Historical Precedents and Policy Analysis in the Development of Proposed Nuclear Mishap Response Plans

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Abstract

Since 1945, the potential of nuclear proliferation has posed a major threat to global security and the balance of power. As the desire for nuclear weapons grew, so did their production, inevitably leading to a series of global nuclear mishaps for about half a century. These mishaps were caused by a combination of technical errors and human negligence in scientific, military, and civilian accidents. The threat of these incidents is directly tied to the global nuclear inventory, with the size and age of nuclear weapons playing a key role in their vulnerability.

Global nuclear vulnerability derives from a plethora of factors, many pertaining to the size and security of nuclear materials. Older nuclear states can glean major insights from their experience in preservation and maintenance of nuclear arsenals but face new challenges pertaining to decaying armaments as well as emerging threats such as evolved terrorist networks and governmental actors who continue to develop cyber capabilities. Changing technological advancements and an evolving environment pose new challenges for security, necessitating modern-day solutions that build on lessons from past failures.

Significant changes must occur in the implementation of nuclear policy as well as the modernization of nuclear technology in order to reduce future risk of mishap and construct adequate response plans. A combination of eliminating the hair-trigger alert, reducing national reliance on nuclear weapons, and decreasing the number of deployed long-range weapons will provide a realistic countermeasure to the ever-increasing threat of mutually assured destruction.

I. Introduction

Currently, it is only possible to completely prevent further nuclear detonations by destroying nuclear weapons altogether. Yet in recent years, progress towards this goal has stalled, with the failure of 2012 negotiations to rid the Middle East of nuclear weapons a strong case in point. In this work, we hope to both recall the serious and dire threat of nuclear weapons to the forefront of readers' memory and adopt a comprehensive, multilateral solution that places disarmament as the highest goal and mitigates concurrent risks.

The focus of this paper is centered around global nuclear vulnerability (GNV), a key risk exacerbated by the retention of nuclear weapons. Defined as the worldwide vulnerability to nuclear weapon detonations, GNV is primarily characterized by the potentiality for accidental nuclear accidents, or "close calls." Section II details the consequences of nuclear incidents (both accidental and deliberate). Section III delves deeper into prior close calls, identifying the common causes behind these incidents and extrapolating methods to reduce current safety risks. Section IV provides recommendations for future nuclear weapons policy, combining potential safety procedures from Section II with a reiteration of the necessity of hastening disarmament and enforcing nonproliferation.

II. Effects of Nuclear Detonation

The detonation of a nuclear device would have large and widespread effects on public health, domestic policy, and international geopolitical calculations far beyond the initial blast. Nuclear explosions result in release of radiation, which has both an immediate and residual impact. The radiation that is emitted during the first minute after a nuclear explosion is mostly comprised of gamma and neutron radiation. Statistically, there are few casualties from initial radiation. The weapon debris, fission products, and irradiated soil all result in residual radiation. For humans, exposure to residual radiation can have devastating impacts.

According to Benoit Pelopidas of the University of Bristol, there are three major sequential components to a nuclear detonation: the actual blast, the fires caused by the detonation of a bomb, and the radiation caused by the blast itself. Some of the major effects of residual radiation are birth defects, cancers (e.g. leukemia), sustained land infertility leading to famine, and potential contamination of water supplies. Environmental issues include a nuclear winter (where the sun is overshadowed by dust and debris, similar to a volcanic eruption), leading to land and water contamination. General health issues may include trauma, elevated stress, higher incidence of cardiovascular disease, various other mental health disorders, and suicide.

Alarmingly, as of 2015, per the Federation of American Scientists, the total number of nuclear warheads stood at 15,800 (Kristensen & Norris 2015). Iran has an advanced nuclear weapons program and Syria is also believed to be developing a weapons of mass destruction program. Since the continued existence of these nuclear weapons poses a threat to humanity, we support the effort to prohibit the use of nuclear weapons.

III. Global Nuclear Vulnerability and the Current Nuclear State

Global Nuclear Vulnerability

Global nuclear vulnerability (GNV) is a general term used to describe sociopolitical threats posed by nuclear weapons. By recognizing the possibility of accidental launch and launch caused by misperception, GNV encompasses the danger perpetrated by nuclear weapons that other theories seek to alleviate. GNV emphasizes the discourse of vulnerability, bringing the total devastation that nuclear weapons may cause to the forefront of individuals' minds. Although many factors may seek to exacerbate or diminish GNV, the concept of nuclear vulnerability will continue to exist to some degree as long as nuclear weapons exist in tandem. A broader conception of the nuclear state, GNV encompasses nuclear deterrence, nonproliferation, security, and disarmament as ways to diminish—not eliminate—vulnerability.

Game Theory as an Explanation for GNV

Game theory, the study of conflict and cooperation between intelligent rational decision-makers, can model the threat of global nuclear vulnerability. Game theory analyzes situations in which one actor's decision will affect another actor's expected wellbeing. The most common example of this mutual interdependence is modeled by the Prisoner's Dilemma (Stanford Encyclopedia of Philosophy):

> Prisoner A and Prisoner B have been arrested on suspicion for committing a crime together. Both care much more about their personal freedom than about the welfare of their accomplice. A conditional offer is made to both prisoners yielding the following possible results:
>
> 1. Both prisoners may choose to confess or remain silent.
> 2. If one prisoner confesses and the other prisoner remains silent the prisoner who confesses will go free.
> 3. If both prisoners confess, both prisoners are sent to jail.
> 4. If both prisoners remain silent, both prisoners go free.

This "dilemma" represents the conflict between individual and group interests and can be extended to many fields, including the study of global nuclear vulnerability. In the case of nuclear proliferation decision-making between the United States and the Soviet Union, a two-by-two matrix represents the actions between which these players can choose:

		United States	
		Not Build	Build
Soviet Union	Not Build	***n,n*** ***(3,3)***	***n,b*** ***(1,4)***
	Build	***b,n*** ***(4,1)***	***b,b*** ***(2,2)***

Preference Orders:
Soviet Union: ***bn*** > ***nn*** > ***bb*** > ***nb***
United States: ***nb*** > ***nn*** > ***bb*** > ***bn***

Figure 1: The Prisoners' Dilemma as a Model for Arms Races

Assuming a simplified and adversarial model that includes the United States and the Soviet Union, the outcomes that this matrix portrays can explain the slow pace of nonproliferation. The ideal strategy for the Soviet Union is *bn*: that is, the United States chooses 'not to build' nuclear weapons and the Soviet Union does 'build'. Conversely, the ideal strategy for the United States is *nb* by the same reasoning. It is important to note that the most favorable strategy for the United States is the least favored for the Soviet Union, and vice versa. For each nation, the second-most preferred strategy is *nn*, which saves money and reduces nuclear vulnerability. However, a simple case study demonstrates that the 'build' strategy *dominates* the 'not build' strategy:.

- **Case 1: United States plays the *n* strategy.** If the United States chooses to not build, the Soviet Union receives its most preferred strategy by building. Therefore, it plays *b.*
- **Case 2: United States plays the *b* strategy.** If the Soviet Union plays *n,* it receives its least preferred strategy. Therefore, it plays *b* in accordance with the Prisoner's Dilemma.

Both superpowers are motivated to build nuclear weapons. Thus, the United States and Soviet Union engage in an arms race, although the mutually beneficial strategy would be to cease production of nuclear weapons and reduce existing stores. In addition, according to a principle called *Nash equilibrium*, neither player has any incentive to change their strategy (*bb)* because any change would result in their least preferred outcome. Finally, the lack of third party arbitration exposes the fundamental flaw in nonproliferation efforts. With a third party able to mediate agreements and enforce them effectively, both nations would abide by the agreement and the entire dilemma would be resolved. However, due to the anarchic nature of the international system, no such enforcement is realistically possible and deep distrust and fear sustains proliferation efforts (Basel Peace Office).

This relatively simple game model goes a long way in explaining the issues underlying global nuclear vulnerability. No purely self-rational country is motivated to reduce their nuclear stores, and international agreements are largely ineffective in pursuing common nonproliferation goals.

Because GNV's existence is conditional on the existence of nuclear weapons, rational self-interest on the part of each nuclear nation is a major cause of continuing nuclear vulnerability.

Confounding Factors in Nuclear Vulnerability

It is well known that global nuclear vulnerability, by its very nature, is an exceedingly complicated and multidimensional issue. Potent factors undermining the abolition of nuclear weapons (and thereby increasing our state of nuclear vulnerability) include the modernization of nuclear warheads, novel small and stealthy weapons, diplomatic stresses, high-alert intercontinental ballistic missiles (ICBMs), the risk of accidental launch, and the advent of nuclear terrorism.

<u>Modernization of Nuclear Weapons</u>

Although the modernization of nuclear weapons helps keep technology updated and ensures reliable detonation, upgrading these weapons ultimately poses greater risks to our safety. President Obama has recently announced plans to modernize US nuclear arsenals over the next ten years (as the air launch cruise missile developed in the 1980s is rapidly becoming outdated), investing over 300 billion dollars (Foster & Lawler 2015). Within this broad "nuclear weapons update," however, the advanced cruise missile has come under particular scrutiny. Estimated to cost up to 30 billion dollars for 1,000 upgraded weapons, these nuclear missiles are especially destabilizing as they are composed of both a nuclear and a conventional warhead (Broad & Sanger 2016). Irrevocable after launch, these missiles instill an additional risk of miscalculation and error of judgment due to the ambiguity of the warhead used.

<u>Small, Stealthy, and Precise Weapons</u>

The modernization of nuclear weapons tends to devote resources to producing smaller, stealthier, and more precise weapons. With the ability to target underground locations with great precision and modify yield, these weapons might enable military commanders to justify more proliferative use. Smaller, more precise weapons could in fact increase usability, increasing nuclear vulnerability. As General James E. Cartwright, a retired chairman of the Joint Chiefs of Staff, remarked, "[W]hat going smaller does, is to make the weapon more thinkable" (Broad & Sanger 2016).

<u>Diplomatic Stresses</u>

Though a global nuclear fallout is not a fairytale scenario, both the United States and Russia refuse to take a "no first use" pledge with regards to nuclear weapons use (Starr 2008). Only China—of the five nuclear states—has committed to an unconditional no-first-use policy, relegating the communist nation to a vulnerable position. Such diplomatic stresses relegate each nation to a modernization frenzy, both to enhance survivability and maintain a credible minimum nuclear deterrent.

High-Alert ICBMs

Since their development in 1962, ICBMs and launch-on-warning (LOW) missiles have been used by militaries extensively due to their ability to detect an enemy nuclear attack and order a retaliatory launch. These missiles, however, are launched prior to confirmation of detonations resulting from the perceived attack, rendering them problematic from a nuclear vulnerability standpoint. Furthermore, such weapons are generally operational rocket-mounted nuclear warheads capable of being launched in less than fifteen minutes (Starr 2008). Keeping weapons on "hair-trigger alert" or "launch on warning" increases the potential for miscalculation, thereby raising concerns of exacerbating global nuclear vulnerability.

As depicted in Figure 2, approximately 2,600 warheads were on high alert in 2008 (between the United States and Russia). Other nations with nuclear capability—namely Britain and France—placed their weapons on low levels of alert, and China's nuclear forces were completely off-alert alongside weapons of other nuclear armed nations (e.g. India, Israel, North Korea, and Pakistan).

	Missile numbers	Warhead numbers	Total yield (MT)
USA	560	1302	315
Russia	340	1279	870
Total	***900***	***2581***	***1185****

Figure 2: Total High-Alert Nuclear Forces in 2008 (Starr 2008)

** Total yield of US and Russian operational nuclear arsenals is approximately 2657 MT, thus about 45% of the yield is on high alert*

The safety measures currently in place are undoubtedly working as, in spite of some very close calls, we have been able to avoid a nuclear launch. But as the probability of a nuclear mishap is non-negligible, our luck so far does not guarantee continued avoidance in the future. We remain highly vulnerable to nuclear attacks.

Risk of Accidental Detonation

Some of the factors as noted in *Reducing The Risk Of Nuclear War: Taking Nuclear Weapons Off High Alert* (Union of Concerned Scientists) that may lead to accidental or mistaken missile launch include

- False alarm due to warning sensor malfunction

- False alarm due to accurate (but ambiguous) warning data
- False alarm due to human error
- Technical problems with command and control systems

Although it may seem that the probability of each of these events occurring independently is quite low, high-alert ICBMs and fragile nuclear diplomacy magnify these risks. With the ever-looming domino effect overshadowing the fallout, even one mistake in any of these arenas may be the cause of massive damage to both nuclear and non-nuclear weapons states alike.

<u>Nuclear Terrorism</u>

The continued presence of nuclear weapons puts citizens at risk of cyberterrorism—that is, remote control of any nation's massive nuclear arsenal by a terrorist agency or individual. With the advent of sophisticated cyber-attacks on civilian and government systems, "The US military system has not kept up with the cyber adversary tactics and capabilities, and with present capabilities and technology it is not possible to defend with confidence against the most sophisticated cyber attacks" (Defense Science Board 2013). Additionally, especially with NSA's practice of inserting vulnerabilities into computers, the grid is vulnerable to cyber attacks. Nation states like Russia and China and rogue actors are developing highly potent offensive capabilities. Notably, vulnerabilities exist within Supervisory and Control Data Acquisition (SCADA) systems that control various aspects of the grid. If a cyber attacker were to attack the grid via SCADA systems, important elements like nuclear power plants could be destabilized.

Critical Zones of Vulnerability

There is more to global nuclear vulnerability than the mere presence of weapons; the geographic location of these weapons also plays an important role in how likely any given weapon is to be detonated. Longstanding critical regions such as India, Pakistan, and the Middle East must be watched, especially in light of global competition and deteriorating US-Russia relations. We cannot assume that the five nuclear weapons states are any less vulnerable. Particular hotspots include Indo-Pak relations and growing disturbances in the Middle East (Israeli-Palestinian relations).

<u>US/Russia Relations</u>

Russia is redrawing the map of Europe: the Ukraine crisis, annexation of Crimea, and threats against other Eastern European States are cases in point (Gertz 2015). Along with such militaristic objectives, there is increasing tension in relations between the United States and Russia. Russia's large-scale buildup of nuclear forces challenges the United States' nuclear reduction goals. Russia's revised nuclear doctrine and open threats to use nuclear weapons have undermined strategic stability, further impacting US nuclear disarmament policies (Gertz 2015).

Indeed, the arms race is not a binary one; United States' plans to modernize nuclear weapons have triggered a new arms race with Russia. Russia called the B61 tests recently conducted by US as "irresponsible" and "openly provocative" (Broad & Sanger 2016). As we will note in Section IV, high tensions impact credibility, and the risk of miscalculation or human error tend to soar.

Chinese Diplomacy

China is considering putting nuclear weapons on high alert for the first time and to build an early warning system to detect an incoming attack (Union of Concerned Scientists). China has decided to take this course of action to address concerns on part of the Chinese military about retaining a credible nuclear retaliatory capability in the face of US missile defenses and the modernization of its arsenal. Additionally, China's recent announcements of its plans to build the country's first commercial-scale reprocessing facility starting in 2020 (to be completed in 2030) to process spent nuclear fuel into plutonium that could be used in weapons are raising further concerns to the risk of nuclear nonproliferation (Spegele 2016). Different countries currently have different policies in place to handle potentially dangerous waste created by commercial nuclear reactors. In the United States, reprocessing of spent fuel is banned out of proliferation concerns and spent fuel is treated as sensitive material and stored. Though China's reprocessing is intended for commercial use, it raises concerns—especially by the United States—since it faces challenges of international cooperation and transparency in the Asia-Pacific region. Larger stockpiles of plutonium would increase the risk of weaponization, drastically affecting GNV.

North Korea

North Korea's secretive nuclear and missile programs have always kept the world on edge. The North has had a weapons building program for almost twenty years, but the extent of the advancement of the program is unknown to all; in fact, the tyranny has recently completed three nuclear tests. North Korea's aim to build nuclear tipped missiles with the intent of mass destruction is a constant threat to US and Asia, but it defends its pursuit of a hydrogen bomb by fetishizing the ever-growing nuclear threat of the United States.

The Current Global Nuclear Inventory

This section provides an overview of the nuclear arsenals of all confirmed and suspected nuclear-weapon-holding states. These states comprise the five nuclear weapons states recognized in the Nonproliferation Treaty (NPT)—the United States, Russia, France, Britain, and China—as well as the non-NPT states holding or suspected to hold nuclear weapons—India, Pakistan, North Korea, and Israel.

As of 2015, these nine countries share a stock of approximately 15,800 nuclear weapons (Figure 3). As expected, Russia and the United States hold the vast majority (93%) of the total inventory (Figure 4).

Status of World Nuclear Forces 2015*

Country	Deployed Strategic	Deployed Nonstrategic	Reserve/ Nondeployed	Military Stockpile	Total Inventory
Russia	1,780[a]	0[b]	2,720[c]	4,500	7,500[d]
United States	1,900[e]	180[f]	2,620[g]	4,700[h]	7,200[i]
France	290[j]	n.a.	10[j]	300	300
China	0[k]	?[k]	260	260	260[k]
United Kingdom	150[l]	n.a.	65	215	215[l]
Israel	0	n.a.	80	80	80[m]
Pakistan	0	n.a.	120-130	120-130	120-130[n]
India	0	n.a.	110-120	110-120	110-120[o]
North Korea	0	n.a.	<10	<10	<10[p]
Total:[q]	**~4,120**	**~180**	**~6,000**	**~10,300**	**~15,800**

Figure 3: Status of World Nuclear Forces in 2015 (Kristensen & Norris 2015)

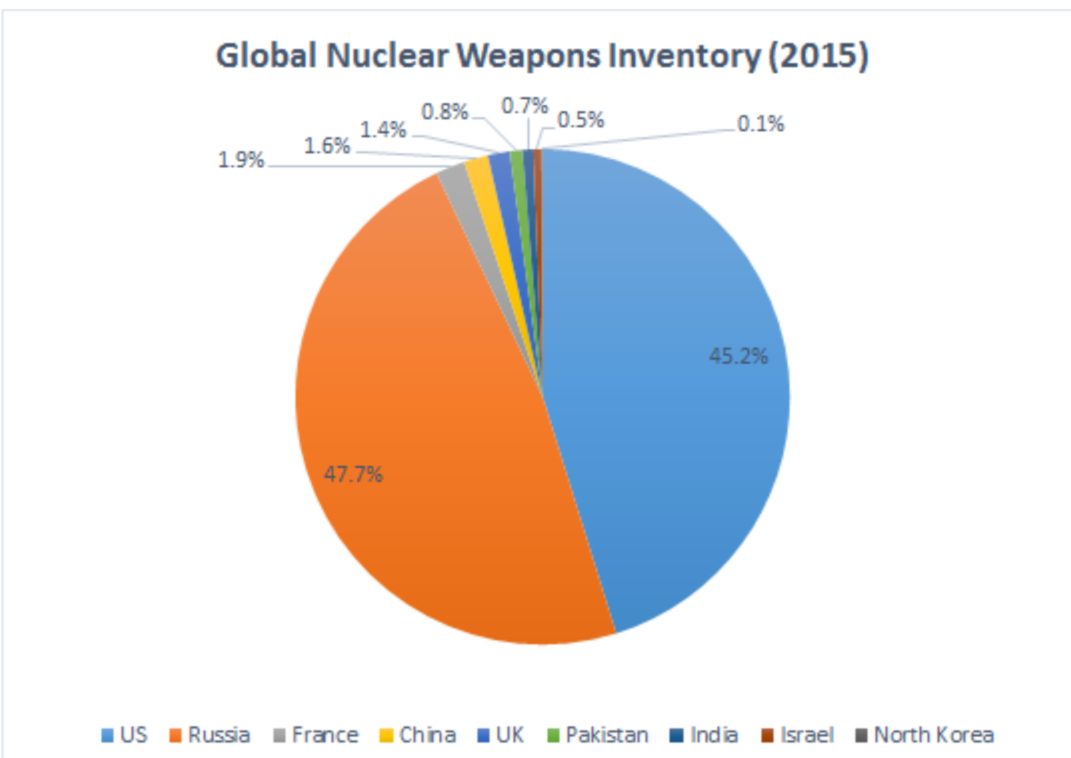

Figure 4: The key players in the nuclear realm (Kristensen & Norris 2015)

Despite years of Cold War competition and nuclear arms acquisition, the United States and Russia have made significant progress in reducing their nuclear weapons stockpiles. Since the end of the Cold War, the United States and Russia have both reduced their nuclear arsenals impressively. The United States reduced its deployed and storage weapons from their peak of 23,000 in 1986 to 4,760 in 2014, while Russia similarly cut its stockpile of deployed and storage weapons from a peak of 40,000 in 1986 to 4,300 in 2014 (Union of Concerned Scientists 2015).

However, both face significant challenges to further disarmament. A deeper look into the comparison of US and Russian nuclear arsenals reveals that many challenges threaten to stymie further progress in disarmament. A high number of nuclear weapons remains in storage or awaits dismantlement in both the countries. In 2014, as shown in Figure 5, 2,340 nuclear weapons awaited dismantlement in US versus 3,200 in Russia. Similarly 2,680 nuclear weapons were in storage in US versus 2,520 in Russia.

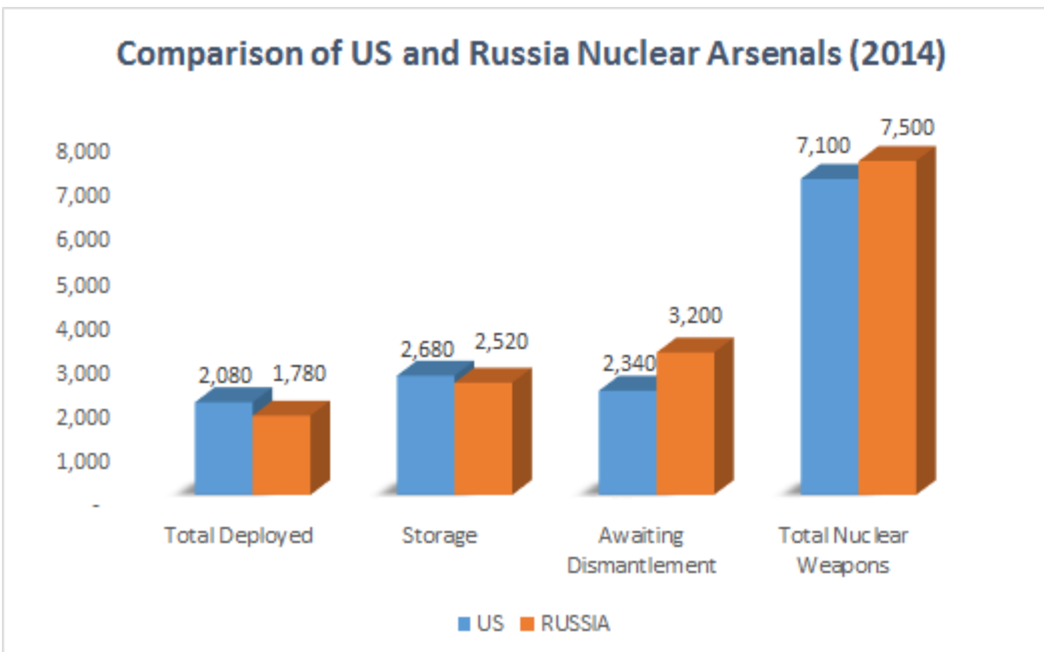

Figure 5: Comparison of United States and Russia Nuclear Arsenals

After the Cold War, it was easy to achieve the aggressive nuclear reductions in the late 1980s and early 1990s as both US and Russia recognized that the accumulation of nuclear weapons had spiraled out of control. Progress on this front certainly still exists: for example, in 2009, President Obama resurfaced the issue of nuclear disarmament by acknowledging his quest for “global zero” at the Prague conference (Foster & Lawler 2015). Furthermore, in 2010, US and Russia signed the NEW START Treaty, setting a new goal for the reduction of strategic nuclear warheads to 1,550 by 2018 (Raphael 2016). However, both countries have reached the point where further nuclear reductions will be challenging, and it is not possible to bring other nuclear weapons countries who possess very small nuclear weapon stocks into disarmament talks until US and Russia have made significant nuclear reductions.

IV. Prior Nuclear Device Mishaps

In order to understand the real risk of conducting nuclear experiments, we should identify key incidents involving nuclear materials. There are quite a few examples of experiments involving nuclear materials and devices that have malfunctioned in some way, causing environmental fallout and extensive panic.

To organize these incidents, we have categorized them as either scientific, military, or civilian. We classify as scientific incidents occurring during the course of developing a nuclear weapon, be it during manufacture as in the Tomsk-7 incident or during testing as with the Baneberry incident. Military incidents are those that occur under military oversight, and civilian incidents are those that involve non-military and non-scientific personnel, notably politicians. As some incidents may belong in multiple categories, we have selected the category which we believe most accurately characterizes the nature of the incident's oversight.

Demon Core (Scientific)

During the creation and testing of the "demon core" subcritical mass of plutonium at the Los Alamos National Laboratory, two scientists were subjected to radiation poisoning when they stopped the core from going supercritical.

On August 21, 1945, during a criticality test, Harry K. Daghlian Jr. accidentally dropped a plutonium brick onto another, creating a supercritical core. He knocked it away, subjecting himself to a lethal dose of radiation, and died 25 days later from radiation poisoning (Atomic Heritage Foundation). In the wake of the incident, safety measures were implemented, but they did not prevent the incident from recurring one year later.

On May 21, 1946. Louis Slotin, a Canadian scientist, was performing a demonstration by bringing together two beryllium-coated plutonium cores with a screwdriver when an accident occurred. The screwdriver slipped and the two cores came into contact, so Slotin shielded his students and coworkers with his body and separated the spheres. He died of massive radiation poisoning nine days after (Atomic Heritage Foundation). Many spectators were also subjected to radiation poisoning, and some developed serious health problems.

Damage during the accidents included the deaths of Harry K. Daghlian Jr. and Louis Slotin; radioactive release during the accident is also linked to health problems that had developed in spectators. However, both scientists narrowly averted devastating destruction: the demon core was later detonated in Operation Crossroads, which yielded a 23 kiloton-explosion (Atomic Heritage Foundation). If the demon core had accidentally been detonated in either accident, it would have produced a similar explosion, causing a citywide nuclear detonation with hundreds of immediate deaths and massive radioactive contamination.

Castle Bravo (Scientific)

On March 1, 1954, US military tested a hydrogen bomb on the Marshall Islands in Project Castle Bravo. The bomb's yield turned out to be over twice the yield of 6 megatons that scientists had predicted. Although many islanders were evacuated, radioactive contamination and fallout led to radiation poisoning and death among neighboring inhabitants. A nearby Japanese fishing ship was severely contaminated, and one crew member was killed (Preparatory Commission for the Comprehensive Test Ban Treaty Organization).

The bomb's yield was 15 megatons, 2.5 times greater than the expected yield and over 1000 times the Hiroshima bomb yield. Damages included radioactive fallout over a 11,000 km radius and long-term health damages to the islands' inhabitants (Preparatory Commission for the Comprehensive Test Ban Treaty Organization). These damages could have been avoided if the scientists had accounted for a greater margin of error when preparing for the bomb test.

Goldsboro (Military)

On January 24, 1961, a bomber broke up in flight over North Carolina, inadvertently dropping two hydrogen bombs. In the event of such a crash, parachutes were expected to open up, but only one parachute opened, leaving the other bomb to free-fall. The impact of the crash caused the fuzing sequences in both bombs to initiate. In the bomb that was parachuted, the final arm/safe switch luckily remained at "safe," while in the second, although the indicator read "armed," the switch contacts had in fact broken, so the bomb was likewise unarmed. It would be an exaggeration to claim that "one switch stood in the way of a massive nuclear detonation," as one commentator has remarked, but it is clear that these bombs were extremely close to detonation (Jones 1969).

If detonated, each device would have produced a 2-2.5 megaton explosion, so both devices would have yielded an explosion of 4-5 megatons in total (de Montmollin & Hoagland 1961). According to a story published by ibiblio, a project of the University of North Carolina–Chapel Hill's School of Journalism and Mass Communication and the School of Information and Library Science, "The blast from a ground-level detonation of four megatons would have left a crater in the ground a third of a mile wide and leveled homes five miles away, while the heat would have set fires and inflicted third-degree burns to a distance of nine miles from the point of detonation." In short, a detonation would have inflicted home destruction and severe burns to neighboring residents. Radioactive fallout and subsequent poisoning and contamination would result largely from the fission sequence that fueled the fusion sequence. This incident could be prevented by implementing security procedures and thoroughly checking the plane.

Cuban Missile Crisis (Civilian)

After the United States attempted to overthrow the Communist Castro regime in the 1961 Bay of Pigs invasion, Cuba requested nuclear missiles from the Soviet Union. When in October 1962 an American spy plane discovered that the Soviet Union was attempting to sneak medium-range (SS-4) and intermediate-range (R-14) ballistic missiles into Cuba—weapons posing a clear threat to American national security—the United States imposed a blockade on Cuba and demanded that the weapons be sent back. However, the Soviet Union refused to back down. This standoff lasted from October 16 to October 28, 1962 (US Department of State Office of the Historian 1962).

With nuclear weapons easily at hand and tensions at fever pitch, it appeared that the only way out of the crisis led to nuclear war. Thankfully, in the end Kennedy and Khrushchev negotiated that the Soviet Union would remove its missiles from Cuba in exchange for the United States' removing its missiles from Turkey (Allison 2015).

The projected event yield is unknown. In the worst-case scenario, it may have led to nuclear war, where an untold number of missiles would have been fired. The consequences of a nuclear war would have been disastrous, ranging from immediate civilian death to long-term radioactive contamination, radiation illness, and the political and economic instability these events would trigger, not to mention irreparably damaged US-Soviet political relations. This incident could have been prevented through better communication and negotiation.

Palomares Accident (Military)

On January 17, 1966, when a US Air Force bomber carrying four hydrogen bombs collided with a tanker off the coast of Spain, the tanker exploded and explosives in two of the hydrogen bombs detonated when the bomber hit the ground. Plutonium and other radioactive material was scattered across a 2-square-kilometer area in an agricultural region dotted with villages (Schwartz).

Despite joint decontamination efforts by US personnel and the Spanish Civil Guard, the level of contamination was never confirmed and villagers were only sporadically monitored. The reason was mainly that protocols for an accident in a hilly civilian region were never established (at the time, protocols only for the flat desert regions in which nuclear bombs were tested existed).

If either device had detonated, it would have produced a yield of 70 kilotons to 1.45 megatons; the maximum yield would have been 2.8 to 5.8 megatons in total (Schwartz). Given the similar yields, detonations in this event would have had similar consequences to a detonation in the Goldsboro incident: property destruction and burns to the nearby population. The fission sequence triggering the fusion sequence would also cause radioactive contamination. This incident could have been prevented by checking the planes thoroughly and implementing damage control techniques for the plutonium bombs.

Baneberry Incident (Military)

On 18 December 1970, US military conducted an underground nuclear weapons test in Yucca Flat, Nevada, since the Partial Nuclear Test Ban Treaty (1963) forbade atmospheric, outer space, and underwater nuclear testing. After the test, as a result of a faulty venting system, 80,000 curies of radioactive iodine-131 leaked out of the test site and into the atmosphere, later raining down (Preparatory Commission for the Comprehensive Test Ban Treaty Organization & United States Department of Energy).

The bomb's yield was 10 kilotons. Although nobody got radiation poisoning, radioactive fallout affected eighty-six workers at the test site, two of whom later died from leukemia (Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization). In addition, winds carried radioactive dust into California, Oregon, and Washington State, potentially spreading it into rain clouds and causing radioactive materials to rain on the population or farmland. Given that no radiation would have leaked if the venting system had been intact, these damages could easily have been avoided if the venting problem had been identified and repaired prior to the test.

NORAD Incidents (Military)

On November 9th, 1979, the North American Aerospace Defense Command's Cheyenne Mountain site, the Pentagon's National Military Command Center, and the Alternate National Military Command Center in Fort Ritchie, Maryland all reported a massive Soviet nuclear attack. In response, US launched parts of its continental air defense force. It was later proved false by NORAD; in reality, a training scenario had been accidentally uploaded into the program (United States Department of Energy).

On June 3rd, 1980, a faulty computer chip created a scenario where the Soviet Union was again pointing missiles at the US. William Odom, an army general, originally alerted the National Security Advisor who was prepared to inform the president; however, he was soon notified of that the scenario was false (Lewis, Williams, Pelopidas, & Aghlani 2014). As a result of the previous incident, many officers did not believe in the report; however, if this incident were truly a Soviet attack this disbelief would have been fatal. These incidents could have been prevented by constantly checking systems, implementing more security procedures, and establishing independent systems.

The NORAD incidents can be attributed to technical mishaps; a full blown war with the Soviet Union was avoided through communication. However, although precautions were implemented after the first NORAD incident, a second incident still occurred. All in all, the NORAD incidents again prove that precautions may not be enough.

Damascus Incident (Civilian)

In 1980, in Damascus, Arkansas, when a technician performing routine maintenance on a Titan II missile accidentally dropped a wrench on the missile's fuel tank, the fuel tank exploded, blasting the attached nuclear warhead about 200 yards away (Koblentz 2014).

By sheer luck, the warhead itself, which contained the uranium and plutonium, was mostly intact, but if it had detonated, it would have exploded with a force of 9 megatons, destroying the entire town, inflicting damages and burns to neighboring farms and cities, and exposing neighboring populations to radioactive contamination.

Tomsk-7 (Scientific)

Tomsk-7 (also known as Seversk) was a secret city housing a uranium reprocessing complex. Run by the Soviet government, it produced fuel for Soviet nuclear weapons. On April 6, 1993, the complex sustained a serious accident in which overpressure caused uranium nitrate solution to burst out of a tank, resulting in an explosion. The most likely cause is that when nitric acid was added to uranium to be extracted, the operator did not add enough air to mix the compounds thoroughly. When the compounds subsequently settled into layers, the nitric acid oxidized the uranium in a highly exothermic and gas-releasing reaction (International Atomic Energy Agency).

Radioactive material leaked out through the ventilation system and through the side walls, causing limited radioactive contamination. Authorities took immediate action to contain the spread of contamination, rapidly decontaminating nearby land, allowing livestock to eat only imported feed, and immediately evacuating all children. A recent snowfall that absorbed much of the radiation probably aided decontamination (International Atomic Energy Agency).

There was no nuclear detonation, but radioactive fallout would have contaminated local agricultural fields, leeching into food and poisoning inhabitants. In addition, contamination in the air and water would have damaged civilian life expectancy and increase the rates of radiation-caused illnesses like cancers.

Black Brant Scare (Military)

On 25 January 1995, Norwegian scientists seeking to study the aurora borealis fired a rocket with scientific instruments over Russia with the intent of landing it in the North Pole. They had notified governments of the project, but radar technicians were not told about the rocket. Hence when Russian early warning radars detected it, they mistakenly deduced from its trajectory that the rocket might be a US Navy-launched Trident submarine missile and alerted the military. Yeltsin, Russian president at the time, was even presented with the "nuclear suitcase," which would have allowed him to launch a retaliatory nuclear missile. Fortunately, the scientists and Yeltsin soon determined that the rocket was heading away from Russia and posed no threat to national security (Lewis, Williams, Pelopidas, & Aghlani 2014).

Extrapolating from records on nuclear weapons test yields from the CTBTO Preparatory Commission, we find that if a fission bomb were fired, its yield would have been between 13 to 23 kilotons, and if a hydrogen bomb were fired, it would have detonated an explosion of between 200 kilotons and 56 megatons. Physical damages resulting from explosions of this magnitude would include property damage from the shockwaves, severe burns to civilian populations, and radiation poisoning and radioactive contamination. In addition, the blunder would potentially irreparably damage US-Soviet relations.

V. Proposed Future Response Plans

Our analysis of the aforementioned mishaps reveals that the underlying cause of many unfortunate nuclear situations can be tied to some form of carelessness. This carelessness may manifest itself in different forms, like accidents or misinformation, but at heart, carelessness is what allows the circumstances of an accident to exist, and carelessness is what leads people to neglect to mention information or use imprecise language.

Although carelessness was the underlying cause of these mishaps, different brands of carelessness were responsible for each. We can categorize these variations of carelessness as follows: misinformation close calls; incidents and accidents resulting from negligence; and completely unpredictable and unpreventable accidents. Of course, these categories overlap somewhat, but for the sake of clarity we will assign each mishap only to one category below.

Misinformation close calls resulted when, all systems operating correctly, a human provided incorrect data or information out of ignorance. This category applies to the NORAD incident and the Black Brant scare, both cases where the systems' functioned properly would actually have led to nuclear disaster if the incorrect information had not been found out in time. In the Black Brant scare, early-warning radar operators had not been informed that a Norwegian rocket was going to be launched over the area and, mistaking the rocket for a missile, alerted authorities, who in turn activated the national notification system. The line of alert functioned properly, ultimately reaching President Boris Yeltsin, and would have ultimately produced the intended response—a retaliatory missile—*assuming that a missile had actually been fired*. However, the radar technicians responsible for diagnosing the foreign object in the airspace had lacked the crucial piece of information that the object was in fact a scheduled civilian rocket. Clearly, in this case miscommunication nearly compromised the world's nuclear security. Although the NORAD incident is less evidently a result of misinformation, the missile warning systems tipped off in that incident had received inaccurate data about the number of incoming missiles, and thus wrong information, whether it was from an exercise tape on the US side or from a malfunctioning computer chip on the Soviet side.

Negligence close calls resulted in cases of equipment or procedural failure caused by a problem not diagnosed in time. The widespread contamination following the Baneberry incident resulted from a failure in the venting system, part of the mechanical safety apparatus. Safety mechanisms embedded in procedures failed in the case of Tomsk-7, when an operator failed to perform a volatile chemical reaction according to all standard procedures, causing the explosion that caused widespread contamination. Arguably, the Demon Core incidents and the Damascus incident also belong to this category. Though Daghlian and Slotin's mistakes were undoubtedly unpredictable, the circumstances allowing these mistakes to cause significant radiation damage were completely preventable with the implementation of proper safety protocols. In fact, after the first incident, safety protocols were implemented, but clearly they failed to prevent a second recurrence of much the same mishap, representing one form of negligence. The same can be said of the Damascus incident: Although, again, dropping a wrench is unpredictable and understandable, it is not impossible to prevent if the circumstances under which a wrench's puncturing layers of protection are averted in the first place. The failure to do so suggests a design flaw, a failure in the procedure of designing safety features.

Lastly, some close calls were, if not genuinely unforeseeable and unpreventable, extremely difficult to prevent. As long as bombs are carried in aircraft and as long as multiple pieces of aircraft can be present in a given airspace at a given time, even if all safety protocols are followed to the letter and all equipment functions correctly, one cannot reduce the possibility of a single-plane accident or a multi-plane crash to zero. The Palomares and Goldsboro incidents, the former involving an unexpected plane crash and the latter involving an unlikely plane breakup, fall under this category.

Many of these instances could have been prevented with greater precision and diligence in delivering instructions and messages, and with greater attention to execution in equipment maintenance and design procedures. However, the risk of utterly unforeseeable accidents will remain nonzero, even if we curtail it to the best of our ability. It may seem unreasonable to demand demanding absolute perfectionism of the international community, enmeshed in an increasingly intricate network of policy interactions. Nevertheless, the consequences of even a single realized mishap are too drastic for us to consider leaving even one incident unprevented. Our analysis suggests that based on our precedents, to minimize risk as much as possible and to ultimately achieve zero risk of a nuclear mishap, we must approach it from multiple angles. First, we must target the root cause of carelessness by educating and training the people who might be potential agents of carelessness. And next, we must reduce the danger of, and ultimately eliminate, the circumstances that allow carelessness to have such dramatic consequences.

To address the immediate problem of accidents, individual governments should promote by both funding and implementing worker safety and information programs that involve not only training in best technical practices but also constant reminders of the consequences of an accident. Also, bearing in mind that the consequences of a nuclear accident will exist as long as nuclear weapons also continue to exist, both individual governments and international bodies must continue to enforce nonproliferation. It will be difficult, considering that national security is an increasingly pressing concern particularly for South Korea and Japan, non-nuclear-weapon states that feel increasingly threatened by a nearby potentially weapon-holding state (North Korea). However, we must bear in mind the prisoners' dilemma: As long as one state holds nuclear weapons, every state will feel obliged to hold them, but if no state held nuclear weapons then nobody would feel the need to hold them.

Considering that nonproliferation only stops the *spread* of nuclear weapons and does not actually strip down arsenals, we recommend a third branch of policy: accelerating disarmament by creating incentives for governments to strip down their arsenals. After the Cold War, both US and Russia made significant progress in reducing their nuclear arsenals. But despite the progress, more work is needed towards the goal of "global zero" and nuclear disarmament. Additional steps to further reduce the risks posed by nuclear weapons and work towards the path of abolition of nuclear weapons may include:

- Reducing United States reliance upon nuclear weapons in national security—President Obama is the first president to make nuclear disarmament a centerpiece of American defense policy. He had pledged in 2009 to "reduce the role of nuclear weapons in our national security strategy" (Futter 2011).
- Reducing the number of deployed long range weapons in the United States and Russia. Both United States and Russia do not need the high arsenal of nuclear weapons. The Pentagon has determined that US does not need more than 1,000 deployed nuclear warheads, irrespective of Russia's policy (Union of Concerned Scientists 2015).
- Reducing the number of stored weapons and dismantling them. Currently there are no treaty limits on nuclear weapons in storage. US uses the stored weapons as a "hedge force" to increase its deployed arsenal if needed under any circumstances. To overcome

this challenge, future treaties should consider setting a limit on the total number of deployed and stored weapons (Union of Concerned Scientists 2015).

- Speeding up the dismantlement of retired warheads to make reductions less easily reversible. Currently, the United States and Russia together have approximately 6,000 retired nuclear warheads that are waiting to be dismantled. These stored weapons are intact and could be returned to service any time, posing a huge risk to GNV (Union of Concerned Scientists 2015).
- Eliminating the remaining short-range battlefield weapons.
- Taking ballistic missiles off hair-trigger alert, especially the land-based missiles, to reduce the chance of an accidental or erroneous launch (Union of Concerned Scientists). The benefits of such an action are multifold. First, such a policy would prevent a "re-alerting race." Second, a high alert status is not needed for deterrence or "nuclear warfighting," so its elimination would reduce time pressured presidential decision-making in the case of a crisis. Finally, the United States' decision to take missiles off high alert could affect the internal Chinese debate and influence China to refrain from putting its own nuclear weapons on high alert.

VI. Conclusion

We can conclude with certainty from the prior nuclear mishaps case studies that there is a high probability of a nuclear war due to accidental launch and human or technical error. Moreover, we are also witnessing deliberate acts of terrorism in today's world. The development of high-alert ICBMs, the trend towards modernization of nuclear weapons, the creation of smaller and stealthier weapons are increasing the diplomatic tension. The threats to increasing GNV are very real, and we should choose to cooperate and work together towards the abolition of nuclear weapons to avoid their catastrophic consequences.

VII. References

1. Allison, G. (2015). The Cuban Missile Crisis at 50: Lessons for US Foreign Policy Today. In *Masters of International Relations*. Retrieved from https://www.foreignaffairs.com/articles/cuba/2012-07-01/cuban-missile-crisis-50 (Reprinted from *Foreign Affairs*, *91*(4), 11-16, 2012, July/August)
2. American University, Washington, D.C. (n.d.). *Lucky Dragon Incident* [Fact sheet]. Retrieved January 31, 2016, from http://www1.american.edu/ted/lucky.htm
3. [Area of radioactive contamination from the Palomares incident]. (2012, October 22). Retrieved from http://ichef.bbci.co.uk/news/624/media/images/63308000/gif/_63308854_palomares_bombs_624.gif
4. Atomic Heritage Foundation. (n.d.). *Harry Daghlian* [Fact sheet]. Retrieved January 31, 2016, from http://www.atomicheritage.org/profile/harry-daghlian
5. Atomic Heritage Foundation. (n.d.). *Louis Slotin* [Fact sheet]. Retrieved January 31, 2016, from http://www.atomicheritage.org/profile/louis-slotin
6. Broad, W. J., & Sanger, D. E. (2016, January 11). As U.S Modernizes Nuclear Weapons, 'Smaller' Leaves Some Uneasy. *The New York Times*. Retrieved from http://www.nytimes.com/2016/01/12/science/as-us-modernizes-nuclear-weapons-smaller-leaves-some-uneasy.html?_r=0
7. de Montmollin, J. M., & Hoagland, W. R. (1961, February). *Analysis of the Safety Aspects of the MK39 Mod 2 Bombs Involved in B-52G Crash near Goldsboro, North Carolina* [PDF]. Retrieved from http://nsarchive.gwu.edu/nukevault/ebb475/docs/doc%205%20AEC%20report%20Goldsboro%20accident.pdf
8. EUCOM History Office. (2012, January 23). January 25, 1995—The Norwegian Rocket Incident. Retrieved January 31, 2016, from United States European Command website: http://www.eucom.mil/media-library/article/23042/this-week-in-eucom-history-january-23-29-1995
9. Fallout from the Baneberry test [Map]. (n.d.). Retrieved from https://www.ctbto.org/specials/testing-times/18-december-1970-the-baneberry-incident/
10. Foster, P., & Lawler, D. (2015, April 30). Generals Call On US and Russia To End To Nuclear Hair-Trigger. Retrieved from http://www.telegraph.co.uk/news/worldnews/northamerica/usa/11575200/Generals-call-on-US-and-Russia-to-end-to-nuclear-hair-trigger.html
11. Futter, A. (2011, November). *Obama's Nuclear Weapons Policy In a Changing World*. Retrieved from http://www.lse.ac.uk/IDEAS/publications/reports/pdf/SR009/futter.pdf
12. Gertz, B. (2015, September 2). Russia's Nuclear Weapons Buildup Challenges Obama's Reduction Goal. Retrieved April 2, 2016, from http://www.washingtontimes.com/news/2015/sep/2/inside-the-ring-russias-nuclear-weapons-buildup-ch/?page=all
13. International Atomic Energy Agency. (1998). *The Radiological Accident in the Reprocessing Plant at Tomsk* [PDF]. Retrieved from http://www-pub.iaea.org/mtcd/publications/pdf/p060_scr.pdf

14. Jones, P. F. (1969, October). *Goldsboro Revisited; or, How I Learned to Mistrust the H-Bomb*. Retrieved from http://www.theguardian.com/world/interactive/2013/sep/20/goldsboro-revisited-declassified-document
15. Koblentz, G. D. (2014). Command and Combust: America's Secret History of Atomic Accidents [Review of the book *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety*, by E. Schlosser]. *Foreign Affairs*, *93*(1). Retrieved from https://www.foreignaffairs.com/reviews/review-essay/command-and-combust
16. Kristensen, H. M., & Norris, R. S. (2015, September 28). Status of World Nuclear Forces. Retrieved January 21, 2016, from Federation of American Scientists website: http://fas.org/issues/nuclear-weapons/status-world-nuclear-forces/
17. Kuhn, S. (2014). Prisoner's Dilemma. In *Stanford Encyclopedia of Philosophy* (Fall 2014 ed.). Retrieved from http://plato.stanford.edu/entries/prisoner-dilemma/
18. *The Prisoner's Dilemma and the Problem of Cooperation*. (n.d.). Retrieved from http://www.baselpeaceoffice.org/sites/default/files/imce/articles/News/nuclear_prisoners_dillemma.pdf
19. Lewis, P., Williams, H., Pelopidas, B., & Aghlani, S. (2014, April). *Too Close for Comfort Cases of Near Nuclear Use and Options for Policy*. Retrieved from https://www.chathamhouse.org/publications/papers/view/199200
20. Los Alamos National Laboratory. (1945, October 2). [Recreation of the 1945 Los Alamos criticality incident]. Retrieved from https://upload.wikimedia.org/wikipedia/commons/1/13/Partially-reflected-plutonium-sphere.jpeg
21. [Nikita Sergeyevich Khrushchev and John Fitzgerald Kennedy at the US embassy in Vienna]. (1961). Retrieved from Britannica Image Quest database.
22. Operation Crossroads. (n.d.). Retrieved March 6, 2016, from Atomic Heritage Foundation website: http://www.atomicheritage.org/history/operation-crossroads
23. Preparatory Commission for the Comprehensive Test Ban Treaty Organization. (n.d.). *18 December 1970—The Baneberry Incident* [Fact sheet]. Retrieved January 31, 2016, from https://www.ctbto.org/specials/testing-times/18-december-1970-the-baneberry-incident/
24. Preparatory Commission for the Comprehensive Test Ban Treaty Organization. (n.d.). *1 March 1954—Castle Bravo* [Fact sheet]. Retrieved January 31, 2016, from https://www.ctbto.org/specials/testing-times/1-march-1954-castle-bravo
25. *The Prisoner's Dilemma and the Problem of Cooperation*. (n.d.). Retrieved from http://www.baselpeaceoffice.org/sites/default/files/imce/articles/News/nuclear_prisoners_dillemma.pdf
26. Raphael, T. J. (2016, January 15). Why President Obama is Moving Ahead With the Biggest Modernization of US Nuclear Weapons in Decades. Retrieved from http://www.pri.org/stories/2016-01-15/why-president-obama-moving-ahead-biggest-modernization-us-nuclear-weapons-decades
27. Russian nuclear accident opens up military complex. (1993). *Nature*, *362*(6421). Retrieved from ProQuest Research Library database. (Accession No. 8464506, 01516611)

28. Schmalz, D. (2013, October 10). Eric Schlosser burrows into one of the US's biggest nuclear threats: our own weapons. *Monterey Country Weekly*. Retrieved from http://www.montereycountyweekly.com/content/tncms/assets/v3/eedition/6/7e/67efde51-5fbf-546c-81f1-57cdf0dbd788/5256e01211823.pdf.pdf
29. Schwartz, S. I. (n.d.). Broken Arrows: The Palomares and Thule Accidents. Retrieved January 31, 2016, from The Brookings Institute website: http://www.brookings.edu/about/projects/archive/nucweapons/box7-3
30. Spegele, B. (2016, March 18). China's Nuclear Plans Worry US *The Wall Street Journal*, p. A6.
31. Starr, S. (2008, Fall). High-Alert Nuclear Weapons: The Forgotten Danger. *Scientists For Global Responsibility*, (36). Retrieved from http://www.sgr.org.uk/publications/sgr-newsletter-no-36
32. Talesnik, D. (2015, January 16). Assessing Health Effects of Japan's Quake, Tsunami, Nuclear Accident. *NIH Record*, *68*(2). Retrieved from https://nihrecord.nih.gov/newsletters/2015/01_16_2015/story2.htm
33. The 3 A.M. Phone Call. (n.d.). Retrieved March 27, 2016, from The National Security Archive website: http://nsarchive.gwu.edu/nukevault/ebb371/
34. Types of Nuclear Weapons. (n.d.). Retrieved March 6, 2016, from Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization website: https://www.ctbto.org/nuclear-testing/types-of-nuclear-weapons/
35. Union of Concerned Scientists. (n.d.). *Reducing The Risk Of Nuclear War: Taking Nuclear Weapons Off High Alert*. Retrieved from http://www.ucsusa.org/nuclear-weapons/us-nuclear-weapons-policy/reducing-the-risk#.VwCxVfkrLIU
36. Union Of Concerned Scientists. (2015, February). *Success In Cutting US and Russian Arsenals*. Retrieved from http://www.ucsusa.org/sites/default/files/attach/2015/02/Cutting%20US%20and%20Russian%20Nuclear%20Arsenals.pdf
37. United States Department of Energy. (1971, May). *Baneberry Summary Report* (Technical Report No. TID—25931) (United States Atomic Energy Commission, Author) [PDF]. Retrieved from http://www.osti.gov/scitech/servlets/purl/4679984
38. University of North Carolina–Chapel Hill. (n.d.). The Full Story behind the Goldsboro Incident. Retrieved March 6, 2016, from http://www.ibiblio.org/bomb/story.html
39. US Air Force. (1961). [Close-up of one of the bombs involved in the Goldsboro incident]. Retrieved from https://upload.wikimedia.org/wikipedia/commons/b/b0/Goldsboro_Mk_39_Bomb_1-close-up.jpeg
40. US Department of Energy. (1954, March 1). *Nuclear weapon test Bravo on Bikini Atoll.* [Photograph]. Retrieved from https://upload.wikimedia.org/wikipedia/commons/5/5d/Castle_Bravo_Blast.jpg
41. US Department of State Office of the Historian. (n.d.). *The Cuban Missile Crisis, October 1962* [Fact sheet]. Retrieved January 31, 2016, from https://history.state.gov/milestones/1961-1968/cuban-missile-crisis
42. Wikimedia. (n.d.). [Baneberry Plume]. Retrieved from https://upload.wikimedia.org/wikipedia/commons/b/b2/Operation_Emery_-_Baneberry.jpg