore we have taken steps to protect those military circuits to the levels that we feel are the threat levels and provide a protection for those critical circuits.

My statement basically was geared towards the use of COTS equipment, which is now becoming more prevalent within military systems, and, in fact, the COTS equipment has been showing up as being surprisingly resistant to EMP effects. To counter any deficiencies that equipment is, in fact, tested on a case-by-case basis. The levels are, in fact, identified that the equipment fails at, solutions identified, and, in fact, modifications are retrofitted to that equipment before they are fielded.

For systems that go into an EMP environment, EMP threat environment, are intended to be used in an EMP threat environment, they are, in fact, protected at the EMP levels that are identified as the threat.

Mr. WELDON. Mr. Jakubiak, your statement doesn't seek, was at least my impression—and I certainly could be wrong, I have been wrong in the past—but in the hearings we have held in the past, one of which was an opportunity to have General Clark here, he basically left me with two impressions. One, we were dismissing the potential threat; and, two, we were characterizing the cost as being too excessive to deal with as the reasons why we weren't taking aggressive steps.

Furthermore, my understanding is, and maybe again I am incorrect, that the only systems that have really been hardened are ICBM systems that would be used in the event of an all-out nuclear attack against the Russians, and that, in fact, the rest of our systems are not hardened to any level of certainty that they could withstand an EMP. That may be wrong, and I am going to ask you each to respond to that, but that has been my assessment.

I guess the specific question is, I think it was in Dr. Woods' testimony, he mentioned that we had spent at one point in time $5 billion, I think was the figure you used. Is that correct, Dr. Wood?

Dr. WOOD. That is what has been spent, just by what is now the nuclear component of the Defense Threat Reduction Agency, sir. That is a small fraction of what has been spent by DOD overall.

Mr. WELDON. I don't know of any specific line that is being spent on EMP in our current year's budget, and I have chaired this subcommittee for five years, and I have asked this question frequently. My suspicion is that because no one service has EMP as a priority program, as we have faced a very difficult budget process, that funding and investment in hardening has gone by the wayside. I would ask you all to respond to those statements that I have just made in the positive or the negative. Why don't we start with Mr. Jakubiak.

Mr. JAKUBIAK. The requirement for an EMP protection is addressed on a system-by-system basis when you get outside of the nuclear command and control area. The ICBM systems you talked about, they are protected. The SSBN systems are protected. The bomber systems are protected. All of the communications that are used to provide survivability for execution of those forces are, in fact, protected to EMP levels that are specified in a DOD standard that has been produced by, in fact authored by, the Defense Threat Reduction Agency.

When we get to the tactical battlefield, the individual systems that are used in the battlefield come before a requirements panel. The utilization of that equipment as to what environment that equipment might be used, whether it would be—whether it would be used under an EMP umbrella or EMP threat environment is considered, and a decision is made as to whether that equipment will, in fact, be provided EMP protection or designed to EMP standards. For instance, the M–1 battle tank, that is EMP protected. That is a tactical system, not a strategic system. There are several others that I will be able to address in closed session of tactical systems that, in fact, have been protected to EMP standards.

Mr. WELDON. Would the others like to comment on this statement? Dr. Graham first and then Dr. Woods.

Dr. GRAHAM. Mr. Chairman, as far as the cost issue goes, on those systems which have been EMP-hardened, the cost of the hardening is embedded in the system cost.

My experience is that with systems designed from the ground up for military application, if the hardening is taken into account early in this system, conceptual design and development, it can be as small as a percent or two of the system cost.

On the other hand, if the system is completely designed, engineered, manufactured, and then you want to harden it, it can be up in the tens of percents of system cost or higher, and generally is regarded as prohibitive. So when you do it is very important.

I have much less experience with COTS equipment, but my impression is that at least in cases where you are using what might be called global hardening, shielding and penetration control, you are probably going to come into about the same situation, where thinking of it early has a tremendous payoff, including the EMP hardening early is very valuable.

I would also say that when looking at hardened systems, hardened against EMP, you have to look at what was in the design and manufacture of the system, how the system was tested and how the system is maintained.

It is perfectly possible to start out with an EMP-hardened system, but because the maintenance program and the operational program doesn't incorporate EMP-related issues, the system can become vulnerable very rapidly.

Finally, I would like to say that you mentioned strategic missiles. There are other systems that have been designed for EMP hardness. For example, the best example, the best case of an airplane being hardened to EMP, I know, is the Navy and Strategic Command's EA–6B Tacamo aircraft, which is a highly modified 707, which has been very extensively hardened to EMP, and there is still some maintenance program associated with EMP ongoing.

Mr. WELDON. Dr. Wood.

Dr. WOOD. It is indeed the case, Mr. Chairman, as you said, that the strategic war machinery of this country has received by far and away the greatest attention with respect to EMP hardening, and, at that, the unhappy fact of the matter is that these efforts have been incompletely successful. I obviously can't speak to details except perhaps in closed session.

The situation that Mr. Jakubiak seems to be emphasizing is concerned with tactical capabilities and, in particular, with COTS equipment involved in tactical circumstances.

It should be pointed out that there is essentially no COTS equipment in the strategic war machine, both because the strategic war machine has not seen significant amounts of upgrading since the emphasis on COTS equipment utilization in DOD, and also because of the very special nature of much of the equipment, it is really not conducive to use of COTS gear. So most of the—most all of the use of commercial off-the-shelf, or COTS, equipment is necessarily confined to tactical systems.

Because of the disagreement which first surfaced when Congressman Bartlett held a discussion along these lines in his office most of a year ago, I went out to the Defense Threat Reduction Agency and spent most of the day reviewing the studies and the associated

documentation that was referred to by Mr. Jakubiak in these previous discussions, and I discovered several things that were pertinent in their fundamentals to the points that have come up.

First of all, the studies, and in particular the Army study to which Mr. Jakubiak made extensive reference, has in its notes an indication that cables were not connected to the study during the EMP testing. As my colleague Dr. Graham has pointed out, it is not sufficient to analyze the box. It is required to analyze the box and the cables whenever you are looking at the EMP hardness of any equipment, because it is the cables that intercept most of the energy of the electromagnetic pulse and drag it into the equipment where it then does damage. If you don't have cables connected during EMP testing, you really haven't tested under circumstances which are at all realistic. It is a little bit like showering in a raincoat. The water flows, and it trickles down the drain and so forth, but the body doesn't see much water.

The second point is that the study notes also indicated that the equipment was sometimes powered up and sometimes was not powered up during the testing. Again, as Dr. Graham has pointed out, reverse breakdown of semiconductors depends very strongly for its effectiveness in damaging equipment with the equipment being powered up. If it is not powered up, there is no energy in the power supply that then flows into the semiconductors that have undergone reverse breakdown, and there is no damage along that mechanistic line.

On the other hand, if the equipment is powered up, it is the power supply itself whose energy tends to destroy the compromised semiconductors. So it is extremely important if you are doing a full-up EMP vulnerability assessment to have the equipment not only have its cables connected, but to have it powered up, and that was not always the case in these studies. It apparently was not a subject that was given a great deal of attention by the people conducting the study.

Indeed, the people conducting this study documented their statement that it was hastily constructed test equipment, that the systems were using only very small data sets, and their manifest and declared orientation was to find specific problems and see how they could fix them on particular pieces of equipment with insertion of more or better components.

From a physics standpoint, probably the most striking thing about these tests was that they used only the lowest frequency component of the EMP threat spectrum, the so-called E–3 component. They did not use what I think Dr. Graham and I would both tell you in most circumstances is the most threatening portion of the EMP spectrum, namely the E–1 component, the high frequency component that tends to be especially penetrating of enclosures, especially unforgiving of cracks and other sort of deficiencies in these protective enclosures, and what, in tests conducted by the Defense Nuclear Agency over the decades, has been the most damaging to most types of electronic equipment.

It is the low-frequency component, the E–3 spectrum, against which protective compartments, protective decoupling devices and so forth is most effective. It is not a blunder on the part of the people doing the tests. Under some circumstances the E–3 threat spec-

trum may be the most interesting to look at, but it is not the most threatening to look at.

So for these reasons, I found the tests that were done by the Army chemical and nuclear laboratory to certainly be commendable in that they were looking for inexpensive, quick ways to upgrade COTS equipment to the point where it might possibly be useful, but they were in no sense up to DOD standard with respect to how you thoroughly evaluate the EMP vulnerability of equipment, and, therefore, I would caution you that the results which Mr. Jakubiak presented to you in summary—and I am certainly not suggesting it was anything other than in good faith that they were presented, but I must caution you that those results from a technical standpoint can be impeached from several directions.

Mr. WELDON. Thank you.

One final quick question, and I would like you to try to narrow this down to a simplistic answer in what is a very complicated and difficult subject, I realize, but I am going to try and do this. We are doing this public hearing for the American people.

North Korea, possessing, let's say, a low-complexity SCUD missile, puts a nuclear warhead on the top, puts it on a ship so we don't know it is North Korea, fires that missile into the atmosphere off of our coast and detonates it. How prepared is America, from a military systems standpoint and a civilian standpoint, to respond? Would we be able to handle it with no problem? Would it create some degree of problem for perhaps the military, or would it wreak havoc on the people of our country?

I would like to go down the row and ask each of you what you think would be the impact today if North Korea, which both has the SCUD missile capability and a warhead capability of a low-yield capacity, if they, in fact, deployed an EMP, what would be the impact on America both militarily and civilian? Mr. Jakubiak? Would it be significant or nonsignificant?

Mr. JAKUBIAK. A single weapon off of the coast of the U.S. would be—naturally it would be a concern, but it would not be a drastic or catastrophic event that would wipe out the civilian infrastructure. That is my personal opinion. I think that the people you would have to talk to to see the more analytical approach as to what the impact on the infrastructure would be would be the national communications systems, the Office of National Communications System, which is responsible for overseeing the survivability of the public telephone switching network infrastructure. Their results have shown that, in fact, that infrastructure would survive, no problem; that, in fact, your phone calls would get through. In fact, even in a panic calling environment, where people repeatedly would try to redial again, they have shown that, in fact, the infrastructure would survive, and your calls would get through at a 70 percent rate, which by no means is a catastrophic event.

In the area of the military communications systems, our nuclear command and control system would continue to operate properly. We would be able to detect that launch. We would be able to advise the President as far as what his options were, in fact, from a nuclear command and control perspective. And, in fact, if any activation of nuclear weapons was, in fact, required on the U.S., that could still occur after the EMP occurred.

Mr. WELDON. Who would we attack?

Mr. JAKUBIAK. I am just saying that, in fact, the President would be advised of his options as far as what nuclear capability he has to respond if he wants to respond.

Mr. WELDON. So even if it was an EMP laydown where no damage was done to individuals, you think perhaps we would think that was justification to have a nuclear response against another country?

Mr. JAKUBIAK. The President is always advised of what his nuclear capability is as far as the scenario.

Mr. WELDON. Dr. Bernardin, what would be the impact of that kind of a one, single warhead detonation would be?

Dr. BERNARDIN. Mr. Chairman, I am only able to speak to the field levels that would be produced on the ground, and, in fact, I have in closed testimony some presentations to show on what North Korean weapons would produce.

Mr. WELDON. Let's say a 1-kiloton warhead that is fired on a low-complexity SCUD off of our eastern coast, what would be, in your personal professional opinion, the impact of that? Could we handle it, no problem, minimal problem, significant problem, civilian and military today?

Dr. BERNARDIN. The effects on our civilian and military infrastructure I am not prepared to speak to. That is outside my area of expertise.

Mr. WELDON. As a professional. You are a physicist.

Dr. BERNARDIN. I am. My impression would be that we would have low effects due to a 1-kiloton-type weapon detonated over the United States.

Mr. WELDON. Dr. Graham.

Dr. GRAHAM. Mr. Chairman, I don't know the answer to your question, and I—.

Mr. WELDON. Let's increase that to 10- to 20-kiloton.

Dr. GRAHAM. Either way it turns out the fields more or less are logarithmic in the nuclear weapons yield, so they vary fairly slowly with the yield, and I don't believe the analysis has been done which would give a definitive answer to that question.

However, pieces of the analysis have been done and other systems looked at that while I think the United States would survive such an event, there are such a large number of capabilities, both in our military forces directly and even more in our civilian, supporting infrastructure that we need, that it is quite possible that the effects could provide a major disruption and delay in our activities.

As you know, to deploy military forces in an expeditionary fashion overseas, we require massive logistics to get them there, equip them and sustain them there, and that requires a heavy use of the civilian infrastructure, air transport, surface transport, telecommunications, computing capability. Monetary flows in the United States are primarily electronic today and throughout the world. All of those capabilities depend heavily upon civilian electronics and somewhat military electronics. All of those would be subject to disruption and confusion. None of the civilian infrastructure that I know of has been designed with EMP threats in mind, and, therefore, is likely to experience some degree of disruption. So

if we were in a time-critical situation where we have to get men and women to a theater rapidly, such an attack could cause us a significant delay and, therefore, a military problem.

Mr. WELDON. Dr. Wood.

Dr. WOOD. Mr. Chairman, the question or the set of questions that you posed are certainly the most pertinent ones. They also elicit answers which not only are a bit extended, but really is—some portions of them would have to be made in closed session.

But to speak to the issue as much as feasible in open session, the North Koreans certainly have the ability to deliver a small nuclear explosive to the U.S. at the present time. The ballistic missile capability which they have demonstrated could deliver a warhead weighing substantially more than a tenth of a ton and substantially less than one ton anyplace that they chose to in the United States, including any height of burst that they choose over the continental United States.

So that is something which I think the Rumsfeld Commission predicted would happen. It is something of which the test of last August 31, 1998, indicated they indeed had that capability.

The press reports are saying that they could strike Alaska or they could strike Hawaii. That is striking in reference to a 1-ton warhead. With a fractional-ton warhead, that same missile could deliver that warhead to any point over the continental United States, over the 48 contiguous states. It is not necessarily the case that the referenced 1-ton warhead is what the North Koreans would use. It is very well known that U.S. strategic warheads that are in stockpile at the present time have masses of tenths of a ton, and not very many tenths of a ton. So if the North Koreans had access to a single sheet of paper, whether it could come to them in a fax from a Soviet nuclear weapons laboratory, they could use the materials that they are known to have in hand to create a warhead, not, Mr. Chairman, that was one kiloton or even ten kilotons, but substantially higher yield than that.

My colleague Dr. Graham has said that the EMP yield of a warhead is very weakly dependent on its energy yield. That is true, but it is true in spades. Special purpose nuclear warheads, on a kiloton scale, can have much more of EMP effect than ordinary nuclear warheads on the megaton scale. Less than ten kilotons properly employed in the type of warheads which have actually been examined, both in the Soviet Union and in the United States experimentally, warheads of less than 10-kiloton yields can put out very large EMP signals. So it is necessary to understand that it doesn't take a megaton to do an awful lot of damage. You can do an awful lot of damage in ten kilotons or less.

Mr. WELDON. What would be the damage done by that, in your opinion? That is what I am trying to get at, and I know there are all kinds of variations. Are we prepared, militarily and civilian, for the kind of capabilities North Korea has?

Dr. WOOD. In order to be noncontroversial, I will just quote a CIA estimate that has been briefed by a senior cognizant CIA national intelligence officer on the Hill here during the last year, on an unclassified basis, where he considered a hypothetical laydown of the type that could be posed by a Taepo Dong missile over the central United States and presented the unclassified calculations of

what the EMP yield or the EMP consequences would be at the coasts of the United States; in other words, most distant from the explosion. The EMP field strengths that were calculated there—and nobody seriously questions these calculations, they are with tool sets that are community tool sets that have been around for decades—with the field strengths that were demonstrated at the coasts, the maximum distance, you would see upset or damage to a wide variety of civilian equipment that has been documented to fail at these field strengths, and you would see some damage to military equipment.

The consequences of such a laydown are very strongly dependent on what you assume is the nature of the explosive, as well as what you assume is the vulnerability of the equipment, but with documented equipment vulnerability of the type that has been measured for sensitivity to these threat spectra during the last two to three decades, you would see major damage as far out as the coasts to civilian gear. You would also see it to a substantial amount of military gear.

It must be said, sir, that Mr. Jakubiak is vastly more optimistic than I am with respect to the vulnerability and survivability of civilian infrastructure. He said the telephone companies said that their equipment would just come through unscathed, or essentially unscathed; that you would not notice the difference essentially. Well, this is the same telephone company that can't carry my traffic when I try to call my mother on Mother's Day. And they aren't out 70 percent or 30 percent of the time, they are out for hours at a time, where I get an all circuits are busy now, please place your call again next weekend.

The Defense Department didn't believe that the telephone company would survive a nuclear EMP laydown. They built an independent telephone system during the Cold War to carry vital strategic traffic, and they did all kinds of things that the telephone company doesn't do in the hopes that that system might actually survive a nuclear laydown. But neither the Strategic Air Command, nor the Joint Chiefs of Staff, nor the Defense Communications Agency during the Cold War believed that the civilian telephone or telegraph or whatever infrastructure would survive a nuclear laydown in any fraction. They thought it would be knocked down completely and forever, and this was extensively documented, Mr. Chairman, in the studies, the Post Nuclear Attack Survivability and Recovery Studies (PONAST) of the 1970s. There was nothing left. It was totally burned down, and statements by AT&T or whoever else may be making such statements that they are in vastly better shape today are very, frankly, sir, hogwash.

Mr. WELDON. Thank you.

Mr. Pickett.

Mr. PICKETT. Thank you, Mr. Chairman. I guess what we are all really concerned about here is the basic question—we are the government policymakers here, and we are trying to get an assessment of whether or not there has been an adequate determination of what the threat is to our country, and then whether or not we have developed an adequate response to the threat.

So you all know that we as elected representatives operate in an environment where we have to somehow make an assessment of

the technology involved, the economics involved and the response that is fashioned for our country, and we have to bring all of this about in a political environment where we have to persuade the public that what we are spending that money for is justified.

So my question is, first of all, do you on the panel believe that there has been an adequate assessment of the threat to our country from EMP; and, secondly, if there is a threat there that requires a response, has enough been done by our country to respond to the threat, and, if not, can you make some suggestions about what addition would have to be done in order for our country to have an adequate response to the threat that we have identified?

Dr. WOOD. Mr. Pickett, by far and away the most effective thing that could be done in terms of cost efficiency to see that our country doesn't suffer damage from the EMP threat is to make sure that nuclear explosions never occur over our country.

Mr. PICKETT. You are alluding to an adequate missile defense system; do I understand you correctly?

Dr. WOOD. That is one approach to it, sir.

Mr. PICKETT. Yes. Okay.

Dr. WOOD. There are others that take exceedingly dire retaliatory threats that would presumably have something—some efficacy along those lines, if those threats were considered credible.

Mr. PICKETT. Anyone else? Yes, Dr. Graham.

Dr. GRAHAM. Well, I agree with Dr. Wood about the importance of trying to prevent nuclear weapons explosions over the U.S. Using every diplomatic, economic and military capability we have or can develop, I believe we would still face the possibility that it might occur. For example, one of the ways an offensive nuclear weapon on a missile can be armed is in what is called a sympathetic or a salvage fusing mode, so that even if you intercepted above the atmosphere before it reaches its target, once it knows it is being attacked, once the offensive nuclear warhead knows it is being attacked, its fusing system may choose to detonate itself there to get at least the EMP and space radiation effect of the weapon.

So it is very hard to eliminate that possibility completely, although we should certainly take every action we can to do so.

I think from the point of view of the Congress, it would prove an interesting exercise to ask the Defense Department and officials in the national security area to review the systems which they think should function through a possible at least high-altitude nuclear attack, and then to describe which of those systems were designed to be hard to it, which were tested to be hard to it, which are being maintained to be hard to it, with some description of what is transpiring in each of those areas, and then to do the same thing in the civilian area.

I am familiar with some of the civilian telecommunications tests, in particular a number five electronic switching system test that was done in the Aries simulator, which I did the preliminary design for in 1968. The cables that normally extend hundreds of miles into that system were represented by cables coiled up and placed under the mobile vans it was carried in. So, as we mentioned earlier, that is certainly not a good representation of the stress that the system would receive.

I am not trying to say that this is the complete work that has been done, but it is indicative of the concerns that a review of the subject by your committee might find both informative for you and beneficial for the defense authorities.

Mr. PICKETT. Dr. Bernardin.

Dr. BERNARDIN. I would like to respond to your question, Mr. Pickett. I believe that the United States is investing quite adequate resources in studying the threat; that is, studying what countries are out there that are trying to develop nuclear weapons through the intelligence agencies, and what those weapons might look like through the national laboratories. In terms of identifying how serious is that threat that requires EMP testing, I would point out I believe one of the panel members may have left a misimpression, that there is quite extensive testing that has been done of military systems, and it has been to the E–1, the high-frequency EMP. Dr. Graham just mentioned he tested at Aries facility. That is an E–1 simulator of high-frequency EMP, and as you fly into the airport in Albuquerque, you can't help but notice these EMP simulators that are taking up large areas of space, on the order of a football-sized field. Those are E–1 simulators.

So the military has done quite a bit of testing of EMP for vital equipment, as Mr. Jakubiak talked about which equipment really needs to be EMP-protected.

As far as civilian systems go, I can't speak to that, and I don't know what our vulnerability is on the civilian side.

Mr. PICKETT. Mr. Jakubiak, can you respond?

Mr. JAKUBIAK. Let me endorse what Dr. Bernardin just said, that the military has, in fact, invested quite a bit of money into assessing what the threat is over the years and the changing threat. The threat is different from what it was back in 1970. The threat today is different, and we are looking at that threat on a continuing basis. That is why we have funded the effort at the national laboratories to continuously look at the threat, to tell us if the threat is getting worse or if it is getting better, and designing our EMP programs and equipment to meet that threat in today's environment and in the environment of the future.

As far as the commercial infrastructure is concerned, the military—and I am not involved with assessing what the commercial infrastructure vulnerability is, I have access to the reports that have been done by those that are responsible for that. It is not just the telephone companies. It is the National Communications System, which is a Federal agency that, in fact, oversees the survivability of the commercial telephone infrastructure. It is their reports and their testing that I am quoting here, and it is their performance under EMP environment that I am speaking to when I mentioned that the phone system will work at a 90 percent level with normal loading and at a 70 percent with panic loading under EMP environment. They have tested that to the EMP levels that, in fact, we test military equipment to, and that has been their result. So if you would like to have more information on the commercial infrastructure, I would strongly suggest that you get a representative of their survivability program, the National Communications System, and have him provide a briefing also on the work they have been doing and are continuing to do.

In fact, it is my understanding, from a phone call I had this morning with the National Communications System, the person in charge of the survivability effort, that they are continuing to provide testing on survivability of the public telephone system, and, in fact, their current testing is more concentrated along blast damage than it is EMP, because they feel their system will survive an EMP event.

Mr. PICKETT. Okay. Thank you very much.

Dr. WOOD. Mr. Pickett, you should be advised that the national capability to do EMP testing is basically in shambles relative to 10 or 15 years ago. For instance, the system that Dr. Bernardin referred to that you see when you fly into Albuquerque Airport is the wreck of the trestle system. It has been decommissioned. It has been completely nonfunctional for a number of years. It would take many tens of millions of dollars to bring that back into operational capability.

The national capability to test against EMP vulnerability of satellites and system-generated EMP died when the U.S. ceased to do underground nuclear testing. There are very few of the major facilities that existed 20 years ago, sir, that are in operational condition today, and the ones that are in existence are used very seldom.

This is a Potemkin village of an EMP vulnerability and hardening program that exists at the present time, sir. I strongly suggest that this committee would be well advised, in all respects, to ask for documentation along these lines. You will find that there is nothing behind the facade to a first approximation.

Mr. PICKETT. Thank you.

Mr. BARTLETT [presiding]. Thank you very much. We must recess briefly for another vote, and it will be very brief this time.

I would just like to pose a question that I would like you to be thinking about while we are gone. Our last real life experience in EMP effects was Starfish, 1962. There was essentially no electronic equipment in Hawaii. It was electrical equipment. There was massive, relatively massive, disruption of those crude, crude systems in 1962.

I am having a lot of trouble with the simulations today that can't come even close to that real-life test. I mean, what you are telling me is that these highly vulnerable systems that we have today, because we are so sophisticated, would be far less affected by EMP than these crude systems that we had in Hawaii that shut down their telephones, turned off their street lights. I am just having trouble with the validity of your tests.

We have to go to the real world sometimes to get a validation of your tests. I am just very skeptical of the validity of these tests when they can't come even close to predicting the kind of damage that you had in the only real life experience that we have had, and I don't know how you can be sanguine about your tests when they can't verify what, in fact, you know happened in Starfish in 1962.

I would like a brief discussion of that when we return, and we must now recess our committee briefly, and we will return shortly.

[Recess.]

Mr. WELDON. [presiding.] If we could reconvene, I would return to my distinguished colleague Mr. Bartlett.

As an editorial comment, I understand in response to Mr. Pickett's questions, that there was a statement that was made that was said could be refuted in a classified session. For the public that is here and the media, I will say this on the record, we will have a classified session after this, and we will have a chance for that data to be refuted, but I will also give those who are criticizing the opportunity, and I will let the public know whether or not there has been a refutation of the claims made by the administration in this case on that data. I can't get into the details of the data, but it is unfair, I think, to just use the item that we are going to do that in classified session, which I understand your reason why, but I also understand that in classified session there may be disagreements over that data, and I plan to make that known to the public if there is disagreement in a classified session between the panelists that we have here.

So I don't want anyone to read the fact that we can supposedly refute something in a classified session that the public will not know. The public will not know the specifics of it, but they will know whether or not Dr. Wood and Dr. Graham, and perhaps Dr. Lunt, disagree with the assertions made in terms of refuting certain items by Mr. Jakubiak.

Mr. Bartlett.

Mr. BARTLETT. Thank you.

Let me come first to the question I posed just before I recessed, and that is how can you be sanguine about your simulation results when they, as I understand, come far short of predicting what we know happened in 1962 at Johnston Island? If I believe your simulation results, then what happened in 1962 didn't happen.

How do you explain that?

Dr. WOOD. There is a fairly noncontentious way to begin to understand that difference, Mr. Bartlett, and that is that the simulations necessarily do not fully represent what happens in the real world. One of the mechanisms or one of the distinctions along those lines that came up during the break, so the break was actually useful for clarifying this, is that when people put these boxes like the large telephone switches into an EMP simulator, as Dr. Graham pointed out, they curl up the cables and set them underneath, and it is kind of like sitting on your hands, if you will, and they then test to see if the equipment inside the box is vulnerable or not.

But in the real—and they sometimes find out that, hey, it survived the test, but in the real world those cables, as Dr. Graham says, extend out for hundreds of miles. They pick up the real, honest-to-goodness EMP, and they haul it into the box through the penetrations, through the protective enclosure, through the back door, if you will, and it is that aspect of EMP which damages equipment inside the box.

Well, if you are working with strategic systems, and your boss, the general, has said, I want you to make absolutely certain that thing is going to survive in a real EMP environment, what you do is you not only set the box inside the EMP simulator, but you inject current representing the EMP into those cables that in a real system go out for hundreds of miles; you inject current pulses into them to see—which is known to represent the EMP that the cables pick up, and you see if it survives under those circumstances.

You often find out that, oh, with current injection the thing died. However, if I just curl the cables up and set them underneath, it came through fine.

So a lot of the difference between the tests and what is seen in the real world is how rigorous the tests are, how close to the real world they are made to be.

There is just an enormous difference between what you can say happened in an EMP simulator and what happens in the real world if the EMP simulator is not realistic. You might as well, in some circumstances, not have done the test at all.

Mr. BARTLETT. Dr. Graham.

Dr. GRAHAM. Particularly concerning the Starfish event, which was above the horizon, but over 1,000 miles from Oahu, the Hawaiian Islands, and approximately that distance from the other islands, a number of events were observed on the islands that were almost certainly related to the EMP from the event. Of course, the EMP wasn't understood at that time, and, therefore, the phenomenon that occurred wasn't understood in any but the vaguest possible way as being something that happened at about the same time as the Starfish event.

However, there was a body of anecdotal data of things that had happened that were unanticipated, coincident with Starfish, and I must admit we were probably a little slow on this, but it wasn't until about a decade later that we made a systematic effort to collect all of that data and describe it. We undoubtedly missed some things that had been lost in the intervening decade, but we had a list of phenomena that were observed, and by that time, say around 1972 or so, we understood the high-altitude EMP effects much, much, much better than we did in 1962.

I don't know of any effort to go back and deliberately simulate those effects by applying electromagnetic fields and currents to the equipment that was affected during Starfish. However, I believe most—the effects that were observed, as best I can recall them, were in generally what I would call generally at least qualitative accord with the electromagnetic field levels from Starfish that were incident on the Hawaiian Island chain.

So it is really a case of not having done all of the simulation and perhaps not even all the analysis we might, but having, I think, a generally plausible agreement between what we discovered had happened on the event and the electromagnetic field strength we expected in retrospect at Hawaii from Starfish.

Mr. BARTLETT. It is fair to say then, I gather, that we do not know the extent of our vulnerability because of our inability to test whole systems and even complements of systems realistically under the kind of environment that would exist with an EMP laydown? Is that a fair statement?

Dr. GRAHAM. I don't think it is quite fair. I would say it is slightly differently. I think you can do reasonably good simulation even on systems that are quite extended, cables running off everywhere, antennas, power lines and so on. All of those systems seem to have the characteristic that the really complicated stuff, like electronics and computers, is in one or a few nodes, and all the stuff that goes off great distances is things like wires and cables and antennas, which are relatively simple.

It is not possible to simulate the EMP field effect by directly subjecting long, long wires to that field. The generators, the EMP generators, would have to be too big to do that. However, by directly injecting the current that we predict would be picked up by those cables, antennas and wires, and possibly simultaneously simulating the fields on the more compact and complex parts of the system, I believe you can do a reasonably good job of an overall EMP effect simulation. Interestingly enough, I think, as we mentioned before, the effects on the wires, that is the current injection tests, will have greater effects than the field simulation tests in most cases.

Mr. BARTLETT. Dr. Wood.

Dr. WOOD. The ability, sir, to simulate EMP for reasonably compact systems that definitely have existed in the past to a regrettably good approximation doesn't exist at the present time. Perhaps the single largest such facility was the trestle facility to which Dr. Bernardin referred to at Kirkland Air Force Base. That could actually take and was built to take an entire B–52 bomber and could subject it to quite realistic of an EMP environment, and was built specifically for that purpose. The comparable facilities existed and were created typically on special-purpose bases at the Nevada test site in underground facilities for testing of exceedingly important spacecraft that had to survive during nuclear explosions in space in a strategic environment, and those facilities were made to be exceedingly realistic because it was discovered that unless you were exceedingly realistic, you got results that were off by a country mile; and they were off, and off in an optimistic direction. That is to say, unless you did the job very realistically, you concluded that your spacecraft would survive, but when you are honest about it, you discovered that they would not. Those facilities ceased to be used nearly a decade ago when the U.S. entered the current testing moratorium.

So when you have sufficiently compact systems, yes, you can do very realistic testing. It is necessary to, in some circumstances, people being just human, to confront folks with the prospect of realistic testing in order to elicit candor from them.

We heard at the present time the telephone company says that the telephone infrastructure would survive extremely well. However, when they were asked formally, less than two decades ago, if they could provide service to the Defense Department during a nuclear war situation, they said, not a chance. So the Defense Department went off and spent well over a billion dollars creating a hardened telephone system of an exceedingly extensive geographic nature, but an extremely limited nature as far as service, to connect the national command authority with the strategic war machine here in North America.

That money was spent not because people were so eager to go out and spend money on a hardened telephone system. It was spent because the telephone company said that there is no chance at all that their systems could survive because they were confronted with a prospect of realistic testing.

The same situation pertained to the electric power system. Three decades ago the electric utilities of this country formally assured the government that the power system would ride through a nuclear war; that because there would be so much load lost as cities

were vaporized, that there would always be an excess of electric power generating capability relative to what was needed throughout a nuclear war and afterwards.

Then came the 1965 blackout in the Northeast, followed by large-scale blackouts in this country that were attributed to the effects of solar magnetic storms; that is to say, exceedingly weak EMP of the type that God generates when the sun fluctuates in the output of solar wind. The Earth's magnetosphere rattles around as a result. As a result, there are very low-frequency but, over large geographic scales, large-amplitude electric field disturbances around power systems, and the power systems fall apart; not believed to do so, but they have done so, repeatedly. You know, you actually read in the newspapers occasionally that such and such a blackout was attributed to a geomagnetic storm.

Well, after these events, the power—the electric utilities became much more realistic and in the PONAST studies of the 1970s they told the government that they should assume that due to EMP effects, not due to blast and heat or elimination of cities, but due to EMP effects, they should assume the power systems would go down nationwide, and it would be very difficult to reconstitute for the reasons that Dr. Graham said, namely that when a power system goes down, if a piece of it goes down, the rest of the power system can be used to pick it back up and make it operational again. But when the whole system goes down, when a whole interconnection goes down, it is exceedingly difficult to bring it back up. In the case of the northeastern blackout in 1965, in some places it took two or three days to bring it back because people had never brought a power system back before that had gone down over such a wide scale.

So as people are confronted with the prospect of realistic testing, or sometimes they are just humbled by natural phenomena such as large geomagnetic storms, they become much more realistic about whether their systems can survive, and in particular can survive EMP.

So I would suggest to you that the primary reasons why people are thumping their chests now, are reportedly thumping their chest and saying we are so robust against EMP, is they simply know they won't be tested.

Mr. BARTLETT. Let me see if I can get an answer to my concerns another way. The three of us here were sitting in a hotel in Vienna just a few months ago with Vladimir Lukin, Ambassador from Russia to the United States, at the end of Bush, at the beginning of Clinton, who is now the chairman—.

Dr. WOOD. I remember him well.

Mr. BARTLETT. Sir?

Dr. WOOD. I remember him well. He was the final Soviet hardliner.

Mr. BARTLETT. Yes, and he was one of the Duma members who was negotiating with us a resolution of the Kosovo fiasco; we were discussing a resolution of that debacle.

He said, during those deliberations, if we really wanted to hurt you, we would detonate a nuclear weapon at high altitude over your country—by the way, he started out to say, if we really wanted to hurt you without any fear of retaliation, we would detonate

a nuclear weapon at high altitude over your country and shut down your entire power grid and your communications system for a month or two.

Did he not know what he was talking about?

Dr. WOOD. That is probably a realistic assessment of the time that it would take to reconstitute the power system in this country. When the most vulnerable portions of a power system die, and these are usually the very high-powered transformers in major switching stations, when they go out, the time scale to replace them, if only one is lost, is about 90 days. If you lost 100 of them or 300 of them or whatever, it might be as long as a year or more before you could reconstitute a large portion of the major interconnect points that switch and convey electric power in this country.

It is certainly true that the type of EMP levels that the Soviet Union, or nowadays the Russian Federation, could lay down on this country without killing anybody would be easily sufficient to bring down the entire power grid.

So with respect to how long would it take to come back up, that is a little bit problematic. But with respect to their ability to do it, they could do it today or any time they chose, and if they did it in the middle of the day, on a sunshiny day, you might not even see the bomb go off.

So, yes, it represents a way that the Soviet Union could impose pain—or the Russian Federation could impose pain, and indeed in my prepared statement I suggested that they will retain that particular whip hand over the planet for as long as that government is still in existence.

Mr. BARTLETT. Mr. Jakubiak, why would he say "without fear of retaliation"? This was Vladimir Lukin. He said "without fear of retaliation.".

Mr. JAKUBIAK. I do not know what—.

Mr. BARTLETT. You can't figure out that?

Mr. JAKUBIAK. I can't understand what his thinking was behind that.

Mr. BARTLETT. You see, if this came from the homeland, there is no reason to launch it from your homeland because then we would know where it came from. You would have to be pretty dim-witted to launch a nuclear device on our country from your homeland. It is a big ocean. There are a lot of ships out there and submarines on their part. But if it was launched from the ocean, how would we know who launched it in today's world? In the old Cold War world, we knew who would have launched it. It would have been the Soviets. But in today's world, how would you know who launched it?

Mr. JAKUBIAK. I don't feel qualified to discuss that.

Mr. BARTLETT. Sir, even if we did know, if all they had done is electronic warfare, they have knocked out your power grid, they have knocked out your communications, they have not hurt one person or broken one window, are we then justified in incinerating their grandmothers and babies?

Mr. JAKUBIAK. I think that is a decision that the national command authority would have to make.

Mr. BARTLETT. Who would it incinerate if it came from the ocean?

Mr. JAKUBIAK. Sir, I don't feel qualified to address that question.

Mr. BARTLETT. The point I am trying to make is that we face a real vulnerability here, and I think that this is such a hard question, there are military people that would rather not discuss it, which is why we are discussing it today, because I think it has to be discussed.

What would be the effect on our satellites, both prompt and delayed effects on our satellites? How many of them would survive a high-altitude blast?

Dr. Wood, can you tell us how many would survive?

Dr. WOOD. It would depend quite critically, sir, on where the blast occurred, and the total fission yield of the blast. The satellites would die promptly due to gamma ray effects, so-called system-generated EMP, and other satellites that were not necessarily even in the line of sight of the blast would die at a timescale of hours to weeks due to the so-called pumping up of the Van Allen Belts, the radiation belts surrounding the Earth, by the beta decay products from the fission products of the explosion.

So the extent of the damage to satellites in space is difficult to say without specifics, but it was demonstrated by the U.S. in the Argus test series in the late 1950s that even very modest nuclear explosives detonated in the Van Allen Belts created large and enduring fluxes of radiation which are confidently expected to be of magnitude such that they would destroy satellites at low- to medium-level Earth orbits.

Mr. BARTLETT. Two satellites that would assuredly survive are the MILSTAR satellites?

Dr. WOOD. MILSTAR is deployed very far from the Earth, and it represents reasonably hard satellite technology, so MILSTAR—if any satellite survived, the MILSTAR satellites would probably be among them.

Mr. BARTLETT. But the other $50 billion of our satellites are vulnerable?

Dr. WOOD. To varying degrees depending on their orbits, sir, they are vulnerable. The ones close to the Earth and in medium Earth orbit in the inner Van Allen Belts would be highly vulnerable to a nuclear explosion at most any location above the Earth's atmosphere.

Mr. BARTLETT. Let me ask one additional question, then I will save the rest. We are told that recent hardware procurements are waiving EMP-hardening. That adds on to our discomfort. Can you tell me that that is not true? We are told that we are now waiving both chemical and EMP-hardening because the ten percent roughly, maybe less than that, extra cost buys more weapons systems, and the budget is so tight that our military is making the judgment that they would rather have the more weapons systems than have the lesser number hardened. Is that true as far as you know?

Mr. JAKUBIAK. Well, let me caveat. The answer to that question is that the systems that are waived-EMP go through a process of reviewing what the requirement is, where that system might be used under an EMP environment, and what the risk is associated with not having that EMP protection on that system.

Mr. BARTLETT. I understand.

Let me interrupt you just a moment, and then I will pass on because I don't want to consume all the time. At a hearing just like this when our field people were in here, I asked one of them how much of his capability would remain after an EMP laydown, and he told me, he told the committee, it is on the record, five percent. He would lose 95 percent of his capability with an EMP laydown.

Now, you know if that is true, I don't know how effective we are with five percent of our capability remaining, and, therefore, should we not look carefully at policies of procurement which waive EMP-hardening?

Mr. JAKUBIAK. I think one would have to look at his understanding of the EMP environment before you make the judgment.

Mr. BARTLETT. Mr. Chairman, let me yield back.

Mr. WELDON. Thank you, Mr. Bartlett.

Dr. WOOD. Mr. Bartlett, if I might respond very briefly to the hypothesis that you had in your question which I didn't speak to. Some might consider your suggestions with respect to EMP-based launches from the sea to be somewhat exotic, and along those lines I would just like to bring to the committee's attention the statement made by former Defense Secretary William Perry last Saturday speaking to the Nobel symposium in Stockholm and as quoted by the Associated Press. He said, quote, last year's India test ruptured the fragile barrier of the nonproliferation treaty. Not surprisingly, Pakistan quickly followed suit, and my expectation is that we will see Iran, Iraq, and possibly Syria go nuclear as well, end quote.

Now, the significance of this, other than pointing out that, hey, everybody is getting them as fast as they can, is that it has also been reported in *The New York Times* that the Iranians have been seen testing the launch of SCUD-type missiles from barges in the Caspian Sea, and so they are not waiting to develops ICBMs, Shahab-5 and so forth; that the CIA has publicly said they will likely have in well under a decade, they are looking to a possibility, one which was identified by the Rumsfeld Commission and tabled before the Congress, of shipping their short-range ballistic missiles presumably with weaponry of mass destruction in them as close to the U.S. as they can get in tramp steamers or barges or whatever and launching them from there.

This is not a conjecture anymore. They have been seen testing such equipment in the Caspian Sea.

Mr. WELDON. It is the intent of the Chair that we will finish the public section with Mr. Saxton. The three of us have to be at an event at 1:30. We need time to clear the room. So it would be the Chair's intent to reconvene at two o'clock. So I will turn over to you, and so if you will adjourn it—recess it at when Jim is finished, and then we will come back at 2:00 for the closed session, and then the staff will have a chance to clear the room.

Mr. SAXTON. [presiding.] Thank you, Mr. Chairman. First let me thank all of you for being with us today and for helping us understand the technical aspects of this very important subject. I would like to look at it from a slightly different angle for a few minutes, if we may. Let me begin by saying that earlier this week, the United States Commission on National Security for the 21st Cen-

tury was here with us to present us with their report on phase one of their three-phase study. And, of course, in that report they draw some conclusions. And I found the conclusions very interesting because they, in part, go hand in hand with what we have been hearing from you this morning.

But there is a theme through their conclusions, and I would like to try to summarize that theme by reading part of their conclusions to you, if I may.

They say that America will become increasingly vulnerable to hostile attack on our homeland—a scary thought and similar to some of the things that we have been hearing from you this morning—and our military superiority will not entirely protect us. States, our traditional adversaries as well as terrorists and other disaffected groups will acquire weapons of mass destruction and mass disruption, and some will use them.

And then they go on in another part of their conclusions and say, foreign crises will be replete with atrocities and deliberate terrorizing of civilian populations. The essence of war will not change. What will change will be the kinds of actors and the weapons available to them.

We talked about some of the weapons that are—that will be available to them. They include nuclear EMP. They include radio frequency weapons. It includes weapons used in cyberattacks, chemical weapons and biological weapons of warfare. All scary thoughts.

And when I saw this theme running through their conclusions, it reminded me of something that I think about often, and that is the fact that in today's world we no longer have the luxury, if you will, of being able to identify our foe as we did during the Cold War. Funny thing to call a luxury. But in a sense at least it gave us a pretty clear idea of what we had to deal with.

But today, I think, at least beginning in the early 1990s when we demonstrated to the world that we had the kind of conventional capability which very few around the world can compete with, there emerged, I think, an enhanced determination on the group of people who want to influence world events through other means to use terroristic types of activities in order to accomplish those goals. They proved, for example, in Afghanistan that those kinds of guerrilla warfare tactics and terrorist tactics were pretty effective.

My question to you is can you help us understand with regard to radio frequency weapons which have been discussed here to some extent this morning, and, of course, EMP as well, what kind of capability this might offer in a nonstrategic—I don't know what we call it today. There is probably—as far as I know, there has not been a phrase termed or developed to really describe this issue—but in terms of terrorists, small groups of people, guerrilla-type warfare, what kind of capability and what kind of attack does this type of technology—what kind of capability does that give these other types of groups that are nontraditional types of adversaries? May I just ask each of you to respond? Dr. Wood, would you start?

Dr. WOOD. Very substantial capabilities, sir, to impose damage, and in some circumstances perhaps impose very considerable pain and even loss of life.

The means for generating very large pulses, electromagnetic pulses, without nuclear explosives have been published in the technical literature for over three decades, and they are of the nature and scale that would suffice to attack in a very effective fashion an entire urban industrial complex like, for instance, greater New York City in an attack that, for instance, might be mounted from a light aircraft, privately-owned light aircraft.

It is obviously not appropriate to provide technical detail in open session, but I would be happy to expand on the possibilities in closed session. There is no point in coaching the bad guys. But the possibilities basically are very substantial ones.

We saw what could be done by incompetent amateurs with deadly intent in the Tokyo subway attacks using neurotoxins. Just a little bit more competence on the part of those people in dispersing the material that they had prepared, and instead of killing a dozen people and permanently injuring a couple of hundred, the likely casualty levels would have been about two orders of magnitude higher. They probably would have killed on the order of 1,000 people and crippled 100,000 just with the materials they had if they had used them in a more effective manner.

So the prospects for terrorists imposing really wide-scale damage by a variety of means these days are peculiarly potent, and EMP just happens to be one of the more technically advanced ways to do the job.

The low-tech stuff would be what was done at the World Trade Center. The story that Jim Woolsey, former CIA Director, relates there was that the guy who masterminded that particular attack was being taken by helicopter over Manhattan by Federal agents for arraignments, and one of the Federal agents pointed to the World Trade Center and said, it is still standing, and Ramsi Yosef said, yes, but if I had had $5,000 more materials, it wouldn't be.

If they had knocked over the World Trade Center, they would have killed 100,000 people. That is the super low-tech garden fertilizer approach. The medium-tech is the Tokyo subway approach. The high-tech way would be just to destroy the electronic and electrical infrastructure in large part over an entire urban industrial complex with an EMP weapon, a nonnuclear EMP weapon of the type that a very small terrorist group could build.

Mr. SAXTON. When you speak of a nonnuclear EMP-type weapon, are you referring more to the radio-frequency-type weapon-type situation?

Dr. WOOD. I would recommend, if it is agreeable to you, that we speak about this in closed session.

Mr. SAXTON. Any of you other gentlemen? Dr. Graham? Dr. Bernardin?

Dr. GRAHAM. You asked a question that is both very broad and very deep as to how we respond as a country and a society to the growing range of potential threats that we face at different levels.

Mr. SAXTON. Let me try to narrow it down because we are going to run out of time, and I didn't mean to ask that broad a question.

With regard to nuclear EMP and with regard to radio frequency weapons, are these effective weapons that can be used by small groups who want to effect political change?

Dr. GRAHAM. Certainly they both, and the nuclear the most, can send dramatic messages to the U.S. We implicitly have an insular mentality, because it has been so long since we have been attacked to any substantial degree. I believe any kind of an attack against us which has either a major infrastructure, military, or population effect will have the same effect on our country as Sputnik had on our science and technology in 1957. It—1956, I guess. It will cause us to think about the world in a different way than we think about it now.

Mr. SAXTON. Could an individual or a group of individuals use an radio frequency weapon to, say, shut down significant parts of Wall Street?

Dr. GRAHAM. I would prefer to address the specifics in closed session, if that is all right. But certainly attacks against our infrastructure using radio frequency weapons as well as the possibility of the other threats that you mention is a definite possibility. Steps we can take, of course, to counter that are first to have a coherent, consistent national policy on how we are going to approach such concerns; second, on being able to tell if such an attack is, in fact, being mounted against us not just by our intelligence to anticipate it, but, when it is actually being put into effect, to be able to know what is happening; and then third, having plans to respond to it.

And I believe we can make a great deal of progress in each of those areas, and certainly some very careful thought in that is warranted.

Mr. SAXTON. Dr. Bernardin?

Dr. BERNARDIN. I am a nuclear weapon expert and speaking on nonnuclear matters, nonnuclear type of weapons, I have limited knowledge. I know that both our laboratories have explored the technology in the past, both Livermore and Los Alamos.

Mr. SAXTON. Let me ask you a nuclear question then.

Dr. BERNARDIN. Okay.

Mr. SAXTON. Mr. Bartlett a short time ago asked the question about the Koreans potentially detonating a nuclear device off one of our coasts and what kind of damage that would do. Is it feasible in your mind that someone like Osama Bin Laden, who reportedly has a wealth of about $7 billion, could acquire the necessary equipment, ships, SCUD missiles, to detonate such a device? Is that within the realm of feasibility?

Dr. BERNARDIN. I think it is within the realm of feasibility to acquire the launching equipment like a missile. Acquiring the special nuclear materials in order to fashion a nuclear weapon is something that the intelligence agencies would have to address.

Mr. SAXTON. You don't think he would buy one?

Dr. BERNARDIN. That is another possibility. A loose nuke is certainly a scenario that has been postulated.

Mr. SAXTON. Tough question, I understand.

Dr. BERNARDIN. It is.

Mr. SAXTON. Mr. Jakubiak?

Mr. JAKUBIAK. The military has always looked at various scenarios, and that includes situations such as loose nukes appearing and being detonated over the U.S., and we play those scenarios in war games and see what the impact would be on military systems.

Mr. SAXTON. I am going to stop.

Dr. WOOD. Mr. Chairman, if I could just give a very brief personal example that ties some numbers to your question, last year a few of my colleagues and myself, as a demonstration along these lines, offered to take a vanload of equipment which we estimated would cost less than $10,000 and go out and in a fashion that would be totally fingerprint-free destroy a government facility that cost about $1 billion to build, could not possibly be reconstituted now, and would punch a very major hole in the national strategic capabilities, and do so at no risk to ourselves. And the equipment was specifically EMP weaponry. But it obviously didn't involve nuclear energy, and as I said, it packed into a rental van—I mean, an ordinary passenger van.

Mr. SAXTON. Thank you. We really have to stop because we have some people waiting for us at 1:30. But I have, as some of you know, been interested in this general subject of nonconventional attack by smaller groups for quite some time, and now the United States Commission for National Security for the 21st Century has come to the same conclusion. And this is very serious and something that we as a committee and we as a governmental institution and we as a society need to be more aware of and need to be able to deal with more effectively, and so I thank you for helping me to make these points in public. Thank you.

Mr. BARTLETT [presiding]. I want to thank Mr. Saxton for joining us. He is not a member of our subcommittee, and we are very pleased that he is here with us because of his concern in this area. Because a number of our Members could not be here and are very interested in this, I would ask unanimous consent that the record be held open so that they can make comments or pose questions to which I hope you will give answers.

Hearing no objection, so ordered.

We now need to adjourn technically. We need to adjourn this because this is a hearing. The next event will be a briefing, and so a recess would not be appropriate. We need to adjourn this, and then we will reconvene at the briefing, our committee Chairman said, at two o'clock. This meeting is adjourned.

[Whereupon, at 1:32 p.m. The subcommittee was adjourned.]

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APPENDIX

OCTOBER 7, 1999

42

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PREPARED STATEMENTS SUBMITTED FOR THE RECORD

OCTOBER 7, 1999

44

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OPENING STATEMENT
REP. CURT WELDON
CHAIRMAN
RESEARCH & DEVELOPMENT
SUBCOMMITTEE
HEARING ON EMP THREATS TO
U.S. MILITARY AND CIVILIAN INFRASTRUCTURE
OCTOBER 7, 1999

This morning, the Military Research and Development Subcommittee meets in open session to receive testimony on the potential of an electromagnetic pulse attack to disrupt the United States' military and civilian electronic infrastructure. Our open hearing will be followed by a closed, classified briefing. The classified briefing will give our witnesses an opportunity to brief members in greater depth, and to respond to questions that may be too sensitive to fully answer in open session.

Part of our purpose today in holding an open hearing on EMP is to help educate the public on this still not widely understood threat. An electromagnetic pulse can be generated when a nuclear weapon is detonated at high altitude, above the atmosphere. The EMP produced by such an explosion can, potentially, damage or destroy electronic systems across vast areas of the Earth's surface.

The United States has evolved into a technologically-dependent society, with high potential vulnerability to EMP. The widespread paralysis of electronic computer systems, communications, power grids, and transportation systems would not be merely an inconvenience. Nor would an EMP attack have only commercial consequences.

Our modern way of life, and life itself, depends upon the functioning of our electronic society.

How severe would the consequences of an EMP attack on the United States be? Some have argued that an EMP event could be like putting the United States in a giant time machine and, in the blink of an eye, transforming our high-tech society into a primitive, pre-industrial one, circa the 19th century. Others argue that, while the consequences of an EMP attack would be serious, the effects are likely to be much less severe and more manageable.

The EMP threat may have acquired new, and urgent, relevance as the proliferation of nuclear weapons and missile technology accelerates.

North Korea, for example, is assessed as already having developed one or two atomic weapons, and is on the verge of testing an ICBM capable of delivering a nuclear warhead to the United States. North Korea already has missiles capable of delivering a nuclear warhead against U.S. regional allies and U.S. forces based in Japan and South Korea.

Is it possible that, given the small size of North Korea's nuclear arsenal, Pyongyang may consider an EMP attack the most efficient military option, the best way to inflict the maximum damage on the United States and its allies in the event of a conflict? Or perhaps the best way to blackmail or deter the United States in the event of a crisis?

There are differences within the scientific community over just how damaging an EMP attack would be. There are differing opinions among experts over the likelihood that a rogue state armed with a small number of nuclear missiles would prefer to perform an EMP attack, as opposed to blasting a city or a military base.

The main purpose of our hearing today is to air and explore these differences of opinion about the EMP threat by receiving testimony from two panels representing differing points of view. On our first panel, representing the Administration and the Joint Chiefs of Staff, are:

Mr. Stanley Jakubiak

Senior Civilian for Nuclear C3 and EMP Policy

Joint Chiefs of Staff

Dr. Michael Bernardine

Provost for Theoretical Institute of

Thermonuclear Studies

Los Alamos National Laboratory

The second panel is of independent experts:

Dr. William Graham

Former Science Advisor to President Reagan and

Rumsfeld Commissioner on the Missile Threat

Dr. Lowell Wood

Member of the Director's Technical Staff

Lawrence Livermore National Laboratory

We welcome you and thank you all for being here. However, before I turn the floor over to you, I want to call upon Mr. Pickett, the ranking Democrat on the R&D Subcommittee, respectfully.

Mr. Pickett...

[AFTER MEMBER OPENING REMARKS]

Mr. Jakubisk, the floor is yours.

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HOUSE OF REPRESENTATIVES

STATEMENT OF
Mr. Stanley J. Jakubiak
Senior Civilian for Nuclear Command and Control
And
High Altitude Electromagnetic Pulse
Programs and Policy
Directorate for Command, Control, Communications
and Computer Systems
The Joint Staff

Before the
Research and Development Subcommittee
of the
Armed Services Committee
United States House of Representatives

7 October 1999

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ARMED SERVICES COMMITTEE
HOUSE OF REPRESENTATIVES

Mr. Chairman, members of the Committee.

I am grateful for the opportunity to address the Committee on the Electromagnetic Pulse (EMP) threat environment and to discuss its impact on commercial off the shelf (COTS) equipment used in military command and control systems.

The detonation of a nuclear weapon between 50 and several hundreds of kilometers above the earth's surface will produce an electromagnetic pulse that can, under certain conditions, damage electronic equipment operating under its footprint. Although the EMP phenomenon has been studied for many years, its impact on unprotected electronic equipment is at best uncertain. We know it will impact electronic equipment, but due to the variation of tolerances built into commercial equipment and the different system configurations, we can't accurately predict how wide spread any damage or disruption will be.

To counter the EMP threat, we have in the past taken a simplistic approach to the problem by assuming that all unprotected systems, including the entire commercial infrastructure, could not be relied upon for critical military operations. Critical military command and control nodes and systems that must operate throughout an EMP event have been identified and provided the necessary protection. In selected systems this includes the provision of EMP protected back-up power generators to mitigate any failure of the commercial power grid.

To capitalize on leading edge technologies, military systems are becoming increasingly dependent on commercial off the shelf (COTS) equipment, which are not specifically designed to mitigate the effects of an EMP environment. To insure reliable operation in an EMP environment, systems incorporating COTS equipment are tested in simulators to the projected threat. Failures are analyzed and modifications retrofitted to the system to meet EMP protection requirements.

Testing of COTS equipment has allowed us to make some observations regarding the vulnerability of COTS equipment to a range of EMP environments that may be of some use in assessing the impact of an EMP environment on the unprotected commercial infrastructure. In general, it is possible that some equipment upset can occur when the EMP environment field strengths are between 3 – 8 kilovolts per meter (kV/m). When the field strengths reach above 8 kV/m the risk that some equipment will upset becomes more probable. In the range of 7 – 20 kV/m there is a possibility that some equipment will be damaged, above 20 kV/m damage is probable. Results from some recent testing of COTS computer equipment in September 1998 reconfirmed these observations.

In conclusion, due to the sensitivity of COTS equipment to various EMP field strengths we have, over the past several years, sponsored an effort at the Los Alamos National Laboratory to assess the potential field

strengths that can be produced by nuclear weapons. When you receive Dr. Michael Bernardin's assessment in closed session keep in mind the COTS vulnerability levels that I have addressed in my statement.

Mr. Chairman and Members of the Committee, on behalf of the Chairman of the Joint Chiefs of Staff, I appreciate this opportunity to present the Joint Staff's insights on the EMP environment.

TESTIMONY OF

DR. MICHAEL P. BERNARDIN

PROVOST FOR THE THEORETICAL INSTITUTE FOR

THERMONUCLEAR AND NUCLEAR STUDIES,

LOS ALAMOS NATIONAL LABORATORY

TO

THE SUBCOMMITTEE ON MILITARY RESEARCH AND DEVELOPMENT

COMMITTEE ON ARMED SERVICES

U.S. HOUSE OF REPRESENTATIVES

OCTOBER 7, 1999

Written Statement by Dr. Michael P. Bonnerdin
Provost for the Theoretical Institute for Thermonuclear and Nuclear Studies
Applied Theoretical and Computational Physics Division
Los Alamos National Laboratory

I have been employed in the nuclear weapon design division at Los Alamos National Laboratory since 1985 to work on nuclear weapon design, nuclear outputs, and high-altitude electromagnetic pulse (HEMP) assessment. I discovered the impact of x-rays on HEMP and quantified the impact of two-stage shadowing effects on it as well, revolutionizing the understanding of realistic HEMP environments. From 1992 – 1995, I was the Laboratory Project Leader for the Joint DoD/DOE Phase 2 Feasibility Study of a High Power Radio Frequency (HPRF) Weapon. This study effort focused on the feasibility and effectiveness of developing an HPRF weapon for offensive purposes. Since 1996, I have been the Provost for a post-graduate nuclear weapon design Institute within the Laboratory, chartered with training the next generation of nuclear weapon designers.

The issue to be addressed this morning is the impact to the civilian and military infrastructure of a high-altitude nuclear detonation over the United States. A high-altitude nuclear detonation would produce an electromagnetic pulse (EMP) that would cover from one- to several-million square kilometers, depending upon the height of burst, with electric fields larger than those typically associated with lightning. In such an event, would military equipment deployed within the area of EMP exposure be seriously impaired? Would civilian communications, the power grid, and equipment connected to the power grid catastrophically fail?

The answers to these questions depend on (1) the types of threat weapons deployed, (2) the EMP produced by these weapons and (3) the effects that are caused by the EMP.

Types of Threat Weapons

The types of threat weapons deployed in foreign arsenals are discussed in closed session. It is noted here that the Department of Energy nuclear design labs, Los Alamos and Lawrence Livermore National Laboratories, work closely with the Defense Intelligence Agency (DIA) and the Central Intelligence Agency (CIA), along with other members of the intelligence community, to computationally model foreign nuclear weapons. The Labs each have over 25 years of experience in modeling foreign nuclear weapons.

With Russia included in the list of countries possessing nuclear weapons that could potentially be detonated over the United States, the list of potential nuclear weapon technologies of interest for evaluation ranges from single-stage, unboosted weapons, through modern, two-stage thermonuclear weapons. Through an understanding of how EMP is produced, it is possible to correlate the severity of the EMP environments with the appropriate class of nuclear weapon technology. This correlation will be presented in closed testimony.

EMP Environments

The EMP produced by these weapons is also a topic delegated largely to closed session. However, it is possible to discuss in an open forum the process by which high-altitude EMP is produced in the atmosphere, its propagation down to the earth's surface, and some of the generic features of the resultant EMP.

The Defense Threat Reduction Agency (DTRA), through contractors that it employs, is the principal DoD organization for EMP assessment. Los Alamos also has a capability for assessing the large-amplitude portion of the EMP, and has provided the Joint Staff with independent EMP threat assessments since 1987.

The production and characterization of EMP is a highly technical subject. To assist the discussion of this subject, I have brought some graphics for illustration.

Graphic 1 illustrates the area coverage of direct EMP exposure from a 200-km height of burst over the United States. The area coverage varies with the height of burst. For a 200-km height of burst, which might be appropriate for a hypothetical multi-Mt weapon, the horizon is located at about 1600 km (or 1000 miles) from the point on the ground directly beneath the burst. For a 50-km height of burst, which might be appropriate for a 10-kt fission weapon, the horizon is located at about 800 km from the ground point beneath the burst.

Graphic 2 illustrates the temporal features of an EMP waveform at the earth's surface resulting from a high-altitude burst. The EMP has three temporal components, designated as E_1, E_2, and E_3. The early-time or E_1 component is defined as the first microsecond of the pulse. It is produced largely by prompt gamma rays generated in the explosion. A characteristic amplitude of the electric field is 30,000 volts per meter (V/m) (Longmire, 1978). The intermediate-time component is defined as the portion of the pulse from one microsecond to one second, and it is produced primarily through prompt gamma rays that have been scattered in the atmosphere and

by neutrons produced in the explosion. This component is characterized by a peak electric field value of 100 V/m (Radasky, 1988). The third component, the late-time component, is defined as the portion of the pulse beginning at one second and lasting up to several hundred seconds. It is produced primarily through the interaction of the expanding and rising fireball with the earth's geomagnetic field lines. This EMP component is characterized by a peak field of 0.01 V/m. The E_3 component is thought to couple well to very long lines, on the order of 100 km or greater.

Graphic 3 illustrates details of some additional specifics of the EMP generation process for the E_1 portion of the pulse. A high-altitude nuclear explosion produces gamma rays, x-rays, neutrons, and debris. Some of the gamma rays propagate down into the earth's atmosphere, where they collide with air molecules, producing recoil electrons. The electrons are created with a velocity directed principally radially outward from the burst. The electrons are turned by the earth's magnetic field, which results in synchrotron radiation. The radiation adds coherently to form the electromagnetic pulse. As the electrons traverse their trajectories, they collide with other electrons, creating a sea of electrons known as ionization. Ionization can be enhanced by atmospheric breakdown or avalanching due to the presence of the EMP electric field. The ionization shorts out the EMP, limiting its value to typically 30,000 V/m.

High-energy x-rays produced by the exploding weapon can also enhance the ionization in the high-altitude EMP source region. This source of ionization was largely ignored in EMP assessments until 1986. Inclusion of the x-rays lowered the assessed values of the peak field for many weapons.

Note in graphic 3 that a thermonuclear weapon consists of two stages. The primary stage is typically of relatively low yield and is used to drive the secondary stage that produces a relatively large yield. Each weapon stage produces its own E_1 EMP signal. But the primary stage gamma rays leave behind an ionized atmosphere from their EMP generation that is present when the secondary stage gamma rays arrive. Thus, the primary stage can degrade the EMP associated with the secondary stage.

Graphic 4 shows the spatial distribution of the peak EMP fields for a hypothetical weapon detonated over the United States. The directionality of the earth's magnetic field causes the largest peak-field region to occur to the south of the burst point. The larger numbers on the plot are peak electric field values, in thousands of volts per meter (kV/m), and the smaller numbers are distance increments in kilometers. Note that the peak field ranges from 12 to about 25 kV/m.

EMP Effects on Infrastructure

Given an understanding of the resultant EMP field levels from a high-altitude nuclear detonation, the effects of these fields on military and commercial infrastructure remains to be determined. There are many organizations that have expertise and experience in evaluating the effects of EMP on commercial and military systems. These organizations include the Military Services, DTRA, and the DOE National Laboratories, among others. I urge the Committee to consult with these organizations for additional information.

The effects of EMP on the infrastructure cannot be quantified simply by drawing upon nuclear testing experience. High-altitude EMP was produced on ten atmospheric nuclear tests conducted by the United States in 1958 and 1962, and damage or upset (i.e., temporary glitches) of electronics was noted on a number of systems. However, these weapons are not truly representative of the foreign nuclear weapons in existence today, and the electronics of the modern era is vastly different from that which existed in 1958 – 1962. Moreover, the U.S. atmospheric tests were conducted over large bodies of ocean, and thus, the exposure of extended, landline systems to EMP fields was quite limited.

It is worthwhile reviewing the most famous of the EMP effects from U.S. atmospheric testing, namely the simultaneous failure of 30 strings of streetlights in Oahu during the Starfish event. Starfish was detonated at 400 km above Johnston Island in the Pacific on July 9, 1962. It had a yield of 1.4 Mt (about 115 times the yield of the bomb dropped on Hiroshima). Oahu was located approximately 1300 km from the designated ground zero of the burst, which was within line of sight of the detonation. A post-mortem following the event indicated that the failure of the strings of streetlights resulting from the Starfish event was due to damaged fuses. This event was analyzed by Charles Vittitoe, a Sandia National Laboratory scientist, in a report published in 1989 (SAND88-3341, April 1989). He notes that the observed damage is consistent with the magnitude and orientation of the EMP fields impinging on the streetlight strings that suffered damage. More importantly, he notes that the 30 strings of failed streetlights represented only about 1% of the streetlights that existed on Oahu at the time. Thus, the effects were not ubiquitous.

A much more extensive set of vulnerability data has been accumulated over the years through EMP testing in laboratory simulators. Tested items include aircraft, tanks, automobiles, computers, telecommunication equipment, etc. Both upset and damage have been obtained for

some of the systems at certain field levels. DTRA and the Military Services should be consulted for a review of these data. A limitation with this type of testing is that the simulators are of finite volume and are not able to expose electric lines of length greater than about 50 m to EMP. Systems connected to power or communication lines are frequently tested with current injection, but even these tests are limited.

The most authoritative study to date on the likely impact of EMP on the U.S. power grid was published in an Oak Ridge National Laboratory report (Barnes, 1989). The report summarizes work performed from 1983 through 1988, and it includes a list of review panel members, which includes both leading experts in EMP and in the commercial power industry, who reviewed the work. The study examined the effects from all three high-altitude EMP environment components, namely E_1, E_2, and E_3. The third witness on our panel will address the study results.

Electronic systems can be protected against EMP. Standard protection techniques include enclosing systems or subsystems in metal enclosures, and adding surge arresters to power lines, cables, etc. Simulator and line-driven testing have shown that EMP protection is effective. There are cost and practical considerations associated with implementing EMP protection. The Services, DTRA and others should be consulted for more detail.

Conclusions

The conclusions to be drawn are dependent on the validity of the EMP environments imposed on military and commercial systems of interest. These are to be examined in closed session. It is clear that EMP is a real effect and that damage is virtually certain.

To establish that the problem is well understood, one must begin with a model of, say, Starfish, and demonstrate that the predicted EMP environments, EMP coupling, and effects match observation. Then, one must be able to establish that the model retains its fidelity when the weapon model is changed, when the burst location is moved over land and changed in elevation, when the electromagnetic coupling paths change, when the vintage of electronics changes, and with the incorporation of EMP test simulator data, that the results are reliable. While it is conceivable for a model to achieve all of this, any such model should be peer-reviewed by a high-level review group (e.g., National Academy of Science or Defense Science Board) before predictions of catastrophic damage are to be believed.

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TESTIMONY

before the

House of Representatives

Committee on Armed Services

Subcommittee on Military Research and Development

on

The Effects of Electromagnetic Weapons

by

William R. Graham, Ph.D.

October 7, 1999

RESUME

William R. Graham

1997-Present: Chairman of the Board and President of National Security Research, Inc.

1998-1998: Served as a Commissioner on the Congressionally-established Commission on the Ballistic Missile Threat to the United States (The Rumsfeld Commission) and is a former Chairman and current member of the Department's Ballistic Missile Defense Advisory Committee.

1994-1997: Senior Vice President of the Defense Group Inc., headed the corporate programs in counter-proliferation and other related defense activities. Served as a member of the Department of Defense's Defense Science Board Task Force on Theater Ballistic Missile Defense.

1988-1993: Chairman of the Defense Department's Strategic Defense Initiative Advisory Committee and member of the Defense Science Board.

1986-1988: Dr. Graham served as Science Advisor to President Reagan and was confirmed by the Senate to serve concurrently as Director of the White House Office of Science and Technology Policy. During that time he was also Chairman of the Federal Coordinating Committee on Science, Technology, and Engineering, which provides high-level coordination for federal research and development programs, and the U.S. Joint Telecommunications Resources Board, which is responsible for joint emergency telecommunications planning and operations between the federal government and U.S. commercial telecommunications companies. As Science Advisor, his responsibilities included developing and staffing presidential initiatives in science and technology, serving as a member of the U.S. Arms Control Experts Group that negotiated with the Soviet Union during U.S. - U.S.S.R. Ministerial and Summit meetings, and serving as counterpart to foreign ministers of science and technology. In the latter role he lead the successful negotiation of U.S. bilateral science and technology cooperation agreements with Japan, India, and the Soviet Union, as well as a multilateral agreement with the 24-nation Organization of Economic Cooperation and Development. He was Co-Chairman of the U.S. - China Council on Cooperation in Science and Technology, led U.S. delegations to the Organization of Economic Cooperation and Development's Science and Technology Minister's Meeting in Paris in 1987, and to Japan, India, and the Association of Southeast Asian Nations in 1988. He left government service as a Presidential Appointee at the end of the Reagan Administration to return to private industry.

1985-1986: Confirmed by the Senate to serve as the Deputy Administrator of the National Aeronautics and Space Agency. He left to become Science Advisor to President Reagan.

1988-1989: Dr. Graham was confirmed by the Senate to serve as the Chairman of President Reagan's General Advisory Committee (GAC) on Arms Control and Disarmament. At the President's request, Dr. Graham led the GAC in preparing the first and to date only comprehensive review and analysis of the Soviet Union's arms control compliance record. The report, issued in October 1984, was entitled A Quarter Century of Soviet Compliance Practices Under Arms Control Commitments: 1958 - 1984. He subsequently briefed the report to the President, the other members of the National Security Council, and to congressional committees involved in national security affairs. This report was instrumental in changing the focus of arms control from verification to compliance in the 1980s.

1971-1988: Dr. Graham was a founder of R&D Associates, a high-technology defense firm. He managed the largest of five divisions of RDA, and was Director of Computing Operations. As Division Manager, he was responsible for all aspects of the Defense Nuclear Agency (DNA) Base Contract, and oversaw research in all aspects of DNA's technical program. While at RDA, he also made technical contributions to the theory of nuclear weapon-generated EMP phenomenology, its coupling to military and civilian systems, and the design of strategic systems for surviving nuclear attack. Developed the method used by DNA to generate and measure EMP phenomenology and effects on underground nuclear tests. He left RDA to become Deputy Administrator of NASA.

1965-1971: Member, Professional Staff, Physics Department of the RAND Corporation, Santa Monica, California. While there he developed the theory of the nuclear weapon-generated EMP near the surface of the ground in the high overpressure region, including the Graham-Schaefer effect subsequently observed on underground nuclear tests, and developed a method for increasing the EMP output of high altitude nuclear explosions. He also conceived and designed the large-scale ARES high altitude nuclear EMP simulator that is still in use at Kirtland Air Force Base. He left to form RDA.

1962-1965: Served on active duty with the Air Force as a project officer at the Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico. He was in charge of the first test of a military system (the NORAD 425L Combat Operations Center) to the EMP fields produced by an electromagnetic simulator, and managed a research group carrying out experimental and analytical EMP research. He left when he completed his tour of duty with the Air Force.

Honors and Awards include membership in Tau Beta Pi and Sigma Xi, and receipt of the Air Force Commendation Medal and the American Defense Preparedness Association's Strategic Defense Award.

Statement for compliance with Rule XI, Clause 2(g) of the Rules of the House of Representatives of the 105th Congress:

William R. Graham has not received any Federal grants, subgrants thereof, contracts, or subcontracts thereof during the current fiscal year or the two previous fiscal years, and he does not represent any entity in his appearance today before the House of Representatives.

Electromagnetic Weapons and their Effects on Electronic Systems

Mr. Chairman distinguished Members of the Committee on Armed Services, thank you for inviting me to testify today on the threats to U.S. civilian and military infrastructure from electromagnetic pulse attacks. Today, I would like to address the threat from both nuclear and non-nuclear electromagnetic weapons, and limit my prepared testimony to a brief description of the range of effects that such weapons can produce in modern electrical and electronics systems.

The Electromagnetic Pulse Generated by A High Altitude Nuclear Explosion (HEMP)

I would like to begin with a few examples of the circumstances in which another nation might wish to employ a nuclear weapon-generated EMP effect against the United States, and the benefits sought through such use. The possible scenarios cover both political and military use, and run from the tactical to the strategic level.

Like many important scientific discoveries, the intense electromagnetic pulse produced by an exo-atmospheric nuclear weapon explosion was discovered by accident. It was first observed both directly and by its effects on civilian systems during the first U.S. exo-atmospheric nuclear test series, code-named FISHBOWL, conducted above the Pacific Ocean in the early 1960s. The generation and effects of nuclear EMP have been studied and simulated since that time.

One possible use of EMP would be against U.S. forces stationed overseas, for example on the Korean Peninsula or in the Persian Gulf. By exploding a nuclear weapon over the theater, the ability of U.S. and allied forces to make full use of their electronic systems, including communications systems, fire control systems, radar systems, and certainly the networked systems envisioned for our 21st-Century forces, would be degraded to some degree. Depending on the yield of the weapon, the height at which the weapon was detonated, and the degree of EMP hardening enjoyed by U.S. and allied systems, such degradation could range from a nuisance to a major hindrance in the employment of electronic systems throughout the theater.

Another possible use of a nuclear weapon would be against U.S. space assets supporting military forces in a theater. The detonation outside the atmosphere of even a small nuclear weapon, perhaps a few tens of kilotons, would produce sufficient direct and delayed radiation to degrade or destroy satellites in line-of-sight, as well as producing EMP near the earth's surface that would interfere with the satellite ground components. U.S. satellite assets are a significant part of our military's overall capability, providing communications, surveillance, on-demand intelligence and database access, and GPS data. Interruption of satellite availability thus could pose a serious problem to our regional warfighting capability. A logical use of this option would be to disrupt U.S. satellite systems immediately prior to an

adversary's attack on a U.S. ally, or to interrupt an impending U.S. attack.

Another possibility would be the use of EMP because an adversary does not have confidence in its ability to target precisely a U.S. asset. For example, an adversary might not be able to pinpoint a carrier battle group or amphibious ready group, but could produce an EMP effect over the presumed operating area of the group. The same approach could apply to an Army formation on the ground. Another possibility might involve an adversary with a long-range but relatively inaccurate ballistic missile, or a short-range ballistic missile mounted on a ship or submarine, and a relatively low-yield nuclear weapon. In this case, the weapon could more confidently be used for an EMP attack than a direct attack.

Another reason for employing EMP would be simply to demonstrate that the nation had both functional nuclear weapons and the ballistic missile capability to deliver these weapons. This demonstration might be sufficient to dissuade U.S. intervention in a region, to coerce regional allies into denying U.S. access to their facilities, or to weaken the coalition-building efforts of the United States in a regional crisis. One can easily imagine the effect an Iraqi nuclear demonstration might have had on our country, our allies in the Persian Gulf, and the Coalition nations that assisted our efforts to liberate Kuwait in 1990-91.

It should also be pointed out that a direct nuclear attack on U.S. forces could reasonably be expected to result in an overwhelming U.S. response, making EMP use a more attractive option for an adversary. If EMP use did not result in any U.S. or allied casualties, it might be safer for the adversary nation than a direct attack. Given the United States' greater reliance on sophisticated electronic systems throughout our military and civilian infrastructures, and the strong taboo against nuclear weapons use built up over a half-century, even our ability to respond in kind with an EMP attack would be problematic. These are just examples of possible EMP employment, but I believe they demonstrate the range of utility of an EMP attack to a U.S. adversary.

Finally, I would like to mention an aspect of the effect of nuclear EMP that is unique. While all electronics systems can fail spontaneously for a myriad of reasons, in the case of a reliable system these failures occur infrequently and even then only at single points. Therefore, experience is gained in dealing with single point failures during the normal operation of the systems. However, since the nuclear EMP from a single exo-atmospheric detonation covers a wide area of the ground and the atmosphere above it, nuclear EMP can produce electronic system failures at many widely distributed points simultaneously. Unless special nuclear EMP recovery preparation and training has been implemented, system operators will have no experience with recovering the system from simultaneous, widely distributed, nuclear EMP-induced multiple failures, and will have to discover how to do so at a highly stressful time.

Non-nuclear Electromagnetic Weapons: High Power Radio Frequency and Microwave Devices

Turning next to non-nuclear electro-magnetic weapons and their effects, there are again several characteristics of such weapons that could make them attractive to an adversary. Most

such weapons are high-power, pulsed radio-frequency devices. They require varying degrees of technical competence to build, but can be as small as a briefcase or as large as a school bus, depending on their desired output.

Radio-frequency weapons, or RF weapons, have the potential disadvantage of requiring closer proximity to their targets to be effective than do nuclear EMP weapons. For example, a small RF device might have a range measured in feet, while a relatively large RF device might produce upset or damage in electronics systems at a range measured in hundreds of feet, and interference at a range of hundreds of miles. However, RF weapons are more suitable to covert use than are nuclear EMP weapons. A targeted asset may not realize that its problems are the result of an RF attack, or that an RF attack has taken place at all.

If used simultaneously against multiple sites, RF weapons could cause confusion and slow restoration efforts. The ability to use RF weapons selectively and intermittently, as well as the ability to disguise them as ordinary objects, could allow adversary covert operatives to interfere with U.S. or allied systems in a more controlled manner than a nuclear EMP attack.

Finally, RF weapons provide an opportunity for their users to escape detection and capture, and potentially can be used repeatedly against U.S. assets. A truck-mounted RF weapon, for example, likely would be large enough to act from a distance, and mobile enough to have a reasonable chance of escaping.

It should be noted that RF weapons are not as damaging over a large area as nuclear EMP weapons. However, in regard to the specific target against which they are employed, RF weapons can produce effects ranging from temporary interference, to the need to shutdown and re-start the system, to physical disablement of the targeted system by literally fusing or melting sensitive internal components. Especially due to their greater applicability for covert use within the United States, they must be given serious consideration.

Research on such devices has been underway in the U.S., Russia, and elsewhere for several decades. While the nuclear EMP from a single exo-atmospheric detonation can cover large areas of the country with intense electromagnetic fields, non-nuclear electromagnetic generators can use pulsed and continuous wave electromagnetic fields to expose systems to disruptive effects more regionally from distances that range from direct contact to several hundred miles. The following summarizes the type of effects that both nuclear and non-nuclear electromagnetic weapons can produce.

Types of Electromagnetic Weapon Effects

1. At the lowest electromagnetic field strengths, there is the complex world of electronic warfare (EW), which involves the non-nuclear generation and transmission of narrowly to moderately broadband electromagnetic signals designed to interfere with or spoof enemy systems. Examples include continuous wave (CW) jamming enemy transmission channels, spoofing enemy fire control radars, and blanking GPS receivers with locally generated signals. EW is a well-established field.

2. At near-zero electromagnetic field strengths (noise, carrier and modulation effects, usually involving CW electromagnetic field interaction in ways not considered in the design of the system, come into play. In addition to pickup on deliberate system antennas, the most likely coupling mechanism of these signals and those in the following three paragraphs is pickup on other conductors extending from the case of the system and acting like electromagnetic antennas. Examples of these effects include use of a CW carrier with audio modulation picked up on telephone lines attached to a computer, rectified, and interpreted as a telephone control signal; and the penetration of a microwave electromagnetic signal into a missile, where it is rectified and interpreted as a missile guidance and navigation command.

3. Electromagnetic field levels of sufficiently high amplitude to induce signals comparable in size to the normal signal levels in a digital system, injecting anomalous bits, corrupting data and/or producing system upset. Electromagnetic weapons can cause system upset by inducing pulses, on either external or internal signal lines, that digital systems interpret as proper binary signals, but which in fact corrupt digital information. Well designed systems anticipate noise in transmissions on external signal channels, and when these anomalous bits occur on such channels, for example telephone lines, they will usually be rejected; but when the anomalous bits are picked up by internal signal lines, such as computer mouse wires or hookup cables, they are usually interpreted as system signals and processed accordingly, resulting in data corruption and/or system upset. Upset may not cause permanent damage to the electronics hardware in the system, but often requires manual intervention to reboot and restart the system, and data recovery or replacement to remove the corruption. Examples of this effect include computer lockup (which can be as benign as to only require rebooting in a PC or as fatal as complete system loss if it occurs in a missile guidance computer in-flight), and mis-routing of digitally switched communication channels that are being connected when the pulse arrives.

4. At electromagnetic field levels higher than those required to cause digital upset, signals induced on conductors can lead to semiconductor junction breakdown followed by system power supply-induced permanent damage. Electromagnetic weapon pickup "antennas" include power lines, communication cables, computer network cables, and computer peripheral cables. In this case, the electromagnetic weapon-induced signals do not contain enough energy to damage the system, but rather act as a triggering mechanism by breaking down a semiconductor junction that is in a reverse bias (and therefore high impedance) state. A system power supply or other stored energy source then provides the much larger amount of energy that damages the junction by driving substantial current through it in the reverse direction. Circuits where this type of failure can occur are usually located near external interfaces, and include power supply rectifier diodes, telephone line modem interfaces, and PC peripheral line interfaces. These triggering effects require additional sources of energy beyond the electromagnetic weapon, and therefore occur only when the system is powered.

5. Finally, at still higher electromagnetic field levels, there are direct electromagnetic power-

[redacted]

The effects described in paragraphs 1. and 2. above are produced primarily by CW non-nuclear electromagnetic sources, and the affected systems' electronics usually return to normal operation when the electromagnetic field is removed if the response of the system has not induced some consequent damage, such as a jammed GPS system causing an aircraft to crash.

The effects described in paragraph 3. are usually produced most efficiently by a pulsed field source, such as an ultra-wideband non-nuclear source or a nuclear EMP, since it is the introduction of individual pulses in a digital system that causes the system upset. In the first three cases, if the system survives the consequent effects of the electromagnetic-induced malfunctions, removal of the fields will leave the system hardware undamaged, although in the case of paragraph 3., the software and/or data may be permanently corrupted.

The permanent damage effects described in paragraph 4. are also usually produced most efficiently by a pulsed field source, since a single pulse can initiate the breakdown process. In the case of the permanent damage effects described in paragraph 5., either CW or pulsed electromagnetic fields can produce the effect.

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PREPARED STATEMENT

Supporting Invited Testimony To Be Presented By

Dr. Lowell Wood*

On

Electromagnetic Pulse (EMP) And The National Interest

Before The

Subcommittee on Research and Development

Committee on Armed Services
United States House of Representatives

1000 AM, 7 October 1999
2118 Rayburn House Office Building
U.S. Capitol

"If you would have peace, prepare for war."
– Benjamin Franklin

I am grateful for the Committee's kind invitation to offer testimony today on electromagnetic pulse (EMP) and its implications for our Nation's military capabilities and, indeed, for the continuation of American civilization.

BACKGROUND. I have been an interested observer of both American and foreign capabilities with respect to electromagnetic pulse (EMP) phenomena for three decades, and I have been actively involved with both offensive and defensive aspects of electromagnetic pulse weaponry for the past quarter-century. During the '70s, I served on the Defense Nuclear Agency's Scientific Advisory Group on Effects (SAGE), the DoD's senior technical review group concerned with nuclear electromagnetic pulse, as well as all other military nuclear issues having a technical character. In the late '70s and early '80s, I worked on "Third Generation" nuclear weaponry, a major component of which was nuclear explosive-driven generators of electromagnetic pulses of potentially greatly increased efficiency and military effectiveness; spinoffs involving non-nuclear means of generating potent EMP also engaged my attention. Later in the '80s and early '90s when strategic defense was emphasized, I worked on the development of defensive technologies of very high efficacy against nuclear EMP, with particular reference to military space systems. With the fall of the Soviet Union, my attention in these respects has turned to the

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implications of EMP in a nuclear-equipped world, while remaining mindful of the EMP implications of the enduring Russian strategic nuclear force structure.

I have been privileged to appear on a number of occasions before the Subcommittees of the Armed Services Committee of the House of Representatives during the past quarter-century, testifying on a variety of national security topics; I last testified here on the subject of nuclear EMP in July 1997, and I also testified on this subject earlier this year before the Small Business Committee's Subcommittee on Government Programs and Oversight. I have served the Armed Services Committee in a technical advisory capacity, initially under Chairman Les Aspin over a decade ago, and more recently under the leadership of Chairmen Floyd Spence and Duncan Hunter.

[redacted]. More than a third-century ago, due both to unanticipated fears over British plans and to some truly striking experimental results, military technologists in the United States became generally aware that high-altitude nuclear explosions often generated electromagnetic effects of completely unprecedented magnitudes, physical and temporal scales – and effects on both the physical environment and human handiwork. (It had been appreciated in a rather qualitative manner for some time previously by American workers that electromagnetic phenomena of singularly large magnitudes and quite exotic natures occurred in the immediate vicinity of nuclear fireballs created near the Earth's surface, but these effects were largely ignored against the background of the nuclear explosion-unique blast and heat effects.)

The first American high-altitude nuclear weaponry experiments after the Soviet breaking of the nuclear test moratorium of '58-'61 revealed a wealth of phenomenology of completely unprecedented – and largely completely unanticipated – character. *Most fortunately, those tests took place over Johnston Island in the mid-Pacific rather than the Nevada Test Site, or "electromagnetic pulse" would still be [illegible] in the minds of the citizenry of the western U.S., as well as in the history books.* As it was, significant damage was done to both civilian and military electrical systems throughout the Hawaiian Islands, over 800 miles away from ground zero. The origin and nature of this damage was successfully obscured at the time – aided by its mysterious character and the essentially incredible truth.

Intensive efforts commenced to understand what had happened – and what might happen in the event of hostilities involving high-altitude nuclear weaponry usage. These efforts were spurred by the knowledge that the Soviets had experimented extensively with high-altitude nuclear weaponry, including some uniquely high-yield explosions, during their '58-'61 test series, and presumably understood the implications of these at least as well as we did. American efforts were complicated by the cessation of high-altitude testing associated with implementation of the Atmospheric Test Ban Treaty in '63, so that access to experimental truth was greatly complicated and, in some crucial respects, entirely precluded.

At this point, the Soviet Union and the United States commenced to engage the nuclear EMP issue somewhat analogously to two men fencing with very sharp blades in utter darkness: both knew that the weaponry which they wielded was extremely

potent, but neither knew the other's time-varying posture, let alone the precise location of either vulnerable spots or especially well-armored ones. This deadly duel continued for three decades, through the collapse of the Soviet Union. It continues today. It will continue into the foreseeable future. EMP crippling of the American military machine and of the modern American nation remains real prospects.

THE NATURE OF EMP. Electromagnetic pulse is sufficiently alien to ordinary human experience that it seems to many to be either magic or illusion. Such entirely understandable human reactions have not facilitated the development or implementation of apt responses to the profound threats which it poses, either by political or military leaders. Thus, a few operationally-oriented fundamentals may be of use:

EMP is really severe static electricity, everywhere, all at once. Without needing to understand the undeniably esoteric means by which EMP arises in various military circumstances, it suffices to recall that it presents itself as something closely akin to static electricity, extremely intense but exceedingly brief, everywhere within line-of-sight to a high-altitude nuclear explosion, "all at once." (This "static electricity" pulse is carried on radio-frequency electromagnetic waves of uniquely high intensity. The bomb's extraordinarily intense prompt radiations essentially transform the entire atmosphere underneath it into a gigantic radio transmitter-antenna radiating at maximum-possible intensity – for a very brief interval. The bomb's fireball, expanding rapidly in the presence of the Earth's magnetic field, gives rise to a second manifestation of EMP which is of particular significance for long metallic lines, such as electrical and telephone systems.)

Extended metallic structures within line-of-sight of the explosion – telephone and electrical lines, radio and TV antennas, fence wires, etc. – then serve to gather up the broadcast energy of EMP and deliver it into whatever they connect to, often with locally ruinous results which appear retrospectively to be basically similar to those resulting from a lightning-strike. However, since the damage occurs thousands of times more swiftly than does that of a lightning-strike, most types of lightning-protective devices are essentially useless. Since it travels at the speed-of-light, EMP arrives essentially instantaneously, from the general direction of the explosion.

EMP can blanket an entire U.S.-sized continent from a single source. EMP originates primarily in the interaction of gamma-radiation from a nuclear explosion with the Earth's atmosphere at altitudes of a few dozen kilometers and propagates predominantly toward the Earth's surface. (The low-frequency, long-time component of EMP arises from fireball interactions with the Earth's magnetic field, as already noted.) Thus, since you can readily see a bomb explosion a few hundred kilometers above the central U.S. from anywhere in the "lower 48", the EMP arising from that explosion's interactions with the Earth's atmosphere can also "see" you.

To be sure, at greater distances, the intensity of the pulse will be smaller, but usually not as indicated by the familiar inverse-square-of-the-distance law. Likewise, its severity is generally not well-related to the yield, or total energy production, of the bomb. (The initial sharpness of the EMP actually depends rather sensitively on esoteric aspects of the bomb's design and operation. Low-yield specially-designed

bombs may pose as large – or even larger – EMP threats, at both low and high electromagnetic frequencies, as do high-yield "ordinary" ones.)

EMP doesn't linger. Since it arises from a nuclear explosion's promptly-emitted gamma radiation interacting with the Earth's atmosphere, nuclear EMP goes away very quickly. It is a phenomenon of compelling interest only for time-scales of the order of microseconds – millionths of a second, although its long-time component may be present for milliseconds – thousandths of a second. (Within these time-frames, however, it can be quite dramatic in its effects.) It has none of the lingering characteristics of nuclear radioactivity or fallout.

EMP isn't caused by people, and it doesn't damage the human body. The nervous system and specialized sensory faculties of people are essentially totally insensitive to electromagnetic radiation of the frequency, intensity and the time-duration of EMP. We don't sense it in any way. Because it arises and then goes away so exceedingly quickly, electrical currents due to it do not really begin to flow within our bodies, and no physiological damage of any kind takes place. EMP really "speaks" only to metallic objects, and to things connected to them which are sensitive to high-frequency currents.

EMP is much more threatening to big electrical systems than to small ones. Because metallic objects of many different shapes can effectively gather up and then concentrate the energy associated with EMP, physically large systems comprised of metal – lines, cables, wire and dish antennas – often manifest exceptionally great vulnerability to EMP damage. Their spatially extended components "harvest" the EMP energy broadcast by the bomb-atmosphere interaction, which falls fairly uniformly over wide areas, and bring it to wherever the system's "horn" may be – the often-centrally located components of the extended system which may be quite sensitive to electrical overload conditions. Physically small systems usually don't get EMP "illumination" so well-collected or -focused within themselves, and thus tend to be more durable to its effects. An obvious exception to this smaller-is-safer rule-of-thumb are communications systems, whose extension and high-sensitivity "front ends" almost unavoidably make them highly vulnerable.

EMP is much more threatening to modern electronics than to old-fashioned ones. Old- -fashioned electrical and electronic systems are generally built out of massive ... _ate, which are innately much more tolerant of the effects of EMP. Vacuum tu... for example, are extremely EMP-rugged, while the ever-tinier transistors which have almost totally replaced them in the U.S. military machine – as well as in U.S. civilian electrical/electronic systems of all types – are ever-more-vulnerable to EMP destruction. (Moore's Law – which states that leading-edge integrated-circuit electronics shrink in area by two-fold every year-and-a-half – assures that this vulnerability will become ever more severe, into the foreseeable future.) The Soviet technological lag behind the Americans has constituted a substantial – and vigorously exploited – advantage in this somewhat perverse respect.

EMP in space is different from EMP near the ground, and is typically weaker. EMP arising in spacecraft due to exposure to nuclear hard-x-ray and gamma radiations – even from great distances – is often extremely tedious to eliminate effectively and

with adequately great assurance. (It is assuredly possible to accomplish, however, even against the most severe threats, although it is often quite costly to do so.)

Nuclear EMP thus poses an extremely serious threat to the assured functional survivability of space assets, both military and civilian, the more so as the essential system-level testing always was expensive and currently is effectively impossible.

EMP defenses are simple, and traditionally have added ~10% to military system costs. For typical military systems which do not operate in space, the rule-of-thumb has been that robust hardening against EMP effects adds 3-10% to the total system life-cycle cost – "the cost to the Nation to own" – if such hardening is engineered-in from the outset. For systems which are mass-produced, the EMP hardening cost may be as low as 1%, while few-of-a-kind items such as the MILSTAR spacecraft may have a fractional cost attributed to wartime survivability of a few tens of percent. (To be sure, cost attribution in DoD often is a political art, not an economic science.)

Such hardening consists primarily of *high-integrity* albeit thin (e.g., tinfoil-like) metallic shielding to keep the EMP radiation out of enclosed volumes containing vulnerable systems components and of special electrical devices – e.g., high-tech analogs of lightning arresters – for protecting absolutely essential penetrations of such seamless metallic enclosures from inadvertently admitting significant amounts of EMP energy into the interior "sanctuary." The major fractions of the added-cost for EMP hardening have traditionally been spent in engineering design, prototyping, performance-testing and *life-cycle maintenance* of EMP-robustness, not in the mass-production of the "sanctuary" itself. Indeed, significant economies might be realized in these cost-dominating areas in future efforts by intelligent use of more modern technologies, particularly commercial ones which have been very effectively employed in the past several years. If, on the other hand, EMP hardening is back-fitted to an existing military system, costs have generally been in the neighborhood of 10% of total system cost-to-the-nation-to-own.

Quite notably, substantial EMP hardening of a wide variety of COTS – commercial off-the-shelf – equipment (e.g., personal computers and communications gear) currently being acquired by the Services has been demonstrated to be attainable with a few dollars' worth of parts-and-labor.

SOME FUNDAMENTAL TECHNICO-MILITARY DIFFERENCES. There were several fundamental differences in the technical and military approaches which the Soviet Union and the United States took toward EMP. These differences are reflected in the postures of the two nations' military machines today, and likely will be enduring ones.

The Soviets basically decided that EMP represented not only an exceptionally severe threat to the integrity of their military apparatus and their civilian infrastructure, but also offered extraordinary opportunities to their strategic offensive forces. Relatively deficient in supercomputer-based computational modeling tools with which to understand the quantitative details of EMP generation and interaction with a wide variety of particular structures and systems, they took a generic, highly empirical "belt and suspenders" approach to

protection of both military and civilian systems against EMP, deploying protective hardware quite lavishly (as compared to the U.S.) and providing extensive counter-EMP training to both civilian and military personnel involved in the operation and maintenance of these systems. This preparative emphasis continues virtually undiminished through the present time.

Soviet strategic strike forces characteristically have featured weaponry well-suited to efficient EMP generation over completely wide areas. *That EMP strike component exists today in the Russian strategic order-of-battle, moreover likely at its maximum Cold War strength. I very confidently predict that it will be one of the last features of Soviet strategic nuclear weaponry to be retired from the Russian strategic force structure.* It has long been considered highly likely by U.S. strategic war planners that a Soviet first-strike would commence with a multi-explosion "laydown" of high-intensity EMP all over the continental U.S., significantly before any target on the ground is brought under attack, simply because the cost of such an attack-commencement is low and the benefits gained are great. Indeed, recollections of strategic war games long past have as a major common feature the beginning of the game with a massive Soviet EMP laydown all over the U.S., followed immediately by an extended "time-out" while the game's referees sip up huge handfuls of U.S. military capability of all types and throw it away as likely EMP-ruined.

We Americans, in contrast, collectively saw EMP as a major nuisance which could be rather precisely understood, defended against "well enough" – and thereafter largely ignored. The Defense Atomic Support Agency (DASA), succeeded by the Defense Nuclear Agency (DNA) and then by the Defense Special Weapons Agency (DSWA) and currently buried somewhere in the Defense Threat Reduction Agency (DTRA), working in exceptionally fruitful long-term collaboration with dedicated components of American industry (of which the RAND Corporation Physics Department, later re-organized as R&D Associates, and the Mission Research Corporation were particularly distinguished leaders), developed a really outstanding technical appreciation of EMP, how to model and simulate it with high fidelity, and how to effectively defend major military systems against it. Indeed, I estimate that half of DASA/DNA/DSWA's third-billion dollar (US $) three-averaged annual budget was expended for purposes of defense against EMP and related nuclear effects, over an interval of three decades.

Programs then came into existence to express and embed this evolving understanding – excellent albeit imperfect – of EMP in major American strategic warfare systems, primarily the offensive ones but also the defensive components. However, because neither supervisors nor senior commanders really understood – or, in some cases, believed in the existence of – EMP and its effects, these EMP hardening programs too often followed uncertain trumpets, and their assessed effectiveness was not exceedingly high. (At that, U.S. strategic military systems were much better EMP-protected, on the average, than were our tactical ones.)

Some CINCs stand out in my memory as exceptionally diligent in their efforts, the results of which were especially praiseworthy. (A few senior Navy admirals, enjoying unusually great tenure and discretion over the resources of their large commands, did very well by the enduring National interest in these respects.) All

too often, though, protecting against a poorly-understood, deemed-unlikely threat of a semi-magical character lost out in the unceasing battles-for-resources, and was deferred, largely or completely, to "next year" – a well-known point-in-time which is never quite attained in DoD-Land. In some notable EMP-hardening programs, sustained and strenuous efforts were made without securing desired results, outcomes which were sometimes obscured to the present day by lack-of-candor leveraged with high security classifications. Case histories abound, but are not appropriate for open discussion.

As a result, the present-day U.S. strategic force structure is a veritable "patchwork quilt" with respect to its EMP durability. The bottom line is that, in "reality land weather", this "quilt" won't keep "warm" the fundamental National interest. *This situation is undoubtedly known, even in many of its details, to our potential near-peer and sub-peer adversaries – and it presumably incentivizes their exploitation-directed efforts. At most, America's strategic forces may be substantially hardened against EMP attack; them are our deployable tactical forces.* However, I commend to your favorable attention the substantial ongoing efforts of the Services to attain improved EMP hardness levels of tactical military equipments of many kinds, dubious recent coordination efforts from the Joint Staff notwithstanding.

The EMP robustness of the civilian infrastructure of the United States can be summarized far less equivocally: it is entirely non-existent. *Our civilian telephony, electricity, broadband communications and electronics plants are all naked to our nuclear-armed enemies.* They were neither designed, nor engineered, nor constructed nor are they operated so as to survive nuclear explosion effects, even at very great distances – for the 'invisible hand' of the marketplace provides no incentives for EMP robustness, nor penalties for failing to so prepare. Large electric power and telephony systems are known to fail under the effects of solar storms, which impose far smaller electromagnetic stresses than are known to arise from high-altitude nuclear explosions of even modest yields. *Consequently, even a modest, single-explosion EMP attack on the U.S. might well disorganize us as a modern, post-industrial nation.*

PECULIAR ASPECTS OF EMP ATTACKS. Indeed, a nuclear EMP attack on a nation is, in the large, the obverse of what the neutron bomb was asserted (utterly falsely by anti-deployment-directed Communist propaganda, but nonetheless with great political effect) to be in the small: an arch-capitalist weapon which killed people but didn't destroy the capital plant in which the people were located. *EMP weaponry (potentially even in single copy), in acute contrast to this now-ancient canard, potentially destroys in a highly effective manner the high technology electrical/electronic plant of any advanced nation – the heartland of modern civilization – while not directly harming people at all.*

It is profoundly unsettling that the electrical/electronic infrastructure of a large modern nation – which may be valued at more than ten thousand dollars per capita, or a few trillions of dollars for a nation such as the U.S. – can be so seriously threatened from afar by a single nuclear explosion, whose marginal cost may be a few million dollars, or a million-fold less. That this can be done

without harming people – potentially even invisibly, if done in broad daylight – gives real pause for thought, in a self-troubled, nuclear-multipolar world. *Nuclear EMP is the quintessential asymmetrical and unconventional threat.*

<u>*ASPECTS OF THE INTERNATIONAL STATE-OF-PLAY.*</u> Several aspects of the current and likely-future geopolitical state-of-play seem impacted by such considerations.

Through the end of the Cold War, we Americans could "attribute" any EMP attack on us with exceedingly high confidence to precisely one source: the Soviet Union. Moreover, we usually anticipated that such an attack would merely comprise the precursor of a "mass raid on North America" and, as such, "will be met with a full retaliatory response." Toward the end of the Cold War, American strategic war planners worried about more nuanced Soviet attacks, possibly EMP-intensive ones involving quite limited damage-on-the-ground, and puzzled as to how to most appropriately respond to such damage-intensive but "casualty-poor" attacks. Such perplexities seemed to many observers to be largely obviated by the end of the Cold War and the cessation of such "virtual hostilities" with the Soviets.

But were they really? It is widely-known that we Americans contemplated, briefly and in a non-pervasive fashion, a nuclear EMP laydown on Iraq (a Non-Proliferation Treaty signatory legally entitled to immunity from all nuclear attacks) as an exceptionally high-effectiveness commencement to Operation *Desert Storm* – and that two-thirds of the American people polled on the subject in that season explicitly supported the use of nuclear weaponry to protect the lives of American troops. It certainly should not be surprising if other nuclear-capable nations were thereby stimulated – if indeed any such external stimulus was needed – to contemplate employment of a similar tactic against their various politico-military adversaries, of which the U.S. may well be one.

What would the U.S. response be to a nuclear EMP "bolt from the blue" – or even one from a geopolitically overcast sky? What if such an attack, e.g., executed with a single rather modest Earth-orbiting bomb, arguably could have been mounted not only by Russia, but also by China or India or Pakistan or Iran – or North Korea? Particularly if none of our fellow citizens died as a direct-and-immediate result of such an attack, what degree of certitude of attack attribution would we require of ourselves before an American President would order a retaliatory strike imposing condign punishment on the suspect nation? Paralyzed as a modern nation, thrown back decades in time in industrial capabilities but still retaining a reasonably full set of nuclear teeth in our national mouth, just how would we Americans then choose whom to bite – if anyone?

That scenarios of this general flavor are currently considered "within the pale" is illustrated by the "Army 2025" war game conducted at Carlisle Barracks two years ago. Especially notable for its openness, this exercise postulated a U.S. expeditionary force in the Ukraine clashing with an invading Russian force, two decades hence. When the Russian force fared poorly in ground combat operations, the Russian General Staff used a set of nuclear explosions in space to effectively destroy the "high eyes and ears" of the U.S. military – and most

civilian economic and Russian space systems, as well – in order to express "national resolve." In addition to the far-distant Russian nuclear explosions giving American decision-makers real pause for thought, the entirely unexpected, abrupt and total loss of the "high ground" conferred by U.S. space assets nearly cost the American expeditionary force its collective skin. Just as this game was ending in a Russian-American armistice, the Chinese, noting America's unprecedented military ingenuity, commenced to make their long-expected moves in the Far East . . . .

At that, wafting out of this unusually thought-provoking exercise was a faint aroma of "Mao-preferred Red responses," a well-known key ingredient of politico-military folly. The Army's game-designers were willing to postulate nuclear explosions in space of a flavor which acted over time-scales of hours to days to dramatically "burn down" American space assets largely owned-or-operated by the Air Force. However, these game-designers didn't care to consider an arguably equally plausible Russian nuclear EMP lapdown over the Ukrainian territory within which the American expeditionary force was operating – which, without inflicting casualties directly, may well have devastated the electrical/electronic sinews of American tactical military assets – ones incidentally almost entirely owned-and-operated by the Army in this particular scenario.

Indeed, EMP lapdowns constitute a generically attractive response on the part of any regional nuclear power – not just Russia – to virtually any American power-projection attempt. They exemplify what is termed a "technologically " asymmetric response" to the impending *Revolution in Military Affairs*, one in which our adversary acts purposefully to leverage his set-of-strengths and exploit our set-of-weaknesses. (Saddam Hussein fought us entirely on our terms in *Desert Storm*; we must assume that we will not be gifted with a similarly inept adversary for some long time.) *Because a very small number – potentially just one – nuclear weapon exploded at high altitude over an American expeditionary force attempting forced entry against a major regional power could potentially tip the balance against our efforts, all such powers who contemplate someday possibly confronting us will be incentivized to develop, acquire or retain nuclear weaponry – quite contrary to the goals of ongoing nuclear nonproliferation efforts and to the objectives of the Revolution in Military Affairs.* It might be noted in this context that there are over 10,000 ballistic missiles presently owned by over 30 countries which are potentially capable of lofting a nuclear weapon to high altitudes over proximate U.S. forces – and that *many of the ballistic missile defense programs of the current Administration aim at military "products" which could defend against such "pre-emptive" nuclear EMP attacks thrown by ballistic missiles against U.S. forces.*

Either as a demonstration-of-military capability or a show-of-national resolve, exploding a nuclear weapon continues to have no peer. (The South African example naturally comes to mind in the current context, both with respect to its motivations and its successful sweetness.) If exploded so as to also cripple opposing military forces without also inflicting mass casualties, the potential attractiveness of such weaponry likely becomes quite compelling. A few nuclear weapons and unstoppable delivery systems (e.g., attacking ballistic missiles facing only Cluetenscopus missile defenses) which can throw them into space, one

[redacted] at a time, over an invader's forces thus naturally rise to the top of the "wish list" of many types of national leader. *North Korean options of these types relative to American forces deployed in South Korea and Japan come immediately to mind.*

[redacted]

[redacted] *Thus, for several reasons, such are good and sufficient, the U.S. would be well-advised to complicate for every offensive scenario-driven premise at present regarding EMP attacks against its national territory and against its forces abroad.* [redacted]

EMP DEFENSE FACING THE DEFENSE DEPARTMENT. Against such current and anticipated future geopolitical backgrounds, then, what are the major EMP-related issue-sets facing the DoD?

First, having incompletely triumphed in its EMP hardening efforts during the Cold War – when the threat was clear-and-present and the resources were relatively plentiful – how can credible DoD responses to present and emerging EMP challenges be rationally anticipated now? Specifically, how would a reasonable skeptic be persuaded of the seriousness and effectiveness of any new-found DoD sense-of-purpose with respect to EMP defenses?

Second, how can DoD reliably eliminate the prospect of a single nuclear explosion occurring at high altitude over the U.S.? (Indeed, how can it detect that such an EMP attack is underway, or that it is likely?) How can it robustly attribute the origin of such an attack, noting that at least Russia, China and India manifestly have the capability to execute such an attack today, and that North Korea – a nation with which the United States is still nominally at war – may gain such capability within a time-frame of months? *If reliable defense is not feasible and robust attribution for deterrence is not possible, how is a national attack to be rationally judged to be still unlikely?*

Third, how much is DoD willing to carve out of its present-day, still-shrinking-in-real-terms budget to defend itself and (a closely independent issue) to defend its Nation-sponsor from EMP attacks? Where, in particular, is how much money going to come from? How is this amount to be seen as credible, relative to what level of EMP defensive/hardening requirements? This issue-set is posed against the background of the current small-scale internecine strife within DoD between the "EMP Establishment" and a small but well-positioned set of heretics seemingly bent on minimizing the possible magnitude and significance of EMP from any-and-all national perspectives.

Fundamentally, DoD must decide that it is significantly more important to engage the EMP issue now that it was a decade or two ago, or no intra-Departmental initiative is possible in the current budgetary environment. The (non-)emphasis given EMP issues in the most recent QDR and in the even more recently concluded White House-commissioned study of infrastructure durability-under-attack seem diagnostic.

DoD must then learn the lessons of how-and-why it succeeded in some EMP defensive programs and more-or-less failed in many others, over the past three decades. (The associated large-scale scrapping of pleasant fairy tales and reversion to full candor necessary for such self-education in this area may be possible only because so much time has elapsed since most such programs culminated.)

Then resources adequate to the EMP defensive tasks must be identified and robustly fenced, and a single, highly-capable, long-term-accountable, senior-level-reporting individual given responsibility for all aspects of program execution, from start to finish. *Only* under such circumstances is it realistic to rationally expect real progress.

Finally, the Department would be well-advised to lead from its few positions-of-relative strength among its myriad components. Notable among these in the EMP context are STRATCOM, the Defense Special Weapons Agency (DSWA) operation recently merged into DTRA, and the Army's Nuclear and Chemical Agency.

At the bottom line, however, it's difficult to be optimistic regarding a much- improved DoD posture on EMP. Indeed, quite the opposite seems to be the odds-on bet.

EMP ISSUES FACING THE CONGRESS. With all due respect, the only *fundamental* issue facing the Congress is determining the degree of its own concern regarding the EMP threat to National military capabilities and to the at-risk portions of the Nation's infrastructure.

Once the degree of this concern is determined, the Congress may then ascertain quite readily whether or not it is sufficient to elicit a voluntary, "If you want it done, we're willing to do it" response from the DoD. If it isn't, then the only remaining question is whether the Congress is minded to mandate in statute the desired response from an unwilling DoD – with all the well-known risk, cost and subsequent oversight hassles thereto pertaining – very notably, with respect to infrastructure defenses, which are not Federally owned.

It's of fundamental importance for all such Congressional consideration to realize that *the ways-and-means for defending against EMP threats are far more readily available, less expensive and more effective today than they were even a decade ago.* This nearly-qualitative change in EMP-defensive capabilities has arisen as a direct consequence of the proliferation of very high-performance electronics throughout American civilization, i.e., personal computers and telecommunications devices. An unavoidable consequence of the ever-higher performance of these devices is that they *continuously* generate very low-level EMP-like signals; also, due to their very small size, they are exceptionally sensitive to interference in their operations from EMP-like signals.

These considerations have motivated manufacturers of these systems to provide passive defensive means against interference with their normal operation by EMP-like signals coming from outside of them; also, the manufacturers, on their own and due to Government regulations, have constructed these systems so that they emit very little of the EMP-like signals which they generate in normal operation. Together, these passive defenses not only make a substantial fraction – indeed, the most modern fraction – of the American infrastructure more robust against EMP threats, but they also provide the ways-and-means, both technological and intellectual, for extending this relative robustness into many other EMP-vulnerable portions of our Nation's electrical and electronic infrastructure – both its military and civilian components.

These defenses have two basic forms. The first consists of enclosing electronics in high-integrity metallic shells, since even quite thin layers of metal essentially completely stop both the most threatening aspects of EMP and the low-level electromagnetic interference resulting from high-performance equipment operation. The second defensive step consists of simple, very low-cost means for suppressing electrical surges on consumer-level electrical power and signal lines, so that feeding electrical power to equipment or connecting telephone or cable signals into it don't also provide pathways for ruinous EMP to damage or destroy its circuitry.

The fundamental reason that significant portions of the American infrastructure are much more robust today than a decade ago against EMP threats is simply due to the now-pervasive use of these two technology-sets in the modern portions of the computing and telecommunications plants of the United States. This constitutes an applicable track and an excellent example for enhancing the robustness of much of the currently unprotected infrastructure of our country, military and civilian.

RECOMMENDATIONS FOR CONGRESSIONAL CONSIDERATION. If the Congress chooses to initiate an EMP defensive program, I respectfully recommend that any such initiative include the following features:

Mandated Organization-For-Success. A brand-new, single-purpose organization is a political luxury in DoD, but it is a time-proven "high road" to programmatic success. If order to be maximally effective, such an organization must be run by a highly competent, surpassingly dedicated "benevolent dictator" whose enjoys unquestioned tenure and direct reporting to top-level DoD officials. (E.g., the House's FY'96 Defense Authorization Bill mandated such a reporting line for the Director of BMDO).

The government staff of this organization must be exceedingly few in number, exceptional in professional preparation and highly empowered. Industrial collaborators must be carefully selected for across-the-board competence, trusted and empowered thereafter and without exception – and likely compensated on a CPFF basis. External meddling in organizational business must be sharply minimized, and programmatic turbulence of all types – particularly with respect to budget and "mission creep" – rigorously suppressed.

DoD doesn't create many of these operations, for reasons both regrettable and obvious; if the Congress really wants EMP defensive programmatic success, it'll mandate such an operation into existence. (All of these are features identified in a fairly recent RAND study of the F-117 Stealth fighter program to be common to those DoD acquisition programs that perform in peacetime as well as the really crucial ones usually do in wartime.)

Mandated *Across-The-Board* Competition. All routes to programmatic success must be fairly and objectively evaluated, and defensive hardware from all vendors evaluated objectively on a common basis. Insisting on "picking winners and losers" is a regrettably common way for ego-blinded DoD program managers to fail. *Mandating* such pervasive competitive arrangements is the only reliable way to gain them.

Assured Managerial Accountability and Stability. Most DoD acquisition programs perform as abysmally as they do, relative to the closely comparable people-sets working in American industry, primarily because managerial stability is distinguished by its absence and managerial accountability is correspondingly non-existent. "State property is nobody's property" as the old Soviet saying went, and the U.S. Government's proprietary interest in programmatic success of its Defense acquisition programs is almost invariably "co-owned" by precisely no one, civilian or military. Even a superficial comparison of Soviet and American experience over the past few decades indicates clearly that, without some type of proprietorship, no "property" will be decently looked after, and the long-term consequences likely will be telling ones. The Congress would be well-advised to act accordingly with respect to creation of EMP defenses: the program's senior managers should be "lashed to the mast" until the programmatic ship weathers the inevitable storms.

Design-To-Cost Focus. One pervasive problem encountered in the DASA/DNA/DSWA/DTRA EMP hardening program was a single JCS specification for EMP hardness which had to be met by specified construction techniques, no matter what the attendant cost or difficulty might be for particular military systems. While the hardness level had a quite fundamental and rational basis, it might be more appropriate under prevailing circumstances to mandate hardening to a *performance*, rather than a *construction*, specification-set and to design hardening to a specified, not-to-exceed total cost-per-system hardened. Congressional cost caps of undoubted robustness would wonderfully concentrate both the bureaucratic and the defense-industrial minds -- particularly if contractor profits-and-fees are specified-in-advance to be paid out the wrap-up portion of the program's capped total budget.

"Free Fixes" Arrangements With DTRA Customers. One of the standard ways-to-crash in the DASA/DNA hardening program arose from the fact that the agency's folks were chartered to provide all manner of free assessment, advice and technical consulting to the military customer, but the customer had to pay all of the actual costs of hardening his own systems. As a consequence, only the unusually rich or the exceptionally diligent customer ever managed to pay for more than a small fraction of the hardening work to be done. An obvious fix for

this fatal hesitation is to subsidize – perhaps even completely – EMP hardening work, and maybe even offer incentives to sign up for hardening. Again, cost caps on 'front' – perhaps supplemented by fee incentives for on-spec/under-budget performance – may serve usefully to keep overall program budgets on-track.

Independent Periodic Assessments. For nearly three thousand years, the applicable maxim of Western jurisprudence has been "No man is an apt judge of his own cause." Particularly in its oversight of any Congressional initiative – one in which DoD co-ownership might be somewhat lacking – the Congress would be well-advised to commission independent reviews and assessments of programmatic progress made and problems encountered. No honest program will object to a single swiftly-executed annual review by competent-and-objective folks who can be "brought up to speed" without undue effort or delay. DoD's own Operational Testing Office might serve quite usefully in this capacity.

Frequent Full-Up Trials Of Prototypes. Those DASA/DNA/DSWA EMP hardening programs which were more likely to be successful had frequent testing of hardened sub-systems and systems as a major feature. Such exercises build confidence that progress is being made while also uncovering problems when they're small and relatively quick-and-cheap to fix. They're not diversionary, and should be mandated if simple encouragement to do so is insufficient.

It is notable in this context that the system-level EMP hardness of most all American space assets currently is entirely conjectural, due to a pervasive lack of realistic full-up testing in recent years; any assertions to the contrary can be most charitably characterized as white lies. That a National capability to conduct realistic full-up system-level testing of critical space assets was developed and exercised so tellingly – and then abandoned – is a major "blot on the copybook" of several recent OSD senior management crews with respect to safeguarding crucial features of the National interest. A clear and firm Congressional mandate is the only "sure cure" for this problem.

Credible Performance Certifications. Several large-and-venerable investment houses have sustained titanic losses in the past few years by allowing their high-rolling traders to run their own back-offices, with the result that losses were effectively concealed until they run into ten figures. Government programs that are allowed to monitor, review and appraise their own performances often run into similar difficulties – with the notable difference that these failures are typically entombed discreetly in classified document repositories. Certification of EMP hardness of various military and civilian systems in transparently-operated all-DoD test facilities is a *sine qua non* for programmatic integrity.

Mandated Balance Between Military- And Civilian-Directed Efforts. Encouragement by the Government of civilian builders and operators of EMP-vulnerable components and systems should be pervasively encouraged – *using all necessary means* – to design, build and operate EMP hardness into their systems. These means may range from building to GSA-issued EMP standards in order to provide equipment to any Government agency to GFE-type testing and certification of industrial equipments offered to the commercial market, akin to a UL seal-of-approval, and may include mandates to federal regulatory agencies, e.g., the FCC,

which supervise and license EMP-vulnerable national infrastructures. In any case, the Congress should periodically re-visit and, as necessary, re-tool statutory language aimed at balanced hardening efforts in the military and civilian sectors, so that national security "front-doors" are not locked while "back-doors" are left wide open. *It obviously makes no sense to gain an EMP-robust military machine while the National civilian electrical/electronic infrastructure remains tissue-soft.*

Obvious features of hardening of civilian infrastructure will surely include regularly hardness-tested "backbone" systems, e.g., for essential communication functions, and regularly exercised rapid-reconstitution ways-and-means, e.g., for restoring large-scale electrical power systems from hardened, distributed component stores. While largely civilian-sector in character, ensuring that such minimum essential capabilities either reliably survive EMP attack or can be quickly re-constituted thereafter surely falls well within the Congressional ambit of ". . .*providing for the common defense*".

Continuing Congressional Engagement. Accompanying all of the above is a need for continuing Congressional engagement with the DoD's best thinking and analysis, of the general character which is traditionally associated with Congressional oversight proceedings which review mandated annual reporting and *ad hoc* certifications. Indeed, and again with all due respect, the Congressional follow-up with respect to the existing statutory demand on the SecDef and the DCI for an EMP posture statement will be pragmatic.

Congressional oversight with which I'm familiar in the strategic warfare area has been highly commendable in its peak intensity, its intellectual acumen and its cogency but, again with all due respect, has been less-than-perfect in its regularity and follow-through. *Constancy and perseverance will be crucial in seeing Congressional mandates faithfully and efficiently translated into DoD programs and EMP defenses-in-being*, as cognizant Government officials-and-officers come and go with remarkably high frequency. Commitment of highly capable, single-task Congressional staff members to such functions would have both symbolic and practical significance.

CONCLUSIONS. Electromagnetic pulse (EMP) is a "weapon of mass *hardware* destruction", even one instance of which could cripple much of the U.S. military machine and which also can lay waste to modern American civilization – without directly harming a single American. Technical means of defense against EMP exist which are of unquestioned technical feasibility and military effectiveness. *Whether EMP defenses are financially and programmatically feasible to produce and display is for the Congress to determine – for corporate DoD seems to have elected to mostly turn its face from this esoteric but possibly historic issue.*

I thank the Committee once again for this opportunity to appear and comment on these matters of enduring significance for our Nation's security.

Information Submitted In Compliance With
Rule XI, Clause 2(g) of the House of Representatives

Dr. Lowell Wood is a Visiting Fellow at the Hoover Institution on War, Revolution and Peace at Stanford University, and a permanent staff member (currently on the Director's Technical Staff) of the Lawrence Livermore National Laboratory, operated under long-term contract (since 1952 through the present) by the University of California for the U.S. Department of Energy and its predecessor organizations, under Contract W-7405-eng-48.

The Hoover Institution has received grants and contracts in support of its scholarly research activities from the Federal Government for many years, including the grant of its principal office building pursuant to an Act of Congress in 1974 memorializing President Herbert Hoover. The Livermore Laboratory, designated a National Laboratory by Act of Congress, has received total funding of the order of $1 billion (FY'90 $) annually for several decades from many agencies of the U.S. Government, with approximately 89% currently coming from the Department of Energy, approximately 8% coming from the Department of Defense and 10% from other Federal agencies.

Dr. Wood is unaware of any funding currently being received for any purpose by either the Hoover Institution or the Livermore Laboratory – or funding received during the past three years, or funding which is anticipated or being negotiated for – on the subject of his testimony. In particular, Dr. Wood has received or benefited from no such funding personally.

Dr. Wood is not representing the Hoover Institution or the Livermore Laboratory, or presenting positions of either of these organizations, in the course of his appearance before the Subcommittee. (To the best of his knowledge, neither of these organizations maintains any positions on any of the subject matter of his testimony.)

Neither the Hoover Institution nor the Lawrence Livermore National Laboratory have contributed to the preparation of his testimony, which has been prepared by him as a private individual. Dr. Wood's testimony is offered as being solely his own, not necessarily representing the opinion of anyone – or anything – else.

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Education

B.S., Chemistry and Math, U.C.L.A., 1962
Ph.D., Astrophysics, U.C.L.A., 1965
Dissertation title and advisor: "Hypothermal Processes In The Solar Atmosphere"; Professor Willard F. Libby

Professional History

Member, Technical Advisory Group, U.S. Senate Select Committee on Intelligence, 1977-present

Visiting Fellow, Hoover Institution, Stanford University, 1994-present

Officer and Member, Board of Directors, Fannie and John Hertz Foundation, 1996-present

Professional Staff Member, University of California Lawrence Livermore National Laboratory (1972-present)
Director's Technical Staff and Associate Physics Department Head (1972-75)
Special Studies Group Leader (1975-80)
Special Studies Division Leader (1980-84)
Special Studies Program Leader (1975-84)
Advanced Technology Program Leader (1980-84)
Professional Research & Teaching Leave to Hoover Institution, Stanford University (1994-96)
Director's Technical Staff (1996-present)

Assistant Professor, Department of Applied Science, University of California, Davis/Livermore (1966-72, half-time)
Teaching and research in the applied physical sciences, with emphasis on computational physics and artificial intelligence, electrodynamics, biophysics and the conceptual foundations of technical innovation.

Consultant, University of California, Lawrence Livermore National Laboratory (1965-1972, part-time)
Research concerning the terminal phases of stellar life cycles, with emphasis on supernova radiative hydrodynamics; research into nuclear explosive-based national defense systems; studies of thermonuclear physics and technology culminating in technical proposals leading to the establishment of the national inertial confinement fusion program.

Assistant Research Geophysicist, U.C.L.A. (1965-72, full- and half-time)
Research into nuclear reaction processes in the solar atmosphere, and terrestrial consequences thereof.

Awards and Honors

National Merit Scholarship, 1958
Phi Eta Sigma, 1959
Phi Beta Kappa, 1962
National Science Foundation Fellowship, 1962-65
NASA Predoctoral Traineeship, 1965-65
Sigma Xi, 1965
E.O. Lawrence Prize (National Security), US Department of Energy, 1981
Abmassador Award (Technical Leadership), American Defense Preparedness Association, 1991
Defenders of Freedom Award, Doctors for Disaster Preparedness, 1995
Golden Plate Award, American Academy of Achievement, 1997
R&D 100 Award (Gamma Watermark), 1999

Professional Memberships

American Association for the Advancement of Science
American Physical Society
American Institute of Aeronautics and Astronautics
American Chemical Society

Major Professional Interests

Advanced computing systems and technologies; ultra-high power density systems; laser physics and technology; high energy astrophysics, particularly stellar explosions; controlled fusion; biophysics; space systems; national defense high technologies.

DOCUMENTS SUBMITTED FOR THE RECORD

October 7, 1999

89

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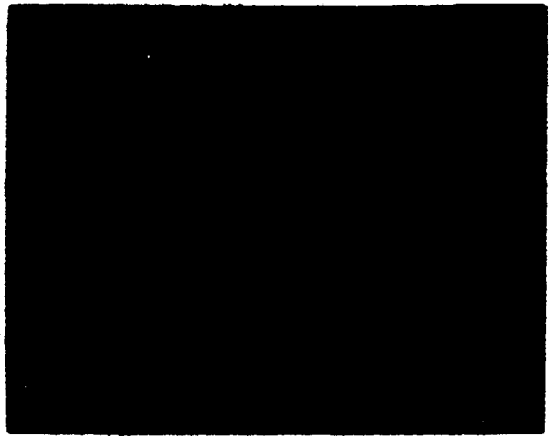
Testimony to the R+D Subcommittee of the House Armed Services Committee - Open Session Testimony

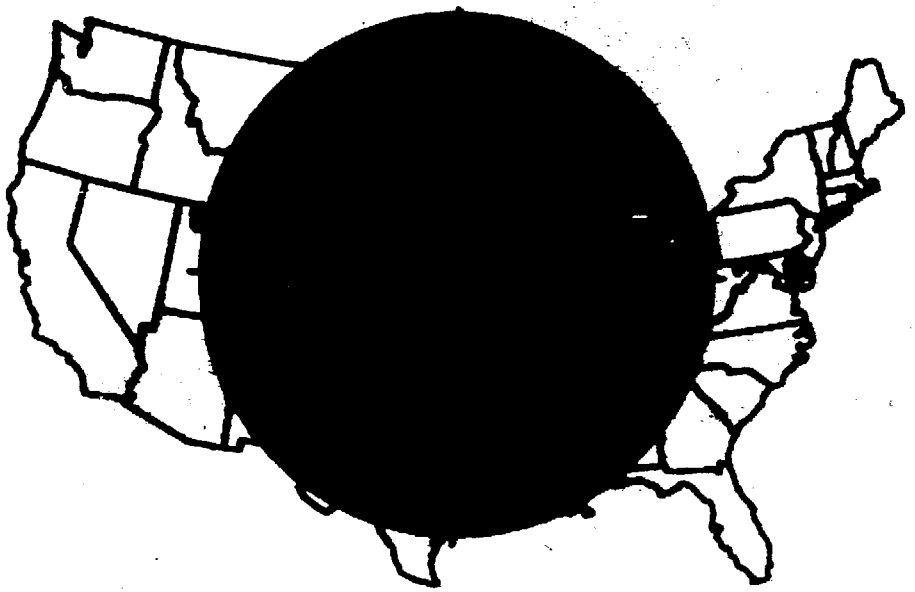
Dr. Michael P. Bernardin

Los Alamos National Laboratory

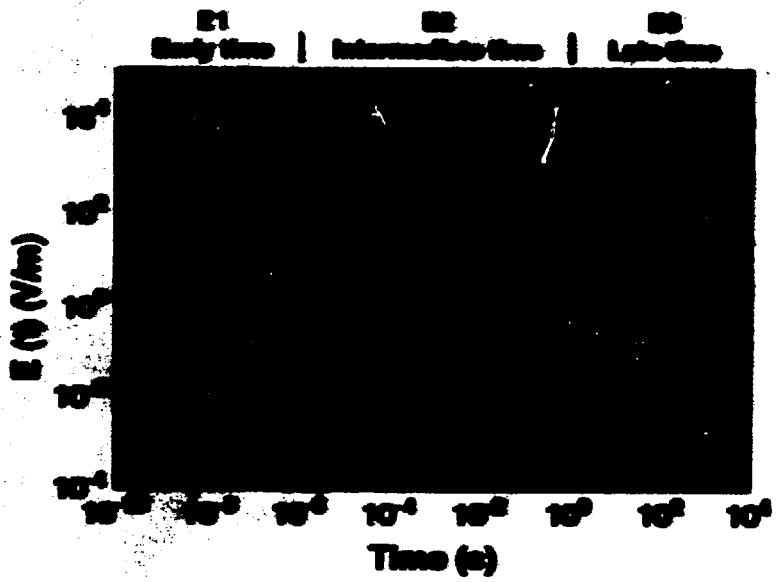
October 07, 1999



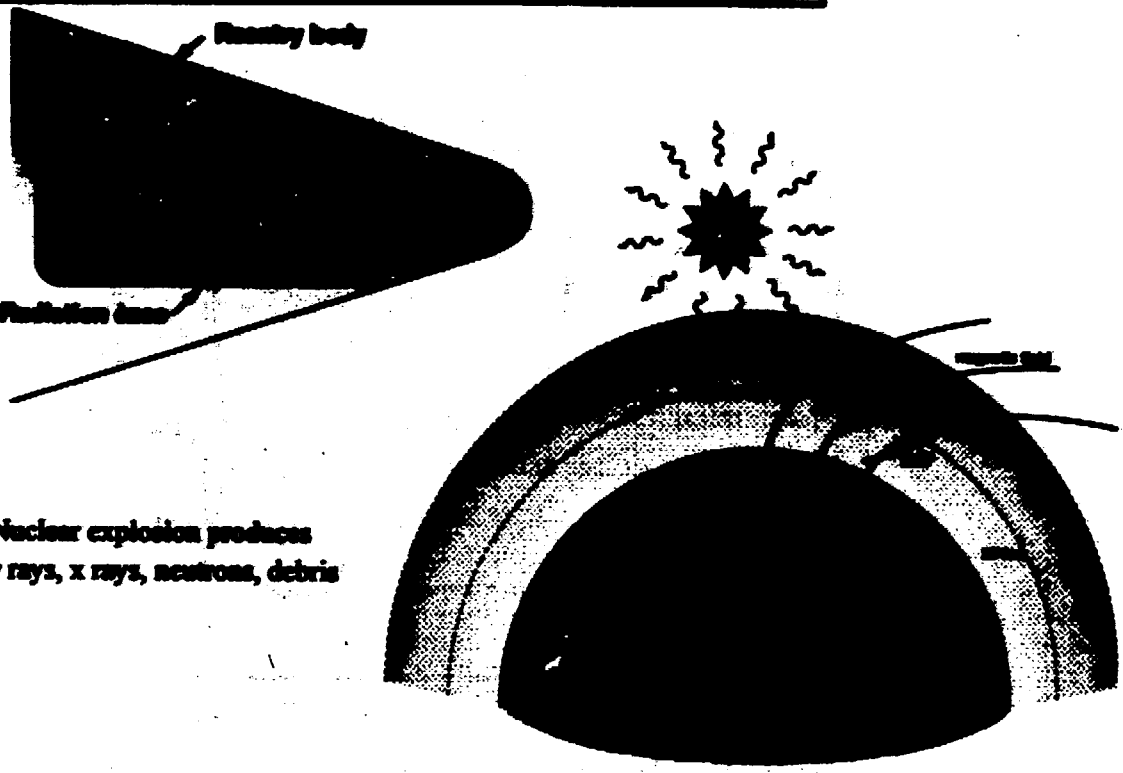
The area coverage of direct EMP exposure from a 200-km height of burst.



A qualitative EMP waveform from a high-altitude nuclear detonation.



High-altitude EMP generation mechanisms



Unclassified

Thermoelectric Applications

Because of the directionality of the earth's magnetic field, an idealized E_1 footprint has the shape of a smile.