The A. Q. Khan network

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Sammendrag

Dr. Abdul Qadeer Khan var sentral i utviklingen av den pakistanske atombomben. Det har lenge vært kjent at Pakistan har importert både teknologi og materialer for anriking av uran fra Europa, og det har vært antatt at Dr. Khan stjal den nødvendige informasjonen mens han var ansatt i et nederlandsk firma tilknyttet anrikingsindustrien. Det har lenge vært spekulasjoner rundt enkelte lands mulige atomvåpen-programmer og hvor de eventuelt kunne få teknologien fra. I 2004 tilsto Khan at han også hadde solgt teknologien videre til andre land.

Etterforskning viser at Khan var startpunktet for et verdensomspennende nettverk av personer og selskaper som til sammen har kunnet levere det meste et urananrikingsprogram behøver. Iran og Libya har innrømmet å ha handlet med nettverket. Nord-Korea benekter derimot å ha kjøpt anrikingsteknologi, til tross for at Khan har tilstått å ha solgt denne teknologien til Pyongyang.

Pakistanske myndigheter hevder Khan opererte som privatperson for sin egen vinning og uten at verken hans militære eller sivile overordnede var klar over hva som foregikk. De har plassert Khan i husarrest og nekter det internasjonale samfunnet direkte kontakt med ham. Dette vanskeliggjør etterforskningen og reiser spørsmålet om Pakistan virkelig ønsker at den fulle sannheten skal komme fram. Et tjuetalls personer med tilknytning til Khan har blitt forhørt i Pakistan, men ingen av dem har blitt tiltalt eller dømt.

Utenfor Pakistan har et ukjent, men forholdsvis lavt, antall personer blitt etterforsket. Rundt femten personer i åtte ulike land på tre kontinenter har så langt blitt tiltalt for brudd på eksportkontrollover, og i sakene som er avgjort har dommene variert fra bøter til sju års fengsel. Samarbeidet mellom landene i denne globale etterforskningen har vært mangelfullt, sannsynligvis fordi enkelte land ønsker å beskytte egne etterretningskilder og -metoder.

Avsløringen av Khan-nettverket har vist at eksisterende eksportkontrollregimer kan omgås. For å bøte på dette har FN vedtatt en resolusjon som stiller strengere krav til medlemsstatenes innføring og håndheving av nasjonale regelverk. Andre internasjonale organisasjoner har kommet med tilsvarende forslag for sine medlemsstater.

English summary

Dr. Abdul Qadeer Khan was central in the development of the Pakistani nuclear bomb. It has long been known that Pakistan has imported both hardware and technological know-how for uranium enrichment from Europe. It has been presumed that Dr. Khan illegally appropriated the necessary information for this while working for a Dutch firm in the enrichment industry. There have long been speculations surrounding the potential nuclear weapons programmes in some countries, and from where these states could be acquiring the technology. In 2004, Khan admitted that he had sold enrichment technology to other countries.

Investigation shows that Khan was the starting point for a global network of persons and companies that were able to provide most of the necessary components for a uranium enrichment program. Iran and Libya have admitted to dealing with the network. North Korea denies having bought enrichment technology, even though Khan has admitted selling such technology to Pyongyang.

The Pakistani government maintains that Khan acted for his own personal gain and without the knowledge of neither his military nor civilian superiors. Khan is under house arrest, and the international community is not allowed direct access to him. This complicates the investigation and raises the question of whether Islamabad really wishes the full truth to be known. Around twenty persons connected to Khan have been questioned in Pakistan, but none of them have been prosecuted.

Outside Pakistan, an unknown but relatively low number of people have been investigated. About fifteen persons in eight different countries on three continents have so far been charged with violations of export control laws. In the concluded trials, the sentences have spanned from fines to seven years in prison. The cooperation between states in this global investigation has not been optimal, possibly because some countries wish to protect their own intelligence sources and methods.

In light of the exposure of the Khan network, it has become obvious that existing export control regimes can be circumvented. To remedy this, the UN has passed a resolution that requires member states to introduce and implement national regulations. Other international organisations have suggested similar measures for their member states.

Contents

1 Introduction

In February 2004, Dr. Abdul Qadeer Khan, nicknamed “father of the Pakistani bomb” and national hero in Pakistan, admitted to having sold nuclear secrets. The confession was made on public television and was phrased as an apology to the Pakistani people for jeopardizing Pakistan’s national security. He also claimed full responsibility and denied any government authorisation of his actions.[1] He was arrested, was pardoned within a day and has since been held in house arrest. No one outside the Pakistani government has so far been allowed to interview him directly.

Still, a picture of what has taken place is forming. The International Atomic Energy Agency (IAEA) has conducted investigations using their safeguards inspectors’ expertise, and several states around the globe have investigated their own citizens’ involvement. What they have found is a clandestine network of individuals and companies selling nuclear know-how and hardware to aspiring nuclear states. It appears A. Q. Khan was the central connecting point for extended proliferation activities.

This report is an attempt to give a coherent and updated account of what is known of how Khan established his international proliferation network and of how it operated, looking into the international consequences and at how similar enterprises could be exposed and stopped. The study is based on press reports and open government sources. Some of the information in this report has been published in Norwegian in previous FFI reports.

2 History

2.1 Establishing the position

Abdul Qadeer Khan was born in British India in 1936. His Islamic family lived in Bhopal, a town ending up in the Hindu India after the partition of India in 1947. The situation for Muslims in India was difficult, and Khan migrated to Pakistan in 1952, following older brothers that had already made the move. He has later told of how these early events shaped his view of pan-Islamism and gave him a strong sense of patriotism [1]. In 1961 he moved to Europe to complete his studies, first in West Berlin, Germany, then in Delft, the Netherlands. He received his Ph.D. in metallurgical engineering from the Catholic University of Leuven in Belgium in 1972.[1;2] He is described as a sociable man, and he soon built up a network of academic sponsors and friends, some of which would continue to support him later on [1].

After graduation Khan was employed by the Dutch firm Physical Dynamic Research Laboratory (FDO), a subcontractor of Ultra Centrifuge Nederland (UCN). UCN is the Dutch partner in

[1] Full text of the speech is provided in Appendix A.

the Urenco uranium enrichment consortium.[2] His assigned task was to help strengthen the metal centrifuge components to create faster spinning "ultracentrifuges"[3] [2]. Within one week of employment he visited the Urenco enrichment facility in Almelo, the Netherlands, to familiarise himself with the relevant aspects of the operation. FDO got Khan a limited Dutch security clearance, based on the facts that he had lived several years in Europe and was married to a Dutch woman.[1;2].[4] He was not officially cleared to visit the enrichment facility, but did so repeatedly with the consent of his employers. Once inside he seemed to meet no further barriers to moving to higher security areas. The formal security rules were very strict, but the persons working in the plant showed a relaxed attitude towards following them [2].

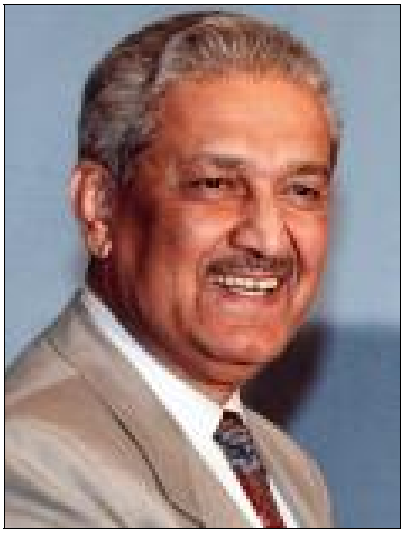

Figure 2.1 Dr. Abdul Qadeer Khan.

As a multi-lingual engineer Khan was given the task of translating highly classified technical documents describing centrifuge designs, first for the early Dutch SNOR and CNOR machines and the German G-1, then in 1974 the most sophisticated design at the time, the German G-2. He had unsupervised access to these documents for a total of 16 days in the lax security atmosphere at Almelo.[2;5] He is also believed to have had access to some details of an experimental design, in sources known as 4-M or M-4 [6].

Already in the early 1970s, Dutch intelligence began monitoring Khan, alerted by technical inquiries not directly related to his own projects. American intelligence officials, however, convinced Dutch authorities not to arrest him, so that his activities could be monitored further.[7;8;8] In the spring of 1974, his neighbours started noting cars with diplomatic plates coming to his house. They did not think this strange at the time, but came forward with the observation when the investigation into Khan's activities finally started [2]. In October 1975, on the insistence of Dutch authorities, FDO transferred Khan away from enrichment work. This was triggered by his reportedly asking suspicious questions at a trade show in Switzerland [7]. In a recent interview with the *BBC* journalist Gordon Corera, Khan's friend and colleague at FDO, Frits Veerman, claims to have told his superiors of Khan changing behaviour in 1975. Veerman, a technical photographer, was asked by Khan to provide him with picture of the centrifuges. Giving more cause for concern was Khan openly discussing sensitive matters with Pakistanis both on the phone and visiting his office [1]. Veerman was also interviewed for a BBC documentary in 2006, repeating his story and also claiming he was told by Dutch officials, not to inform media of his suspicions [9].

[2] Urenco was jointly established by Germany, the Netherlands and the United Kingdom to ensure a steady supply of fuel for their nuclear power plants [1;2]. The group researches advanced centrifuge designs and has several enrichment facilities [3].
[3] More on centrifuge design in Appendix B.3.1.
[4] This was a false premise; his wife is a Dutch-speaking South-African with British passport [4]. Later several efforts have been made to assign the blame for the ease with which Khan got access to classified material; Urenco blamed FDO, FDO blamed Dutch security authorities and the authorities blamed Urenco [2].

There is no evidence that Khan was planted at FDO by Pakistan or that he took the job with the intention to conduct espionage. He was recommended for the position by his thesis supervisor because he had the ideal set of skills [1;2]. Once inside, however, he apparently seized the opportunity presenting itself, to aid his country.

At the end of 1975, Khan went to Pakistan "on vacation" and later sent a letter of resignation to FDO, effective as of March 1976 [2]. It is assumed that he brought with him centrifuge designs, possibly both for the CNOR, G-1 and G-2 (sources differ), as well as assembly instructions for the centrifuges and a list of about one hundred suppliers used by FDO and Urenco [6;10;11].

2.2 The Pakistani nuclear programme

FFI report [12] gives a thorough description of the Pakistani nuclear programme. In this work we focus on the development of the enrichment technology and only present the big picture as a backdrop.

Pakistan Atomic Energy Commission (PAEC) was founded in 1956, and it still leads the national nuclear programme. During the 1950s and 1960s many Pakistani scientists and engineers were trained in the United States and Western Europe. Through Atoms for Peace,[5] Pakistan received nuclear assistance. Their first research reactor (PARR-1[6]) reached criticality in 1965 and a commercial power reactor (KANUPP[7]) was operational from 1971 [12].

In 1968, the Non-Proliferation Treaty (NPT)[8] was made available for signing, but Pakistan to this day is not a signatory. Signing would mean accepting the status of non-recognized nuclear weapons state and having to adhere to the ban against developing nuclear technology for military purposes. Not signing means that Pakistan is not in a legal sense breaching any international treaties when pursuing nuclear weapons and that the international community and the International Atomic Energy Agency (IAEA) have no formal right to inspect Pakistan's nuclear installations. Pakistan has never admitted IAEA inspectors to their centrifuge plants. A direct result from declining to sign was that Western countries suspended their nuclear assistance, and from the mid-1970s Pakistan was on its own [12].

In May 1974, the first, "peaceful" Indian nuclear test was conducted. In September Khan wrote to the Pakistani Prime Minister Zulfikar Ali Bhutto, offering his services to Pakistan [4]. Bhutto was known to favour nuclear weapons. As foreign minister in 1965 he said "If India builds the bomb, we will eat

[5] "Atoms for Peace" is a programme introduced in 1953 by the American president Dwight D. Eisenhower. He offered American assistance to all countries wanting to develop peaceful nuclear energy under an American verification regime.
[6] Pakistan Atomic Research Reactor.
[7] Karachi Nuclear Power Plant.
[8] The Treaty on the Non-Proliferation of Nuclear Weapons, in short the Non-Proliferation Treaty (NPT), defines the recognized nuclear weapons states. The criterion is that the state had detonated a nuclear device prior to January 1, 1967. This includes the United States, Great Britain, China, France and USSR/Russia. The recognized states are bound not to share nuclear weapons technology, and the non-recognized states are under obligation only to use nuclear technology for peaceful purposes.

grass or leaves, even go hungry. But we will get one of our own".[9] In 1971, he became prime minister and secretly started a nuclear programme only a few months after his inauguration [2;16]. It was the demonstration of Indian nuclear capabilities, however, that made Islamabad shift great resources into the development of the nuclear bomb, trying to close the power gap. The offer from Khan was perfectly timed. He was told his services would be required, but that he should stay in the Netherlands for a while to garner more expertise [1].

Pakistan began simultaneous efforts to produce plutonium and uranium of weapons quality.[10] The plutonium could have been produced in KANUPP and reprocessed in a plant, Chasma, which a French firm was to deliver in the late 1970s. But after American pressure on France, Chasma was never finished, and Pakistan now only has a small pilot plant for reprocessing. This plant, New Labs at the complex PINSTECH[11] in Rawalpindi, was built by Pakistan alone but based on the French technology [10]. At least until 1998, when a new reactor was finished, the plutonium road was abandoned.

Pakistan lacked the necessary industry and scientific knowledge to construct an enrichment facility, and therefore had to import the required materials, components and technology from abroad. In August 1975, Pakistan started buying components for uranium enrichment from Dutch Urenco suppliers [17]. It is widely believed that Khan provided the information necessary for this [10]. Analysts quote a German official stating that Pakistan also obtained components and information from Germany [18]. This is to a certain extent supported by the arrest of several Germans thirty years later (see Section 4.2).

Khan began centrifuge work at PAEC in 1976, but within a year he moved to Engineering Research Laboratories (ERL) which exclusively focused on enrichment technology [4]. At the same time he also was in charge of establishing an enrichment plant in Kahuta. Later the laboratories also worked on missile technology [19], a significant fact when looking at possible dealings with North Korea (see Section 5.2). ERL was in 1981 renamed Khan Research Laboratories (KRL)[12] in his honour. PAEC continued research in competition with A. Q. Khan and went on to develop the first generation Pakistani nuclear weapons. Despite the widespread perception to the contrary, Khan was never involved in the weapons development itself [4].

The suppliers of components for centrifuges and equipment for producing centrifuges were willing to provide Pakistan with the quantities they wanted, and export control regimes were lax. Before the world understood what was happening and was able to put in place counter-measures, two Dutch companies had delivered 6200 unfinished rotor tubes in maraging steel, essential for the more advanced centrifuge designs [5;20]. Dutch authorities asked the companies to refrain from the export, but had no specific export ban to invoke. The order was too big for the commercial companies to turn down, and so they chose to go ahead with the delivery despite risking a falling-out with the government [2]. This was a common feature for most of the European companies selling to Pakistan, both private and partly

[9] For more on the Indian-Pakistani arms race, see FFI reports [12-15].
[10] A short technical background on nuclear weapons is provided in Appendix B.
[11] Pakistan Institute of Nuclear Science and Technology
[12] KRL and Pakistan Atomic Research Corporation merged into Nuclear Defence Complex in 2001.

state operated: Economic bolstering of the enrichment industry overrode the caution towards a regime which intelligence services suspected of having nuclear weapons ambitions [20].

After several fairly open attempts, with varying level of success, to buy a range of different technologies from Germany, South Africa, Switzerland and France, the attempt to buy high frequency inverters with specifications only suitable for uranium enrichment centrifuges sparked investigations in Britain [2]. This intensified the suspicion in Western Europe of a Pakistani nuclear programme.

The procurement efforts eventually lead to international sanctions. In 1977 (invoking the Glenn amendment to the Foreign Assistance Act, aimed at plutonium production) and again in 1979 (invoking the Symington amendment, aimed at enrichment technology), the United States stopped all economical and military support to Pakistan. Both the amendments were waived from 1981 to 1989, during the war following the Soviet invasion of Afghanistan in 1979, where the Americans needed Pakistan as an ally [16;19].[13] Other providers required full IAEA supervision before making deliveries, and this limited the import. Smuggling attempts has been revealed, however, some of them successful.

The Kahuta plant was not fully operational until 1984. There were technical difficulties for which a solution could not be bought. The political pressure to quickly reach the goal led to shortcuts and emphasis on speed over precision, and hence the centrifuges broke down and had to be replaced [21]. Chinese technicians worked at Kahuta in the early 1980s, but the extent of the official Chinese assistance is unknown [18]. The Carnegie Endowment for International Peace refers to a declassified US Secretary of State report on the Pakistani nuclear programme in 1983, speculating that China assisted both in fissile material production as well as nuclear device design [1;16]. It is widely accepted that from the mid-1980s, Pakistan was able to produce weapons grade uranium on a large scale [10;16;21].

In the late 1980s, KRL seems to have mastered the basic concept of centrifuge production and gone on to more advanced centrifuges. The laboratory's scientists began publishing works on the construction of maraging steel centrifuges and how to etch grooves in the bearings to facilitate lubrication, an essential detail to make ultracentrifuges work [5;21]. In total, the U.S. Department of Defence, Pentagon, has discovered dozens of reports and conference proceedings on this topic by Khan and his associates [22]. The techniques described were not revolutionary, and the publications were clearly mostly intended for announcing Pakistan's mastering of the technology. The reports nonetheless revealed details Western states wished to keep classified. Khan expressed his motives for publishing within the documents themselves: "This is to pierce the clouds of the so-called secrecy", meaning the non-proliferation regimes in the established nuclear weapons states [22].

In 1998, India detonated five devices in nuclear tests on May 11 and 13. Pakistan responded with six nuclear tests on May 28 and 30, and by this became a *de facto* nuclear state [15]. For Khan personally, this led to further enhancement of his public status.

[13] Since 1985, the American aid is provided only if the president is convinced Pakistan is not possessing nuclear weapons. In 1990 President Bush could not make this certification, and military assistance was suspended [16;19]. After the nuclear tests performed by both India and Pakistan in 1998, the Clinton administration soon waived economic and military sanctions on both countries [19].

3 Disclosure and investigation

3.1 What Western intelligence knew

Starting in 1978, A. Q. Khan was named in numerous Western media reports on secret procurements for the Pakistani uranium enrichment programme [4]. The Dutch authorities kept investigating after Khan left for Pakistan. There are indications that they were under a lot of pressure from other nations, first and foremost the other Urenco partners, Britain and Germany, but also Israel [2]. In 1983, Khan was sentenced *in absentia* to four years in prison for stealing centrifuge information from Urenco [20]. He appealed the conviction, and two years later the case was dismissed on the technicality that he was never properly served the summons. Because he was shielded by Pakistani security, Khan was supposedly impossible to reach with new summons, and the Dutch government decided against renewing the case [4;5;20]. Despite this, Khan travelled repeatedly to the Netherlands in the 1980s without hindrance. Intelligence officials in Europe and the United States claim this was because the CIA wanted to keep watching his movements in the hope of learning more about his methods and contacts [7;23].

Khan himself used the dismissal of the case as proof of his innocence in nuclear espionage, arguing that all he had appropriated from Urenco had been previously published, ordinary technical information available for decades [4]. In an interview with a *Financial Times* journalist in 1993, he claimed the Dutch authorities had retracted the espionage accusations in a letter to his lawyer [24]. Khan also maintained that the Pakistani nuclear programme was entirely indigenous and only used local know-how and locally produced equipment, although he admitted they had based some of the development on "books, magazines and research papers" [4].

A declassified U.S. State Department memo from 1983 shows that the United States knew that Pakistan had a nuclear weapons programme based on stolen European technology [22;25]. Most of the middlemen active in the 1990s version of Khan's network were already in the 1980s investigated or convicted for supplying nuclear technology to Pakistan [11;20;25].

A Pentagon official, then assistant Secretary of Defence Henry Rowen, claims the Pakistani army chief from 1988 to 1991, General Mirza Aslam Beg, told him face to face in 1990 that Pakistan would share their nuclear technology with Iran if they could not get adequate support from the United States. Beg on the other hand dismisses this as a lie [25;26]. The first Bush administration did little to follow up on the perceived threat, and the subsequent Clinton administration apparently did not get this information passed on [25]. The present president Bush says the United States only has become aware of the Khan network in the last few years [25]. The analyst and former IAEA inspector David Albright claims American intelligence believed Pakistan provided Iran with drawings and machining tools in the early 1990s but did not have enough proof to get political support for acting against this [9;27].

In March 2001, both Khan and the PAEC chairman were retired without an official explanation by then General Pervez Musharraf. They were offered ceremonial titles of "special advisers" to the general, a title which Khan rejected. He is now referred to as "special adviser to the chief executive on strategic

and KRL affairs". The speculations on why they had to go ranged from rivalry between the two nuclear research groups turning the public opinion against the nuclear programme, to the military feeling that these two civilians had too much influence over a mature military project [28]. A U.S. Congressional Research report claims the removals came upon American insistence [29]. Pakistani officials have later stated that the removal of Khan was motivated by his corruption [5;23].

After the seizure of the *BBC China* in October 2003, a freight ship with centrifuge components destined for Libya among its cargo (see Section 4.1), the Khan network was exposed and Islamabad was put under pressure from the IAEA and the United States to apprehend Khan [5;30]. At first the Pakistani government was reluctant to arrest the national hero, but after then U.S. Secretary of State Colin Powell made a personal call to President Musharraf, in Powell's own words telling him "we are going public with this in a few weeks, this is your chance to deal with it", Khan was taken into custody [31]. Up to this point, the American government had pushed Pakistan on the matter of proliferation on a general basis for several years, without getting any concessions [7;25].

Soon after his arrest, in February 2004, Khan admitted to having provided nuclear technology to Libya, North Korea and Iran. Within a day he received a conditional pardon and was put under house arrest [30]. Reportedly Khan signed a 12-page confession soon after his arrest but this document has not been made public [8]. Rumour has it the confession was made under pressure, which further frustrates the hunt for the true story of his actions [19]. Both the United States and the IAEA have requested direct interviews with Khan. This has been refused by Islamabad, ending in a compromise where the IAEA can submit written questions to Pakistani authorities and they report back Khan's answers. Some questions allegedly never have been answered and there is a doubt as to the authenticity and completeness of the answers actually conveyed [7;30]. Pakistani officials explain the shielding of Khan with the national security risk direct interviews with someone intimately involved in the nuclear weapons programme would represent [9].

3.2 What the Pakistani government knew

There are many speculations on to which extent Islamabad knew what was going on. The little consequence Khan has felt; a quick pardon and getting to keep his illegally gained riches, hints at Musharraf protecting him and possibly trying to stop information on government involvement from surfacing. Pakistani authorities must at the very least have been aware of the discrepancy in Khan's official earnings and his amassed wealth: He owns a hotel in Mali and a villa at the Caspian Sea in Iran as well as several luxury estates in Pakistan [22;23]. Corruption was also cited as the reason for his removal from office in 2001 (see section 3.1). On the other hand, Khan apparently had a blank cheque when running KRL; the freedom to make purchases at his discretion and unlimited financial means to pay for this [32]. This included access to cargo planes and no customs inspection on neither import nor export goods [21]. It may have been quietly accepted that he made a certain personal profit through the years. In contrast, other high-ranking officials have been punished with deportation from Pakistan for corruption on a much smaller scale [19].

Musharraf is not a popular leader and may have been seeking to share Khan's glory. The easy treatment of Khan may be in deference to his status as a national hero. Bringing him down could reflect badly on the president. American analysts go far in suggesting that internal power struggles in Pakistan are taking precedence over finding the truth [19]. Shortly after Khan's arrest, Pakistani opposition in the Parliament accused the government of covering up the military's role in the proliferation and using Khan as a scapegoat to mollify the United States [19]. Pakistani officials on their side, have been eager to portray Khan as a megalomaniac, obsessed with personal glory and gain [9;23].

General Beg denies ever controlling Khan, claiming this privilege belonged to the civilian leaders at the time, Prime Minister Benazir Bhutto and President Ghulam Ishaq Khan [25;26]. Ms. Bhutto counters this allegation, stating that she ran a "no exports of nuclear technology" policy when in power and saying that even though she was not informed, the military must have known what was going on [33]. This is supported by the fact that she, during her first tenure as prime minister, was denied access to KRL by General Beg with the rationale that "briefings at Kahuta were on a need to know basis" [11;23]. Khan himself claims on the one hand to have been pressured by two individuals close to Prime Minister Bhutto to sell nuclear secrets to Tehran [23], but on the other hand alleges that these transfers were approved by army officers [11].

Former U.S. Ambassador to Pakistan, Robert Oakley, alleges that General Beg in 1991 told him of an understanding between Islamabad and Tehran where Pakistan would help Iran with the nuclear programme in return for oil and conventional weapons [19]. This is in concordance with the claims made by a Pentagon official around the same time (see Section 3.1). Beg has later admitted to being informed by Khan of a transfer of used centrifuges being carried through, but insists that he at the same time was assured that the equipment was outdated and would be of little help for Iran in the short run [5;23].

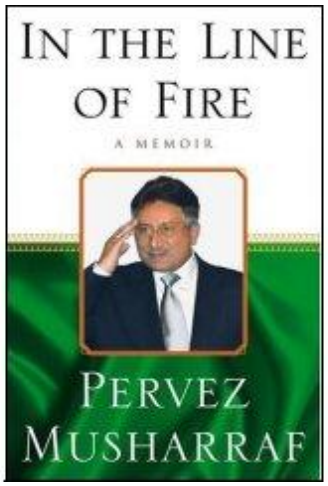

Figure 3.1 President Musharraf published his memoirs in the fall of 2006. Here he gives his version of the Khan case.

There have been rumours that Khan's daughter, Dina, smuggled out of Pakistan documents showing that senior military officers, including Musharraf, were aware of the proliferation activities [23]. In a press statement in October 2006, Dina Khan confirmed that the family outside Pakistan has Khan's written version of events, but said the information will only be revealed if Khan is killed or disappears [34]. In the same statement she rebuffs the accusations made in Musharraf's memoirs that the documents contain nuclear secrets (see Figure 3.1).

Individuals in the Pakistani nuclear programme allegedly informed military and intelligence officials of Khan's corruption already in the early 1980s [23]. In 1998, scientists at KRL supposedly warned the authorities that Khan was involved in suspicious activities [19]. Musharraf admitted in February 2005

that he long had suspected Khan, but claims the United States did not provide evidence of proliferation activities until the fall of 2003 [7;19;21;23].

Between 11 and 25 employees of KRL, and all the leading civilian and military personnel in the laboratory, have been questioned in connection with the scandal. Most were held in custody for some weeks, but no one has been prosecuted [19;30;35]. At the same time as Khan was arrested, Pakistan banned all scientists working on the nuclear weapons programme from leaving the country. Officially this was to keep them available for questioning, but it is speculated that the true purpose was to ensure that they did not talk to foreign investigators or journalists [19]. In May 2006 the Pakistani Foreign Ministry declared that Pakistan had conducted a thorough investigation of Khan and his Pakistani collaborators, and that the conclusions have been shared with the IAEA and relevant countries [8].

The two possibilities for the ease with which Khan could carry out his operations for such a long time are equally frightening: Which is worst; Khan operating without the knowledge of the government, implying that the nuclear programme was out of state hands; or the government actively proliferating nuclear secrets? Even if the government knew nothing of the transactions going on, they would not be as innocent as Musharraf holds: Any state should have security measures in place around their nuclear secrets, ensuring that it is not possible to divert them for personal gain. If the central, civilian-military control is as fragmented and easy to fool as would have to be the case, this suggests a state nearing total chaos.

Despite Islamabad's attempts to absolve itself from proliferation charges, few are convinced that Khan and his associates acted completely without at least tacit acceptance from powerful sections or individuals among the top political or military executives. The tight security, under military control, surrounding the nuclear weapons programme in combination with the rumours and leaks circulating in Western intelligence for decades makes complete ignorance implausible.

Looking at the scope of the transactions, most non-proliferation experts are of the opinion that Khan must have had logistics cooperation from either military or civilian authorities or both [29]. Musharraf argues that most of what has been transferred was *knowledge*, impossible to detect in transmission [23]. This is countered by Western investigations showing large quantities of sensitive hardware being both imported to and exported from Pakistan over a long period of time.

3.3 Further international investigation

Because Pakistan refuses to give the international community direct access to Khan, the most important investigations are conducted by the IAEA and authorities in other states. There has been little cooperation between different countries, something that makes the unravelling of the global network difficult. Separate arrests and prosecutions have been made in Germany, Japan, Malaysia, the Netherlands, South Africa, Switzerland, Turkey and Great Britain [30]. The investigations reportedly pursued in France and Spain have so far not led to any arrests [36].

The IAEA and the United States are leading two separate investigations, reportedly with little or no communication between the Agency and neither the Bush administration nor American intelligence

officials. The Americans have openly declared that they are reluctant to share classified information with the IAEA, as they believe it is prone to leaks in the sense that some of the member states may be using the Agency to get hold of nuclear secrets [7].

The IAEA is using its safeguards inspectors to look for technical clues, but the Agency is also setting up a unit of experts to facilitate analysis of covert nuclear trade activities [7;37]. The unit, also called NUTRAN, has a low profile, but the around six specialists contribute to the State safeguards implementation reports issued by the IAEA [38]. Dr. Mohamed ElBaradei, Director General of the IAEA, stated in March 2006 that the Agency so far has uncovered 30 companies in 30 countries involved in the Khan network [39]. The countries have not been named.

4 How the network operated

4.1 Structure and methods

The network started with one individual, described as a charming, multi-lingual man who easily made friends in all levels of society and of all nationalities [2]. Khan seems to have used his personal contacts to begin supplying the Pakistani gas-centrifuge programme [20;40]. The entire network as so far unveiled is an intertwined web of friends, friends of friends, business partners and family. Khan operated by personal meetings with suppliers and customers, often in third locations like in Dubai or Casablanca in Morocco.

As the import succeeded, more contacts were established and effective methods were found, the operation slowly transformed into a two-way network. In the mid-1980s Western intelligence reportedly could not understand why Khan began ordering twice the amount of components needed for the Pakistani programme. Apparently the international community believed Khan only was focusing on the domestic programme [32].

During the 1990s the network could be seen as a professional organisation able to provide both enrichment technology and weapons designs [30]. The network offered information on suppliers and smuggling techniques as well as advice and trouble-shooting services during the operational phase of enrichment [23]. At the later stages Khan acted as a broker, using his network for buying large quantities of equipment and reselling it, without the equipment necessarily passing through Pakistan at all [32].

The apparent head of the network was in Pakistan, but scientists, engineers and business executives on three continents were involved (Figure 4.1), in as diverse countries as the United Kingdom, the United Arab Emirates, Turkey, South Africa, Switzerland and Malaysia [30;32]. Dubai served as a hub for shipments and financial activities. Suppliers for the network were found in many countries, also among member states of the Nuclear Suppliers Group (NSG).[14]

[14] NSG is a voluntary group of nuclear supplier countries, which seek to prevent proliferation of nuclear weapons through implementing guidelines for nuclear related exports in national laws. Because all

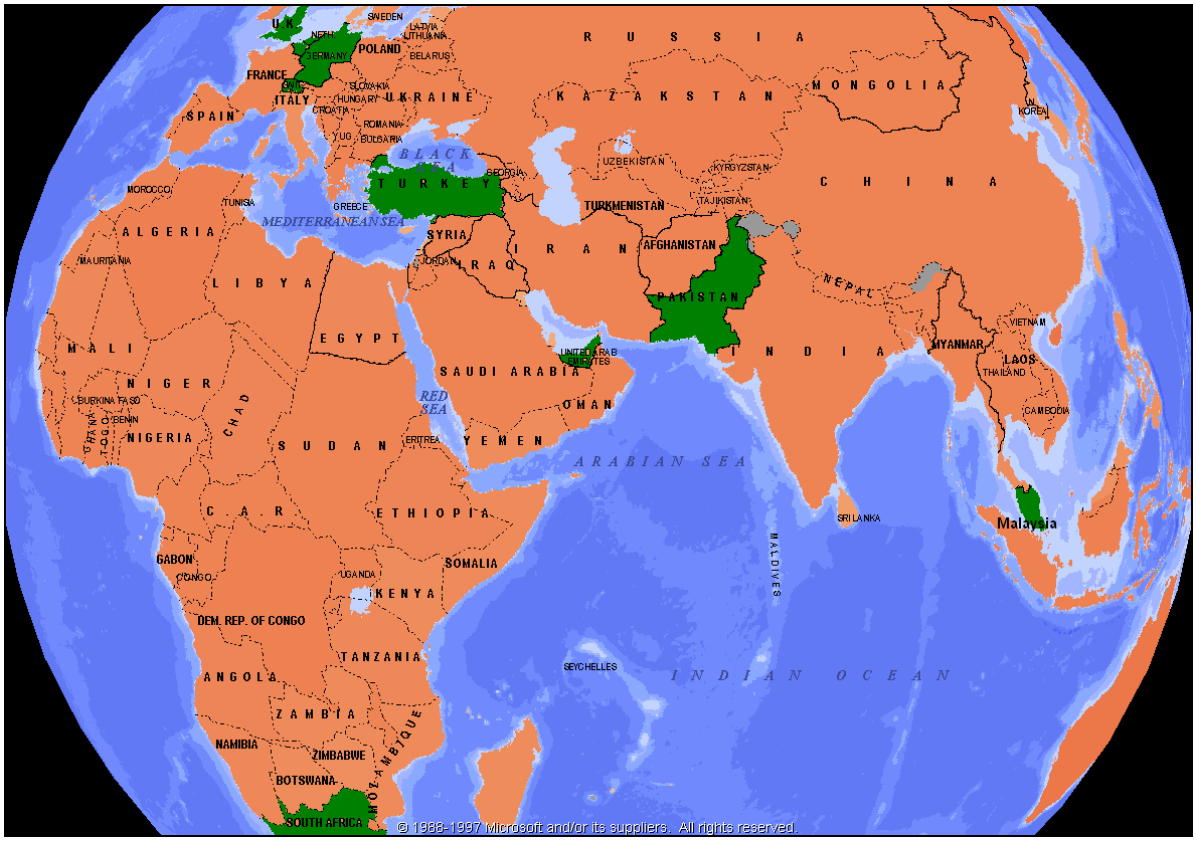

Figure 4.1 The major players in the network were located on three continents. Their bases are marked in green.

Khan was aggressively marketing his services. Advertisements for enrichment technology began to appear, sporting mushroom clouds as eye-catchers. Some of the advertisements were official announcements from the Pakistani government that they were able to export nuclear equipment [5;22]. In November 2000, the first international arms exhibition in Pakistan was arranged. KRL had a stand displaying a range of conventional military equipment, but also brochures for nuclear technology (Figure 4.2). The British resource Jane's Information Group reports to have secured one catalogue of dual-use equipment and another headed "nuclear-related products". KRL officials on the stand assured that all items on offer had governmental approval for export [11]. When confronted with the brochures by Jane's, Pakistani intelligence denied the authenticity of them [8;11]. This is not convincing, considering the earlier announcements from the government.

KRL also produced promotional films, where the competence and capabilities of the laboratory and Khan himself was emphasised. A copy of this was found in Libya in 2004 [9].

member states are supposed to have implemented strong export measures, shipments of dual-use items between NSG members are less stringently inspected [41].

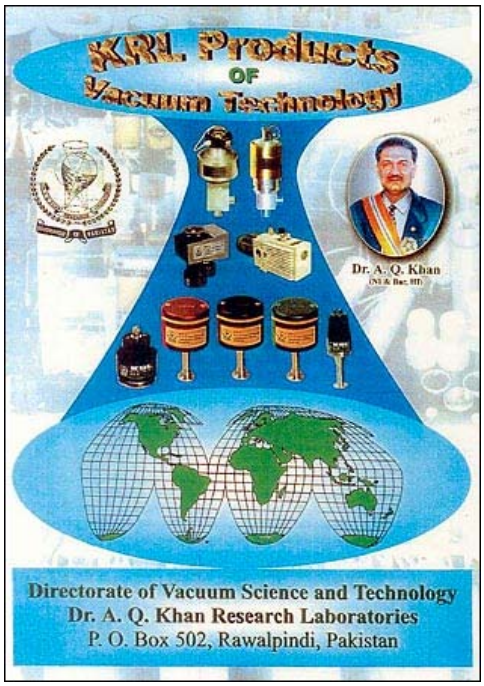

Figure 4.2 Front page of the brochure Jane's reporter Andrew Koch allegedly acquired at the arms exhibition in Karachi in 2000 [11].

For years, rumours of Khan's dealings were abundant in both Pakistani and American intelligence. The breakthrough for American intelligence came in October 2003, with the interception of a shipment of parts for centrifuges, bound for Libya. The shipment was tracked from Malaysia, via repackaging in Dubai and reloading to the German owned *BBC China* [32]. The search of this ship in an Italian port gave additional leverage in the ongoing effort to make Libya renounce its weapons of mass destruction programme.

Even though the centrifuges and their major parts were classified and under export control in most Western countries, the individual basic components were not [2]. In addition, the network exploited loopholes in the control regimes, giving false end user information or exporting items falling just below the control list specifications or amounts just under triggering levels [35].

Workshops were contracted to manufacture components, not complete centrifuges. To do so, they imported the necessary materials and subcomponents from different countries, produced the items and sent them to a third country, most often Dubai, under a false end-user certificate. There the parts were repackaged and shipped to the final customer where the centrifuges would be assembled. From information found in Libya, at least six workshops in Europe, Africa, Southeast Asia and the Middle East have been identified. Each workshop specialized in different parts for the centrifuges [30]. In all probability, only a few persons in each workshop knew the real end use for the components.

Malaysia seems to have been an important country in the later years, with the network exploiting an apparently weak export control regime [30]. Malaysia is a party to the NPT, but has not signed the

Additional Protocol,[15] and apparently only feel obliged to report movement of fissile material to the IAEA. In the police report following investigations into the Khan network, it is stated that Malaysia is under no obligation to make any enquiries into export of even single-use nuclear items, much less dual-use equipment [40]. In 2002, when Khan no longer was at Kahuta, one of the largest workshops producing components for the network, Scomi Precision Engineering (SCOPE), was set up here as a substitute. Supposedly the owners were unaware of the true purpose of operations [40]. Malaysian police found in their investigation that the employees at SCOPE thought they were manufacturing components for the gas industry in Dubai, and that they had no way of understanding that the components really were intended for a different end user in the nuclear industry [40]. American officials reportedly doubt this account, but have accepted the assurance that the workshop no longer produces the centrifuge parts [32]. It is noteworthy in the context of the investigation that the owner of SCOPE's mother company is the son of the Malaysian Prime Minister Badawi (2003-present) [36].

Other companies have also been investigated. Two German-owned companies, Bikar Metal Asia and Döerrenberg Edelstahl, exported raw materials to SCOPE. South Korean Hanbando Inc. and De Young Engineering cooperated in providing equipment for centrifuge manufacturing to Libya. None of these firms have been found guilty of export control violations and most likely, only De Young had any idea what they were involved in [35;36]. Mitutoyo Corp. in Tokyo exported sensitive machinery to other Japanese companies based in China and Thailand. The machines allegedly were found in Libya by IAEA inspectors. Four executives in the firm have been in the custody of Japanese authorities since August 2006 [35;36]. In December 2006, the four pleaded guilty in illegally exporting equipment to Malaysia, and the company promised to put in place measures to prevent similar incidents in the future [42].

4.2 The persons involved, their roles and the consequences to them

One of the important players in the network, the Sri Lankan businessman Buhary Seyed Abu Tahir, was "held for questioning" in Malaysia from 2004 to 2005, but the Malaysian government denied others access to him.[16] Since 2005 he is believed to be a free man in Dubai [36]. From what is known, Tahir was the chief organizer for the network in Dubai, running a computer company acting as a front for shipments and money transfers [7;32]. Khan apparently treated him like a son and even paid all expenses for his wedding in Dubai, the only occasion where most of the network's players ever were gathered in one location [1].

When interrogated by Malaysian police, Tahir alleged that he first got involved in the network in 1994, organizing a shipment of two containers of used centrifuges from Pakistan to Iran and arranging the transfer of US$3 million in payment from Tehran [40]. In December 2001 Tahir signed a US$13 million contract for 25,000 aluminium centrifuge components with SCOPE [17]. Tahir has exposed several middlemen and explained their roles in the network. Most of the persons named in the report from the Malaysian police are investigated and to some extent prosecuted in their home countries.

[15] The Additional Protocol among other things requires signatories to report export of single-use nuclear items.

[16] Malaysian police deemed this a national matter because B. S. A. Tahir is married to a Malaysian woman and is a permanent resident of Malaysia, even though he spends much of his time in Dubai.

Figure 4.3 Buhary Seyed Abu Tahir.

Tahir claims that a British owned company, Gulf Technical Industries (GTI) which was set up in Dubai in 2000, was an important intermediary in the shipment of precision machining equipment [40]. In Great Britain and the United Arab Emirates there have been investigations into GTI and its owners, father and son Griffin [30]. Investigations have been terminated without any prosecution [36]. Griffin senior has admitted to "selling all that could legally be sold" through other firms to Pakistan for two decades, but denies any involvement in the further proliferation network [32]. He sued a London newspaper over allegations that he was found guilty in Malaysia, and was awarded damages [35;36].

Two Turkish engineers, Gunas Jireh and Selim Alguadis, allegedly supplied metallurgical and electrical equipment to Libya [40]. Jireh, director of the engineering firm ETI Elektronik, died in 2004 before any investigation was initiated [35]. Alguadis, president of another electronics company, is under investigation. So are two of his employees. If convicted, they may have to serve up to 20 years in jail [35;36].

Tahir further pointed to a Swiss engineer, Friedrich Tinner. He supposedly was a central supplier of centrifuge components from all of Europe since the 1980s. His son, Urs Tinner, was a consultant at the SCOPE workshop in Malaysia [35;40]. His other son, Marco, supplied specialized equipment to SCOPE. Friedrich Tinner was arrested in Germany in October 2004 after investigations based on the allegations from Malaysia. Since 2005 Tinner has been awaiting trial in Switzerland, as have his two sons. Swiss authorities have appealed for information from the United States, without success. It is speculated that the Tinners have struck a deal with the CIA [35]. Marco Tinner is simultaneously investigated in Turkey and Malaysia, and faces up to 32 years imprisonment in Turkey if convicted [35].

Two Germans were named, Heinz Mebus in connection with transferring centrifuge designs to Iran in the mid-1980s and Gotthard Lerch for trying to supply Libya with workshop components [40]. Mebus was a friend of Khan's from their student days in Berlin and spent time with him in Pakistan until Mebus' death in 1992 [1;35]. Swiss authorities arrested Lerch shortly after Tinner was arrested in Germany, allegedly in a coordinated operation between the two states [30]. He has been extradited to Germany and put on trial; however, some procedural mistakes were made and the trial will have to start over. German requests for judicial assistance from Lichtenstein, Switzerland, Malaysia and South Africa have not been answered [35].

In September 2004, in South Africa, Johan Meyer of Trade Fin was arrested on suspicion of manufacturing centrifuge parts for Libya. He was released after six days in custody and all charges were dropped, even though he could have faced up to fifteen years in prison if convicted [35]. This led to speculations that he cut a deal not only admitting to the accusations, but also giving information

leading to further arrests [30;36]. The German Gerhard Wisser owned Krisch Engineering in South Africa and had been arrested on similar charges in Germany a month earlier, but released on bail. When Meyer led South African authorities to him, they too had to let him go on bail after a short time [30]. Wisser's employee Daniel Geiges is also suspected but not detained. Both men are awaiting trial in March 2007 [35]. Geiges appeared on a BBC documentary in the end of 2006, admitting to producing a small scale centrifuge plant in cooperation with Trade Fin. Geiges knew the plant was destined for Libya, and confirms that it would have been able to produce around 25 kilograms of 90 % enriched uranium pr. year. He is unrepentant, as he claims the United States has no place in dictating which countries are to have nuclear weapons [9]. This operating plant, as well as several crates of enrichment equipment necessary for handling gaseous uranium, have been found, strengthening the case against all of the South Africans involved [7;36].

There have also been investigations into the activities of individuals not named by Tahir, but who have in one way or another attracted the attention of Western intelligence or have been arrested for violating national export control laws. Many of these cases are interconnected.

In 2005 Rainer Vollmerich was sentenced to a little more than seven years in prison for falsifying end user documentation. This is the longest sentence so far meted out in connection to the Khan network. Vollmerich functioned as a middleman procuring nuclear materials in Germany and shipping them to Pakistan via South Africa [35;36].

In 1998, the German businessman Ernst Piffl was convicted of having violated German export control laws by exporting centrifuge parts to Pakistan and was sentenced to almost four years in jail. At the end of his trial he let slip that he had started cooperating with the German foreign intelligence (BND) on keeping track of the Pakistani effort to supply the nuclear programme [6;35]. Despite this revelation, Khan continued placing orders with Piffl's firm through 2001. Through Khan's correspondence with Piffl, BND learnt that logistics for one order was to be arranged by an intermediary in the Netherlands, Henk Slebos. The shipment was intercepted and turned out to consist of ball bearings exactly matching the specifications for the Urenco centrifuge design stolen 25 years earlier [6].

Slebos was not an unknown name to Western intelligence services. He met Khan at Delft university, and they kept in touch ever since [1]. He was investigated in the Netherlands in 1979, suspected of exporting maraging steel tubes to Pakistan, but nothing was proven. In 1983, he was convicted for re-exporting an American-made oscilloscope to Pakistan via the United Arab Emirates. Through the 1990s, his firms on average made one shipment to Pakistan every week, consisting of various technical items bought from other companies. He was several times warned by Dutch export control authorities not to export the items, but ignored this. In April 2004, Dutch authorities charged Slebos with exporting a wide range of dual-use items to Pakistan. During the investigations, he has also been connected to the Turkish engineering firm involved in setting up SCOPE in Malaysia. In December 2005, he was sentenced to four months in prison and a large fine. He has appealed the conviction [6;35]. Slebo's employee Zoran Filipovic has been sentenced to 180 days of community service and a small fine for smuggling items to the Balkans so that they could be shipped from there to avoid the Dutch export control regime [35;36].

The only trial in Britain so far was the conviction of the originally Bangladeshi Abu Siddiqui. He received a suspended jail sentence and a small fine for illegally exporting advanced metallurgical equipment to Pakistan [1;35].

5 Customers

5.1 Libya

Libya's undisputable ruler for several decades, Revolutionary Leader Colonel Muammar Gaddafi, said in 1975: "Soon we shall be able to buy an atom bomb and all its component parts" [2]. It seems the Khan network was able to give a helping hand in fulfilling this vision.

The dealings between Libya and Pakistan go back to the 1970s, when Tripoli is rumoured to have financially supported the Pakistani nuclear weapons programme. President Bhutto and Colonel Gaddafi were close personal friends, and allegedly shared the dream of the Islamic bomb. In 1974, Tripoli agreed to pay up to $500 million to the Pakistani enrichment research in exchange for the technology that was developed [1;2].

Libya was the one customer to trigger the unravelling of the network, by being coerced to come clean on its total weapons of mass destruction programme. Tripoli has admitted to ordering a gas-centrifuge plant sufficient to produce enough weapons grade uranium for ten nuclear weapons annually. That is 10,000 so called L-2 centrifuges, consisting of more than one hundred components each. IAEA experts have determined that L-2 has many common features with P-2 and is very similar to early European designs [43]. The deal made in 1997 was for a turn-key facility and on-going technical assistance both in assembling and operating the plant [30].

Libya also received a nuclear weapons design, assembly instructions and component fabrication information [32;43]. The documents found were a mixture of hand-written and printed, in good condition and dirty copies of copies, chiefly in English, but some pages were Chinese text [44]. This is the same design that is believed to have been provided to Pakistan by China in 1983 [8]. Much of the information was also digitalized and fitted on one disc [43]. Quoting "American government officials", analysts report that the weapons design appears to be of Chinese origin, of a type tested in the 1960s. It was a design that clearly worked, but apparently some important details were omitted [7;30;44]. Reportedly the design specifications are for a ten-kiloton implosion weapon[17] of 435 kg, a size possible to mount on a missile [7;11;23;30]. One source claims that the design has implosion-based detonation [5]. In addition Libya ordered a complete workshop for producing centrifuge components, presumably to be self-sufficient in replacing and repairing centrifuges [30;40]. The present Bush administration says the total deal earned Khan $100 million [7;45].

Already in 1997, Libya received its first shipment from Pakistan, 20 assembled P-1 centrifuges and parts for 200 more. It was when the supply of these obsolete models turned out not to be enough for

[17] For more on weapons design, see Appendix B.4.

their ambitious plans that Tripoli decided to switch to a variant of the P-2 design, later designated L-2 [11;23].

Libya, according to the IAEA, has received approximately 1.5 metric tons of uranium hexafluoride (UF_6) as partial delivery of an order for 20 tons [43]. The UF_6 was directly airlifted from Pakistan [23]. American intelligence claims North Korea sold the UF_6 to Libya. This is based on chemical traces on the outside of the cask found in Libya. These traces have been matched to plutonium samples from Yongbyon, North Korea's main nuclear site. Critical voices, among others the Carnegie Endowment, say this only proves that the cask has been in North Korea, not that the contents originate from there [17;46]. North Korea has a uranium mining industry and produces reactor fuel but it has not been proven that it has a facility making UF_6[18] [46]. Tripoli has not disclosed the origin of the uranium, if they indeed know it.

Libya was anxious to get the bomb, and tried to buy equipment also from other sources than Khan, a fact complicating the picture when investigating their nuclear programme in relation to the Khan network. The IAEA has found proof for earlier transactions, notably a complete uranium conversion facility ordered in 1984 but never completed [1;43]. The Pakistani *Daily Times* reports that Western diplomats believe the company supplying the modules for this was Japanese [47].

All above is known because Colonel Gaddafi decided to totally abandon programmes for all weapons of mass destruction after the seizure of the *BBC China* in 2003. One proof of the new openness was the report which the IAEA and American intelligence received when the *BBC China* finally arrived in Libya after passing through several ports since Italy. It appears investigators overlooked one crate of centrifuge parts when searching the ship, and Libya notified both the United States and the IAEA of this, adding that other orders they had placed might be completed later [1;48].

5.2 North Korea

The analyst Albright quotes an "anonymous US government official" claiming evidence strongly suggested that North Korea has received centrifuge designs, sample centrifuges and lists of potential suppliers [30]. The *Bulletin of the Atomic Scientists* quotes then Secretary of State Colin Powell as saying that the enrichment procurement from Pakistan started on a small scale in 1998 [49;50]. In a written statement to the Pakistani government, Khan reportedly admits to supplying both discarded centrifuges with drawings and technical data, as well as unenriched uranium hexafluoride to Pyongyang [11;51].

A report from the US Congressional Research Service claims there are strong indications that Pakistan has been the main source for centrifuges or components for the North Korean enrichment programme. American reports of procurements date as far back as the mid-1980s, but here other sources differ [50;52]. In 2002, the CIA distributed a short white-paper to Congress stating that the Agency recently had obtained evidence that North Korea was constructing an enrichment plant that could produce enough weapons grade uranium for two or more weapons per year. They also had learnt that

[18] Background on uranium treatment and enrichment is provided in Appendixes B.2.2 and B.3.

Pyongyang had started procurements related to centrifuge construction.[53] The *New York Times* journalist David E. Sanger claimed in a speech at Stanford University in 2004, that the discovery of the enrichment programme in fact was due to South Korean intelligence [22]. A Carnegie Endowment working paper supports this by reporting that a defector to South Korea from the North was the intelligence source [52]. Jane's Information Group refers to a classified US Intelligence document from 2002, more precisely estimating that the HEU production could be operational in 2005 [11].

As late as in 2003, German authorities had a ship bound for North Korea stopped in the Suez Canal. The steel tubes found on board had the exact dimension of the outer casing of a G-2 centrifuge [5;22].

A Pakistani official involved in the Khan investigation is quoted both in American as well as Pakistani sources as saying that North Korea ordered P-1 centrifuge components from 1997 to 2000 [29;51]. An American intelligence source reportedly claims the amount corresponds to 2000 centrifuges [52]. Nevertheless, Pyongyang totally refuses all allegations of having a uranium enrichment programme [19].[19] According to the American negotiator James Kelly, North Korean officials admitted to an enrichment programme at a meeting in 2002 [52;54], but this is denied by Pyongyang. The *Bulletin of the Atomic Scientists* supports Pyongyang in this [49]. When North Korea was faced with the charges, this was a contributing factor leading to the IAEA inspectors being ejected and the country exiting the NPT.

Several western official sources report that Khan made up to 13 trips to North Korea during the 1990s. In the same time period Pakistan bought North Korean *No-dong* missiles [9;19;29]. At this time the Pakistani economy was at a low point. How could they afford expensive military equipment? One theory is that Islamabad bartered nuclear technology for missile technology with Pyongyang. In 2004 President Musharraf denied this, stating that "whatever we bought from North Korea is (*sic*) with money" [9;19;22;29].

More speculatively, the *Disarmament Diplomacy* analyst Christopher Clary claims that Pakistan in 1997, when proliferation to North Korea supposedly started, already had acquired superior Chinese missile technology and that a more probable swap would have been enrichment technology for plutonium reprocessing technology [21]. Either way; in his memoirs, published in September 2006, Musharraf admits that nuclear secrets have been sold to North Korea [29]. In a hearing before a Congressional subcommittee in May 2006, the analyst Dr. Leonard Weiss claimed that President Musharraf has admitted that Khan delivered centrifuges to North Korea [5;8].

In 2000, American officials reportedly raised suspicions with Pakistan of nuclear transactions between Pakistan and North Korea. There supposedly are satellite photos showing Pakistani freight planes in North Korea [5]. The Pakistani investigation following this, revealed large sums of money in the personal accounts of several KRL scientists. Pakistan did not deny that the money could stem from North Korea, but insisted that the persons concerned acted as individuals [29]. Khan has in his

[19] North Korea is known to have a plutonium based weapons programme, and the nuclear test 9 October 2006 is supposed to have been a small plutonium device. More on the North Korean nuclear weapons programme can be found in FFI report [54].

confession alleged that military officials knew of the transactions with North Korea [29], naming 1994 army chief of staff General Abdul Waheed and his successor General Karamat [5]. Karamat was in charge of the *Ghauri I*[20] missile barter deal, implying that the next army chief of staff and head of the *Ghauri* programme, Musharraf, was informed [5].

5.3 Iran

Pakistan and Iran are suspected of having signed a secret agreement on peaceful nuclear cooperation in 1986 or 1987. Iranian scientists received training in Pakistan, and Khan may have visited the reactor under construction in Bushehr. The subject matter of the supposed visits is unknown, but the visits may have been the start of Khan's assistance to Iran [19;55]. It is suspected that Khan offered a package of nuclear technologies, including uranium metal casting assistance. The IAEA has been shown a copy of a one-page summary of what Iran claims is the first offer made in 1987, for the supply of complete centrifuges, parts, drawings, specifications and calculations as well as equipment for uranium re-conversion and casting [1;17;56]. Tehran claims no other written documentation exists from this meeting and has so far denied the IAEA copies of the document [56].

An Iranian opposition group exposed the location of the enrichment plant under construction in Natanz in August 2002. This led to IAEA inspections in 2003, which revealed that the technology Iran possessed was more sophisticated than previously suspected, and that a cascade of 164 centrifuges was being finalized [11;57].

In 2003, Tehran admitted to the IAEA that P-1 centrifuges had been purchased through an intermediary for the first time in 1987. Additional and replacement, more advanced, centrifuges and components for another 500 centrifuges were purchased in 1994, 1996 and 1997 [27;57]. At the same time, Iran received drawings for P-2 centrifuges. This supports the claims made by Tahir of starting his involvement in 1994 (see Chapter 4). The first centrifuges were surplus, used models, some even defective, and Tehran was not happy with paying full price for old technology contaminated with uranium [9;27;32]. The Iranians had not taken the trouble to remove markings showing company details of the suppliers [27]. This tell-tale information, combined with the contamination with highly enriched uranium found by IAEA inspectors in 2003, led to Iran pointing to Pakistan as a supplier to prove that their own programme had not gone so far as to actual enrichment [11;57]. According to their safeguards agreement, Iran is required to inform the IAEA 180 days before they introduce fissile material into any nuclear facility.

A Pakistani official claims the Iranians came to Islamabad in the fall of 2003, warning that they were under investigation by the IAEA and would have to admit to having received sensitive components and designs from "individuals from a South Asian country" [58]. The IAEA had in fact been provided with a list of five European and Middle Eastern names, implying that these individuals had resold designs from Pakistan. Analysts believe the more probable scenario is that Pakistan provided designs to Tehran along with names of these persons, persons that could be helpful in acquiring necessary components [27].

[20] *Ghauri I* is the Pakistani name for the missile they maintain to have developed indigenously, but which is assumed to be *No-dong.*

Tehran officially denies having received any weapons designs, and according to the Pakistani government Khan also denies having provided this [30].

5.4 Iraq

Iraq's nuclear programme was revealed after the first Gulf war. In 1992, the IAEA performed inspections and uncovered information on among other things a centrifuge enrichment programme. Several Western European companies and individuals, mainly German, was shown to have contributed know-how and hardware in the same manner later found in the Khan network. The centrifuges found were adaptations of German Urenco designs [59]. At the time, the source of the Urenco blueprints was not exposed.

The analyst Albright refers to documents found in Iraq in 1995, regarding an offer made by Khan. According to this, he was prepared to provide Iraq with designs for a nuclear weapon and to assist in uranium enrichment and in manufacturing the actual weapon. He would also ensure necessary supplies from Western Europe. Apparently Baghdad was sceptical, fearing an American-driven sting operation, and declined the offer. The IAEA tried investigating the matter, but both Pakistan and Iraq have denied the authenticity of the documents [11;23;30;60]. The source of the documents was Saddam Hussain's son-in-law who fled from Iraq after falling out with Hussain's sons [1].

A German intelligence investigation concluded already in 1991 that Iraq, and possibly North Korea and Iran, obtained information on the complex uranium melting and casting process from Pakistan in the late 1980s [19;29].

5.5 Other countries

The bomb blueprints found in Libya indicates nuclear trade between Pakistan and China. It is known that Khan travelled several times to China. R. Einhorn of the U.S. State Department and other intelligence experts believe Khan traded centrifuge technology for the Chinese bomb design [7]. It is known that China has provided assistance to the official Pakistani nuclear programme (see for example Section 2.2).

Pakistani investigations reportedly have found that both Syria and Egypt was approached with offers from the network, but that nothing came out of the negotiations [30]. Khan allegedly travelled to Syria to meet with top officials in the mid-1990s [58]. In 2005, former chief of the Israeli Intelligence, Mossad, Ephraim Halevy indicated Syria, Egypt or Saudi Arabia may have received nuclear information from the Khan network [38]. In a Congressional hearing in May 2006, it is claimed the CIA has revealed that Khan sold nuclear technology to Syria [8].

There are also circumstantial evidence that Saudi Arabia received offers of assistance [11;23;30]. Here the Pakistani government seems to be involved, and the role of Khan is more uncertain. An Israeli analyst claims that in 2003, Saudi Arabia and Pakistan signed an agreement on nuclear cooperation, giving Pakistan oil and ensuring Saudi Arabia deployed nuclear weapons [61]. The claim of Saudi

Arabia financing the Pakistani programme is repeated by the *BBC* journalist Gordon Corera, although he suggests this started already under Zulfikar Bhutto [1].

Khan is known to have travelled to 18 different countries in Asia and Africa between 1997 and 2003 (Figure 5.1). According to several sources who know him both professionally and personally, Khan seldom travelled for leisure only. There are speculations that some of these states were potential customers, although some of them might as well have been suppliers of raw materials like natural uranium [7]. Notably, Afghanistan was one of the countries, and it is known to have been the base of Al Qaeda and possibly other terrorist organisations at this time [30]. It was not necessarily the government of the states that were the customers, it might as well have been groups based in the countries.

There is every reason to believe that the extent of the network may be greater than has so far been proven. A report for American Congress from 2005 supports this view [19]. In April 2004, J. R. Bolton, then under-secretary of State for arms control and international security, claimed the network had more customers than could be discussed publicly [7].

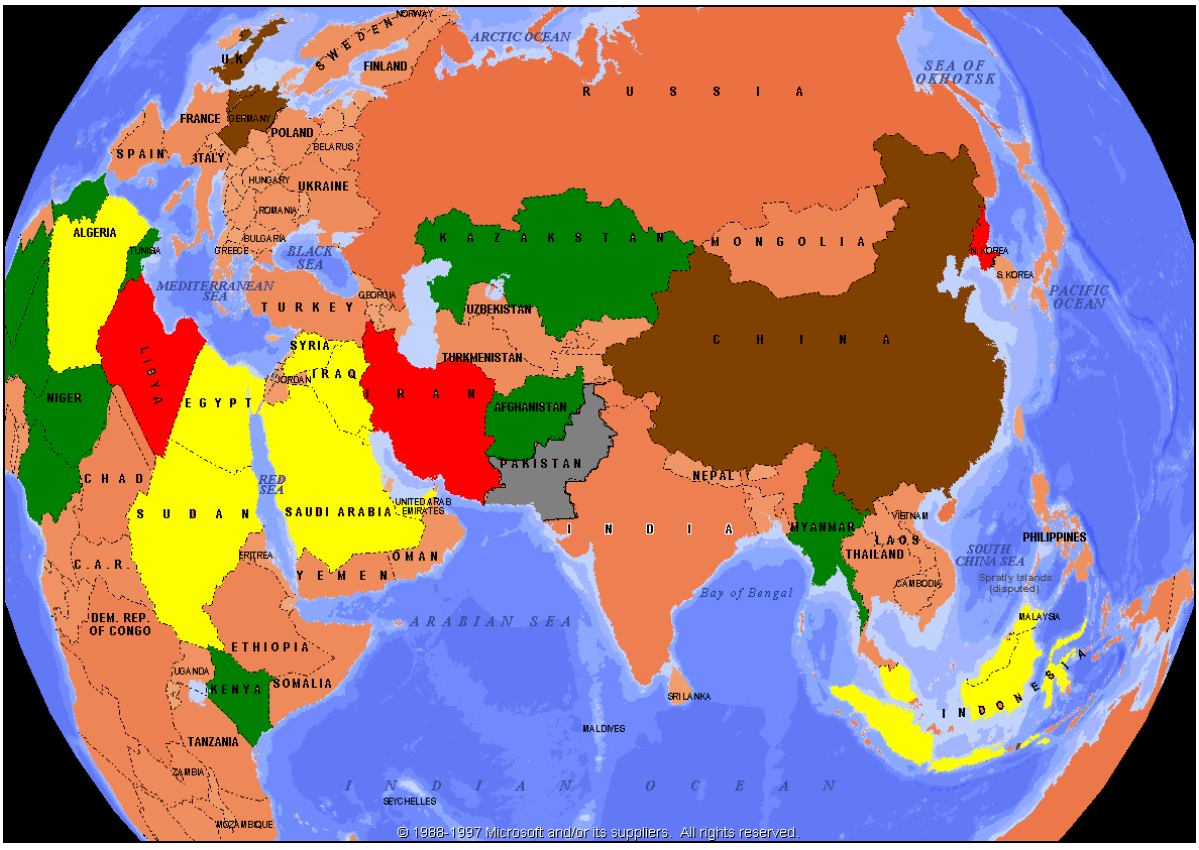

Figure 5.1 The countries in brown were the origin of information to Pakistan. The countries marked in red are the customers Khan has admitted selling to. The yellow colouring shows suspected customer states and the green represents countries that Khan visited in later years for unknown purposes.

6 Lessons learned

The exposure of the Khan network demonstrates that the export control regimes have not been effective enough in stopping nuclear proliferation. The network circumvented the control regimes by falsifying end-user information and cargo manifests. Some countries appear not to have followed up on international and national guidelines, and some that were not considered potential suppliers of nuclear items have been shown to possess industries that can be exploited. By targeting these states, the network was able to acquire and transport sensitive materials and equipment.

Whether it was due to political deliberations deemed more important or the wish to expose more contacts in the network, Western intelligence seems to have seriously misjudged the situation. The intelligence mistake apparently made in the case of the Khan network, was underestimating the scope of the operation and so, despite the awareness of some of what was going on, allowing the network to grow into a complicated structure that now may be difficult to completely uproot. The crucial point that was missed was the turning from import only to re-export.

6.1 Measures taken

In April 2004, the UN Security Council passed resolution 1540, requiring all UN member states to criminalize proliferation to non-state actors. In addition, the resolution states that export control systems should be established, implemented and reviewed [30].

At its May 2004 plenary meeting, the NSG decided that all member states should establish a catch-all mechanism in the export control regimes already in place, providing the legal basis for denying export of items not on a control list if there are suspicions that the item might be intended for a nuclear weapons programme [30]. This aims at removing one of the loopholes exploited by the Khan network. At the same meeting, it was agreed to improve information flow among members and from member states to the IAEA [30].

One proposed improvement in the IAEA safeguards system is amending the Additional Protocol to require reports from states on import and export also of dual-use items. This would give the IAEA a better overview of the nuclear capabilities and infrastructure of a state [30].

Dr. ElBaradei of the IAEA has further called for a binding treaty similar to UN resolution 1540 [30]. Such a treaty would give the legal right to verify a state's completeness of reporting and also impose requirements on states not implementing the Additional Protocol. In an interview following his receipt of the Nobel Peace Prize, Dr. ElBaradei maintains that export control measures alone no longer are sufficient to stop proliferation, as the know-how seems to be out of state control and in the hands of unknown individuals [39].

President Bush announced the Proliferation Security Initiative (PSI) in May 2003. The initiative calls for bilateral ship-boarding agreements to facilitate inspections and seizure of suspicious cargo. Including the United States, eleven western countries form the core group of the initiative, and more than 60 countries have expressed their support [62]. Critics of the programme point out that PSI

depends on precise intelligence and willing allies, and that it has to use the national laws at the point of interception, not an internationally agreed framework [22]. The greatest achievement of PSI to date is the interception of the *BBC China*, although the fact that not all crates were found even when it was known what to look for, highlights the limitations of the method.

The United States' focus of retaining Pakistan as an ally seems to have been at the expense of non-proliferation. American analysts see the slow progress in the Khan investigation as signs that the American government still holds back in the hope of not jeopardizing the Musharraf regime's support in the so called "war on terrorism" [19].

After the test in 1998 revealed Pakistan as a *de facto* nuclear state, the country actually issued regulations for controlling nuclear exports. This includes a list of single-use nuclear items that PAEC has to approve for export. Two important exceptions undermine the effectiveness of these guidelines: Fissile material is not mentioned, and the Ministry of Defence is explicitly exempted [29]. This means weapons programmes under military control could circumvent the export control. The European Union is concerned with the quality of the Pakistani export control regime, and a delegation visited Islamabad in December 2006 to discuss this with Pakistani officials [63]. In January 2007, Islamabad announced Pakistan's intention to join NSG.

As seen in Section 4.2, the consequences for the persons involved in the network have not really been severe, even when they admit to their crimes. Only three individuals have both been found guilty and imprisoned; Slebos, Vollmerich and Piffl. The longest sentence to date is seven years. Others have been fined, in many people's opinion a punishment not deterring others from helping aspiring nuclear weapons states ahead in their nuclear programmes.

There are still persons under investigation, but the pattern emerging from the finished trials suggests that the reactions will be of a less than deterring level for others contemplating entering the proliferation business. This could be due to the low penal frameworks specified by national export control laws, but also due to the choice governments apparently have had to make between bringing individuals to justice and pursuing intelligence-gathering opportunities. In addition there are several cases in which countries have had difficulties getting information from other states, implying that intelligence sources or methods are being protected.

7 Are there other networks?

In January 2004, American officials revealed another illicit trafficking ring, exporting dual-use items for nuclear weapons and missile systems from the United States to Pakistan. Asher Karni, an Israeli arms dealer based in South Africa, was arrested on vacation in the United States, after an American sting operation. The components were imported to South-Africa as spare parts for medical equipment and exported from there to Pakistan via Dubai [64]. Karni pleaded guilty on five different charges of unlicensed export of sensitive dual-use American technology [19]. His accomplices have not so far been prosecuted.

American intelligence claims this is only part of the evidence for continuing proliferation activities in Pakistan or that at least nuclear supply networks operates in Pakistan [19;23;35]. Pakistan is still not self-sufficient in all the specialized materials needed for nuclear weapons. European intelligence reports support this, warning that Pakistan still is importing more components and materials than needed for spare parts for its own programme [1;8].

European intelligence has reportedly found that Sudan was used for storing millions of dollars worth of advanced dual-use equipment that the country had no use for. The equipment itself has not been found. Because it is believed that Libya has turned in its entire nuclear programme, it is speculated that the Sudan storage was part of a smuggling network set up independently by Iran [65]. The analyst Andrew Koch claimed in a testimony to the U.S. House Subcommittee on International Terrorism and Non-proliferation in May 2006, that Iran has rebuilt a supply network for its nuclear and ballistic missile programmes, using European and Russian firms as well as individuals connected to the Khan network [8;35].

Because the backbone of the Khan network was information based, like designs and manufacturing manuals, one needs to track down every involved person and every copy of the information to be sure of totally demolishing the network. As hiding a drawing or a digital file is relatively easy, there is every reason to believe the total recovery of information is impossible, and that the information could be used to establish new networks. One further complicating factor is that much of the technical information has been digitalized, as shown by IAEA's findings in Libya (see Section 5.1), and so is even easier to convey.

On the hardware side, components ordered by Libya but never actually delivered may have been produced in an unknown location and could be sold to others, thus making a starting point for a new network [7]. It is known that complete P-2 centrifuges *en route* to Libya were stopped by the network in Dubai after Libya's confession, and Tahir claims they were destroyed [1;7]. Given their value, this is not entirely believable. It could well be that they either have been sold to another customer or that they are still sitting in storage somewhere.

Khan claims his motive was the good of Pakistan and the Muslim part of the world as a whole [66]. Most analysts believe the true driving force was money, supported by the fact that the secular North Korea hardly can be claimed to be a part of an Islamic brotherhood. But they also open for the possibility that pan-Islamism and contempt for Western nuclear technology control might have played a part [23;30;32]. Others may have the same sentiments as well and act upon them. *BBC* journalist Gordon Corera suggests even another motive for Khan's turning to sales: That spreading nuclear technology to other states would draw the world's attention away from Pakistan's own nuclear weapons programme [1].

Customers receiving information may already have given or sold it to others. Dr. ElBaradei is quoted as believing that some countries may have put aside centrifuges as a stockpile for possible future use [7]. One country often mentioned as a proliferation risk is North Korea. Already a major supplier of missile technology and always in need of dollars, it is not hard to envision Pyongyang capitalizing on nuclear

technology. On the other hand, the admissions from Iran and Libya, especially the detailed information given by Tripoli, are likely to give potential proliferators pause: The stakes are raised if customers cannot be trusted to protect their suppliers.

Terrorist groups have made apparent the wish to acquire nuclear weapons. Dr. ElBaradei has expressed the view that the greater threat is terrorists using nuclear weapons, not states [39]. This is a view supported by many analysts. One thing is clear; there still is a demand for nuclear technology. And where there is a market, states, groups or individuals will try to make a profit. Most of the associates in the Khan network were businessmen and engineers, participating in the proliferation not from any geopolitical agenda but for the money.

The information is out there and must be considered outside state control. Non-state actors could have a lower threshold for selling to terrorist groups, but how great a threat this actually poses is an open question. Although the technical information is easily transferred, the actual acquisition of the hardware in sufficient quantities without detection is still time-consuming and expensive.

Appendix A Full text of Dr. Abdul Qadeer Khan’s statement

Islamabad, February 4, 2004

"My dear ladies and gentlemen
It is with the deepest sense of sorrow, anguish and regret that I have chosen to appear before you in order to atone for some of the anguish and pain that has been suffered by the people of Pakistan on account of the extremely unfortunate events of the last two months.

I am aware of the vital criticality of Pakistan's nuclear programme to our national security and the national pride and emotions which it generates in your hearts. I am also conscious that any untoward event, incident or threat to this national capability draws the greatest concern in the nation's psyche.

It is in this context that the recent international events and their fallout on Pakistan have traumatised the nation. I have much to answer for it.

The recent investigation was ordered by the government of Pakistan, consequent to the disturbing disclosures and evidence by some countries to international agencies, relating to alleged proliferation activities by certain Pakistanis and foreigners over the last two decades. The investigation has established that many of the reported activities did occur, and that these were invariably at my behest.

In my interviews with the concerned government officials, I was confronted with the evidence and the findings, and I have voluntarily admitted that much of it is true and accurate. My dear brothers and sisters, I have chosen to appear before you to offer my deepest regrets and unqualified apologies to a traumatised nation. I am aware of the high esteem, love and affection in which you have held me for my services to national security, and I am grateful for all the awards and honours that have been bestowed upon me.

However it pains me to realise in retrospect that my entire lifetime achievement of providing foolproof national security to my nation could have been placed in serious jeopardy on account of my activities which were based in good faith but on errors of judgement related to unauthorised proliferation activities.

I wish to place on record that those of my subordinates who have accepted their role in the affair were acting in good faith, like me, on my instructions. I also wish to clarify that there was never ever any kind of authorisation for these activities by a government official.

I take full responsibility for my actions and seek your pardon. I give an assurance, my dear brothers and sisters, that such activities will never take place in the future. I also appeal to all citizens of Pakistan, in the supreme national interest, to refrain from any further speculations and not to politicise this extremely sensitive issue of national security. May Allah keep Pakistan safe and secure."

Appendix B Production of nuclear weapons

This appendix provides a brief introduction to nuclear weapons technology to better understand what sensitive technologies an illicit trafficking network may be concentrated on. It is by no means a comprehensive and detailed review of the technologies involved.

B.1 The process

To make nuclear weapons is an extremely demanding process both in labour and funding. If a state, or a non-state group, could by-pass some of the necessary steps, much would be won for them.

An outline of the process could be:

1. Producing fissile material;
2. Testing the material in experiments;
3. Making a paper design for the weapon;
4. Building a weapon from the design;
5. Carrying out a nuclear test to prove the design;

The Khan network mainly focused on the enrichment of uranium (step 1) but also offered simple designs for the complete weapon (step 3).

B.2 Fissile material

Fissile material is material that can sustain a nuclear chain reaction and therefore can undergo a nuclear explosion. Uranium-235 (U-235) and plutonium-239 (Pu-239) are the two nuclides practical for use in nuclear weapons. Both nuclides are produced from natural uranium. If a state is to be totally self-reliant, it needs to mine uranium ore and be able to extract uranium from the ore. The end product from this extraction process is known as “yellow cake”, U_3O_8.

B.2.1 Plutonium

Weapons grade plutonium is produced by irradiating natural uranium in a reactor. The plutonium must subsequently be chemically separated from the remaining uranium and the fission by-products in a *reprocessing plant*. Different reactor types produce different amounts of the desired Pu-239. Telltale signs of plutonium production are reactors optimised for producing Pu-239, and also operation of a reprocessing plant.

B.2.2 Uranium

Natural uranium contains 0.7 % of the isotopeU-235 and 99.3 % of the heavier isotope U-238. Uranium with less than 20 % enrichment is classified as low-enriched uranium (LEU), and uranium with more than 20 % is known as highly enriched uranium (HEU). Weapons grade uranium is usually defined as uranium containing more than 93 % U-235, although much lower percentages can be made to work. Usually the natural uranium will be transformed to gaseous uranium hexafluoride (UF_6 or “hex”) via uranium tetrafluoride (UF_4 or “green salt”) before further treatment in large-scale plants. Especially UF_6 is a very corrosive substance, necessitating equipment made of unusually inert materials. The

enrichment process is considered one of the most difficult stages in nuclear weapons production, and the details of the plants are attempted kept secret.

After enrichment, the uranium gas must be converted back to metal that can be cast and machined to the desired size and shape for the bomb design. This process also is complicated, and the furnaces used must be of very high quality.

B.3 Enrichment technology

Because different isotopes of the same element behave almost identically chemically, enrichment is usually based on the physical differences created by the different masses of the two uranium isotopes. The quantitative measure of how difficult it is to separate isotopes of different atomic masses is the *separative work unit (SWU).* Given the starting percentage distribution of the two isotopes and the desired residue concentration of U-235, it is possible to calculate the number of SWUs needed to produce a kilogram of a specific enrichment percentage. Typically, to produce one kilogram of weapons grade uranium, 200 SWUs is needed [67].

Depending on the reactor design, power reactors may be fuelled by natural uranium or uranium enriched from typically about 3 % to 5 %. Some special purpose reactors even use HEU fuel. The process of enriching natural uranium to 20 % enrichment is more time consuming than enriching from 20 % to 93 % U-235. A state with a large stockpile of LEU nominally for reactor fuel will be able to produce HEU much faster than if starting from natural uranium.

Different enrichment methods have different power requirement per SWU, ranging from 100 kWh to 4000 kWh [67]. The two predominant technologies in use today are gaseous diffusion enrichment and centrifuge enrichment. The power requirement for the former is 20-30 times greater than for the latter [67]. This means centrifuge enrichment will be easier to implement than gaseous diffusion for states with a limited power supply.

In diffusion enrichment, the UF_6 gas is passed through a successive row of porous membranes. The lighter U-235 atoms pass through more quickly than the heavier U-238 atoms, and after each membrane the gas will be slightly enriched in U-235. Enriched gas is sent to the next membrane, and the depleted gas is led back to a previous stage. The plant must be factory sized with complex piping arrangements. The properties of the membranes are classified. Large amounts of electricity are required to run the compressors forcing the gas through the membranes [67].

Other, less common enrichment methods include atomic vapour laser isotope separation or molecular isotope laser separation, electromagnetic isotope separation and chemical or ion exchange isotope separation.

B.3.1 Centrifuges

In centrifuge enrichment, the UF_6 gas is led into a cascade of centrifuges spinning at 250 meters per second up to 600 meters per second or even faster at the outer wall. This corresponds to up to 100.000 revolutions per minute. The heavier U-238 is pushed closer to the wall and subsequently led back to the

beginning of the cascade. The lighter U-235 is collected from the inner part of the cylinder and brought to the next centrifuge. A cascade consists of hundreds or thousands of centrifuges.

The centrifuge materials must be carefully selected to withstand both the mechanical strain and the corrosive UF_6 gas. Precise machining of the components is crucial to avoid imbalances. Vacuum technology is essential to prevent air from oxidizing the UF_6, as well as to minimize the air drag on the rotors.

The main components of a centrifuge are (refer to Figure B.1):

- A vacuum tight outer casing that also acts as a container for shrapnel in case of centrifuge failure;
- Top and bottom bearings; the upper suspended by special alloy ring magnets, the bottom balancing on a pin;
- A molecular pump stopping the UF_6 from entering the vacuum at the bearings;
- A rotor spinning the gas, driven by a stator designed to operate in vacuum;
- End-caps and baffles, scoops, valves and non-corrosive pipes leading the gas in and out.

The power supply must be very stable to sustain the high speeds required. To achieve this, a frequency converter must be installed. A converter suitable for one centrifuge is easily obtained off-the-shelf, but the specifications required for powering a cascade of perhaps a hundred centrifuges are much more specialised.

Nearly all the above-mentioned components are dual-use items that also have applications in advanced civilian industry, but the intended use can be given away by for example specifications with manufacturing tolerances in tenths of micrometers.

SNOR and CNOR are first generation centrifuges designed by the Dutch company UCN. SNOR is subcritical,[21] with one aluminium rotor. CNOR is supercritical, with several aluminium rotors connected by bellows. The bellows enable the rotors to overcome the first mechanical resonance vibration [6]. The separative capacity is 2 to 5 SWU per year. Physically each centrifuge is 2.5 meters tall and 11 centimetres in diameter [10]. Urenco officials say only a fingerprint on one of the spinning parts is enough to disrupt the balance and make the centrifuges crash immediately. Expected lifetime of these early designs was originally estimated to ten years, but most of the original centrifuges installed at Almelo are still spinning 25 years later [6].

[21] Spinning rotors have several vibrational resonant frequencies, giving rise to mechanical strain on the materials. Subcritical centrifuges never spin as fast as the first resonant frequency, while supercritical (ultra) centrifuges are able to withstand the strain and so can spin faster.

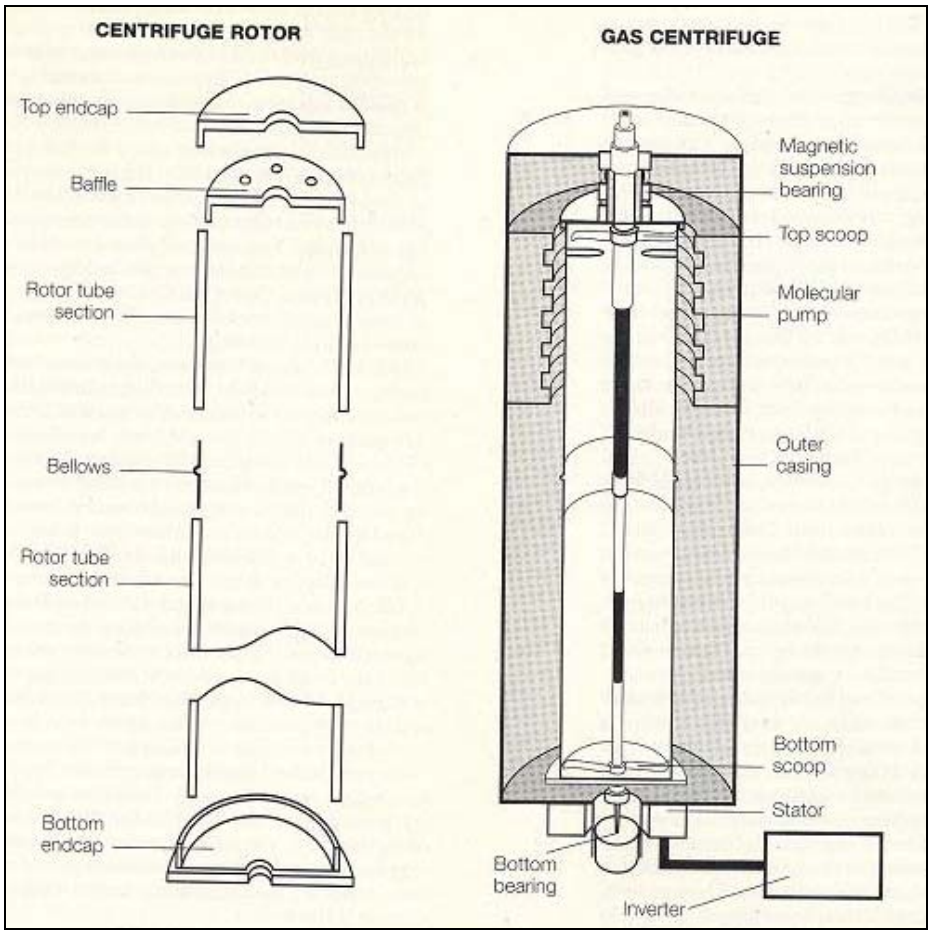

Figure B.1 A schematic drawing of a centrifuge. Copyright © 1992 by Bulletin of Atomic Scientists, Chicago, IL 60637. Reprinted by permission of Bulletin of the Atomic Scientists: The Magazine of Global Security, Science, and Survival.

G-1 and G-2 are German-designed centrifuges, the former a simple subcritical design [6]. G-2 has both bellows and rotors in a material called maraging steel. Maraging steel is a class of low-carbon alloys giving superior strength and malleability. This material can withstand the higher resonance frequency vibrations and thus spin faster than aluminium components, giving rise to the name ultra-centrifuges. Such centrifuges have greater separative capacity, at least 5 SWU per year. They are shorter than the Dutch design, with a height of 1.25 meters, but have a slightly larger diameter of 15 centimetres [10].

P-1 and P-2 are the Pakistani versions of G-1 and G-2. P-2 is based on, and not directly copied from, the stolen design and has been further developed by KRL. Nevertheless, it is still easy to identify its origins. The centrifuges found in Libya were essentially P-2, but were given the designation L-2 by the IAEA inspectors first examining them.

The design variously known as 4-M or M-4 was in early stages of development at UCN around 1975 [6]. This centrifuge reportedly has four aluminium rotors connected by maraging steel bellows, has a diameter of ten centimetres and is two meters tall [27].

B.4 Design

The fissile material alone does not constitute a bomb. To produce a self-sustaining chain reaction, enough fissile nuclei must be close enough together for, on average, more than one of the released neutrons to interact with another nucleus. This can be achieved with a large enough mass (the definition of critical or supercritical mass) or by compressing a subcritical mass to a density where it reaches criticality.

There are two main designs for fission bombs. In a gun-type design (Figure B.2), a smaller piece of uranium is fired into a larger in a “gun barrel”. Precision machining of all metal parts is of vital importance to make this work. This design is only used for uranium, as the joining method is too slow for plutonium. Plutonium has higher probability for spontaneous fission than has uranium. The chain reaction may therefore start before the two parts are completely merged, giving an explosion of lower yield than anticipated, also known as a *fizzle*.

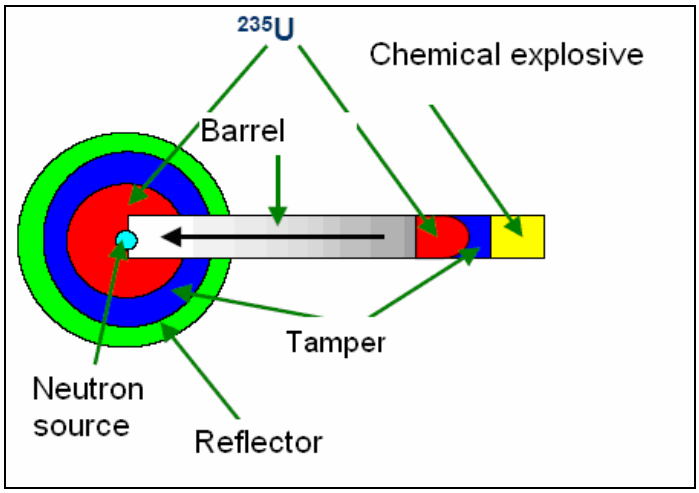

Figure B.2 A schematic drawing of a gun-type design.

The implosion design (Figure B.3) is based on the compression of a sphere to higher density by conventional explosives detonated simultaneously over the whole surface. This design is more compact and technically more advanced that the gun-type, but can give a larger explosion for smaller amounts of material if successful, because the fission yield is higher. This design can be used for both uranium and plutonium weapons.

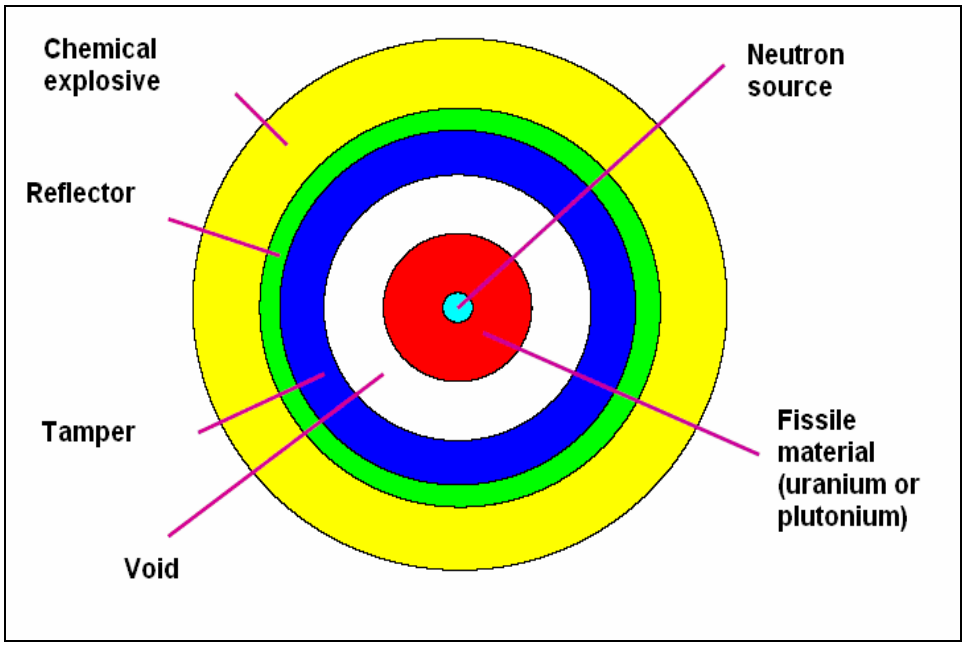

Figure B.3 A schematic drawing of an implosion-type design.

B.5 Weaponisation

There is an important distinction between bomb and the finished nuclear weapon. A weapon is a bomb combined with a system for delivery to a target. The bomb must be small enough to be carried by available delivery systems and robust enough to withstand acceleration and elevated temperatures. Missile technology is important for advanced nuclear weapons. Simple designs, which can be expected developed by less advanced states, are often too large for the missiles available to the same states, but could possibly be delivered by an airplane.

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