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Nuclear Missile Delivery Capabilities in Emerging Nuclear States

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INTRODUCTION

If a non-nuclear weapon state plans to manufacture nuclear weapons, it must perform the following:

(i) conduct research on the design of nuclear weapons;

(ii) acquire a sufficient quantity of weapon-usable fissile material; and

(iii) integrate its nuclear weapons with its delivery systems (missiles or aircraft).

The third step is sometimes referred to as the "weaponization" of nuclear devices.

International efforts have been made to counter various activities associated with the acquisition of nuclear weapons. The nuclear weapon production capability of a non-nuclear weapon state party to the Non-Proliferation Treaty (NPT) is constrained by its agreement to place its fissile material under International Atomic Energy Agency (IAEA) safeguards; and the transfer of missile capabilities to the third world is limited by the Missile Technology Control Regime (MTCR). But there is no effective way to prevent a non-nuclear state from designing certain kinds of nuclear weapons.

It is believed that a proliferant can, using only publicly available information and a level of scientific expertise that can be found in many countries, design a pure fission bomb and have considerable confidence that the bomb will work without any nuclear explosive test.[1] This paper examines the nuclear weaponization capabilities of proliferants based on some observations about their experiences and expertise in relevant areas.

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There are three types of systems which can deliver nuclear weapons over a considerable distance: aircraft, ballistic missiles and cruise missiles. Ballistic missiles have the advantage of high confidence in penetration of enemy air defenses and partly for this reason they are preferred by some third world countries. Indeed almost all emerging nuclear states have at least short-range ballistic missiles. In contrast, long-range cruise missiles are not immediately realistic for most emerging nuclear states from the third world and are not further discussed here. Some emerging nuclear states do have high-performance aircraft which can be used for nuclear missions. However, because there is no doubt about the nuclear delivery capability of some aircraft, we also do not discuss aircraft in this paper. Our focus is on ballistic missiles.

If a state wants to mate a nuclear weapon with a missile, the weight, sizes and the shape of the weapon must be compatible with the missile.

HISTORICAL EXPERIENCES IN ACQUIRING DELIVERABLE WEAPONS

The Five Declared Nuclear States

The first U.S. missile-deliverable nuclear weapon was the Mk-5 which weighed 1,400 kg. It took seven years from the first U.S. nuclear test to the time when Mk-5 entered into stockpile.[2] More than thirty U.S. nuclear tests were conducted during this period. Not all of these tests were for the improvement of the design of Mk-5 because several other types of nuclear weapons were also produced in the U.S. during this period and some tests were used to study weapon effects.

The first Soviet nuclear-armed missile, the SS-3, entered service in 1955, six years after the first Soviet nuclear test. The Soviet conducted about ten tests during this period. The payload of the SS-3 is unknown, but the following missile, the SS-4 had a payload of 1,300–1,400 kg. [3]

Britain acquired its small nuclear weapon, "Red Bread," in the late 1950s. It took about seven years and more than ten tests after the first British test. The weight of Red Bread was about 900 kg. Since Britain didn't build missiles until much later, it integrated its nuclear weapons first only into its bombers.[4]

France's first light warhead, the AN 11 (1,500 kg), was first tested in 1962, two years after the first French test. This test was the sixth French test.[5]

The fourth Chinese nuclear test was of a nuclear warhead mated to and launched on a DF-2 missile. It was conducted two years after the first Chinese test. The payload of the DF-2 missile is 1500 kg.[6]

These data show that (1) states which began their nuclear program later required less time and fewer nuclear tests to acquire ballistic missile warheads; and (2) the weights of all the first missile deliverable nuclear weapons of the nuclear states were about 1,500 kg except Britain's, which was one-third lighter.

Sweden

Sweden began its research on nuclear reactor principles soon after the end of World War II, and its first experimental nuclear reactor R1 started operation in 1954.

The Swedish nuclear weapon program was disclosed in 1985, many years after its termination. Its secret nuclear weapon program started in the late 1940s and was expanded in the early 1950s. By 1958, Sweden had its first nuclear weapon design. Swedish scientists repeatedly tested all the key components of the weapon, except the nuclear core until the nuclear program finally terminated in 1968, gaining high confidence that the weapon would work. The Swedish nuclear weapon design was based on the principle of implosion and it used plutonium (Pu) for the fissile core. The device, as designed, would have weighed 600 kg and had a yield of 20 kilotons.[7]

South Africa

South Africa began its nuclear scientific research in the late 1940s and substantially expanded its efforts at the end of 1950s. In 1961, it purchased a U.S. light water research reactor called SAFARI-1. In 1967, its second research reactor, designed and built in South Africa, went into service.[8]

South Africa's nuclear weapon program formally began in the late 1960s. From 1974 to 1976, the South African Atomic Energy Board (AEB) conducted a series of laboratory tests to investigate a gun-type nuclear device. In 1977, it produced its first gun-type nuclear device, but its planned test at the Kalahari test site that year was canceled as a result of international pressure. In 1978, a second, smaller device was made, but was never converted into a deliverable weapon. By 1989 or 1990, when the South African nuclear program ended, four more reliable nuclear weapons had been produced and a seventh was about to be assembled. They were all bomber deliverable. All of South Africa's seven nuclear weapons were gun-type devices of nearly identical design, but detailed changes were made in the last few weapons constructed to enhance their reliability. Each device contained about 55 kg of highly-enriched uranium, weighed approximately 900 kg and had a diameter of 0.64 m and a length of 1.83 m.[9]

Iraq

Iraq began its nuclear research in the 1960s. Its first nuclear reactor, the IRT-5000, purchased from the Soviet Union, started operation in 1968. Iraq's nuclear research was substantially expanded in the mid-1970s when it purchased a French reactor. The reactor, however, was destroyed by Israeli air attack in 1981, before start-up. Iraq never designed a reactor by itself, but it trained its technical personnel on imported reactors and in some western countries.[10]

The Iraqi nuclear weapon program grew markedly at the beginning of the 1980s. The United Nation's inspection team in Iraq found that it had made substantial progress in uranium enrichment and was developing an implosion bomb using uranium as the fissile core when the program was interrupted by the Gulf War. The Iraqis probably also hoped to develop boosted fission devices. Basic computations and high explosives testing for component development had been carried out in Iraq, but a practical design of an implosion-type weapon had not been achieved prior to the Gulf War.[11]

The nuclear weapon designs in Sweden, South Africa and Iraq were at different stages before their weapon programs terminated. Sweden had designed implosion-type nuclear devices as light as 600 kg. This achievement relied on the strong scientific and industrial capabilities of Sweden. South Africa had built gun-type nuclear devices weighing 900 kg. It also had a strong nuclear research capability, evidenced by the fact that South Africa was able to design its own nuclear reactor as early as 1967. Iraq had a relatively short nuclear research history. That was one reason why it could not finish a weapon design before the Gulf War.

A nuclear reactor is not only a potential source of nuclear material but also a place to train nuclear weapon experts. There are some common technologies shared by reactor design and weapon design. Experience in using and designing nuclear reactors could therefore provide technical benefits to a weapon design effort.

Sweden, South Africa and Iraq provide benchmarks to assess the weapon design capabilities of other emerging nuclear states. By comparing the reactor design capabilities and experiences of a potential proliferant country to those of the above three countries, we can make some educated guesses about the weapon-design capability of the country.

NUCLEAR WEAPON DESIGN

Fissile Materials and Nuclear Weapon Design

Fission weapons can be divided into two categories: gun-type and implosion-type. A gun-type device achieves a self-sustained chain reaction by bringing together two or more pieces of subcritical fissile material to form a critical mass. An implosion-type device achieves criticality by compressing the fissile core to a higher density.

Plutonium is not suitable for gun-type devices, which have a longer assembly time than implosion devices, because the high rate of spontaneous fission of Pu-240 in even weapon-grade plutonium would cause predetonation and thus substantially reduce the yield of the explosion. Highly-enriched uranium can be used as fissile cores of both gun-type and implosion-type devices. The design of an implosive device is technically more complicated than that of a gun-type device, but an implosion-type device needs less uranium than a gun-type device and some emerging nuclear states have pursued implosion-type devices because of their very limited supply of highly-enriched uranium.

Based on the experiences of the nuclear weapon states, both gun-type and implosion-type devices can be made small enough to be delivered by missiles. But an emerging weapon state is unlikely to have the same capabilities as the U.S. and Russia to design very compact warheads.

A "nuclear capable" missile is defined by the MTCR as one with a payload capability in excess of 500 kg combined with a range in excess of 300 km. This definition is based on an assumption that an emerging nuclear state will be unable to build nuclear warheads weighing less than 500 kg.

Implosion-Type Device

In 1990, Fetter *et al.* used a simple model of a hypothetical implosion fission explosive with the weight and volume of typical light warheads or primaries in the U.S. and Soviet nuclear arsenals to estimate the neutron and gamma radiation from such warheads. This hypothetical fission explosive had a weight of 130–180 kg and a radius of 0.21–0.23 m. This is reasonably consistent with what is known about modern U.S. warheads.[12]

The first U.S. nuclear explosive device, called the "Gadget," was tested in 1945 at the Trinity Site, New Mexico. It had a plutonium core weighing 6.1 kg, which was imploded by some 2,300 kg of high explosives. The bomb based on the Gadget design, the Fat Man dropped on Nagasaki, had a weight of 4,900 kg and a diameter of 1.52 m.[13] Compared to the model used by Fetter, the weight of the plutonium core of Gadget is about the same, but the weight of its high explosives is 30–40 times greater. A large amount of high explosives in a nuclear weapon requires a big metal shell which also adds extra weight to the weapon. So the main task in reducing the weight of an implosion nuclear device is to reduce the amount of high explosives.

The pioneering nuclear weapon designers used a large quantity of high explosives for several reasons. First, the energy transfer efficiency from the high explosives to the nuclear core in early designs was much lower than in modern designs. Scientists have developed several concepts, e.g., levitated pit and hollow core designs, to increase the energy transfer efficiency. So less high explosive is needed in modern designs to gain the same compression. Second, since the pioneering designers might not be very sure how long the super-critical phase could be sustained before disassembly, they developed conservative designs that used more high explosives. Third, the additional high explosives also helped to compensate for other uncertainties in the early design.

The designers in a later emerging state have more favorable conditions for designing lighter nuclear weapons. They know from the public literature how small a nuclear weapon can be, which sets a goal for them in making consistent efforts to reduce the amount of high explosives in a device. Publicly-available literature can also help weapon experts in a proliferant state apply more advanced concepts into their early designs. So they can reach a lower weight for even their first device than the first types of nuclear weapons of the five declared nuclear states.

Many uncertainties in nuclear weapon design can be clarified by non-nuclear explosive tests. For example, hydrodynamic experiments can help weapon designers understand if the device can reach a super-critical condition. By using these non-nuclear explosive tests, the designers can reduce the amount of high explosives in a device until the uncertainties in the design affect their confidence. Although the designers cannot optimize the design due to the lack of nuclear explosive tests, they can gain confidence that their nuclear weapon will work and will generate at least a minimum yield of energy.

Gun-Type Device

A gun-type warhead could be made as light as about 100 kg. For example, a U.S. W33 warhead had a weight of 114–135 kg, a diameter of 0.40 m and a length of 0.94 m. This warhead is so small that it can be launched by artillery.[14]

The first gun-type weapon, "Little Boy," which was produced by the U.S. in World War II, was much bigger and heavier. It was 3.05 m long, 0.71 m in diameter and weighed 4000 kg. It contained 60 kg of highly-enriched uranium.[15] In the design of Little Boy, considerable weight was allocated to the chemical explosive and tamper.[16]

South African designers reduced the weight of their nuclear devices by a factor of four and the volume by a factor of two compared to the Little Boy bomb, although the amount of the highly-enriched uranium in South African devices was about the same as in the Little Boy bomb. The South African scientists used less tamper and chemical explosive. The average density of a whole South African bomb was about 1.68 grams per cubic centimeter, even less than the density of chemical explosive (1.9 grams per cubic centimeter). This means that the South Africans still kept a large empty volume in the gun barrel to get high closing speed for the sub-critical uranium components. Compared to W33 warheads, there is still much room left to reduce the weight and volume of South African bombs by using even less chemical explosive or by shortening the gun barrel.

Thus, publicly available data could help designers in later emerging nuclear states make lighter and smaller gun-type warheads for missiles.

WEAPONIZATION CAPABILITIES OF DE FACTO NUCLEAR STATES

Israel

The Israeli nuclear weapons program was launched in 1956. Its first nuclear reactor, the IRR-1 supplied by the U.S., started up in 1960. The second one, designed by France, started up in 1963. This reactor was enlarged by the Israelis in the early or mid-1970s.[17] This means that the Israelis had mastered the technology for nuclear reactor design by then. Israel's main effort to produce weapon-usable fissile material was to get plutonium, which indicates that Israeli nuclear weapons are implosion-type. Given Sweden's nuclear experience, Israel should also have the capability to design nuclear weapons as light as Sweden's 600 kg. Israel is suspected of at least one nuclear test on September 22, 1979.[18] If true, the test could have helped Israel design even more compact devices.

Israel is also thought to have obtained data from the first French nuclear test in 1960 and information about the design of French nuclear weapons at the same time. Israel was reportedly able to gain access to information concerning U.S. tests from the 1950s to the early 1960s, a period during which the U.S. was developing very compact warheads such as the W25 and W44.[19] If Israel did have substantive access to the U.S. weapon designs, it could design weapons nearly as light as those of the U.S.

There are various estimates of the size and weight of Israeli nuclear weapons. According to an article in the *New York Times* on January 24, 1975,[20] it would not be difficult for Israel to develop an atomic warhead to fit into the U.S. Lance missile, which has a range of 70 miles and a payload of 1000 lb (454 kg). Another *New York Times* article dated on April 1, 1986, also indicated that the weight of Israeli nuclear devices was much lower than 750 kg.[21] In October 1986, the *London Sunday Times* published a long story about the Israeli nuclear program, based on the revelation of an Israeli nuclear technician Mordechai Vanunu. On the basis of Vanunu's testimony and photos, former U.S. weapons designer, Theodore Taylor, concluded that Israeli nuclear weapons are significantly smaller than the first types developed by the five declared nuclear states.[22] Some reports even said that Israel has a nuclear warhead which is 0.61 m long, 0.51–0.56 m in diameter and 103 kg in weight.[23] This size and weight are similar to those of very compact U.S. warheads.

All these reports indicate that the weight of Israeli nuclear weapons would not be more than 500 kg or so. This is in accord with the facts that Israel has at least as strong nuclear research capabilities as Sweden did in the 1950s and that it also has had access to nuclear weapon data from some nuclear countries.

Israel began to develop its Jericho I missile with the assistance of France in the 1960s. Today it has the Jericho I and Jericho II missiles and the Shavit space launch vehicle. The Jericho I has a range of 480 km with a payload of 500 kg. The Jericho II reportedly has a range of 1,450 km or longer with a payload of 1,000 kg.[24] Israel launched satellites weighing 155 kg and 160 kg into earth orbit with its Shavit launch vehicles in 1988 and 1990. It is believed that the Shavit launch vehicle, which has a diameter of 1.2 m for all stages, is a modified version of Jericho II.[25] So the Jericho II presumably would have the same diameter. The weight of a plutonium fission device with a 1.2 m diameter would be between 1,800 kg and 2,900 kg (see figure A.2 in Appendix A). This means that the size of a warhead weighing no more than 1,800 kg could match those of the Jericho II and Shavit. A device weighing 500 kg would have a radius between 29 cm to 38 cm, which is much less than the radius of Jericho II and could, therefore, be easily mated to the Jericho II.

The Jericho II missile could reach most of Israel's potential adversaries in the Middle East and North Africa with a 1000 kg payload. The Shavit launch vehicle could also be revised into a missile. An analysis, prepared by a researcher at the U.S. Lawrence Livermore National Laboratory, has estimated its potential ranges as 7,500 km for a 500 kg payload and 4,800 km for a 900 kg payload. Another analysis concluded that a missile based on the launch vehicle could carry a 500 kg payload more than 4,800 km and a 1,000 kg payload more than 3,200 km.[26]

So if we assume the Israeli warheads weigh 500 kg, Israel would be able to deliver its nuclear warheads to any part of the Middle East and South Europe. Even for warheads weighing between 1,000 kg–1,500 kg, Israel's nuclear capable missiles could still cover the whole Middle East.

India

India has a very long history of nuclear research. An India-designed small experimental reactor started operation in 1956, two years after Sweden's first nuclear reactor started up. Since then, India has designed and built several other reactors. Its nuclear weapon program is believed to have been formally launched in the mid-1960s. India refuses to join the Non-Proliferation Treaty concluded in 1968 and thereby retains the option to build nuclear arms. In 1974, India conducted its first and only nuclear test, which it referred to as a "peaceful nuclear explosion." Former Prime Minister of India, Rajiv Gandhi, hinted in 1985 that India had made the components for nuclear arms and, if it chose, could assemble such weapons rapidly.[27] India does not have a large scale uranium enrichment program. Therefore, its weapon designs would use plutonium cores and be of the implosion-type.

India established the Indian National Council for Space Research in 1962 and the Indian Space Research Organization in 1969 to plan, manage and execute its activities in space. It began to develop its four-stage, solid-fuel Space Launch Vehicle (SLV-3) in 1973. The SLV-3 was used to launch an Indian satellite into orbit in 1980. Several kinds of launch vehicles with greater thrust and payloads are still under development. India's missile program is based on its space research. It started an Integrated Guided Missile Defense Program in 1983 and tested its first ballistic missile, the Prithvi, with a range of 250 km and a payload of about 1,000 kg, in 1988. In 1989 and 1992, India tested its Agni missile, which reportedly has a range of 1,500–2,500 km and a payload of about 1,000 kg. Recently, the Indian government stated that it was halting the Agni program. There are several other missiles proposed to be developed in the future.[28]

Compared with the five declared nuclear states at their early stages of nuclear weapon development, India has access to more published information about nuclear weapon design. It should therefore be able to design a missile-deliverable nuclear warhead with fewer nuclear tests, i.e., it might be capable of producing a warhead weighing 1,500 kg or less based on the results of its single nuclear test.

India should have a capability to produce light nuclear warheads similar to that of Sweden. India got its first nuclear reactor at almost the same time as Sweden, and India's nuclear establishment could have developed considerable confidence in relatively compact nuclear designs with non-nuclear explosive tests, building on its only nuclear test.

It has been reported that the design of the Agni missile is based on the first one or two stages of the SLV-3 rocket.[29] The diameters of these two stages are one meter and 0.8 m respectively and the third stage has a diameter of 0.815 m.[30] So the Agni missile may have the capability to carry a warhead with a diameter of one meter.

A plutonium fission warhead weighing 1,000 kg might have a radius of about 39–49 cm and one weighing 1,500 kg might have a radius of about 47–56 cm (see figure A.2 in Appendix A). So warheads with weights no more than 1,500 kg could match the size of the Agni missile.

Table 1: Parameters in the model.

	Loaded mass (kg)	Fuel mass (kg)	Specific impulse (sec)	Burn time (sec)
First Stage	10,400	8,660	253	49
Second Stage	4,800	4,000	267	40

Table 2: Estimate of ranges and payloads of Agni missile.

Payload (kg)	Range (km)
500	2,600
1,000	2,000
1,500	1,500

In order to know how the maximum range of the Indian Agni missile varies with the payload, we have built a model based on the parameters of the first two stages of SLV-3. The model parameters and estimated ranges and payloads are shown in tables 1 and 2.

An Indian Agni missile with a range of 2,000 km could reach almost the entire territory of Pakistan no matter where in India the missile was deployed. It could also reach almost all cities in China if it were deployed in the eastern portion of India. If the range of Agni missiles were reduced to 1,500 km, due to a heavy warhead weighing 1,500 kg, it could still reach central China from the eastern portion of India or reach a number of big cities in southwest China from a more central location in India. If India could produce nuclear warheads as light as about 500 kg (MTCR definition), Agni missiles could also cover the Middle East.

Pakistan

Pakistan's first research reactor, supplied by the U.S., started up in 1965. Its nuclear weapon program began in the early 1970s. Since Pakistan, like India, has not joined the Non-Proliferation Treaty, it has retained the option of developing nuclear weapons. The public became aware of Pakistan's efforts to acquire nuclear devices in the mid-1970s. Its nuclear program expanded in the early 1980s while the U.S. was focused on the Soviet invasion of Afghanistan.

Its uranium enrichment plant, Kahuta, began to produce enriched uranium during this period. Former Pakistani President Zia confirmed in 1987 that Pakistan had achieved the capability to produce nuclear weapons.[33]

Since Pakistan's main effort in the production of fissile materials has been on getting highly-enriched uranium, it has the option to build either gun-type or implosion-type nuclear devices.

U.S. officials have said on many occasions since the early 1980s that Pakistan received a proven weapon design from China. The design was said to be that used in China's fourth nuclear weapon test. Reportedly 15–20 kg of weapons-grade uranium is needed in this implosion-type design.[34] The warhead used in the fourth Chinese nuclear test reportedly weighs about 1,500 kg, including the whole package.[35]

Because Pakistan's nuclear research capability is stronger than Iraq's prior to the Gulf War, it should have been able to design implosion-type devices. But Pakistan's capability in nuclear reactor design is probably not as strong as Sweden's when it developed its nuclear weapons in the 1950s. So it would be difficult for Pakistan independently to develop a nuclear warhead much lighter than Sweden's. Even if Pakistan's devices were based on the Chinese design mentioned above, there would still be a long way to go from a 1,500 kg device to 500 kg or even lighter. One analyst has stated that Pakistan would probably have required several years to build the bomb after getting the design.[36]

If Pakistan faced too many technical difficulties in designing a light implosive device, it could also choose instead a gun-type device, which could have a similar weight to South Africa's devices. A weapon of this kind might weigh 1,000 kg or so.

It is not clear when Pakistan started its missile program. It claimed in 1989 that it had two missiles: Hatf I and Hatf II. China reportedly supplied M11 missiles to Pakistan later.[37] Hatf I, Hatf II and M-11 each has a payload of 500 kg. Their ranges are respectively 80 km, 280 km and 300 km. The Hatf II has a diameter of 0.55m.[38]

If Pakistan intends its missiles to reach New Delhi or other nearby big cities in India, it would need to extend the range of its missiles to at least 400 km. Neither of the above three missiles could fly so far without reduction of payload. But it is unlikely that Pakistan could produce nuclear warheads weighing much less than 500 kg. Therefore, Pakistan's nuclear missile capability probably has mostly symbolic value. However, Pakistan has aircraft capable of delivering its nuclear weapons to targets in India.

Pakistan is reportedly developing missiles with a range of 600 km and a payload of 500 kg.[39] This would be a substantial step toward a strategically significant nuclear missile delivery capability.

WEAPONIZATION CAPABILITIES OF STATES OF CONCERN

Democratic People's Republic of Korea

In 1965, North Korea received its first small Soviet-supplied nuclear reactor, which started up sometime before the early 1970s. Another small nuclear reactor, possibly designed indigenously, started up in 1987. Two big power reactors were under construction in the late 1980s, suggesting that North Korea had mastered reactor design.[40]

It is not clear when North Korea formally launched its nuclear weapon program. Some activities closely related to nuclear weapon development became apparent in the early 1980s. These activities include building a plutonium reprocessing plant and the conduct of high explosives tests of the sort used to design an implosion-type nuclear device.[41]

North Korea produced some weapon-grade plutonium by unloading the core of its first small power reactor in 1989. Estimated amounts of plutonium separated range from the 0.1 kg reported by North Korea to an upper bound of 7–14 kg. According to its agreement with the U.S. in 1994, North Korea will not be able to get any more weapon-grade plutonium because it has agreed to freeze its reprocessing activities and place its fuel rods in long-term storage.[42]

The CIA believes that North Korean scientists did not receive any training in nuclear weapon technologies from Russia or China. It estimates that North Korea could have only a first-generation implosion design and the mass of a device within North Korea's capabilities would probably be between 500 kg and 1000 kg.[43] Unlike the de facto nuclear states, North Korea has declared many times that it has neither the intention, nor the capabilities to manufacture nuclear weapons. After it signed its agreement with the U.S. in 1994 to freeze some of its nuclear activities, its potential to produce nuclear weapons became significantly limited.

By comparing North Korea's nuclear reactor design experience with Sweden's and South Africa's when they developed their nuclear weapons, we could conclude that North Korea could potentially design nuclear devices with weights not much greater than 1,000 kg.

North Korea has received Soviet designed Scud-B missiles and it has adapted the design into three independently-built versions. All of them have the same diameter of 0.88 m and their ranges are 300 km, 340 km, 500 km with payloads of 1,000 kg, 1,000 kg and 700 kg respectively.[44] According to the CIA assessments, the Scud-type missile would not be capable of carrying a North Korean-designed device weighing 500 kg–1000 kg.[45] However, it is not a problem for the Scud-B missile to carry a warhead of this mass. The other concern is the size of such a device. An implosion-type, plutonium device weighing 1,000 kg would have a diameter of 0.79–0.98 m while the diameter of the Scud missile is 0.88 m (see figure A.2 in Appendix A). Therefore, our conclusion here is that a 1,000 kg device might potentially fit on a Scud-type missile, though barely. If the weight of the device is below 1,000 kg, the size matching would not be a problem. North Korea's Scud-type missiles could reach many South Korean cities, but they could not reach Japan's territory. North Korea's Nodong missile, however, which is still under development, could have a diameter of 1.3 m and a range of 1,000 km with a payload of 1,000 kg.[46] This missile would be able to deliver a North Korean-designed nuclear warhead to some of Japan's big cities. Even if North Korea could only design a nuclear device weighing 1,500 kg, the Nodong missile would still be able to deliver such a device over 800 km,[47] which is greater than the distance between North Korea and parts of Japan.

If the 1994 U.S.-North Korea agreement can be implemented, North Korea will not have the capability to produce nuclear weapons. Therefore, its missiles could not be used for nuclear missions unless North Korea has already separated enough plutonium for one or two warheads.

Iran, Libya, Algeria and Syria

Iran's first nuclear reactor started up in 1967; Algeria's first one started up in 1989; and Libya's first one started up in 1981. So far none of the above countries has acquired the capability to design a nuclear reactor. Syria does not have any significant nuclear facilities.[48]

Iran has been engaged in acquiring more powerful nuclear reactors and uranium enrichment technology.[49] However, most analysts believe that Iran will not be able to produce a significant quantity of weapon-usable fissile material by the end of this century.[50] So far, IAEA experts have not found evidence of military-production programs or diversions of nuclear materials from safeguarded civilian nuclear programs.[51] This suggests that the Iranian nuclear weapon program (if it exists) would be on a very small scale and at an early stage.

Libyan leader, Colonel Khadafi, has expressed strong interest in acquiring nuclear weapons. But Libya has very limited nuclear capabilities and it has made very little nuclear progress.[52]

So far, no apparent evidence of nuclear weapon research has been found in either Algeria or Syria.

Iran, Libya and Syria all have missiles which are nuclear capable as defined by MTCR.[53] But neither they nor Algeria has stronger nuclear research capabilities than Iraq. So they are unlikely to be able to design nuclear weapons by themselves, and even more unlikely to be able to design nuclear warheads for their missiles.

Table 3: Summary of the nuclear delivery capabilities in some emerging nuclear states.

Missile	Status	Diameter of missile (*m*)	Possible type of nuclear device	Maximum weight of a nuclear device that could fit missile (*kg*)[a]	Maximum weight of deliverable nuclear device (*kg*)[b]	Covering areas of the missile	Needed range of the missile (*km*)	Nuclear missile delivery capability
Israel								
Jericho	in service	1.2	implosion	1,800–2,870	1,000	substantial parts of Middle East and North Africa	1,500	yes
Shavit	in service launch vehicle	1.2	implosion	1,800–2,870	1,000[c]	Middle East, North Africa and South Europe	3,200	yes
India								
Agni	tested	1	implosion	1,070–1,800	1,500	Pakistan, Central and South China	1,500	yes
Pakistan								
Haft-2	in service	0.55	implosion	250–470	350[d]	some big cities in India	>400	unlikely
Haft-2	in service	0.55	gun-type	<1,000[e]	350	some big cities in India	>400	unlikely
DPRK								
enhanced Scud-B	in service	0.88	implosion	750–1,300	1,000	some big cities in South Korea	340	marginal
Nodong	tested	1.3	implosion	2,280–3,530	1,000	South Korea and some cities in Japan	1,000	yes

a. The diameter of a missile warhead cannot be greater than that of the missile to carry it. The maximum weight of a nuclear device here refers to the weight of a nuclear device which has the same diameter as the missile listed in the same row. The data in this column are derived from figure A.2 in Appendix A.

b. The range of a missile varies with the payload. The maximum weight of a deliverable nuclear device here refers to the payload of the missile when the range is as listed in the same row.

c. Two data are given by different analysts. We use the data which gives a shorter range. See the section on Israel.

d. See Chandrashekar.[54]

e. The South African gun-type device weighing 1,000 kg has a diameter of 0.64 m, which is greater than that of the Haft-2 missile.

CONCLUSIONS AND DISCUSSIONS

On the basis of the nuclear experiences of the five declared nuclear states, and Sweden, South Africa and Iraq, we can make some assessments of the capabilities of emerging nuclear states to deliver nuclear weapons by ballistic missiles. Israel and India both appear to have the capability to deliver nuclear weapons by missiles beyond their neighboring areas. Pakistan, by contrast, still needs to develop missiles with greater payload and longer-range or to reduce the weight of its nuclear devices if it wants to be able to deliver nuclear weapons over long distances by ballistic missiles. North Korea is obtaining a significant missile capability to support nuclear missions to targets as distant as Japan. But its capability to produce nuclear weapons is limited by its 1994 agreement with the U.S. The situation in North Korea will depend on how this agreement is implemented. Although Iran and other countries of concern have nuclear-capable missiles as defined in the MTCR, they probably have not designed nuclear devices. The nuclear delivery capabilities by missiles in these countries are summarized in table 3.

Although the gun-type nuclear devices are technically less complicated and more suitable for missile delivery, most emerging nuclear states cannot adopt this option because they are not able to get enough highly-enriched uranium. So the constraint on the production of weapon-usable fissile materials plays some role in delaying the development of nuclear delivery capabilities in some emerging nuclear states.

The MTCR is an important regime for limiting the transfer of nuclear-capable missiles and their technologies into emerging nuclear states in the developing world, but it still needs to be formalized into a treaty to enhance its effectiveness. In the meantime, the seriousness of the transfer of nuclear capable aircraft should not be ignored. A universal ban on the transfer of all nuclear capable delivery systems would be helpful to prevent more emerging nuclear states from developing nuclear delivery capabilities.

A Comprehensive Nuclear Test Ban Treaty (CTBT) has now been negotiated and signed by most of the emerging nuclear states. The CTBT could prevent many of these states from reducing the weights and sizes of their nuclear weapons by nuclear tests. So the CTBT will hopefully be an obstacle for the emerging nuclear states to develop their nuclear delivery capabilities.

APPENDIX A: CALCULATION OF THE SIZE FROM THE WEIGHT OF AN IMPLOSION TYPE FISSION DEVICE

The detailed design of nuclear weapons is classified, but the general characteristics of fission weapons are well known by now. Fetter *et al.* constructed theoretical models of nuclear weapons to estimate the radiation characteristics of hypothetical fission explosives.[55] The weights and sizes of fission explosives in the models are consistent with those known about modern U.S. warheads. So they can also help us understand the relation between the size and weight of a nuclear weapon.

In Fetter's models, a fission explosive, or the primary of a thermonuclear bomb, is represented by a series of concentric spherical shells. The innermost is fissile material with outside radius of 7 cm for weapons-grade uranium (WgU) and 5 cm for weapons-grade plutonium (WgPu). A spherical hollow with radius of 5.77 cm for WgU and 4.25 cm for WgPu is at the center. Surrounding the fissile material is a 2-cm-thick beryllium shell as neutron reflector. The next is a 3-cm-thick tamper made of either depleted uranium or tungsten. Next is the high explosives which has a 10 cm thickness. A 1-cm-thick aluminum case is assumed to tightly surround the high explosives.

Fetter's models represent very compact nuclear devices. An emerging state may not be able to design such small devices. Its weapon designers would use more high explosives to ensure that a device would work. We assume that the first three layers (weapon-grade-fissile material, neutron reflector and tamper) of a device remain the same when more high explosive is involved. The size of the case will increase to contain more high explosives. For example, the U.S. first nuclear explosive device, Gadget, used 6.1 kg of WgPu which is about the same in Fetter's models. It had about 2,300 kg of high explosives, which is much more than a compact warhead, and a much bigger case.

In Fetter's model, the high explosive is contained by a perfect spherical case which has a minimum weight. The shape of an actual case may not be spherical. So its weight could be heavier than a spherical one with the same inner radius. We assume that the total weight of the actual case is more than the weight of a spherical shell but is less than ten times that.

Based on these assumptions, we can estimate the weight of an implosive device with a given radius. In Fetter's models, the weight of the first three layers (fissile core, reflector and tamper) w_0 is 94 kg for uranium device; w_0 is 58 kg for plutonium device; the inner radius of the high explosives r for uranium device is 12 cm; r is 10 cm for plutonium device; the density of high explosives ρ_h is 1.9 g/cm^3; the density of aluminum case is ρ_a is 2.66 g/cm^3; the thickness of the case is one centimeter. So the weight of the spherical case is:

$$w_e(kg) = (4\pi\rho_a/3)[R^3-(R-1)^3]/1000 \qquad \text{(A.1)}$$

where R is the outer radius of the case. The weight of the high explosive is:

$$w_h\ (kg) = (4\pi\rho_h/3)\,[\,(R-1)^3 - r^3\,]/1000 \qquad \text{(A.2)}$$

The weight of an implosion type fission device w is assumed to be between w_1 and w_2:

$$w_1 \le w \le w_2 \qquad \text{(A.3)}$$

where,

$$w_1 = w_0 + w_h + w_c$$
$$w_2 = w_0 + w_h + 10w_c \qquad \text{(A.4)}$$

The calculation results of w_1 and w_2 are shown in figure A.1 and figure A.2.

The calculation tells us that the radius of the Fat Man bomb which weighed 4,900 kg could have been between 74 cm and 84 cm. The actual radius of Fat Man was 76.2 cm, which is right in the given range. Using this method we can also estimate the size of implosive fission warheads made by modern emerging nuclear states.

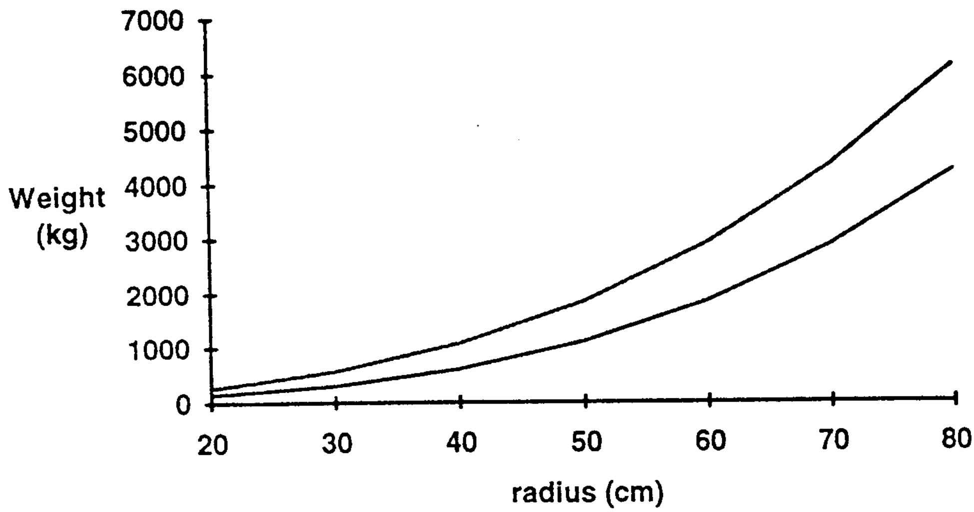

Figure A.1: Maximum and minimum weights of implosion-type device with uranium core vs. the radius of the device.

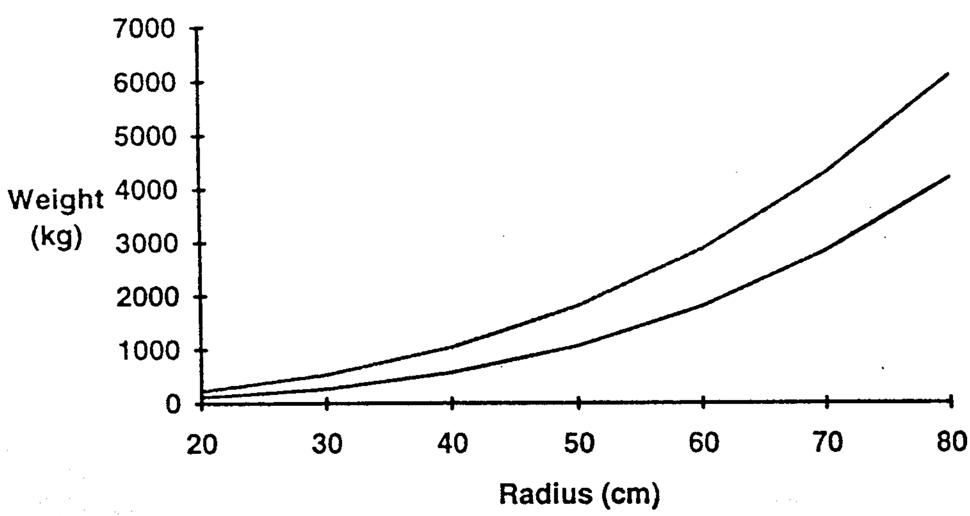

Figure A.2: Maximum and minimum weights of implosion-type device with plutonium core vs. the radius of the device.

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The payload of the Agni missile is reportedly 1,000 kg and its range is reportedly 1,500–2,500 km with this payload. We choose a set of parameters based on those of the SLV-3 missile to produce a model of a generic missile with a range of 2,000 km for a 1,000 kg payload, and then use this model to calculate the maximum range such a missile would have when the payload is 500 kg and 1,500 kg (see table 2).

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