Nuclear proliferation—thirty years after Hiroshima

The winner of the Leo Szilard Award re-examines a 30-year-old position—that the only way to ensure an atom-bomb-free future is by strict international control over fissionable materials and their means of production.

Bernard T. Feld

Nowadays there is a tendency among historians and social scientists to think of the postwar scientists' movement as a quaint aberration, and to dismiss the ideas we developed in the late 1940's as politically naive or irrelevant. Some go even further and would have us believe that time has shown the wisdom of those politicians who insisted on the need for maintaining American pre-eminence in nuclear armaments, despite our urgent warnings that this was a futile and dangerous course. As evidence, they cite the facts that for thirty years nuclear war has been averted, in spite of recurrent international crises, and that the number of nuclear-weapons states has remained much smaller than the number that we predicted would be able to produce nuclear weapons on a time scale of thirty years.

The facts are undeniable, but their interpretation of cause and effect could not be more mistaken (though, God knows, their record in this regard is unblemished—show me the historian or the economist who predicted the oil crisis and its political and economic consequences).

It is my belief that avoidance of nuclear war and the relatively small number of nuclear-weapons states have occurred, not *because* of US attempts to maintain our nuclear pre-eminence, but *despite* these attempts. A good case can be made for the argument that nuclear war has been avoided mainly because of incessant warnings from the world-wide scientific community, bringing a realization of the horrendous consequences that would result from any use of a nuclear weapon. In other words, the limited proliferation of nuclear weapons has been a consequence of the insistence of we scientists and our allies that the security of nations is better served through restraining the nuclear arms race rather than through its enlargement.

However, the struggle to avoid another nuclear war, pioneered by Edward Condon, Albert Einstein, James Frank, H. H. Goldsmith, Willy Higinbotham, David Inglis, Robert Oppenheimer, Eugene Rabinowitch, John Simpson, Leo Szilard and many others, has until now been in the nature of a delaying tactic: what we have called "arms control." We have been concerned with shoring up the dyke, with plugging the holes as they appear. But we simply do not have enough fingers for the job. The dyke is about to burst, and the problem we face—the life-or-death problem, foreseen thirty years ago by the nuclear pioneers—is what can we do, as scientists and as concerned citizens, to hold back the deluge.

Any solutions we may devise must be workable and achievable, both technically and politically. We must not, however, be bound by too narrow a definition of political realism—a concept that is usually invoked to disguise a paucity of imagination and ingenuity, or an inbred unwillingness to take calculated risks. If we scientists have anything special to offer, aside from our understanding of the scientific and technical realities, it is our willingness to reexamine and discard outworn premises and approaches—qualities often conspicuously absent from the considerations of our political leaders and their advisors.

Three realities

In the last few years, while devoting a major portion of my efforts to an international enterprise known as the Pugwash Conferences on Science and World Affairs—one of those social inventions in whose beginnings Szilard had a prominent role—I have been forcibly struck by the relevance of the ideas developed by the scientists' movement in the immediate postwar period. Our approach then was based on three realities: First, there can be no scientific secrets. Nature is an open book to all those trained in its reading; hence, no nation could maintain a monopoly on nuclear weapons. Once it was demonstrated that atomic bombs are possible, the rest is simply a matter of effort and investment. Second, there is no defense against nuclear weapons, now or in the foreseeable future. Partial protection under special circumstances, even if possible, is no defense; if nuclear war breaks out, anything short of one hundred per cent protection means disaster. Finally, accepting the first two premises, we were forced to the conclusion that the only way to ensure an atom-bomb-free future was by a system of strict international controls over fissionable materials and their means of production.

The intervening thirty years have brought many surprising new developments, but none that can demolish these three pillars of nuclear wisdom:

Bernard T. Feld, currently on leave from his position as professor in the department of physics at Massachusetts Institute of Technology, is secretary-general of the Pugwash Conferences on Science and World Affairs. He received the 1975 Leo Szilard Award for physics in the public interest, presented on 29 April at the APS Spring Meeting in Washington, D.C.; this article is an adaptation of his remarks on that occasion, which were originally titled "Thirty Years After Hiroshima, or, Rethinking the Unthinkable."

no secret, no defense, therefore international control. These truisms remain the inescapable bases for any program that hopes to save our world from nuclear devastation.

Unfortunately, despite the apparent advantages of irrefutable facts and unassailable logic, we have never been able to sell these ideas, completely, where it really counts—in the seats of power. If we can't have a monopoly, we have been told, we can still stay ahead, taking advantage of superior American production capacity and technology. We all know where that delusion has got us, locked as we are into a continuing nuclear arms race with the Russians that (SALT notwithstanding) commits both nations to nuclear-bomb delivery capacities at least a hundred times beyond any sensible level.

The notion of defense dies hard. We thought we had finally won that battle, when the first Strategic Arms Limitation Treaty (SALT I) outlawed antiballistic missiles—only to witness a replacement of the myth of defense by the myth of counterforce. This newer principle tells us that, with multiple warheads and smart bombs, we can now fight a clean nuclear war and win it by concentrating our attack on military targets. And so what we used to call "deterrence" has been re-named "MAD" (for "mutually assured destruction") by the smart bombers, in their campaign to discredit the accepted doctrine that nuclear weapons should only be used in retaliation against a nuclear attack, and to replace it by the truly insane concept of permitting to the military the option of a nuclear first strike.

International control was unfortunately an early casualty of the cold war. Since we couldn't have it, many of us convinced ourselves that we could do without it and still keep the spread of nuclear armaments under control. And so for a number of years we were lulled into a sense of false security by the combination of some partial successes in the arms-control arena—most notably the nuclear test ban and the non-proliferation treaty—coupled with strong economic and political incentives for non-nuclear nations not to squander badly needed resources on weapons of questionable utility.

End of an era

But, like it or not, we have come to the end of an era. The consequences of international nuclear anarchy, so clearly foreseen by the founders of the Federation of Atomic Scientists, are about to burst upon us. Nuclear weapons technology is being handed to scores of nations on a uranium platter—under the spur of the competition among the technologically developed countries to sell nuclear fission power to any nation that has the cash (or the oil) to buy it. Although only six nations have publicly demonstrated an independent capability of nuclear detonation, there is no doubt that many others could do so on short notice, and are preparing to do so under the guise of peaceful nuclear explosions, following the Indian example of 1974.

The nuclear non-proliferation treaty is a shambles. The 98 signers to date do not include such nuclear-capable countries as Argentina, Brazil, India, Israel and South Africa, not to speak of France and the People's Republic of China; five years after the treaty has come into effect, Egypt, Japan and Pakistan, together with 12 other signatories, continue to withhold ratification. The treaty's safeguard provisions amount to little more than accounting procedures for verifying the efficiency of national or regional inspection systems, and the six nuclear-weapons states remain exempt from verification except for the voluntary inclusion of some non-military programs in the UK and the US.

There is, of course, no substitute for nuclear disarmament. But having bitten the apple, there is no turning back. For better or for worse, the knowledge of how to make nuclear bombs is with us for as long as our species can avoid its self-destruction.

Proliferation

Dangerous and wasteful as the continuing superpower nuclear arms race is, the threats that it poses are, in my view, today dwarfed by those associated with the widespread proliferation of nuclear weapons technology. The nightmare of scores of itchy fingers on the nuclear trigger is almost upon us. Un-

Working with Szilard

I was particularly fortunate in the accidents of time and place that brought me, as a student, under the influence of such giants as Enrico Fermi, I. I. Rabi, Hans Bethe, Willis Lamb and Leo Szilard. But it was Szilard, more than anyone else, whose influence shaped my future.

As a physics major at the City College in New York, and then as a graduate student at Columbia University starting in 1939, I had noted the arrival of Fermi and Szilard just before the outbreak of the war in Europe. My fellow graduate students and I soon came under Fermi's spell; he gave superb lectures on the greatest variety of subjects:—nuclear physics, thermodynamics, cosmic rays, quantum theory, geophysics—and I had the enviable privilege of being his assistant in some of these courses, and was paid for it to boot.

Columbia. Szilard was to us a mystery. He occasionally appeared at colloquia, and when he intervened one could be sure that the comment or question would be particularly incisive. We knew he was involved somewhere upstairs in research on the newly discovered fission reaction, about which there seemed to be much excitement. But, immersed as we were in absorbing those basic fundamentals that go into the making of a physicist, we were hardly conscious of being silent witnesses to a revolutionary new development.

Szilard remained a remote and exotic figure, with whom I had never even spoken, until one day in the spring of 1941. That morning, while working on my research in Rabi's laboratory, I received a 'phone call, brief and typically to the point: "This is Leo Szilard. Can you have lunch with me today at the King's Crown Hotel at 12:30?" I accepted with puzzled pleasure.

At lunch, Szilard came straight to the point. He had been looking for an assistant, and after some inquiries had decided that I might fit the bill. Without waiting for my response, he launched into a description of what he had in mind. Fermi and he had been developing the idea of a nuclear chain reaction based on uranium fission. One serious obstacle was that, to sustain the chain reaction, it was necessary to embed the uranium in a medium capable of slowing the neutrons down without absorbing them in the process. Hydrogen was the obvious choice, but it was too absorbtive; so water was out of the question. Heavy water and beryllium, the next most obvious candidates, were too rare and expensive to produce. So he and Fermi had decided that carbon, in the form of graphite, was the most hopeful candidate. But there was another difficulty, in that uranium absorbed neutrons in the intermediate energy range in a non-fission reaction. They had therefore concluded that the ideal solution would be to isolate the uranium from the graphite by compacting the uranium into lumps; then the fission neutrons would be slowed down in pure graphite and diffuse into the uranium lumps where, as slow neutrons, they would be most effective for producing additional fission neutrons to maintain the chain.

The problem was to determine the most effective size of uranium lumps and their optimum spacing in the graphite matrix. Szilard had some ideas on how to compute the neutron economy in a lattice arrangement, and he needed someone with patience, the ability to manipulate a slide rule, and some understanding of nuclear physics to carry out a systematic study of the optimization problem.

I listened with mounting excitement; well before Szilard was through, I knew what my answer would be. Not only was this fascinating physics, but it was a way of getting involved in the war against Hitler—a war that I was sure the United States must soon and inevitably join.

But I had sense enough to remember that I was still a graduate student, with courses to complete and my responsibilities in Rabi's lab, and I could not just walk less drastic and radical steps are taken immediately to shore up the crumbling non-proliferation regime, that nightmare will inevitably turn into a reality before the end of this century. Here are some facts about proliferation:

Within roughly a factor of two, it takes about 10 kilograms of pure uranium-235 or plutonium-239 to make an atomic bomb. Although current production of highly enriched uranium and plutonium, of the order of a few tens of tonnes per year (enough for a few thousand bombs), is confined to a handful of technically advanced nations, current nuclear power programs will be producing in 1980 enough plutonium in the developing world alone for some 1000 bombs per year; it is projected that this bomb capacity will increase thirty-fold by the year 2000. The corresponding figures for the so-called developed nations are around seven to ten times larger, or enough for more than 200 000 bombs per year by the end of the century.

In these circumstances, and considering the political anarchy that prevails in today's world, it is all too easy to conclude that we have already passed the point of no return as far as nuclear proliferation is concerned. But I am not ready to pronounce non-proliferation dead, and I would be greatly surprised if most of my readers were. There is little time left to us, but there may still be some effective ways of frustrating the apparently inevitable if we can concentrate our collective intellectual and political efforts on the problems.

The immediate focus for these efforts should be the Non-Proliferation Treaty Review Conference, the first stage of which took place in Geneva during the month of May. Convened in response to a provision of the treaty—that its workings were to be reviewed five years after its coming into effect—it was already seriously flawed from the start. Only adherents to the treaty could participate. Even worse, most of the preparatory efforts, at least as far as I have been able to discover, have been devoted to considering what concessions need to be made to the nuclear have-nots to keep them in the system. Because all the pressures are for concessions that weaken the restraints—such as relaxed safeguards for easier access to so-called "peaceful" nuclear explosion technology—it begins to appear that the treaty's emasculation is being demanded as the price of keeping it alive. Worst of all, there has been little advance consultation by the nuclear-capable countries to work out a common ap-

out. However, Szilard had thought about that too—he was always two steps ahead on any problem. For the time being, I could work on his problem in my spare time, finish up the semester's courses, and put in my time in the lab as well. But because Rabi's lab was slowly closing down and his team in process of moving up to Cambridge to work on radar problems, it would make better sense for me to shift from an experimental to a theoretical research problem. Szilard had already asked Willis Lamb whether he would be willing to take me on as a thesis student, and if we could agree on an appropriate problem, Lamb was willing. This time Szilard was only half-a-step ahead of me, however, since I had for some time been thinking in terms of a theoretical thesis based on some anomalies in the line shapes of spectra obtained in our molecular-beam experiments.

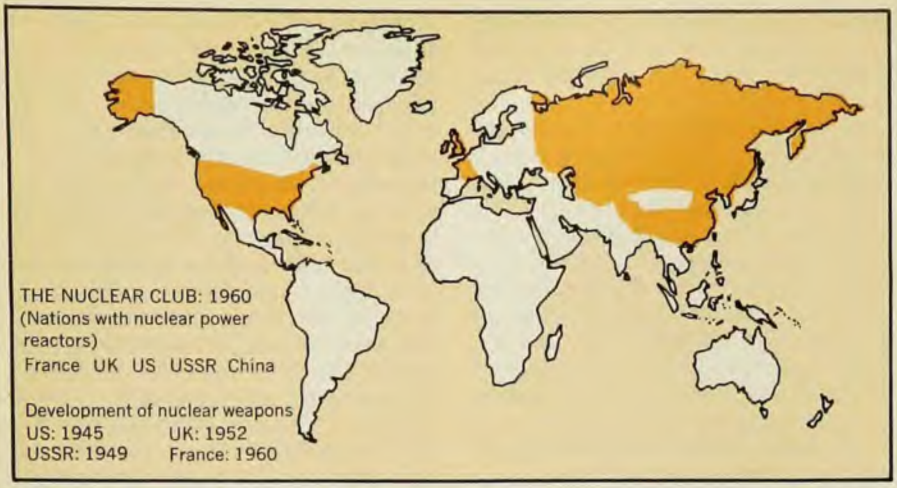
My token resistance overcome, Szilard took me up to his room, got out his notebooks and spent the afternoon explaining in detail what calculations he had already done, the theory and data on which they were based, and how he expected me to carry them further. He ended by presenting me with a fresh note book and a twenty-inch slide rule, and told me that, until he could make better arrangements, I was free to work in his room, because he would be away for the next few weeks.

And so began a collaboration that was to last for the rest of Leo's life. Having not yet acquired that addiction to sleep that characterizes the onset of middle age, I very happily divided my time between Szilard's room, my classes, Rabi's lab, the library for study, napping and slipping in some work on my thesis, and last, but by no means least, brick laying. This latter was a part of the deal that I have neglected to mention: Fermi was just starting the exponential pile experiments for testing uranium-graphite combinations to determine their neutron multiplication properties, and all available hands were needed. But Szilard had no liking for piling and unpiling graphite bricks, for packing uranium-oxide powder into cans of various sizes, for dashing down the hall with an exposed indium or rhodium foil in time to catch the rapidly decaying radioactivity—for all of which pastimes I soon developed a happy facility. Besides, he was too busy oiling the wheels for the necessary further steps—always one or two beyond the obvious next move—to ensure the success of the project: rushing up to Boston to cajole the carbon manufacturers into producing more, denser and purer graphite at more reasonable prices; dashing down to Washington to extract greater support; stopping off at Princeton to consult with Einstein and the Wigner group. I was to be his proxy hands at Columbia.

Chicago. After Pearl Harbor, we all eventually moved to Chicago to become part of the Metallurgical Laboratory. Szilard set up two groups: one, of which I was put in charge, concerned itself with experiments aimed at understanding some of the smaller effects involved in the chain reaction—such as the contribution of fast neutron fission to the multiplication constant. We also helped him with engineering design calculations for a variety of new reactor types that he was already busy inventing for the post-war world—among others, the helium and the boiling-water-cooled thermal reactors and the fast breeder reactor. For the fast breeder he had me redesign, for the circulation of a liquid bismuth or sodium coolant, an electromagnetic pump that he and Einstein had invented in Berlin in the 1930's for circulating noxious refrigerator coolants. His second group, under Edward Creutz, concentrated on the (real) metallurgy of uranium and on problems of coating uranium fuel elements to prevent fission products from escaping into the reactor coolant. As usual, he remained two jumps ahead of everybody else.

Once the chain reaction had been demonstrated under the University of Chicago's West Stands on 2 December 1942, and when the Hanford plutonium-producing reactors advanced beyond the design stage, Szilard's thoughts turned towards the realities of the atomic bomb and the effects that its use would have on the postwar world. I shall not add to what has already been written about the attempts of the Chicago group to convince our government of the importance of a public demonstration of the bomb before using it against a Japanese city; of the atomic scientists' campaign for civilian control of nuclear energy, and of their attempts to educate the American public on the futility of secrecy and the importance of international collaboration to eliminate nuclear weapons and prevent their spread. Leo was in the thick of all these activities, and frequently far ahead of the troops. Nor shall I describe here his later efforts to bring rationality into the American political scene through the Council for a Livable World. I can only say how proud and fortunate I am to have had the privilege of working with him in so many of these enterprises.

Bernard T. Feld



proach for rescuing the treaty and for achieving universal adherence to it. All of which, if not remedied in time to affect the next stage of the Review Conference, spell its doom.

The tragedy is that the Non-Proliferation Treaty could still be made into an effective instrument, given a concerted resolve to introduce such changes into the system as will overcome its deficiencies and render it capable of doing the job for which it was intended.

Need for political changes

The needed changes are, however, not trivial. Some are essentially political; while I cannot dwell on these political needs here, it is worth noting briefly which of them appear to be most important.

First, there is an urgent need for the United States and the Soviet Union to redeem their pledge, made in Article VI of the Non-Proliferation Treaty, "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament."

Then there is the question of security guarantees against nuclear attack for those nations that voluntarily forgo an independent nuclear-weapons capability. A direct approach has not worked in the past. A number of indirect approaches, however, merit serious exploration—the concept of nuclear-free zones, for one example, and that of a comprehensive pledge of no-first-use of nuclear weapons against nations adhering to the NPT, for another.

A solution to the problem of so-called peaceful nuclear explosions must also be found, within the context of a universal and comprehensive nuclear test ban, so as to eliminate this excuse for nuclear-weapons acquisition.

But the major political loophole in the treaty is that which allows the technically advanced countries to provide aid in peacetime nuclear technology to any nation, and the recipient countries to accept such aid, irrespective of whether or not the countries involved adhere to the treaty. As long as nations continue to indulge in this sort of blatant hypocrisy, the incentives for accepting the treaty are worse than nonexistent—they are negative.

Security and nuclear energy

However, politics aside, the NPT Review Conference will be a pointless exercise unless the technical problems of providing assurance against the diversion of nuclear weapons-grade materials can be solved. As I have previously noted, the problems stem from a worldwide commitment to a vast increase in nuclear fission power in the coming decades. If carried out, this commitment will result in a situation in which hundreds of tonnes of plutonium, of uranium highly enriched in the U-235 isotope, and eventually of uranium-233 will be floating around the world, in various vehicles of transport and stages of refinement, with processing going on in hundreds of plants, governmental and private. Under these circumstances, even with the best possible accounting system, it will be absolutely impossible to prevent the loss or the diversion, intentional or accidental, of enough material to produce many bombs.

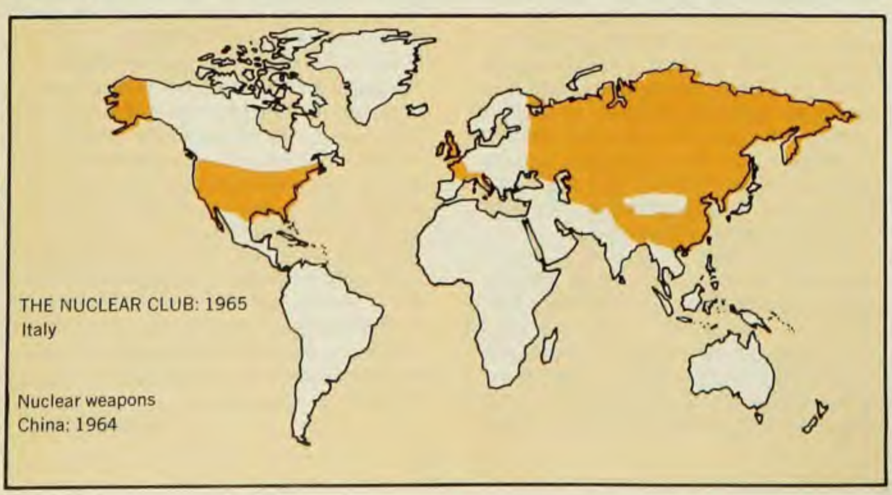
But, nevertheless, I am convinced the problems are solvable.

To begin with, it makes a great difference what approach one takes to the future of nuclear fission energy. If one regards it as the main hope of Mankind for satisfying our energy demands as far ahead as one can foresee, then nuclear breeders become inevitable; the problems I've outlined will be with us indefinitely, and they will become worse as time passes. On the other hand, if one adopts the view that nuclear fission energy can only be an interim solution, aimed at satisfying Man's essential needs—rather than his uninhibited demands—for at most a few decades, then many steps can be taken to keep the problem of diversion under control.

Thus, thinking of fission energy as an interim solution permits us to reexamine the need for a nuclear breeder economy. Without the breeder all the associated problems are much reduced. Ideally, we might hope to convince nations to adopt reactor types that utilize natural uranium or only very weakly enriched uranium, and to discard the accumulated plutonium (together with the other radioactive wastes) without ever attempting to remove it from the spent fuel elements. Such a system could be quite competitive with the plutonium-based systems now being developed. And it would be infinitely safer from the point of view of plutonium proliferation.

However, if it should turn out to be impossible to turn back the clock on nuclear programs that involve relatively large-scale plutonium recycling, then there is no choice but to return to the solution foreseen thirty years ago by the atomic scientists' movement. The only controls that have any prospect of working are *custodial* controls—actual physical possession, at all stages, of plutonium and highly enriched uranium by agencies capable of ensuring that these materials will not fall into unauthorized hands.

Such controls will be most effective if all the plutonium processing—from the handling of the spent fuel elements through the fabrication of new elements



to go back into the reactor—is done in a single, heavily guarded installation. If we assume that the physical protection of the installation can be made airtight, there would be only two stages in the cycle where plutonium could be diverted: during the transport of the spent fuel elements from the reactor to the processing complex (and here the tremendous radioactivity provides the greatest protection) and during the shipping of the new elements back to the reactor. This last operation would require the greatest degree of physical protection.

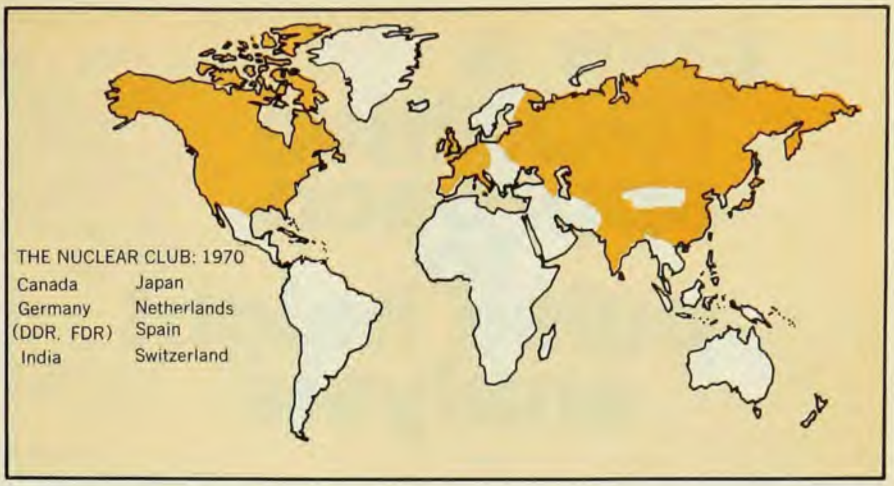
For such a system to be effective, the number of processing complexes—plutonium Fort Knoxes, so to speak—would have to be very limited. And it would be essential to place them under international control, not only for physical reasons, but also to ensure access to the needed materials by all qualified nations on an equitable basis.

Problems with plutonium

Even with the adoption of custodial controls, however, the existence of huge quantities of weapons-grade uranium and plutonium will still provide an ever-present temptation for diversion and thus remain a source of danger and concern. In the uranium case, keeping the degree of enrichment low will present a formidable physical obstacle to the conversion of peace-time stocks to weapons-grade material. For plutonium, on the other hand, Nature has not been quite kind enough.

The plutonium-239 produced in nuclear reactors always contains a proportion of the heavier plutonium-240 isotope, which does not undergo fission when absorbing slow neutrons. Furthermore, another attribute renders plutonium containing an appreciable Pu-240 admixture much more difficult to detonate explosively: The rate of spontaneous fission of the heavier isotope is abnormally high, thus providing a large neutron background, which leads to a tendency for pre-detonation during the process of bomb assembly. This is the reason the early bomb designers were forced to adopt the implosion technique for the plutonium weapon, rather than the much simpler gun-type assembly method that can be used for a uranium-235 bomb.

The greater difficulty of detonating plutonium containing an appreciable admixture of Pu-240 led us, in the early days, to place great hope in the possibility we called "denaturing"—that is, of rendering reactor plutonium non-explosive by increasing its Pu-240 content. Because the fraction of Pu-240 increases with the length of time that the fuel elements remain in the reactor this feature is under the control of the reactor designers. By proper design, the Pu-240 content of the extracted plutonium can be as high as about fifty per cent.



Unfortunately, sophisticated bomb designers have been able to design effective bombs in spite of this obstacle.

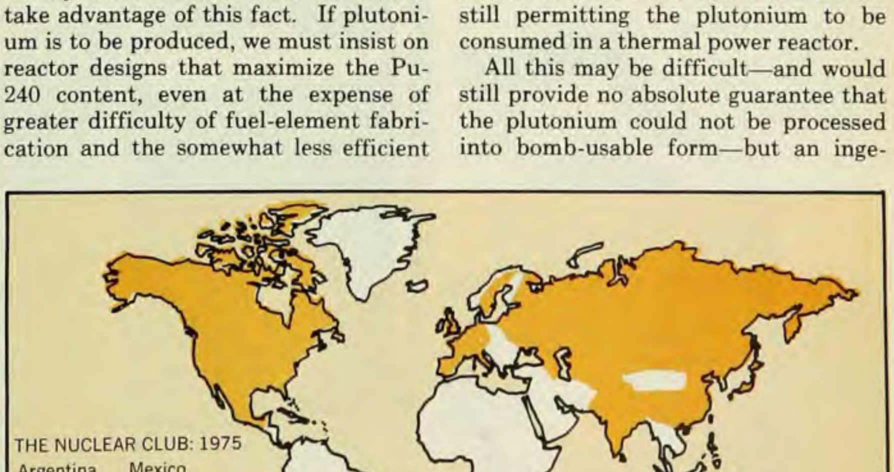
Furthermore, what may be an unacceptably inefficient or unreliable weapon to a bomb designer could still be a weapon of horrendous power in the hands of a terrorist group. The detonation of 10 kilograms of plutonium with an efficiency of only one tenth of one per cent (or two orders of magnitude less than the efficiency of the Nagasaki bomb) would still amount to the equivalent of around 200 tonnes of TNT, or approximately two freight-car loads of high explosives! Imagine the effect of such an explosion in the heart of a major city, not to speak of the longer-term lethal consequences of the exposure of the surviving population to ten kilograms of plutonium distributed over a large area.

Even though a high content of Pu-240 does not absolutely prevent detonation, it does nevertheless render it sufficiently more difficult that we should take advantage of this fact. If plutonium is to be produced, we must insist on reactor designs that maximize the Pu-240 content, even at the expense of greater difficulty of fuel-element fabrication and the somewhat less efficient fuel cycle that is a consequence.

Other prospects for denaturing deserve much greater attention than they have thus far received. The previously mentioned critical-mass figure of around 10 kilograms corresponds to a bomb made out of metallic plutonium of relatively high purity. But the critical mass is extremely sensitive to such factors as the density of the plutonium (it is roughly proportional to the inverse square) and to the nuclear properties of any contaminants. Advantage should be taken of these factors in fabricating reactor fuel elements containing plutonium, so as to ensure that the amount of such plutonium that would be needed for a bomb would be both as large and as uncertain as we can manage through human ingenuity.

Plutonium should only be transported as chemical compounds of low density, and serious efforts must be made to mix it with contaminants with unfavorable fast-neutron absorption properties and of chemical natures that make their separation from the plutonium as difficult as can be, while at the same time still permitting the plutonium to be consumed in a thermal power reactor.

All this may be difficult—and would still provide no absolute guarantee that the plutonium could not be processed into bomb-usable form—but an inge-



take a TPOSitive approach to pulse height analysis

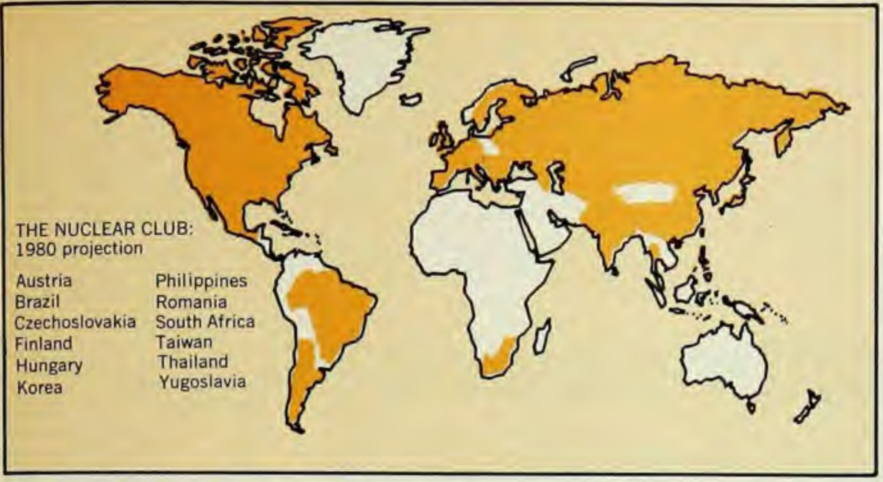
Our new TPOS is the most powerful, most flexible software system commercially available for pulse height analysis work. It's the latest improvement we've made in the TP-5000 PHA system . . . already preferred by researchers in major labs across the country. With this new software system, the TP-5000 is TPOSitively unbeatable for a wide range of experiments. For example, user analysis programs run at least 300% faster with TPOS.

If you are considering a PDP-11 computer-based PHA system for your lab, give us a call at 615/482-3491.

Or write: Tennecomp Systems, Inc., 795 Oak Ridge Turnpike, Oak Ridge, Tn. 37830

TENNECOMP SYSTEMS INC.

Circle No. 18 on Reader Service Card



nious denaturing program could go a long way towards inhibiting the production of clandestine weapons.

And if the weapons are used . . .?

But the clandestine, terrorist bomb is only one aspect of the problem. Governments, large and small, can also be irresponsible, and nuclear capabilities are already widely proliferated. Given the proclivity of all governments to resort to force in pursuit of what they regard to be their national interests, it is difficult to be optimistic about the chances of preventing the use of a nuclear weapon in some future conflict.

And yet, even if a nuclear weapon should be used—be it through mischief or accident or inadvertence or just plain madness—it is not inevitable that this should lead to the ultimate holocaust: not inevitable, perhaps, but (if history is any guide) much too likely.

We must therefore also be concerned with the prevention of escalation of a nuclear conflict should one break out. Certain fire-breaks against nuclear escalation have been built into the international system in recent years, most notably the multiplicity of "hot lines" between the major nuclear powers. Beyond this, we are dependent on the universal acceptance of a high threshold of conflict, before nuclear weapons would be used. In the case of the two superpowers, insofar as there is mutual acceptance of the doctrine of deterrence, this threshold is mercifully high. In the case of the East–West confrontation in Europe, and in other regions of possible conflict, the threshold is much too low.

What is even more dangerous is the fact that the deterrent threshold has become fuzzy and ill-defined. Furthermore, there has been a very strong tendency in recent years to reduce the threshold even further, through the dangerous military counterforce doctrine and through the development of the technologies of high-accuracy guidance (the smart bomb) and of mini-nuclear weapons. Unless firm steps are taken to resist these tendencies, there is the gravest danger that present thresholds will be completely eroded.

This danger is exacerbated by a widespread belief that it is precisely the uncertainty about the threshold for introduction of nuclear weapons into a conventional conflict that inhibits the other side from pursuing policies that could lead to a military confrontation. Whether or not this form of deterrence is psychologically sound, it appears to me to be equivalent, on the international level, to permitting children to play with guns in order to teach them about their dangers.

The ignoring of inhibitions against the use of new technological methods of mass destruction is unfortunately one of the characteristics of our age. In my view, this is primarily a consequence of unthinking adherence to the 19th-century military doctrine that war is merely an extension of politics by other means, coupled with a naive faith in new technology on the part of military leaders, which can best be characterized as a narrow military "light-at-the-end-of-the-tunnel" vision.

Belief in limited war, either nuclear or conventional, represents the perpetuation of a myth; the fact is that the intensity of even conventional wars, as measured by the amount of high explosives used divided by the time span of the conflict, has been increasing exponentially from the Boer War to the Yom Kippur war, with the same doubling time, of roughly ten years, as most other modes of technological pollution.

Nor can we have much faith in the ability, let alone the will, of political leaders to limit the growth of nuclear war. I leave aside the arguments over whether or not the Hiroshima bomb was appropriate or even necessary. But I believe that the example of the second bomb, used against Nagasaki, is unequivocal and highly relevant. This inexcusable, militarily irrelevant destruction of a city and its population, when the Japanese were already suing for peace, was for no military purpose other than the testing of a new type of weapon and the demonstration of its effectiveness. This example is a striking reminder of the dangers of allowing *carte blanche* to the military in the choice of means for waging war. In this technological age, Mankind is much too vulnerable for such choices to be left to the generals.

Szilard's example

Concerning escalation of nuclear conflicts, Leo Szilard and his colleagues in the post-war scientists' movement understood very well the dangers and devoted considerable thought to means of preventing it in the event that their campaign to eliminate nuclear weapons should fail. Thus, Szilard and others explored the idea of adapting the primitive notion of hostages through a formal agreement between the United States and the Soviet Union to maintain a constant high level of exchange of the most promising of their young students, scholars and artists. However, as nuclear weapons accumulated on both sides, Szilard realized that this aim was in effect being achieved, in that the entire population on both sides had become hostage to continuing peace. This, like it or not, is what is meant by "deterrence," and, in the absence of disarmament, Szilard was convinced that the formalization of deterrence provided—as it still provides—the most effective barrier against the outbreak of nuclear war between the superpowers. The erosion of the strategy of deterrence represents a terribly dangerous regression towards the uncertain and frightening world of nuclear anarchy that the nuclear pioneers accurately foresaw and strove to avert.

But Szilard's legacy involves more than his prevision of today's world. As the prototype of the involved scientist, who regarded his responsibility to the public interest as of equal importance to the pursuit of pure science, his example should serve as a beacon to guide today's generation of scientists in their search for scientific relevance.

There remains for us the task of converting the example of Leo Szilard from the exception into the rule. We are not all endowed with those unique qualities of foresight and ingenuity that characterized the genius of Szilard; but that does not absolve us from our responsibility. The problems of ensuring that science will be used for Mankind's benefit rather than its destruction are as challenging as those we undertake in our normal scientific pursuits. And the rewards are as great, or greater. Not only do they involve the satisfaction of joining in the communal scientific enterprise of unravelling the secrets of nature, but they touch on our deepest instincts for ensuring the survival of the species. □