A peril and a hope

With the discovery of fission mankind entrained cosmic forces with human irrationality; we must face the problem of reducing the tens of thousands of nuclear bombs ready to be released in seconds.

Victor F. Weisskopf

Forty years ago Otto Hahn and Fritz Strassmann discovered fission. The existence of this phenomenon could have been predicted before it was found if the theoretical physicists at that time had shown a little more inventiveness: It is a simple consequence of the facts that the Coulomb repulsion increases with the square of the number of protons and the nuclear attraction only with the first power. In 1938 enough was known about the nuclear force that it would not have been too hard to conclude that the nucleus must become unstable against a split in two parts around atomic number Z = 90.

Although the fission process itself was not foreseen, the possibility of a nuclear chain reaction was indeed thought of in the early 1930's by Leo Szilard. The implementation of such a reaction with fission would depend upon the number of neutrons released in the process. This number was not easily predictable; even today it would be hard to determine it theoretically from our knowledge of the nuclear forces. That this number is considerably larger than unity does not appear to be based upon any fundamental property of the nuclear forces. There are no very deep reasons; it might have been less than one, but it was not.

Cosmic fire

The fact that the number of neutrons emitted per fission is around two seems to be of very minor importance to Mother Nature. Apparently the only major roles of the fission process are to provide an upper limit to Z and to influence to some extent the abundance of fission products. Apart from this, we may forget about fission if we are interested only in the major features of our world. This is even more true about the chain reaction itself. Nature has not made much use of it; recently evidence was found that a natural chain reaction happened a billion years ago below the soil of Africa; but, to our knowledge, nuclear chain reactions have never played any role in the development of our Universe.

Do we humans count in this Universe? If we do, my previous statement is totally wrong. For humankind the existence of this chain reaction is of decisive importance, probably greater than we can fathom today. We know that fission can be used destructively as an explosive and constructively as a source of useful energy. It is therefore a very effective instrument of power, both political power and physical power.

This, in itself, is nothing new in the history of the natural sciences. New discoveries have led to new weapons, to new energy sources, and to countless applications from which a lot of good has emerged—as well as some results that have not been so good. (In the last 20 years it has been fashionable to emphasize the "not so good," but let us be objective and fair.)

There is indeed something different in the latest developments of physics, which I will call "the leap into the cosmos." Previously we were dealing mostly with processes similar to those occurring in our terrestrial environment. In the last few decades, however, we have taken a decisive step: We now deal with extraterrestrial phenomena. Nuclear physics and subnuclear physics deal with the excitation of quantum states that are beyond the reach of ordinary terrestrial energy exchanges: In general, nuclear reactions do not take place on Earth. Nuclear dynamics is dormant in our environment. It is of course true that natural radioactivity occurs on Earth, producing the heat in the depths of our planet, but these radioactive elements are the remnants of a very different age and of a different environment: They are the last embers of the cosmic explosion that produced terrestrial matter.

Today we physicists deal with cosmic processes in which many millions of electron volts per atom are exchanged rather than the few electron volts that are customary here on Earth. Of these cosmic processes, the fission chain reaction was one of the first to lead to major technological applications. Two hundred million electron volts per atom, twenty million times more than the most powerful chemical reaction. This is cosmic and not ordinary fire.

The first major application was a destructive one, which ended World War II by killing a quarter of a million people with two bombs. It is not surprising, therefore, that people are fearful and bewildered, and that they have misgivings even in regard to the more benign applications. The arm of technology grew by a factor of a million within the lifetime of one generation.

In 1940, however, we took little time to speculate on these questions. The discovery of fission came at a dark time in the history of mankind. Germany was in the grip of a collective mental disease of unparalleled virulence. The whole world was threatened by the expanding cancer of Nazism; the Germans discovered fission, and they might have used it if it had been usable at that time. Many of us physicists—those who were not yet too deeply involved in the development of radar, which saved England from being destroyed—worked hard to improve our

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0031-9228/78/3107-0030$0.50

understanding of fission. Many of us hoped that the number of neutrons per fission would be low enough to prevent the making of a bomb. But it was not.

History takes a turn

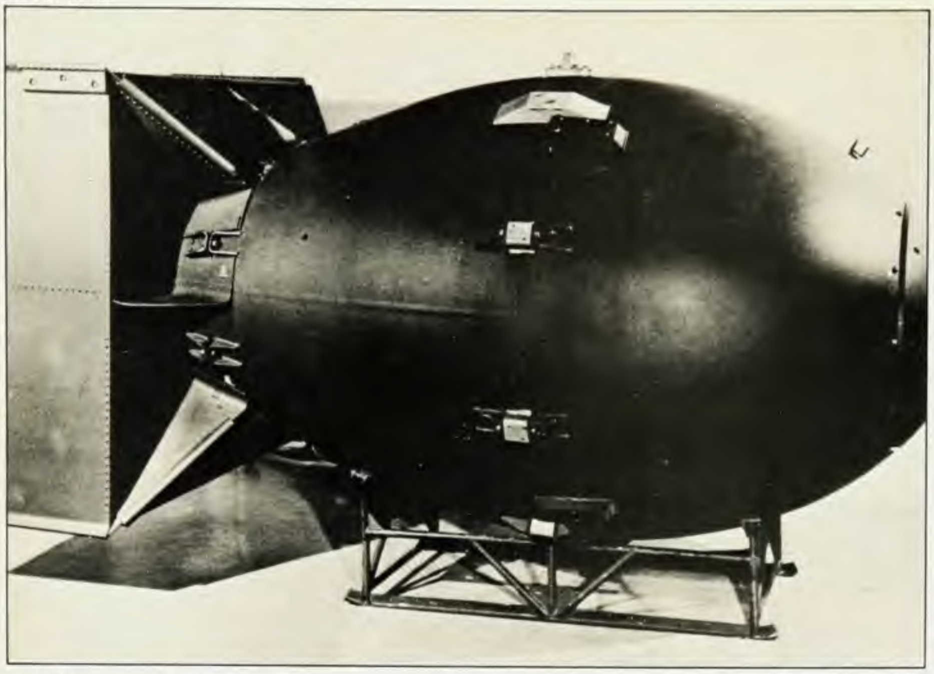
A tremendous collective effort began. Within two years, the first nuclear chain reaction was produced under the leadership of Enrico Fermi, and within another three years, with the collaboration of many European physicists—in a truly international effort—a nuclear bomb was developed. On 16 July 1945 the first nuclear explosion was set off in a desert of southern New Mexico, at a place called Jornada del Muerte (a Spanish army perished there two hundred years ago). Human ingenuity had succeeded in the release of cosmic forces that were hidden and unknown 13 years earlier, when James Chadwick discovered the neutron.

Some of us saw this event, which, at our observation post, had the intensity of twenty midday suns: an expanding fire ball, white, and then yellow and orange, rising majestically into the sky, surrounded by a halo of blue light. The air was fluorescent with radioactive radiation.

Here it was: The laws of Nature did admit an explosive nuclear chain reaction. Because of some little detail in the equations of nuclear matter, the number of neutrons per fission was large enough. The history of mankind took a turn.

From then on, political developments, and no longer scientific ones, determined the course of events. Two bombs were exploded over Japanese cities; over 200 000 people lost their lives. Why two bombs? Why over populated areas? I am not sure I can answer these fateful questions. The bombs ended the war; they made an armed invasion unnecessary

US AIR FORCE



"Fat Man," the plutonium bomb dropped on Nagasaki, Japan on 9 August 1945. Larger than "Little Boy," the uranium bomb detonated over Hiroshima, it had about the same yield, some 20 000 tons of TNT. The production of nuclear chain reactions gave Man control over cosmic forces.

and thus perhaps saved more people than they killed. But Japan may have given up anyway under the pressure of a near defeat and a Soviet declaration of war. Whatever the answer, the stigma has remained upon the United States, as the first and only country to have used nuclear bombs. I can not tell you whether the decisions were right or wrong—I don't know.

The war ended, and it was physics that had helped to win it, with radar and the atom bomb, as well as many other new gadgets. Physics and the physicists moved onto center stage in public life; the significance of basic physical science became generally recognized. New means of research, technical and financial, suddenly were available to physicists. The radar technology created sophisticated new methods for producing electromagnetic waves of all kinds. Maser and laser physics emerged from it, and with it a deeper understanding of the fundamental interactions of light and matter, leading to quantum electrodynamics, as well as of the structure of solids under various extreme conditions.

Nuclear and subnuclear research experienced an almost explosive development, with an ever growing array of cyclotrons, synchrotrons and linear accelerators. The cosmic scope of physical research widened and penetrated into new realms of phenomena:

- On the microscopic side, into the GeV region—with its mesons, hyperons, antiparticles, heavy electrons and quarks, entering the innermost structure of matter;
- On the macroscopic side, into plasma physics, space physics, a new cosmology and astrophysics—with its quasars and pulsars, and the observation of the optical reverberation of the birth of the Universe, the famous three-degree radiation in space.

The physicists experienced a tremendous surge of support for their activities. This in turn led to an unparalleled expansion of their fields of endeavor and to a large range of new technical applications, both destructive and constructive, such as fusion bombs, rocketry, transistors, space travel, computers and many more. The physicists now moved to the center of public attention. It was their enthusiasm and self-confidence, spurred by their successes during and after the war, that brought them into contact with the great social and political problems of the times.

Many tried, and some succeeded, to bridge the "communication gap" between politicians and scientists. Attracted by great, optimistic ideas of how to establish a new order in the world they had helped to engender, they embraced the idea of international control of nuclear explosives. They hoped this would stop all future wars, and direct the applications of fission and fusion away from destructive bombs and towards an unlimited benign source of energy for all mankind. Some of them, perhaps, also experienced a reaction against their feeling of guilt for having been involved in the creation of a device that could annihilate all mankind.

Power—and anxiety

The political realities, however, were not conducive to the ideals of those who tried to unite the nations. Stalinism in the Soviet Union, and nationalism all over the world, including our own country, led to a breakdown of attempts to lift nuclear matters beyond national sovereignty. Of course, neither the physicists nor the politicians had much experience in dealing with such complicated technical matters on an international scale. With the development of fusion bombs, the nuclear arms race began in earnest.

Among the benign implications of nuclear physics, there still remained the great promise of unlimited energy through the use of fission reactors and, perhaps later, through controlled fusion. But over the decades following World War II, doubts were raised even on that account. Because the yield per atom is so many million times higher than in any conventional way of producing power, the consequences of accidents caused by human error are much worse. A nuclear power station certainly can not explode like a bomb, but the possibility of accidents that could spread large amounts of radioactivity can not be completely excluded. Even if human ingenuity and care can keep the accident rate at an acceptable level, the public and some of the experts look with some anxiety at this "extraterrestrial" way of producing energy in our terrestrial abode. The fact that the public is acquainted with this cosmic force only through the experience of nuclear bombs strengthens this anxiety. Furthermore, the use of fission for power constantly creates new raw material for bombs, which, in a nationally and politically divided world, adds to the danger of further spread of nuclear weapons.

The dangers and the promises of nuclear-power generators are today in the center of discussion; many studies have been undertaken and more are under way. Emotion and vested interest unfortunately have led to a sharp division of opinions, and the arguments used on both sides are too often beyond the limit of dignified scientific discourse.

Apotheosis of irrationality

At the same time the nuclear arms race between the superpowers continues in an almost uncontrolled way. The Soviet Union and the United States assemble increasing numbers of bombs, and perfect their efficiency and their mode of delivery. More than 50 000 nuclear bombs are deployed and ready for use. Each country now has the capability of destroying the other many times over. Current science is totally unprepared to discuss intelligently, let alone to predict, the totality of horrors that would result from an all-out nuclear war. Consider only the effects of the vast amounts of radioactivity released upon our environment; these would be so devastating that the condition of life would be permanently and dangerously altered, without much hope of recovery. Even the detonation of a single weapon of modern design over a city would be a catastrophe unprecedented in human history. Yet two large countries keep building more and more of these horrendous means of annihilation, knowing well that any actual use of these devilish gadgets would mean certain destruction of a large part of the world—making it unfit for habitation, with little chance of a recovery of civilization. Why? Why? Why? Only because neither side knows where to stop, and both go on producing nuclear weapons intended for all sorts of imagined missions. Only because each party is under the grip of an unrealistic measure-countermeasure syndrome. It is the apotheosis of irrationality and antilogic; it is the triumph of craziness.

In comparison to this overwhelming threat the nuclear power controversy dwindles to picayune dimensions. What are the dangers of nuclear-power stations compared with the dangers of tens of thousands of bombs that can be released within seconds by a small group of human beings? What is the so-called "worst reactor accident" compared to nuclear war? The damages done by the former, which would come mainly from effects of radiation—serious as they are—are far less than the effects of a single bomb. Now think of the number of victims of a nuclear war and its irreparable effects on our environment, on our souls, alive or dead, and on our planet as a whole.

And the probabilities? Nobody really can estimate the probability of an all-out nuclear war, but one fact is clear: With all those bombs around, it is not zero. Nuclear power may be too risky, or it may not; I do not pretend to know the answer. But I *know* that tens of thousands of stored bombs are too risky.

Undoubtedly, it is extremely improbable that the US or the Soviet government will decide outright to set off a nuclear war, thereby annihilating both countries simultaneously. However, a nuclear clash may develop from local wars between smaller countries that have acquired, or will soon acquire, a few nuclear weapons, and may make use of them in desperation. Or it may develop from an escalation of the use of so-called "tactical" nuclear weapons, which are meant to be applied in defense against aggression by conventional weapons. The tens of thousands of nuclear bombs are a mighty tinderbox; they may explode whether it was directly intended or not.

HIROSHIMA PEACE MEMORIAL MUSEUM

Nothing obscures the view south from the roof of a building around Yamaguchi cho. The city of Hiroshima has become a bare scorched field; Motoujina and a gas tank appear to be near at hand.

Is there a way out?

I am only too well aware of the difficulties in the way of reducing that danger. I know also that the presence of these weapons is given credit for having prevented a world war for a longer period than ever before. But, as time passes, the weapons multiply and become more efficient; they are adapted to all kinds of purposes, such as the neutron bomb. They are therefore more likely to be used. The outbreak of a volcano becomes more violent after long pauses. Here we have a man-made volcano: It could be removed.

I used the phrase "almost uncontrolled" in referring to the nuclear arms race. There have indeed been a few hopeful attempts, albeit small and tentative, that slowed it down a bit. One was the cessation of bomb tests above ground; the other was the first SALT agreement six years ago, which will, I hope, be expanded in the near future. They are not much, but they are two small steps in the right direction, and we can be proud that some of our colleagues were active in bringing them about.

The difficulties of going further are enormous. Some raise the fear that the other side will gain more, or might even dare to take the tremendous risk of a first strike regardless of the consequences. There are those who say that a free society can not compete in terms of nuclear armaments with an authoritarian system in any other way but through an all-out technological arms race. Voices are heard that we should not be too confident of negotiated contracts with our opponents; that we should rather assure a reasonable survival rate by a large effort of organized civil defense in order to make the population as ready as one can be for the great holocaust. I honor the intentions of those who advocate such measures but, to make them effective, if this is at all possible, would thoroughly change our way of life. I can not help sympathizing with the majority of our population, who do not want to live under a constant awareness of mankind's ultimate self-destruction.

We can not go on forever living under a continuous threat of annihilation. There must be ways and means to decrease the number of nuclear bombs. Certainly this task can not be accomplished from today to tomorrow; it is bound to be an extremely difficult process.

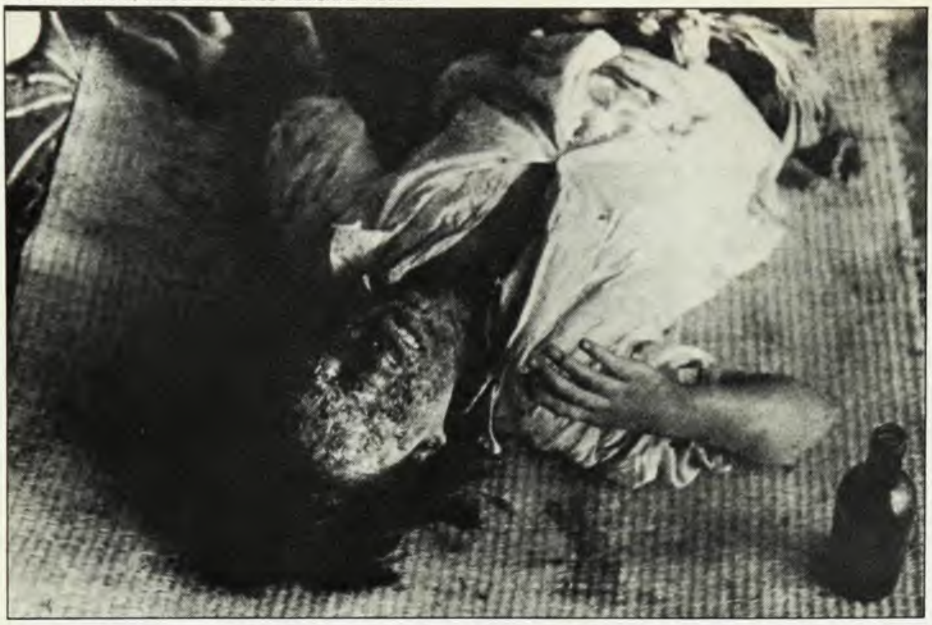
The foremost problem

There is a hope and not only a peril in the nuclear development. The growing recognition of this awful threat may still change the attitudes of the sovereign states, to lead slowly to the recognition that ultimate military preparedness is much less safe than a reduction and eventual abolition of nuclear weapons. J. Robert Oppenheimer said in 1945, shortly after the end of the war:

> "The point is that atomic weapons constitute a new field and new opportunities . . . when people talk of the fact that this is not only a great peril, but a great hope, this is what they should mean. I do not think they should mean the unknown, though sure, value of industrial and scientific virtues of atomic energy, but rather the simple fact that, because it is a threat, because it is a peril and because it has special characteristics, there exists a possibility of realizing, of beginning to realize, those changes which are needed if there is to be any peace."

The task must be faced; it is the first and foremost problem of our time. Any one of us can and should play a role in this task, as a scientist and as a human being. The most important step is a new setting of priorities. The reduction and eventual abolition of nuclear weapons *must have absolute priority;* everything else must be subordinated to this goal. The consequences of nuclear war are irreparable, whereas the consequences of other setbacks in world politics can be corrected.

HAJIME MIYATAKE; HIROSHIMA PEACE MEMORIAL MUSEUM



A victim of the atom bomb exploded over Hiroshima. Over 200 000 people lost their lives in the two Japanese cities bombed in World War II. Today more than 50 000 nuclear bombs vastly more powerful than these are deployed and ready for use, and the inventories are growing every day. Weisskopf: "The reduction and abolition of nuclear weapons must have absolute priority."

This change of priority is essential and can be achieved only by constant pressure of public opinion. Remember how effective public opinion was during the Vietnam War. In nuclear matters, the public is now interested only in the relatively unimportant issue of nuclear power. This must change. The issue of getting rid of nuclear armaments must receive much more public attention, support and pressure than it receives today. There is much too little discussion of these essential questions: Do we not already have enough bombs for deterrence? How would the Soviet Union react to a restraint in development or to a cutback? We must find that right balance of risks most conducive to lowering the levels of nuclear armaments. What is needed is a combination of new technical ideas and common sense, based upon humane considerations.

Only when we see a chance of success in the abolition of nuclear armaments can we scientists be proud of the achievements we gained during the last decades: our leaps into the cosmos; our penetration into the innermost structure of matter; our achievements in getting at the basic processes of life, the workings of DNA and RNA, and the tremendous developments in our knowledge of organized matter.

US STATE DEPARTMENT

To peace! At the SALT talks in Vladivostok, November 1974, Soviet premier Leonid Brezhnev and US President Gerald Ford raise their glasses in a toast. What is needed to find the "right balance of risks" are "new technical ideas and common sense based upon humane considerations."

It is not the first time in history that human greatness and human folly grew side by side in the same period. Think of the Gothic cathedrals, together with the senseless and murderous crusades, 700 years ago. Think of the blossoming of art and philosophy during the Renaissance, along with the decimation of Europe's population during the religious wars, 500 years ago. Think of the music of Mozart and Beethoven, and of the slave ships plying the oceans, 150 years ago. Think of the greatest achievements of scientific thought, quantum mechanics and relativity theory, and the ascendancy of the murderous periods of Nazism, Fascism and other authoritarian regimes, 50 years ago. Finally, think of the great achievements of science today, together with the folly of the nuclear arms race.

The last folly is more serious than all the previous ones. We are dealing with cosmic forces. Our epoch may be the end of what has been a great age of mankind, great in spite of all the strife and wanton destruction. Our age has been great in its achievements in art, architecture, literature, music; great in its numerous social innovations, in spite of the fact that in most parts of the world social organization and the quality of human life leaves much to be desired; great in its medical successes, which have resulted in the doubling of the average age of man; great in its means of food production, communication and transportation—which makes a united world without hunger and want a possibility, if not a reality. And, last but not least, ours has been a great civilization because of the constant growth of our insights into the mysteries of Nature, the continuous opening up, leaf by leaf, of the blossoms of truth and wonder.

The age of insight

If we do not succeed in abolishing the nuclear arms race and a nuclear war results, all these great steps will be brought to naught. The twentieth century would then be remembered as the time of preparation for the great catastrophe, and science would be seen as the main culprit and the main instrument of destruction. The twentieth century ought to be remembered as the age in which mankind acquired its widest and deepest insights into the Universe, and learned to control its martial impulses.

Let us hope, strive and act so that it will.

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This article is an adaptation of a talk given 24 April 1978 at the Washington, D.C. meeting of The American Physical Society, as part of a commemorative session marking the fortieth anniversary of the discovery of nuclear fission. □