Nuclear Power, Nuclear Weapons, and Nuclear Terrorism

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Nuclear Power, Nuclear Weapons, and Nuclear Terrorism

1. Introduction

Most of us would like to have our only planet able to sustain human civilization comfortably for a pretty long run. We can imagine our children, grandchildren, and maybe great-grandchildren needing the planet to be there for them. Perhaps we buy into the Native American idea of providing for seven generations into the future.

We know that both militarization and climate change threaten the future of human civilization. Increasing numbers of people wanting more stuff challenge our finite resources including clean water and air. Throw into the picture growing numbers of weapons, some very, very dangerous, and human fallibility, and things don't look too promising. The Chinese have a saying, "Unless we change direction, we are likely to end up where we are headed." Time to change.

The issues of militarization and climate change are strongly linked. Nuclear power proponents claim that nuclear power can provide energy for the world without the CO_2 emissions that the planet is currently getting from our mostly fossil fuel energy. This study guide will enable readers to see that a nuclear power renaissance could easily lead to nuclear weapons proliferation and an increase in the threat of nuclear terrorism. Since all the energy for the world can be affordably provided by renewable sources, should new nuclear power have a place in the world's energy mix? Will new nuclear power lead to new military dangers?

In order to think about these questions, you need to know more about nuclear power and particularly the connections between nuclear power and nuclear weapons. These chapters are devoted to explaining the relationship between nuclear power, nuclear weapons, and nuclear terrorism. This study guide doesn't explain the environmental issues connected with permanent disposal of the high-level radioactive waste produced in nuclear reactors. This study guide does not deal with the health issues related to the nuclear infrastructure. Nuclear power is questioned here because of its connections to nuclear weapons and nuclear terrorism.

The chapters are meant to provide an elementary education about the cords that bind nuclear power, nuclear weapons, and nuclear terrorism.

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January 7, 2014

Nuclear Power, Nuclear Weapons, and Nuclear Terrorism
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Section 1. Nuclear Power

Nuclear power plants produce electricity using a nuclear chain reaction in their fuel to heat water, turning it to steam that turns a turbine to make electricity. Putting **nuclear power** into Google will get you lots of information and opinions on nuclear power.

1. Pro-Nuclear Power

If you visit this website from the Nuclear Energy Institute (NEI), a nuclear power industry voice, you will get a quick and favorable overview of the process of generating electricity from uranium fuel. The website explains many positive aspects of nuclear power. http://resources.nei.org/images/2010_Just_The_Facts/

2. About Atoms

Let's learn a little bit about atoms to help understand the fission that produces the heat to boil the water in the nuclear power reactor. The center of the atom is called the *nucleus* and it is made up of *protons* and *neutrons*. Protons are positively charged small particles and neutrons are about the same size, small, but with no electrical charge. So you can see the nucleus has an inherent potential instability because things with the same electrical charge repel each other. As you know, negatively charged particles are attracted to positively charged particles. Hence the saying "opposites attract." The protons, all positively charged, repel each other. The nucleus is amazingly held together by nuclear *binding energy*.

Uranium is a large atom, with *atomic number* 92, which means it has 92 protons, positively charged, in its nucleus, and a cloud of 92 electrons circling around the nucleus, each negatively charged and having almost no mass. So the entire atom is electrically neutral. The electrons do not go flying away because they are attracted to the protons in the nucleus. Neutrons in the nucleus separate the protons from each other and allow them to exist together while repelling each other. Large atoms such as uranium need a lot of neutrons to allow the protons to coexist in the nucleus.

Uranium, as all atoms, comes in several varieties, called *isotopes*. Isotopes of the same element have different amounts of neutrons in their nucleus.

The most common isotope of Uranium is U-238. 238 is its *atomic mass*, which means U-238 has 238 protons and neutrons in its nucleus. Since all atoms of uranium have 92 protons, U-238 has 238 – 92 = 146 neutrons.

3. Fission

In rare cases, a neutron flying by can hit a nucleus and break it into two smaller nuclei, releasing *excess neutrons* in the process. A few of the neutrons become “excess” because the two smaller nuclei, containing fewer protons each, don’t need quite as many neutrons in total as the larger atom did to keep the peace with the protons. When an atom splits releasing excess neutrons, the process is called *fission*. In addition to new elements with smaller atomic masses being created, and excess neutrons being released, large amounts of energy are also produced. The energy comes from breaking the binding energy of the original large atom and forming new atoms each with their own binding energy, plus a small amount of mass is turned into energy. $E = mc^2$.

U-235 is a rare isotope of uranium with 235 – 92 = 143 neutrons. Very few elements fission, but U-235 fissions.

Each splitting of a U-235 atom produces excess neutrons, which spit more atoms. When splitting atoms produce excess neutrons that split more nearby atoms, this process is called a *chain reaction*. If a chain reaction is controlled to happen slowly in a nuclear reactor, manageable heat is produced. If a chain reaction is uncontrolled, an explosion occurs. An atomic bomb has its explosive power from an uncontrolled fission chain reaction.

Watch the fission animations on the Atomic Archive website, which also has lots of other interesting stuff on it as well!

http://www.atomicarchive.com/Movies/index.shtml

4. Before and After Fission

None of the isotopes of uranium are highly radioactive. Uranium is mined and handled with relative safety. Uranium mining is similar to coal mining and does provide health risks to the miners, but the risks do no come from a high level of radioactivity. The *half-life* of an element is the length of time it takes the spontaneous radioactivity of the element to change half of the element to other elements. Elements with short *half-lives* are very radioactive, changing quickly. The half-life of U-238 is 4.5 billion years, so you can see it is not changing rapidly, and thus is not very radioactive. The half-life of U-235 is 700 million years, so U-235 is not very radioactive either. The fission in the reactor produces heat and other unnatural atoms, most of which are highly radioactive. In fact, all of the highly radioactive substances on earth come from fissioning natural, not highly radioactive, materials.

5. Key Idea

All of the highly radioactive materials on earth were created by fission in a nuclear reactor.

6. Mostly Unanswered Questions

This study guide is designed to help answer only the last of these important questions.

- What is done and what can be done with the highly radioactive spent fuel produced in the reactors that make nuclear power electricity?
- Is nuclear power electricity cheap or expensive?
- Can nuclear reactors be protected from an ordinary terrorist attack?
- What would happen if a terrorist group exploded a nuclear weapon at a reactor complex?
- Is it moral to produce very long-lived lethal radioactive material to create short-lived electricity in the present?
- Would an increase in nuclear power for the world lead to an increase in nuclear weapons?

7. Questions for You

1. Which fissions, U-238 or U-235?
2. Is the fuel for a nuclear reactor highly radioactive?
3. Is the fuel that is no longer useful and must be removed highly radioactive?
4. What is the neutron difference between U-238 and U-235?
5. What can U-235 do that U-238 cannot do?
6. I-131, an isotope of iodine produced in the fission process of U-235, has half-life of about 8 days. Is I-131 highly radioactive?
7. Cesium-137 is highly radioactive and has a half-life of 30 years. Which loses its radioactivity quicker, I-131 or Ce-137?
8. Strontium-90 is highly radioactive and has a half-life of about 30 years also, which means it hangs around in the environment pretty long. Sr-90 settles in bones. The discovery of Sr-90 in children's bones and teeth helped pass the treaty banning atmospheric testing of nuclear weapons. How did the Sr-90 get into the children's bones and teeth?
9. Pu-239 is produced in nuclear reactors. Pu-239 has a half-life of 24,000 years. How does the radioactivity of Pu-239 compare to that of Ce-137 and Sr-90?
10. Which of the unanswered questions interests you the most and why?

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Section 3. Enrichment

Nuclear reactors run on *enriched* uranium fuel, and *enriched* uranium can be used to produce nuclear weapons, but the amount of enrichment is different for each application. In order to think about the implications of this connection between nuclear power and nuclear weapons, we have to get a better understanding of the *enrichment* process.

1. Need More U-235 to Fission!

Simply put, nuclear reactors maintain a controlled chain reaction to produce heat that turns water to steam that turns a turbine producing electricity. They are similar to coal burning power plants except that the heat in a reactor is produced by fission, not fire. Nuclear reactors use fuel made out of *Uranium*, the heaviest naturally occurring metal.

Uranium is a heavy metal that is mined. Mined uranium is about 99% U-238, which doesn't fission, and less than 1% U-235, which does sustain a fission chain reaction. Most nuclear reactors require fuel which has been *enriched* to about 5% U-235 in order to sustain a fission reaction in the reactor. This fuel is called LEU*, low-enriched uranium*.

Enrichment is a name for the process that increases the percentage of the fissile U-235 isotope in uranium obtained from the ground. Enrichment is a challenging industrial process requiring a lot of infrastructure and energy. Three methods of enrichment are:

(a) gaseous diffusion (used in US from WWII to present)

(b) centrifuge enrichment (the issue with Iran these days)

(c) laser enrichment (a potentially dangerous development which could allow clandestine enrichment by non-state actors)[1]

2. HEU vs. LEU

Enrichment technology allows the enricher to enrich uranium to 5% U-235 which is reactor fuel (LEU). However the enricher might continue enriching to *High-Enriched Uranium (*HEU*)* levels of 80% U-235 or more, which is *weapons-grade* material. HEU can explode. Thus if a nation has the technology to enrich to reactor fuel levels (LEU), that same technology would enable enrichment to bomb levels (HEU).

Actually the ability to enrich to HEU is even more worrisome than you might think because the enriching process isn't linear. You might imagine that 5% enrichment is pretty far from 80% enrichment, but look at the approximation below using a mathematically easy-to-understand doubling per enrichment cycle and a little rounding.

Number of enrichment cycles	0	1	2	3	4	5	6	7
% U-235	0.7	1.4	2.8	5	10	20	40	80

Note that in this approximation, 5% is almost halfway to a bomb level of enrichment, 80%, and 20% is only two cycles away from 80%. Iran is enriching to 20% levels at present, so you can see why folks are worried. The World Nuclear Association has a more detailed explanation on their website.[2]

3. Propulsion, Research, Medical, and Production Reactors

Not all reactors produce electricity and not all reactors run on LEU. Hundreds of smaller reactors run on fuel of higher enrichment levels, all the way up to weapons grade HEU. Submarine and icebreaker propulsion reactors propel the boats and run on HEU. Many small research reactors run on HEU fuel exported by the US. Lots of work is being done to upgrade these small research reactors to use safer LEU fuel. Medical reactors produce highly radioactive isotopes used in radiation treatments in hospitals and run on fuel with varying degrees of enrichment. Iran's medical isotope reactor runs on 20% enriched fuel, and Iran has been enriching to 20% levels despite UN Security Council Resolutions forbidding enrichment. Production reactors produce plutonium for weapons. The International Atomic Energy Agency has databases on the locations and fuels of the world's research reactors posted.[3]

4. Atomic Bombs from HEU

The bomb that the US dropped on Hiroshima in 1945 was a "gun-device" using HEU as its explosive nuclear material. This weapon had never been tested. The technology was and is simple enough to not need testing.[4] Because an HEU nuclear weapon is relatively easy to make, HEU must be closely guarded and enrichment facilities must be closely watched. It only takes about 100 pounds of HEU to build a simple gun-type weapon.[5]

5. Countries that Enrich Reactor Fuel

US, Russia, UK, France, and China enrich reactor fuel and are allowed to enrich uranium for nuclear weapons by the Nonproliferation Treaty (NPT).

Brazil, Netherlands, Germany, Japan, and others are allowed to enrich reactor fuel by the NPT. Enrichment to reactor fuel levels is a peaceful nuclear technology.

Iran enriches but has been forbidden to enrich by four separate UN Security Council Resolutions because of improprieties in obeying the NPT.

6. Depleted Uranium (DU) is Leftover from Enriching

Remember that enriching uranium is increasing the concentration of the U-235 isotope. So any enrichment method producing a higher concentration of U-235, leaves behind U-238. According to the International Atomic Energy Agency, each ton of LEU produced leaves behind 8 tons of U-238 in the enrichment process.[6] Left over U-238 is called *depleted uranium (*DU*)*.

According to World Nuclear Organization an ordinary 1000 MW reactor uses 27 tons of (LEU) reactor fuel per year.[7] So the annual 27 tons of LEU for one reactor leaves behind 216 tons of DU. In addition, about 120,000 tons of uranium tailings from the mining stage are left behind annually for each reactor. A lot of DU is left over from producing the fuel for the 100 nuclear reactors in the US and over 400 in the world. So when thinking about the efficiency of producing electricity from a relatively small amount of LEU, you must think about all the material left behind to get the LEU.

DU is a very controversial subject. DU is U-238, an isotope of uranium, and the heaviest naturally occurring metal, and thus is very dense. The US makes both armor for tanks and anti-tank armor penetrating projectiles out of DU. DU is cheap since there is a lot of it around and it is low-level radioactive waste and would need to be disposed of in a somewhat costly way. DU is not very radioactive but strong claims abound on the Internet about serious consequences of using DU anti-tank weapons. The World Health Organization (WHO) says DU weapons are ok. You be the judge. DU weapons are definitely not nuclear weapons. Nuclear weapons explode with a fission or fusion explosion. DU weapons contain chemical explosives.

7. Key Idea

Mastering the technology of enrichment allows the actors to produce the explosive material for the most easily made nuclear weapons.

8. Parting Thoughts

A nation that has the ability to enrich uranium can also relatively easily make atomic bombs. If the nation belongs to the Nonproliferation Treaty (Chapter 5) it is subject to international inspections by the International Atomic Energy Association (IAEA) and cannot openly work on nuclear weapons. If the nation does not belong to the NPT, (Israel, India, Pakistan and North Korea), or withdraws from the NPT, only constraining actions of other nations could prevent an enriching nation that wanted to make atomic bombs from doing so.

9. Questions for You

1. What is “enrichment”?
2. Name three enrichment technologies?

3. Are all countries belonging to the NPT allowed to enrich reactor fuel?
4. What prevents a country from enriching to higher than reactor fuel levels?
5. What was the explosive material for the weapons dropped on Hiroshima?
6. The easiest-to-make nuclear weapons are fueled with what nuclear explosive?
7. How many tons of DU is left behind producing the fuel for one ordinary commercial nuclear reactor for one year?
8. About how many commercial nuclear reactors does the world have at present?
9. About how many tons of DU are produced in total each year?
10. What does a medical reactor produce?
11. What kind of fuels do smaller reactors use?
12. What makes research reactors a nuclear-weapons-proliferation risk?
13. Are research reactors more of a nuclear-weapons-proliferation risk than ordinary commercial electricity-producing reactors? Explain why or why not.

Footnotes

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Section 4. Reprocessing

The fissioning of the fuel in a nuclear reactor produces plutonium (Pu) and a bunch of other much more radioactive substances. Plutonium, as well as HEU, is a nuclear explosive and can be used to make nuclear weapons. The process of removing the plutonium from the highly radioactive spent nuclear fuel is called *reprocessin*g. If the plutonium is left in the highly radioactive spent nuclear fuel of the reactor, the radioactivity of the spent nuclear fuel makes it unusable. If the plutonium is removed from the spent fuel, separated plutonium can be fashioned into nuclear weapons.

1. Spent Fuel from a Nuclear Reactor Is Highly Radioactive!

Uranium is only weakly radioactive, so the fresh fuel going into the reactor is only a tad radioactive. However, after the U-235 in the fresh fuel has fissioned for several years in a reactor, much of the U-235 and some of the U-238 (most of the fuel) have decayed into other highly radioactive elements. The no-longer efficient fuel must be removed robotically and replaced with new fresh fuel that will fission efficiently again to boil water and turn a turbine to produce electricity.

The removed old fuel is called Spent Nuclear Fuel (SNF). SNF is highly radioactive, as you can see from the table below. Remember, fresh fuel is not highly radioactive. The fission process has produced the high radioactivity in the fuel.

> "Below is a table which shows the surface dose rate of SNF discharged from a reactor – approximately 500 Rem is considered to be a fatal dose of radiation, while much smaller levels can cause permanent health effects."[1]

Table 2.1.2 Radiological Characteristics of Spent Nuclear Fuel

SNF Age (Years Cooled)	Surface Dose (rem/hour)
1	234,000
5	46,800
10	23,400
50	8,640

Source: US DOE, DOE/NE-0007, 1980

Notice that after 50 years the surface dose will be fatal to a human in 500/8,640 = 0.058 hours = 3 ½ minutes.

2. What Happens to the Highly Radioactive Spent Fuel?

Spent Fuel is robotically removed from the reactor after several years and placed in a water-filled spent fuel pool. The water in the pool must constantly circulate to cool the spent fuel and prevent the spent fuel from spontaneously combusting. After five years or more the spent fuel can be removed from the spent fuel pond.[2]

3. What Does Spent Fuel Have to Do With Plutonium?

Plutonium only comes from reactors. It is not a naturally occurring element. LWR refers to light water reactors, the commonest kind of commercial nuclear reactor.

> For LWR spent fuel …., the spent fuel consists of about 93.4% uranium (~0.8% U-235), 5.2% fission products, 1.2% plutonium (12 kg or 1.5 weapon equivalents per ton of fuel), and 0.2% minor transuranic elements (neptunium, americium, and curium).[3]

What went into the reactor?	5% U-235	Weakly radioactive.
	95% U-238.	Weakly radioactive.
What comes out of the reactor?	0.8% U-235	Weakly radioactive.
	92.6% U-238	Weakly radioactive.
	1.2% Plutonium	Weakly radioactive.
	5.2% fission products	Highly radioactive!
	0.2% minor transuranic elements	So-so radioactive.

As we have observed, the intense radioactivity of the SNF is a serious environmental issue. But right now we are interested in the Pu in the spent fuel.

An ordinary commercial electricity-producing nuclear reactor uses about 30 tons of fuel/year.[4] So if enough Pu to make 1.5 nuclear weapons is produced from one ton of fuel, then each reactor is producing enough Pu to make about 45 nuclear weapons every year.

What is Pu used for? Well it can be used for nuclear weapons or to make mixed oxide (MOX) reactor fuel. Reactor operators in the US do not want MOX fuel and reprocessing spent fuel to extract the Pu is prohibitively expensive. Fortunately the intense radioactivity of the SNF makes the Pu in the SNF pretty inaccessible, so a good idea is to just leave the Pu in the spent fuel.

4. Reprocessing

Reprocessing is robotically separating the stuff in the SNF. Production reactors are smaller than commercial electricity-producing reactors and are designed to produce Pu for nuclear weapons. The spent fuel from production reactors is reprocessed and the Pu is used for nuclear weapons.

Sometimes SNF from commercial electricity-producing reactors is reprocessed. France, UK, Russia, Japan, and India reprocess SNF from civilian reactors. The US does not. In all those cases, the Pu is used to create a special type of reactor fuel called Mixed-Oxide Fuel (MOX).

The Nuclear Fuel Cycle from the World Nuclear Association outlines the complex steps required to make and reuse reactor fuel.[5] The Union of Concerned Scientists, a very reputable NGO, warns that reprocessing spent fuel leads to nuclear weapons proliferation, possible nuclear terrorism, and is unreasonably expensive as well as environmentally damaging by creating millions of gallons of highly radioactive acid, a new waste issue.[6]

The Belfer Center for Science and International Affairs at Harvard University has an excellent article on the economics of reprocessing spent fuel.[7] In this article they conclude that reprocessing spent fuel does not make sense economically. Although those favoring nuclear power claim that reprocessing is like recycling, about the only similarity is that both words begin with the letter "r."

5. Plutonium Weapons

The first-ever nuclear explosion was a US plutonium bomb, affectionately nicknamed Gadget, in Almagordo, New Mexico, in 1945 in a nuclear weapons test called Trinity. Plutonium bombs are *implosion* devices which are a much trickier technology than gun-type weapons using HEU. Scientists were not really sure if this first bomb would work and also a little worried that it might set the atmosphere on fire.

The Federation of American Scientists (FAS) explains how implosion weapons work. They can be fueled with Pu or HEU. It takes about 9 pounds of plutonium to make a nuclear weapon.[8]

6. Mixed Oxide Fuel

Plutonium and uranium can make a reactor fuel called mixed oxide fuel (MOX). The US had been planning to make MOX fuel out of 30 tons of separated plutonium removed from dismantled weapons. The MOX fuel plant is way over budget and problematical at present. Duke Power tried to upgrade one of its Catawba reactors to run on MOX and had so many problems with the fuel that Duke withdrew from the DOE sponsored program. Recently the DOE has been trying to get the Tennessee Valley Authority (TVA) to use MOX in its Susquehanna reactor, but so far to no avail. The issue of making MOX fuel out of already separated Pu in the US is almost dead in the water.

Reprocessing spent fuel from commercial reactors to make more Pu accessible cannot even seem potentially sensible unless we figure out what to do with the 30 tons of excess weapons Pu we already have and do not know what to do with.

7. Vitrification

Nonproliferation experts do not like MOX fuel because it is not highly radioactive and separating the plutonium in it, or diverting plutonium in the process of making MOX, is a nuclear weapons proliferation risk. There is no compelling argument for separating out the plutonium from commercial spent nuclear fuel, but two hundred tons of separated plutonium already exist in the world. This separated plutonium needs to be secured by vitrification, making it into glass logs and burying it.

7. Parting Thoughts.

Because separated plutonium is a nuclear weapons proliferation risk, it would be better not to produce any new plutonium. If new plutonium is being produced, it would be better to leave it in the spent nuclear fuel, where the high radioactivity protects it. No new plutonium should be separated from spent fuel by reprocessing.

Questions

1. What is *reprocessing*?
2. Where does all plutonium come from?
3. Is plutonium highly radioactive?
4. Is MOX fuel highly radioactive?
5. How much available plutonium is in the world?
6. Why must available plutonium be carefully accounted for and guarded?
7. How much plutonium does it take to make a nuclear weapon?
8. Each commercial electricity-producing reactor makes enough plutonium in one year to make how many nuclear weapons?
9. All of the world's commercial reactors make enough plutonium in one year to make how many nuclear weapons?
10. Can nuclear weapons be made using spent nuclear fuel as their explosive?
11. What materials will explode with a nuclear fission reaction?
11. How does reprocessing spent fuel and making MOX out of the plutonium differ from ordinary "recycling"?

Footnotes

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Section 5. The Nonproliferation Treaty

"Atoms for Peace" was a US program designed to promote the peaceful use of nuclear fission for producing electricity. Initially Atoms for Peace pretty unconditionally supported other nations in their development of nuclear power. Then, worried about the connections between nuclear power and nuclear weapons, promoters of "peaceful nuclear technology" realized that countries who were receiving these technologies needed to agree not to use these nuclear technologies for nuclear weapons. The Non-Proliferation Treaty was to be that agreement needed to prevent the spread (proliferation) of nuclear weapons to more than the five "have" nations already possessing nuclear weapons.

1. Who?

In 2012, all nations except 4 belong to the Non-Proliferation Treaty. The four that don't belong include three countries that never signed on, India, Pakistan, and Israel. One country joined and then withdrew, North Korea.

2. What?

Under the NPT the five legal nuclear weapons states (NWS), US, Russia, UK, France, and China, agree to share peaceful nuclear technology with other states joining the treaty. These five NWS states also promise to work on reducing their arsenals in the famous Article VI.

All the rest of the countries agree not to develop nuclear weapons and be permanent non-nuclear weapons states (NNWS).

The actual UN Treaty on the Non-Proliferations of Nuclear Weapons, commonly called the Non-Proliferation Treaty (NPT) treaty is short. Download and read it.
http://www.un.org/en/conf/npt/2010/npttext.shtml

The Arms Control Association has a nice article, "The Nuclear Nonproliferation Treaty: History and Current Problems," providing more information.[1]
http://www.armscontrol.org/act/2003_12/Bunn

3. When?

In 1968, the NPT was available for joining and by 1970, 43 nations had ratified the treaty which went into force that year.

4. Where?

NPT applies to Planet Earth.

5. Why?

Explosions of nuclear weapons by Russia, UK, and then France followed the US nuclear weapons explosions in 1945. In 1964 China, a pretty primitive country, exploded a nuclear weapon demonstrating that even an unindustrialized nation could develop the nuclear weapons. The world became concerned that nuclear weapons would spread (proliferate) to many countries.

6. The International Atomic Energy Agency (IAEA)

President Eisenhower, in his "Atoms for Peace" speech, given in 1953, sought to relieve the world's worries about the growing US atomic arsenal by suggesting that atomic energy was a force for good that could be shared with the world. [2]

The IAEA was set up in 1957 as part of Eisenhower's "Atoms for Peace" program. The Atoms-for-Peace goal of the IAEA is to "promote safe, secure and peaceful nuclear technologies." When the NPT went into force, the IAEA became the agency charged with preventing the proliferation of nuclear weapons that might ensue from promoting nuclear energy.

In 1974 India confirmed for the world that spreading nuclear energy can spread nuclear weapons. In that year, India exploded a "peaceful nuclear explosive" (PNE), commonly called Smiling Buddha, made out of Pu obtained by reprocessing spent fuel from a reactor that the US and Canada had provided. The IAEA helped by setting up an atomic energy center in India to train Indian scientists in nuclear technology. Smiling Buddha was an implosion device, the trickier bomb technology.

7. The Additional Protocol

The ability of the IAEA to detect nuclear weapons programs has been hampered by the need to obtain permission from the country to be inspected and give warning of upcoming inspections. After the first Gulf War, in April 1991, UN Security Council Resolution 687 set up the UN Special Committee (UNSCOM) to eliminate Iraqi Weapons of Mass Destruction (WMD) and ballistic missiles with a range greater than 150 km. UNSCOM discovered that Iraq was well on the way to making nuclear weapons despite the fact that Iraq was an NPT member state and had been subject to IAEA inspections, demonstrating that the IAEA inspection abilities were not sufficient.

UNSCOM destroyed the Iraqi nuclear, and biological, weapons facilities, which were never rebuilt. CIA operatives, originally hired by UNSCOM to interpret U-2 photographs, used UNSCOM to set up information-gathering covert devices in Iraq, ultimately causing Iraq to expel UNSCOM. UNSCOM was replaced by a new commission, the UN Monitoring, Verification, and Inspection Commission (UNMOVIC) established by UN Security Council Resolution 1284 in December 1999.

In 2003, the US warned UNMOVIC inspectors to leave the Iraq and invaded Iraq allegedly to eliminate the Iraqi WMD threat. The US found Iraq without WMD but the Iraq War has been long and expensive both in human casualties and money. Joseph Stiglitz, winner of the 2001 Nobel Prize in Economics, and Linda Bilmes of Harvard University published a book about the Iraq invasion in 2008 called *The Three Trillion Dollar War*.

IAEA *safeguards* are the measures which the IAEA uses to prevent the spread of nuclear weapons including inspections with warning in places allowed by the country being inspected. In the case of Iraq, UNSCOM inspectors discovered after 1991 that these safeguards had not worked. In response, the IAEA developed a system allowing surprise inspections anywhere, called the "Additional Protocol."

How well received has the Additional Protocol been? As of November 2013, the additional protocol was in force for 122 out of 145 IAEA member nations. Pretty good. However it is not in force in Iran.[3]
http://armscontrolcenter.org/policy/nonproliferation/articles/iaea_additional_protocol/

8. Key Idea.

The NPT institutionalizes the double standard of nuclear weapon "have" and "have-not" nations. Eventually this distinction will no doubt vanish in a world of all "have" or all "have-not" nations.

9. Parting Thoughts

The Non-Proliferation Treaty has done a pretty good job of keeping nuclear weapons from spreading beyond the first five nuclear powers. Three nations did not sign the treaty and did develop nuclear weapons, Israel, India, and Pakistan. North Korea signed the treaty but withdrew from it and also developed nuclear weapons. The world is concerned that Iran may withdraw from the NPT and produce nuclear weapons once it has perfected its enrichment skills.

The original inspection abilities of the IAEA were hampered by national interests as was demonstrated by Iraq's nuclear weapons program before the first Gulf war. The Additional Protocol gives IAEA inspectors freedom to inspect more effectively.

10. Questions for You

1. Why was the NPT needed?
2. How is the NPT enforced?
3. Does the NPT contain any arms limits?
4. Why are so many countries willing to not have nuclear weapons?
5. What benefits came to countries willing to become NNWS?
6. The US has agreed to share peaceful nuclear teachnology with which country that doesn't belong to the NPT?
7. Does the NPT allow enrichment by NNWS?
8. Does the NPT allow reprocessing by NNWS?
9. What important countries have not signed and ratified the Additional Protocol?
10. Why is the Additional Protocol important?
11. What countries never joined the NPT?

12. What country joined and then withdrew from the NPT?
13. “Break Out” refers to the idea of a country in the NPT taking advantage of developing an ability to enrich or reprocess while a member and then withdrawing from the treaty and going on to develop nuclear weapons. Which country seems most likely to “break out” of the NPT?

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http://www.iaea.org/About/atomsforpeace_speech.html

3. Safeguards and verification. IAEA.org. 22 Nov 2013. (Cited 21 Dec 2013)
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Section 6. Effects of Nuclear Weapons

We remain sane by not thinking about the effects of nuclear weapons and the number of nuclear weapons on our planet. To get to a sustainable planet, we need to face these ugly facts and change them.

1. Measuring Nuclear Weapons

The explosive power of a nuclear weapon is measured in kilotons (KT) or megatons (MT). A kiloton explosive has the same blast effects as 1000 tons of dynamite. To put that in perspective, V-2 rockets in World War II carried a payload of less than 1 ton of dynamite. The HEU atomic bomb that destroyed Hiroshima was about 15 kt. The biggest nuclear weapons ever exploded was the USSR's Tsar Bomba with a yield of more than 50 MT = 50,000 KT.

2. A Single Weapon - The New York City Example

Atomic Archives has posted a tutorial on what would happen if a 150-kt nuclear weapon were exploded at the foot of the Empire State building. A 150-kt weapon is more akin to a weapon in the present-day arsenals of the nuclear weapons states than to a terrorist weapon. A terrorist weapon would be smaller than 150 kt. So when you are looking at these effects you should be perhaps envisioning accidental nuclear war, a possibility with so many nuclear weapons on a high-alert status, able to be fired in minutes.

http://www.atomicarchive.com/Example/Example1.shtml

Other important effects are not mentioned on this website. The economic costs are pretty unimaginable: Medical care, firefighting, evacuations, restoring water and electricity, cleanup, decontamination, reconstruction, reparations, relocations, lose of business revenue, etc. What about the stock market? The world economy? War? Loss of civil liberties? End of the Republic? [1]

2. Catastrophic Human Consequences of Nuclear Weapons

The Nobel-Prize winning International Physicians for the Prevention of Nuclear War (IPPNW) released a report on December 10, 2013 in which they estimate that two **billion** people, a quarter of the world's population, would be at risk of starvation in the event of a limited nuclear exchange of 100 warheads, such as could occur if India and Pakistan used only half of their arsenals. [2]

The IPPNW studies conclude that if the arsenals of the US and Russia were exploded, human civilization would certainly end and possibly human beings would become extinct. Another independent presentation of this scenario can be found on the International Network of Engineers and Scientists Against Proliferation (INESAP) website in the article titled "Catastrophic Climate Consequences of Nuclear Conflict."[3]

The IPPNW has a thoughtful and persuasive video about the catastrophic human consequences of nuclear war. Everyone should watch and listen and remember. http://www.youtube.com/watch?v=Ug-DJtvHFE0&feature=youtu.be

3. Key Idea.

Nuclear weapons are too destructive to be useful for anything.

4. Parting Thoughts

A sort of critical mass of believers is needed to achieve a world without nuclear weapons. If that ultimate goal is not credible for you, having a goal of constantly decreasing the number of nuclear weapons on the planet will do. In the past, both Russia and the US each had about 15,000 strategic warheads. Now these two nuclear weapons powerhouses are down to about 1500 strategic warheads each! Visualize 150 each, then 15, with the other nuclear weapons states following suit.

5. Questions for You

1. What will a shock wave of 20 psi do to buildings and people?
2. What will a shock wave of 10 psi do to buidings and people?
3. In the NYC example, 1.5 miles from the blast anyone in the direct line of sight will be killed instantly by what?
4. In the NYC example, half of the buildings that do not collapse will be destroyed by what?
5. How does flying glass produced as the overpressures blow out windows affect people?
6. In NYC, where would you be relatively safe from the first effects of a nuclear explosion?
7. If you weren't vaporized, would your burns be more severe if your clothing was light or dark?
8. Will firefighters be on the job putting out fires?
9. Flashblindness and retinal injuries to those with a clear view of the explosion extend out 20 miles. Would there be more of these with a ground burst or an air burst?
10. A ground burst causes more early fallout and radiation sickness because the explosion makes radioactive particles out of dirt, streets, buildings, where it explodes. Is a terrorist weapon likely to be an airburst or a ground burst?
11. Will travel by vehicle be possible?
12. Will medical help be available?
13. Will electricity be available?
14. Will cell-phones work?
15. Will restaurants be open?
16. Will food be readily available?

17. What can people do to protect themselves from radioactive fallout?
18. Will the stock market go up or down?
19. How do the deaths compare to the 3000 killed in the collapse of the World Trade Centers?
20. If 100 nuclear weapons are exploded in major cities, the climatic consequences will affect agriculture dramatically and perhaps two __________ people will die of hunger.

Footnotes

1. Nuclear terrorism: local effects, global consequences. The Saga Foundation. 2005 (Cited 12 Dec 2013) http://www.sagafoundation.org

2. New report from IPPNW: two billion at risk from nuclear famine. International Physicians for the Prevention of Nuclear War. 10 Dec 2013. (Cited 12 Dec 2013) http://peaceandhealthblog.com/2013/12/10/nuclear-famine-two/

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Section 7. Nuclear Arsenals

President Obama received the Nobel Peace Prize in 2009 for espousing a world without nuclear weapons. Other famous people have pointed to this goal of a world without nuclear weapons including Mikhail Gorbachev, George Schultz, Bill Perry, Sam Nunn, and Henry Kissinger. The last four first published their opinion in a Wall Street Journal editorial in 2007, have consistently repeated the vision in the WSJ, and have established the Nuclear Security Project to support it.[1]

How far are we, or aren't we, toward that vision?

1. Global Nuclear Weapons Inventory 2013[2]

Country	Deployed Strategic	Non-Strategic	Non-Deployed Warheads	Total Inventory	Growth Trends
USA (2013)	1,950	200	2,650 (+3,000 awaiting dismantlement)	7,700	Decrease
Russia (2013)	1,800	0	2,700 (Est.) (+4,000 awaiting dismantlement)	8,500	Decrease
UK (2011)	<160	-	65	225	Decrease
France (2011-2012)	<300	50	-	298-300	Slight Decrease
China (2013)	-	-	240-300	300	Growing
India (2013)	-	-	80-100	80-100	Steady
Pakistan (2013)	-	-	90-110	90-110	Steady
Israel (2013)	-	-	80	80 (200)	Growing
North Korea (2013)	-	-	<10	<10	Growing
Total Nuclear Weapons in the World: 17,325					

2. New START Treaty

This bilateral treaty between the US and Russia entered into force on February 5, 2011. It limits strategic warheads to 1550 each and limits delivery systems also. *Strategic* nuclear weapons are long-range weapons that can be *delivered* to other nations. The verification and transparency regime includes on-site inspections, data exchanges, and national technical means for treaty monitoring. In addition, the treaty provides for an annual exchange of telemetry on an agreed number of ICBM and SLBM launches.[3]

At the height of the arms race, the US and the USSR had about 15,000 deployed strategic nuclear warheads each. The New START Treaty allows about 10% of the old peak. Real progress

3. How are the nuclear weapons deployed?

US and Russia: land based intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missile (SLBMs) and bombers that can drop gravity bombs or air-launched cruise missiles.

France: SLBMs on 4 nuclear submarines.

UK: SLBMs on 4 nuclear submarines.

China: 20 long-range ICBMs, new alleged SLBM ability[4], and bombers.
Israel: Medium-range ballistic missiles (MRBMs)[5], 5 German Dolphin-class diesel powered "nuclear capable" submarines[6], and bombers.

Pakistan: MRBMs and bombers.

India: ICBMs, SLBMs soon, and bombers.

North Korea: Working on ICBMs.

4. Questions for You

1. Which two countries each have as many nuclear weapons as all of the other NWS combined?
2. Which countries have, or soon will have SLBMs?
3. Which countries have ICBMs?
4. Which countries have more than 10 but less than 1000 nuclear weapons?
5. Which country has less than 10 nuclear weapons?

Footnotes

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2. Fact sheet: Global Nuclear Weapons Inventories in 2013. The Center for Arms Control and Non-Proliferation. July 2013. (Cited 12 Dec 2013) http://armscontrolcenter.org/issues/nuclearweapons/articles/fact_sheet_global_nuclear_weapons_inventories_in_2012/

3. New START. US Department of State. (Cited 15 Dec 2013) http://www.state.gov/t/avc/newstart/index.htm

4. Yu M. Inside China: Nuclear submarines capable of widespread attack on US. 31 Oct 2013. The Washington Times. (Cited 15 Dec 2013) http://www.washingtontimes.com/news/2013/oct/31/inside-china-nuclear-submarines-capable-of-widespr/?page=all

5. Missile. Israel. Country Profiles. Nuclear Threat Initiative. Feb 2013. (Cited 15 Dec 2013) http://www.nti.org/country-profiles/israel/delivery-systems/

6. Israel gets fifth 'nuclear-capable sub.' RT. 30 April 2013. (Cited 15 Dec 2013) http://rt.com/news/israel-dolphin-submarine-nuclear-598/

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Section 8. Nuclear Terrorism

Nuclear weapons can be made of plutonium or HEU and the world has large stockpiles of both, sometimes not highly secured. It is possible that terrorists could acquire Pu or HEU and build a nuclear weapon. Theft of intact non-strategic nuclear weapons is also possible. A less likely possibility would be terrorists causing the launch of a NWS's strategic weapons through misinformation, insider ability, or cyber war.

1. Nuclear Terrorism: The Ultimate Preventable Catastrophe.

Graham Allison is a widely accepted expert on the subject of nuclear terrorism. This website is part of the Belfer Center for Science and International Studies at Harvard University. It is an authoritative website. Check it out. http://www.nuclearterror.org/ Read Graham Allison's bio.

Try out the blast maps. Compare to the New York City example posted on Atomic Archives: http://www.atomicarchive.com/Example/Example1.shtml
The New York City example is describing a 150-kiloton explosion and Allison's is a more realistic 10-kiloton explosion.

Well, actually that is not all the bad stuff. The economic costs are pretty unimaginable: Medical care, firefighting, evacuations, restoring water and electricity, cleanup, decontamination, reconstruction, reparations, relocations, lose of revenue, what about the stock market? War? Loss of civil liberties? End of the Republic?

Another serious possibility is not presented on the website which is the possibility of a terrorist attack of a nuclear power reactor with a single nuclear weapon. Terrorists would not have to penetrate the security of the nuclear power plant. A small nuclear weapon exploded outside the facility would do the trick. Bennett Ramberg's book, *Nuclear Power Plants as Weapons for the Enemy*, effectively recounts the dangers.

An attack on a spent fuel storage pool of a commercial reactor would not even require a nuclear weapon. If the water drains out of the pool and the spent fuel rods become exposed to the atmosphere, an uncontrollable fire will put much more radioactivity airborne than happened in Chernobyl. "One estimate is that if a fire broke out at a Connecticut storage site, 29,000 square miles, including NYC and Long Island, might become uninhabitable.[30]" [1]

Print out Graham Allison's FAQs. These are the basics ideas of Allison's book and are not controversial.

2. How Can Nuclear Terrorism Be Prevented?

Robert Gallucci recently put forth the answer below. Robert Gallucci is the president of the MacArthur Foundation and a man who is qualified to speak authoritatively on the subject.[1]

> There is clear evidence that terrorist organizations, such as al-Qaeda, are interested in acquiring and using nuclear weapons. They seek to inflict maximum damage with an economy of means; nothing can accomplish this end more effectively and with more certainty than a nuclear weapon.
>
> We have no reason to believe that a traditional defense against this threat will be effective. We cannot expect to prevent access to our territory, and we cannot expect to deter a terrorist who values our death more than his life.
>
> The danger is not only to the United States or Western Europe, as terror attacks in Moscow, Mumbai and Bali demonstrate. Any nation that faces a threat from terrorism should be concerned.
>
> To prevent such a disastrous attack from happening, we must focus on fissile material—highly enriched uranium and plutonium -- because getting it is the most difficult step in any plan to attack an American city with a nuclear weapon. Once a reasonably sophisticated terrorist group has obtained fissile material, building the weapon and sneaking it into the United States are not major obstacles.
>
> The challenge for the United States is that only a very small amount of fissile material—think of a baseball—is required for a bomb. There are a couple thousand tons of fissile material spread out over 32 countries, stockpiled mostly in nuclear weapons and nuclear energy programs.
>
> National leaders need to acknowledge this as a shared problem. Nations with nuclear material—whether military or civilian—must secure and eliminate stocks of highly enriched uranium and plutonium.
>
> In addition, we should follow some simple advice: when you find yourself in a hole, first, stop digging.
>
> The United States should forswear the production of fissile material, now or in the future, and urge other countries to follow our example. A fissile materials production ban would mean no more separation of plutonium from spent fuel and no more enrichment of uranium to high levels. It would entail ending our reliance on fissile materials for any purpose. There is no need to reprocess spent fuel for radioactive waste management or to fuel the current generation of nuclear power reactors. Unless a nation was planning to produce

more nuclear weapons - Pakistan and India come to mind—this policy would pose no hardship. If an immediate ban is not politically possible, we should seek a moratorium.

The threat of nuclear terror is not just possible, it is quite plausible; if effective action is not taken, over time, it is probable.[2]

3. Local Effects, Global Consequences

Visit http://www.sagafoundation.org/ . You can find the executive summary and the whole article "Nuclear Terrorism: Local Effects, Global Consequences" detailing the bigger picture of a single terrorist nuclear weapon explosion.

4. Parting Thoughts

The actions needed to prevent nuclear terrorism are challenging. Securing nuclear materials is very complex. Securing nuclear weapons is similarly difficult. In the very long run, a sustainable world will not produce highly enriched uranium or plutonium and will have eliminated its nuclear weapons, its separated plutonium, and its highly enriched uranium.

Footnotes

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Questions:

All of Graham Allison's FAQs.

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Section 9. Securing Fissile Materials

We now understand that both HEU and plutonium can be used to make nuclear weapons. Unfortunately there are hundreds of tons of each on our planet. Ideally it all needs to be eliminated and no more made. In the short run, it needs to be secured.

1. How much fissile material is there and who has it?

HEU and Pu are the fissile materials that could be made into nuclear weapons. As you know, HEU comes from enriching mined uranium and Pu comes from reprocessing SNF. Making either type of fissile material requires massive infrastructure (except for laser enrichment perhaps) so non-state actors probably can't make fissile materials. Thus keeping the existing fissile materials well guarded and accounted for is imperative.

As of January 2013, the global stockpile of highly enriched uranium (HEU) is estimated to be about 1390 tonnes. The global stockpile of separated plutonium is about 490 tonnes, of which about 260 tonnes is the material in civilian custody.

	HEU, tonnes	Non-civilian Pu, tonnes	Civilian Pu, tonnes
Russia	695	128	50.1
United States	604	87.0	0
France	31	6	57.5
China	16	1.8	0.014
United Kingdom	21.2	3.5	91.2
Pakistan	3	0.15	0
India	0.8	5.2	0.24
Israel	0.3	0.84	-
North Korea	0	0.03	-
Others	15	-	61
TOTAL	**1390**	**234**	**260**

Production of military fissile materials continues in India, which is producing plutonium and HEU for naval propulsion, Pakistan, which produces plutonium and HEU for weapons, Israel, which is believed to produce plutonium. North Korea has the capability to produce weapon-grade plutonium and highly-enriched uranium.

France, Russia, the United Kingdom, Japan, and India operate civilian reprocessing facilities that separate plutonium from spent fuel of power reactors. China is operating a pilot civilian reprocessing facility.

Twelve countries - Russia, the United States, France, the United Kingdom, Germany, the Netherlands (all three are in the URENCO consortium), Japan, Argentina, Brazil, India, Pakistan, and Iran - operate uranium enrichment facilities. North Korea is also believed to have an operational uranium enrichment plant.[1]

2. How much SNF containing Pu is there and who has it?

As of the end of 2009, about 240,000 metric tons (as heavy metal) of spent fuel were in storage worldwide, most of it at reactor sites. About 90% was in storage ponds; the balance was in dry-cask storage. The annual spent fuel generated is approximately 10,500 tons of heavy metal per year.[2]

Spent fuel inventories in cooling ponds and dry-cask storage at the end of 2007 for the 10 countries in the present study.[2]

Country	Spent Fuel (tons) 2007	Spent Fuel Disposal Policy
Canada	37,300	Direct disposal
Finland	1,600	Direct disposal
France	13,500	Reprocessing
Germany	5,850	Direct Disposal (now)
Japan	19,000	Reprocessing
South Korea	10,900	Storage, undecided
Sweden	5,400	Direct disposal
United Kingdom	5,850	Reprocessing (now)
United States	61,000	Direct Disposal

The U.S. has by far the largest holding of spent fuel. As of the end of 2010, the total U.S. stockpile of spent power-reactor fuel was 64,500 tons, including 15,350 tons in dry casks.[2]

The International Panel on Fissile Materials has lots of information on their website including a Global Fissile Material Report 2011. Read it.
http://www.fissilematerials.org/blog/2012/01/ipfm_releases_global_fiss_1.html

3. Excess HEU can easily be downblended.

One of the happy points in the problem of securing fissile materials is that it is pretty easy to dispose of excess HEU. Why would you have excess HEU? Well, one place a lot of HEU has come from is from the dismantling of US and Russian nuclear weapons as the arsenals decreased from 15,000 to 1500 warheads.

The HEU can be mixed with depleted uranium (DU) and made into LEU and used for reactor fuel. One program that has successfully done a lot of this *downblending* as it is called is the Megatons to Megawatts program. Interestingly, a private corporation, US

Enrichment Corporation (USEC) does the downblending and has eliminated the HEU from 20,000 warheads in this fashion! [3]

4. It is harder to eliminate excess separated Pu.

If Pu is left in the SNF, it is pretty secure because of the deadly radioactivity of the SNF. Pu in SNF is not accessible. However if the Pu has been extracted from the SNF by reprocessing, the Pu is now accessible and must be kept very securely. Pu has a half-life of 25,000 years and is only weakly radioactive, so it can be handled by people, stolen, transported, and fashioned into weapons.

Pu and HEU are both only weakly radioactive and fissile, which makes them both especially dangerous. Humans can work with these materials and build nuclear weapons using Pu or HEU for explosive power. Separated Pu which has been incorporated into MOX fuel is also a weapons proliferation risk. **Humans can handle MOX fuel and retrieving the Pu from weakly radioactive MOX is a simple matter**, unlike reprocessing the Pu out of the highly radioactive SNF.

The global stockpile of separated Pu is about 500 tons. Since it only takes about 9 lbs of Pu to make a nuclear weapon, having 500 tons around is a problem. What can be done to eliminate the separated Pu?

There are basically two options. The nonproliferation community generally prefers the *vitrify and bury* option. Basically separated Pu would be mixed with ground up spent fuel to make it dangerously radioactive again and mixed into a liquid glass. The glass would solidify into highly radioactive glass logs which would be buried somewhere. [4]

The other option is to make the separated Pu into MOX fuel and use it in nuclear reactors to generate electricity. Russia and the US originally agreed to a "Dual Track Program" to eliminate about 34 tons each of excess weapons Pu. The dual tracks were to be vitrifying some of it and making some of it into MOX.

Very serious cost overruns combined with an inability to find utilities that would be willing to use the MOX fuel have put this project on hold. [5]

5. The Fissile Material Cut-Off Treaty (FMCT)

With about 2000 tons of fissile material already in the world, many people and nations favor an international Fissile Material Cut-Off Treaty. Such a treaty would forbid enriching HEU for weapons and reprocessing Pu for weapons. This should raise two questions in your mind. What other reasons are there for making HEU and reprocessing Pu? Who wants to make HEU or reprocess Pu for weapons anyway?

HEU is used as reactor fuel powering nuclear submarines, as fuel in Russian icebreakers, and as fuel in *research* reactors and *medical-isotope-producing* reactors.

Research reactors are in universities and laboratories and, as the name implies, used for nuclear research. The sources of radiation in medical radiation treatments for cancer are called medical isotopes. Medical isotopes are produced in small nuclear reactors. According to the International Panel on Fissile Material, there were more than 100 small reactors worldwide using HEU as reactor fuel in 2009, almost all of which could be converted to use LEU as fuel instead. That count doesn't include submarine or icebreaker reactors. New technology enables the use of LEU fuel for these 100 small reactors, but the conversion process is expensive and owners are often not willing to incur the costs.[6]

Plutonium is reprocessed to make MOX fuel for commercial nuclear reactors producing electricity in France, UK, Russia, Japan, and India.

Currently Pakistan is the only nation blocking a Fissile Material Cutoff Treaty (FMCT) proposal from the Conference in Disarmament (CD) in the UN, which operates on a consensus basis with its 65 member states. Pakistan argues that forbidding the production of fissile materials by Pakistan without ensuring the destruction of existing stockpiles of fissile materials by other nations puts Pakistan at a disadvantage.[7]

6. Key Idea

HEU and Pu are very dangerous nuclear explosives. Better to eliminate them and not make any more.

7. Parting Thoughts

We now understand that both HEU and plutonium can be used to make nuclear weapons. Unfortunately there are hundreds of tons of each on our planet. Ideally it all needs to be eliminated and no more made. In the short run, it needs to be secured.

To accomplish these objectives, and the others in this study guide, education is needed. The problems need to be understood before the political will can be generated to solve them.

8. Questions for You

1. How much HEU is in the world?
2. How much HEU is needed to make an atomic bomb?
3. Is HEU highly radioactive?
4. Could a would-be terrorist steal small amounts of HEU without a risk of high-level radioactivity?
5. How much Pu is in the world?
6. How much Pu is needed to make an atomic bomb?
7. Is Pu hightly radioactive?
8. Could a would-be terrorist steak small amounts of Pu without a risk of high-level radioactivity?

9. To eliminate the international need for HEU, an alternative propulsion would need to be found for what two types of boats?
10. To eliminate the international need for HEU, what two types of reactors would need to be upgraded to run on LEU?
11. Why isn't LEU a weapons proliferation risk?
12. Which is easy to dispose of, HEU or Pu?
13. What is the preferred method of Pu disposal?
14. What is the risky method of Pu disposal?
15. What makes the risky method of Pu disposal risky?
16. Is the world supply of separated Pu increasing or decreasing?
17. Is the world supply of HEU increasing or decreasing?
18. What countries legally enrich?
19. What is the FMCT? Is it operational?
20. What country opposes the FMCT and why?

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Section 10. Radiation

Most naturally occurring elements are not very radioactive, but fission in nuclear reactors and nuclear weapons both produce a lot of highly radioactive elements. Radioactive isotopes from reactors are used in medical diagnosis and treatment, for food preservation, for insect sterilization, and in other beneficial ways. Radiation also causes cancer and even death and radioactive waste disposal presents a serious problem. So a basic understanding of radiation is important.

1. What Types of Radiation Are There?

The radiation one typically encounters is one of four types: alpha radiation, beta radiation, gamma radiation, and x radiation. Neutron radiation is also encountered in nuclear power plants and high-altitude flight and is emitted from some industrial radioactive sources.

- **Alpha Radiation** Alpha radiation is a heavy, very short-range particle and is actually an ejected helium nucleus. Some characteristics of alpha radiation are:
  - Most alpha radiation is not able to penetrate human skin.
  - Alpha-emitting materials can be harmful to humans if the materials are inhaled, swallowed, or absorbed through open wounds.
  - Alpha radiation travels only a short distance (a few inches) in air, but is not an external hazard.
  - Alpha radiation is not able to penetrate clothing.
  - Examples of some alpha emitters: radium, radon, uranium, thorium.
- **Beta Radiation** Beta radiation is a light, short-range particle and is actually an ejected electron. Some characteristics of beta radiation are:
  - Beta radiation may travel several feet in air and is moderately penetrating.
  - Beta radiation can penetrate human skin to the "germinal layer," where new skin cells are produced. If high levels of beta-emitting contaminants are allowed to remain on the skin for a prolonged period of time, they may cause skin injury.
  - Beta-emitting contaminants may be harmful if deposited internally.
  - Clothing provides some protection against beta radiation.
  - Examples of some pure beta emitters: strontium-90, carbon-14, tritium, and sulfur-35.
- **Gamma and X Radiation** Gamma radiation and x rays are highly penetrating electromagnetic radiation. Some characteristics of these radiations are:
  - Gamma radiation or x rays are able to travel many feet in air and many inches in human tissue. They readily penetrate most materials and are sometimes called "penetrating" radiation.
  - X rays are like gamma rays. X rays, too, are penetrating radiation. Sealed radioactive sources and machines that emit gamma radiation and x rays, respectively, constitute mainly an external hazard to humans.

Dense materials are needed for shielding from gamma radiation. Clothing provides little shielding from penetrating radiation, but will prevent contamination of the skin by gamma-emitting materials.

Gamma radiation and/or characteristic x rays frequently accompany the emission of alpha and beta radiation during radioactive decay.

Examples of some gamma emitters: iodine-131, cesium-137, cobalt-60, radium-226, and technetium-99m.

2. How Is Radiation Measured?

The International System of Units (SI) for radiation measurement is now the official system of measurement and uses the *sievert* (Sv) to measure the effect of radiation on humans. Smaller fractions of these measured quantities often have a prefix,

Milli (m) means 1/1,000. For example, 1 Sv = 1,000 mSv.

Micro (μ) means 1/1,000,000. So, 1 Sv = 1,000,000 μSv.[1]

The average background radiation dose for people living in the US is about 3.1 mSv/year. The Health Physics Society provides a lot of information about radioactivity on their website.[2]

Radioactive substances emit radioactivity whether or not people are around. The radioactivity of a material is usually measured in

- Becquerels (Bq) which is one radioactive decay per second. (Small)
- Curies (Ci) which is 37 billion radioactive decays per second. (Big) Named after the Curies (Marie and Pierre) this is the radioactivity of a gram of radium.
- Picocuries (pCi) which is 1 trillionth of a Curie or 0.037 radioactive decays per second or 0.037 Becquerels. (Very small)

3. Occupational Doses

There are approximately 800,000 nuclear industry workers worldwide, and more than two million workers in health care that are exposed to radiation. Most average doses are below 2 mSv/year with the exception of uranium mining with an average dose of 4.5 mSv/year and Uranium milling with an average annual dose of 3.3 mSv/year.[3]

In unusual circumstances, radiation doses may be higher. The article quoted below and published April 28, 2012 describes some of the radiation doses connected with the Fukushima reactor catastrophe in Japan.

Tokyo Electric Power Co. said Thursday that a total of 16 employees whose cumulative radiation doses have exceeded 100 mSv, a government-set limit, will continue to work at the crippled Fukushima No. 1 nuclear power plant.

According to TEPCO, the 16 are engaged in equipment operation and radiation control and have advanced expertise and extensive experience at the nuclear plant crippled by the March 11 earthquake and tsunami last year.

Following the accident at the plant, the health ministry raised the cumulative dose limit to 250 mSv for workers there. But this measure will expire at the end of April. The cumulative limits revert back to 50 mSv per year and 100 mSv over a five-year period.

As the 16 people are vital for containing the plant's nuclear crisis, the company will keep them at work and take steps to reduce radiation levels at the quake-proof building used for its disaster response team, it said.[4]

4. High Dose Effects of Radiation

Here's what the Nuclear Regulatory Commission (NRC) says

Because radiation affects different people in different ways, it is not possible to indicate what dose is needed to be fatal. However, it is believed that 50% of a population would die within thirty days after receiving a dose of between 3500 to 5000 mSv to the whole body, over a period ranging from a few minutes to a few hours. This would vary depending on the health of the individuals before the exposure and the medical care received after the exposure. These doses expose the whole body to radiation in a very short period of time (minutes to hours). Similar exposure of only parts of the body will likely lead to more localized effects, such as skin burns.[5]

5. Radiation at Fukushima, two and a half years after the accident

On Wednesday the country's nuclear regulation authority said radiation readings near water storage tanks at the Fukushima Daiichi nuclear power plant have increased to a new high, with emissions above the ground near one group of tanks were as high as 2,200 millisieverts [mSv] per hour – a rise of 20% from the previous high. [6]

6. Radiological Dispersion Devices (RDDs)

Terrorists unable to make or acquire a nuclear weapon might make a "dirty bomb," a weapon that scatters a lot of radioactive material using a chemical explosive. The table below is helpful in understanding the radioactivity risks of some highly radioactive materials.

Radioisotopes that Pose the Greatest Risk[7]

Reactor-made Isotope	Half-life	Radiation (curies/gram)
Co-60	5.3 years	1100
Ca-252	2.7 years	536
Ir-192	74 days	500
Sr-90	29 years	140
Cs-137	30 years	88
Pu-238	88 years	17
Am-241	433 years	3.4
Natural Isotope		
Ra-226	1600 years	1

A radiotherapy machine may have roughly 1000 Ci of a radioisotope such as cesium-137 or cobalt-60. This quantity of nuclear material can produce serious health effects with only a few minutes of exposure.

6. Parting Thoughts

This section has been an intentionally brief look at only a few aspects of radiation, providing a basic understanding of some of the most common measures of radiation. Ordinary radiation exposure for humans is about 3 mSv/year. Balancing that, at the acceptable high end of radiation exposure, we find a career limit of 1000 – 4000 mSV for astronauts. [7] Wikipedia has a fascinating list of civilian radiation accidents at http://en.wikipedia.org/wiki/List_of_civilian_radiation_accidents
many of which involve the impressively radioactive Co-60.

7. Questions for You

1. Translate the Sept 2013 reading of 2200 mSv/hr into mSv/year and compare to ordinary background radiation.
2. Radiation of 2000 mSv/hr would produce the potentially lethal 3500 – 5000 mSv in about how many hours?
3. Your skin protects you from alpha particles and your clothing protects you from beta particles, yet both of these types of ionizing radiation can be very dangerous to you. Explain how.
4. Curies and Becquerels measure the radioactivity of a substance. What measure are used to measure the effects of radiation on humans?

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Section 11. Ballistic Missile Defense

How is ballistic missile defense connected to our general interest in getting to a safer world through nuclear weapons nonproliferation and disarmament? Ballistic missile defense seems to make nuclear weapons nonproliferation and disarmament unnecessary, and nonproliferation and disarmament are the only real paths toward a safer world.

1. What is Ballistic Missile Defense (BMD)?

BMD is the policy of the United States to deploy as soon as is technologically possible an effective National Missile Defense system capable of defending the territory of the United States against limited ballistic missile attack (whether accidental, unauthorized, or deliberate) with funding subject to the annual authorization of appropriations and the annual appropriation of funds for National Missile Defense.
– National Missile DefenseAct of 1999 (Public Law 106-38)[1]

The history of ballistic missile defense is long and complicated. The various systems are remarkably diverse. Lots of information on the subject is available on the Internet with the Missile Defense Agency website given in footnote 1 a good place to start. Basically ballistic missile defense consists of defensive missiles designed to hit offensive missiles headed toward a nation. It is desirable to be able to intercept short-range, medium-range, and long-range missiles effectively. The defensive interceptors are often called anti-ballistic missiles (ABMs).

Problems with ballistic missile defense.

- Ballistic missile interceptors undermine deterrence by theoretically being able to prevent effective retaliation. Nuclear weapons allegedly deter would-be attackers by promising devastating retaliation. If a nation has BMD, it cannot be deterred.

- Ballistic missile interceptors have not been very successful even when programmed with the target missile's location. ICBMs are travelling 16,000 mph as they near their targets and they can maneuver and wiggle.

- A BMD system would involve very complicated system computer technology which can never be tested until it needs to work.

- ICBMs can deploy hundreds of decoys which are indistinguishable from the real warheads, compromising BMD.

- Offensive missiles are cheaper than interceptors, so a BMD system can be cost-effectively overwhelmed by a nation producing more offensive missiles.
- BMD does not protect against terrorist weapons that could be delivered by a boat, a small airplane, a van, or in a shipping container.
- BMD undermines disarmament with false promises of safety.
- BMD is very expensive and takes money away from foreign aid, education, environmental remediation, renewable energy, and other arenas that would actually make the world safer.
- BMD, especially if it leads to weapons in space, is decidedly hegemonic and unfriendly and sparks unfriendly responses in nations who are not staunch allies. Russia, in particular, is threated by US BMD. China is threatened by the possibility of weapons in space.

Americans in general support BMD because BMD appears to make us safer. The more BMD we have, the safer we will be, or so it seems. The military-industrial complex loves BMD! The need for interceptors is essentially infinite, hence unending highly paying jobs are available to those in the military-industrial complex. And BMD can be exported also!

2. What is the Military-Industrial Complex?

Originally called the Military-Industrial-Congressional complex, the expression refers to the cozy relationship between war planners furthering political interests abroad and defense contractors receiving lucrative deals. Militaryindustrialcomplex.com provides much information about both the military and the corporate involvement including an up-to-date Contracts Leaderboard.

Interestingly, President Eisenhower, the great military leader of the Allied invasion of Europe in WWII, warned about the growing influence of the Military Industrial Complex in two famous speeches. The first was his "Cross of Iron" speech from 1953.

> Every gun that is made, every warship launched, every rocket fired signifies, in the final sense, a theft from those who hunger and are not fed, those who are cold and are not clothed. This world in arms in not spending money alone. It is spending the sweat of its laborers, the genius of its scientists, the hopes of its children… This is not a way of life at all, in any true sense. Under the cloud of threatening war, it is humanity hanging from a cross of iron.[2]

Later, in his Farewell Address in 1961, President and General Eisenhower warned us again.

> In the councils of government, we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military-industrial complex. The potential for the disastrous rise of misplaced power exists and will persist. We must never let the weight of this combination endanger our liberties or democratic processes. We should take nothing for granted. Only an alert and knowledgeable citizenry can compel the proper meshing of the huge industrial and military machinery of defense with our peaceful methods and goals, so that security and liberty may prosper together.[3]

3. The ABM Treaty

In 1972 the US and the USSR ratified a bilateral Anti-Ballistic Missile Treaty agreeing to a maximum of 100 interceptors each and banning research on space-based interceptors. Both nations understood that anti-ballistic missiles undermine deterrence and could create a new offensive arms race in attempting to overwhelm defensive interceptors. In 2002 the US withdrew from this treaty in order to pursue space-based interceptor research and to have the ability to deploy more than 100 interceptors.

4. Key Idea

War is profitable for those involved in it. Ballistic missile defense is profitable to the military-industrial complex. Disarmament, arms control, and ballistic missile control are less profitable and thus lower-visibility in the public eye. Some call the military-industrial complex the military-media-industrial complex because of the media glorification of militarization, so the public is not generally well-informed.

5. Parting Thoughts

Education is needed to produce the "alert and knowledgeable citizenry" that will prevent the "acquisition of unwarranted influence" by the military-industrial complex.

6. Questions for You

1. Why did the US and the USSR agree to the ABM treaty?
2. What did the ABM treaty require?
3. Why did the US withdraw from the ABM treaty?
4. Which is more profitable, making weapons or disarming?
5. Which is more profitable, international agreements to control the production of ballistic missiles or BMD?
6. Give three reasons as to why BMD might not make the world safer.
7. Give three good ways to spend money making the world safer. Explain each.

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Section 12. Weapons in Space

On of the reasons for the US withdrawal from the Anti-Ballistic Missile treaty between the US and Russia in 2002 was to allow us to research and develop space weapons (weapons in low-earth orbit). According to the advocates of BMD, US space weapons would be purely defensive, able to strike ballistic missiles in their slow *boost phase* on their launch pad within their own country.

1. Space weapons would not be purely defensive.

Other nations do not welcome the idea of orbiting US weapons which could be used offensively as well as defensively. Put **Vision for 2020** into Google to see an old US Space Command official government document "Vision for 2020" describing US plans for dominating space. This document, which used to be prominently displayed on the home page of the US Space Command, has since been pushed inward on the website and finally archived.

In their "Vision for 2020" the Space Command made the goal of US control of space rather explicit. The Space Command became the Air Force Space Command and on page 35 of their "Strategic Master Plan FY06 and Beyond" the new AFSC writes equally clearly

> 6.1.5.2. *Conventional Strike*. Our vision calls for prompt global strike space systems with the capability to directly apply force from or through space against terrestrial targets. International treaties and laws do not prohibit the use or presence of conventional weapons in space.[1]

Ballistic Missile Defense, always popular with the public, may lead to the US deploying weapons in space.

2. Prevention of an Arms Race in Outer Space (PAROS)

PAROS is a group within the UN dedicated to the prevention of weapons in space. Outer space, in this issue, is not Mars and beyond. Outer space is low-earth orbit, where the communication satellites dwell.

Paul Meyer states the case for a UN treaty banning weapons in space in his article, "The Judgement of PAROS: How Best to Prevent an Arms Race in Outer Space." The abstract reads

The international community will soon need to judge as to what measures should be agreed to prevent an arms race in outer space. The world depends increasingly on services provided by space-based assets and recent anti-satellite weapon tests have raised the prospect of space becoming a weaponized conflict zone. Several diplomatic proposals have been made by Russia, China, Canada and the EU aimed at reinforcing the present regime for outer space security. The leading space power, the United States, has for several years remained on the sidelines, neither endorsing any of the existing proposals nor advancing ideas of its own. Domestic political considerations appear to be hampering the Obama Administration's capacity to engage actively in the current outer space diplomacy. Early in 2012 however, it declared support for an International Code of Conduct on Outer Space Activities based on an earlier EU draft. Such a draft, despite its modest security content, offers a promising array of mechanisms for international cooperation on outer space security at a time when the world depends increasingly on the unimpeded operation of some one thousand satellites.[2]

The Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force Against Outer Space Objects (PPWT) was first proposed by China and Russia in February 2008 as an international legally binding treaty that would outlaw the weaponization of space. [3]

The UN Office for Outer Space Affairs (UNOOSA) hosts the UN Committee on the Peaceful Uses of Outer Space (COPUOS).[4] A very complete history of UN documents related to preventing an arms race in outer space has as its last entry the draft resolution from Sri Lanka called "Prevention of an arms race in outer space, 12 Oct 2011.[5]

3. Space Debris

The UN has been working on keeping outer space peaceful since 1958. Among their many activities is keeping a registration of space objects. *Space debris* is a big problem as objects of space debris can collide with important satellites, potentially destroying the satellite and creating more space debris. Space debris is tracked and occasionally satellites have to adjust their positions to avoid space debris. Go to http://earthobservatory.nasa.gov/IOTD/view.php?id=40173 for a fascinating "look" at the problem of space debris.

The danger that space debris will interfere with commercial satellites is another good reason for keeping weapons out of space.

4. Anti-Satellite Weapons (ASATs)

Because space hosts so many valuable communication satellites, weather satellites, media satellites, military satellites, etc., it is important to keep this arena free from weapons. Weapons on satellites could be tracked and shot down by anti-satellite weapons (ASATs). But space debris would be created that would interfere with these other important satellites. Both the US and China have already demonstrated their ability to take down their own satellites using ASATs, both creating a lot of space debris in the process and earning international criticism.

5. Parting Thoughts

A US organization called the "High Frontier" advocates US control of space as a way of advancing our national interests. Perhaps better ways of advancing US national interest exist.

6. Questions for You

1. What countries put forth a treaty in 2008 banning weapons in space?
2. In what words does the US Space Command document "Vision for 2020" clearly articulate the US goal of controlling low earth orbit?
3. What subsequent US government document again explicitly stated the goal of weaponizing space and striking terrestrial targets from space?
4. What type of weapon could be used to eliminate weapons in space?
5. What countries have already demonstrated ASAT abilities?
6. Why are weapons in space popular with advocates of BMD?
7. What makes a weapon in space a poor choice for BMD?
8. How might US national interests might be advanced by not putting weapons in space?

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Section 13. Money Matters: Budgets and Subsidies

Many times I have learned the hard way "You get what you pay for." Apparently this belief is widespread. According to About.com, the Chinese have a similar saying: 一分钱一分货, "yi fen qian, yi fen huo" (pronounced ee fen chee-ahn, ee fen hoo-oh). This translates literally to one cent gives you one cent's worth of merchandise.[1]

In this section we look at the costs of many quite different things, just to get an idea of how costs compare.

1. Fossil Fuel Subsides - $523 billion/year

The International Energy Association estimates that fossil fuel subsidies reached $523 billion in 2011, up from $142 billion in 2010.[2] As I was writing this page earlier, I received by e-mail a letter from NC Senator Kay Hagan, dated May 18, 2012, saying that the US failed to repeal a bill granting $21 billion in subsidies to the five largest oil companies in the world. She said that those five oil companies had generated $137 billion in profits in 2011 and that "I do not believe American taypayers should be subsidizing a mature industry making record profits." The problem is worldwide and fossil fuel subsidies help the rich, not the poor, and definitely not the environment.

What do fossil fuel subsidies have to do with nuclear power and nuclear weapons? Renewable energy, the answer to the world's climate issues, needs a level playing field to compete. So either renewables need to receive proportionate subsides or these fossil fuel subsides need to be removed. Kay Hagan makes a persuasive case for the latter.

2. Nuclear Fuel Subsidies

New nuclear power plants in the US will receive tax-credits on energy generated and federally backed loans (making construction costs lower). In addition, the Price-Anderson Act makes the US government responsible for the costs of any catastrophe. The federal government has accepted the responsibility to store the high-level radioactive waste, the spent nuclear fuel, produced by the reactor.

Costs of Chernobyl are in the hundreds of billions of dollars according to the very conservative viewpoint of the IAEA.[3] Costs of Fukushima could total $257 billion.[4] Costs of nuclear power electricity never include these costs.

The question of nuclear power subsides is a murky one. A comparison for 2007 made by the Global Subsidies Institute of the International Institute for Sustainable Development breaks out preliminary international subsidies by type as follows: fossil fuels to non-OECD consumers, $400 billion; nuclear energy, $45 billion; renewable energy for electricity generation excluding hydroelectric power, $27 billion; and biofuels, $20 billion.[5]

3. Budget of the Department of Energy - $28 billion

For 2014 the DOE energy programs cost $11 billion. The DOE atomic energy defense activities total $18 billion! Much more than half of the DOE budget goes to our nuclear weapons program. The Department of Energy budget is small, only $28 billion, and more than 60% of the DOE budget goes to the US nuclear weapons program. [6]

4. Budget of the UN - $5 or $15 billion

The UN budget for 2014-2015 will be $5.5 billion.[7] According to the "Peacekeeping Fact Sheet," the value of UN peacekeeping forces is almost $10 billion.[8] So we can think of the total expenditures for the UN and UN peacekeeping as about $15 billion.

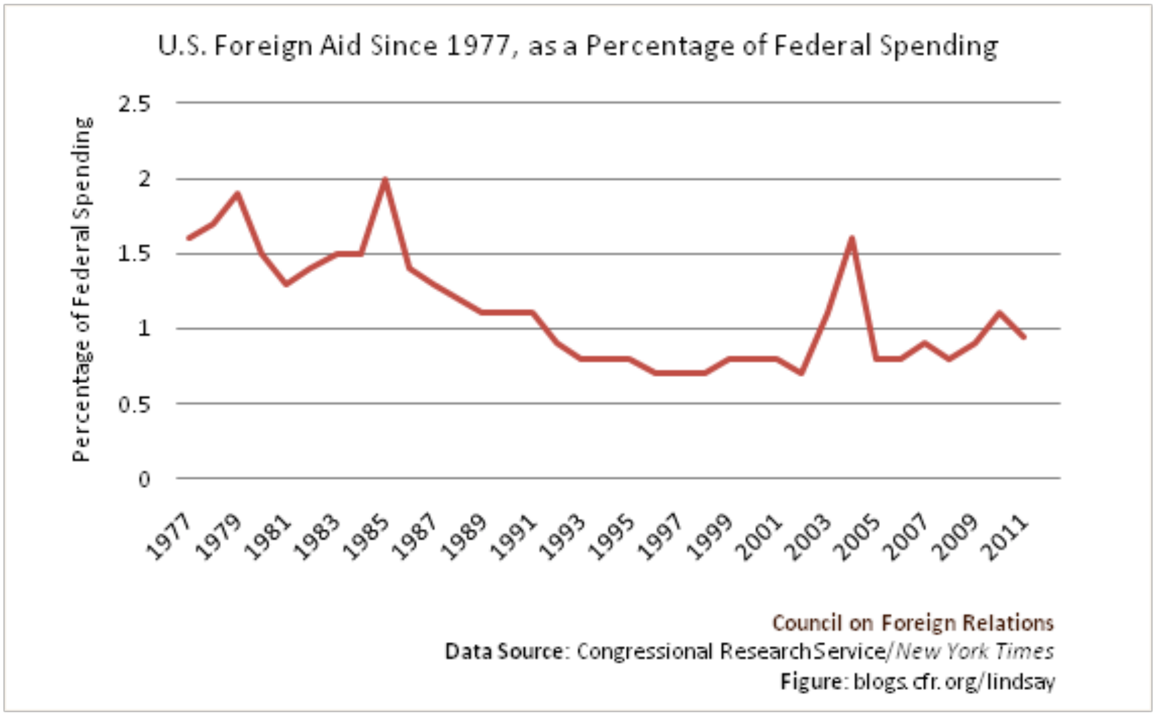
5. Budget of the International Atomic Energy Agency - < $ ½ billion

The total budget of the IAEA is $0.354 billion of which $0.031 billion goes to Nuclear Safety and Security, that is IAEA safeguard-related stuff. $350 million to the IAEA is a pretty small budget considering their many tasks and $31 million for watchdogging all enrichment and reprocessing facilities is a very small budget indeed![9]

6. Foreign Aid Spending - $60 billion

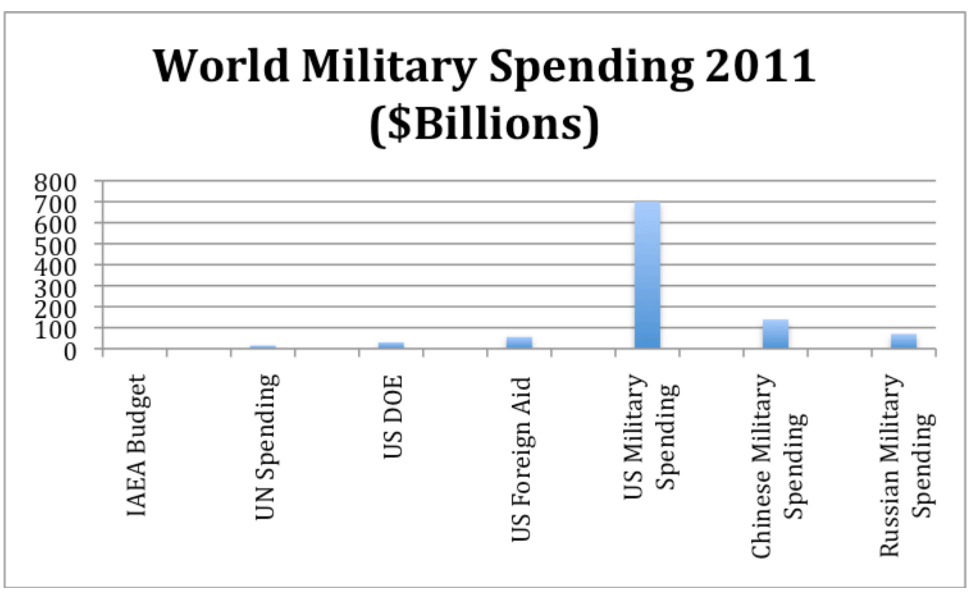
The fact that the world is anarchic and unequal is one of the reasons for military spending and puts the sustainability of the world in question. Anarchic would seem to require help from the rather lightly funded UN. Inequality might be helped if nations would meet their UN development aid goal of contributing 0.7% of GDP to international development aid.

For 2013, The US federal budget request for the State Department and USAID is $47.8 billion. US GDP is about $15.5 trillion, so US foreign aid spending is about 0.3% of GDP,[10] well under our 0.7% commitment. For lots of details about US foreign aid operations, visit www.foreignassistance.gov. The graph below gives foreign aid as a percent of federal spending, not as a percent of GDP.



7. World Military Spending - $1753 billion
US Military Spending - $700 billion

According to the Stockholm International Peace Research Institute (SIPRI), the authority on the subject, world military expenditures were about $1753 billion in 2012, with US military spending 39% of the world total followed by China at 9.5%, Russia at 5.2%, and UK, Japan, and France each at 3.5%. This puts the US at about $700 billion in 2012.[11]



8. Parting Thoughts

We are back to the need for an "alert and knowledgeable citizenry" to end the unwarranted influence of the military industrial complex. Spending more money on reducing poverty, enabling human rights, environmental remediation, education, renewable energy, and in other arenas that make the world less dangerous will work toward alleviating the spectre of nuclear disasters. Unrelenting military buildup on one small planet with growing population and diminishing resources is not a pretty prospect.

9. Questions for You

1. Give four ways the federal government subsidizes nuclear power.
2. Military spending for the planet is how many times the UN budget including peacekeeping?
3. How much money does the DOE spend annually on energy matters?
4. US military spending is how many times US energy spending?
5. US military spending is how many times Chinese (#2) military spending?
6. US military spending is how many times Russian (#3) military spending?
7. US military spending is how many times US foreign aid spending?

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