The Laboratory of the Atomic Age

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All of us hope that, in the long run, the energy of the atomic nucleus will be used only for peaceful purposes. After a half century of nuclear explosives and nuclear reactors, the practical effect of the former has been more important, both in our thinking and in our expenditures. The existence of nuclear weapons has had a decided influence on human affairs. Los Alamos, since its beginnings in March 1943, has been a unique place, distinguished both by its nature as a community and its continuing influence on world history. I will speak to several aspects of both characteristics.

In 1938, Enrico Fermi, my wife, Mici, and I were planning to drive from Stanford, California to the East Coast. I clearly remember Oppenheimer's suggestion that we stop on the way and spend some time in New Mexico. Even more particularly, I remember Fermi's remark that New Mexico would be an ideal place to develop weapons. That remark struck me as rather peculiar at the time because it wasn't until a year later that Fermi made the final decision to emigrate from Fascist Italy to the United States.

When we arrived in Los Alamos in late March of 1943, we found a striking contrast between the beautiful mountain surroundings and the dreary, green, barracks-like buildings in which we were going to live and work. Today, nothing is left of those early structures. After the Second World War, people were permitted to own the houses in which they lived, and the once uniform dwellings were replaced by a beautiful variety.

Los Alamos is different from all other communities not only in appearance but also in spirit. It was founded by scientists, and throughout its existence, has been led by scientists. The result has been an ongoing liberalism in the old sense of the word, that is, an unquestioned—perhaps even unnoticed—tolerance of widely different ideas. Another remarkable fact about Los Alamos is the uniformity of the standard of living of its residents. There are no very rich and no very poor. Perhaps this characterization of Los Alamos sounds too good to be true, but I think such praise is not unfounded. In large part, this liberal environment is attributable to the founder of Los Alamos, Robert Oppenheimer.

Los Alamos National Laboratory, together with its sister laboratory in Livermore, California, is currently near the center of a great controversy. On one side, it can be claimed that the efforts undertaken by the weapons laboratories won the Cold War and are ultimately responsible for the collapse of the Soviet Union. If even a small portion of this claim is justified, the implied effect on

world history is most important—particularly because expenditures on nuclear weapons amounted to roughly only 3 percent of the United States military budget over the past half century and, even more so, because the Cold War was won without any significant loss of life. On the other side of this argument, it is claimed that we would be better off had we never created atomic bombs, and, now that the Cold War is over, we may forget about them forever.

I intend to address this controversy at some length as well as its relevance to the future of the weapons laboratories. But to discuss the future, we must first consider the past.

The most important accomplishment of Los Alamos was the construction of atomic bombs in the two years and four months from the founding of the Laboratory to the test in Alamagordo. Before this history-making period I had been working in the Manhattan Project laboratory in Chicago, which was codenamed the Metallurgical Laboratory, and while there I saw a lot of my good friend Eugene Wigner. I had come to learn that he was almost always right, and he strongly advised me not to go to the new Los Alamos laboratory. The only difficulty, according to Wigner, was the production of the needed nuclear explosive material, that is, plutonium. Once we had enough of that, he asserted, it would be easy and obvious to put together an atomic bomb. For once Wigner was completely wrong.

Just a few weeks after we arrived in Los Alamos, Emilio Segré discovered spontaneous fission, a most important and unwanted source of neutrons. This discovery meant that as we tried to assemble the fissile material into a configuration that would result in a nuclear explosion, the neutrons from spontaneous fission would trigger a diverging chain of nuclear-fission reactions, and a premature explosion of far lower energy-yield, that is, a fizzle, would result. It was not many months afterwards that the complete concept of the solution appeared: an elaborate spherical assembly of the fissile material wrapped in "lenses" of chemical high explosive, the operation of which would result in substantial compression of the "incompressible" plutonium (or uranium).

The implementation of this concept required a great deal of refinement of both the techniques for handling chemical explosives and the calculations required for reliable estimates of the performance of the design. The result was the experimental production of unprecedented pressures, exceeding even those that we knew existed at the center of the earth. In a period of twenty-eight months, several new branches of experimental physics and numerous calculational techniques were opened up. All this was made possible by the skillful leadership of Oppenheimer.

That we "created" the atomic bomb is not an entirely correct statement. The atomic bomb had been long since predicted by Leo Szilard, and it would have been developed, in any case, in the next one to two decades. That the nuclear explosives were made available in time to write a favorable conclusion to the Second World War is the great accomplishment of Los Alamos.

In fact, the early availability of nuclear explosives and the subsequent possession of an overwhelming military force at a continuing cost of a small fraction of 1 percent of our gross national product (counting only the essential nuclear explosives on which this force was centered) have made it possible for the United States to retain great influence in world affairs during the following half century. It was, in my opinion, an unprecedented situation in history: that low-cost military power should become available and nonetheless not be used for conquest, or for the imposition of our wishes in general, but rather for the sole purpose of deterrence, stability, and peace on a global scale.

In the meantime, the development of nuclear weapons in the Soviet Union, Great Britain, France, China, India, Israel, and Pakistan is proof that the technology to make nuclear weapons is there to be used by anybody. The detailed facts about such developments have been kept secret and can therefore not be quoted. But in the special case of Iraq, a commission of the United Nations has investigated, in an open manner, the work of Saddam Hussein's regime. They found not only that Iraq was within a few years of having nuclear weapons but also that these developments had required the expenditure of billions of dollars and the work of more than twenty thousand remarkably well-trained Iraqis in addition to the importation of a great deal of equipment and supporting technology. The UN commission's findings have undermined two opposing myths: First, that a nuclear explosive could be secretly developed and completed in someone's garage, and second, that secrecy will stop the proliferation of nuclear weapons.

After the Second World War, Oppenheimer's slogan concerning Los Alamos was, "Let us give it back to the Indians." To his great credit Norris Bradbury, as the first postwar director of Los Alamos, prevented that from happening. As for the further development of nuclear explo-

sives, Oppenheimer's attitude was summarized in the statement he made to me in the fall of 1945, "We did a wonderful job and it will be many years before anybody can improve on it."

After the war I left Los Alamos to go to the University of Chicago, but I came back for frequent visits. In the summer of 1946, I traveled to Albuquerque to participate in discussions with the military regarding further developments of nuclear weapons. The military stated their opinion in very clear terms: The weapon used in Nagasaki is exactly what is needed and no changes whatsoever are to be recommended. Fortunately, Bradbury and the other leaders at Los Alamos did not accept this opinion and instead worked on significantly reducing the weight of nuclear explosives without sacrificing any of their effectiveness. Without such a development our postwar weapons would have quickly become rather ineffective in comparison with the capabilities of other nations, particularly those of the Soviet Union, Britain, and France.

Thus, the question of whether the efforts of Los Alamos were still needed in the period after the Second World War has been clearly answered in a positive manner. I believe that the historical situation following the Second World War is, in some respects, comparable to the one we are facing at present. In the current post-Cold-War period, we cannot simply conclude that the weapons laboratories have become superfluous. Indeed, it is a fundamental characteristic of technology, particularly in modern times, that new possibilities continue to open up and, soon thereafter, are realized. While some people may believe we are fast approaching "the end of history," I still find myself in agreement with Plato: "Only the dead have seen the end of war."

Although Bradbury took a strong stand on advancing the development of fission weapons, he nevertheless considered the development of the hydrogen bomb to be either an impossibility or, at best, a challenge that would require many years of considerable effort. During virtually all of my second stay in Los Alamos (1949–1951), I worked diligently on planning the first hydrogen bomb and did not consider plans for a sister laboratory. But when the decision to continue a vigorous effort was reached only by a hairsbreadth following the successful test in the spring of 1951, I came to the conclusion that the creation of a second laboratory would serve the national interest by generating competition and maintaining mutual support. These comments notwithstanding, it should always be remembered that the first American hydrogen bomb was created and tested by Los Alamos and that those developments would not have been possible without the cooperation of many of the old-timers.

With the passage of many years, it has become quite clear that the hydrogen bomb played an important role in the national military posture of both the United States and the Soviet Union. I have had the privilege of meeting some of the Russian scientists who worked on nuclear weapons. Most important was Andrei Sakharov, who is credited with the development of the hydrogen bomb in the Soviet Union and who later became an exceptionally courageous advocate of civil liberties in that Communist regime. Sakharov confirmed that the development of the hydrogen bomb proceeded independently and almost simultaneously in the Soviet Union and in the United States. It has also become clear that in the age of fairly accurate, rocket-based delivery systems, hydrogen bombs with yields of many megatons are no longer the most effective weapons. The real significance of the development of the hydrogen bomb is not that it offers exceptionally high yields but rather that it affords many options in explosive power, size and shape, and effects.

I have used the conventional words "Cold War" in referring to the four decades from roughly 1950 to 1990. I believe, however, that the use of the word "war" in that context is an unjustified exaggeration and becomes more so when applied to the development of defenses against the most effective method of delivering nuclear weapons, namely by rockets.

In private conversations Russian scientists have recognized the United States' undoubted leadership in

the area of strategic defense, the accuracy of which depends largely on the use of computers. The need for sophisticated computers may be the reason the Soviet government consistently opposed the development of strategic defense, even after President Reagan suggested a collaboration. A more open attitude became apparent, however, when the Soviet Union collapsed and President Yeltsin took over.

The most significant initiatives for developing defensive arms came from the two nuclear-weapons laboratories. Recently Los Alamos played an essential role in planning the adaptation of nuclear explosives for use in a defensive manner as well as adaptations of satellites in low Earth orbits for a variety of purposes, including not only the prompt reporting of the launching of missiles but also a warning of activities that indicate preparations for aggression. In addition, the adapted satellites can be used for observation of weather, prediction of natural catastrophes, and monitoring pollution on a global scale.

The Russians have shown particularly great interest in the last point. They have openly stated their lack of confidence in the evaluation of pollution and its effects on the former territories of the Soviet Union unless this evaluation is made or supported by authorities thoroughly different from those of the old regime, preferably having a major international component. Thus the competitive development of arms has led to methods of observation of the human environment that can be used in an internationally cooperative manner for important peaceful purposes.

Without the work of the two nuclear-weapons laboratories, the aims of the Soviet Union toward expansion and eventual domination would have proceeded in a more successful manner—these aims were basically a continuation of the policies of the tsars of Russia. Remarkably, the frustration of these aims, coupled with the corruption and ineptitude of the Soviet government, led to the abrupt end of the Soviet Union. It is also not a coincidence that this event followed just a few months after the United States demonstrated in the Gulf of Persia that high-accuracy systems can be used to defeat a big, well-trained army of a dictator at a minimal cost, over the span of a few days, with an incredibly small sacrifice in the lives of our soldiers and those of our allies. The weapons laboratories have thus contributed in more than one significant way to the dissolution of the great and terrible Soviet dictatorship—a victory achieved without war.

Even in the absence of terrible tensions between the Soviet Union and the rest of the world, nuclear weapons remain a reality. Complete elimination of these arms from the stockpiles of the United States and other important powers would merely encourage dictators of small countries to acquire these weapons, thus giving them opportunities for aggression beyond that possessed by their neighbors and also perhaps beyond that of all other nations.

We must also consider the proliferation of missiles of various ranges. Approximately twenty countries now possess this dangerous, rapid means of weapons delivery. These missiles can be used not only to carry nuclear weapons but also chemical or biological weapons and ordinary high explosives, as shown by Saddam Hussein.

The American Strategic Defense Initiative, identified in the minds of many people with nuclear-weapons-based confrontation, actually is planned to provide a defense against rockets carrying any of these means of swiftly executed aggression. Although it would not preclude all use of nuclear weapons, it would make swiftly performed aggression, based on rockets and perhaps based on aircraft as well, far more difficult.

What I have said already implies, to a considerable extent, my answer to the question: What should the weapons laboratories do in the future? For the sake of clarity and emphasis, I will give two direct answers to the question—one is a general answer, the other, a discussion of a specific possibility.

In the present period of "Cold Peace" (a "Hot Peace" would be an active cooperation among all nations for their mutual, general benefit), it is justified to cut back the expensive, routine peacetime activities of our armed forces as well as reduce the number of enlisted personnel, the quantities of military bases, and the amounts of stockpiled equipment and materials. It is, however, by no means justified to cut back research on future military capabilities. This should be clear to everyone from the indisputable fact that such research over the past half century made the real difference in winning the Cold War. It will play a similar role in maintaining peace during the next half century.

Furthermore, with little alteration, modern instruments of war can serve as tools for peaceful purposes. For example, expensive nuclear weapon-tipped missiles can be converted into delivery systems for sending observation satellites into orbit. Such satellites would give us warnings and detailed predictions of hurricanes, storms, and floods not

only in the United States but throughout the world.

Assuming that such research continues as it should, it ought to be concentrated in the present weapons laboratories. Among alternate facilities neither those serving pure research, nor those serving industrial development, nor even the Defense Department's military laboratories will be appropriate for such research and development. The first two lack the necessary contacts with the military and also lack the tradition of R&D on military systems. The other military laboratories, on the other hand, exist primarily for the stepwise improvement of existing weapons based on the closely prescribed requirements of the Pentagon. Compared to Los Alamos and Livermore, they have played essentially no role in the radical improvements, such as nuclear explosives or the instruments of extreme accuracy that have been developed successfully for defense against missiles and to hit point-like military targets. In contrast, the nuclear-weapons laboratories have experience in all these fields. They are the appropriate places for the creation and development of the fundamental advances in military capability on which America's future safety will depend.

In the context of this general answer, I want to discuss the specific issue of whether the DOE weapons laboratories should devote attention to new types of nuclear weapons. We must first consider what kind of new nuclear weapons would be of interest. Through the present time, we have emphasized the development of nuclear weapons using the best of the possible nuclear weapons materials for a broad spectrum of military objectives necessary for the security of the nation and our allies. However, nuclear weapons design for the proliferant nation or terrorist might assume an entirely different character from that of the major nuclear powers, taking paths prescribed by the limited availability of weapons materials and more narrowly defined objectives. Our understanding of these different paths to nuclear weapons is by no means complete. Without a full knowledge about these alternative prospects, we might not be able to detect the development of a weapons stockpile because we might not recognize the technology or even understand the clues that our superior remote sensing systems might provide for us.

One of the more likely paths to nuclear weapons taken by a proliferant nation or terrorists might be through the use of spent reactor fuel. The present worldwide inventory of plutonium in spent fuel is about 1300 tons. If we accept the unclassified information in reports by several Los Alamos scientists, frightening nuclear weapons can be constructed from rather small quantities of plutonium from reactor spent fuel. If the amount required for a threatening nuclear weapon were 10 kilograms, the present worldwide inventory would allow the construction of 130,000 such weapons. Not only do we need to understand how weapons might be designed from plutonium or other materials derived from spent fuel, but we should also understand the various options for the disposition of this material that would prevent its use in weapons.

During the past few years the great changes in the world have produced a clear and urgent necessity to consider major changes in our defense strategy while evaluating possible technical accomplishments. Such a necessity replaces the relatively simple problem of what to do with the DOE weapons laboratories with the difficult task of planning in detail exactly what should be done in a new era. Fortunately, Los Alamos National Laboratory has the intellectual tradition and power to give the needed answers, if not in a perfect way, at least as well as can any other existing institution.

Finally, it should be remembered that, after the Second World War, Los Alamos initiated a number of projects that are not connected with nuclear explosives. Among these, I select one particular enterprise for comment both because of my own interest and because it may have an exceptionally great importance in the future.

In their first half century nuclear reactors have progressed greatly and now produce 17 percent of the world's electricity. In Japan and, even more so, France, the progress is far greater than average. Nuclear-reactor-derived energy is clearly needed if the energy demands of the world in the twenty-first century are to be fully satisfied in an environmentally acceptable fashion. Yet, in the United States, public opinion and thus political trends have brought this development to a full stop.

What is badly needed is not just a safe reactor but an obviously safe reactor, one whose safety is easily recognized, even by non-experts. There are many means to achieve such safety, and Los Alamos is working on one of them. The Los Alamos reactor falls just short of being critical, by producing in each neutronic generation only 90 or 95 percent of the neutrons needed to sustain the neutron population in a steady state. Therefore, the reactor

obviously cannot work at all unless the missing 5 or 10 percent of neutrons are furnished by an accelerator. The electric power for operating the accelerator is in turn furnished by the reactor in such a way that a considerable amount of thermal power is left over for the generation of electricity. The means of ensuring that such a reactor will not become supercritical and "run away" are obvious and easily appreciated—the accelerator design could include an automatic shut-off mechanism.

Furthermore, in the Los Alamos reactor concept the low-pressure hot fuel would be cooled by pumping it to heat exchangers located outside the reactor core but within the same core containment. This technology parallels somewhat the molten-salt reactor developed at Oak Ridge. This approach simplifies the design of the reactor core and utilizes the heat more efficiently. The Oak Ridge reactor had the disadvantage that its breeding capacity was marginal, which in turn imposed constraints on its engineering. Such constraints are removed in the case of the proposed Los Alamos reactor by the presence of the neutron-generating accelerator.

A further important feature of the Los Alamos reactor concept is the continuous removal of the radioactive fission products. In this manner, the great amounts of radioactive materials are removed from the energy-rich, high-temperature portions of the reactor system. The consequences—and, more important, even the likelihood—of a nuclear accident are thereby minimized. Indeed, the main cause of legitimate concern about existing reactors is that means for eliminating an uncontrolled energy release by the reactor might fail, resulting in the scatter of a lot of radioactivity over considerable distances. The Los Alamos reactor concept either eliminates or greatly reduces the possibilites for such accidents.

Much remains to be done before such a reactor concept can become a reality. The need for the accelerator and for continuous fuel-reprocessing equipment could make the reactor economically unattractive. I hope that these objections can be overcome, in which case the reactor could break the deadlock that has prevented further construction of reactors in the United States during the past decade.

I cannot even attempt to discuss all the possibilities for future successes that may be achieved by Los Alamos National Laboratory. What assuredly is needed is thoughtful consideration of the support that may be available from Washington and an open-minded pursuit of the truly limitless possibilities presented to inquiring minds by scientific and technological revolutions.

The conditions clearly exist for surpassing in the next half century the history-making successes achieved in the Laboratory's infancy. Indeed, I have reasons both to criticize and also to agree with Oppenheimer's declaration (slightly paraphrased) of forty-seven years ago: "It will be a long time before anybody can do better." ■