Electric energy from the conversion of nuclear warheads: a contribution to a peaceful world

The relationship between nuclear power for civil applications and nuclear weapons is still today a critical area of public concerns. This article draws the attention to a possible way to convert nuclear warheads producing electricity in civil reactors and recuperating an important part of the amount of money invested on them. This way civil nuclear power plants can reduce the risks of nuclear weapons.

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Introduction

Concerns about links between civil and military uses of nuclear power require attention since this is still today a critical area of public opinion. Both nuclear fission and fusion enormous power can be used for the benefits or for the destruction of mankind. Therefore, a clear distinction is necessary.
Nuclear arsenal is still at very high levels and all the Nuclear Weapon States (NWS) continue to modernize their nuclear forces. The economic recovery after COVID-19 pandemic could be a further reason to limiting the number and danger of nuclear weapons; the budget related to nuclear weapon can be very well diverted to more urgent issues. Moreover, today the only possible way to destroy at least some of the many nuclear fission warheads is to blend down their raw material using it as fuel for nuclear power plants producing electricity and recuperating an important part of the amount of money invested on them.
This process has been already successfully implemented thanks to United States - Russian agreements on nuclear disarmament in the well-known Megatons to Megawatts (M2M) program that provided the uranium to generate about 10 percent of the electricity produced in the United States from 1993 to 2013.

Nuclear fission

The nuclear fission process consists of a subdivision of a heavy atomic nucleus, such as that of uranium or plutonium, into two lighter nuclei of roughly equal mass and of several neutrons. These neutrons can induce fission in a nearby nucleus of fissionable material and release more neutrons that can repeat the sequence, causing a chain reaction in which many nuclei undergo fission and an enormous amount of energy is released.
If fission is controlled in a nuclear reactor, such a chain reaction can provide power for society's benefit.

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Electric energy production is the major civil application of nuclear fission process. There are 442 nuclear power reactors in 30 countries provide approximately 10% of global electrical power with over 2,560 terawatt hours of electricity annually. Despite the 2011 Fukushima Daiichi nuclear disaster in Japan, 53 reactors are under construction in 19 countries [1], [2], [3].
For military applications fission chain reaction is uncontrolled, as in the case of the atomic bomb, leading to an explosion of awesome destructive force.
Two atomic bombs have been used twice in history against Japan in 1945 during World War Two causing enormous loss of life and huge devastation. Today there are more than 13000 nuclear warheads in 8 countries, according to best estimates of the Federation of American Scientists (FAS) [4]. Despite progress in reducing Cold War nuclear arsenals, today's forces are vastly more capable and there are important upgrading and modernization programs. These weapons could be used with catastrophic effects.

Nuclear fusion

In the nuclear fusion process two nuclei, lighter than iron, collide together to form a single and heavier nucleus with the release of energy because the mass of the new nucleus is less than the sum of the original masses. Based on the principle of mass-energy equivalence, this mass difference means that some mass that was "lost" has been converted into energy. Fusion reactions constitute the fundamental energy source of stars, including the Sun.
Research into developing controlled fusion inside fusion reactors has been ongoing since the 1940s, but the technology is still in its development phase.
Fusion researchers have investigated various confinement concepts. The current leading designs are the Magnetic Confinement Fusion (MCF) in tokamak and Inertial Confinement Fusion (ICF) by laser. Both designs are under research at very large scales, most notably the International Thermonuclear Experimental Reactor (ITER) tokamak in France, and the National Ignition Facility laser in the United States. Researchers are also studying other designs that may offer cheaper approaches [1], [2], [3].
On the other hand, research into fusion for military purposes began in the early 1940s as part of the Manhattan Project. A large scale nuclear fusion explosion was first carried out on November 1952, in the Ivy Mike hydrogen bomb test.

Civil and military uses applications

Nuclear weapons are explosive devices designed to release the large quantities of energy produced by nuclear fission (atomic bomb), or by a combination of fission and fusion (thermonuclear/hydrogen bomb).
Fission weapons are normally made with materials having high concentrations of fissile isotopes such as Uranium-235 (U235) or as Plutonium-239 (Pu239).
Nuclear Power Plants (NPPs), on the other hand, use low percentages of fissile materials in order to control the chain reaction, making available, after each fission, a single neutron for further fission. Some nuclear reactors can also use natural Uranium.
Only 0.7% of natural uranium is the fissile U235 (92 protons + 143 neutrons) that, hit by a neutron, breaks up freeing up energy and other neutrons which in turn break other nuclei, generating the "chain reaction". The remainder 99.3% of natural uranium is the fertile U238 (92 protons + 146 neutrons) which, if struck by a neutron, can be transformed into a nucleus of the fissile Pu239.

Isotopic enrichment

The process of "isotopic enrichment" allows to modify the composition of natural Uranium, increasing the percentage of U235 from 0.7% up to:
Less than 5% or Low Enriched Uranium (LEU) for fuel to be used in NPPs,
More than 90% or Highly Enriched Uranium (HEU) in the case of nuclear fission weapons.

In the past, large and complex gas diffusion plants were used for the enrichment process that requires significant energy consumption, which grows exponentially as the final enrichment increases; recently ultracentrifuges are used for this process.
Atomic arsenals have been accumulated by producing HEU in isotope separation plants or by building specifically designed nuclear reactors which produced "weapon grade" plutonium. These early reactors are not built anymore.
Current NPPs do not use HEU and do not produce "weapon grade" plutonium but they are the best way to destroy atomic arsenals producing electricity.

Nuclear safeguards

Nuclear materials such as uranium and plutonium can be used for both peaceful and military purposes. Nuclear safeguards were established to guarantee that nuclear materials would not be diverted to purposes other than those for which they were originally declared.
The International Atomic Energy Agency (IAEA) seeks to independently verify State's legal obligation that nuclear facilities are not misused and nuclear material is not diverted from peaceful uses. States accept these measures through the conclusion of safeguards agreements. In Europe, the safeguards reporting requirements derive from the Euratom Treaty and are detailed in Commission Regulation (Euratom) 302/2005.
In the European Union, users of nuclear material

(uranium, plutonium, and thorium) have to keep a strict system of records and to make declarations about the nuclear material they hold and process to the European Commission. On the other hand, the Commission has to verify these declarations with regard to their correctness and completeness in order to assure citizens, supplier states, and the international community that the nuclear material remains in use only for peaceful purposes.

Nuclear-weapon states

The Non-Proliferation Treaty (NPT) entered into force in 1970 with the aims to reduce the spread of nuclear weapons, but its effectiveness has been questioned, and political tensions remained high in the 1970s and 1980s. Modernisation of weapons continues to this day.
Today only eight nations have publicly announced to possess nuclear weapons (chronologically by date of first test): the United States, Russia, the United Kingdom, France, China, India, Pakistan, and North Korea. The first five are Nuclear-Weapon States (NWS) under the terms of the NPT. Israel is believed to possess nuclear weapons, though, it does not acknowledge having them. South Africa is the only country to have independently developed and then renounced and dismantled its nuclear weapons. Germany, Italy, Turkey, Belgium and the Netherlands are nuclear weapons sharing states.
Nuclear weapons have been used twice near the end of World War II by the United States over the Japanese city of Hiroshima (August 6, 1945) and of Nagasaki (August 9, 1945). These bombings caused injuries that resulted in the deaths of civilians and military personnel. Since the atomic bombings of Hiroshima and Nagasaki, nuclear weapons have been detonated over two thousand times for testing and demonstration.

Nuclear arsenal actual situation

The exact number of nuclear weapons in each country's possession is often covered by a secretive nature. Nevertheless, the Federation of American Scientists (FAS) produced best estimates of each nuclear-weapon state's nuclear holdings, including both strategic warheads and lower-yield tactical weapons. This is possible from publicly available information (between 2010 and 2018 the United States disclosed its total stockpile size), careful analysis of historical records, and occasional leaks. FAS estimates a world combined inventory of 13410 nuclear warheads as of early-2020. Of these, 4090 are awaiting dismantlement but still intact, while the rest 9,320 warheads are in the military stockpiles with 3,720 warheads are deployed with operational forces. Approximately 91 percent of all nuclear warheads are owned by Russia and the United States that each have around 4,000 warheads in their military stockpiles; no other nuclear-armed state sees a need for more than a few hundred nuclear weapons for national security.
The world combined inventory reached a peak of approximately 70,300 in 1986 but, despite progress in reducing Cold War nuclear arsenals, warheads numbers remains at a very high level since today's forces are vastly more capable. All the Nuclear Weapon States continue to modernize their nuclear forces [4].
The United States Strategic Command, the branch of the US military responsible for the nation's nuclear weapons, recently publicly released an infographic (Figure 1) showing how China, Russia, and the United States will be upgrading their respective nuclear forces over the coming years; this important modernization programs have not changed during the recent COVID-19 pandemic [5].

Impact of COVID-19 pandemic on defense budget

The COVID-19 pandemic has had and will continue to have a disastrous impact on the global community. Therefore, governments will likely spend lot of economic resources trying to rescue the economy from the effects of the pandemic and military spending should decline significantly over the next couple of years. All the NWS will find it difficult to keep increasing their defense budget dedicated to modernize their nuclear forces at the pace they have maintained over the past decade. Nuclear weapons programs absorb important governmental resources increasing the likelihood of nuclear war. The real impact of nuclear weapons programs on the size of the defense budget includes the cost of developing and procuring nuclear weapons, support and operations for nuclear weapons and delivery systems.
Defending the homeland from catastrophic threats is more urgent than defending against foreign threats and as bad as this pandemic is, a nuclear war would be much worse.
The Nuclear Weapons Ban Treaty, adopted in July 2017 by 122 states at the United Nations (UN), is based on the considerations that it is in the interests of all humanity that nuclear weapons never be used again, under any circumstances. Each country individually - but also the international system – does not have the capacity to cope with the humanitarian consequences of a nuclear war. The only guarantee of non-use of nuclear weapons is their complete elimination.

"Megatons to Megawatts" program

The elimination of nuclear weapons can be achieved with the conversion of Highly Enriched Uranium (HEU) from nuclear fission warheads into Low Enriched Uranium (LEU) for nuclear power plants fuel. The process was successfully completed in 2013 thanks to previous U.S.-Russian agreements on nuclear disarmament. This program, more commonly known as Megatons to Megawatts (M2M) agreement (see Logo in Figure 2), was signed in February 1993 and ended December 2013.

Under the 20-years agreement Russia agreed to blend down a total of 500 tons of HEU (U235 enriched to 90 percent), equivalent to about 20,000 bombs to 15,000 tons of LEU fuel (U235 enriched to 4 percent) as part of what it called the "vital energy and non-proliferation programme". The program provided the uranium to generate about 10 percent of the electricity produced in the United States from 1993 to 2013. Virtually the entire U.S. nuclear reactor fleet participated in this program by using fuel fabricated with low enriched uranium from the M2M program.
The United States Enrichment Corporation (USEC, now Centrus Energy), as executive agent for the U.S. government, and Joint Stock Company Techsnabexport (TENEX), acting for the Russian government, implemented this 20-year, $8 billion program at no cost to taxpayers. USEC paid Tenex for the separative work units contained in the fuel [6].

The heritage of the "Megatons to Megawatts" program

Centrus Energy is now a supplier of nuclear fuel and services for the nuclear power industry through the reliability and diversity of supply sources of enriched uranium [6].
After the M2M program ended in 2013, the U.S. continued to purchase Russian uranium as part of the diverse global supply system. The Russian commercial fuel supply industry has grown and demonstrated to be reliable. However, unlike the M2M program, the LEU supplied is now coming from Russia's commercial enrichment activities rather than from the downblending of Russian weapons material.
The United States is now without and industrial-scale uranium enrichment capability since the last of its outdated and increasingly uneconomical enrichment plants were shut down in 2013. The U.S. once led the world in uranium enrichment, but current market conditions do not support building a full-scale uranium enrichment plant for commercial purposes.
The M2M main objectives can provide an inspiration for similar new programs. The M2M allowed to:

- definitively eliminate a huge amount of HEU, thus nullifying the risk of its re-use for nuclear weapons in the future, accelerating the dismantling of soviet weapons in excess of the Strategic Arms Reduction Treaty (START) agreements,
- avoid the accumulation of huge amounts of HEU with control and physical protection not always adequate,
- facilitate the conversion of Russian laboratories and scientists from the military to the civil sector,
- provide Russia with economic resources in the difficult economic situation at the end of the Soviet Union,
- reduce US production of LEU for NPPs with energy savings,
- protect the environment from the possible dispersion of HEU without the necessary precautions.

"Megatons to Development" program

The Megatons to Megawatts (M2M) program is the main point of reference for the new Megatons to Development (M2D) program. A technical-economic feasibility study for the conversion of nuclear weapons into development projects in the southern part of the world is proposed. The conversion of weapons of mass destruction into new economic resources, starting from nuclear fission warheads that should be dismantled, would reduce the risk of apocalyptic disasters and create a new atmosphere for peace.
It is possible to draw an economic "dividend" from the conversion of nuclear warheads into fuel for NPPs. A preliminary assessment of this dividend has been performed and with the appropriate support and consensus it can be devoted for the development in the South of the world.
It is necessary to act on the governments of the countries directly involved in the conversion of uranium, so the return can be finalized to development. It is also important to promote intergovernmental cooperation and the European Union can play an important role in this ambitious process. This way the EU can contribute to the conversion of nuclear warheads in disarmament and can help the development of the Poor Countries.
More political and institutional support would be needed in order for the "Megatons to Development" programme to take off. The European nuclear industry, NGOs and European Institutions can contribute to realize this process of conversion and development emphasizing the role of International Organizations.

Conclusions

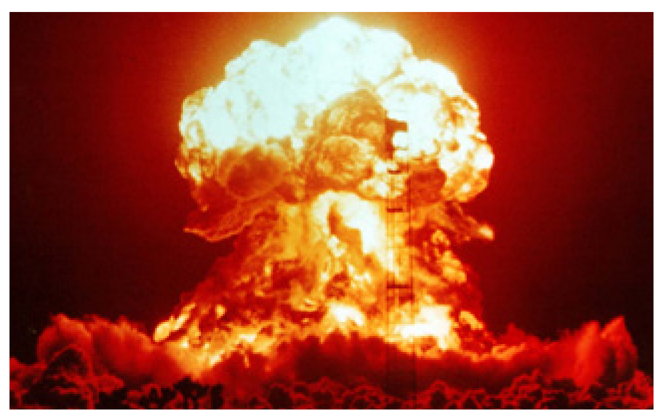
The only guarantee of non-use of nuclear weapons is their complete elimination since the international system cannot cope with the humanitarian consequences of a nuclear war. In order to gradually destroy nuclear fission warheads, it is necessary to blend down their raw material using it as fuel for nuclear power plants producing electricity and recuperating an important part of the amount of money invested on them as already successfully implemented in the described Megatons to Megawatts program.
This article provides the basis to reflect on the essential contribution that nuclear power plants have for an effective solution to the problem of reducing atomic arsenals. It highlights that nuclear power plants do not feed proliferation but reduce it in a safe and sustainable way for the future of the world economy. This conversion process overturns the ever-existing link in public opinion between atomic armaments and nuclear power plants.

Fig. 1

Infographic publicly released by Stratcom showing how China, Russia, and US will be upgrading their nuclear forces.

Fig. 2

Logo of the Megatons to Megawatts program signed in February 1993 and completed in December 2013



Acronyms used

EU	European Union
FAS	Federation of American Scientists
HEU	Highly Enriched Uranium
IAEA	International Atomic Energy Agency
ICF	Inertial Confinement Fusion
ITER	International Thermonuclear Experimental Reactor
LEU	Low Enriched Uranium
M2D	Megatons to Development
M2M	Megatons to Megawatts
MCF	Magnetic Confinement Fusion
NPPs	Nuclear Power Plants
NPT	Non-Proliferation Treaty
NWS	Nuclear-Weapon States
START	Strategic Arms Reduction Treaty
StratCom	United States Strategic Command
TENEX	Techsnabexport
UN	United Nations
US	United States
USEC	United States Enrichment Corporation

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