ARTICLES

Initiatives to Enhance Nuclear Stability and Non-Proliferation in the 21st Century

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There is no lack of problems to be dealt with or new initiatives to be undertaken by the administration of President Barack Obama. And while high-profile issues such as the economy and the never-ending problem of the Middle East are sure to take priority, proliferation and nuclear stability should not fall into a policy abyss: in the mid to long term, they are bound to surface in ever more intractable forms.

There are three initiatives the Obama Administration can undertake that would greatly increase nuclear stability and enhance the non-proliferation regime for many years to come. The first is to ratify the Comprehensive Test Ban Treaty (CTBT); the second is to restructure our strategic nuclear forces; and the third is to create the international structures needed to implement international management of the two technological routes to the proliferation of nuclear weapons: the enrichment of uranium and the processing of used reactor fuel. We will address each of these, but since concerns about nuclear weapons proliferation underlie at least two of those initiatives, it is worthwhile first to address the general issue of non-proliferation.

While current nonproliferation efforts are primarily focused on preventing the further spread of nuclear weapons, the original objective of the Non-Proliferation Treaty (NPT) was to accomplish this while concurrently making available the benefits of nuclear energy to all nations. The existing nonproliferation regime has been quite effective—with a few notable exceptions—but it has some gaps. In particular, existing nuclear-weapon states (NWS) are allowed to retain their nuclear weapons and delivery systems—but only temporarily, at least in principle: Under Article VI of the NPT, the NWS are required to pursue negotiations to achieve nuclear and ultimately "general and complete disarmament under strict and effective international control."

That's an end that will be a long time coming. To be sure, the reduction of stockpiled and deployed nuclear weapons since the end of the Cold War can and should be viewed as a significant step in the direction called for by Article VI. However, given the political state of international relations and institutions, nuclear weapons are not going to be phased out any time soon. Realistically, "general and complete disarmament" remains a distant dream.

While it is rarely explicitly stated, the structure of the present nonproliferation regime is intended to preserve, for an indefinite interim period, a two-tiered world where existing NWS retain their nuclear forces, and non nuclear weapon states (NNWS) are offered a variety of guarantees and incentives to induce them to refrain from developing and deploying such weapons. Despite the appearance of inequity, this may well serve the best interests of all nations, and is probably the best arrangement possible, given current social and political realities. Apparently many nations agree, having chosen not to develop nuclear weapons despite possession of the knowledge and resources to do so—which is why the non-proliferation regime has been as successful as it has been since World War II. Initiatives for the 21st century must preserve and expand the success of the last fifty years.

Nor will the vast improvement in conventional precision weapons and their command and control be able to fulfill the political role of nuclear forces—a role that includes, but is not limited to, enhancing prestige and deterring conventional aggression. While conventional weapons may be far better than the nuclear variety in effectiveness and discrimination for many categories of targets, this is a technical point that will not affect the political and deterrent roles of nuclear weapons. Nevertheless, the number of deployed nuclear weapons can still drastically be reduced without compromising their effectiveness for these roles.

The Comprehensive Test-Ban Treaty

The primary goal of the Comprehensive Test Ban Treaty (CTBT) is to discourage new entries to the nuclear club (rather than to limit further development of nuclear weapons by the NWS, conventional wisdom notwithstanding, although that might be a side effect). Realistically, the constraints imposed by such a treaty will always be trumped by national interest—two classic cases being Israel and the China-India-Pakistan interaction—but the CTBT does appeal to those NNWS who perceive that they would be more secure, with the freedom to use their resources more productively, in a weapons-free zone than in one where each state has its own nuclear retaliatory capability.

The cases of Israel and the China-India-Pakistan nuclear triangle are interesting and instructive. Israel's perception that its very existence was threatened by the Islamic world led to its developing a considerable nuclear arsenal, although, except for a possible clandestine test off of South Africa in September 1979, they have not had a test program involving significant nuclear yields. While the Israeli arsenal is a well-accepted fact, their policy of ambiguity and abstention from testing has served them well.

It was the interplay of perceived national interests that led to the nuclear triangle of China, India, and Pakistan, each of them seeing its neighbors unconstrained by a test ban. China developed nuclear weapons for historical reasons relating both to their differences with the Soviet Union and to U.S. threats during the Korean War. India, concerned about the dual political and military threat from China, developed what might be characterized as a minimal deterrent, and this in turn led to Pakistan's weapons program. Relations between these nations are rapidly evolving, and a CTBT could greatly contribute to stability during the process. In any event, the arsenals of these nations are unlikely to be eliminated until the underlying tensions that led to their development are resolved. And it should be understood that the incentives that led to their development had nothing to do with the testing of nuclear weapons by the principal weapon states.

Given the cost and commitment necessary for a nation to develop nuclear weapons, it takes a compelling sense of vulnerability to motivate such an undertaking. As shown by the examples of Israel and the Asian nuclear triangle, nations develop nuclear weapons when not doing so would put them at a serious political disadvantage, or because they perceive a significant threat to their national survival. Nonetheless, if testing of these weapons violated an internationally accepted norm of the kind that would exist under a CTBT, that would have to be an important consideration in deciding whether to initiate a testing program—with a negative decision further encouraged by the knowledge that any potentially threatening neighbors would be subject to the same political constraints.

Some observers might not believe in the efficacy of such international norms, but many nations do, and ratification of the CTBT by the United States would signal a new intent to take the provisions of Article VI of the NPT seriously. U.S. ratification would therefore have significant political value.

Arguments against ratification have been based on the asserted need for testing to assure reliability of the weapons stockpile or to develop enhanced safety features. However, it seems clear that such objections are largely red herrings, motivated by the desire to maintain funding for the weapons complex. Of course one can always introduce new safety features, but they are not required—the weapons are already very safe. The reliability of the stockpile can be maintained by remanufacture without significant design changes. A series of Lawrence Livermore National Laboratory (LLNL) reports [1] issued during 1987–1991 affirmed "a high degree of confidence in the reliability of the existing stockpile is justified. . . . [It is] sufficiently robust to permit confidence in the reliability of remanufactured warheads in the absence of nuclear explosive proof-tests." In addition, the reports reviewed the "problems encountered with the 14 nuclear weapon designs since 1958 that have been frequently and prominently cited as evidence that a Low-Threshold Test Ban (LTTB) or a Comprehensive Test Ban (CTB) would preclude the possibility of maintaining a reliable stockpile." The study concluded "that the experience has little if any relevance to the question of maintaining the reliability of the stockpile of nuclear weapons that exists in 1987."

Much has also been made of questions pertaining to predicting accurately the yield of the primaries of multi-stage nuclear weapons. In fact, the record of yield predictability is remarkably good. Such an impressive record would not have been possible if U.S. weapons were not comfortably tolerant of the small variations in materials and manufacturing that accompany any practical production process. This is particularly well illustrated by the excellent performance of new primary designs the very first time they were tested. [1]

This does not, however, mean that the computer codes used to design these weapons can be used to design new weapons with different configurations. In the codes there are too many parameters that need to be derived from a nuclear-weapons-testing database. The point is crucial: the ability to design and field an extensive and varied arsenal of nuclear weapons depends on the availability of a large weapons-testing database as well as on the requisite expertise. Only a few countries have access to such a database, and a CTB would freeze this status.

Even if safety and reliability issues have to a large extent been funding-motivated, this does not mean that such funding can be eliminated. Support must be maintained at a level that will indefinitely perpetuate the expertise needed to understand the physics and materials science related to nuclear weapons and to maintain the ability to manufacture their components. Almost all of the senior designers and engineers with hands-on experience have retired or soon will. Funding should be directed toward attracting young people to this job by allowing and encouraging part-time research in related areas such as astrophysics, stellar interiors, and the physics of dense plasmas, in return for taking on the responsibility of maintaining expertise in weapons physics.

The only facilities left for manufacturing some of the components of nuclear weapons are the limited ones at Los Alamos National Laboratory. These are completely inadequate. The United States must remain able to maintain and manufacture all nuclear-force components for as long as they are needed.

The CTBT was opened for signature on September 24, 1996. President Clinton was the first to sign the treaty, and he transmitted it to the Senate in September 1997 for its advice and consent. Consent has not come. By the end of November, 2008, 148 of the 180 signatories had ratified the Treaty. Annex 2 of the Treaty names 44 states that must deposit their instruments of ratification for it to enter into force. Of these, 35 have ratified. The nine hold-outs preventing entry into force are China, Democratic People's Republic of Korea, Egypt, India, Indonesia, Iran, Israel, Pakistan, and the United States.

The benefits of the CTBT far outweigh any risks. It is clearly in its political and strategic interest for the United States to ratify the treaty and do everything in its power to see it come into force. President Obama has called for its ratification. [2]

Restructuring Strategic Nuclear Forces

The second initiative for the Obama administration, the restructuring of nuclear forces, has to do with stability in time of crisis and the role of land-based intercontinental ballistic missiles. Because these missiles cannot survive a nuclear attack, there is an incentive to launch them on warning that a massive missile attack has been initiated.

That risk is minimal now, but some history is instructive: In the Spring of 1986, Donald Latham, then Assistant Secretary of Defense for C^3I (Command, Control, Communications, & Intelligence), told Congress that "our policy is not one of launch on warning, absolutely not." This was disingenuous at best. General Charles A. Gabriel had testified in 1985, when he was Air Force Chief of Staff, that "There are options that I won't go into. Obviously, if [the enemy] were going for our missile silos, there will be a period of time when we can see his weapons coming. We have sensors that tell us that. There are options that obviously do not make them sitting ducks."

Perhaps the least ambiguous comment on this issue came from General John T. Chain, Jr., Commander in Chief of the Strategic Air Command, in 1989. In a letter dated January 26 of that year, in response to a query from Republican senator Pete Wilson of California about a study of strategic weapons modernization done by the Washington-based Center for Strategic and International Studies, he wrote that the assumption that U.S. land-based missiles would not be fired until after enemy warheads began detonating on U.S. territory—in other words that they would ride out an attack—is "unrealistic." In his words, "Only the 'rideout' scenario was used, which is unrealistic and assumes away the value of our silo-based ICBMs."

The threat to the land-based missiles was a serious issue during the late Soviet era. Today that threat is no longer credible, primarily because Russia is no longer an enemy, but also because of the deteriorated state of the Russian nuclear forces and associated systems. It is nevertheless important for the United States to eliminate the inherent instability of silo-based missiles by unilaterally restructuring its nuclear forces as a dyad composed of nuclear-armed bombers and submarine-based nuclear missiles. This will eliminate the threat to crisis stability should the political situation change later in this century. Such a configuration is capable of riding out a nuclear attack, so that retaliation will not occur until it is known for certain that there have been actual nuclear detonations on U.S. soil. The French have already made such a transition.

The instability introduced by land-based missiles was initially accepted because submarine-based nuclear weapons did not have the accuracy of land-based missiles. This was an important consideration, because certain high-value targets in the Soviet Union that were required by national guidance to be held at risk required either weapons with very large yields, several weapons, or high accuracy. But the disparity between the accuracy of land- and sea-based forces vanished years ago, and today submarine-based missiles are perhaps even more accurate than the aging land-based missiles. They are also operationally tested on a regular basis, unlike the land-based missiles—whose success record in testing from operational silos is dismal.

The land-based missiles have served their purpose. Their continued retention is dangerous and consumes badly needed resources.

The Technology of Proliferation

The third nuclear-related challenge facing the administration is the need to deal with the interplay of nuclear power, nuclear waste, and nuclear proliferation. Here is the current situation:

- Although only in its initial phase in the United States, a nuclear renaissance is upon us, with nuclear power plants being proposed, planned, and built in increasing numbers around the world.
- At the 400-odd plants now operating, used fuel—currently seen as "waste" although it retains 95% or more of its original energy—keeps accumulating in temporary storage, raising concerns about safety, long-term management, and the possibility of malicious use.
- The growing demand for reactor fuel will lead to increased need for facilities to enrich uranium and to reprocess spent fuel—facilities that can be subverted to the production of bomb-grade uranium and plutonium, respectively. As the current cases of Iran and North Korea point up, it is the spread of enrichment and reprocessing capability that presents the

greatest potential for the proliferation of nuclear weapons.

Barack Obama inherited the beginnings of a program that recognized the need to deal optimally with those realities. That program, the Global Nuclear Energy Partnership (GNEP), was officially announced early in 2006. It is one of several fuel-management proposals advanced by various countries.[3] Late word is that the program has been all but abandoned.

The GNEP program was formulated at Argonne National Laboratory, a Department of Energy facility near Chicago. The Argonne scientists saw that the looming growth of nuclear electricity brought with it the urgent need to deal with two problems: the ever-larger stockpiles of used nuclear fuel, and the proliferation threat that would increase as one country after another—some of them politically unstable—found it necessary to have its own enrichment and reprocessing infrastructure to provide a reliable source of nuclear fuel. The GNEP became a two-pronged DOE initiative to deal with nuclear waste and proliferation, and one can hope that whatever replaces it will preserve those two essential features.

Waste. Under GNEP, a technology was to be implemented to recycle, in fast-neutron reactors (see box), the used thermal-reactor fuel that is now accumulating. That not only would make accessible the enormous energy resource that the already-mined uranium constitutes, but also would eliminate almost all of the long-lasting radioactivity in the used fuel from today's reactors. Those long-lived components, while amounting to only a little more than a percent of the used fuel, are the source of the concern in the United States about the long-term safety of the Yucca Mountain nuclear-waste repository. [4]

Proliferation. A properly implemented international fuel-management protocol would minimize the spread of weapons-capable technology by confining all enrichment and fuel-processing facilities to nations that already have nuclear weapons, and give all non-weapon signatories an ironclad guarantee of unhindered access to a reliable source of fuel, at a reasonable cost, for their civilian reactors. This would plug a serious hole in the NPT, a defect that is the source of most of today's proliferation risk. Under the NPT, non-weapon signatories have the right to develop a full nuclear fuel cycle, including enrichment and reprocessing—a license that is simply no longer tolerable. For such a proposal to win acceptance, the nuclear club's fuel and waste-disposal services will perhaps have to be operated under the aegis of an international entity such as the International Energy Agency or the International Atomic Energy Agency. In any event, the right to the fuel services will have to be structured so that they cannot be abrogated for political purposes. The negotiations, which are ongoing, will not be easy, but they are worth the effort.

Why has this development not proceeded more vigorously? For one thing, enriched uranium for reactors is cheap these days, leading to the perception that the recycling of spent fuel can be put off. Doing so, however, delays the only sensible resolution of the "waste problem"—using the spent nuclear fuel in fast reactors. Not only would that multiply the energy available from the originally mined uranium by a factor of more than a hundred (90% of the ore's energy never even makes it into the fuel, but remains stored as "depleted uranium"—DU), but in less than five hundred years the activity of the real waste (the fission products) will fall below any realistic level of concern. Only one U.S. geological waste disposal facility would be needed for the rest of this century—perhaps longer.

A regime of fast reactors would allow the sustainable generation of large amounts of electricity for the indefinite future, while presenting no threat to the environment in terms of emissions or waste, and would significantly reduce the potential for the spread of nuclear weapons.

A little-appreciated fact is that the DU that is now on hand in the United States constitutes an enormous energy resource, containing as it does about ten times as much energy as all the U.S. coal reserves.[5] That energy can be accessed by fast reactors, postponing for centuries the need to mine any more uranium—and eliminating forever the need to enrich uranium. The DOE recently announced plans to spend more than $400 million to dispose of the DU as low-level radioactive waste.

The potential of fast reactors is discussed in more detail in a number of places.[6],[7],[8] Unfortunately, appreciation of the fast reactor's advantages has been slow to permeate the U.S. Congress, which remains, at best, lukewarm to the idea, and the latest news is that the Obama administration has postponed indefinitely the commercial demonstration of fast-reactor technology. Thus the role to be played by the United States in the development of reactor technology remains to be seen. As of now, U.S. leadership in the development of fast-reactor technology seems to have been abandoned. Ironically, what is arguably the best of the advanced reactors—the IFR (Integral Fast Reactor)—is a U.S. design.

U.S. foot-dragging is not being emulated by other countries. Notably, India, China, Russia, France, Japan, and South Korea are fully aware that their energy mix will have to include fast reactors and the recycling of fuel, and they have active development programs.

Summary

A vital and urgent next step in implementing rational management of nuclear power is to demonstrate the viability of the fast-reactor recycling technology on a commercial scale. To do so would cost an estimated one or two billion dollars—which could easily and reasonably come from the $30 billion, largely unspent, that ratepayers have already contributed to a government-run nuclear waste fund.

We suggest that the Obama administration would be well advised to resume the lead—to act decisively in bringing order to an otherwise chaotic and dangerous international situation. Dealing with the disheveled economy is bound to have top priority, but the initiatives proposed here should not be neglected. They would have limited financial impact and would greatly enhance nuclear stability and non-proliferation for the 21st century.

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Fast Reactors

Reactors come in two general varieties, "fast" and "thermal." Almost all of today's nuclear power is produced by reactors of the *thermal* variety, so-called because their neutrons are *moderated*—slowed down to low "thermal" velocities before causing fuel nuclei to fission. In fast reactors the neutrons are not moderated. The fuel-consuming capabilities of the two kinds of reactor are very different.

Uranium in nature is comprised of two principal isotopes—U-238 (99.3%) and U-235 (0.7%). U-235 is likely to fission when it absorbs a neutron, and is said to be *fissile*. U-238 is called *fertile* because it soon becomes fissile (Pu-239) after absorbing a neutron. Thus plutonium is created in any reactor that contains uranium, and some of that plutonium is subsequently consumed as the reactor keeps running. In a typical thermal reactor, some 60% of the energy is coming from fissions in plutonium by the end of the fuel's useful life.

Most of today's thermal reactors are moderated by ordinary ("light") water, and hence are called LWRs. They are fueled with uranium that is enriched to 3–5% U-235. Their "spent" fuel still retains about 95% of the energy it started with. Since, further, some 90% of the energy in the original ore is left behind as depleted uranium (DU) "tailings" from the enrichment process, LWRs (along with other kinds of thermal reactor) are incapable of utilizing even 1% of the energy in the mined uranium. (Even the French reprocessing, using MOX [mixed oxides of U and Pu] can barely reach the 1% level.)

For every GW-yr of electric power, a reactor (*any* reactor) produces about a ton of fission products. Thus the annual "waste" from a 1-GWe LWR consists of about 19 tons of heavy metal and a ton of fission products. The heavy metal portion breaks down into, roughly, 18.8 tons of uranium and 480 pounds of TRU (transuranic elements—Pu and above).

It's the 480 pounds of TRU that almost all the fuss is about. First, the growing global inventory of reactor-grade plutonium raises proliferation worries (although no weapons designer would attempt to utilize it), and, second, TRU contains almost all the long-lived isotopes that get people fired up over questions of how safe a repository would be in 10,000 years.

Enter fast reactors, for which the technology has advanced markedly since the French Phénix and Superphénix reactors were designed and built. Fast reactors produce more neutrons per hundred fissions than thermal reactors do, which gives them increased ability to convert fertile nuclei to fissile ones, and that permits consumption of all the actinide elements from thorium on up. This has two very important consequences.

First, fast reactors can be fueled very nicely with the TRU from spent LWR fuel, along with some of the uranium, thereby reducing the 10,000 year waste problem to a 500 year problem. This means that fast reactors with sensible recycling—e.g. the Integral Fast Reactor (IFR) system—have the potential eventually to sequester all existing plutonium behind heavy shielding in operating power plants and all but eliminate commerce in plutonium. With on-site recycling, once an IFR has been fueled, the only input per GW-yr is a ton of heavy metal (any mix), and the only output is a ton of fission products with trace amounts of actinides.

Second, they can be operated in any one of three modes: (a) as actinide burners, consuming more TRU than they produce; (b) in a break-even cycle, generating only the fissile material they need to keep themselves going; or (c) as breeders, generating fresh fissile when new reactors are to be started up.