Emerging nuclear energy systems and nuclear weapon proliferation

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Abstract

Generally when considering problems of proliferation of nuclear weapons, discussions are focused on horizontal proliferation. However, the emerging nuclear energy systems currently have an impact mainly on vertical proliferation. The paper indicates that technologies connected with emerging nuclear energy systems, such as fusion reactors and accelerators, enhance the knowledge of thermonuclear weapon physics and will enable production of military useful nuclear materials (including some rare elements). At present such technologies are enhancing the arsenal of the nuclear weapon states. But one should not forget the future implications for horizontal proliferation of nuclear weapons as some of the techniques will in the near future be within the technological and economic capabilities of non-nuclear weapon states. Some of these systems are not under any international control.

Zusammenfassung

Neue Kernenergiesysteme und Kernwaffen-Proliferation

Wird das Problem der Proliferation von Kernwaffen erörtert, so steht im Mittelpunkt der Diskussionen meistens die horizontale Proliferation (Ausbreitung der Kernwaffen auf andere Länder). Die neuentwickelten Kernenergiesysteme zeigen jedoch gegenwärtig eine starke Auswirkung auf die vertikale Proliferation (Steigerung der Anzahl und Qualität der Kernwaffen). Die vorliegende Studie weist darauf hin, daß die mit neuartigen Kernenergiesystemen, wie z. B. Fusionsreaktoren und Beschleunigern, verbundenen Technologien die Kenntnis der Physik der Kernwaffen erweitern und die Herstellung von militärisch nutzbaren Kernmaterialien (einschließlich einigen seltenen Elementen) ermöglichen. Zur Zeit verstärken solche Technologien nur die Arsenale der Kernwaffenstaaten. Man sollte aber nicht die künftige Auswirkung auf die horizontale Proliferation von Kernwaffen vergessen, wenn einige dieser Techniken bald auch den technologischen und wirtschaftlichen Fähigkeiten von Nicht-Kernwaffenstaaten zugänglich sind. Einige dieser neuen Energiesysteme unterliegen keiner internationalen Kontrolle.

INIS-EDB-PB-DESCRIPTORS

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PROLIFERATION
NUCLEAR MATERIALS
POSSESSION
FORECASTING
PERFORMANCE
TECHNOLOGY UTILIZATION
TECHNOLOGY TRANSFER

1. Introduction

The term "proliferation of nuclear weapons" covers (a) the increase in the number and the quality of such weapons within the five nuclear weapon states (namely France, the People's Republic of China, the UK, the USA and the USSR); and (b) the spread of nuclear weapons to other countries. While the former is known as vertical proliferation, the latter is called horizontal proliferation. New technologies affect vertical proliferation by increasing the knowledge of the basic physics of thermonuclear weapons, which may lead to improved nuclear weapons and even to the development of new types of weapon. Moreover, some new technologies may even increase the production capacity of fission and fusion materials needed for use in nuclear explosives. While these are some of the major implications for vertical proliferation, the spread of the technologies will eventually contribute to horizontal proliferation as well.

In the production of energy from nuclear fission or fusion processes, high-energy beam technology is important because fusion is commonly initiated using such beams, while fission or fusion materials could be produced using particle accelerators or enriched using lasers. The fission, fusion and high-energy beam processes and their related technologies clearly show a growing interdependence in their application for emerging nuclear energy systems [1]. Likewise, the possible spread of fission weapons, the perfecting of fusion weapons, and the spectacular development of high-energy beam technologies have become more and more interconnected [2; 3]. These new ties of a technical nature may further entangle the multiple aspects of the problem of non-proliferation of nuclear weapons.

This paper will focus only on the major emerging nuclear energy systems of direct relevance for nuclear weapon proliferation. In Section 2 we examine the impact of emerging systems on vertical proliferation. In Sections 3 and 4 we study those systems which may produce very large amounts of fusion, fission and other special nuclear materials of military interest. In Section 5 we review some proposals for compact nuclear energy systems which could be within the financial possibilities of relatively small states, and therefore may provide new paths to horizontal proliferation of nuclear weapons. In Section 6, before concluding, we examine new systems which could reduce the risk of nuclear weapon proliferation.

2. Thermonuclear energy and nuclear weapon-related knowledge

Emerging nuclear energy systems may contribute to vertical proliferation in the areas of weapon-physics research, weapon-effects simulation and conception of new weapons. Success in controlled thermonuclear fusion would, for example, result in considerable understanding of weapon-related thermonuclear plasma physics, where several problems have yet to be solved.

2.1. Weapons physics research

In the area of weapons physics research, the main direct contribution is from inertial confinement fusion (ICF) systems [4; 5; 6].

Charged particle and laser beams are capable of concentrating large amounts of energy onto small targets. These targets may consist of non-nuclear materials, fissile materials or fusion materials. The very high pressures and shock strengths possible with the kind of beams necessary to drive ICF systems, enable hydrodynamic behaviour and material equations of states to be studied in a parameter range for which little data is available. The complexity of ICF target experiments requires that they be analysed by simulating the experiment with one- and two-dimensional hydrocodes. Thus verification and improvement of weapon design codes will be an intrinsic part of the ICF experiments [5]. Also, independently of the work with thermonuclear targets, the dynamics and stability of im-

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plosion (of either passive or nuclear materials) can be studied using ICF system drivers.

Knowledge of many processes related to thermonuclear fusion is still incomplete. For example, macroscopic processes like plasma ignition are still not well understood. In a hydrogen bomb, the soft X-rays emitted by a relatively large fission atomic bomb are used to start the thermonuclear reaction. Thus, special ICF targets which absorb the driver energy and convert it to X-rays enable H-bomb physics to be studied directly. The designs of these so-called hohlraum targets are classified [7].

Considerable scientific data necessary for the design of ICF and magentic confinement fusion (MCF) systems is also crucial for thermonuclear weapons. For example the temperature- and pressure-dependent opacity functions for high-order Z-elements are classified because this information is needed to make such weapons. Techniques for measuring these opacities are improving because of the availability of high-energy lasers. These can be used to measure opacities directly at laser frequencies [8], or indirectly by converting the laser radiation to X-radiation, and measuring opacities in the X-ray region [9]. X-rays from synchrotron radiation sources will soon provide an even better method [10; 11]. The introduction of commercial ICF power plants may lead to the declassifying of this type of information, similar to the declassification of neutron interaction cross-sections at the UN Geneva conferences in 1955 and 1958.

A last aspect of ICF which is of importance in weapons physics is that of rate-dependent neutron process. For instance, the production of some super-heavy nuclei by multiple capture of neutrons is currently only possible with nuclear explosions [12; 13]. An ICF system can easily expose a recoverable target to fluxes comparable to those of full size nuclear explosion. Another example is the study of properties and behaviour of materials under pulsed external conditions such as laser excitation, applied stress, and magnetic and electric fields [14].

Apart from nuclear explosions a classical method of generating intense short pulses of neutrons is the so-called "fast burst reactor". These reactors consist of supercritical assemblies, pulsed mechanically, or by means of electron accelerators. Shorter and more intense pulses of neutrons could now be produced by means of high-energy accelerators coupled to storage rings. Storage rings enable large numbers of protons to be accumulated and ejected in a single short pulse onto a spallation target. These facilities provide a spectrum of spallation neutrons with a relatively low level of gamma rays [15]. On the other hand, electron accelerators provide intense X- and gamma-rays with negligible neutron background. However, only ICF has the potential to enable laboratory study of the dynamics of nuclear [4] and thermonuclear explosions.

Table 1 compares the various methods available for producing intense bursts of neutrons. For each method, the table gives the maximum achievable instantaneous neutron flux (n/cm²/s).

Classical methods consisting of two-stage gas guns and explosively driven systems are also used to study certain aspects of weapons physics. With the help of high current flash X-ray accelerators (FXR), they are used to study equation of state and implosion physics [5]. Development of magnetic- and rail-guns for impact fusion [16] as well as the construction of more powerful beam generators for various new energy systems, will considerably improve the capabilities of these classical methods [17; 18; 19].

Table 1: Maxim. instantaneous neutron fluxes of some existing and projected pulsed neutrons sources

		$n/cm^2/s$
Fast flux reactors with chopper		
ILL (France)	60 MW	$1\ 10^{15}$
Leningrad (USSR)	100 MW	$3\ 10^{15}$
Photoneutron sources (electron accelerator, heavy target)		
ORELA (Oak Ridge, USA)	140 MeV	$1\ 10^{19}$
Harwell (England)	136 MeV	$1\ 10^{17}$
Electron linac pulsed fast assemblies		
GGA (USA, 1955)	100 MW	$4\ 10^{13}$
IBR-II (USSR, 1977)	2 MW, 30 MeV linac, Pu^{239} core, 5 pps	$1\ 10^{17}$
Spallation neutron sources		
IPNS (USA)	W, 30 pps, 200 ns	$6\ 10^{19}$
KENS (Japan)	U^{238}, 15 pps, 100 ns	$1\ 10^{20}$
WNR (USA)	U^{238}, 12 pps, 270 ns	$3\ 10^{20}$
WNR (USA)	U^{235}, 720 pps, 1 ns	$2\ 10^{21}$
Magnetic confinment fusion		
Tokamak		$5\ 10^{13}$
Inertial confinment fusion (ICF)		
Shiva (USA, 1978) 2 pulses/day		$2\ 10^{17}$
Shiva-Nova II (USA, 1984) ? pulses/hours		$2\ 10^{22}$
Dense plasma focus (4 pulses/hour)		
DPF 6½ (USA) 420 kJ, DD		$1\ 10^{19}$
DPF 6½ (USA) 420 kJ, DT		1 10[illegible] 21
Fast burst reactors (1 pulse/hour)		
Army Pulse Radiation Facility (USA)		$4\ 10^{22}$
Underground nuclear explosion (1 pulse/month)		
1 kt at 100 m		$2\ 10^{23}$
150 kt at 100 m (maximum allowed by TTBT)		$3\ 10^{25}$

2.2. Weapon-effects research

In the area of weapon-effect simulation ICF systems enable both nuclear and non-nuclear effects to be studied. The latter consists of the effects of low and high altitude nuclear single and multiburst detonation in the atmosphere [4; 20]. Such studies enable (a) prediction of the effects of subsequent bursts in a multiburst environment; (b) evaluation of the spatial extent and duration of satellite communications interference; and (c) evaluation of radar shielding effects which hinder detection of secondary missions [5]. Because of the Partial Test Ban Treaty, such problems cannot be studied with real nuclear explosions in the atmosphere.

The total radiation field of a nuclear explosion is composed of X-ray, gamma-ray, neutron and electromagnetic pulse (EMP) components. The intensity of each of these is strongly dependent upon the specific design and the yield of the weapon. Also, the presence or absence of some of these radiations depend on the environment in which the nuclear detonation occurs. For example, in an underground explosion some of the radiation will be absent compared to an atmospheric or high altitude explosion [5]. At present synergistic testing is done through underground explosions, but ICF could provide an alternative method for carrying out such tests in a laboratory [23]; an ICF exposure experiment is expected to cost less than 1 per cent of an underground experiment [4].

Furthermore, experiments with an ICF facility are much more convenient and reproducible [23]. For example, metre-sized costly equipments such as reentry vehicles, missiles, satellites, can be exposed to neutron fluxes of 10^{13}

to 10^{14} neutrons/cm^2, or 3 to 30 cal/cm^2 X-rays [4], without completely destroying them.

Tokamak test reactors have been proposed for similar use. The main advantage is the very large volume with uniform irradiation flux of more than 10^{13} n/cm^2/s offered. However, because of the very long pulse length compared with ICF, tokamak test reactors are best suited for determining the permanent damage due to neutron (and gamma) radiation to total-dose-dependent rather than dose-rate-dependent devices and subsystems. The Princeton tokamak fusion test reactor is to provide operational and performance data for a prototype tokamak fusion generator. This information will be used to help define an optimized tokamak radiation effects facility that could be implemented by the early 1990s in a suitable location [24].

2.3. *New types of nuclear weapons*

The current trend in weapon development is towards warheads with reduced yield and tailored effects [25]. Specific goals are to reduce the residual radioactivity and to enhance blast (RRR bombs), radiation (ERW bombs) or electromagnetic pulse effects (EMP bombs) [26]. Such goals may require the use of advanced fusion fuels and the perfecting of fission triggers, possibly using transplutonium fissile materials. For instance research on neutron-poor thermonuclear fuels [27], such as D-He^3, p-Li^6 or p-B^{11}, will help the design of blast-enhanced weapons with strongly reduced radioactivity. Similarly, the discovery of a compact fusion-igniter would dispense with the need for a fission bomb as a trigger for thermonuclear weapon [28; 29]. Finally, breakthroughs are possible, for example with magnetized [30] or polarized [31] fusion plasmas, antiproton beams [32], or when concepts such as thermonuclear shaped charges or gamma-ray lasers become feasible [33].

3. Production of nuclear weapon materials

In all nuclear weapon states weapon-grade fission and fusion materials as well as other militarily significant radioactive isotopes (e. g. Pu 238, Am 241, Pu 242, Cm 245, Cm 247, and Cf 252) are produced in special reactors. Most of these reactors will have operated beyond their design lifetime by the end of this decade. Various replacement systems are under evaluation [34; 35; 36]. In this context emerging nuclear energy systems could be of interest.

The potential advantages of more advanced systems include their capability to efficiently produce materials and energy simultaneously. Furthermore, defence requirements are changing. For example, there is a new interest in tritium production.

Among various emerging systems of interest for production of weapon-grade material are accelerator breeders (also called electrical breeders) and fusion-fission hybrids.

3.1. *Accelerator breeders*

When a high-energy particle hits a complex nucleus, nucleons are ripped off. If the energy of the spallation products is sufficient, a nuclear cascade is generated. For a natural uranium target, up to 100 neutrons per 1000 MeV proton [37] can be generated. In the study of the physics of nuclear weapons, the spallation target may consist of U 235 instead of U 238. In this case, the number of neutrons generated in a thin target is multiplied by 20 for a small assembly close to criticality [15].

The knowledge and skills for building linear and circular accelerators suitable for producing substantial amounts of plutonium are presently available. Moreover, it has been suggested for some time that accelerator breeding of fissile materials may become economically attractive [38]. It has been calculated that a beam of 300 mA, 1000 MeV protons could produce from 3000 to 4000 kg of plutonium or about 10 kg of tritium per year [37].

Grand [38] gives some details on accelerator-breeder projects in Canada and the USA, and on other possible uses of high-energy accelerators in the nuclear fuel cycle. Such systems may become attractive to countries interested in means other than reactors for producing fissile materials. This may be the case for countries poor in uranium or relatively rich in thorium. The Federal Republic of Germany, Japan and Switzerland are also interested in such systems [39; 40; 41].

Moreover, the interest in beam weapons given an added impetus for developing accelerator breeders in the case of some nuclear weapon states, as the technologies are very similar [42].

Another important military use of accelerators is the production of special isotopes such as Y 88 [43], and possibly of super-heavy elements.

The intense spallation neutron sources existing or proposed in the world are generally built for fundamental or applied nuclear physics research and enable the basic development work for nuclear material production systems to be carried out as well.

In the past the main problems with accelerators suitable for breeding related to the injector and low energy section. These problems have been overcome with the invention of the "radio frequency quadrupole" [44]. A 100 mA, 35 MeV deuteron accelerator using this technology is under construction in the USA [45]. This accelerator will also provide data for the production of fusion materials with intense charged particle beams.

3.2. *Fusion-fission hybrids*

Fusion-fission hybrid reactors are technologically extremely sophisticated and their use is likely to be confined for some time to the nuclear weapon states. They are thus a vertical proliferation problem. Such devices could produce yearly from 1000 to 10 000 kg fissile material and would also, as with other fusion reactors, produce tritium in large quantities (10 to 100 kg per year) more efficiently than currently-used specialized reactors [46; 47].

The sub-critical blanket of a hybrid reactor is more appropriate for nuclear fuel material production than a critical reactor. With an appropriate design, a continuous flow of the fuel production will be made possible. Even for long neutron irradiation times in the blanket, the quality of the plutonium produced in a fast hybrid blanket is better than that produced in a critical reactor [48]. This is due to the very low σ_c/σ_f ratio of Pu-239 for high neutron energies [49]. It should be remembered that the neutron spectrum in a fast hybrid reactor is even harder than that of a fast breeder [50].

There is a possibility of producing very precious transplutonium fissile isotopes with the help of the very hard neutron flux in a hybrid reactor.

Recent studies indicate that certain transplutonium isotopes such as Am 241, Am 243 and Cm 244, which are produced in substantial quantities in light water reactors (LWRs) as nuclear waste material [51] can be incinerated with great efficiency in a hybrid blanket. During this process, the transplutonium nuclear waste from LWRs acts as a very efficient neutron multiplier in the blanket under the very energetic 14 MeV fusion neutron irradiation. Besides fission processes in the hybrid blanket, significant neutron capture will also take place [50].

In these blankets, some non-standard nuclear fuel will also be produced, as follows:

^{241}Am (n, γ) ^{242}Am half life = 16 hours, probability 65% [52]
^{241}Am (n, γ) ^{242m}Am half life = 152 years, probability 35% [52]
^{243}Am (n, γ) ^{244}Am half life = 10 hours
^{244}Cm (n, γ) ^{245}Cm half life = 8532 years

Among these isotopes only Am 242m and Cm 245 can be considered as potentially important nuclear fuels due to their relatively long lifetimes. They allow one to realize mini fission systems or miniature fission warheads, neutron bombs with very low fission energy liberation, etc.

Hybrid reactors could be based on either ICF or MCF systems. From a nuclear materials production point of view, the main difference would be that in the ICF case the very fast neutron burst from the exploding pellet would enable very heavy isotopes to be produced by multiple neutron capture. In particular, this could allow the production of large quantities of Cf 252, a fissile material with a very small critical mass. Such heavy isotopes are produced most efficiently by incorporating selected actinides within the micro-explosion pellet itself.

Being neutron-poor and tritium-poor, the D-He^3 fusion reaction is potentially very attractive from a environmental point of view. However, as He 3 is extremely rare in nature, it will have to be produced by nuclear transmutation, for example in a deuterium-based fusion reactor [53]. As He 3 is potentially also a future nuclear weapon material, its production might require special controls, similar to those involved with tritium.

The necessity to maintain the secrecy associated with tritium production seems to be an important factor for installing fusion reactors inside national laboratories and using them first for military applications [54; 24]. In the USA, a civilian fusion-dedicated tritium laboratory is under construction in Los Alamos. Although this facility was initially intended to be open to international collaboration under the auspices of the International Energy Agency (IEA), this does not seem to be the case any longer [55].

4. Enrichment technologies

In enrichment facilities, isotopes of interest for fission (e.g., U 235) or fusion (e.g., tritium) are separated from other isotopes. In general, an enrichment step can precede or follow transmutation. With the availability of high-energy laser enrichment technology and the perceived need to increase the number of warheads, some states have considered separating Pu 239 from the spent fuel available from commercial nuclear reactors [74]. Furthermore, new technologies could completely change the situation prevailing since 1945, namely, the fact that enrichment facilities are in general much larger, more complicated and expensive than simple production reactors. For example, the electromagnetic separation technique used to make the U 235 for the Hiroshima bomb was abandoned in 1946 because the method was impractical [56]. But with the development of superconducting magnets and high-current heavy ion sources and beams the whole question needs re-evaluation. The most significant new enrichment technology, however, appears to be the laser, the development of which may lead to very compact isotope separation facilities [57].

5. Compact systems

Most systems considered above are technologically very complicated and it is likely that their use will be confined, for some time, to the most technically advanced countries. There are, however, other methods which require less sophisticated technology. Furthermore, studies indicate the possible realization of compact fusion devices as a competition to the giant tokamak-type constructions. Possession of a small fusion device would be within the financial posibilities of relatively small countries and would enable them to produce strategic weapon materials, such as weapon-grade plutonium, transplutonium fissile isotopes or tritium. Among these compact devices one may cite: the plasma focus, muon-catalysed cold fusion, and mini magnetic fusion devices.

5.1. The dense plasma focus

Compared with other technologies, including fission reactors, the dense plasma focus [58] is a relatively crude device. By initiating discharges with a capacitor bank in a deuterium-tritium atmosphere, one obtains a powerful burst of 14 MeV neutrons. If such discharges can be generated at a sufficient rate, a hybrid system can be built, producing tens of kilograms of Pu 239 or U 233 per year [59].

5.2. Low current accelerator-breeder boosted by muon catalysis

To produce significant amounts of plutonium, i.e. a few tens of kilograms of Pu 239 per year, the average current of a high-energy proton accelerator for a spallation breeder should be in excess of a few mA. However, if the muons produced in the spallation target are used to catalyse fusion in a cold deuterium-tritium gas, the 14 MeV fusion neutrons may induce further neutrons in a fission blanket. Although between 5 to 10 GeV may be required to produce one muon, each muon could catalyse over 50 fusion reactions. Thus, combining spallation, fusion, and fission multiplication in a blanket, it is possible to design an accelerator-driven hybrid producing hundreds of kilograms of fissile material per year, with a relatively low-current accelerator [60].

Proton accelerators with beams in the mA range exist or are under construction in several Third World countries, in particular Brazil, India and South Africa [61]. Although various accelerators are operating or planned in other Third World countries, the necessary technologies are not widely spread. But interest in accelerators for fundamental and applied research in nuclear physics is growing in some of these countries [62].

Compared with other alternatives for obtaining nuclear weapon materials, accelerator-based neutron generators are considered to be an easier route than getting plutonium from a power reactor [63].

It is therefore interesting to note that while all nuclear facilities in a state party to the Treaty on the Non-Proliferation of Nuclear Weapon are under strict international control, the accelerators are not subject to any such control, nor is there any debate about this technology from the point of view of proliferation of nuclear weapons [64].

5.3. Mini fusion devices

Mini fusion systems, with energies in the 10 to 100 MW(e) range, and good environmental acceptability, would be of great interest to electric utilities [65].

No such system has been demonstrated yet, but various concepts may become feasible; for example, a magnetic system with toroidal confinement, ignited by ohmic heating alone, called the OHTE fusion reactor [66]; or, the MIGMA colliding-beam fusion power source [67].

6. Proliferation-resistant systems

Although the new concepts may help to facilitate the proliferation of nuclear weapons, they may also help in achieving better control to prevent the diversion of nuclear material. Several emerging nuclear energy systems have been studied under the auspices of the Non-Proliferation Alternative Systems Assessment Programme. We briefly review the features of two such systems.

6.1. Gaseous core reactors with very small plutonium discharge

One of the most favourable aspects of high-temperature gas-cooled reactors (HTGR) is the possibility of an order-of-magnitude reduction in the plutonium content of the spent fuel [68]. For example, whereas the amount of plutonium discharged from a 1000 MW(e) LWR is of the order of 200 kg per year, calculations show that it would only be about 15 kg for a HTGR of same power. This would merely slow down the proliferation process. Furthermore, the initial fuel will have to be 10 per cent enriched uranium, which would have to be severely safeguarded.

6.2. Accelerator or hybrid-reactor fuel enricher or regenerator

Theoretically, it is possible to irradiate spent fuel elements to increase their fissile material content and therefore "rejuvenate" them. It has been suggested that this could be done using a hybrid reactor or an accelerator breeder, thus dispensing with the need for reprocessing [69; 70]. Diversion would be complicated because the spent fuel would be highly radioactive and difficult to handle, and diverted material would need reprocessing. Furthermore, if the initial fuel consisted of a mixture of thorium and natural uranium, "enriched" at a hybrid complex, the advantages would be similar to those of denatured fuel. Ideally, enrichment rejuvenation complexes would be located in an international centre.

7. Conclusions

The brief survey of the emerging nuclear energy systems indicates that some of these technologies enhance considerably the vertical proliferation of nuclear weapons. For example, research in inertial confinement fusion as a power source will increase the knowledge of the basic physics of thermonuclear weapons which may lead to improved weapons and even to the development of new types of weapon. Some countries have put much ICF research under defence programmes [71; 72]. Thus, fusion obviously does not fit the ideal of an infinite supply of energy for purely peaceful applications [73]. ICF has no immediate relevance to horizontal proliferation but once many of the non-nuclear weapon states acquire the necessary high level of scientific knowledge and industrial base, it will become an equally important issue.

From the point of view of non-proliferation of nuclear weapons, the situation is being complicated by the development of new methods, such as accelerator technology, for producing fissile materials. While all facilities in the nuclear fuel cycle in a non nuclear weapon party to the 1968 Treaty on the Non-Proliferation of Nuclear Weapons are under strict international control, facilities such as accelerators are not subject to any control by the International Atomic Energy Agency (IAEA), nor is there any debate about the technologies from the point of view of proliferation of nuclear weapons.

Recently some of the nuclear-weapon states have offered to put their civilian nuclear facilities under the IAEA's control. While such a gesture has some political value, some of the emerging energy technologies tend to reduce the value of this considerably. For example, about a year ago, the possibility of using civilian reactor-grade Pu 239 in nuclear weapons was considered in the USA [74]. High-energy laser would be used to separate Pu 239 from other plutonium isotopes. Thus availability and application of a relatively cheap enrichment technology would further diffuse the distinction between military and civilian nuclear energy systems and increase the problems of safeguards.

Since the ICF device would reproduce on a laboratory scale much of the basic physics of nuclear weapons, and many of the radiation effects of nuclear weapons could be studied in laboratories, the need for underground testing of weapons would almost be eliminated. In the event of a treaty banning the testing of nuclear weapons in all environments, ICF technology would present the greatest hazard. It would allow nuclear weapon designers to continue designing new weapons and obtain much of the data needed without conducting many tests. Thus the purpose of a treaty banning all nuclear tests would be lost since the qualitative nuclear arms race would continue.

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