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IMPACT OF THE STRATEGIC DEFENSE INITIATIVE ON RESEARCH AT LOS ALAMOS NATIONAL LABORATORY*

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The theme of my talk today will be to discuss how the Strategic Defense Initiative has impacted basic and applied research at Los Alamos National Laboratory. To put this talk in proper context, you must realize that SDI programs count for less than 25% of the activities at our Laboratory. Our primary mission is to utilize our strength in science, engineering, and technology to address problems of national security. We have a statutory responsibility to design, develop, and maintain the nuclear warheads that make up our nation's nuclear deterrent force. In addition, we also have many other non-nuclear programs which address important defense issues, such as Strategic Defense Initiative, but also in the areas of conventional munitions, armor/anti-armor programs, and other specialized applications of our research and technology. We also address problems of importance to national security in other arenas, such as: energy research and purely fundamental research in various scientific disciplines. In conducting these programs we utilize research efforts which are part of our technology base in physics, chemistry, mathematics and computational science, engineering, materials science, geosciences, and life sciences.

Before I discuss how the Strategic Defense Initiative has impacted the search of these disciplinary areas, it is important to point out that we

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were involved in all the directed energy technologies prior to the President's speech in March of 1983, which outlined his vision for the Strategic Defense Initiative. The reason for our involvement was that many of our scientists and our management recognized the importance of the ability to direct energy to defensive strategy for our country. In the remainder of this presentation I will discuss the specific activities in our non-nuclear SDI programs, with emphasis on defining what important research areas exist for the successful development of the various technologies. I will then attempt to identify how this research will impact both the SDI as well as other non-SDI areas, including the potential impact on basic research opportunities and technological applications.

The first major SDI program at Los Alamos that I would like to discuss is that of the Neutral Particle Beam. The goal of this program is to develop the technology to emplace an accelerator in space capable of providing intense beams of high-energy protons which can be used for either of two missions. These include the discrimination between reentry vehicles and decoys, and the actual destruction of incoming RVs or busses. Accelerator technology has been with us for many decades. The particular type of accelerator envisioned for this mission is a linear proton accelerator for which Los Alamos has developed significant capabilities emanating from LAMPF (Los Alamos Meson Physics Facility) which is the world's highest intensity, high energy research facility.

The challenge for us in this program is to show that one can develop the characteristics of the accelerator which will allow us to address the SDI mission. The basic concept of the Neutral Particle Beam begins with a high intensity negative hydrogen ion source followed by a device to increase its energy sufficiently to inject into the following linear accelerator structure, which is a series of linear accelerating cavities that bring the proton beam up to its proper energy. The accelerating region is followed by a device to strip the lightly bound electron on the negative hydrogen beam so that one has remaining a neutral atom which can propagate in space without being deflected by the earth's magnetic field. To reach the parameters necessary to make such an accelerator system applicable to SDI, requires advances in each of these portions of the overall system. First, ion sources have been around for many years, but they have been known to be temperamental devices, and in fact, the development of such sources has many times been referred to as "sorcery." What will be required and what we are attempting to do is to develop ion sources which are more predictable, easier to start up, and easier to operate without human intervention. In addition, we are doing research to improve the quality of the beam that emanates from the ion source. All of these present considerable challenges to our scientists, but new ideas are emerging rapidly.

The next step of the system involves the first accelerating stage which prior to five or six years ago required an immense structure for proton beams known as a Cockroft-Walton accelerator; however, building on a Soviet theoretical concept, scientists at Los Alamos have been able to develop a new device called radio frequency quadrupole (RFQ) which reduces the scale of the first accelerating section immensely. It is developments such as the RFQ which will make the overall concept of the Neutral Particle Beam system feasible for the SDI mission. The next stage of the system involves the linear accelerator itself which consists of a series of radio frequency (or RF) cavities which accelerate the protons on the electromagnetic wave, much like the surfer rides the waves on Maui. The challenge for the SDI program will be to develop accelerating structures with gradients which can eventually reach high enough levels so that the overall length of the accelerator can be reduced significantly. In addition, it will be extremely important for the quality of the emittance of the beam which results in the linear accelerator to be of high quality so that the subsequent propagation of the neutral proton beam will have low divergence.

One major technological development that will be important for the space application is that of the RF power used to feed the linear accelerator cavities. To date the requirement on the RF power has been such that it would account for as much as 65% of the overall space platform weight for a neutral particle beam system. The weight per watt of RF power that existed eighteen (18) months ago was on the order of 1.2 g/W. Today, through developments by our industrial partners, that figure has been lowered to 0.5 g/W with the overall goal of our program being less than 0.1 g/W. The point of this is that in a rather short period of time the system constraints of the SDI program has driven industrial talents to develop lightweight RF power in a fashion that previously was not thought easily achievable.

Another major challenge for our scientists occurs at the point of the neutralizer at the place at which the extra electron must be stripped from the negative hydrogen beam. Today this occurs with a lower efficiency than one would like and with less selectivity than is desired. This can result in positive hydrogen ions, the normal proton, heading off into space and being captured on the magnetic field lines, reflecting back and forth on these magnetic field lines, thereby providing a radiation background to many of our detectors and satellites that is not desirable. However, it may be possible, through scientific research, to develop a more selective scheme to detach this extra electron so that a higher efficiency can result. In addition, it is important that we can determine where this particle beam is going. We must be able to aim the beam and to correct that aiming procedure, as well as minimize the overall emittance of this beam as it comes out of the neutralizing region. All of these represent R&D challenges for our scientists. Some of our best young people have risen to this challenge with some outstanding new research ideas that will be pursued at a new facility at LAMPF called HIRAB (High Resolution Atomic Beam).

The next part of the neutral particle beam system requires us begin able to determine whether or not we have hit an object, and if so, whether that object is a real target or a decoy. This represents a major challenge for the SDI, regardless of the defensive weapon system involved. The advantage of the neutral particle beam is that a high-energy proton is extremely penetrating, thereby making it difficult for your adversary to add shielding that would reduce its effectiveness. The penalty that the adversary would have to pay is one of weight; thereby making it extremely unattractive as an option. When an intense proton beam of high energy interacts with material that might be part of a reentry vehicle, copious amounts of gamma rays and neutrons are generated which can be detected by sensors located far from the reentry vehicle itself. Through calculations and measurements we have determined that the signal generated will be above any background that could be created by our adversary. This makes the signal a very distinct one for an RV versus a decoy which would generate very little signal. This requirement has pushed some of our best nuclear and space scientists to investigate new types of sensors, or detectors, that will have significant applications in other arenas in space research. As a matter of fact, one idea will be utilized in the Mars observer mission.

I recognize that accelerators with the characteristics I have described are challenging to build even if they would be used here on the ground. The additional requirement of their operating in space, of course, adds to the challenges. In addition, I certainly know that accelerators are difficult to operate and maintain without a large crew of technicians and highly sophisticated scientists and engineers. The challenge to automate such operations and to make such an accelerating system highly reliable is very significant, but we are embarked on the research that will tell us how such a system can be achieved, and for what cost.

Now what important research areas do I feel have a long-term impact on science and technology as a result of this SDI program and the Neutral Particle Beam program? First, I think that the development of three-dimensional accelerator design codes which can more accurately predict the interaction of a high-intensity beam of particles with the accelerating structures will be of long-lasting importance. In particular, the inclusion of plasma effects, such as space charge, will require innovative solutions to problems that have long plagued accelerator designers. The development of new accelerating structures themselves which have higher gradient fields will require many new developments both in conceptual arenas, such as new accelerating methods, and in the development of new materials which can withstand high fields without breakdown. One long-range area will probably be that of the super-conducting accelerator cavity. Superconducting cavities today can produce high field gradients, but with the additional requirement of high beam power this technology is not capable of providing the characteristics that one would desire. However, I believe that superconductivity will impact SDI significantly in the future.

Another important area will be that of magnetic materials and the development of magnetic optics themselves. Clearly this is important for the NPB because the beam that emanates from a magnetic structure must retain the high-quality characteristics that one needs for the final application. In addition, a requirement of siting such magnets in space is driving us to research on new solutions which will impact utilization of magnets here on earth where they are today not practical.

I would now like to turn to the application of this technology to other research areas. That is, the question "Will any of these developments, if they occur, have any impact on other fields of importance to this country?" High-current particle accelerators can play a very significant role in the generation of intense sources of neutrons with a variety of applications. One application whose promise has not been achieved to date, because it is only beginning to unfold, is that of the use of an intense proton beam as a spallation neutron source for research into material science, chemistry, biology, and condensed matter physics, via neutron scattering. The most common way to accomplish this research today is through a nuclear research reactor. The world's most intense research reactor exists at the Institute Loue Langevin in Grenoble, France, and this facility has had a significant impact on the world's research community in the above fields. It appears possible to build higher flux reactors for research purposes; for example, one is being discussed by Oak Ridge National Laboratory which could achieve a factor of five (5) higher intensity than the LLNL, at a cost of between $300M to $400M. However, it may be difficult to push the research reactor much further than is envisioned by Oak Ridge, primarily because they are approaching the power density limits for a given neutron flux. The main difference between a reactor and a proton spallation source is that for each nuclear fission event that occurs in a reactor, approximately two and one-half neutrons are generated for potential use; while in a spallation source each proton can generate many more neutrons with much less waste heat generated in the process. For example, an 800 MeV proton beam can generate approximately twenty (20) neutrons for each proton incident on a heavy metal target. The long-range implications of this are that proton spallation sources could replace research reactors for the applications I mentioned above if they can achieve certain characteristics. One being high intensity, the second being much higher reliability. Both of these are goals of the SDI. The German government pursued such a concept for their country a few years ago in a project called the SNQ project. This project was cancelled, however, because the technology in hand to achieve the parameters desired for this neutron source were too expensive. However, the developments required for the SDI could result in a technology which would make the proton spallation source the research neutron source of the 21st century.

High-intensity, high-energy proton beams are also utilized to produce special isotopes which have many medical applications. These are routinely produced at the Los Alamos Meson Physics Facility (LAMPF) today; however, for commercial applications of the medical radioisotopes it would be much more attractive to have a dedicated high-intensity accelerator with high reliability which industry could operate themselves, thereby producing more isotopes and in a more timely fashion than could be accomplished today. This could be a potential growth area for the future in the medical industry.

Another potential medical application is where accelerators have been used to generate copious amounts of both neutrons and pions for radiation therapy. Pion therapy was investigated at LAMPF in the period from about 1975 until 1983 and is continuing in Europe today. The results of pion therapy were not totally conclusive, although there are some attractive features potentially for pion therapy involving the very intense deposition of radiation in a specific area. If one were able to reduce the size, cost, and complexity of high-energy intense proton accelerators, I believe this application would be reopened in the U.S. In addition, as I mentioned, neutrons can be produced in copious amounts by such accelerators. They have the additional characteristic that the high-energy neutrons that are generated in a very forward peak distribution which could be effectively utilized for neutron therapy. Although it isn't clear that this is a cost-effective way for pursuing such therapy, my belief is that significant accelerator developments would reopen the issue of their application.

The other major non-nuclear SDI program at Los Alamos, is the Free Electron Laser (FEL). Our program here, again, is based on an RF linear accelerator where the electron beam is accelerated to any particular energy and then passed through an alternating magnetic field structure called a "wiggler," which forces the electrons to oscillate in their path as they are affected by the magnetic field, and thereby emitting radiation as their path is curved. Our system is an oscillator system in which the emitted radiation from the electrons is returned via an optical system to the wiggler section in phase so that it stimulates coherent emission from a succeeding bunch of electrons. This causes the radiation to build in intensity and become more focused on each pass through the oscillator. The gain builds as the light passes through on each succeeding path. The wavelength of the light that results from this system is a function both of the magnetic field period and of the electron energy. Thus, the free electron laser can produce a source of coherent light that is tunable to a desired frequency and with significant amounts of power in the laser beam.

The SDI application of an RF-based free electron laser can be both in a space-based system or a ground-based system. In the ground-based system the light must be propagated through the atmosphere to a set of mirrors which can relay the beam to any particular target with the most attractive and vulnerable target being an adversarial missile in its boost stages. The other scenario would be to locate a free electron laser in space as a weapon either to accomplish the same mission mentioned above, or to act as a defender of the space assets that we might have in orbit.

Many of the issues surrounding an RF free electron laser are similar to those of the Neutral Particle Beam in the accelerator technology arena. For example, ion sources are again a major consideration in providing both the intensity and the quality of beam necessary for optimal free electron laser performance. We have under development at Los Alamos an electron ion source based on photo-electron production by laser pulses on a cathode. The main value of such a system is to provide both intense sources of electrons, but also high quality beams for injection into the linear accelerating sections. Similar characteristics of the accelerating stages for protons apply to the electron situation; that is, one requires the ability to generate high field gradients in terms of MV per meter, so that the overall length of an accelerator could be reduced. In addition, the weight of the RF power supply is an identical issue. As the electron beam leaves the accelerator and enters the wiggler section, there are many very important scientific issues that arise. One is the question of the magnetic system itself. There are several ways to generate the required magnetic field structures.

Today the most attractive is the use of permanent magnets which can be locked in place, thereby creating the appropriate magnetic field structures. If we are able to generate higher magnetic fields with new permanenet magnet materials, this will improve some of the systems requirements outside of the wiggler system. These result primarily from the amount of laser power that must be handled by the mirrors that make up the optical resonator. If the beam of electrons must be kept very small in diameter to pass through a magnetic field system of adequate strength, then the resulting photon beam will be of a similar diameter, and therefore, as the power builds will require either higher power optics or grazing incidence optics. If this diameter constraint can be lessened by expanding the region of the permanent magnets through the development of new magnetic materials with higher field strengths then the problem becomes more tractable.

As one looks at the scientific issues surrounding free electron laser development, again it becomes apparent that they challenge many different scientific fields from accelerator design to materials development. I already mentioned potential improvements in accelerator design, including three-dimensional code development, which would have a major impact on any accelerator-based system. In the FEL case important questions to be solved surround the high-power optics required and the magnetic wiggler system itself. In the optics arena surfaces and interfaces become an important area of research. This field is one of great importance outside of the SDI arena as well, so that there should be significant synergistic interaction between the development of high-power optics and other applications of surface physics issues.

In the area of physics of the free electron laser there are significant laser physics issues remaining in the understanding of how to scale this type of laser. In particular, there are significant collective and non-linear phenomena that occur as these intense electron pulses pass through the magnetic fields and interact with the laser light in the resonator. It is necessary to be able to understand and control all of these so that the resultant laser pulse is of the quality required for any particular application.

Now, will the development of high-power free electron lasers have any application outside the SDI arena? I believe that there will be significant applications of free electron lasers in which the research that is required for SDI will be extremely important. For example, in Los Alamos we are studying the possibility of developing an intense, coherent source of XUV light which would be utilized to study a variety of problems in physics, chemistry, and material science and biology, that cannot be undertaken today. For comparison, such a source would have a beam brightness of XUV radiation that would be as much as six (6) orders of magnitude brighter than the highest intensity source being planned in the world today. The application of such a source would be primarily for fundamental scientific questions in the field mentioned above. Free electron lasers in general will have many applications in technology, primarily because of their ease of wavelength tunability. There is considerable interest in the application of free electron lasers to industrial processing and diagnostics, for example, in the chemical industry. In addition, the medical industry is very excited about the potential of free electron lasers, again because of their wavelength tunability.

I would now like to turn to the question of what other aspects of the SDI program can impact research not only at Los Alamos, but also in the country, in a very constructive manner. This discussion will be essentially independent of the weapon system under consideration. First, it is the question of space-based systems. Although it is very likely that we will be able to develop the capability to assemble and operate an accelerator in space at some point in the future, another major issue surrounds our ability to develop the necessary space infrastructure to support any in-place SDI architecture. The main issue will be what resources will be required to bring the necessary support to the space arena to keep such a system reliable and operational. This immediately opens up the whole question of long-term utilization of space, which is a question that has been discussed at length in this country, but I think has been restimulated by the SDI program. One question will be how well our current space aircraft, namely, the space shuttle, will be capable of handling the demand in the future. The spinoff of developing new ways of lifting heavy masses into space could have major impacts on our ability to develop the use of space in a way not possible today. For example, utilization of the tremendous wealth of materials on the moon in future generations could be enhanced by developing the necessary lifting power required for SDI systems. This is an area which perhaps seems far down the road, but in fact could have long-lasting effects on our country and our civilization.

Another major impact could occur in the area of computational science. This field has been in a growth mode ever since its inception. However, the demands of the SDI architecture are challenging but not overwhelming -- much like the original demands of nuclear weapons design pushed the computer developers toward the super-computers that we have in place today. In the area of controlling any of these weapon systems, we will have to have expert or intelligent systems that will allow decisions to be made on a rapid time-scale and to feed back information to the hardware itself, thereby providing the reliability and diagnosis of problems in a quick, reliable manner. This should have major spinoffs to applications in both the industrial and medical communities. For example, it should impact control systems in chemical plans, nuclear reactor plants or for hospital medical systems, where reliability and the ability to handle large amounts of data on a rapid time-scale are extremely important. SDI will drive the demand for more powerful, smaller, lighter, rugged super-computers which can be dedicated, in effect, to each weapon system, but yet can be tied together in an effective and reliable manner should have major impacts on how we do computing today in both the scientific arena and industrial arena.

Now I would like to turn to a very fundamental issue that surrounds not only the SDI program, but any major program of similar magnitude and importance to this country. One can refer back to this nation's commitment to put a man on the moon by the end of the '60s and criticize it for its ineffective use of resources that could have been directed into other problems of national importance, including poverty, national health, etc. One only has to read the letters to the editor in any of today's newspapers to recognize that we have a similar situation surrounding the SDI that we had twenty (20) years ago in the NASA arena. One question I think that needs to be asked is: "Would this research be accomplished without the SDI?" I think the answer to this question is "yes." But perhaps the next question that needs to be asked is: "Would it be accomplished by the United States on a time scale consistent with maintaining our economic position in the world?" The answer to this question is, "not necessarily." We are no longer the first country to develop technology in every arena, as we were twenty (20) years ago. It is clear that our technological position and our economic competitiveness with other countries in the world is slipping rapidly. How do we strengthen our economic competitiveness? There has been lots of discussion on this issue. Some people favor investing lots of money on various industrial problems. It is certainly one way, but I would maintain that the primary thing that drives competitiveness in any arena is the need. The old saying that, "Need is the mother of invention," may sound like a worn out cliche, but in fact, it is the drive for a particular goal, however difficult it may seem at the beginning, that leads people to be innovative and to accomplish things that we never thought were possible. It is easy to criticize this point of view, but in fact, without it I think our country is in serious danger of losing what made it the great place it is. One only has to go back and look at the accomplishments of Alexander Graham Bell or other pathfinders of the nineteenth century to recognize that what they dreamed about seemed outrageous to the people at that time. However, if we are to become so cynical that we cannot look toward goals which seem out of reach today, then they will be out of reach. Civilization will move on and without or without SDI we will make significant accomplishments. However, it is my opinion that the Strategic Defense Initiative will push on us to accomplish things at a speed that may be very important in the 21st century for other reasons. This is a world that has a significant number of resources, but they are finite. Many of the problems that await future generations will depend a lot on the accomplishments of our society during this time. We must be willing to be bold and to develop technology that makes this a safer world. For SDI to have a lasting impact on society I think it must be recognized by everyone that its goals are fundamentally very laudable, and that it is a long-term program and that requires a balance between the exploratory research necessary to actually achieve the parameters that would make an SDI system an effective deterrent for nuclear war and the near-term milestones that allow people to see we are making progress toward the ultimate goal. This has been a difficult aspect for our society to handle. We work with annual budgets which require rejustification every year. We don't seem to have the foresight as a country to look toward the future and strike out on a path and stick to it, making whatever alterations are necessary along the way to get to our goal. I believe that this is a fundamental flaw in our method of doing business and it applies to other areas as well as SDI. One only has to look at how well the Japanese followed their own path starting around 1960 to focus on a twenty (20) year program to achieve parity with the United States in certain industrial areas. The result is that not only are they competitive in the industries that they set out to be strong in, but the impetus led others in their society to recognize the strength of their methods and to apply it to other major fields, such as electronics and computers, and in the near future I believe medical technology.

The conclusion of my talk is that I believe there are many challenging problems created by the SDI, in both a scientific and technological sense. SDI has impacted research at Los Alamos in almost every field that we do research, and it is likely to do so in the next five to ten years even if the SDI as a program were to be eliminated as a budget line item. The problems addressed by the SDI will not go away so easily, and I believe that the research that will come out of addressing the SDI objectives will have a major impact on our society, much as those that came out of our program to put a man on the moon did in the 1960's.