An Assessment of North Korea's Nuclear Weapons Capabilities

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Abstract

In February of 2013, North Korea conducted its third nuclear weapons test. Speculations are that this test was conducted to further develop a warhead small enough to fit on an intercontinental ballistic missile. This test further strained North Korea's relationship with the international community. North Korea has continued to make steps towards advancing its military capabilities using nuclear weapons, and has even threatened an attack on U.S. soil. The steps that North Korea are currently taking could have detrimental effects on the stability of the region.

The role of enrichment technology in the production of nuclear weapons material and the history of North Korea's nuclear program is described. The effect of a nuclear weapons attack on the United States is presented and analyzed. The number of casualties could be or is estimated to be on the order of several thousand people, in addition to the destruction of infrastructure.

Although a highly unlikely scenario, these calculations have implications for future policy decisions. This discussion shows the importance of verifying North Korea's nuclear program. Verification would facilitate a better relationship between North Korea and the international community. This could lead to economic support and security assurances for North Korea. Furthermore, it would help the United States avoid a potential attack.

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1 Introduction

The ability to enrich uranium greatly increases the ability of a country to manufacture nuclear weapons. Uranium enrichment is a major issue for international nuclear policy and security. At present, there is particular interest in North Korea's uranium enrichment program.

Over the years it has been difficult to truly determine the extent of North Korea's nuclear program. From facilities to nuclear tests, the Democratic People's Republic of Korea (DPRK) has made very clear that it will reveal information on its own terms. Furthermore, because the international community has significant doubts about the capabilities of this program, this allows North Korea to conduct space launches and nuclear tests as a way to provoke fresh concern.

There are a variety of paths that North Korea could take in the next 5 to 10 years. The uranium enrichment program would allow them to produce nuclear weapons using highly enriched uranium (HEU). The HEU could then be used for warheads on intercontinental ballistic missiles (ICBMs) that could have the potential to reach the contiguous United States (CONUS).

The first part of this thesis focuses on North Korea's nuclear program history. Enrichment technology is discussed here to signify the difficulty in estimating the purpose and capability of such a program. The next section focuses on the current status of the program and the stockpile of the materials produced over the years. The final section focuses on a hypothetical attack on the CONUS, its effects, and implications.

Although the likelihood of such an attack may be very low, based on DPRK capability and likelihood of devastating U.S. retaliation, it is important to recognize the effects of such an attack. These effects have major implications on policy as the United States assembles defense measures and prepares strategies for attending to North Korea.

2 Enrichment Technology

In the past, gaseous diffusion and plutonium production were methods used to acquire the fissile material needed to fabricate a nuclear weapon. However, uranium enrichment has become more popular. The technology most used for this process is the gas centrifuge. The gas centrifuge is the most economically efficient way to enrich [1]. However, its properties allow it to easily be transformed and used for non-peaceful purposes, such as the production of HEU for nuclear weapons.

The gas centrifuge uses centrifugal force to separate chemically identical isotopes by the variation in isotopic weight. To do this, a hollow cylindrical tube is spun at very high speeds about its axis. This creates a product stream and waste stream. However, a single centrifuge cannot simultaneously produce useful enrichment levels and product flow rates. Thus, centrifuges are connected in cascades. Connecting the centrifuges in series allows the enrichment level to be increased, and connecting the centrifuges in parallel, allows the product flow rate to be increased. In the cascade, each row of parallel centrifuges is called a stage. The number of stages is determined by the performance of each centrifuge and the desired enrichment level [1].

Unfortunately, there are two specific properties of centrifuges that make safeguards difficult, rapid breakout and clandestine plants. Rapid breakout is the speed with which any peaceful-use plant can be converted to non-peaceful purposes. As described in Wood, Glaser, and Kemp, "even for a first-generation centrifuge, the gas needs only to pass through a series of 30-40 stages to reach the high enrichment levels used in nuclear weapons. The combination of few total stages with the short equilibrium time per stage produces a breakout time line that is also small. A cascade designed to produce low-enriched uranium for fuel can be re-fed its low-enriched product and begin converting it to highly enriched uranium suitable for weapons use in a matter of days – a procedure called batch recycling. Alternatively, the machines can be reconfigured into a narrower but longer cascade with more stages, a process that requires additional time before production of highly enriched uranium can begin but is more efficient than batch recycling [1]." This allows the proliferating country the opportunity to produce HEU before the international community has a chance to act. Also, Wood, Glaser, and Kemp state that, "compared with nuclear reactors and large gaseous-diffusion plants, a centrifuge plant uses little electricity and produces little detectable signal, so it is much easier to hide the plant and evade safeguards altogether [1]." These characteristics make it hard to distinguish centrifuge plants from normal industrial facilities. Thus, allowing a non-proliferating state to quickly become a proliferating state without any indications of this action to the international community.

3 North Korea's Nuclear Program

This section gives an overview of the history of North Korea's nuclear program.

Preparation for a Nuclear Program

North Korea's nuclear program did not appear to be a threat until the mid 1980s, when the weapons program emerged [2]. However, the beginning of the nuclear program is estimated to date back to the 1950s.

Using Korean labor, Moscow undertook uranium mining in northern Korea, as early as 1946. North Korea's earliest known interest in nuclear technology was for peaceful purposes and that their first discussions of nuclear weapons, including reported preparations for defense against nuclear attack, date from this period [3]. The DPRK's first generation of nuclear scientists were educated in Japanese universities during the 1930s and returned to Korea in the mid and late 1940s. These scientists ties to Japan provided North Korea with early access to nuclear expertise and technology. Some of the DPRK's earliest nuclear weapons research took place at the Atomic Energy Research Institute. The Atomic Energy Research Institute was founded in 1952 under its Academy of Sciences. Lee Sung-ki[1] was named the first director [3]. The first generation scientists then oversaw the training of a second generation of nuclear specialists, many of whom benefited from advanced training in the Soviet Union. Subsequent generations were trained in North Korea but also gained knowledge from international contacts [3].

In 1956, the Soviet Union and the DPRK signed agreements on the peaceful use of atomic energy and on research collaboration in nuclear science. Soviet documents also allude to an

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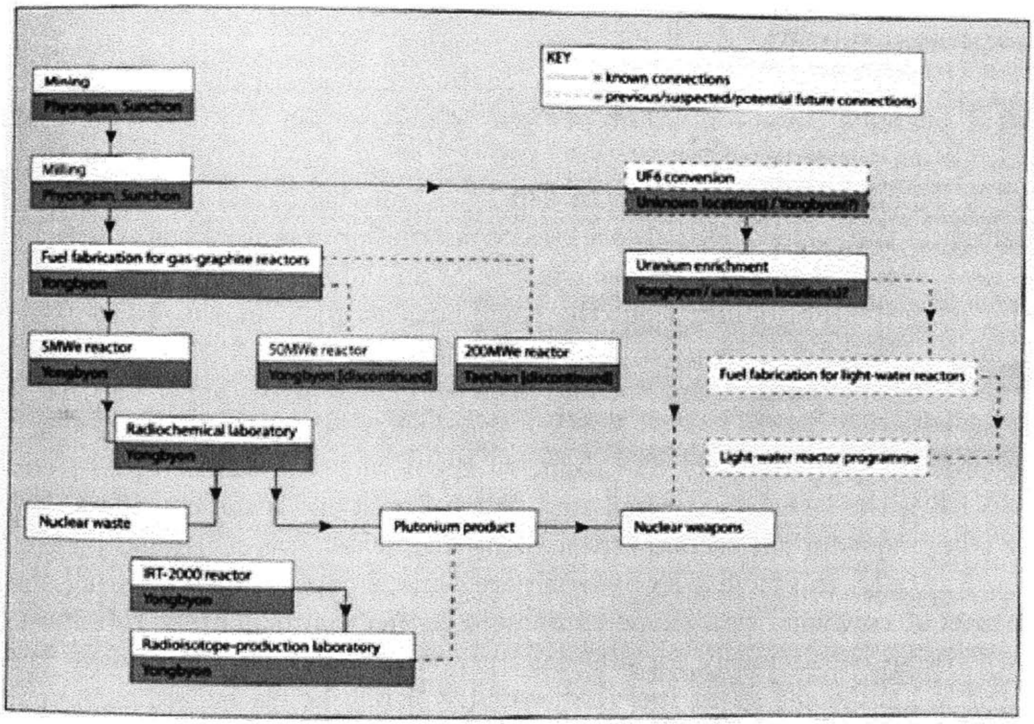
[1] Lee Sung-ki is a chemist best known for the invention of vinalon, also know as 'juche fibre' in the DPRK.

inquiry from Pyongyang on the provision of power reactors [3]. In September 1959, they signed a protocol enabling joint nuclear projects. This included planning for nuclear activities near Yongbyon, which was designated as a Special District of the State Administrative Council and thus contained more tightly controlled access [3].

The Atomic Energy Research Center was established in Yongbyon in November 1962. The Soviet Union transferred an IRT-2000 2MWt research reactor and additional equipment. Additional facilities were built including a radio chemical lab for isotope separation and waste storage sites. All of these facilities were constructed according to Soviet-supplied blueprints, with total costs in 1962 estimated at a U.S. $500 million [3].

The Buildings of the Nuclear Program

In 1980, Pyongyang started a major campaign to build a series of industrial-scale nuclear facilities that were intended to produce weapons grade plutonium and nuclear energy. This program was comprised of three gas-cooled, graphite-moderated, natural uranium fueled reactors. Figure 1 shows an overview of North Korea's nuclear program.



[4]

Figure 1: North Korea's nuclear program

North Korea began mining uranium at various locations in the late 1970s or early 80s. The raw uranium-bearing ore was shipped to milling factories, processed to produce uranium ore concentrate or 'yellowcake', and then transported to the Yongbyon Nuclear Research Center for further processing and fabrication. Typically, one tonne of North Korean uranium ore contains about one kilogram of uranium [4]. Therefore, about 50,000 tonnes of ore had to be mined and processed in order to obtain 50 tonnes of the natural uranium needed for the initial fuel load for the 5MWe reactor [4]. Between 1980 and 1985, North Korea built a factory at Yongbyon that would refine yellowcake and produce uranium metal fuel elements for its graphite-moderated reactors. According to North Korean officials, in 1992, the plant was producing roughly 100 t of uranium fuel per year, equal to approximately 16,000 fuel assemblies [4].

The 5MWe research reactor was operated from 1986 to 1994, when it was shut down under the Agreed Framework. However, the operational history of the reactor during this time is shrouded in mystery. From April to May 1989, the reactor was reportedly shut down to remove a few hundred damaged fuel rods. North Korea claimed that after the fuel removal, the reactor was able to operate more regularly at 20 MWt, close to full power. During the initial International Atomic Energy Agency (IAEA) inspections in April 1992, North Korea claimed that about 17kg of plutonium had been produced. By the time the reactor was completely de-fueled, the spent fuel probably contained about 25-30 kg of plutonium. In theory, operating at full power for 300 days per year, this reactor could produce approximately 7.5 kg of weapons grade plutonium annually in the discharged spent fuel. Actual annual plutonium production would depend on the fuel's irradiation level, which is a function of the reactor's power level and the number of days per year that it was operational [4].

The DPRK also started to construct larger reactors. In 1984, North Korea began constructing a 50 MWe reactor at Yongbyon. This reactor was theoretically capable of producing about 55 kg of weapons grade plutonium per year. Construction also began on a 200 MWe, which was a full-scale version of the 50 MWe reactor. If operated at full power, this reactor is theoretically capable of producing up to 220 kg of weapons grade plutonium. However, with the signing of the Agreed Framework, this construction was frozen [4].

Also in 1984, North Korea began construction of an industrial-scale reprocessing plant. Reprocessing separates plutonium from the spent nuclear fuel. at the Yongbyon Nuclear Research Center. The reprocessing purpose was confirmed by the IAEA in 1992. The IAEA also discovered that one reprocessing line had been completed at the plant and that a second was under construction. According to North Korean officials, at that time, the facility was designed to process approximately one tonne of spent fuel over three days of continuous operation. In 1994, the IAEA discovered that North Korea had made considerable progress in installing equipment for the second reprocessing line, which was scheduled for completion in 1996. Theoretically, the facility's one completed line is capable of processing the 5MWe reactor's entire 50t core load in a single campaign, lasting approximately 150 days. If both lines were operating continuously for 300 days per year, the plant would have been more than sufficient to handle the spent fuel that would typically be discharged each year by the 5MWe and 50 MWe reactors [4].

North Korea and the International Atomic Energy Agency

Pyongyang acceded to the Non-Proliferation Treaty (NPT) on April 18, 1985. From 1992 to 1993, the IAEA conducted six inspections. As previously stated, North Korea informed the IAEA as part of the initial inspection process that it had conducted a one-time plutonium extraction experiment on "damaged" fuel rods removed from the 5 MWe reactor in 1989. The IAEA was given access to the small amount separated. The small amount was approximately 90 grams, or less than 1/40th of the amount required to build a nuclear device [2]. The

IAEA's chemical analysis of the samples, however, contradicted North Korea's claims that it had previously separated only the 90 grams of plutonium on one occasion. Instead, the IAEA results indicate that the North had separated plutonium in four campaigns over a three-year period, starting in 1989. On February 11, 1993, Hans Blix officially requested a "special inspection" of the two suspected waste sites, marking the first time in the IAEA's history that it had used its right to conduct such visits. Although these sites had been visited by the IAEA during the third inspection in September 1993, North Korea did not permit full access to the sites, which were not included in its "initial declaration." Ten days later, North Korea's Atomic Energy Minister informed Blix that the DPRK was refusing the IAEA's special inspection request. On March 12, North Korea stated through letter, that it was exercising its right of withdrawal from the NPT, to take effect in 90 days. After a round of negotiations with the United States in June 1993, North Korea agreed to "suspend" its withdrawal one day short of the 90-day countdown. However, North Korea asserted that it was no longer a full party to the NPT and that the IAEA no longer had the right to conduct even normal routine and ad hoc inspections. In the following months, Pyongyang severely constrained the IAEA inspection activities that were needed to preserve the "continuity of safeguards." This led Blix to declare in December 1993 that IAEA safeguards in North Korea could no longer provide "any meaningful assurances" that nuclear materials were not being diverted to weapons uses.

In March 1994, as part of a complicated package deal with the United States, North Korea initially agreed to an IAEA inspection of its declared facilities, but it then blocked the IAEA from taking key radioactive samples at the plutonium extraction plant at Yongbyon. The crisis escalated further in May 1994, when North Korea announced that it was going to defuel its 5 MWe reactor. The need for the IAEA to gain access to the fuel removed became of international concern for two reasons: 1) the fuel contained up to 30 kilograms of plutonium, and 2) getting access to the fuel and taking appropriate samples, the IAEA could determine whether the fuel had been in the reactor since its initial operation in 1986, or if the fuel was a second batch. If there was a second batch, this would indicate that North Korea had indeed removed an entire load of fuel from the reactor during the 1989 shutdown [2].

On October 12, 1994, North Korea signed the Agreed Framework. There were many terms in the agreement. Mainly, it required North Korea to freeze and eventually dismantle its nuclear facilities and eliminate its nuclear weapons capabilities in exchange for the construction of two modern nuclear power reactors. The nuclear facilities frozen were key facilities needed for the plutonium production program and included the uranium conversion and fuel fabrication plant, the 5 MWe, 50 MWe, 200 MWe reactors, and the reprocessing facility [4]. The agreement also required North Korea to remain a member of the NPT and to come into full compliance with its IAEA safeguards agreement once a "significant portion of the light water reactor (LWR) project is completed, but before delivery of key nuclear components." In return, the United States pledged not to use or threaten to use nuclear weapons against the DPRK. The agreement also included a North Korean commitment to implement the 1992 North-South Joint Declaration on the denuclearization of the Korean Peninsula, which banned uranium enrichment and plutonium reprocessing in the entire peninsula [2]. However, the IRT-2000 reactor and its related radio chemical laboratory were exempt from the freeze because they could be used to produce radioisotopes for medical and industrial purposes, but these facilities were subject to IAEA inspections. Furthermore, to verify that the facilities were not operating and that all construction had been terminated, the IAEA placed seals on the main access points, installed monitoring devices, and stationed a small team of resident inspectors at Yongbyon [2]. These inspectors were allowed to conduct short-notice inspections of different parts of the facilities subject to the freeze [4].

To supply North Korea with the two LWRs, which had a "target date" of 2003, an international consortium, the Korean Peninsula Energy Development Organization (KEDO) was formed. The countries that made up the organization at the beginning were the United States, Japan, and South Korea [4]. The concrete foundations of the first reactor were laid in August 2002. However, no significant nuclear components were delivered for the LWRs because North Korea was first required to account for its plutonium production prior to 1992. Although, the Agreed Framework did not require immediate North Korean compliance to account for the plutonium produced before 1992. After many discussions and the uncovering of North Korea's clandestine uranium enrichment program, the Agreed Framework collapsed in late 2002 [4]. KEDO stopped shipments of heavy oil to North Korea in December 2002 [5]. As a result, North Korea disabled IAEA monitoring equipment at the 5 MWe reactor, the spent-fuel storage pond and the reprocessing facility, expelled IAEA inspectors, and took steps to revive its plutonium production program. In April 2003, North Korea withdrew from the NPT [4].

Six-Party Talks

In an effort to resolve the crisis, six-party talks commenced in August 2003. The members of the group were the United States, South Korea, Japan, China, Russia, and North Korea. Two more rounds of six-party talks took place in 2004. In February 2005, North Korea decided to suspend indefinitely its participation in the six-party talks because they felt it was serving no purpose. North Korea's Ministry of Foreign Affairs explained that hostile bilateral relations, specifically the Bush administration's nuclear threat against the DPRK, the suggestion that military force could be used to depose the current government, and Secretary of State Condoleezza Rice's labeling of the DPRK as an "outpost of tyranny" caused this decision [5]. It was also announced at this time, because of Japan's increased hostility, that North Korea had built nuclear weapons for defensive purposes. In July 2005, with pressure from Beijing, North Korea decided to rejoin the six-party talks [5]. The six-parties issued a Joint Statement on how to achieve verifiable denuclearization of the Korean Peninsula, in September 2005 [6]. However, with the freezing of DPRK funds by the United States, the six-party talks were again boycotted in November 2005. This led to the testing of a nuclear device in October 2006 [5].

On February 13, 2007, North Korea reached an agreement with the other members of the six-party talks to begin the initial phase of implementing the Joint Statement. Phase 1 included the shut-down of plutonium production at the Yongbyon nuclear complex in exchange for an initial fuel oil shipment. Phase 2 included the disablement of facilities at Yongbyon and a "complete and correct" declaration of DPRK nuclear activities, in exchange for the delivery of fuel oil and the removal of the Trading with the Enemy Act (TWEA) and the State Sponsors of Terrorism (SST) designations. North Korea submitted a declaration of its past plutonium production activities in June 2008. With this, President Bush removed

North Korea from the TWEA list but would only remove the SST designation when North Korea agreed to verification provisions. However, North Korea did not accept initial U.S. verification proposals and threatened to restart reprocessing plutonium in September 2008. In October 2008, a bilateral agreement on verification was reached and North Korea was then removed from the SST list. Yet, the agreement was verbal, and North Korea claimed that it did not agree to sampling at nuclear sites. This sampling is a key element in verifying past plutonium production [6]. The six-parties met in December 2008, but did not reach an agreement on verification measures. Disablement at Yongbyon continued through April 2009, when North Korea expelled international monitors. Afterward, North Korea announced it would restart its reprocessing plant and boasted progress in uranium enrichment technology development. Soon after, North Korea tested another nuclear device. Six-party talks have not been held since spring 2009 [6].

4 Uranium Enrichment

Some experts believe North Korea's interest in enrichment technology dates back to the 1970s. North Korea's efforts of centrifuge procurement accelerated during the 1990s when they provided Nodong missiles to Pakistan in exchange for centrifuge parts and technology arranged through A.Q. Khan. According to former Pakistani President Pervez Musharraf, Khan transferred nearly two dozen centrifuges to North Korea along with "a flow meter, some special oils for centrifuges, and coaching on centrifuge technology, including visits to top-secret centrifuge plants [4]." Also, Khan reportedly provided a "shopping list" to North Korea, which would have enabled Pyongyang to purchase additional components directly from other foreign suppliers. An unclassified CIA report to U.S. Congress dated November 19, 2002, argued that by 2001 North Korea had begun "seeking centrifuge-related materials in large quantities" and had "obtained equipment suitable for use in uranium feed and withdrawal systems." The report also concluded that North Korea was "constructing a plant that could produce enough weapons-grade uranium for two or more nuclear weapons per year when fully operational, which could be as soon as mid-decade [7]." In April 2003, a shipment of aluminum tubing from a German company, intended for North Korea, was intercepted. In total, one North Korean procurement agent is known to have sought enough aluminum tubing for about 6,700 centrifuges. North Korea did manage to obtain 150t of tubing from a Russian company. This is approximated to be enough for 2,700 centrifuges, which are sufficient to produce about 55 kg of HEU annually, or about two nuclear weapons (assuming 25 kg of HEU needed for each device) [4].

In April 2009, North Korea claimed that it would begin enriching uranium. This uranium would be used to fuel their future LWR. In September 2009, the DPRK announced that their "experimental uranium enrichment [had] successfully been conducted to enter into completion phase." However, the technical implications of this statement were unclear until a year later. In November 2010, Siegfried Hecker and two Stanford University colleagues were invited to visit Yongbyon, where they were shown a modern-looking uranium enrichment facility. The facility contained approximately 2,000 centrifuges.[2] The enrichment capacity of the facility

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[2] This is the number claimed by North Korea. It is also the upper limit of how many would fit in the limited floor space [4].

was said to be 8,000 separative work units[3] (SWU) per year, or 4 SWU per machine. If true, this is double the capacity of Pakistan's P-1 centrifuge and slightly less than the 5 SWU design capacity of Pakistan's second-generation P-2 centrifuges. Intelligence agencies that debriefed Hecker concluded that the machines he saw were P-2s. North Korea's stated SWU capacity would be sufficient to produce about 2.5t of LEU in the form of UF_6 a year. This would be enough for the needs of the 25-30 MWe experimental LWR North Korea said it had built. However, Hecker judged that the centrifuges could be reconfigured to produce 30-40 kg of HEU annually, sufficient for at least one nuclear weapon. Hecker and others have also assessed that it is more likely that the centrifuge and related equipment had been assembled in another location, and then transferred to Yongbyon [4]. If this is the case the amount of uranium produced could be even greater depending on the capabilities of the other location.

5 Nuclear Tests

North Korea conducted underground atomic test at Phunggye in October 2006 and May 2009. A third nuclear test was conducted on February 12, 2013.

The first test on October 9, 2006, had a range of reported yields. Most estimates, based on seismic data, fell below 1 kiloton (kt). A press release from the Office of the Director of National Intelligence (ODNI), on October 16, stated that the detection of radioactive debris confirmed that a nuclear test had taken place, and that the yield of the explosion was "less than a kiloton". Hecker was later told by the Chinese Ministry of Foreign Affairs that China had been told that the expected yield would be around 4kt. The North Koreans told Hecker that only 2 kg of plutonium had been used in this test [4].

The second test, which took place on May 25, 2009, appeared to be more successful. Seismic data suggested that this device had achieved a higher yield, of up to 4 kt. However, unlike the detonation in 2006, no radioactive debris were detected. Although the 2009 test was more successful than the one in 2006, the expected yield was significantly smaller than the 10 - 20 kt range expected for a first generation, Nagasaki-type design. A comparison of the first tests of nuclear states is shown in figure 2. Various theories have been presented as explanations for the low yields of both tests. The theories presented in the text were: 1) North Korea used a small amount of plutonium in order to conserve its stockpile, 2) North Korea intended the tests to have a smaller yield so as to contain the blast more effectively, and 3) North Korea tested a design with an intentionally smaller yield and/or one which used less plutonium, so as to assist with the development of a warhead deliverable by ballistic missile [4].

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[3] The Separative Work Unit or SWU is a measure of work expended during an enrichment process. It factors in the feed material, the waste (or stripped) material, and the product (or enriched) material. Here, the unit is defined as SWU per year which refers to separative power. http://www.fas.org/programs/ssp/nukes/effects/swu.html

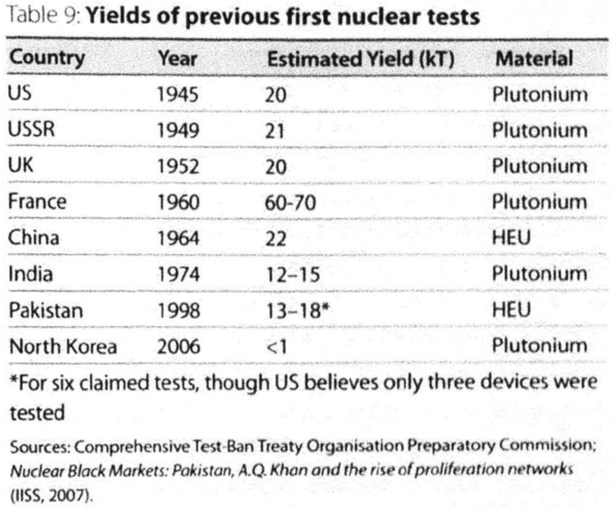


Table 9: **Yields of previous first nuclear tests**

Country	Year	Estimated Yield (kT)	Material
US	1945	20	Plutonium
USSR	1949	21	Plutonium
UK	1952	20	Plutonium
France	1960	60-70	Plutonium
China	1964	22	HEU
India	1974	12–15	Plutonium
Pakistan	1998	13–18*	HEU
North Korea	2006	<1	Plutonium

*For six claimed tests, though US believes only three devices were tested

Sources: Comprehensive Test-Ban Treaty Organisation Preparatory Commission; *Nuclear Black Markets: Pakistan, A.Q. Khan and the rise of proliferation networks* (IISS, 2007).

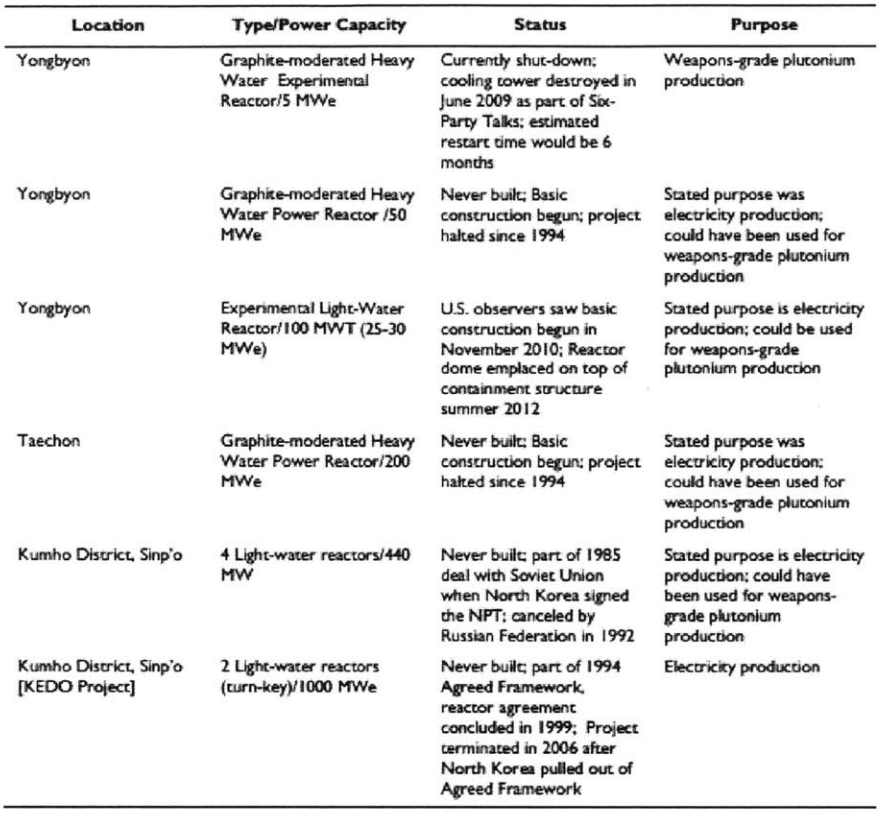
[4]

Figure 2: Comparison of the first nuclear tests yields. It is important to note how small the DPRK's yield was to that of the other states.

On February 12, 2013, a third nuclear test was carried out. The South Korean Ministry of Defense estimated that the test yield was between 6 and 7 kilotons. North Korea claimed that this test was to develop a "smaller and light" warhead. It is not known if this was a plutonium or uranium device, but it is assumed that this test would likely contribute to North Korea's ability to develop a warhead that could be mounted on a long-range missile [6].

6 Current Status of the Nuclear Program

North Korea openly acknowledged a uranium enrichment plant in 2009, but stated that its purpose was for the production of fuel for nuclear power. In November 2010, North Korea showed Hecker and colleagues, early construction of a 100 MWt (~ 33 MWe) LWR in addition to a uranium enrichment plant at the Yongbyon site. This topic will be discussed in the next section. No construction has occurred at the 50 MWe or 200 MWe gas graphite reactors built by the DPRK since 2002 [6]. Figure 3 shows the nuclear power projects that North Korea has worked on.



Location	Type/Power Capacity	Status	Purpose
Yongbyon	Graphite-moderated Heavy Water Experimental Reactor/5 MWe	Currently shut-down; cooling tower destroyed in June 2009 as part of Six-Party Talks; estimated restart time would be 6 months	Weapons-grade plutonium production
Yongbyon	Graphite-moderated Heavy Water Power Reactor /50 MWe	Never built; Basic construction begun; project halted since 1994	Stated purpose was electricity production; could have been used for weapons-grade plutonium production
Yongbyon	Experimental Light-Water Reactor/100 MWT (25-30 MWe)	U.S. observers saw basic construction begun in November 2010; Reactor dome emplaced on top of containment structure summer 2012	Stated purpose is electricity production; could be used for weapons-grade plutonium production
Taechon	Graphite-moderated Heavy Water Power Reactor/200 MWe	Never built; Basic construction begun; project halted since 1994	Stated purpose was electricity production; could have been used for weapons-grade plutonium production
Kumho District, Sinp'o	4 Light-water reactors/440 MW	Never built; part of 1985 deal with Soviet Union when North Korea signed the NPT; canceled by Russian Federation in 1992	Stated purpose is electricity production; could have been used for weapons-grade plutonium production
Kumho District, Sinp'o [KEDO Project]	2 Light-water reactors (turn-key)/1000 MWe	Never built; part of 1994 Agreed Framework, reactor agreement concluded in 1999; Project terminated in 2006 after North Korea pulled out of Agreed Framework	Electricity production

[6]

Figure 3: North Korean Nuclear Power Projects

The two projects that are currently being observed by the international community are the experimental LWR and the 5 MWe reactor. Satellite imagery from May to June 2012, shows construction progressing at the Yongbyon LWR [8]. As shown in figure 3, a dome was placed on top of the containment structure in the summer of 2012. In an article, the IAEA is quoted saying that "significant progress" had been made in the reactor's construction since its previous report in 2011. This progress also included indications that some components may have been installed inside the building and a system for pumping water from a river to the reactor for cooling purposes has also been built, the IAEA report said. Experts estimate that the reactor could be completed in the second half 2013 [9]. In addition to the work on the LWR complex, construction activity occurred on a series of buildings to the north of the LWR. Roofing was stripped off two adjacent buildings which were then combined into a single building with a common roof, which is visible in imagery taken on June 5, 2012 [8].

North Korea announced plans to restart the 5 MWe in April 2013, as shown in figure 3. Satellite imagery shows that in the six weeks prior to this announcement construction activity started at the 5 MWe reactor. From the imagery, there appears to excavation that is speculated to be related to replacing the sections of the secondary cooling loop that were cut and removed in accordance with the six-party agreement. It is also proposed that North Korea may simply connect the secondary cooling system to the pump house built for its new LWR which is located next to the old reactor, instead of building a new cooling tower [10].

Other facilities have also had construction activities. The fuel fabrication facility, which houses a gas centrifuge plant, in a February 3, 2012 image showed three building under construction. In the June 5, 2012 image, one of the buildings appeared completed while construction continued on the other two buildings. Construction was also seen on February 3, 2012, taking place at the radiochemical lab, which was used to separate plutonium from irradiated fuel. The image shows a clear patch on the roof of one of the support buildings, which suggests a source of considerable heat under that part of the roof. In later images, that section of the building does not show any distinguishing factors. It is speculated that this building may store hot radioactive waste or have another source of heat [8].

Stockpile

This section discusses the estimates of the production of weapons grade material will be discussed.

Plutonium Production

A great deal of uncertainty remains concerning the amount of plutonium produced by North Korea before 1992 [4]. A reasonable conclusion is that no more than 10 kilograms of plutonium were separated prior to 1994. Until 2003, the bulk of plutonium produced by North Korea remained in almost 8,000 irradiated fuel rods, stored in a pond near the 5 MWe reactor and subject to monitoring by the IAEA. Since restarting the Radiochemical Lab in 2003, North Korea is believed to have reprocessed most of the 8,000 irradiated fuel rods [11].

The amount of plutonium in a natural-uranium fueled core can be estimated with the following equation:

$$\text{Plutonium} = P * C * 365 * 0.9\text{x}10^{-3} \tag{1}$$

where P is the reactor's thermal power in MW_t, C is the capacity factor[4] times the number of days the reactor runs per year[5], and the last factor is a standard plutonium conversion factor in $\text{kg/MW}_\text{t}\text{d}$ for a gas-graphite reactor when the plutonium is weapons grade [12].

During the six-party disablement process in 2008, North Korea declared that it had about 30 kilograms of separated plutonium. This net value reflected plutonium consumed by the 2006 underground test and the inevitable loss of some plutonium in the operation of the plutonium separation plant. The last reactor core reportedly contained about 8 kilograms of plutonium, increasing North Korea's declared total to 38 kilograms prior to the 2009 test. Subtracting the estimated amount used for the test, the DPRK is estimated to have a stock of 34-36 kilograms of plutonium for nuclear weapons [13].

Furthermore, the LWR is estimated to be 100 MWt, or 4 to 5 times larger than the existing Yongbyon reactor, which could produce about 20 kilograms of weapons grade plutonium per year [13].

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[4] The capacity factor represents the ratio of the total annual heat output to the annual heat output based on continual full-power operation. This ratio is often stated to be the fraction of the year that the reactor operates at full power [12].

[5] This factor can be changed based on the number of days the reactor is running, this specific equation studies the annual production of weapons grade plutonium [12].

Uranium Production

It is very difficult to estimate the amount of uranium, especially weapons grade uranium (WGU), without knowing specifics about the facility. North Korea has stated that the plant's total enrichment capacity is 8,000 separative work units per year. With 2,000 centrifuges, the average would be 4 SWU per year per centrifuge. This could produce approximately 40 kg of HEU per year [13]. Assuming that the North Korea acquired HEU for 3 years and that each weapon would need about 25 kg of material, this would allow North Korea to have approximately 4 nuclear weapons that it could use on it's ICBMs.

7 Scenario

This is a hypothetical example of the outcome of a nuclear attack on the city of Los Angeles, California. The selection of this city was chosen mainly for location and the fact that it is the second most populated city in the United States.

Weapons Delivery

Missile History

North Korea has conducted a number of missile tests. In April 2005, the DIA's director stated in a congressional testimony that the Taepodong-2 could potentially deliver a nuclear warhead to the United States. In March 2009, the Defense Intelligence Agency (DIA) director stated that "North Korea may be able to successfully mate a nuclear warhead to a ballistic missile." Two years later the new director testified that North Korea could "have several plutonium-based warheads that it can deliver by ballistic missiles and aircraft as well as by unconventional means [4]." In June 2009, Postal and Wright said of North Korea's ballistic missile capability that if the Unha-2 was designed to launch a relatively lightweight satellite, its structure may not allow it to carry a 1,000 kilogram warhead. If it could carry this weight, the estimate is that it could have a range of 10,000 to 10,500 kilometers, allowing it to reach Alaska, Hawaii, and roughly half of the lower 48 states. If a 1,000 kilogram payload were launched by the first two stages of the missile, it could have a range of 7,000 to 7,500 kilometers. This would limit the range to only Alaska and parts of Hawaii [14].

In December 2012, North Korea, after many failed attempts, finally boosted a small satellite into orbit using a domestically assembled Unha-3 rocket. Susan Rice, the U.S. ambassador to the United Nations, in referencing this launch, asserted that North Korea had fired "a multistage rocket using ballistic missile technology." The technologies of space launchers and long-range ballistic missiles are very similar. Both use powerful rocket engines, high-strength and lightweight airframes, inertial navigation and guidance units, and payload separation mechanisms. However, key features differentiate the two systems, apart from the payload itself. Of these features, one of the most important is re-entry technology. Protecting a long-range missile's payload from the extreme heat and structural loads experienced during re-entry requires the development and production of special material. This material must be tested and validated under real conditions. Thus, the universal trend has been to convert ballistic missiles into space launchers, not the opposite. However, it is stated that North

Korea could contemplate using the Unha-3 as the basis for an ICBM [15]. If North Korea were able to further develop this technology, it is possible that this ICBM could reach the United States.

Postulated Delivery Vehicles

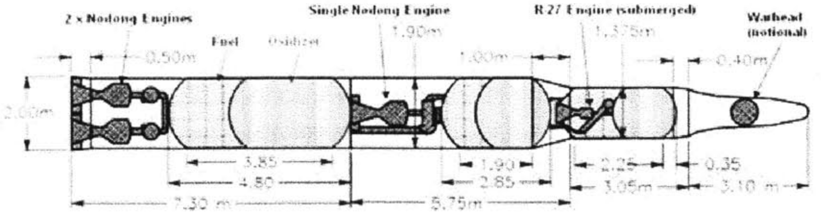
Currently, the missile that is assumed to be used to target the United States is the KN-08 ICBM. This was the missile displayed at the military parade in Pyongyang on April 15, 2012. Although, it is assumed that these displays were mock-ups, it is plausible that North Korea intends to build a road-mobile ICBM. In an article by John Schilling, he attempts to reverse engineer the design of an actual missile behind these mock-ups. These estimates are presented below and will be used as the basis for weapons delivery in this scenario [16].

From an image of one the several KN-08 missiles displayed, Schilling was able to estimate the dimensions of the missile and produce four different configurations based on the technology that North Korea has proven to possess or could possess in the near future. The first stage is assumed to use two Nodong engines. The R-27 engine is a submerged engine[6], and cannot be clustered without substantial redesign. However, Schilling presents a "KN-08D" option which uses a cluster of three modified R-27 engines in the first stage. The second stage could use a variety of engines. For the third stage, only the R-27 engine is considered because of the overall length of the upper stage. In all three stages, propellant tanks are assumed to fill all space not required by engine bays or other equipment, with a minimum of 5 cm dynamic clearance between engines and tanks of successive stages[7]. The dimension estimates and configurations are shown below in figure 4.

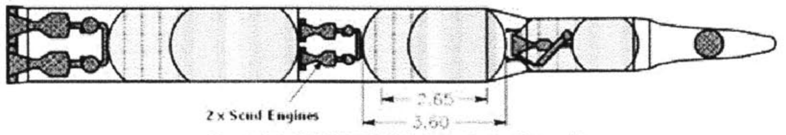
---

[6] A submerged engine is one in which the placement of the engine is within the fuel tank, this reduces the external dimensions. For more information on the structure of the R-27 engine, please see the article located here: http://www.b14643.de/Spacerockets_1/Diverse/R-27/

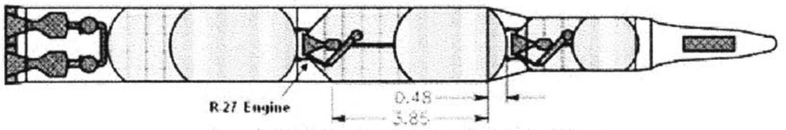
[7] For a detailed account of each configuration please see the article located here: http://lewis.armscontrolwonk.com/files/2013/01/Schilling-KN-08-Assessment-small.pdf



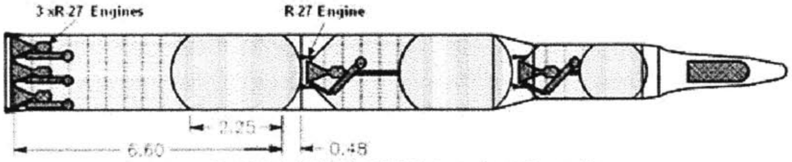
Postulated "KN-08A" internal configuration



Postulated "KN-08B" internal configuration



Postulated "KN-08C" internal configuration



Postulated "KN-08D" internal configuration

[16]

Figure 4: The Four Postulated KN-08 Configurations

For this scenario, the missile is assumed to launch from Musudan-ri as it does in Schilling's paper. To calculate the ground track of the missile the following equation is used:

$$\cos\Lambda = \sin L_o \sin L_T + \cos L_o \cos L_T \cos \Delta l \tag{2}$$

$$\Delta l = l_T - l_o$$

where Λ is the range angle (in degrees), range angle from the launcher to the target, L_o and l_o are the latitude and longitude of the launcher, and L_T and l_T are the latitude and longitude of the target. To get kilometers, the range angle is multiplied by 10,000 km/90° [17]. Using this equation, the ground track from Musudan-ri to Los Angeles is approximately 7,700 km.[8] To calculate the maximum range of each missile configuration, the burnout radius and velocity must be calculated. The constants used in these calculations are shown in Table 1. The equations and calculations can be found in the Appendix. This calculation assumes a throw weight of 1000 kilograms and a weapon yield of 10 kt.

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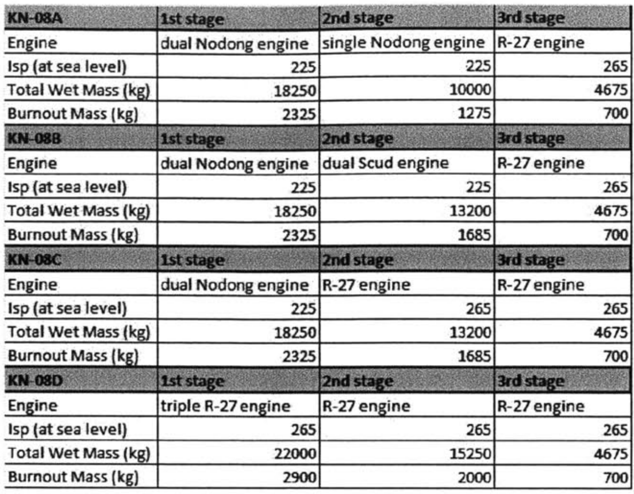
[8] For exact values see Appendix 9.



KN-08A	1st stage	2nd stage	3rd stage
Engine	dual Nodong engine	single Nodong engine	R-27 engine
Isp (at sea level)	225	225	265
Total Wet Mass (kg)	18250	10000	4675
Burnout Mass (kg)	2325	1275	700
KN-08B	**1st stage**	**2nd stage**	**3rd stage**
Engine	dual Nodong engine	dual Scud engine	R-27 engine
Isp (at sea level)	225	225	265
Total Wet Mass (kg)	18250	13200	4675
Burnout Mass (kg)	2325	1685	700
KN-08C	**1st stage**	**2nd stage**	**3rd stage**
Engine	dual Nodong engine	R-27 engine	R-27 engine
Isp (at sea level)	225	265	265
Total Wet Mass (kg)	18250	13200	4675
Burnout Mass (kg)	2325	1685	700
KN-08D	**1st stage**	**2nd stage**	**3rd stage**
Engine	triple R-27 engine	R-27 engine	R-27 engine
Isp (at sea level)	265	265	265
Total Wet Mass (kg)	22000	15250	4675
Burnout Mass (kg)	2900	2000	700

[16]

Table 1: Constants for Each Missile Configuration

From these calculations, KN-08C is the configuration of choice for this scenario as its calculated maximum range is approximately 9,700 km. Although KN-08D, has a longer range, KN-08C seems to be more attainable in the near future for North Korea.

Weapons Type

The Schilling article presents two possibilities for the type of warhead, either a gun-assembly fission bomb or a first-generation thermonuclear weapon with cylindrical primaries [16]. This scenario assumes a gun-type assembly. This design is one in which one piece of weapons grade uranium is fired into a second piece of WGU in order to create a supercritical mass. Unlike an implosion device, which can have either plutonium or uranium as its fissile core, a gun type device can only be built with HEU because spontaneous neutrons emitted by plutonium are likely to cause premature criticality which can significantly reduce the overall explosive yield [4]. This is an important assumption as it greatly limits the number of warheads that North Korea could use with this weapon-design.

Weapons Effects

In this scenario, the KN-08C missile configuration is chosen. This missile then travels to Los Angeles, CA and detonates a 10 kt bomb. This section discusses the weapons effects based on the yield of the weapon.

Equations for Approximation

The size of the fireball increases with the energy yield of the explosion. Thus the radius of the fireball can be calculated by the following equation,

$$\mathrm{R} \approx 90\mathrm{W}^{0.4} \tag{3}$$

where R is the radius in feet and W is the yield in kilotons. Theoretically, a given pressure will occur at a distance from an explosion that is proportional to the cube root of the energy yield. Full-scale tests have shown this relationship between distance and energy yield to hold for yields up to (and including) the megaton range. Thus, cube root scaling may be applied over a wide range of explosion energies. According to this law, if D_1 is the distance (or slant range) from a reference explosion of W_1, kilotons, at which certain overpressure or dynamic pressure is attained, then for any explosion of W kilotons energy these same pressure will occur at a distance D given by,

$$\frac{D}{D_1} = (\frac{W}{W_1})^{1/3} \tag{4}$$

but this equation is simplified by choosing a reference explosion of 1 kt so that$W_1 = 1$. Therefore Equation 4 is reduced to:

$$D = D_1 * W^{1/3} \tag{5}$$

Scaling laws are used to calculate many of the characteristics of an explosion such as the optimal height of burst. The optimal height of burst is the burst height that will result in a maximum surface distance from ground zero to which an overpressure extends. The optimal height of burst, for an overpressure of 10 psi or more, is given by the following equation,

$$H = 220(W)^{1/3} \tag{6}$$

For many of the effects such as radiant exposure, overpressure, and dosage, scaling is used to find the distance at which a given parameter can happen or the magnitude of an effect. The technique is to scale down the given height of burst or distance to the reference yield of 1 kt, using Equation 5.[9] Then using graphs for the 1 kt bomb, the value of the effect is determined, and finally scaled back up to the original bomb yield. The calculations used for this scenario can all be found in the Appendix [18].

Effects on Los Angeles

The effects radii using the above equations are shown in Figure 5 below using Nukemap.[10]

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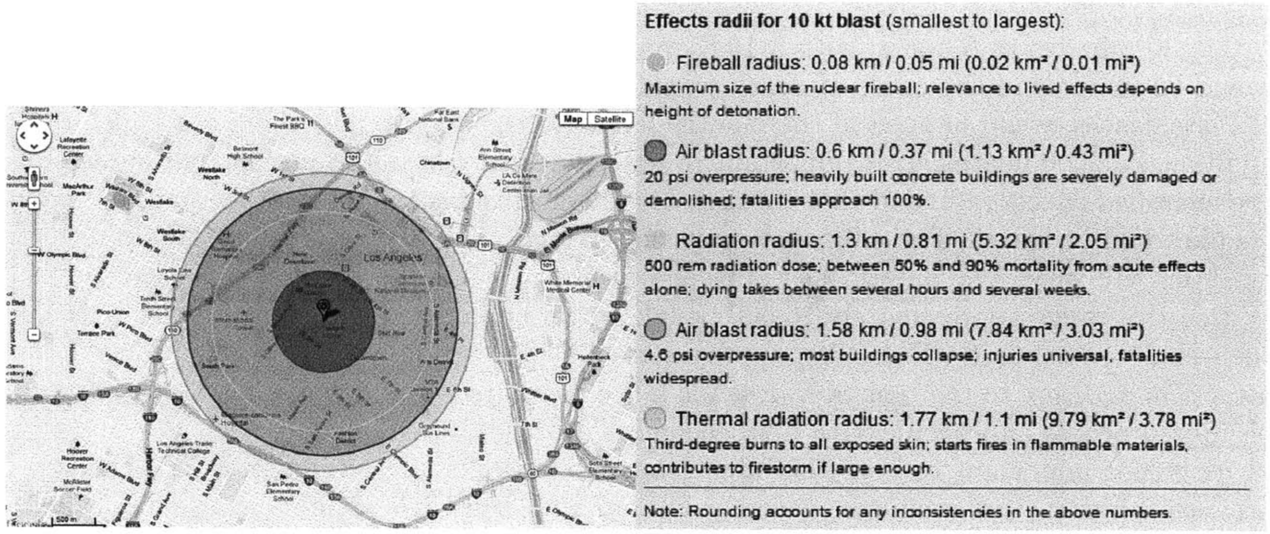
[9] This same equation can be used for height, where D is replaced by H which is reference height, and D_1 is replaced by H_1 which is the height of the bomb detonation.

[10] http://www.nuclearsecrecy.com/nukemap/



Effects radii for 10 kt blast (smallest to largest):

● Fireball radius: 0.08 km / 0.05 mi (0.02 km² / 0.01 mi²)
Maximum size of the nuclear fireball; relevance to lived effects depends on height of detonation.

● Air blast radius: 0.6 km / 0.37 mi (1.13 km² / 0.43 mi²)
20 psi overpressure; heavily built concrete buildings are severely damaged or demolished; fatalities approach 100%.

● Radiation radius: 1.3 km / 0.81 mi (5.32 km² / 2.05 mi²)
500 rem radiation dose; between 50% and 90% mortality from acute effects alone; dying takes between several hours and several weeks.

● Air blast radius: 1.58 km / 0.98 mi (7.84 km² / 3.03 mi²)
4.6 psi overpressure; most buildings collapse; injuries universal, fatalities widespread.

● Thermal radiation radius: 1.77 km / 1.1 mi (9.79 km² / 3.78 mi²)
Third-degree burns to all exposed skin; starts fires in flammable materials, contributes to firestorm if large enough.

Note: Rounding accounts for any inconsistencies in the above numbers.

Figure 5: Effects radii for a 10 kt yield

The location show in figure 5 is the neighborhood of Downtown in the city of Los Angeles. This area contains Bunker Hill, fashion district, industrial district, jewelry district, Little Tokyo, Old Bank District, skid row, and the Civic Center. The Civic Center is the administrative core of LA and has the largest concentration of government employees in the United States outside of Washington, DC. This neighborhood has a population density of 4,470 per square mile which is lower than most population densities in LA. The population in 2008 was 34,811. However, the daytime population is approximately 207,440 which is about a 500% increase. This is important for weapons effects approximations.[11]

The radius of the fireball, at an optimal height of burst of 1,555 feet, is approximately 0.07 kilometers. At this height the fireball does not touch the ground. The fireball is a source of extremely bright visible like and can potentially blind an observer. The fireball incorporates the weapons residue and material from the surrounding medium to form an intensely hot and luminous mass. This causes it to emit thermal radiation capable of causing burns. Very soon after the explosion, a blast wave develops in the air and moves rapidly away from the fireball. The radius of the fireball extends for about one block of the location. From the blast wave formed, fires can be started by upset stoves, water heaters and furnaces, electrical short circuits, and broken gas lines. The spread of the fire is determined by the amount and distribution of combustible materials in the vicinity and will account for a large number of deaths on the order of tens of thousands [18]. For the remaining calculations it will be assumed that the attack takes place in the daytime to account for the maximum number of deaths. Also, because this is an air burst, the effects from fallout will be minimal and are thus ignored in this scenario.

The 20 psi overpressure extends for 0.6 kilometers, which is about 9 blocks. As shown in the figure all buildings within this area would be demolished and would account for an additional 9,000 fatalities. The radiation radius extends for 1.3 km or about 21 blocks. This radius is calculated for a 500 rem dose. The initial phase of acute radiation occurs

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[11] All population information was found at the following website: http://projects.latimes.com/mapping-la/neighborhoods/neighborhood/downtown/

within 30 minutes to 6 hours, with a 100% probability of vomiting. The incidence of death would be 70%[12] and the cause of death would be hemorrhage or infection. Although some of these deaths would happen in the months following the attack, this would account for an additional 33,000 deaths. It is important to note that many hospitals are located outside of the identified effects radii and that through blood transfusions and antibiotics, some of these people could be saved. The 4.6 psi overpressure extends 1.58 kilometers and the number of fatalities will vary. The outermost radius shown in figure 5 is the thermal radiation radius. Within this range approximately 16,000 people would be inflicted with third-degree burns if their skin was exposed. Therefore, approximately 60,000 people would be killed in such an attack, in addition to the tens of thousands killed from fires. There would also be a number of injured people and people with first, second, and third degree burns.

It is also important to note the impact on public works and public services. The governance infrastructure would be severely limited with the Civic Center being demolished. The health care system and emergency services would be strained with the vast amount of injuries. Using figure 12 located in Appendix 9, the damage distance relationships can be determined. Thus, any homes within a distance from ground zero of 1.83 kilometers and any office building within a distance of 0.37 kilometers would be severely damaged and would have either collapsed or be on the verge of collapsing. Electromagnetic pulse (EMP) effects could also degrade electrical and electronic system performance [18].

8 Implications

Reviewing Section 7.3.2, Effects on Los Angeles, it is clear the impact a 10 kt bomb would have on Los Angeles. Presently, it has not been confirmed if the KN-08 missile is capable of reaching the CONUS. North Korea will have to conduct more tests to make this hypothetical missile a reality. Even if North Korea was able to manufacture such a missile, without more tests the missile would be very unreliable. Without further testing it may be that the DPRK will not attack because they cannot be sure that a missile will reach the United States and detonate at the optimal height. Furthermore, missile defense might deter such an attack since it is assumed that North Korea's WGU stock is fairly small and would not want to risk wasting some of its limited WGU.

Therefore, it is maybe highly unlikely, that the DPRK would conduct such an attack. However, what steps should be taken to avoid any possibilities? As Jeffrey Lewis stated, "We ought to be careful about encouraging the North Koreans to prove it to us [19]." By openly doubting the capabilities of North Korea, the international community could be asking them to "prove it to us." In the past, this disbelief in capability has led to North Korea and other countries conducting a variety of tests to flex their weapons capabilities.

Of highest priority, should be the verification of North Korea's nuclear program. By allowing inspectors back into the country, North Korea would gain some support from the international community and make their nuclear program more transparent. This transparency would give the international community a better understanding of North Korea's capabilities. As a country, missile defense has become one of the United States major pri-

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[12] This value was based off of a range of 0-90% incidence of death for doses from 200-600 rems [18].

orities and by better understanding the capabilities of other countries interested in this technology, the United States would be able to better defend ourselves from attack.

In years past, the United States and other nations, have tried to provide North Korea with incentives to cooperate. This technique tends to have the same result: North Korea accedes for some time, then claims that a deal was misunderstood or not delivered, and then reneges on the agreement. This leads to sanctions which further damage North Korea's already weak economy and push it to continue acting against the will of the international community. In the future, more focus needs to be placed on the goals that North Korea is attempting to achieve.

Currently, it seems that North Korea's greatest priority in developing its nuclear weapons capabilities is defense. At present, the Obama Administration is focused on not rewarding any of North Korea's "provocative behavior". Some advocates suggest imposing stricter sanctions. The cost of helping North Korea disable its program has also been a cause for concern. In the future, my recommendation is that instead of giving North Korea oil, nutritional assistance, or any other incentives, the international community focuses on what it is that North Korea actually desires for its nuclear programs. In order to do this, there will have to be a way for diplomatic talks to commence again. These talks need to be extensive and not focus explicitly on making North Korea dismantle their programs. The focus, instead, should be placed on the purpose of their nuclear programs. The difficulty in this exploratory approach is that it may well be that North Korea desires nuclear weapons. Thus, allowing North Korea some type of defense may help deter them from this path.

9 Conclusions and Future Work

Finally, this thesis attempts to understand and analyze the role of enrichment technology in North Korea. The history of North Korea displays its dedication to the secrecy of its nuclear program. The DPRK's interactions with the international community further solidify its desire to develop its program, even against the international communities' will. This isolation makes it difficult to communicate and bargain with North Korea. The use of enrichment technology enables North Korea to produce uranium warheads that could potentially be loaded onto missiles capable of reaching a variety of targets and maybe the United States. Because North Korea has threatened to attack U.S. soil, this thesis provides an analysis on the effects of such an attack. The damaging effects of nuclear weapons are well known, but the specific location of Los Angeles is a strategic location for many reasons. Los Angeles is within range of the KN-08 missile, has the second largest population after New York City, and has the second largest concentration of government personnel after Washington, D.C., making it a target of great devastation.

In the future, if North Korea conducts more weapons tests, these test emissions will need to be carefully studied to help determine the sophistication of their weapons. Space launches and missile tests will also need to be monitored and analyzed for the application of technology to ICBM manufacturing. It is highly unlikely that any country, especially North Korea, would use nuclear weapons. Thus the question often becomes, does it matter if they have nuclear weapons capabilities? If North Korea continues to advance their capabilities this presents an even greater threat to the international community. Without better transparency of their nuclear programs and goals, it becomes almost impossible to predict North Korea's attack plans. This creates distress in the international community and puts countries in the region such as Japan and South Korea on the defensive. This instability will only further lead to more hostility, weapons testing, and could even escalate to confrontation. Therefore, in order to maintain stability, it is important that North Korea does not become a nuclear-weapons state.

References

[1] H. G. Wood, A. Glaser, and R. S. Kemp, "The gas centrifuge and nuclear weapons proliferation," *Physics Today*, vol. 46, pp. 40–45, 2008.

[2] J. Cirincione, J. B. Wolfsthal, and M. Rajkumar, *Deadly Arsenals: Nuclear, Biological, and Chemical Threats.* Carnegie Endowment for International Peace, 2nd ed., 2005.

[3] J. D. Pollack, *No Exit: North Korea, Nuclear Weapons, and International Security.* Routledge, 2011.

[4] J. Chipman, *North Korea Security Challenges: A Net Assessment.* The International Institute for Strategic Studies (IISS), 2011.

[5] A. DiFilippo, *US-Japan-North Korea Security Relations.* Routledge, 2012.

[6] M. B. Nikitan, "North korea's nuclear weapons: Technical issues," April 2013.

[7] "Cia unclassified document," November 2002.

[8] D. Albright and R. Avagyan, "Update on north korean light water reactor construction project," August 2012.

[9] F. Dahl, "North korea makes "significant" nuclear reactor progress: Iaea," August 2012.

[10] N. Hansen and J. Lewis, "Satellite images show new construction at north korea's plutonium production reactor; rapid restart?," April 2013.

[11] D. Albright and P. Brannan, "The north korean plutonium stock, february 2007," February 2007.

[12] D. Albright, "North korean plutonium production," 1994.

[13] D. Albright and C. Walrond, "North korea's estimated stocks of plutonium and weapon-grade uranium," August 2012.

[14] D. Wright and T. Postol, "A post-launch examination of the unha-2," June 2009.

[15] M. Elleman, "Prelude to an icbm? putting north korea's unha-3 launch into context," March 2013.

[16] J. Schilling, "An assessment of the north korean kn-08 icbm (if it really exists)," May 2012.

[17] J. J. Sellers, *Understanding Space.* McGraw-Hill, 1994.

[18] S. Glasstone and P. J. Dolan, *The Effects of Nuclear Weapons.* US DOD and US DOE, 3rd ed., 1977.

[19] J. Lewis, "North korea's big bang," February 2013.

[20] D. Hafemeister, *Physics of Societal Issues: Calculations on National Security, Environment, and Energy.* Springer, 2007.

Appendix

Appendix A

Ground Track Geometry Matlab Code

```
% Ground track geometry
    %Launcher @ Musudan-ri (40.85N, 129.67E)
    %Target @ Los Angeles,CA (37.07N, 118.39W)
    Lt = 34.07; % latitude of target in degrees
    lt = 118.39; % longitude of target in degrees
    Lo = 40.85; % latitude of launcher in degrees
    lo = 230.33; % longitude of launcher in degrees, it is important to not that because it is west the degrees had to be modified.
    dl = lt - lo;
    R = (acosd(sin(Lo)*sin(Lt)+ cos(Lo)*cos(Lt)*cos(dl)))*(10000/90) % Range traced over the Earth's surface in km
    R =
    7.7195e+03
```

Appendix B

Maximum Range of Ballistic Vehicle

To find the maximum range of a missile first, the burnout velocity, $\mathrm{V_{burnout}}$ or $\mathrm{v_f}$, needs to be calculated. This is given by the following equation,

$$\mathrm{v_f} = \mathrm{V_{ex}} \ln(m_o/m_f) \tag{7}$$

where $\mathrm{V_{ex}}$ is the exhaust velocity of the gas with respect to the rocket, $m_o$is the initial launch weight, and m_f is the final weight. Oftentimes "specific impulse," I_{sp}, is used rather than exhaust velocity as a parameter and is defined by:

$$I_{sp} = \mathrm{V_{ex}}/g \tag{8}$$

where g is the acceleration of gravity. Furthermore, to calculate the burnout velocity of a multistage missile, sum the $\mathrm{v_f}$ values found at each stage[20].

After calculating $\mathrm{v_f}$, a trajectory parameter needs to be defined :

$$\mathrm{Q_{burnout}} = \frac{\mathrm{V^2_{burnout}}}{\mathrm{V^2_{circular}}} = \frac{\mathrm{V^2_{burnout} R_{burnout}}}{\mu} \tag{9}$$

where$\mathrm{V_{burnout}}$ is the burnout velocity (or $\mathrm{v_f}$), $\mathrm{R_{burnout}}$is the burnout radius, and $\mu$is the gravitational parameter (for the Earth the value is $3.986 \times 10^5 \mathrm{km}^3/\mathrm{s}^2$).

After $\mathrm{Q_{burnout}}$ has been calculated for a specific ballistic vehicle, then the maximum range angle achievable for that vehicle can be calculated using the following equation,

$$\Lambda_{\max} = 2 \sin^{-1}\left(\frac{\mathrm{Q_{burnout}}}{2 - \mathrm{Q_{burnout}}}\right) \tag{10}$$

which will need to be multiplied by 10,000 km/$90^{\underline{\mathrm{o}}}$ to get the maximum range in kilometers.

It is important to note that these equations are rough estimates and do not apply the rotating-earth correction [17].

Appendix C

Maximum Range of Ballistic Vehicle Matlab Code

```
% Equations for DPRK ICBM
    % Parameters taken from John Schilling "An Assessment of the North Korean % KN-08
ICBM
    %These constants are specific to KN-08C
    % Constants
    Isp1 = 225; % seconds
    Isp2 = 265; % seconds
    Isp3 = 265; % seconds
    g = .0098; % km/s^2 gravity
    Mo1 = 18250; % kg initial mass of nodong missile
    Mf1 = 2325; % kg final mass of nodong missile
    Mo2 = 15250; % kg initial mass of R-27 in 2nd stage
    Mf2 = 1685; % kg final mass of R-27 in 2nd stage
    Mo3 = 4675; % kg initial mass of R-27 in 3rd stage
    Mf3 = 700; % kg final mass of R-27 in 3rd stage
    Mtw = 1000; % kg throw weight assuming 1000 kg for warhead
    Bh = 300; % km burnout height, average height for ICBMs
    Br = Bh + 6378; % km burnout radius
    u = 398600; % km^3/s^2
    % Velocity at Burnout km/s
    Vf = (Isp1*g*log((Mo1+Mo2+Mo3+Mtw)/(Mf1+Mo2+Mo3+Mtw)) + Isp2*g*log((Mo2+Mo3+M
+ Isp3*g*log((Mo3+Mtw)/(Mf3+Mtw))) % km/s burnout velocity
    % Trajectory Parameter
    Qb = Vf*Vf*Br/u
    % Maximum Range in km
    A = real(((2*asind((Qb)/(2-Qb)))*(10000/90)))
    Vf =
    6.9945
    Qb =
    0.8196
    A =
    9.7733e+03
```

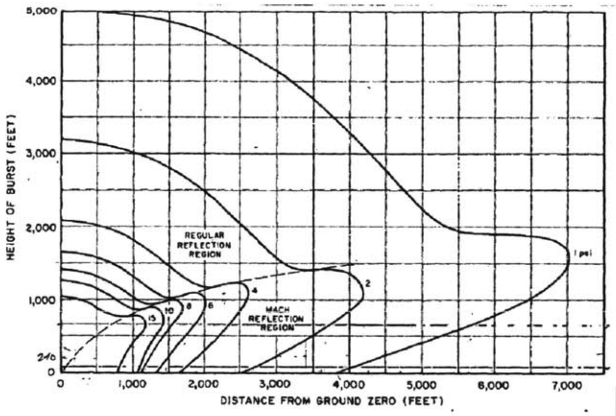
Appendix D

Radii of Overpressure

Figures 6 and 7 shown below are used to find the distance from ground zero of overpressure. Using the optimal height of burst, the scaled height of burst is found using the following equation,

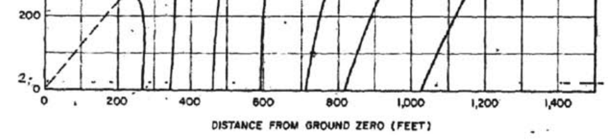
$$\mathrm{H_1} = \frac{\mathrm{HOB}}{\mathrm{W}^{1/3}} \tag{11}$$

where $\mathrm{H_1}$ is the scaled height, HOB is the optimal height of burst calculated using equation 6, and W is the yield in kilotons. Using the figures below and the value of $\mathrm{H_1}$, find the distance the overpressure occurs. Then scale the distance back to the actual yield using equation 5 [18].



[18]

Figure 6: Peak over-pressures on the ground for 1-kiloton burst (low-pressure range).



[18]

Figure 7: Peak over-pressures on the ground for a 1-kiloton burst (intermediate-pressure range).

Appendix E

Calculation of the Fireball Radius, Optimal Height of Burst, and Radii of Overpressure in Matlab

Figures 6 and 7 shown in Appendix 9 are used to find the inputs in the following Matlab code.

```
% Size of fireball
W = 10 % kt yield of bomb
Rf = (90*W^.4)*(0.0003048) % km
% Optimum Height of Blast
Hob = (220*W^(1/3))*(3.28084) % ft
Hobkm = Hob*(0.0003048) % in kilometers
%Scaled Height of Burst
h1 = Hob/(W^(1/3))
%To calculate the distance an overpressure extends use the scaled height of
%burst to answer prompt
prompt = ’Using graph what is the distance from ground zero at the specified overpressure? ’;
result = input(prompt);
Dfb = result;
%Use Dfb to scale back to the actual yield and find the distance
d1 = Dfb*(W^(1/3))*(0.0003048) % distance in km
Rf =
0.0689
Hob =
1.5550e+03
Hobkm =
0.4740
h1 =
721.7848
Using graph what is the distance from ground zero at the specified overpressure? 800
d1 =
0.5253
Using graph what is the distance from ground zero at the specified overpressure? 2400
d1 =
1.5760
```

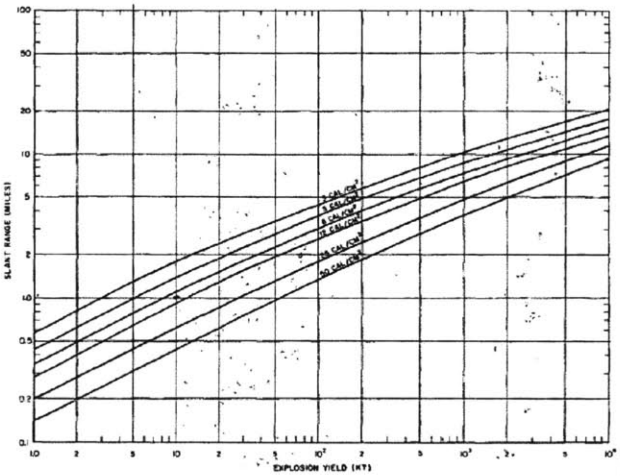
Appendix F

Calculating Radiant Exposure

To calculate radiant exposure, first the slant range must be calculated using the following equation,

$$r^2 = d^2 + h^2 \tag{12}$$

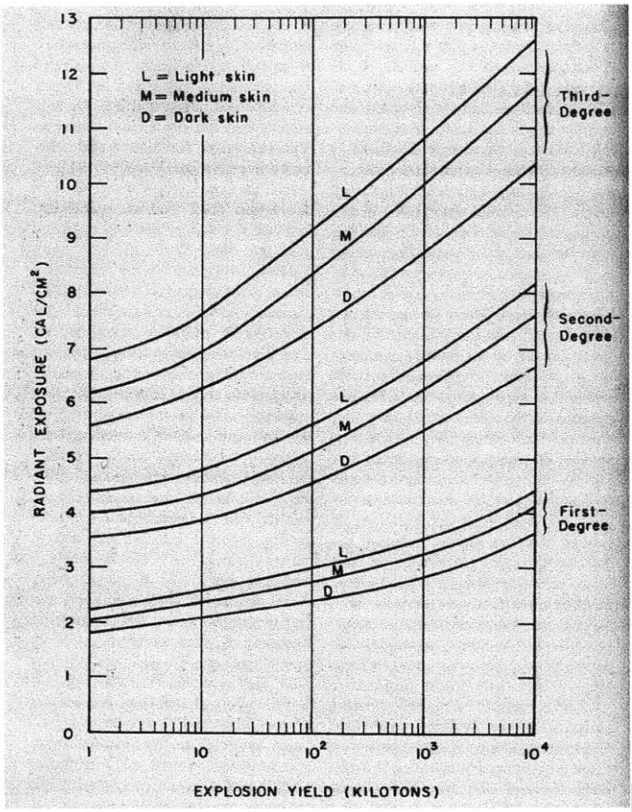
where r is the slant range in miles, d is the distance in miles, and h is the height of burst in miles. The slant range is used with the explosion yield to estimate the radiant exposure using figure 8 below [18].



[18]

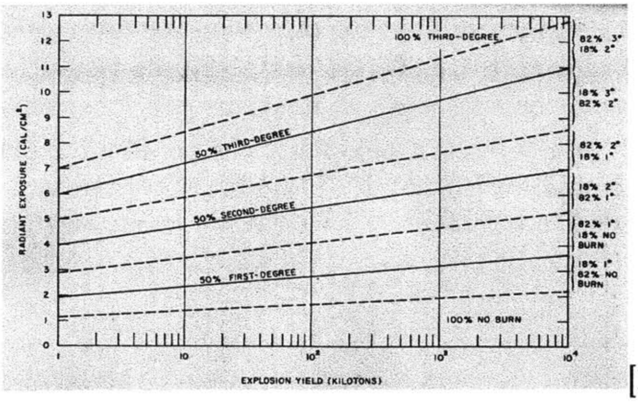
Figure 8: Slant ranges for specified radiant exposures on the ground as a function of energy yield of air bursts at altitudes up to 15,000 feet for a 12-mile visibility.

Furthermore, figures 9 and 10 shown below use the resultant radiant exposure value to estimate the intensity of a skin burn.



[18]

Figure 9: Radiant exposure required to produce skin burns for different skin pigmentation.



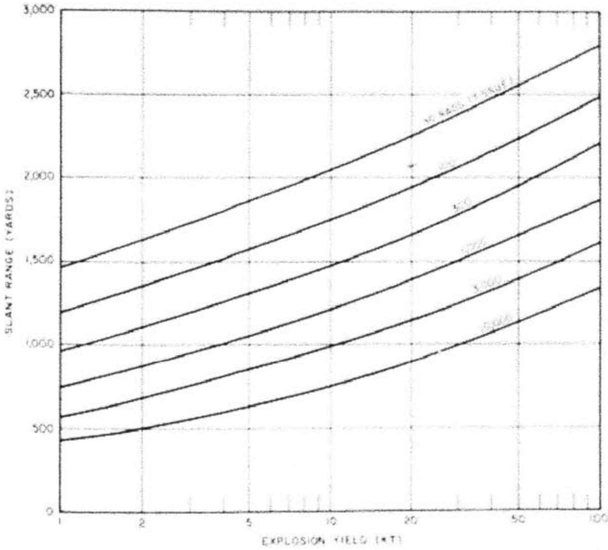
[18]

Figure 10: Skin burn probabilities for an average unshielded population taking no evasive action as a function of explosion yield and radiant exposure.

Appendix G

Calculating Prompt Dose (exclusive of fallout)

Dosage is calculated the same way as radiant exposure. First, the slant range must be calculated in yards. Then figure 11 shown below is used to calculate the dosage [18].



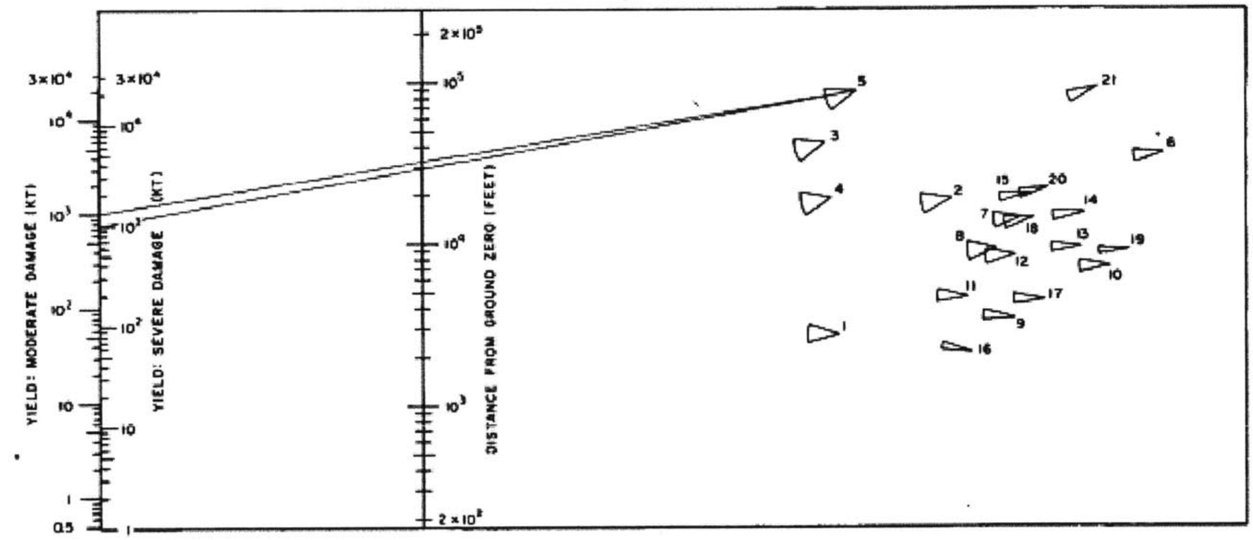
[18]

Figure 11: Slant ranges for specified gamma-ray doses for targets near the ground as a function of energy yield of air-burst fission weapons.

Appendix H

Damage Distance Relationships

Using the graph in figure 12 shown below, and a table in Glasstone that gives the structural types depicted by the points on the graph, one can estimate the damage-distance relationships for above ground structures. To do this a point is chosen based on the structure then a straight line is drawn from the point to the yield, which then gives the distance from ground zero in feet. Points of interest are: 5, which is a wood frame building, and 9, which is a steel frame office-type building with earthquake resistant construction [18].



[18]

Figure 12: Damage-distance relationships for above ground structures.