Fourth Generation Nuclear Weapons

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First generation nuclear weapons are all-uranium or all-plutonium atomic bombs. The science and technology of these weapons is widespread, and their intrinsic simplicity is such that their successful development does not require nuclear testing. Today, these weapons constitute the main horizontal proliferation threat. A major military quality of these weapons is that they potentially lead to very reliable, rugged and compact designs. An example is the W33 artillery-fired atomic projectile (first deployed in 1956) which has a yield of 5-10 kt for a weight of about 100 kg.

Second generation nuclear weapons are two-stage thermonuclear devices. A tritium-boosted fission bomb is used to implode and ignite a secondary system in which fusion reactions produce most of the yield. The development of these weapons required extensive testing and resulted in high-yield (100-500 kt) weapons with yield-to-weight ratios comparable to the best first generation nuclear weapons. Progress on these weapons has been slow and the scientific understanding of the details of the secondary system is still incomplete. Nevertheless, after more than 50 years of research and development, no really significant progress is to be expected for this generation of weapons. This is possibly the main technical reason why a comprehensive test ban treaty (CTBT) is now militarily acceptable.

Third generation nuclear weapons are "tailored" or "enhanced" effects warheads (such as the Enhanced Radiation Weapons (ERW), Reduced Residual Radioactivity (RRR) or Electromagnetic Pulse (EMP) bombs) or nuclear-driven "directed energy" weapons producing beams or jets of X-rays, electromagnetic waves, particles, plasmas, etc. Like many tactical nuclear weapons, these devices never found any truly convincing military use. Moreover, none of them provided any decisive advantage (such as significantly reduced collateral damage, absence of radioactivity, etc) and their development would have required a large number of nuclear test explosions. For these reasons, the development of this third generation of nuclear weapons is the most directly affected by a CTBT.

Fourth generation nuclear weapons are based on atomic or nuclear processes that are not restricted by a CTBT. In contrast with second generation nuclear weapons, their development will be essentially science-based, making use of many recent advances in fundamental or applied research. In common with first generation nuclear weapons, they could allow for rather simple and rugged designs, although the special materials they will be made of might be much more difficult to manufacture than plutonium or enriched uranium. Fourth generation nuclear weapons may provide really significant military advantages (especially for tactical uses since most of them will produce no residual radioactivity), and considerable political advantages since their development will be restricted to the most technologically advanced countries - which already possess thermonuclear weapons to deter any potential agressor or proliferator. A number of fourth generation nuclear weapons have been under consideration for a very long time: clean fusion bombs, antimatter bombs, particle and laser beam weapons, laser-triggered bombs, atomic and nuclear isomers, etc. In what follows, we take three examples which have in common the fact that the key scientific instruments for their development are inertial confinement fusion (ICF) devices such as the ones which are planned in the USA (National Ignition Facility - NIF) and France (Laser Megajoule - LMJ).

(1) Metallic hydrogen

The modeling of the interior of the giant planets such as Jupiter (which mainly consists of hot, dense hydrogen), has been the object of considerable work in the weapons laboratories. The reason is not only that understanding the physical properties of planetary interiors is relevant to certain aspects of thermonuclear weapons and ICF, but also that hydrogen is expected to be in a metallic state. It is since long expected that above a certain pressure, hydrogen could be converted into a dense crystalline solid at room temperature, which could be maintained for long periods without containment. Metallic hydrogen is expected to be 25 to 35 times more explosive then TNT, possibly the most powerful chemical explosive conceivable. Research on metallic hydrogen is part of the NIF scientific program.

(2) Nuclear isomers

High explosives have energy contents of the order of 5 kJ/g. Nuclear isomers have available energies of about 1 GJ/g, close to those released by nuclear reactions (e.g. 80 GJ/g is released by fission). A systematic study of the properties of nuclear isomers, and of ways to release their energy, is under investigation in several laboratories. The USA and France started collaborating on this subject under SDIO and NATO contracts. Nuclear isomers can be produced through heavy-ion collisions, or by nuclear synthesis in a burst of neutrons from an ICF micro-explosion. The most promising triggering mechanism uses a high-intensity laser, releasing the energy instantaneously in the form of X-rays, as in a fission explosive, but without producing radioactivity. Like metallic hydrogen, nuclear isomers have the potential to be used as "conventional" weapons, or as triggers in "clean" fusion weapons.

(3) Antimatter

Research on antimatter weapons started in the late 1940s. As with most scientific undertakings, progress has been slow. However, since the capture of the first antiprotons in a magnetic trap in 1986, several crucial measurements have been made. For example, about 16 neutrons are produced by stopped annihilation in uranium. This means that a very small amount of antiprotons would be sufficient to boost a nuclear explosion, or to initiate a chain reaction in a highly compressed pellet of plutonium or uranium. More important, microgram quantities of antiprotons would be enough to trigger a large-scale thermonuclear explosion, or a powerful X-ray of gamma-ray laser. Many military applications of antimatter are feasible, and this explains why antimatter is today possibly the most important fourth generation nuclear weapons research and development program. In the USA, this research is coordinated by the Air Force and former SDIO. At the present time, three main laboratories are involved in the production of antiprotons: CERN (Switzerland and France), FNAL (USA) and IHEP (Russia). These laboratories use large accelerators to produce antiprotons in very small amounts. However, the use of high-energy lasers may result in conversion efficiencies one million times higher than with the use of accelerators. Experiments on the production of antimatter are planned at NIF. To start with, these experiments will study relativistic plasmas and ponderomotive effects near the energy density for electron-positron production.

The arms control problem of fourth generation nuclear weapons is not only that their development circumvents the limitations of a CTBT which, according to an authoritative interpretation, would merely "ban explosively driven or other rapidly assembled systems of *fission* yield sufficient to melt the fissile material – of the order of 100 grams of high explosive equivalent".

The real challenge is that their development is much more closely related to purely scientific research work than it was for weapons of previous generations. Just as military laboratories are opening themselves more and more to non-military research, fundamental research in most areas of modern science is becoming more and more ambivalent. In the case of fourth generation nuclear weapons however, the military character of the "civilian" research on which they are based is clear. In the three examples listed above, the fundamental research, whether in the fields of astrophysics, nuclear physics or elementary particle physics, is devoted to understanding extreme states of matter: very high pressures, very high energy densities, very high energies. If no quantitative or qualitative limit is put on the fundamental research concerned with these asymptotic states of matter, the dynamics of technological innovation will make the development of new weapons based on the resulting knowledge unavoidable.

In conclusion, a necessary condition to achieve the chief purpose of the CTBT (which is to fossilize the technology of nuclear weapons as a first step towards general and complete nuclear disarmament), is to include effective measures of preventive arms control in the treaty, such as internationally binding restrictions in all relevant areas of research and development, whether they are claimed to be for military or civilian purposes.

About André Gsponer and ISRI

Dr. André Gsponer worked on high energy physics at CERN and FNAL between 1971 and 1980. While working at CERN, he discovered in 1978 the existence of research on particle beam weapons, and in 1979 the interest of Iraq in calutron technology for uranium enrichment. For these reasons he left CERN in 1980 to create the Geneva International Peace Research Institute (GIPRI). His research at GIPRI was mostly concerned with beam weapons and nuclear proliferation implications of particle accelerator and fusion technologies.

In 1982, he founded the Independent Scientific Research Institute (ISRI) to concentrate on the analysis of scientific and technical issues of disarmament. The main contributions of ISRI in the 1982-1987 period were on third generation nuclear weapons (in particular the neutron bomb) and antimatter weapons.

Between 1988 and 1994 André Gsponer went back to academic research to work on theoretical physics and science policy problems. Since 1995 he is working again full time at ISRI.

ISRI's current research program is focussed on laboratory nuclear testing, fourth generation nuclear weapons, and on ways of mastering the dynamics of science and technology.

ISRI is looking for two physicists, with post-doctoral experience in neutronics or plasma physics, to work on nuclear weapon disarmament problems. Interested candidates should send their resume to ISRI, Box 30, 1211 Geneva 12, Switzerland.

(21 January 1996)