

The Market for Nuclear Weapons

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The market for nuclear weapons is shady and poorly understood by academics and policy-makers alike. Never-the-less, it is one of the most dangerous in the modern economic system. The insecurity of existing nuclear weapons-materials is the most dangerously unguarded route for terrorist acquisition of nuclear weapons. Those who do obtain fissile materials In the absence of aggressive international intervention, a black-market has emerged for coveted nuclear materials.

The market for nuclear weapons is not, however, a doomsday device against which we may have no hope. There exists a far-reaching literature spanning the social sciences describing deterrence and its potential applications to non-state actors. Moreover, there is extensive evidence that institutions can influence and even manipulate black markets. However, without at least a modest understanding of the relevant nuclear physics, any discussion of nuclear trades would be trite at best.

The next section describes, in brief, the technical details of nuclear weapons (i.e., components and construction). The following section will detail some of the history of illicit nuclear trades. The section following that will discuss some of the policy ramifications and the final section concludes.

How to Make a Bomb

There are two varieties of nuclear bombs: the *gun-type* and the *implosion-type*. The construction of a “gun type” nuclear bomb is relatively simple: it is a deposit of uranium 235 at the nose, a uranium 235 “bullet,” and a conventional explosive to propel the bullet. When the device is triggered, the bullet shoots down the length of the bomb and hits the uranium in the nose of the device. This collision initiates the nuclear fission reaction (Bunn and Weir 2006).

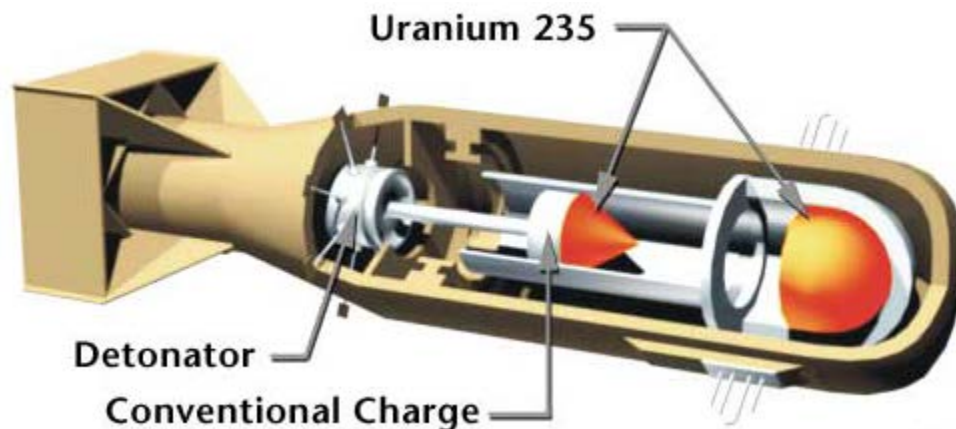


Figure 1: A Gun-type Nuclear Bomb¹

Figure 1 shows a rough representation of the anatomy of the bomb. Because of the simplicity in the physical construction of the device, a lone machinist could construct a functional nuclear bomb, given enough weapons-grade uranium. In other words, except the fissile materials, the components of the bomb are trivially accessible, and thus more difficult to regulate the exchange thereof. The rarest components (and therefore the ones to control) are the Uranium 235 and the apparatus to generate weapons-grade Uranium from naturally-occurring Uranium.

In contrast to the gun-type weapon, an implosion-type bomb is relatively complex. Instead of shooting uranium, the implosion-type weapon surrounds a sphere of plutonium in conventional explosives (which must explode simultaneously from all sides, unlike a conventional bomb which explodes from the point of ignition outward). The detonation of the conventional explosive condenses the plutonium, initiating the reaction. Despite the relative complexity of the device, it has been favored by nations for a number of benefits: it is less prone to accidents, requires less space (i.e., is better-suited to missile warheads), and yields more powerful explosions with less fissile material (Bunn and Weir 2006).

¹ Image from "Little Boy: A Gun-Type Bomb." atomicarchive.com: Exploring the History, Science, and Consequences of the Atomic Bomb. <http://www.atomicarchive.com/>

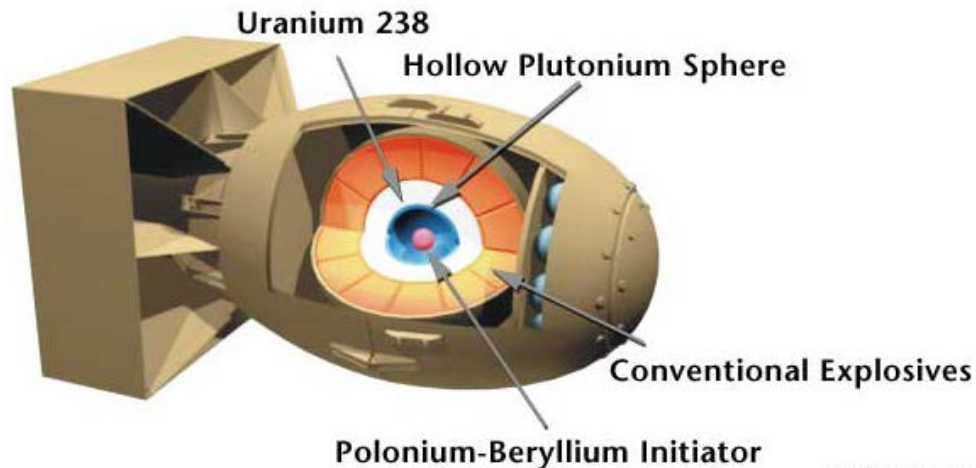


Figure 2: An Implosion-type Nuclear Bomb²

Figure 2 shows the interior of an implosion-type weapon. Besides the complexity of the explosion mechanism, the bomb typically requires multiple rare substances, including plutonium (which, unlike Uranium, does not occur naturally, and thus can only be created in nuclear generators), naturally-occurring Uranium, and a mixture of materials for the initiator (shown as Polonium and Beryllium in the Figure).

Because of the difficulties associated with implosion-type weapons, it is likely that a terrorist seeking to build and use a nuclear weapon will most likely pursue Uranium 235 to build a gun-type bomb (Bunn and Weir 2006). That said, Uranium 235 is not a common substance. It can be obtained in any of three different ways: it can be enriched from natural Uranium (which is a mix of 0.7% U235 and 99.3% U238 by mass); it can be enriched from spent nuclear reactor fuel rods; finally, it can be purchased.

The process of mining natural Uranium for use in nuclear weapons has only been successfully carried out by nations thus far. Doing so requires enormous investments in mining equipment, land with a viable source of Uranium, time and manpower. Given that the minimum

² Image from "Fat Man: Implosion-Type Bomb." atomicarchive.com: Exploring the History, Science, and Consequences of the Atomic Bomb. <http://www.atomicarchive.com/>

amount of Uranium necessary to start a nuclear reaction (also known as the “bare crit”) is estimated to be 52 kg of 94% U-235, anyone wishing to build a bomb must mine nearly 7000 kg of natural Uranium to extract enough U-235. Nations possess a plausible excuse for such mining activities: the pursuit of nuclear power. This excuse also doubles for the apparatus to enrich Uranium to weapons-grade: the difference between “reactor-grade” and “weapons-grade” Uranium is solely the purity of the U-235.

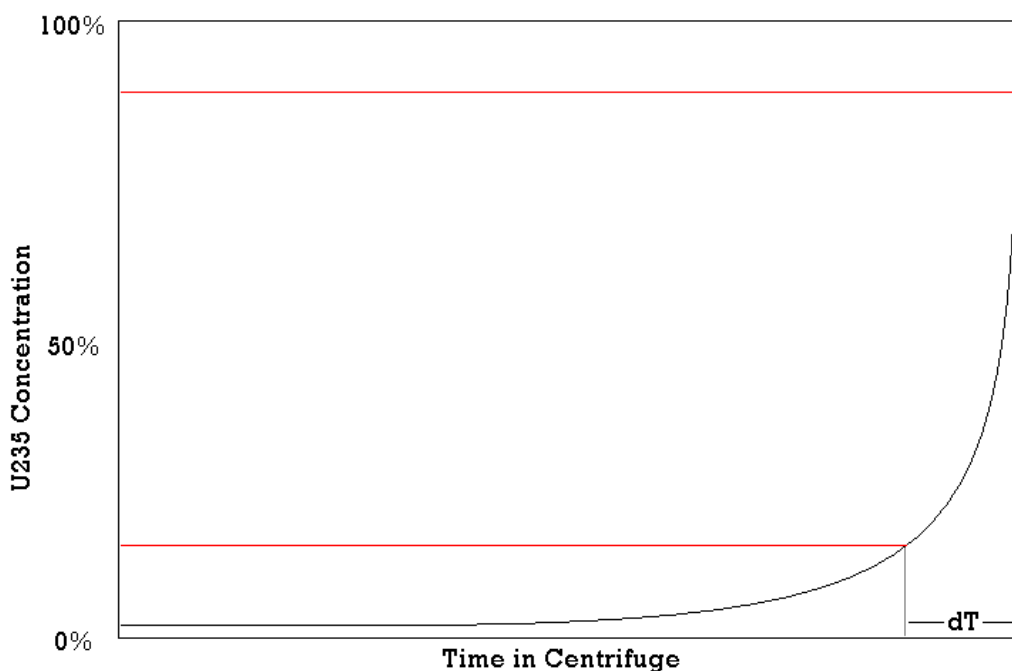


Figure 3³: U235 Concentration (as percentage of mass) over Time in Centrifuge⁴

Figure 3 shows the general trend of U235 concentration in a centrifuge. The lower red line indicates the cutoff point for nuclear fuel-grade Uranium (circa 10%, also called Low Enriched Uranium or LEU), and the higher red line represents the cutoff point for weapons-grade uranium (circa 90%, Highly Enriched Uranium or HEU). Note that, despite the large difference in necessary U-235 concentrations for the two applications, the distance in time between them

³ Plot generated by author.

⁴ The absence of units of time is a reflection of the differences in time needed to purify different amounts of raw natural Uranium. Because of this absence, this graph is to be regarded as purely demonstrative and not reflective of the actual time requirements to generate Highly Enriched Uranium.

(represented on the graph as dT) is small. In other words, a nation with the infrastructure to produce fuel-grade uranium need only operate its centrifuges a little bit longer to enrich uranium to weapons-grade.

To date, only one terrorist organization is known to have attempted to mine Uranium for its own uses. In 1993, the Japanese cult Aum Shinrikiyo purchased a sheep ranch in Banjarn, Australia in an apparent attempt to mine its own Uranium for use in nuclear weapons. The group ultimately failed to find enough Uranium to generate the desired device (Daly et al 2005). Even if they had mined enough Uranium to generate a bomb, they would require considerable technology to enrich the Uranium to weapons-grade.

If mining Uranium does not seem to be a viable approach to acquiring a nuclear weapon, perhaps obtaining nuclear fuel rods for reprocessing is a more attractive route for terrorists. More or less fortunately, however, spent fuel rods are a rarity by comparison to all the other readily available radioactive material in less exotic sources—such as hospitals or batteries—making them an unattractive choice of radiological material for use in dirty bombs. This is useful for informing law-enforcement and intelligence sting operations: anyone pursuing nuclear fuel rods is almost certainly aspiring to construct a nuclear weapon.

There exist a few documented cases in which nuclear fuel rods have purportedly appeared on the black market.

There is another possible avenue by which a terrorist organization may obtain a nuclear bomb: find one. There are anecdotal reports of nuclear warheads missing from former Soviet Union stockpiles, though no such stories are confirmed to be true (CFR 2006). While the resource requirements to successfully orchestrate a find-and-recover mission are immense, it would be folly to consider it impossible. Possible supplies of extant warheads include lost Soviet

caches of weapons and broken arrow⁵ weapons. The United States alone has experienced 32 reported such incidents⁶, several of which have resulted in weapons considered simply to be lost indefinitely. Were a well-connected, well-financed terrorist organization to launch a discrete search for a known missing warhead, it is entirely conceivable that their search might ultimately be successful.

If we were to rank these approaches to obtaining a nuclear weapon (according to how accessible each approach would be), we would be left with a list of controllable nuclear goods and an ordering of how urgent their security would be. While it is impossible to be certain of the relative dangers of these nuclear goods, a reasonable estimate might be (ordered from greatest to least):

- Functional Nuclear Bombs
- Highly Enriched Uranium (HEU, i.e. “Weapons-Grade”)
- Plutonium
- Spent Nuclear Fuel Rods
- Low Enriched Uranium (LEU)
- Uranium Centrifuges
- Natural Uranium

The utility of some of these is conditioned upon the possession of the others. For example, natural uranium will be of little use to a terrorist who lacks the means to enrich it. Likewise, a terrorist in possession of an array of centrifuges will not be able to do anything without Uranium to enrich. With each of these conditions considered, a complete warhead takes the top spot.

⁵ “Broken Arrow” is a term defined by DoD Directive 5230.16 as “an accident involving a nuclear weapon or warhead or nuclear component.”

⁶ List aggregated by GlobalSecurity.org, available at <http://www.globalsecurity.org/wmd/ops/broken-arrow.htm>

Following behind are HEU and Plutonium, each being sufficient alone to build a bomb. HEU takes the higher spot because of the simplicity of the apparatus to incite the fission reaction.

How to buy (or sell) a Bomb

There is no verified record of a sale of a complete nuclear warhead to a non-state actor. This is not to say that such an exchange is impossible or even unlikely. The existence of such a sale or sales is entirely uncertain. For this reason, despite the importance of the question of whether any terrorist possesses a functional Bomb, the best answer is “We cannot tell.”

We can tell, however, about many other components of the list. For example, in November of 2010, two Armenian men were caught on a Train in Georgia in possession of 120 grams of Uranium of an undisclosed enrichment. The man who led the sting operation which captured them, called Pavlenishvili, indicated that Uranium generally sells in the caucuses for approximately \$10,000 per gram. (Associated Press 2011)

The most successful case of Nuclear black market dealing does not come from the former Soviet Union, however, nor does it involve the elements at the top of the threat list directly. Abdul Qadeer (AQ) Khan of Pakistan is perhaps the world’s most successful, high-profile nuclear black market dealers. Khan was a metallurgist who, after finishing his Bachelor’s degree in Pakistan, studied in Europe for his graduate degrees. After receiving his Doctorate (in metallurgy in 1970), Khan began working for the Dutch arm of the International Uranium Enrichers Consortium (URENCO). As an employee, he began researching the enrichment centrifuge technologies.

In 1974, following India’s peaceful nuclear explosion, Khan wrote a letter to Pakistani Pres. Bhutto, appealing for a Uranium enrichment nuclear program (as opposed to a Plutonium-

reprocessing based program). Bhutto was swayed by Khan; in 1976 Khan left Europe to work for the government of Pakistan. Khan starts Khan Research Laboratories, and is placed in charge of Pakistan's entire Uranium Enrichment operation. (Laufer 2005)

At some point in his career, presumably in the late 1970's, Khan begins ordering more centrifuge components than the Pakistani government required to support its nuclear ambitions. Khan is reported to have contacted the governments of Iran and Iraq, and later North Korea and Libya. Libya's decision to forego its nuclear weapons program in 2003 revealed much of Khan's influence on its program. It seems Khan received an excess of \$100 million for his support of Libya's program alone, with possible untold more money from his deals with other nations. (Laufer 2005)

If there is anyone who can be called familiar with the nuclear black market, it is decidedly AQ Khan. Khan had access to sensitive technologies, government funds to purchase components in excess, professional contacts from Europe for the purchase of necessary centrifuge components, and the technical knowledge to market those excess centrifuges to desirous nations. The only certainty about Khan's business transactions is that he sold centrifuge technology to Libya, though it is entirely plausible that he could have sold HEU on the open market.

The network that Khan started lives on and grows, even as Khan is now retired. From Khan, Iran is actively developing its centrifuge arrays and North Korea is known to have replaced the YongByon reactor with a centrifuge array. North Korea is believed to have almost furnished the Syrian government with a nuclear reactor, modeled on the original YongByon power plant schematics. (Hersh 2008)

How to Prevent the Exchange of Bombs

In devising prescriptions to address the problems of the nuclear black market, the dominant paradigms of political economics come to very distinct conclusions. Marxist thinkers will argue that increased government control over individual economic activity will limit the ability of trans-national terrorist organizations to exact the resources to build a bomb, and likewise complicate efforts to transport it. Nationalists will argue that the government must take a stronger stand against these threats than the social organization of the Marxists; threats must be met by a nation directly. The most predominant analytical framework, however, is liberalism.

Liberal theory in economics addresses the needs of individuals and groups with the emergence of markets. Note the conspicuous absence of any government interaction in that relationship: liberals emphasize the natural optimality of markets in the absence of intervening exogenous forces like institutions (Gilpin 1987).

In particular, liberal economic theory is unconcerned with the exchange of particular goods like nuclear weapons. Instead, it views government nonintervention as the means to achieve optimal market stability and efficiency. In the case of nuclear materials, this means the emergence of a thriving, unregulated market where terrorists and pariah states can exchange money for fissile materials, centrifuges to enrich them, and complete bombs entirely at will.

Complementary to this new market would be the market for nuclear *defenses*. Snake-oil peddlers will market inexpensive safety suits and home outfittings to uninformed buyers. Gradually, as the market matures, more appropriate and safe measures (like lead-reinforced emergency basements) will become available to protect the masses from the nuclear attacks which will plague them near-constantly as the price of nuclear materials falls from a glut of suppliers in this lucrative new market.

This laissez faire approach may be efficient in the sense that it achieves a highly unfavorable equilibrium rapidly, but to ask governments to avoid interacting with illegal markets is to ask governments to assume too much risk. The United States, for example, has not faced any existential security threats since the end of the cold war. In the absence thereof, US policy has shifted from a fixation on the threat of Communism and the Soviet Union to that of terrorism and fighting low-intensity conflicts. Facing the US government with the real threat of a nuclear terrorist attack will invariably lead the US to behave in ways better typified by the other paradigms of International Political Economic theory.

Economic nationalists, in contrast to liberals, tend to place the welfare of the state above the welfare of the market. States will act in order to protect their national economic interests, and they have a variety of tools at their disposal to do so. They can place taxes and tariffs on imported goods to incentivize the consumption of domestic goods. They can adjust financial benchmarks like interest rates. They typically control valuations of the currency, which can be used to alter exchange rates and again incentivize consumption of domestic goods. But what about black markets?

There exists some literature concerning black and gray markets, but it is dominated by case studies of drug cartels and trafficking in small arms. What results concerning illegal arms trades are applicable to nuclear weapons trades suggest three points: first, that black markets arise in response to embargoes; second, that gray markets are the economic byproduct of new political economic activities; third and most important, that only collective action will eliminate the trade systemically (Karp 1994). This analysis, while not specific to nuclear materials, suggests that national intervention does indeed sow the seeds of illegal nuclear materials exchanges. Without different data collected from similar systems, however less the

governmental intervention, we cannot conclude that the black market system will be damaged by the decriminalization of nuclear goods. The best we can do is to hypothesize that the black market will then simply become a gray market.

If this is the case, then we likely have the anti-utopian liberal future scenario to look forward. Black markets tend to be small to avoid public recognition, but gray markets flourish and proliferate on the public indulgence (Karp 1994). The government must therefore enlist its socio-political powers—its monopoly on violence—to crackdown upon nuclear traders. This seems to be precisely the tack that governments have taken, thereby establishing a black market and providing very little latitude for a gray market.

Nationalism is restrictive in that it tends to view the international system as zero-sum. In international relations theory literature, this is a hotly debated perspective, as it is intimately tied to nations' abilities to cooperate. If we wish to sleep at night without the specter of a nuclear terrorist attack haunting us, we must consider Karp's advice that only aggressive, cooperative policing of international exchanges can stem the tide of loose nuclear materials.

This leaves us with a single ideological framework awaiting explanation: that of Marxism. Modern economic Marxists have evolved far beyond the original writings of Marx and Engels. Some primary concepts remain from the foundational works of the fathers of Utopian Socialism—class struggle is the source of conflict and change. Thus for a Marxist the quest for a nuclear weapon is akin to a plea for attention; a wake-up call to the western world that those hard-working laborers who support western lifestyles will cast off their shackles and break free from their imperial bondage.

It is interesting to note that these three ideologies can be framed in terms of their sympathies: Marxism is sympathetic to the terrorists, Nationalism to the states, and liberalism to

no one. Because the states are the actors and they aspire to a single, self-interested goal, it is plain to see that without considerable further refinement of these ideological approaches, nationalism is the strongest predictor for both government and market behavior.

How to Stop Worrying

It seems scholars and policymakers are split over the question of whether these avenues of Bomb acquisition are likely to yield a nuclear terrorist attack. Academics, it seems, are by and large optimistic that these modes of acquisition are all fairly unlikely (Enders and Sandler 2006), and thus the expected value of investing many resources in counterproliferation efforts is low. While I doubt many would say so baldly, this is in line with the economic Liberal ideals to which many of them subscribe.

In contrast, two former secretaries of State (Henry Kissinger and George Schulz), a former Secretary of Defense (William Perry), and a former Chairman of the Senate Armed Services Committee (Sam Nunn) published a wildly influential piece in the Wall Street Journal in 2007 calling for increased efforts worldwide to hunt down and secure loose nuclear materials. They have since been popularly branded “the Four Horsemen of the Nuclear Apocalypse.” These men represent the economic nationalists of the debate.

Both arguments have their merits. From a pure probability perspective, it is impossible to predict or forecast a nuclear attack simply because one has never happened. Such an attack is entirely possible, but we can neither tell nor calculate whether it is likely. In this way, both sides are correct: the probability is small, but the potential damage is staggering. This last conclusion, however, mathematically outweighs the former, as a small formal model can demonstrate.

Consider the probability of any nuclear terrorist attack, p , to be small ($p < .01$) in any given year. We can therefore calculate the probability that a terrorist will not occur in the given year to be $(1 - p)$. The probability a terrorist attack does not occur in any number of given years is the product of the above expression with itself the number of years to be represented. Thus, the probability that a nuclear terrorist attack occurs within the next n years, would thus be represented as:

$$\text{Pr (terrorist attack within } n \text{ years)} = 1 - (1 - p)^n \quad (1)$$

When graphed, the function reveals its rather alarming property:

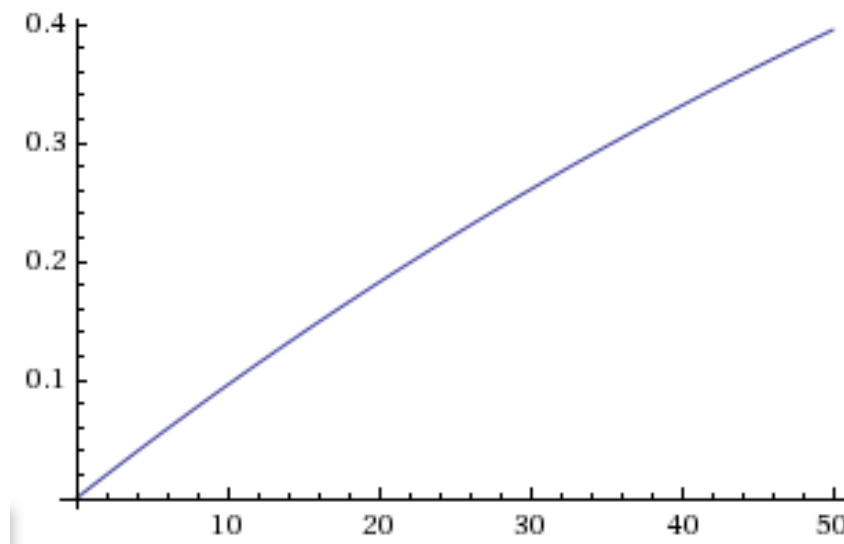


Figure 4: Plot⁷ of Equation 1 with $p=.01$

As time passes, the probability of an attack climbs quickly. As the time horizon (across the x -axis) expands, the curve approaches 1. In other words, unless it is actually impossible for a terrorist to obtain and use a nuclear weapon, it grows increasingly likely over time that a nuclear terrorist attack *will* occur. Factor in the immeasurable damage even a small nuclear weapon

⁷ Plot generated by Wolfram Alpha LLC. 2009. Wolfram|Alpha, <http://www.wolframalpha.com/input/?i=y%3D1-.99^x+from+0+to+50>

would deal in New York City, London, or Washington D.C., and it begins to look very foolish to argue that nuclear terrorism is not a force with which to be reckoned.

The trick to not worrying, therefore, is to follow in the steps of the four horsemen and take up the Nationalist task of protecting the nations of the world against nuclear terrorism.

Nuclear terrorism is a likely occurrence over the long term, and the expected damage should we ignore it is staggering. We are thus left with the question of how best to protect ourselves.

While the science behind the study is fairly clear that HEU is the most present danger, the policies which will secure it and equally dangerous nuclear goods

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