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Nuclear Technology: The "Thin Line" between weaponization and peaceful uses

A Master's Thesis submitted for the degree of
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supervised by
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Affidavit

I, **ANNE-SOPHIE FRAYSSINET, MA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "NUCLEAR TECHNOLOGY: THE "THIN LINE" BETWEEN WEAPONIZATION AND PEACEFUL USES", 78 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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ABSTRACT

In the context of globalization and energy transition, sophisticated communications enable an easier access to nuclear related knowledge, material, and technologies. These changes make the work of responsible authorities such as the International Atomic Energy Agency (IAEA) in monitoring and regulating nuclear facilities more difficult. With the help of the Weaponization Score Index, a tool explicitly created within this paper, this study hopes to demonstrate that while the existing nuclear legal framework efficiently limits and prevents potential nuclear proliferation risks through a full range of legal agreements, a country with an advanced civilian nuclear program, if wanted, can easily transition from peaceful use of nuclear technology to manufacturing nuclear weapons. To do so, nine countries were strategically chosen: Pakistan, Canada, Iran, South Korea, Germany, South Africa, Saudi Arabia, and Ghana, with regards to their civilian nuclear program position. Based on 16 relevant drivers, among them: Human Resource Development, Nuclear Fuel Cycle, and Engineering and Design, the Weaponization Score Index enables a classification of the nine countries in four categories of matter that are Dormant, Latent I, Latent II, and Limited Capabilities. Pakistan, used as reference, reached the highest score of 54. Results of this study showed that countries such as Iran, Japan, Germany, South-Korea or South-Africa, classified into Dormant (40-54), possess most of the required capabilities to operate this transition. In order to thicken the line between peaceful uses of nuclear technology and weaponization, potential solutions will be presented in conclusion.

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LIST OF ABBREVIATIONS

CNS Convention on Nuclear Safety

CSA Comprehensive Safeguards Agreement

CTBTO Comprehensive Nuclear-Test-Ban Treaty Organization

FAO Food and Agriculture Organization

HEU Highly Enriched Uranium

IAEA International Atomic Energy Agency

ISCANT International Convention For The Suppression of Acts of Nuclear Terrorism

IT Information Technology

LEU Low Enriched Uranium

NPP Nuclear Power Plant

NPT Non-Proliferation Treaty

NSG Nuclear Supplier Group

PAEC Pakistan Atomic Energy Commission

TNT Trinitrotoluol

TPNW Treaty on the Prohibition of Nuclear Weapons

UN United Nations

UNAEC United Nations Atomic Energy Commission

WMD Weapons of Mass Destruction

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1. Introduction

1.1 Problem Statement

"The world in which the IAEA implements safeguards today is very different from that envisaged by our founding fathers in 1957. Nuclear proliferation is now easier than it has ever been. Globalization, new technology and modern communications have made it possible to access knowledge, materials and expertise that were previously not widely available." (Amano, 2019).

Under nuclear proliferation, one understands *"the spread of nuclear weapons, nuclear weapons technology, or fissile material to countries that do not already possess them."* (Munro, 2021). Nowadays, nine states – The United States, Russia, China, France, United Kingdom, Israel, North Korea, Pakistan and India – possess nuclear weapons. However, only five states are officially acknowledged as possessing nuclear weapons by the Non-Proliferation Treaty of nuclear weapons (NPT), among them the United States, China, France, Russia and United Kingdom (Arms Control Association, 2020). While the official nuclear-weapon States have committed not to encourage, assist or induce any non-nuclear-weapon States parties to produce or acquire nuclear weapons, non-nuclear-weapon States parties to the Treaty committed themselves to not acquire or manufacture nuclear weapons or other nuclear explosive devices (IAEA, 2020).

To control if States parties to the NPT respect their obligations, International Atomic Energy Agency (IAEA) Safeguards were established, setting an international legal framework enabling a reinforced monitoring and inspection of nuclear facilities and activities.

"The history of the atomic age, however, suggests that for a country with an advanced civil nuclear program, crossing the line into bomb work is relatively easy." (Broad, 2007). As former IAEA Director General Amano stated, in the context of globalization, sophisticated technologies and communications enable an easier access to nuclear related knowledge, education and technical expertise, emphasizing new kind of challenges.

Before a country has the capability to develop a nuclear military program, it needs to possess a stable civilian nuclear program. Beside the military use of nuclear energy, the principal "peaceful application of nuclear energy", also known as "civil use of nuclear power", is the production of electricity (Percebois, 2003). Nowadays, 10% of the worldwide produced electricity comes from nuclear energy which is, alongside hydropower, *"one of our oldest low carbon energy technologies"* (Ritchie, 2021). With around 440 operating nuclear power reactors worldwide, this source of energy represents a valid alternative to fossil fuels, which emit a high level of carbon (Ritchie, 2021). Thus, nuclear technology enfolds not only electricity production but also other sectors, less known of the public, such as scientific research and medicine, water resources, transport and not less than the environment (World Nuclear Association, 2020). Within the context of worldwide energy transition, so-called newcomer countries consider or have started planning to introduce nuclear energy as a low-carbon electricity source to their energy mix (Dyck, 2020; World Nuclear Association, 2021a). However, this growing interest for nuclear power also increases potential risks of nuclear proliferation.

To understand how a country with an advanced civilian nuclear program can easily transit to manufacturing nuclear weapons, one first needs to define how nuclear energy is produced for both ends. *"Nuclear reactors and nuclear weapons derive power through the fission (splitting) of nuclei of uranium or plutonium atoms, a process that releases large amounts of energy."* (UCSUSA, 2009).

Uranium, which occurs naturally, *"consists mostly of two different "isotopes" – atoms of the same element that differ only in their numbers of neutrons and thus have slightly different weights."* (UCSUSA, 2009). Natural uranium includes around 0.7 percent uranium-235 and 99.3 percent uranium-238 (ibid.). One limit range is enriched uranium. *"Enriched to low levels, uranium can fuel a reactor that produces electrical power."* (Broad, 2007). However, uranium, purified long enough in spinning centrifuges, becomes highly enriched and can fill up an atom bomb (ibid.). Enriching uranium is not only technically difficult but also very expensive, since it requires separating isotopes possessing similar physical and chemical characteristics (UCSUSA, 2009). The amount of Highly Enriched Uranium (HEU) needed to build a nuclear weapon depends on the level of enrichment and the weapon design's sophistication. *"In general, the higher the enrichment level, the less HEU is needed to make a bomb."* (UCSUSA, 2009).

Plutonium, in contrast to uranium, occurs only in trace amounts in nature (ibid.). *"In order to use plutonium in nuclear weapons or nuclear fuel, however, it must be separated from the rest of the spent fuel in a reprocessing facility."* (UCSUSA, 2009). Separating

Plutonium is simpler than enriching uranium, since it results from the separation of different elements, meanwhile uranium enrichment results from the separation of different isotopes of one same element (ibid.).

To that affect, reprocessing (separating plutonium from spent fuel) and enrichment (concentrating uranium in the isotope U-235) facilities are called "dual-use technologies", since they both contribute to civilian use of nuclear energy and the production of weapon-grade materials. While reprocessing does not constitute a necessary technology for the actual generation of nuclear power plants, most of the operating nuclear reactors use fuel issued from Low Enriched Uranium (LEU), making enrichment facilities essential to civilian nuclear technology (Acton et al., 2016; Chyba et al., 2005). Next to these dual-use technologies, other components of a civilian nuclear program play a relevant part in a country's potential transition.

As a concrete example, human resource development, which is an essential component of a civilian nuclear program development, offers nuclear science related education programs, supported by the IAEA to train highly qualified personal specialized in civilian nuclear technology matters. However, this acquired knowledge can be misused to military ends, as it will be demonstrated later on with the case of Pakistan. Thus, nonnuclear technology such as Information Technology (IT) and Design, also essential to support and build nuclear reactors, can be dual-use. *"For example, computer codes used to model the core of nuclear reactors or the behavior of plasma or the transport of radiation under certain conditions may be adaptable for use in nuclear-weapon studies."* (Acton et al., 2016).

As demonstrated above, components required for the development of a civilian nuclear program can also enable the production of nuclear weapons. In order to monitor and ensure that these dual-use technologies are not misused by a country to acquire military arsenals, a full range of efforts has been deployed to prevent and expose potential risks of nuclear proliferation.

Main objective of this Master Thesis is to investigate and determine how long countries with an advanced civilian nuclear program, which possess the required scientific knowledge, nuclear facilities, economic resources and political motives, need to transit from civil use of nuclear technology into manufacturing nuclear weapons. To do so, nine countries of strategic choice: Pakistan, Japan, Canada, Iran, South Korea, Germany, South Africa, Saudi Arabia and Ghana, will be classified into four categories of matter that are "Dormant, Latent I, Latent II and Limited capabilities" with the help of the Weaponization Score Index. Aim of this index is not only to determine which country has the capability to transit into bomb work but also to establish transparence on which essential drivers a country already possesses to facilitate its transition. To support the choice of the selected drivers for the establishment of the index and illustrate the technical road from peaceful uses of nuclear technology to the manufacturing of nuclear weapons, Pakistan's concrete example will be addressed. Finally, after having demonstrated how easily countries with sufficient resources and technologies can transition into manufacturing nuclear weapons, potential solutions will be presented to thicken the line between peaceful uses of nuclear technology and weaponization.

1.2 State of the Art

One essential step of a scientific paper is to state all works that have been realized and published in the specific field of research. In the context of nuclear technology's dual-use, several books, articles and scientific reports were published. To get a clear overview of which literature supported the elaboration of this Master Thesis, two works of particular importance will be introduced.

The work of James M. Acton in the 2016 published report *"Governance of Dual-Use Technologies: Theory and Practice"* constitutes one of the main concepts on which this thesis relies. While the whole book examines dual-use of nuclear technology, the first chapter, written by James M. Acton is the one of interest. In Chapter 1 *"On the Regulation of Dual-Use Nuclear Technology"*, Acton corroborates which technologies and materials are dual-use, more precisely which technologies are useful for both civilian and military ends. According to him, Highly Enriched Uranium (HEU) and separated plutonium are the two dual-use nuclear materials of biggest proliferation interest (Acton et al., 2016). However, he argues that nonnuclear technologies can also be used for both civilian and military purpose, which is why efforts have to be deployed in order to manage risks associated with nuclear technology. From these efforts emerged a complex legal framework consisting of legally and politically binding agreements, norms; intergovernmental, nongovernmental and domestic institutions; patterns of interstate cooperation and finally, national laws and practices (ibid.).

Within this framework, two separate systems have risen: nuclear nonproliferation and nuclear security (Acton et al., 2016). While the nuclear nonproliferation regime consists of three key interrelated elements that are:
"National decisions about whether to develop or use a particular dual-use nuclear technology; National laws and international agreements about whether to permit the sale of dual-use nuclear technologies and materials and, if so, under what conditions; International oversight mechanisms to detect and deter attempts by states to acquire nuclear weapons using these technologies and materials" (Acton et al., 2016), the nuclear security regime focuses on preventing nonstate actors from obtaining nuclear material (ibid.).

Hence, physical protection measures are the most important nuclear security measures to deny unauthorized access to nuclear facilities and material (Acton et al., 2016). *"However, because of the potential consequences of failures in physical security, best practice demands multiple layers of protection, an approach known as 'defense in depth'"* (Acton et al., 2016). Besides, deterrence might play an underpart to *"prevention, insofar as nonstate actors may be deterred from even attempting to acquire nuclear material if they believe failure is sufficiently likely"* (Acton et al., 2016).

Finally, preventing terrorist organizations from obtaining access to nuclear material is also one of the numerous measures the nuclear security regime relies on (ibid.). After having reflected the structural differences between nonproliferation and nuclear security, the author comes to the conclusion that while the nonproliferation regime tends to be a comprehensive system relying mostly on legally binding agreements, the nuclear security architecture is a *"patchwork of arrangements, most of which are not legally binding, containing many omissions"* (Acton et al., 2016). Acton's final statement is that although the two systems remain distinct, designing a nuclear security regime in the mold of the nuclear nonproliferation regime would be an alternative to counter nuclear proliferation (Acton et al., 2016).

The second work of importance for the selection of the Weaponization Score Index's drivers is a research paper realized by Jun Li and Man-Sung Yim in 2013, whose title is *"Examining relationship between nuclear proliferation and civilian nuclear power development"*. Aim of this research paper was to investigate the relationship between civilian nuclear power development and potential nuclear proliferation with the elaboration of a database compiling information on a country's civilian nuclear power development and situational factors and different national capabilities (Li and Yim, 2013). After having defined and underlined the essential roles of the IAEA and the NPT ratification for the development of a successful civilian nuclear program, results of this research showed that the success of a country's civilian nuclear program strongly depends on certain factors such as nuclear technological capabilities, economic capabilities, connection to international trade market, political situation, access to human resources of a given country (ibid.). Furthermore, results of this analysis implied that the initial motivation of a country to develop a civilian nuclear program could mostly be dual purpose (ibid.).

1.3 Thesis Structure

Now that the research question and the relevant work within the field of nuclear technology's dual-use were established, one last step remains before getting to the root of the matter. In order to come up with concrete solutions to thicken the line between peaceful uses of nuclear technology and weaponization, one first needs to understand how the legal framework of nuclear technology operates. To that effect, Chapter 2 will establish the differences between peaceful and military uses of nuclear technology (2.1), as well as the rules of using nuclear energy (2.2), where the main instruments in charge of monitoring and regulating nuclear technology's use, such as organs and treaties will be introduced. Chapter 3, which constitutes the central point of this paper, will consist in a short description of the used methodological approaches (3.1), the tables defining capabilities required for peaceful use, military use and dual use of nuclear technology (3.2) and the relevant drivers (3.3) selected for the elaboration of the Weaponization Score Index. In order to support the choice of the selected drivers for the Index and to illustrate the technical road transition of a country's civilian nuclear program into manufacturing nuclear weapons, Pakistan's example will be addressed (3.3.1). The second part of Chapter 3 will be consecrated to the Weaponization Score Index itself (3.4) and its evaluation. Finally, Chapter 4's objective will be, after having demonstrated how easily a country with an advanced civilian nuclear program can transition into manufacturing nuclear weapons, to bring potential solutions to thicken the line between peaceful uses of nuclear technology and weaponization.

2. Legal Framework of Nuclear Technology

Before getting to the main issue of this Master Thesis, which is the elaboration of the Weaponization Score Index, it seems necessary to first define the legal framework in which nuclear technology operates. What is the difference between peaceful use and military use of nuclear technology? What legally binding agreements frame the peaceful use of nuclear energy? Which legally binding agreements dampen the proliferation of nuclear weapons and which institutions are regulating this legal framework? All these questions will be answered within the second chapter, which sets not only the legal framework of nuclear technology but also emphasizes how difficult it can be to thicken the line between peaceful use of nuclear technology and weaponization.

2.1 Peaceful and Military Use of Nuclear Technology

2.1.1 Definition of Peaceful use

While there are no official definitions for peaceful or military use of nuclear energy, one agrees to say that under peaceful use of nuclear energy, also known as civil use of nuclear power, one understands mostly the production of electricity (Percebois, 2003). As written in the introduction, 10% of the worldwide produced electricity comes from nuclear energy which – *"alongside hydropower – is one of our oldest low-carbon energy technologies"* (Ritchie, 2021). With around 440 operating nuclear power reactors worldwide, this source of energy represents a valid alternative to fossil fuels, which emit a high level of carbon (Ritchie, 2021). To produce electricity, fissile material (uranium) undergoes various steps, referred to as the nuclear fuel cycle (World Nuclear Association, 2021b).

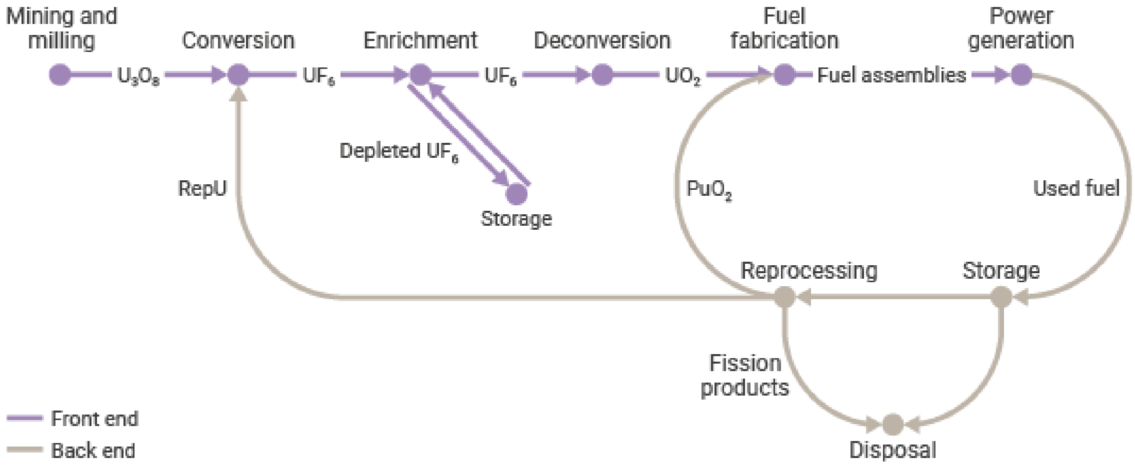

Figure 1 The nuclear fuel cycle (World Nuclear Association, 2021b).

As seen in the figure above, the nuclear fuel cycle begins with the mining and milling of uranium to end with nuclear waste disposal (World Nuclear Association, 2021b). In-between, steps such as conversion, enrichment and fuel fabrication are undergone and form the front end of nuclear fuel cycle (ibid.). After three years of producing electricity in a nuclear reactor, *"the used fuel may undergo a further series of steps including temporary storage, reprocessing, and recycling before the waste produced is disposed. Collectively these steps are known as the 'back end' of the fuel cycle."* (World Nuclear Association, 2021b).

While the production of electricity remains the most common use of nuclear energy, other civil applications, less known of the public, exist. (World Nuclear Association, 2021f). To put an end to this hidden area, some of the other sectors in which nuclear technology can be used at peaceful purposes will be introduced. *"Radioisotopes, nuclear power process heat and non-stationary power reactors have essential uses across multiple sectors, including consumer products, food and agriculture, industry, medicine and scientific research, transport, and water resources and the environment."* (World Nuclear Association, 2021f).

A first use of nuclear energy is made in the supply of radioisotopes. Isotopes are variants of the same chemical element which have nuclei containing the same number of protons but a different number of neutrons (World Nuclear Association, 2021f). Some isotopes are considered as "stable", which means that they don't change over time, while other isotopes are referred as "unstable or radioactive" as their nuclei change over time, due to the loss of alpha and beta particles (World Nuclear Association, 2021f). *"The* *attributes of naturally decaying atoms, known as 'radioisotopes', give such atoms several applications across many aspects of modern-day life."* (World Nuclear Association, 2021f). Within the agricultural sector, radioisotopes and radiations are used in food to help reduce chronic undernourishment (World Nuclear Association, 2021f). One concrete example of how nuclear technology can be used within the agricultural sector is food irradiation. As 25-30% of harvested food is lost due to spoilage before being consumed (mostly happening in hot and humid countries), food irradiation can solve this major issue by exposing food products to gamma rays to kill bacteria and increase shelf life (ibid.).

A second sector more known of the public that uses radiation and radioisotopes is the medical sector, particularly for the identification and treatment of various medical conditions (World Nuclear Association, 2021f). For example, diagnosis (identification) techniques in nuclear medicine use radiotracers (usually short-lived isotopes linked to chemical compound) that radiate gamma rays within the human body and enable to scrutinize specific physiological processes (ibid.). One particular advantage of nuclear over X-ray techniques is that both soft tissue and bone can be pictured efficiently (ibid.). Another important aspect of nuclear medicine concerns its therapeutic purposes. In small amounts, radioactive iodine (I-131) is used to treat cancer and other conditions harming the thyroid gland (ibid.). While the "radioisotopes therapy" is mainly palliative, to relieve pain, a new field of research is targeting alpha therapy, which would control dispersed cancers. *"The short range of very energetic alpha emissions in tissue means that a large fraction of that radiative energy goes into the targeted cancer cells once a carrier, such as a monoclonal antibody, has taken the alpha-emitting radionuclide to exactly the right places."* (World Nuclear Association, 2021f).

Finally, the transport sector could make use of nuclear technology very soon since, in the future, heat or electricity produced from nuclear power plants could be used to produce hydrogen (World Nuclear Association, 2021f). After having introduced some of the sectors using nuclear technology at civilian ends, one personal note would be that nuclear energy, used for peaceful purposes, has a lot to bring since it contributes not only to better living conditions but also could be the solution to any environmental issues.

2.1.2 Definition of Military use

Now that the civil aspect of nuclear technology was deepened, the more controverted use of nuclear energy, the military one will be presented. No need to define what is understood under military use of nuclear energy since everybody will have Hiroshima and Nagasaki in mind. *"Late in 1939 the possibility of using atomic energy for military purposes was brought to the attention of President Roosevelt, who appointed a committee to survey the problem."* (Valković, 2019). After sufficient progress was made in June 1942, the decision of proceeding with plant construction on a large scale was made in December 1942. Up to 30 June 1945, the American Congress had acquired a budget of 1.950 billion dollars for the operation of the project (Valković, 2019). As written in the introduction, uranium is the essential ore to produce nuclear weapons. *"Enriched to low levels, uranium can fuel a reactor that produces electrical power"* (Broad, 2007). However, uranium, purified long enough in spinning centrifuges, becomes highly enriched and can fill up an atom bomb (ibid.). As of May 2020, 22 countries that are classified under the table below (Table 1) possessed at least 1 kg of HEU in their civilian nuclear stocks.

Table 1 Countries with Highly Enriched Uranium in their civilian stocks in 2020 International Panel on Fissile Materials, 2020).

Quantity of HEU in kg	**>10.000**	**1000-10.000**	**100-1000**	**10-100**	**1-10**	**About 1**
Countries	Russia United States	Canada China France Japan Kazakhstan United Kingdom	Belarus Belgium Germany Italy Netherlands South Africa	Israel North Korea Pakistan	Australia India Iran Norway	Syria

Nowadays, two types of nuclear bombs, the atomic A bombs and the thermonuclear hydrogen bombs (H bomb) exist. *"Atomic bombs became the first nuclear weapons to be used in war when the cities of Hiroshima and Nagasaki were bombed at the end of the Second World War."* (Radioactivity.eu.com, 2021). In turn, hydrogen bombs, more powerful than atomic bombs, are activated by nuclear fusion's process, where reactions are triggered through the heat produced by nuclear fission (ibid.). In order to give an estimation of how big a nuclear explosion can be, one measures the power of these bombs in kilotons or megatons of trinitrotoluol (TNT). While the bomb that destroyed Hiroshima in August 1945 measured 21 kilotons, the most powerful explosion ever produced was the soviet H bomb in 1961, that measured 50 megatons (ibid.).

As of today, five states worldwide are officially acknowledged as nuclear-weapon States. The United States, China, France, United Kingdom and Russia possess such weapons, recognized by the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Four other countries possess nuclear weapons: Pakistan, Israel, North Korea and India. Since they did not sign the treaty, they are not officially recognized as nuclear-weapon States. *"According to Arms Control Association (2018) the world's nuclear-armed states possess a combined total off estimated 15,000 nuclear warheads; more than 90% belong to Russia and the United States."* (Valković, 2019).

Table 2 Estimated nuclear warhead inventories (Arms Control Association, 2018).

Country	Number of nuclear warheads	Year of first nuclear test
Russia	6850	1949
USA	6550	1945
France	300	1960
China	280	1964
United Kingdom	215	1952
Pakistan	145	1998
India	135	1974
Israel	80[a]	1966 (?)
North Korea	15	2004

As written in the introduction, *"The history of the atomic age, however, suggests that for a country with an advanced civil nuclear program, crossing the line into bomb work is relatively easy."* (Broad, 2007). In order to dampen and prevent the construction and use of nuclear weapons, different institutions, organs and legal agreements have been established within the last fifty years. Within this subchapter (2.2), the several organs in authority of the legal framework of nuclear technology will be introduced and deepened.

2.2 The Rules of using Nuclear Energy

"Those who work in the nuclear field must contribute their thinking and expertise especially to two vitally important items on this new world agenda: the practical elimination of nuclear weapons and the safe and expanded use of nuclear energy for health, development and environmental protection." (Blix, 1994). Indeed, peaceful uses of nuclear energy are paradoxically often associated to the prospects of nuclear proliferation, which in turn result from the difficulty to distinguish between the knowledge, materials and expertise required to produce nuclear power and those needed to produce nuclear weapons. As a result, a complex network of international and national measures has been set to ensure that energy is used safely and peacefully (ElBaradei et al., 1995). Over the past decades, international cooperation between organizations and institutions has enabled to set a mix of legally binding rules, regulations and advisory standards which will be introduced in the next paragraphs (ibid.).

2.2.1 IAEA (Safety, Security, Safeguards)

"Scientists involved in the secret US nuclear weapons program began advocating internationalization of atomic power before the first nuclear weapon was even tested. Their suggestion reflected an idealistic faith in internationalism and in scientific solutions to social problems." (Brown, 2015). After that the United States dropped a nuclear bomb on Hiroshima on 6 August 1945 and another on Nagasaki three days later, killing hundreds of thousands of civilians, the idea that nuclear power was dangerous forced the great powers to create the United Nations Atomic Energy Commission (UNAEC) in 1945 to elaborate international controls (ibid.). However, the international approach only succeeded with the creation of the International Atomic Energy Agency (IAEA), marked trough the U.S Ratification of its Statute by former President Eisenhower on 29 July 1957 (ibid.). To this effect, the agency was created *"in response to the deep fears and expectations generated by the discoveries and diverse uses of nuclear technology."* (IAEA, 2021b). Through its strong link to nuclear technology and its controversial applications, *"the Agency was set up as the world's 'Atoms for Peace' organization within the United Nations family"* (IAEA, 2021b). Its main objectives, stated in Article

II of the IAEA's Statute[1], are to work in tight cooperation with its Member States and partners to promote secure, safe and peaceful nuclear technologies worldwide (IAEA, 1989). These days, 449 nuclear reactors are operated in 30 countries worldwide, whose safety is a primordial matter for the sake of the international community (Uatom 2021).

"Nuclear power plants are among the safest and most secure facilities in the world. But accidents can happen, adversely affecting people and the environment. To minimize the likelihood of an accident, the IAEA assists Member States in applying international safety standards to strengthen nuclear power plant safety." (IAEA, 2021c). Under nuclear safety, on understands *"the protection of people and the environment against radiation risks, and the safety of facilities and activities that give rise to radiation risks."* (IAEA, 2006b). In order to protect not only individuals but also the environment, nuclear safety shall undergo rigorous controls by national regulatory authorities to avoid catastrophes and nuclear accidents (Uatom, 2021). Since regulating and assuring safety is a national responsibility, the IAEA's role is to help Member States achieve their responsibilities through the establishment of international safety standards, which will be introduced in the next lines.

The Safety standards, whose status derives from the IAEA's Statute, authorize the Agency *"To establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property (including such standards for labour conditions), and to provide for the application of these standards."* (IAEA, 2021e).

Therefore, the three Safety Standards Series follow different but complementary objectives. While the primary publication, the *"Fundamental Safety Principles (SF-1) establishes the fundamental safety objective and principles of protection and safety"*(IAEA, 2021e), the second publication, "Safety Requirements" "*establish the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objectives and principles of the Safety Fundamentals"* (IAEA, 2021e).

[1] Article II IAEA Statute "The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose." (IAEA, 1989).

Finally, the third publication which consists of the "Safety Guides", *"provide recommendations and guidance on how to comply with the requirements"* (IAEA, 2021e).

Among the IAEA's key publications, the Safety Standards, global reference for protecting individuals and the environment from harmful impacts of ionizing radiation, *"provide the fundamental principles, requirements and recommendations to ensure nuclear safety"* (IAEA, 2021e).

In order to ensure nuclear safety, the Fundamental Safety Principles, adopted in 1993, not only aim to lead Member States in implementing their safety measures but also serve as reference for the objectives of legally binding instruments such as the 1994 Convention on Nuclear Safety, which will be introduced later on.

Besides the fundamental Safety objective that was mentioned above, ten principles have been established to meet the objective of protecting individuals and the environment from harmful effects of radiation. Within this Master Thesis, two principles (Principle 1 and 2) are of great importance to understand how "easy" it can be for a nation with an advanced civilian nuclear program to cross the line into bomb work.

Principle 1 states that *"the prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks."* (IAEA, 2006b). This involves that the authorization to operate a nuclear installation or conduct an activity may be accorded to one organization or an individual and only this individual or this organization is responsible for the good functioning of the facilities (ibid.). Under some circumstances, the government of a Member State may be held responsible for the safety of activities and facilities (IAEA, 2006b). *"These responsibilities are to be fulfilled in accordance with applicable safety objectives and requirements as established or approved by the regulatory body, and their fulfilment is to be ensured through the implementation of the management system."* (IAEA, 2006b).

Principle 2 implies the governments' role within the nuclear safety regime and states that *"an effective legal and governmental framework for safety, including an independent regulatory body, must be established and sustained."* (IAEA, 2006b). Thus, the government is responsible for the adoption of safety regulations and other measures or standards within its national legal system. Though the prime responsibility is held by the individual or organization operating the facilities or conducting the activities (Principle 1), governments also have an important role to play in establishing the regulatory framework to protect people and the environment against radiation risks (IAEA, 2006b).

However, these Safety Principles, which serve as an essential basis for the good regulation of nuclear safety, are from nature not legally binding on Member States and to that effect, explain how nuclear accidents such as Fukushima could still happen. It is relevant to point out that the Principles *"may be adopted by them[2], at their own discretion, for use in national regulations in respect of their own activities."* (IAEA, 2002).

Previously, one mentioned that these principles serve as reference for the objectives of legally binding instruments. The Convention on Nuclear Safety (CNS), adopted in Vienna on 17 June 1994 in the aftermath of the Three Mile Island and Chernobyl accidents, is one result of this legally binding agreements' implementation.

Within the Convention, *"the obligations of the Contracting Parties are based to a large extent on the application of the fundamental safety principles for nuclear installations contained in an IAEA publication dated 1993, 'The Safety of Nuclear Installations'"* (IAEA, 2017). These obligations cover *inter alia* technical safety obligations related to design, construction, siting and operation of nuclear power plants, the assessment and verification of safety, quality assurance, the availability of adequate financial and human resources and finally emergency preparedness (IAEA, 2017). It also implies that the convention is legally binding when *"contracting parties are required to submit reports on the implementation of their obligations under the Convention for peer review at periodic meetings."* (IAEA, 2017).

Now, one question remains. How could a nuclear accident such as Fukushima still happen after that one specific international legally-binding instrument was adopted? The answer is rather simple. Though *"the Convention on Nuclear Safety aims to commit Contracting Parties operating land-based civil nuclear power plants to maintain a high level of safety by establishing fundamental safety principles to which States would subscribe"* (IAEA, 2017), it is primarily an incentive instrument, whose sole binding element is the peer-review mechanism, obligating its Member States to establish and submit reports on the good implementation of their obligations at periodic meetings (IAEA, 2017).

After having deepened the central role of the IAEA in ensuring nuclear safety, one last aspect needs to be defined, which is nuclear security.

[2] Member States.

"With hundreds of nuclear power reactors, research reactors and fuel cycle facilities in operation worldwide, nuclear terrorism and other nuclear security threats demand continuous attention. The IAEA helps to ensure that measures are taken to control and protect nuclear facilities from such threats." (IAEA, 2021g).

As quoted above, *"nuclear terrorism and other nuclear security threats demand continuous attention."* (IAEA, 2021g). Nuclear security is understood as *"the prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities."* (IAEA, 2021g). To prevent from acts of thefts or sabotage which could occur due to the increasing amount of nuclear or other radioactive material in storage and transit, an effective physical protection system is required and essential (IAEA, 2021g).

To this end, *"IAEA Safeguards play a central role in preventing the proliferation of nuclear weapons through the independent verification of States' compliance with nuclear non-proliferation undertakings. IAEA safeguards are embedded in legally binding agreements concluded between States and the IAEA."* (IAEA, 2021f).

One centerpiece resulting of this international regulatory regime is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), opened in 1968 for signature and enforced in 1970 (IAEA, 2020). Under this treaty, which involves 191 member states, non-nuclear-weapon States parties have committed themselves not to produce or acquire nuclear weapons or other radioactive explosive devices, while nuclear-weapon States parties have agreed not to assist, induce or encourage any non-nuclear-weapon States parties to produce or acquire nuclear weapons or other radioactive nuclear devices (ibid.). As mentioned in the introduction, five Member States are considered official nuclear-weapon States (Russia, United States, United Kingdom, China and France). Though the IAEA is not a party to the NPT, its role is to verify that each State party to the NPT fulfills its national obligations (IAEA, 2021f).

Nowadays, three different types of Safeguards agreements exist, that are *"comprehensive safeguards agreements with non-nuclear-weapon State parties to the NPT; voluntary offer safeguards agreements with the nuclear-weapon State parties to the NPT; and item-specific safeguards agreements with non-NPT States"* (IAEA, 2021f).

To ensure that nuclear plants are not misused, and nuclear material is not detoured from peaceful uses, each non-nuclear-weapon State party must conclude a comprehensive Safeguards Agreements with the IAEA (Virgili, 2020).

The implementation of Safeguards consists of four main processes on an annual cycle basis.

The first step is the collection and evaluation of safeguards-relevant information, which consists of the collection, processes and reviews of all available safeguards-relevant information about a State to evaluate its conformity with the State's declarations about its civilian nuclear program (IAEA, 2021h).

The second step consists in the development of a Safeguards approach for a State, which includes Safeguards measures to meet technical objectives to verify the State's declarations (ibid.).

The third step consists of planning, conducting and evaluating Safeguards activities, where the development of a plan specifying Safeguards activities takes place both in the field and at the IAEA's headquarters (IAEA, 2021h). Once an activity is done, the Agency evaluates the scope to which the activity has reached its technical objectives and identifies any dissonances that might need to be regulated (ibid.).

Finally, the last step consists in the drawing of Safeguards conclusions, which are the final product of the annual Safeguards implementation cycle and procure credible assurances to the international community that States parties to the Safeguards are constant by their Safeguards obligations (ibid.).

Though the implementation of Safeguards agreements has worked quite well in regard to verification activities on declared nuclear material and activities, the IAEA's experience in Iraq and North Korea in the 90s denounced the Safeguards' lack of equipment regarding the detection of undeclared nuclear material. To reinforce the agreements, additional measures were implemented at the end of 1993. The so-called "Additional Protocol" grants the IAEA expanded rights to access locations and information in the States which have a Comprehensive Safeguards Agreement (CSA) (IAEA, 2021f). In 2018, *"Safeguards were applied in 182 States; 174 of these states have comprehensive safeguards agreements, five have voluntary offer agreements and three have item-specific safeguards agreements."* (IAEA, 2021d).

After having pointed out the IAEA's role in preventing the military use of nuclear technology and relevance in the elaboration and promotion of *soft law* standards, one shall not forget the other aim of the Agency, which is to promote peaceful uses of nuclear technology. Within the previous part (2.1.1), it was stated that nuclear technology, used to civilian ends, can help improving living conditions and be a valuable solution to environmental issues. The role of the Agency, in that case, is *"to ensure that nuclear technology is the most effective and appropriate technology to address a particular problem; that the recipient country has adequate infrastructure to adopt and sustain such technology; and that this technology is transferred safely, in the most efficient and effective manner."* (ElBaradei, 1999).

Besides the IAEA, other organs and Treaties such as the UN Security Council or the Treaty on the Prohibition of Nuclear Weapons (TPNW) play an important role in fighting nuclear weapons' proliferation.

2.2.2 Other Organs and Treaties (Security Council, CTBTO (Agreement), Treaty on the Prohibition of Nuclear Weapons (TPNW), Trade Control)

The Security Council's primary objective is to ensure international peace and security. *"The Security Council takes the lead in determining the existence of a threat to the peace or act of aggression. It calls upon the parties to a dispute to settle it by peaceful means and recommends methods of adjustment or terms of settlement."* (United Nations, 2021b). As one of the six main UN organs, this body, in some cases, can impose sanctions and even authorize the use of force to restore or maintain international security and peace (ibid.). Within the previous paragraph (2.2.1), it was mentioned that concern around the spread of nuclear weapons was at first more focused on their acquisition by nation-states than by terrorists. Reasons for it were on the one hand that it was believed, terrorists could not acquire nuclear explosive materials such as HEU and separated plutonium, required to produce nuclear weapons (Valković, 2019). On the other hand, numerous experts thought terror cells' purpose was not to kill thousands of people but rather make a statement in forcing the public to pay attention to the messages they wished to impart (ibid.).

However, *"one of the serious threats the international community is facing in the post-cold war and post 9/11 world is the one concerning the proliferation of weapons of mass destruction (WMD) towards (and also 'among' and 'by') non-state actors, which, in this case, chiefly means terrorist organizations."* (Pedrazzi et al., 2015). To solve the problem of proliferation involving non-state entities, the UN Security Council chose a unified approach. Hence, a comprehensive strategy is needed to prevent nuclear and other radioactive material from falling into the wrong hands (ibid.).

"During the course of the last decades, the international community has elaborated a wide and diversified range of measures that contribute to the contrast of the proliferation of nuclear weapons and related material (in particular) involving non-state actors." (Pedrazzi et al., 2015). Some of these measures are based on legally-binding international agreements or imposed by the Security Council law-making; some of them are non-binding political agreements. In order to better understand the role of the UN body in framing international efforts to fight proliferation of nuclear weapons, it seems necessary to briefly introduce the several mechanisms of law-making it possesses.

"With regard to international conventions, apart from the general obligations contained in Articles 1 and 2 of NPT, the 1980 Convention on the Physical Protection of Nuclear Material (CPPNM) and its 2005 Amendment (not yet in force), dealing with the protection of nuclear material used for peaceful purposes during international and domestic transport and of (peaceful) nuclear facilities, play a central role." (Pedrazzi et al., 2015).

Next to these legal instruments, the 2005 International Convention for the Suppression of Acts of Nuclear Terrorism (ICSANT), plays an increasing role in repressing criminal acts entailing *"illegal possession or use of nuclear device or radioactive material or damage to a nuclear facility with what may be called a 'terroristic' intent."* (Pedrazzi et al., 2015). Another legal instrument, the 2010 Beijing Convention on the Suppression of Unlawful Acts relating to International Civil Aviation implies *inter alia* punishable acts of unlawfully discharging or releasing radioactive substances or nuclear weapons from an airplane in service or using them against an airplane (Pedrazzi et al., 2015). All the above-quoted instruments require States parties to implement their provisions within domestic jurisdiction. However, an efficient system of fighting against proliferation of non-state actors lacks efficient international supervisory mechanisms to control that international obligations have been implemented and enforced correctly (ibid.).

The role of non-binding agreements in the fight against proliferation of nuclear weapons may sometimes be even of a greater importance than the one played by binding treaties, with regard to verification and enforcement (Pedrazzi et al., 2015). To this end, the Security's Council action needs to be located within the above-mentioned framework. Although the Security Council had voted the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) in 1968, it only started actively addressing the issue of non-proliferation of nuclear and WMD in 1992. For the first time on 31 January 1992, the Council made a statement that *"'[t]he proliferation of all weapons of mass destruction constitutes a threat to international peace and security' and its members committed themselves 'to working to prevent the spread of technology related to the research for or production of such weapons and to take appropriate action to that end.'"* (Pedrazzi et al., 2015). To respond to direct nuclear threats of specific actors, the Security Council adopted a series of resolutions. On 28 September 2001, in the wake of the 9/11 attacks pursued by Al-Quaeda, Resolution 1373 was the first instance in which the Security Council imposed general obligations on States (ibid.). The Resolution's paragraph 4 states that:

"'note(d) with concern' the close connection between international terrorism and, inter alia, the 'illegal movement of nuclear, chemical, biological and other potentially deadly materials,' emphasizing the need to coordinate efforts 'on national, subregional, regional and international levels in order to strengthen a global response to this serious challenge and threat to international security.'" (Pedrazzi et al., 2005; Security Council, 2001).

Three years after the adoption of Resolution 1373, binding measures came with Resolution 1540 on 28 April 2004. Adopted under Article 41 of the UN Charter, it states three general obligations on all States:

"(1) to refrain from supporting non-state actors wishing to acquire, develop, or handle WMD and their means of delivery; (2) "to adopt and enforce appropriate effective laws" prohibiting any non-state actor "to manufacture, acquire, possess, develop, transport, transfer or use" WMD or their means of delivery, in particular for terrorist purposes; and (3) "to take and enforce effective measures to establish domestic controls" to prevent the proliferation of WMD, including controls over related materials. This third obligation

encompasses the following duties: (a) to develop effective measures to secure such items in every phase; (b) to develop and enforce physical protection measures; (c) to develop effective border controls and law enforcement measures in order to prevent illicit trafficking; and (d) to develop effective national export and trans-shipment controls and to impose effective penalties for violations of export control laws." (Pedrazzi et al., 2015).

Finally, Resolution 1540 created a two years Committee comprising all members of the Council, whose main objective is to monitor member states' compliance with the adopted Resolution on the basis of member states' reports and to report to the Council (ibid. 183). With the adoption of further Resolutions (1673, 1801, 1977, 2055 and 2118), the mandate of the Committee has been renewed and a group of experts composed of eight individuals was established, with the aim of assisting the Committee in performing its mandate (Pedrazzi et al., 2015).

Now that the role of the Security Council and its instruments to implement law were scoped, one can conclude that the aim of Resolution 1540 was to create general obligations for all Member States (Pedrazzi et al., 2015). However, the legal mechanism created by the Security Council remains more an assisting mechanism than a monitoring system. *"Indeed, the absence of a verification system specifically tailored to the needs of Resolution 1540 may be remedied, at least partially, by the operation of other supervisory mechanisms, which may indirectly play a role in relation to the implementation of the Resolution, such as those existing in the IAEA or in the PSI frameworks."* (Pedrazzi et al., 2015). To this end, the UN body is not an organ in charge of state responsibility, which means that its action in a specific national matter is restricted, even when the behavior of a particular state is considered a threat to peace, which in turn only happens in extreme cases (ibid.). The case of the Russian and Chinese veto on the UN Security Council's resolution to stop using chemical weapons on the Syrian population revealed how ineffective and fragile the Security Council can be when it tries to impose its legislation to maintain world peace (BBC, 2012).

Besides the IAEA and the Security Council, which are the principal organs in charge of the regulation of military and civil use of nuclear energy, other organizations and Treaties such as the comprehensive nuclear-test-ban Treaty Organization (CTBTO) or the Treaty on the Prohibition of Nuclear Weapons (TPNW) are relevant in framing and stemming nuclear proliferation.

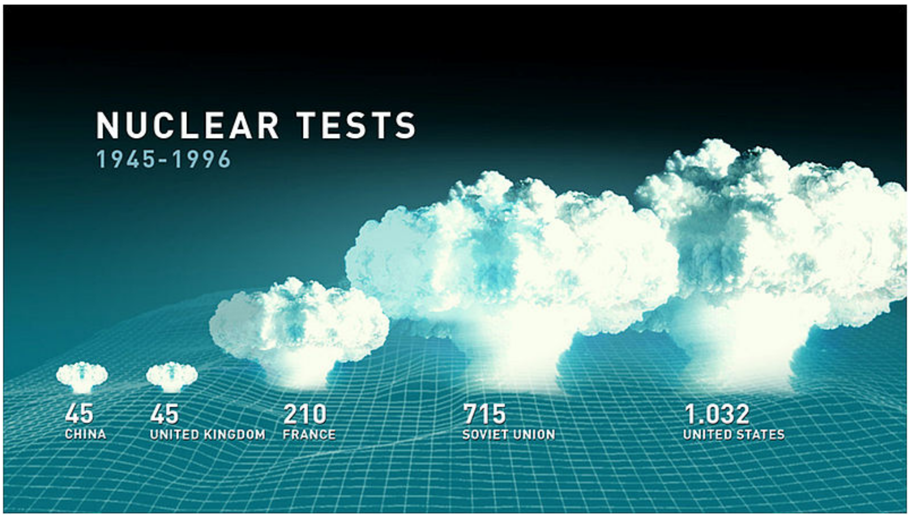

Figure 2 Nuclear Tests between 1945-1996 (CTBTO, 2021).

In a historical context, within more than 2000 nuclear tests were carried out between 1945 and 1996, the Comprehensive Nuclear-test Ban Treaty opened for signature (CTBTO, 2021). Main objective of the treaty is to make it difficult for countries to develop atomic bombs or, if they already have them, to prevent from building more powerful ones through a unique and comprehensive verification regime (ibid.). One other objective is to prevent huge damages generated through radioactivity from nuclear explosions (ibid.). Though several attempts were made to enforce the Treaty, 185 countries have signed it and from the 185 countries, only 170 have ratified it, including three of the nuclear-weapon States such as Russia, United Kingdom and France (ibid.). Before the Treaty can enter into force, 44 specific nuclear technology holders countries have to sign and ratify it (ibid.). From these 44 countries, eight are still missing, among other India, North-Korea and Pakistan, which explains their active nuclear weapons tests since 1996 (ibid.). *"India and Pakistan in 1998, and the Democratic People's Republic of Korea (DPRK) in 2006, 2009, 2013, twice in 2016 (January and September) and 2017."* (CTBTO, 2021).

Beside several attempts of definitively banishing nuclear weapons' use, the increasing level of concern of nuclear weapons on the humanitarian impact led to a series of three international conferences, which *"included participation by a large majority of States, the International Committee of the Red Cross and hundreds of representatives of non-governmental organizations, principally coordinated by the International Campaign to Abolish Nuclear Weapons (ICAN)"* (United Nations, 2021a). By resolution 71/258, the

General Assembly convened a United Nations conference in 2017 to start negotiations on a legally binding instrument prohibiting nuclear weapons (ibid.).

"The Treaty on the Prohibition of Nuclear Weapons (TPNW) includes a comprehensive set of prohibitions on participating in any nuclear weapon activities. These include undertakings not to develop, test, produce, acquire, possess, stockpile, use or threaten to use nuclear weapons." (United Nations, 2021a). The TPNW prohibits not only the application of nuclear weapons on national territory but also any provision of assistance to any State in the deployment of illicit activities (ibid.). Adopted by the Conference by a vote of 122 countries in favor, one vote against and one abstention at the United Nations on 7 July 2017, the Treaty entered into force on 22 January 2021 and marks a major step toward a world free of nuclear weapons (United Nations, 2021a).

Final point of this chapter, before elaborating the principal tool of this thesis, which is the Weaponization Score Index, is the role of nuclear trade controls.

"The merits of nuclear trade controls for helping stem proliferation have been strenuously debated for decades. Some have maintained that the policy of secrecy and denial that the United States pursued in the aftermath of Hiroshima and Nagasaki was a failure and that, instead, sharing the peaceful benefits of nuclear energy under nonproliferation controls and conditions has helped build key elements of the global regime to prevent the spread of nuclear weapons." (McGoldrick, 2013).

Meanwhile, several experts argue that international nuclear trade indeed increases nuclear proliferation risks, more precisely, that the deployment of civil nuclear technologies makes proliferation more plausible (ibid.). In order to understand those differing opinions, it is relevant to briefly enlighten how nuclear trade controls work, by means of which requirements. Nowadays, major nuclear suppliers commonly need non-nuclear-weapon States to provide guarantees and assurances as a requirement for nuclear cooperation (McGoldrick, 2013). *"An essential condition for civil nuclear trade is an assurance by recipient states of peaceful, nonexplosive use. It is also fairly uncontroversial, because 184 non-nuclear-weapon states (plus Taiwan) that have ratified the NPT have already undertaken this commitment."* (McGoldrick, 2013). Other significant requirements for international nuclear trade are the application, as mentioned in the above paragraphs, of the IAEA Safeguards Standards, guarantees of applying efficient physical protection on nuclear materials, such as the NSG Guidelines.

Though the aim of the NSG guidelines is to ensure that peaceful purpose of international nuclear trade is not misused to military ends, it contains significant gaps. *“The so-called grandfather and the safety clauses were used by Russia and China to supply nuclear reactors and fuel to India and Pakistan—two non-NPT parties without comprehensive safeguards.”* (McGoldrick, 2013). Besides, nuclear export control policies cannot address nor solve all proliferations issues since, as we saw in the past, states such as France in the case of Israel or China in the case of Pakistan, deliberately defied the nonproliferation regime by supporting other States in acquiring nuclear weapons (ibid.). *“Nevertheless, the nuclear export policies of the major nuclear suppliers has had some success in increasing the costs and risks of the procurement efforts of such states as Pakistan, Iran, and Iraq and in delaying their acquisition of sensitive nuclear facilities or nuclear weapons.”* (McGoldrick, 2013).

All these agreements, guidelines, measures and efforts taken to secure the civil use of nuclear technology and stem the proliferation of nuclear weapons lead to the third Chapter of this Thesis, which is the elaboration of the Weaponization Score Index. How far are countries with an advanced civilian nuclear program from crossing the line between peaceful use of nuclear technology and weaponization?

3. Analysis

Within the first Chapter, the context in which dual use of nuclear technology takes place was introduced, described and deepened. The second Chapter defined the legal framework in which nuclear energy is set and how institutions, legally binding agreements and other organs can dampen the transition from nuclear civil use of nuclear technology to weaponization. Now that the technical, historical and legal frameworks are set, the central point of this thesis, which is the elaboration of the Weaponization Score Index will be introduced.

3.1 Methods

A crucial step within a Master Thesis is the choice of the methodical approach. Here, both quantitative and qualitative methods will be used, since the elaboration of a score index falls in the category of quantitative empirical research and the case study of Pakistan to illustrate the technical road of civil use into weaponization falls in the category of qualitative research.

Before describing the different drivers (3.3) chosen for the Weaponization Score Index, it is relevant to briefly introduce which steps are required to elaborate a score index within quantitative research and finally, how a case study is realized within empirical qualitative approach.

3.1.1 Index Construction

"Indexes are very useful in quantitative social science research because they provide a researcher a way to create a composite measure that summarizes responses for multiple rank-ordered related questions or statements." (Crossman, 2019). Composite measures of variables enable to summarize different indicators in a single numerical score, while sometimes retaining specific details of all single indicators (Babbie, 2010). In order to create a valid score index, which is no simple task and often led to failures over the past within quantitative research, the four main steps of building an index, on the basis of Earl Babbie's work, that are the selection of possible items (1), the examination of their empirical relationships (2), the index scoring (3) and finally its validation (4) will be introduced (ibid.).

(1) Item selection consists in the selection of possible items for a composite index, which is created to measure several variables (ibid.). Face validity, which is the first criterion to be included in an index to select items, is a simple form of validity which subjectively reviews whether or not the index one created measures what it is supposed to measure (Glen, 2015). In the context of this thesis, one wants to measure how quickly a country with an advanced civilian nuclear program can transit into a weaponization program. The items to measure the degree of weaponization should be amongst other the uranium resources a country already possesses, the infrastructures for civil use of nuclear energy etc. Another criterion to consider in item selection is the amount of variance the items provide. If an

item provides no or little variation, logically, it won't be of significant use in the construction of the index. For example, if one item to measure the weaponization degree of a country would be the "degree of willingness of a country" to obtain nuclear weapons and each chosen country would indicate a willingness of 1 or a willingness of 5, this item would not be useful since there is no variation.

(2) An empirical relationship between items is established when the answers to one question, for example, will help predict how the answers to other questions will be. *"If two items are empirically related to each other, we can reasonably argue that each reflects the same variable, and we may include them both in the same index."* (Babbie, 2010).

(3) Before validating the index, one needs to assign scores for specific responses, in order to create a single composite index through the summation of items (ibid.). In this case, each item score should be weighted equally. Thus, weights indicate the degree of contribution of specific items in the elaboration of the final index score (ibid.).

(4) Finally, if each previous step is carried out correctly, the likelihood of the index measuring the variable is increased. However, to verify the index's success, one first needs to show that the index is valid (Babbie, 2010). How does one prove that? In assuming that an index provides the measure of a variable, *"that is, the scores on the index arrange cases in a rank order in terms of that variable."* (Babbie, 2010). The Weaponization Score Index, whose aim is to measure how quickly a country can transit from civil use of nuclear technology into bomb work, should, if carried out successfully, shows that countries with limited capabilities have a lower score than countries categorized into Latent I.

3.1.2 Case Study

"Case study research, through reports of past studies, allows the exploration and understanding of complex issues. It can be considered a robust research method particularly when a holistic, in-depth investigation is required." (Zainal, 2007). To reinforce the results of the Weaponization Score Index and demonstrate how easily a country with an advanced civilian nuclear program can transition into bomb work, the case study of Pakistan and its technical road from civil use of nuclear technology to Weaponization has been chosen.

Case study method allows the scientist to examine data within a particular context (Zainal, 2007). Within this Master Thesis, a particular geographical area, Pakistan is chosen as the subject of study. *"Commonly, case studies are associated with qualitative research, but often they combine different research techniques. They can illuminate quantitative findings and can incorporate quantitative data."* (Guthrie, 2010). As for other qualitative methods, there are several categories of case study. In the context of this Master Thesis, a descriptive case study is the most adequate approach since *"it includes a concise but thorough account of the facts of the situation and expert commentary to help the audience understand the causes of the problem, the forces behind the solution, the outcomes of implementation, lessons learned, and connections to theories, concepts, policies, and tools relevant to the situation."* (CDN, 2021). On the basis of available data and observation, the historical context of how Pakistan got enriched uranium and how it transited to manufacturing nuclear weapons will be deepened.

3.2 Tables

Before introducing the specific drivers (3.3) chosen to elaborate the Weaponization Score Index, one needs to differentiate between the different capabilities required for peaceful uses of nuclear technology (3.2.1), for military uses of nuclear technology (3.2.2) and finally for dual use (3.2.3). To do so, three tables will be established, classifying the relevant drivers under seven categories, that are (1) Resources, (2) Infrastructures, (3) Legal aspects, (4) Technical aspects, (5) Political aspects, (6) Economic resources and finally (7) Other supporting capabilities.

3.2.1 Capabilities required for Peaceful Use

"The consideration of the nuclear power option and implementation of the first nuclear power project requires a basic infrastructure which addresses the minimum issues to deal with all aspects of a nuclear power project." (IAEA, 2006a).
To address these issues, a table according the infrastructure issues mentioned under the IAEA Milestones Approach will be constructed.

Table 3 Capabilities required for peaceful uses of nuclear technology.

Drivers	Description
(1) Resources 1a. Management 1b.Human resource development 1c. Stakeholder involvement	1a. Sustainable Management system required for efficient decision-making processes, balanced guidance that enables success in undertaken projects. 1b. Human resource development (workshops, guidance documents, training programs) required to train highly qualified specialists, technicians, engineers, experts in relevant fields such as fission, environmental assessment, waste management, nuclear safety, electricity, engineering. 1c. Stakeholder involvement of great importance to enhance public awareness, understanding and confidence.
(2) Infrastructures 2a. Site and supporting facilities 2b. Electrical grid 2c. Nuclear fuel cycle 2d. Transportation 2e. IT	2a. Adequate site and supporting facilities required to construct and operate nuclear power reactors/nuclear research reactors in safe, technically sound and secure manner. 2b. Electrical grid required to ensure safe and economic operation of a nuclear power plant but also to export power from the Nuclear power plant (NPP). 2c. Nuclear fuel cycle required to produce electricity in NPP through several steps: (1) mining/milling or importation; (2) conversion; (3) enrichment at 3-5%; (4) fuel fabrication; (optional steps: temporal storage of spent fuel and reprocessing); (5) radioactive waste disposal. 2c. Nuclear fuel cycle of Research Reactors: Enrichment at 20% (1) fuel fabrication; (2) use in reactor; (3) temporary storage; reprocessing or direct spent fuel disposal; (4) radioactive waste disposal. 2d. Safe and secure transportation of radioactive material requires monitoring system to bring sensitive material for one facility to another. 2e. IT Infrastructure required to support information technology tools, software

	programs for configuration management required to increase NPP's availability, performance, design.
(3) Legal aspects 3a. Nuclear Safety 3b. Legal Framework 3c. Nuclear Security	3a. Nuclear safety required to (1) ensure protection of public, workers and environment (Safety Standards) and (2) the maintenance of nuclear facilities at a high-level of safety through conventions, codes of conduct. 3b. Safeguards required for the good functioning of nuclear power plants/research reactors, but also to prevent proliferation of nuclear weapons, enabled through: → Legal Framework allowing countries to have community access to nuclear technology (uranium importation, centrifuges importation) due to several agreements (NPT, Safeguards Agreements, Additional Protocol, Nuclear-Weapon-Free-Zones, NSG guidelines) 3c. Nuclear security required to (1) protect property, individuals, society and environment from harmful effects of ionizing radiation; (2) to detect, prevent and respond to intentional malicious acts involving radioactive substances.
(4) Technical aspects 4a. Engineering & Design 4b. Procurement 4c. Export	4a. Engineering & Design required to provide safe and effective operation of nuclear power plants/ nuclear research reactors (defense in depth approach) but also to include capability to manufacture reactors. 4b. Goods and services' procurement such as technology transfer (import), services for disposal of spent nuclear fuel, laboratory supplies, isotopes, nuclear imaging etc. required to assist Member States in the good development of their nuclear power program. 4c. Export of technical performance and knowledge required to assist developing countries in their civilian nuclear program.
(5) Political aspects 5a. National position 5b. Historical perspective 5c. International cooperation	5a. National position of a country such as government support, public participation, required to embark on a nuclear power program.

	5b. Historical perspective as trigger for a country to start a nuclear power program (WWII and resources penury). 5c. International cooperation as transfer of nuclear technology, design and expertise from a developed country to another developing country.
(6) Economic resources 6a. Funding & Financing	6a. Funding as how costs of infrastructure are paid for. Costs always met by taxpayers or consumers, required to develop or maintain necessary nuclear infrastructure. Financing as how upfront costs of building infrastructure are met. Costs either met by private (i.e. corporate) or public (government) sector. Two ways to raise finance: through debt financing involving a bank extending loan for a given portion of project costs; Equity financing through investor providing funding in exchange for stake in project.
(7) Other supporting capabilities 7a. Emergency planning 7b. Industrial Involvement 7c. Communication strategies 7d. Public participation 7e. Intelligence Communities	7a. Emergency planning as service provided by IAEA to evaluate their level of preparedness for nuclear emergencies (INES Scale). 7b. Industrial Involvement of national industrial organizations needed to participate in constructing and commissioning of NPPs. 7c. Communication strategies required to convince and guarantee a wide support of new nuclear program. 7d. Public participation can be of importance in supporting/dampening a nuclear power program. 7e. Intelligence Communities can be helpful to monitor and prevent other countries from misusing their civilian nuclear program.

3.2.2 Capabilities required for Military use

"The world's nuclear-armed states possess a combined total of nearly 13,500 nuclear warheads; more than 90% belong to Russia and the United States. Approximately 9,500 warheads are in military service, with the rest awaiting dismantlement." (Kristensen and

Kile, 2020). To understand what a country requires to build a nuclear weapon, a table including all relevant criteria for military use of nuclear technology will be built.

Table 4 Capabilities required for military use of nuclear technology.

Drivers	Description
(1) Resources 1b. Human resource Development	1b. Human resource development such as a team of engineers, physicians, experts trained in the domain of fission or fusion, mechanical engineering, military expertise required.
(2) Infrastructures 2a. Site and supporting facilities 2c. Nuclear fuel cycle 2e. IT	2a. Adequate site and supporting facilities required to build a nuclear weapon (laboratories, NPPs, underground testing). 2c. Nuclear fuel cycle required: capacity of enriching uranium at 90% and reprocessing (plutonium) 2e. IT infrastructure required to support specific computer, software programs, information technology tools to elaborate design nuclear warheads, design delivery systems and simulate launch.
(3) Legal Aspects 3b. Legal Framework	3b. Legal framework required to have community access to fissile materials and centrifuges. (NSG Guidelines, NPT). Legal instruments of the IAEA do not necessary apply to military facilities and materials.
(4) Technical aspects 4a. Engineering & Design 4d. Delivery System 4e. Testing	4a. Engineering and Design such as computer software required to build nuclear warheads (gun-type weapon, implosion weapons). 4d. Delivery system required to deliver the nuclear weapon to the enemy. (Long range ballistic missile, submarine-launched weapons, cruise missiles, bombers, aircraft, aeroplane*) *South- Africa 4e. Testing of nuclear weapon through virtual computer programs required to collect the maximum of data.
(5) Political aspects 5b. Historical perspective 5c. International cooperation 5d. Authoritarian system 5e. Nuclear threat from other country	5b. Historical perspective of great importance for a country to have incentive building or not a nuclear weapon. 5c. International cooperation as assistance and supply of material, technology, design and expertise from a nuclear weapon state to

	a non-weapon nuclear state to develop a military nuclear program. 5d. Authoritarian system can be decisive in process of getting a nuclear weapon as decision only lies by government. (North-Korea example) 5e. Rising threat of neighboring country of great importance to decide getting its own nuclear weapon.
(6) Economic resources 6a. Funding and financing	6a. Funding of nuclear weapons through defense budget of a country. Financing nuclear weapons of a country operated by financial institutions, companies and other countries.
(7) Other supporting capabilities 7c. Communication Strategies 7f. Illicit trafficking & Shell companies	7c. Communication Strategies as camouflage to develop civilian nuclear program when wanting to develop a nuclear weapon. 7f. Shell companies as fictive companies created to hide financial transactions and evade sanctions. Example: North-Korea. Illicit trafficking of uranium, centrifuges parts and designs for countries which do not have legal framework to import materials.

3.2.3 Capabilities required for Dual use

"The same technologies that make fuel for nuclear reactors can also produce explosive material for nuclear bombs. Two pathways are available to either make fuel or bomb-material. These are the uranium and plutonium pathways." (Ferguson, 2007).
After having established both tables for peaceful (3.2.1) and military uses (3.2.2) of nuclear technology, the drivers which can be used for dual use need to be looked up.

Table 5 Capabilities required for dual use of nuclear technology

Drivers	Description
(1) Resources 1b. Human resource development	1b. For peaceful uses of nuclear technology, team of scientists, physicians, engineers trained through workshops and training programs in relevant fields such as fission, mechanical engineering, waste management etc.

	1b. To construct a nuclear weapon, team of engineers and physicians trained in the domain of fission, fusion, mechanical engineering and military expertise required.
(2) Infrastructures 2a. Site and Supporting Facilities 2c. Nuclear Fuel cycle 2e. IT	2a. For peaceful uses of nuclear technology, adequate site and supporting facilities required to construct and operate nuclear power reactors/nuclear research reactors. 2a. For military use of nuclear technology, adequate site and facilities such as NPPs, laboratories, underground testing capacities required. 2c. For peaceful uses, Nuclear fuel cycle required in NPP: (1) mining/milling or importation; (2) conversion; (3) enrichment at 3-5%; (4) fuel fabrication; (optional steps: temporal storage of spent fuel and reprocessing); (5) radioactive waste disposal ; Requirement in Research Reactor: Enrichment at 20% (1) fuel fabrication; (2) use in reactor; (3) temporary storage; reprocessing or direct spent fuel disposal; (4) radioactive waste disposal. 2c. To produce a nuclear weapon, Highly Enriched Uranium (HEU) at 90% required or plutonium through reprocessing. To do that, enrichment and reprocessing facilities required. 2e. For peaceful uses, IT infrastructure required to support information tools, software programs and design programs to implement and improve configuration of NPPs. 2e. To produce nuclear weapons, IT infrastructure such required to support specific computer programs, design software to elaborate delivery system, nuclear warheads.
(3) Legal aspects 3b. Legal Framework	3b. For peaceful uses of nuclear technology, legal framework required allowing countries to have community access to nuclear technology (uranium importation, centrifuges importation) due to several agreements (NPT, Safeguards agreements, Additional Protocol, Nuclear-Weapon-Free-Zones, NSG guidelines) 3b. To produce a nuclear weapon, legal framework required to enable a country to import fissile material and centrifuges parts/designs.

	However, legal instruments of the IAEA applied on peaceful nuclear technologies do not necessarily apply to military facilities.
(4) Technical aspects 4a. Engineering & Design 4d. Delivery system	4a. For peaceful uses of nuclear technology, Engineering & Design through computer aided design and drafting, computational software and hardware equipment required to provide safe and effective operation of nuclear power plants/ nuclear research reactors (defence in depth approach) and include capability to manufacture. 4a. To produce a nuclear weapon, Engineering & Design through computer aided design and drafting, computational software and hardware equipment required to build a nuclear warhead. 4d. Delivery system required for both conventional military use and production of nuclear weapons.
(5) Political aspects 5b. Historical perspective 5c. International cooperation	5b. For peaceful uses of nuclear technology, historical events such as World War II and resource penury lead countries to turn to nuclear energy as electricity production's source. 5b. To produce a nuclear weapon, historical events as trigger for a country to build nuclear weapon. (Sino-Indian war). 5c. International cooperation required for peaceful uses as transfer of nuclear technology, design and expertise from a developed country to another developing country. 5c. International cooperation to produce nuclear weapons as the assistance and supply of material, technology, design and expertise from a nuclear weapon state to a non-weapon nuclear state.
(6) Economic resources 6a. Funding & Financing	6a. For peaceful uses of nuclear technology, Funding as how costs of infrastructure are paid for. Costs always met by taxpayers or consumers, required to develop or maintain necessary nuclear infrastructure. Financing as how upfront costs of building infrastructure are met. Costs either met by private (i.e. corporate) or public (government) sector. Two ways to raise finance through debt financing involving a bank extending loan for a given portion of project costs; Equity financing through investor providing funding in exchange for stake in project.

	6a. To produce a nuclear weapon, funding through defense budget of a government and financing through financial institutions, companies and other countries.
(7) Other supporting capabilities 7c. Communication Strategies	7c. For peaceful uses of nuclear technology, communication important to guarantee public acceptance and a wide support for a new nuclear power program. 7c. To produce a nuclear weapon, communication as a means to an end built on the development of a "civilian nuclear program".

3.3 Relevant Drivers for the Index

Main objective of the Weaponization Score Index, as mentioned in the previous chapters, is to establish transparency in showing how long countries that have the required infrastructures need to transition from a civilian nuclear program to manufacturing nuclear weapons. To verify the primary hypothesis of this thesis, which was that countries possessing an advanced civilian nuclear program can easily transition into bomb work, nine countries will be ranged in four different categories that are Dormant, Latent I, Latent II and limited Capabilities. Before listing the relevant drivers (3.3.3) for the Weaponization Score Index, the four categories mentioned above will be defined, followed by the Case Study of Pakistan (3.3.1) that will support the relevance of the chosen drivers. Last but not least, a short introduction of the other remaining countries (3.3.2) will be given to better understand their technical, legal, political and economic status toward an eventual nuclear transition.

Under the category Dormant, one understands countries which already possess most of the required capabilities to transit from peaceful use to manufacturing nuclear weapons, but which remain in a state of rest or inactivity.

Under categories Latent I and II, one understands countries capable of acquiring or developing capabilities to build a nuclear weapon within a short amount of time but whose capabilities are not visible, obvious or active yet.

Finally, the category Limited Capabilities includes all countries with capabilities that are limited in a way that they don't have the potential to transit from peaceful use to manufacturing nuclear weapons in a short amount of time.

3.3.1 Pakistan – Reference Country

"In the mids-1970s Pakistan embarked upon the uranium enrichment route to acquire a nuclear weapons capability. Pakistan conducted nuclear tests in May 1998, shortly after India's nuclear tests, declaring itself a nuclear weapon state." (NTI, 2019). To illustrate how easily a country can transition from a civilian nuclear program to getting a nuclear weapon, the example of Pakistan's technical road to transition will be introduced.

In 1965, the agreement between the Canadian and Pakistani governments to sell a heavy water reactor to Pakistan sealed the beginning of its civilian nuclear program. Primary aim of this acquirement was to produce energy to meet the country's energy needs, since according to the former high price of oil, production of nuclear energy was an economical substitute to fossil energy (Khalilzad, 1976). After that, the reactor was installed in 1972 (ibid.). In the meantime, Pakistan, which suffered defeat in the conflict with India in December 1971, brought Pakistan's former Prime Minister Zulkifar Ali Bhutto to issue a directive concerning the establishment of a nuclear weapon within the next three years. *"Although the PAEC had already created a taskforce to work on a nuclear weapon in March 1974, India's first test of a nuclear bomb in May 1974 played a significant role in motivating Pakistan to build its own."* (NTI, 2019).

A key figure to Pakistan's route to the bomb is the Pakistani scientist Abdul Qadeer Khan, who earned a doctorate in metallurgical engineering and started working at a subsidiary of the URENCO enrichment corporation in Amsterdam (Netherlands) in May 1972 (Britannica, 2021; NTI, 2019). Meanwhile, the Pakistan Atomic Energy Commission (PAEC), that tried using plutonium from the Karachi Nuclear Power Plant to produce nuclear weapons, was dampened by the new nuclear export controls established in the wake of India's nuclear test (NTI, 2019). A.Q. Khan, who gained access and knowledge to classified centrifuge designs within his time working in the Netherlands, contacted Bhutto after the 1974 Indian test (Britannica, 2021). *"In December 1975, Khan abruptly left his job and returned to Pakistan with blueprints and photographs of the centrifuges and contact information for dozens of companies that supplied the components."* (Britannica, 2021).

Starting this point, Khan began working with PAEC on building and operating a centrifuge plant in Kahuta with all individual components he had bought from different countries, to escape the new export controls regulations (NTI, 2019). By April 1978, Pakistan had built its own uranium enrichment facility and four years later, it was able to produce highly enriched uranium, required to produce nuclear weapons (Britannica, 2021). *"A.Q. Khan would later assert that the country had acquired the capability to assemble a first-generation nuclear device as early as 1984."* (NTI, 2019).

However, one has to mention that the production of Pakistani nuclear weapons would have been strongly dampened if Pakistan did not have had assistance from other countries, in particular from China. *"Beginning in the late 1970s China provided Pakistan with various levels of nuclear and missile-related assistance, including centrifuge equipment, warhead designs, HEU, components of various missile systems, and technical expertise."* (NTI, 2019). In response to the Indian nuclear tests operated on 11 and 13 May 1998, the Pakistani government decided to detonate five explosions on 28 May and the sixth on 30 May 1998 (NTI, 2019). Though the official Pakistani announcement stated back then that the yield of May 28 was on the order of 40 to 45 kilotons, a Western seismic measurement suggested that the yield was on the order of 9 to 12 kilotons (Britannica, 2021). From that moment onwards, there was no doubt that Pakistan abandoned its nuclear ambiguity and officially joined the "nuclear club" (NTI, 2019).

After having illustrated the several steps of Pakistan's transition from civilian nuclear program to military program, this concrete example will be used to constitute the list of relevant drivers that are to be included into the Weaponization Score Index.

The American "Atoms for Peace' program, established in the 50s to train highly qualified personal in peaceful uses of nuclear technologies, unwillingly enabled participating States such as Pakistan, to take advantage in sending students abroad and train them to use their acquired knowledge to military ends (Britannica, 2021). Besides, Doctor Khan's access to classified centrifuges designs during his stay in the Netherlands enabled him to take all required knowledge back to Pakistan in order to build nuclear weapons and escaping the export regulations, thanks to his wide contact network (Britannica, 2021). To this effect, the driver "Human resource development' is the first step and requirement for a country to transit from civil use to military use of nuclear technology.

"In 1965 when petroleum was sold at a much lower price than in 1975, an agreement was signed between Canada and Pakistan for the sale of a heavy water nuclear

reactor intended for energy production. KANUPP, a 137 MW power plant located near Karachi, was financed through subsidized loans from Canada." (Khalilzad, 1976). Since the Pakistani power plant is a heavy water reactor, it can produce up to 137 kg of plutonium per year while operating (ibid.). As mentioned in the previous chapters, 5 kg critical mass of plutonium suffice to produce nuclear weapons, which explains why the PAEC, after India's first test of a nuclear weapon in May 1974, focused on building a nuclear bomb with plutonium, which could be used from the Karachi Nuclear Power Plant. Though those efforts were inefficient due to the established nuclear export controls, Khan's return to Pakistan and its contact information to dozens of components suppliers worldwide enabled the PAEC and himself to build and operate the required facility to enrich uranium (Britannica, 2021). To this effect, the driver "Site and supporting facilities" builds the second step of a country's potential transition and builds an obligatory pre-requirement to undergo the nuclear fuel cycle.

Hereupon, Pakistan's logical procedure after acquiring enrichment facilities was to undergo the several steps of the nuclear fuel cycle from enrichment to reprocessing, which enabled the country to produce enriched uranium at weapon-grade and finally, to produce nuclear weapons in 1984. To this effect, the driver "Nuclear Fuel Cycle" builds the third essential indicator of the list.

To transition from a civilian nuclear program to manufacturing nuclear weapons, no need to explain that sufficient information technology infrastructures are substantial. As a matter of fact, building a nuclear weapon requires a range of information tools and software programs to design not only nuclear warheads but also delivery systems. After Khan's return to Pakistan, he founded the Engineering Research Laboratories in July 1976, enabling him to develop the required technological infrastructure to support information technology tools, required to design military nuclear technology (Britannica, 2021). To this effect, the driver "IT" belongs to the essential indicators of the index.

While the nuclear safety and security legal framework evolved since Pakistan's acquirement of nuclear weapons, making it nowadays difficult for countries to misuse nuclear technologies, legal agreements have already been required back then for a country to start a civilian nuclear program. As a concrete example, the implementation of IAEA Safeguards, more precisely the trilateral Safeguards agreement (INFCIRC/34), signed in March 1962, enabled Pakistan to get its first Research Reactor-1 (PARR-1) (IAEA, 2010). Besides, there is evidence that the existing legal framework back then already tried to prevent from misuses of nuclear technologies, as the progression of Pakistan's military nuclear program was dampened in 1975, due to nuclear export controls established in the wake of India's nuclear tests (NTI, 2019). In order to have community access to nuclear technology, expertise or materials nowadays, a country needs to adhere several agreements such as the Non-Proliferation Treaty, Safeguards or the NSG Guidelines, regulating the import and export of nuclear technologies. To this effect, the driver "Legal Framework" also contributes to a country's capacity to transit from peaceful uses to military uses of nuclear technology.

A next essential step to constructing a nuclear weapon is its engineering and design. *"Khan likely had acquired the warhead design from China, apparently obtaining blueprints of an implosion device that was detonated in an October 1966 test, where uranium rather than plutonium was used."* (Britannica, 2021). With the establishment of the Engineering Research Laboratories in July 1976, Khan and the PAEC have developed software programs enabling them to design the future nuclear weapons. To this effect, the availability of the driver "Engineering & Design" is a significant indicator for a country's potential transition.

One of the last essential steps in acquiring a nuclear weapon is the capacity for a country to deliver it to its target. According to a 2013 US State Department report, Pakistan possesses land-based missiles and aircraft capable of delivering nuclear weapons (Kerr and Nikitin, 2016). While it is believed that Pakistan already had a nuclear device deliverable by aircraft in 1995, Pakistan actually carries on upgrading their nuclear delivery systems for a full range of platforms such as ballistic and cruise missiles (ibid.). To this effect, the driver "Delivery system" is also one major indicator for the Weaponization Score Index.

"In response to the Indian nuclear tests of May 1998, Pakistan claimed that it had successfully detonated five nuclear devices on May 28 in the Ros Koh Hills in the province of Balochistan and a sixth device two days later at a site 100 km (60 miles) to the southwest." (Britannica, 2021). To this effect, the last essential step for a country to join the "nuclear club" and emerge is its capacity to test a nuclear weapon, which makes the driver "Testing" a required element for the index.

Besides the necessary steps required to transit from a civilian nuclear program to building a nuclear weapon, other indicators that are less in the public eye can be of great importance for a country to begin its transition. The historical perspective of a country to pursue or not a military nuclear program is another aspect that should not be neglected.

As seen in the previous paragraphs, *"the main reason for interpreting Pakistan's move in the nuclear field as pointing toward a weapons capacity is its relations with India. Pakistan's animosity toward India has played a determining role as far as its nuclear policy is concerned."* (Khalilzad, 1976). One has to mention that Pakistan's request for a nuclear reactor in the first place was due to India's previous purchase of a nuclear reactor from Canada (ibid.). Another example is Pakistan's non adhesion to the Non-Proliferation Treaty, which followed right after India stated it would not sign or ratify the Treaty. This demonstrates that, besides the historical perspective pushing a country or not to "protect itself" by acquiring nuclear weapons, potential nuclear threat coming from a neighboring country and the chosen country's political system can contribute to a country's will to transit from a civilian nuclear program to a military one. Thus, the acute assistance of China to Pakistan in matter of technology transfer, warhead designs, supply of centrifuge equipment and technical expertise, as demonstrated within the previous paragraphs, enabled Pakistan to develop its military nuclear program, which, without China's help, would have been severely dampened. To this effect, the four drivers "historical perspective", "international cooperation", "authoritarian system" and "nuclear threat from other country" definitely influence a country in its capability to transit.

Besides the political aspects of a country to pursue or not a military nuclear program, the financial aspect is also considerable. *"The analysis by the Reaching Critical Will project of the Women's International League for Peace and Freedom concluded Islamabad is spending $2.5 billion each year on nuclear arms operations"* (NTI, 2012). Government funding through defense budget constitutes an important fraction of the overall financial assistance a country gets for its military nuclear program. Thus, assistance from financial institutions (banks), companies or other countries such as China played an important role in Pakistan's military nuclear program development. To this effect, the driver "Funding and Financing" is a relevant indicator for the establishment of the Weaponization Score Index.

After having demonstrated the relevance of political and financial aspects in a country's potential nuclear transition, three last drivers remain, which also contribute to support countries' efforts in their quest to weaponization.

If done well, a communication strategy can assemble the financial, political support and public acceptance required for a country to develop a nuclear program. In the case of Pakistan, its communication strategy was quite transparent since the Pakistani government stated from the beginning its political will to develop its own military nuclear program in response to India's nuclear tests. *"The Indian nuclear explosion of May 1974 has affected many countries in the world, but Pakistan feels especially threatened by it. On May 19, 1974, the Pakistani Prime Minister called the Indian explosion a "fateful development," a "threat" to Pakistan's security."* (Khalilzad, 1976). Back then, the former Pakistani Prime Minister Bhutto also stated that he would not sign a no-war pact with India anymore, which sealed the beginning of Pakistan's transition from peaceful use of nuclear technology to manufacturing nuclear weapons (ibid.). To this effect, the driver "Communication Strategies" sets one of the last indicators of the index up.

Last but not least, the role of intelligence communities in monitoring, preventing nuclear proliferation from other countries as well as their role in protecting and covering the development of their own countries' military nuclear program should not be neglected. Since there is no official evidence of Pakistan's intelligence community's role in facilitating the supply of centrifuges equipment, warhead designs, technical expertise from other countries, one can however assume that they did play an important part in Pakistan's nuclear program transition. To this effect, the driver "Intelligence Communities" is also relevant for the establishment of the index.

"In December 1975 Khan abruptly left his job and returned to Pakistan with blueprints and photographs of the centrifuges and contact information for dozens of companies that supplied the components." (Britannica, 2021). On the basis of this acquired network, Khan created a vast black-market network which traded or sold centrifuges, nuclear technology, expertise, warhead design and other items to countries such as Iran, North Korea, Libya and others (ibid.). To this effect, the driver "Shell Companies & Illicit Trafficking" can also contribute to develop a country's military program and constitutes the final indicator of the index.

In order to have a clear overview of Pakistan's technical road transition, the timeline which can be found below summarizes the major steps of Pakistan's transition from peaceful uses of nuclear technology to weaponization.

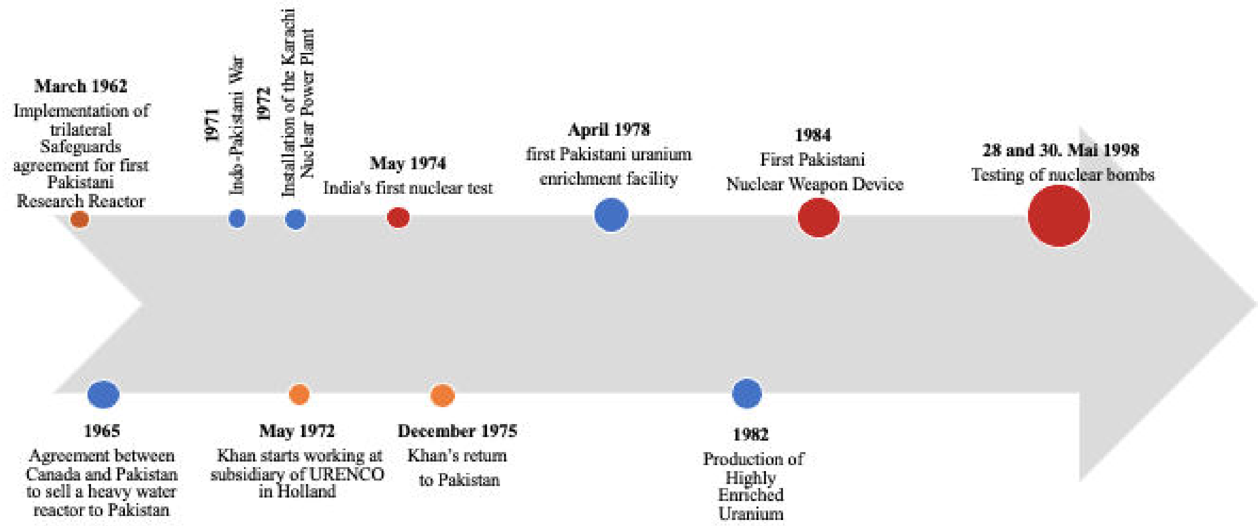

Figure 3 Pakistan's technical road to manufacturing nuclear weapons.

3.3.2 Other Countries

After having argued and supported the choice of drivers for the Weaponization Score Index through Pakistan's Case Study, one last step remains before establishing the index, which is to briefly introduce the other chosen countries, Japan, Canada, Iran, South Korea, Germany, South-Africa, Saudi-Arabia and Ghana, depending on their civilian nuclear program status.

As one knows, Japan has an advanced civilian nuclear program. *"Its first commercial nuclear power reactor began operating in mid-1966, and nuclear energy has been a national strategic priority since 1973. This came under review following the 2011 Fukushima accident but has been confirmed."* (World Nuclear Association, 2021c). As of March 2021, from a total of 33 operable nuclear reactors, only nine pressurized water reactors have received clearance from the Nuclear Regulation Authority (NRA) to restart and are operating (ibid.). Besides the NPPs, Japan possesses three research reactors (JRR-3, JRR-4 and NSRR) contributing to neutron beam and irradiation experiments, medical irradiation, activation analysis and nuclear fuel safety research (JAEA, 2021). According to US President Joe Biden back in 2016, Japan has both technology and materials to acquire nuclear weapons "virtually overnight" (GlobalSecurity.org, 2021). While having considered building a military nuclear program in the past, Japan is the only nation that has experienced the damages of an atomic attack and determined to never acquire nuclear weapons (ibid.).

"For many years Canada has been a leader in nuclear research and technology, exporting reactor systems developed in Canada as well as a high proportion of the world supply of radioisotopes used in medical diagnosis and cancer therapy." (World Nuclear Association, 2020). Besides its advanced nuclear research and technology program, 15% of Canada's electricity is provided through 19 operating nuclear power reactors (ibid.). On the military side, although the country has not signed or ratified the Treaty on the Prohibition of Nuclear Weapons, it supports nuclear weapons' potential use and retention (ICAN, 2021).

The third country on the list is probably one of the most debated subjects nowadays. On 23 February 2021, the IAEA confirmed in a monitoring report that Iran started to produce uranium metal and informed the Agency of its intention to enrich uranium at 60% (Masterson, 2021). Though the Islamic State always denied its political will to get nuclear weapons, an enrichment of uranium at 60% would enable Iran to easily transit to the 90% enriched uranium, necessary for military uses (Le Point International, 2021). Thus, enrichment at 60% would also mark a supplementary step in violating the nuclear deal of 2015, formally known as the Joint Comprehensive Plan of Action, to which Iran engaged in agreeing to dismantle much of its nuclear program (ibid.).

The fourth country, South-Korea, is known as one of the worldwide largest nuclear power producers. *"With 24 operating nuclear reactor units, South-Korea has the highest density of nuclear reactors (defined as the number of reactors per square mile) in the world."* (EIA, 2020). Though South Korea possesses both raw materials and nuclear technology to produce nuclear weapons, its security alliance with the United States made it unnecessary to build a nuclear weapon. However, after Kim Jong Un, actual president of North Korea, declared its ambition to promote national reunification through a strengthened military power at the beginning of 2021, South Korea has confirmed its consideration to develop a nuclear-powered submarine (Ryall, 2021).

"In the 1960s, fear that West Germany could acquire nuclear weapons, either alone or in cooperation with other European nations, was a key driving factor for negotiation of the Nuclear Non-Proliferation Treaty (NPT)" (Meier, 2020). Though Germany ranks nowadays among the powers that have the ability to build nuclear weapons, its history with nuclear energy during World War II led to its signature of the

Treaty on the Non-Proliferation of Nuclear Weapons, which prohibits the development of nuclear weapons for all non-nuclear-weapon States.

"Since abandoning its nuclear weapons program, South Africa has emerged as a champion of both global nuclear nonproliferation and equal access to peaceful nuclear energy." (NTI, 2015). Through its dual-use nuclear capabilities, South-Africa has become on the one hand a potential exporter of technology and know-how and on the other hand, a target for state and non-state actors aspiring after nuclear materials (ibid.).

The fore last State, Saudi-Arabia, does not possess any nuclear power plant yet. However, it is its intention to build a civilian nuclear program to provide its population with 15% electricity produced through nuclear energy by 2040 (World Nuclear Association, 2021d). Though Saudi Arabia possesses a basic civilian nuclear infrastructure, its substantial quantities of uranium in the soil would enable the State, if it was its political will, to develop a military nuclear program (Luck, 2020).

Finally, *"the Republic of Ghana has a long and complicated history with nuclear energy dating back to the country's immediate post-independence period."* (Bosman, 2020). Indeed, Ghana's will to use nuclear energy to produce electricity goes back to 1961, with the establishment of the Kwabenya reactor project, that remained uncompleted through consecutive *coups d'état*. However, the African state showed over the past its capacity to successfully operate a nuclear research reactor, the Ghana Research Reactor-1 (GHARR-1), which demonstrates Ghana's performance to use nuclear technology for peaceful use. *"If the road to nuclear energy in Ghana is anything to go by, it is a telling example to other African countries of the commitment necessary, as well as the importance of political stability and political will in implementing a project that holds vast potential for economic and human development."* (Bosman, 2020).

With all those elements, we can now introduce the relevant drivers for the Weaponization Score Index.

3.3.3 Drivers for the index

Table 6 Relevant drivers for the index.

Drivers
(1) Resources 1b. Human resource development
(2) Infrastructures 2a. Site and supporting facilities 2c. Nuclear Fuel Cycle 2e. IT
(3) Legal Aspects 3b. Legal Framework
(4) Technical Aspects 4a. Engineering & Design 4d. Delivery System 4e. Testing
(5) Political Aspects 5b. Historical perspective 5c. International cooperation 5d. Authoritarian system 5e. Nuclear threat from other country
(6) Economic resources 6a. Funding and financing
(7) Other supporting capabilities 7c. Communication Strategies 7e. Intelligence Communities 7f. Illicit trafficking & Shell companies

3.4 Weaponization Score Index

3.4.1 Developing the Weaponization Score Index

Now that the countries to categorize were introduced, as well as the relevant drivers to score them, the index can be established. To do this, two other columns are required, the first one including the availability of the country for the driver, scored (0) if no availability and (1) if the country possesses it. The second column will be the weighting factor, which will be attributed to each driver from (1) (very weak) (2) weak (3) moderate (4) strong to (5) very strong according how much the driver could contribute to the military transition of a civilian nuclear program's nation. Finally, each country will get a score that will enable to classify them in four different categories mentioned in the previous chapters. In order to get a clear overview of all countries' scores, the seven categories Resources, Infrastructures, Legal Aspects, Technical Aspects, Political Aspect, Economic resources and other supporting Capabilities have been left out of the index, to give space to the 16 drivers mentioned in 3.3.3.

3.4.2 The Weaponization Score Index

Table 7 The Weaponization Score Index.

Countries		**Pakistan (Reference)**		Japan		Canada		Iran		South-Korea		Germany		South-Africa		Saudi-Arabia		Ghana	
Drivers	**Weighting Factor**	Availability	Adjusted Score	Availability	Adjusted Score	Availability	Adjusted Score	Availability	Adjusted Score	Availability	Adjusted Score	Availability	Adjusted Score	Availability	Adjusted Score	Availability	Adjusted Score	Availability	Adjusted Score
Human resource development	**5**	1	5	1	5	1	5	1	5	1	5	1	5	1	5	1	5	0	0
Site and supporting facilities	**5**	1	5	1	5	1	5	1	5	1	5	1	5	1	5	0	0	1	5
Nuclear fuel cycle (Enrichment/ Reprocessing)	**5**	1	5	1	5	0	0	1	5	1	5	1	5	1	5	0	0	0	0
IT	**5**	1	5	1	5	1	5	1	5	1	5	1	5	1	5	1	5	0	0
Legal Framework	**2**	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Engineering & Design	**4**	1	4	1	4	1	4	1	4	1	4	1	4	1	4	0	0	0	0
Delivery System Capabilities	**4**	1	4	1	4	0	0	1	4	1	4	1	4	0	0	0	0	0	0
Testing Capabilities	**5**	1	5	1	5	0	0	1	5	1	5	1	5	1	5	0	0	0	0
Historical Perspective	**3**	1	3	1	3	0	0	1	3	1	3	1	3	1	3	0	0	0	0
Nuclear threat from other country	**3**	1	3	1	3	0	0	1	3	1	3	1	3	0	0	1	3	0	0
Authoritarian System	**3**	1	3	0	0	0	0	1	3	0	0	0	0	1	3	1	3	0	0
International Cooperation	**2**	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	0	0
Funding and financing	**4**	1	4	1	4	1	4	1	4	1	4	1	4	1	4	1	4	0	0
Communicati on Strategies	**1**	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1
Intelligence Communities	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Illicit Trafficking &	**2**	1	2	0	0	0	0	1	2	0	0	0	0	1	2	1	2	0	0

Shell Companies										
Total Score	**54**	**54**	**49**	**29**	**54**	**49**	**49**	**46**	**27**	**8**

1= very weak; 2= weak; 3= moderate; 4= strong; 5= very strong

3.4.3 Evaluation

Now that the Weaponization Score Index is established, one last step remains before bringing up possible solutions to thicken the line, which is to rank the eight countries mentioned above in four categories that are Dormant, Latent I and II and Limited Capabilities. As 54 is the highest score and 0 is the lowest score:

- Dormant includes all countries with a score from 40-54.
- Latent I and II include all countries with a score from 26-39. Since there are not enough countries to distinguish between Latent I which could be 26-32 and Latent II 33-39, the two categories are combined.
- Limited Capabilities includes all countries with a score 0-25.

Table 8 Countries categorized according to the Weaponization Score Index.

Categories	**Dormant**	**Latent I and II**	**Limited Capabilities**
Countries	Japan (49) Iran (54) South-Korea (49) Germany (49) South-Africa (46)	Canada (29) Saudi-Arabia (27)	Ghana (8)

As defined within 3.3, Dormant includes all countries which already possess most of the required capabilities to transit from peaceful use to manufacturing nuclear weapons, but which remain in a state of rest or inactivity. Within the table above, five countries are ranked into the Dormant category.

With a score of 49, Japan shows that it has the required capabilities to build a nuclear weapon within several months, if wanted. However, given Japan's history with nuclear weapons, it is very unlikely that the country will proceed to build a nuclear arsenal in the future, which puts Japan in a state of inactivity.

With a score of 54, Iran demonstrates that, as of today, it possesses the required capabilities to build a nuclear weapon and, according to American intelligence agencies' estimations, it could take two years for the country to build its first two bombs if wanted (Castelvecchi, 2020). However, Iran's nuclear activities being subject to reinforced investigations, controls and monitoring as well as subject to economic sanctions if it would violate the nuclear deal, this puts the country in a state of rest.

With a score of 49, South-Korea possesses one of the worldwide largest atomic energy industries and, with the growing threat coming from North Korea's nuclear arsenal, would have the required know-how and infrastructure to build nuclear weapons (Oswald, 2018). The only reason maintaining South-Korea in a state of inactivity is its alliance with the United-States, which operates as a nuclear shield. However, with the rising lack of confidence in the U.S nuclear "umbrella" among South Korea's conservative party, one estimates that the country would need two years to develop a nuclear weapon (Oswald, 2018).

With a score of 49, Germany actually possesses most of the required capabilities to develop a nuclear weapon in a short amount of time. However, in parallel to Japan, Germany's history with conducting a nuclear weapon program shows that it is very unlikely for the country to build a nuclear weapon in the future.

With a score of 46, South-Africa's history from acquiring nuclear weapons to abandoning it is the perfect illustration of the road to disarmament. South-Africa is actually the only nation worldwide to have built nuclear weapons and dismantled it afterwards. *"On March 24, 1993, in a speech to the South African parliament, President F. W. de Klerk announced publicly that his country had secretly built and dismantled six nuclear weapons."* (World101, 2021). Even though the country is now member of the NPT as a non-nuclear weapon State, South-Africa possesses the required capabilities, if wanted, to develop a nuclear weapon in a short amount of time.

As defined in 3.3, Latent I and II include all countries capable of acquiring or developing capabilities to build a nuclear weapon within a short amount of time but whose capabilities are not visible, obvious or active yet. Within the table above, two countries were ranked in this category.

With a score of 29, Canada was quoted by then-Prime Minister Pierre Trudeau in 1978 as *"the first country in the world with the capability to produce nuclear weapons that chose not to do so."* (Hopper, 2018). Indeed, Canada has the required capabilities such as natural uranium, the technical expertise and know-how to start developing a nuclear weapon if wanted. However, in doing so, Canada would violate a full range of international agreements, which would probably result in Canada's direct ejection from NATO (ibid.). Thus, Canada's delivery system is one issue which would delay its nuclear weapon's production, since the Canadian military does not possess any long-range missiles, dedicated bombers or nuclear weapons- capable submarines (ibid.).

With a score of 27, Saudi-Arabia does not possess the required infrastructures, engineering, design or the material yet to develop a nuclear weapon. However, its political will to develop one if regional rival Iran would acquire a nuclear weapon, according to Crown Prince Mohammed bin Salman back in 2018, shows the country's potential consideration to transit into bomb work (BBC, 2018). With the sufficient funding and financing assistance, Saudi-Arabia could definitely develop a nuclear weapon in a relative short amount of time.

As defined in 3.3, Limited Capabilities includes all countries with capabilities that are limited in a way that they don't have the potential to transit from peaceful use to manufacturing nuclear weapons in a short amount of time. Within the table above, one country was ranked in this category.

With a score of 8, Ghana does not possess any of the required capabilities such as human resource development, sufficient nuclear fuel cycle (enrichment and reprocessing), the IT infrastructure, technical expertise, engineering and design to develop a nuclear weapon. Besides, Ghana, as a developing country that heavily relies on hydro power, still needs to transit into nuclear power as an electricity production's substitute.

After having demonstrated that the Weaponization Score Index is a useful and relevant tool establishing transparency over countries with a civilian nuclear program and capabilities to transit into manufacturing nuclear weapons, one can confirm the hypothesis of this Master thesis. Countries with an advanced civilian nuclear program can easily transit into bomb work. Now, one question remains. How can the thin line between peaceful uses of nuclear technology and Weaponization be thickened, in order to ensure security worldwide?

4. Possible Solutions to thicken the line

Within the previous chapter, the Weaponization Score Index was established, enabling a clear overview of which capabilities countries require in order for them to transit from peaceful uses of nuclear technology to developing nuclear weapons. The index also revealed that, despite an existing reinforced legal framework such as international nonproliferation policies, safeguards inspections that monitor and control nuclear activities of member States, once a country possesses weapon-usable fissile materials, the sufficient technology and infrastructure, it is only a thin step away to transition. In order to find solutions to thicken the line leading to transition, specific drivers (*Human resource development, Site and supporting facilities, Nuclear fuel cycle, Legal framework*) of the Weaponization Score Index will be analyzed, that explicitly contribute to strengthen the civilian use of nuclear technologies and at the same time, enable a country to develop a nuclear weapon. Possible solutions will then be presented to reinforce their current legal security framework.

The first driver of the index, „Human resource development", includes all trainings and education programs required to start a civilian nuclear program. Within this process, scientists, engineers, students from different countries receive an education in nuclear science and engineering in specific fields such as fission, fusion, mechanical engineering, maintenance, design, safety in order for them to be highly qualified in nuclear technology matters. However, these training and education programs can be of dual use, since once an individual acquires the required knowledge to separate isotopes, design centrifuges, this knowledge can be misused. As mentioned in Chapter 3, the concrete example of Pakistan shows how easily misuse can occur, as the country took advantage of the American "Atoms for Peace' program in the 50s to send its students abroad, train them in nuclear technologies and bring them back to Pakistan to use their acquired knowledge to military ends (Britannica, 2021). Another illustration of nuclear technology knowledge misuse is the case of Pakistani scientist Abdul Qadeer Khan back in the 70s. After gaining all necessary access and knowledge to classified centrifuges designs within his time in the Netherlands, he returned to Pakistan and started working with the PAEC on building and operating a centrifuge plant in Kahuta (Britannica, 2021).

Now, what possible solution could be brought up to prevent highly qualified personal to misuse the acquired nuclear knowledge? This is not an easy task. According to the US Nuclear Engineering Enrollments & Degrees Survey Data of 2019, the undergraduate enrollment for nuclear engineering in the United States was of 1.740 students and the graduate enrollment was around 1.690 students in 2019 (see Figure 4) (ORISE, 2020).

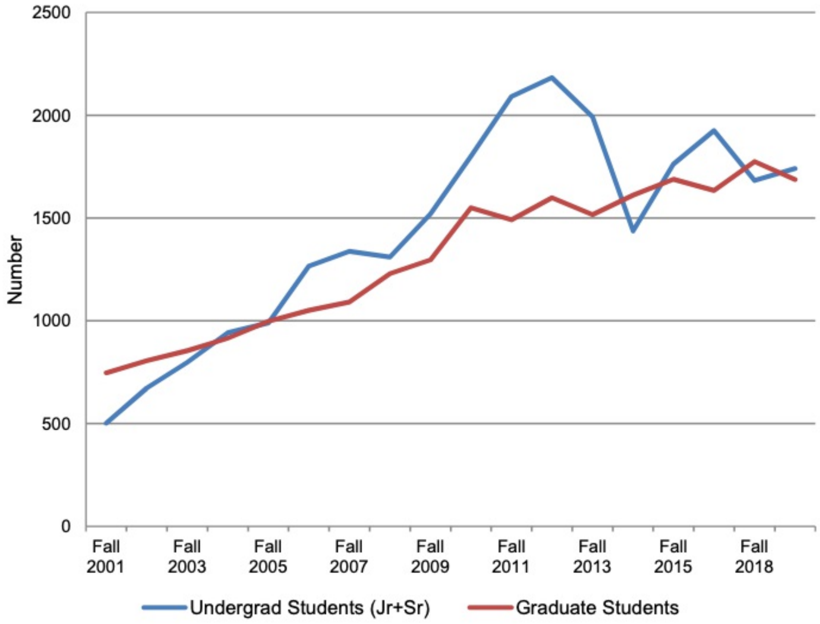

Figure 4 Nuclear Engineering Enrollment Trend 2001-2019 (ORISE, 2020).

However, nuclear engineering does not enfold all affiliated subjects of studies that are also of great importance to acquire nuclear technology knowledge.

With the help of the Weaponization Score Index, that enables to get a clear overview of where a country stands in regard to its potential transition, one existing solution is for national authorities to involve their respective intelligence communities in inspecting the background of students, experts, trainees coming from countries classified as “Dormant” or “Latent”.

Besides, the creation of an accessible register including all students, experts and trainees coming from the above-mentioned countries would establish transparence and allow responsible authorities to better keep track of their evolution.

Finally, at the beginning of their education/trainee program, each student, trainee, expert shall sign a legally-binding declaration stating that they won’t misuse the acquired scientific knowledge, otherwise they will be sanctioned.

The next drivers of the Index, “Site and supporting facilities” and “Nuclear Fuel Cycle” were combined since they include all physical, technological infrastructures required to support construction, design and development of a nuclear program as well as the steps to enrich uranium and produce the needed fuel for a nuclear reactor. Once a country possesses all required infrastructures and technologies, such as nuclear reactors, centrifuge plants, laboratories and highly developed electronic devices, it is one step closer to a nuclear weapons capability. Indeed, the acquirement by a country of an enrichment facility is an essential step to produce the required fuel to load a nuclear reactor but also makes it easier for a country to enrich uranium at a higher grade (Chyba et al., 2005). *“The predominant nuclear reactor in use worldwide today is the light water reactor (LWR), which requires low-enriched uranium as fuel.”* (Chyba et al., 2005).

Though, countries relying on light water reactors either need their own enrichment facilities or import sources of Low Enriched Uranium (LEU) from other countries. Since an enrichment plant producing LEU can be operated or reconfigured to produce Highly Enriched Uranium, which is weapon-grade uranium, countries possessing enrichment plants have the capability to produce nuclear weapons, if wanted (ibid.). Besides, the development of gas centrifuge technology, which is actually the most efficient enrichment method, poses a considerable threat to fighting nuclear proliferation (Chyba et al., 2005). The modularity and inherent energy efficiency of modern gas-centrifuge enrichment plants make it easier to construct small clandestine enrichment facilities (ibid.). To that effect, latent production of HEU in declared nuclear sites or production of undeclared LEU which could be enriched to HEU in smaller facilities remain possible (Chyba et al., 2005).

Beside enrichment facilities, another supporting infrastructure of a civilian nuclear program is the so-called spent-fuel reprocessing. *“Reprocessing is a series of chemical operations that separates plutonium and uranium from other nuclear waste contained in the used (or ‘spent’) fuel from nuclear power reactors.”* (UCSUSA, 2011).

To get a clear overview of the differences between solely enrichment and reprocessing, the two existing types of nuclear fuel cycle will be recalled, as mentioned in the previous chapters. The first nuclear fuel cycle or “open fuel cycle” (see Figure 5), conducted into an enrichment facility, is the one that does not enable spent fuel to be reprocessed. The spent fuel is kept in pending disposal as waste (IAEA, 2005).

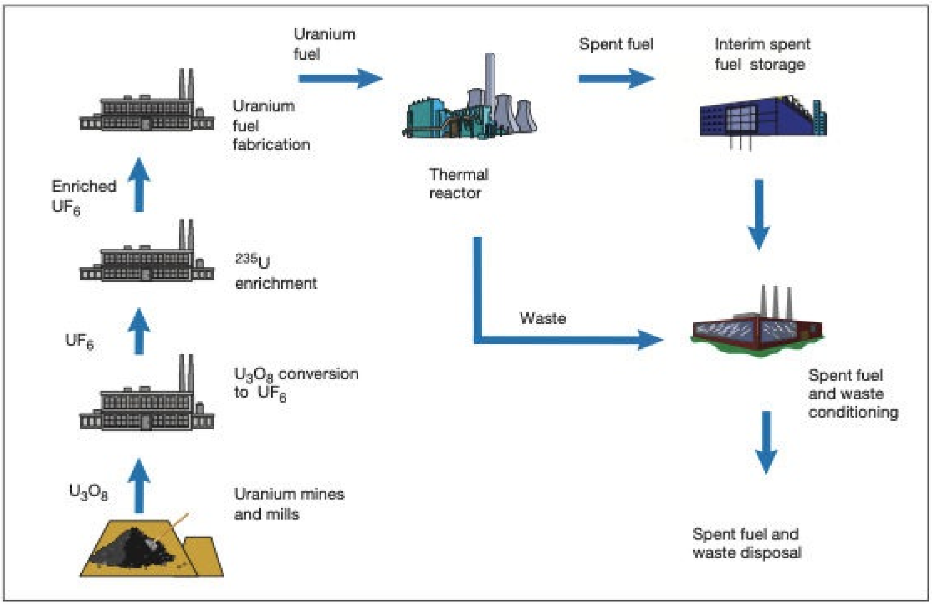

Figure 5 Open fuel cycle (IAEA, 2005).

The second fuel cycle or "closed fuel cycle" (see Figure 6), enables spent fuel to be reprocessed to separate residual uranium and plutonium, which allows the separated plutonium to be used to fill up reactors but also to produce nuclear weapons (UCSUSA, 2011).

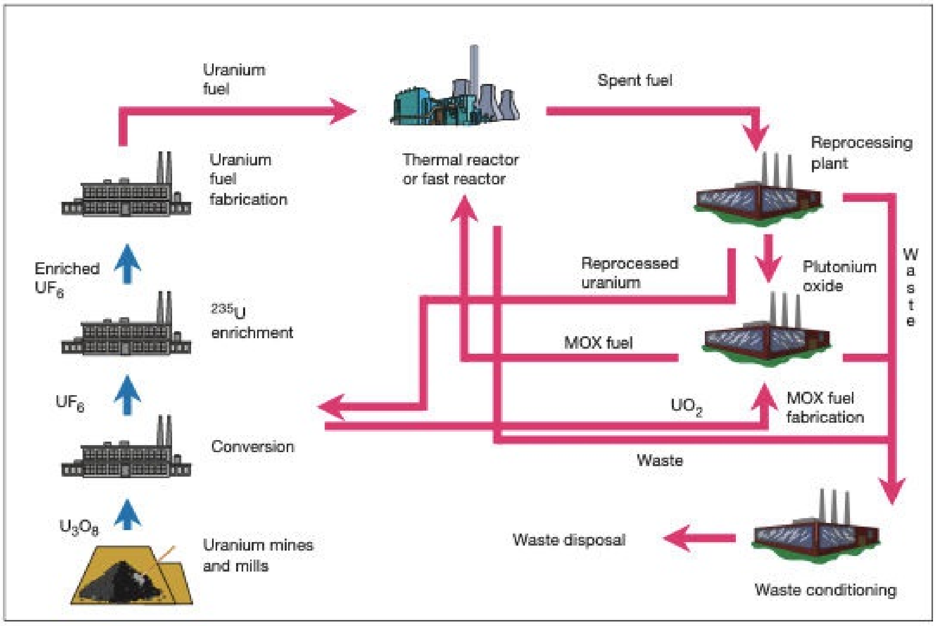

Figure 6 Closed fuel cycle (IAEA, 2005).

While advocates of spent fuel reprocessing believe this technology could moderate the nuclear waste-disposal problem and that *"advanced separation techniques could be developed to make reprocessing more proliferation resistant (and possibly also more economic)"* (Chyba et al., 2005), one has to point out that advanced separation techniques make it more difficult for IAEA inspectors to execute correct measurements and complicate safeguards (ibid.).

To summarize, enrichment facilities can be both operated to produce LEU but also reconfigured to produce HEU and reprocessing facilities can be operated to re-use separated plutonium in nuclear reactors, but also to produce nuclear weapons. To that affect, these facilities are of dual-use, which raise important challenges for the IAEA. Before introducing possible solutions to reinforce the security framework of these facilities and reducing their potential misuse, it seems relevant to briefly resume how the role of the IAEA regarding nuclear facilities' inspections evolved over the past decades.

The first enrichment facilities built to produce HEU for weapons were built in the nuclear-weapon states, that had the monopole for enrichment services' supply of LEU until the mid-1970s (Chyba et al., 2005). However, starting the mid-1970s, three non-nuclear weapon states, Japan, the Netherlands and Germany started building their own centrifuge enrichment plants (ibid.) To control their activities, the NPT required for these facilities to be put under IAEA safeguards. *"Because centrifuge facilities show a high degree of operational flexibility, the natural safeguards approach would be to require intrusive monitoring. However, centrifuge technology holders were concerned that their design secrets might be compromised if the inspectors had access to their machines."* (Chyba et al., 2005).

Resulting from these uncertainties, the question of which access could be granted to IAEA inspectors within the centrifuge facilities, more precisely to the cascade halls, remained debated (ibid.). Nowadays, IAEA inspectors have the capability to perform efficient "in-field" inspections, which cover a set of activities undertaken at nuclear sites or locations outside facilities to investigate if the declared nuclear material has been misused (IAEA, 2021h). To do that, they proceed to a variety of verification activities such as nuclear material accountancy, where they compare information concerning nuclear material accounting declared within the member State's submitted reports, books, records and what is actually at hand at the facility as declared (ibid.); Design information verification, where inspectors verify the design information provided by Member States to confirm that submitted information is accurate and that facilities haven't been misused (IAEA, 2021h.). Finally, through a range of measurement techniques such as weighing, item counting, non-destructive assay with radiation detectors, sample-taking, inspectors verify the inventory of nuclear material (ibid.). There is no doubt that the IAEA plays a primary role in monitoring and verifying nuclear activities in the Member States nowadays.

However, one actual major issue, because of globalization, is that nuclear technology has been made accessible, equipment becomes more and more sophisticated and the amount of nuclear material needed to be placed under IAEA auspices rises. This results in an overburdening of the IAEA inspectors, who do not have the financial means to pursue their inspections in due form (Amano, 2019).

To counter these challenges, several solutions are offered. The Additional Protocol, an important tool that confer the IAEA expanded rights of access to locations and information in the States should be ratified by all States possessing nuclear facilities (IAEA, 2021a).

The number of centrifuge plants built per country should be reduced, so that the risk of proliferation can be minimized, and IAEA inspectors get a clear overview of where nuclear facilities are situated to verify all of them in due form. More precisely, a system of centralized enrichment facilities such as the one existing in Europe should be elaborated so that potential risks of nuclear proliferation are reduced. This solution comes also in line with the strengthening of the next driver "Legal Framework". However, it is important to mention that the reduction of centrifuge plants' number should be executed so that countries still enjoy civilian benefits of nuclear technology (Chyba et al., 2005).

Construction of reprocessing plants, which are not a necessary requirement to develop a civilian nuclear program, shall be approved only if a country is in the capacity to demonstrate that reprocessing would benefit him economically.

Thus, on the basis of the Weaponization Score Index, all countries classified under "Dormant" or "Latent" should open their military sites to IAEA inspections, so that an effective monitoring can be executed, and misuse of nuclear technology can be prevented.

As nuclear technologies become more accessible in the context of globalization, one last additional solution, the technical road of proliferation resistance, *"defined as a nuclear energy system characteristic that impedes the diversion or undeclared production of nuclear material, or misuse of technology with the purpose of acquiring nuclear weapons or other nuclear explosive devices"*(Gabaraev et al., 2006) should be considered.

As mentioned in the previous chapters, certain processes and operations of nuclear energy such as enrichment, plutonium recovery from spent fuel, storage of recovered plutonium, are sensitive to nuclear weapon proliferation. The aim of proliferation resistance consists in designing technologies and using nuclear fuel which minimize potential nuclear risks. To that effect, nuclear fuel such as thorium and small modular reactors are concrete examples of proliferation resistance.

Finally, the driver "Legal Framework" includes all universal, regional and bilateral agreements required for a country to have community access to nuclear material, design, centrifuge equipment, technical expertise. While being essential to develop a civilian nuclear program, it also enables a country to gain access to all required materials and technologies to then pursue a military nuclear program. To understand which "leaks" the legal nuclear framework contains and bring up possible solutions to counter them, safeguards instruments such as the NPT and the NSG Guidelines will be examined.

As mentioned above, a country has to be member to several legal agreements to have access to the required materials, technologies and pursue a nuclear program. The first one is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) adopted in 1970.

Main objectives of the Treaty are to stop proliferation of nuclear weapons, provide security for non-nuclear weapon states that gave up the nuclear option, encourage international cooperation in using nuclear energy peacefully and finally, pursue negotiations towards nuclear disarmament (World Nuclear Association, 2021e).
Within this Treaty, Article IV states that all non-nuclear-weapon States party to the Treaty shall benefit from the full cooperation by other parties in developing civil uses of nuclear technology, as long as theses uses are placed under the auspices of international safeguards (Chyba et al., 2005). First weakness of this Treaty is that it does not stipulate that the use of fissile materials and acquired technologies while being party to the Treaty is only approved as long as the State remains party to the Treaty. A concrete example is the case of North-Korea, which, after joining the NPT in 1985, withdrew from it on 10 January 2003 (Chyba et.al, 2005).

"Subsequently it began to recover plutonium from spent fuel in a reprocessing plant and to produce more plutonium in its small power reactor.[...] The spent fuel, the reprocessing plant, and the reactor had all been under IAEA safeguards. It also appears

that North Korea was clandestinely acquiring uranium enrichment capacity while it was a party to the NPT." (Chyba et al., 2005).

Since its withdrawal, North Korea has developed its own nuclear weapons and conducted not less than six nuclear tests since 2006. Though heavy sanctions were imposed on North Korea for its illicit nuclear activity, the country has continued developing its delivery system and tested its first intercontinental ballistic system successfully in July 2017 (NTI, 2020). In September 2017, the country then conducted a test of a thermonuclear weapon (ibid.). Besides this first issue, another *"weakness of the NPT regime lay in the fact that no obvious diversion of material was involved."* (World Nuclear Association, 2021e). After North-Korea's example, Iran is the country posing an intractable situation for the IAEA nowadays (ibid.).

One other important instrument of the nuclear legal framework are the NSG Guidelines, published in 1978 by the IAEA "*as an Information Circular INFCIRC/254 (subsequently amended) to apply to nuclear transfers to non-nuclear weapons states for peaceful purposes to help ensure that such transfers would not be diverted to unsafeguarded nuclear fuel cycle or nuclear explosive activities."* (NSG, 2018). Aim of the Guidelines is to ensure that nuclear trade only contributes to develop peaceful uses of nuclear technology and is not misused to develop nuclear weapons or other nuclear explosive devices (NSG, 2018). Since those Guidelines are on a voluntary basis and not legally-binding, it remains under national jurisdiction for Member States to apply them or not, which leads to significant gaps. As mentioned in Chapter 2, nuclear export control policies cannot address nor solve all proliferations issues since States such as France with Israel or China with Pakistan deliberately defied the nonproliferation regime by supporting other States in acquiring nuclear weapons materials (McGoldrick, 2013).
To sum it up, the main issue of the nuclear legal framework is its limitation in scope of and adherence to legally binding obligations.

To widen and reinforce its legal scope, several solutions are possible. The first solution would be for all parties to the NPT to sign a legally-binding declaration that, if they tended to or withdraw from the NPT, they would also renounce to their rights of using nuclear materials and facilities acquired within their time as a State party to the NPT.

Secondly, as the Security Council under the UN Charter is empowered to take actions against potential threats to international peace and security, it should reinforce the first brought up solution of a legally-binding declaration, as the withdrawal of a country from the NPT without any safeguards obligations would constitute a threat to peace under Chapter VII of the UN Charter (Chyba et al., 2005). Thus, the Security Council should establish automatic sanctions for every country that violates its obligations.

Finally, in order to prevent illicit trafficking and international assistance of weapon-nuclear states to non-weapon-nuclear states in supplying nuclear related knowledge, material, technical expertise and design parts (China and Pakistan example), the NSG Guidelines should become either legally-binding for all Member States or amended so that at least bilateral inspection rights are established for the IAEA inspectors to control exported enriched uranium and other nuclear items (Chyba et al., 2005).

To get a clear overview of which solutions have been brought up within this chapter to dampen and prevent nuclear proliferation, the table below (see Table 9) has been dressed to sum up all relevant issues and their respective solutions.

Table 9 Possible Solutions to Thicken the Line

Drivers	Issues	Existing Solutions	Additional Solutions
Human Resource Development	Acquired education and knowledge to improve and develop peaceful uses of nuclear technologies can be misused.	Specific background check by Intelligence Communities of students, experts, trainees coming from countries defined as "Dormant or "Latent".	Accessible register for authorities including all students, trainees and experts coming from Dormant and Latent Countries to establish transparence and keep better track of their evolution. Legally-binding declaration signed by each student, trainee, expert at the beginning of their education/trainee program that they won't misuse the acquired scientific knowledge, otherwise sanction.

Site and supporting facilities/ Nuclear Fuel Cycle	Enrichment facilities acquired for civilian nuclear program can be reconfigured to produce HEU/ Reprocessing facilities used either to recycle spent fuel but also to produce nuclear weapons. In context of globalization, nuclear material, technology easily available/accessible and hard for IAEA inspectors to follow because of lack of budget.	Additional Protocol should be ratified by all Member States to simplify and strengthen IAEA inspections rights. Limitation of number of enrichment plants to get better overview of where nuclear facilities are and to enable safeguards inspections in due form. Reprocessing plants construction granted only if State has a valuable economic argument.	Opening of all military sites of Dormant and Latent countries to IAEA inspections to better monitor and prevent misuse of nuclear technology. System of centralized enrichment facilities to reduce potential risks of nuclear proliferation. Proliferation resistance through new designs (SMR) and other nuclear fuel such as thorium.
Legal Framework	NPT regime does not stipulate that countries withdrawing from Treaty still have Safeguards obligations. Security Council's lack of action against potential threats to international peace and security. NSG Guidelines are on voluntary basis and dependent on national jurisdiction.	NSG Guidelines legally-binding to all Member States or amended to at least implement bilateral inspection rights for IAEA inspectors to control exported uranium and other nuclear items and prevent illicit trafficking of nuclear related knowledge, technical expertise and design parts.	All parties to the NPT sign legally-binding declaration to renounce to their rights of using acquired nuclear materials, facilities if withdrawal from NPT. Security Council should reinforce the solution of legally-binding declaration mentioned above, as potential withdrawal from NPT represents threat to international peace and security and put automatic sanctions for every country that violates their obligation.

5. Conclusion

In a context of worldwide energy transition, the number of countries considering adding nuclear energy as a valuable low-carbon electricity source to their energy mix is rising and the required components to develop a successful civilian nuclear program such as scientific knowledge and modern technologies are made accessible through sophisticated means of communications. This direct consequence of globalization's impact led to an increasing risk of potential nuclear proliferation, making the work of responsible organs such as the IAEA in monitoring and regulating nuclear activities difficult.

Central issue of this thesis was based on the hypothesis that a country possessing an advanced civilian nuclear program can easily transit into manufacturing nuclear weapons, if wanted. To investigate and verify the validity of this affirmation, the first step of this paper was to specify the legal framework in which nuclear technology operates and accentuate the weaknesses of its legal mechanisms. First results showed that, despite an established reinforced legal framework operating on the basis of several instruments under the auspices of the IAEA and the Security Council, such as the Non-Proliferation treaty or the NSG Guidelines, limitations regarding the enforcement of this legal framework were established. While the concrete example of North-Korea's nuclear weapons acquirement pointed out the weaknesses of the NPT regime, Chinese assistance to Pakistan in the 70s with the supply of nuclear material, technical expertise, centrifuge equipment and design shows the gaps contained in the NSG Guidelines. However, strengthened cooperation between Member States and the establishment of Additional Protocol allocates IAEA inspectors expanded rights to verify nuclear facilities and slow potential misuses of acquired nuclear technology down.

After having set the legal framework of nuclear technology as well as its limitations, the second step of this thesis was to determine components which, essential for the successful development of a civilian nuclear program, could also contribute to the potential development of nuclear weapons. To do that, three tables were established, including each the capabilities for peaceful uses of nuclear technology, the capabilities for military use of nuclear technology and finally the capabilities required for dual use. From this tables, a list of 16 relevant drivers was established, including *Human resource development, Site and supporting facilities, Nuclear fuel cycle, IT, Legal framework, Engineering & Design, Delivery system capabilities, Testing, Historical perspective, Nuclear threat from other country, Authoritarian system, International cooperation, Funding and financing, Communication strategies and finally, Illicit trafficking and Shell companies*. To clarify and support the choice of these selected drivers, Pakistan's technical road transition from peaceful uses of nuclear technology to manufacturing nuclear weapons was given as reference.

To recall, the objective of this thesis was to verify the hypothesis that a country with an advanced civilian nuclear program can easily transit into bomb work (Broad, 2007). For this purpose, nine countries that are *Pakistan* (reference country), *Japan, Canada, Iran, South Korea, Germany, South Africa, Saudi Arabia and Ghana* were strategically selected, with regards to their civilian nuclear program position. On the basis of the nine chosen countries and 16 drivers mentioned above, the Weaponization Score Index was created, in order to better understand which components are relevant for a country's potential transition and put transparence on how long countries that possess most of these components, need to operate this transition. To this effect, the selected drivers were attributed weighting factors from 1 to 5, depending on their very weak (1) or very strong (5) contribution to a country's potential transition. For example, the driver *Nuclear fuel cycle* got a weighting factor of 5, since a country needs either enrichment facilities or reprocessing facilities to produce nuclear-weapon grade uranium/plutonium. In turn, the driver *Intelligence communities* got a weighting factor of 1 since it can help countries monitor other countries' nuclear activities and prevent from potential misuse but do not contribute strongly to a respective country's potential transition.

After having applied weighting factors to each driver in the Weaponization Score Index, the highest score a country could reach was 54 and the lowest score 0. Pakistan, the reference country, reached 54.

Depending on their final scores, countries were then ranked into one of four categories that are *Dormant, Latent I and II and Limited Capabilities.*

Dormant includes all countries with a score between 40-54, which means that they already possess the required capabilities to transit from peaceful use to manufacturing nuclear weapons but, regarding different reasons, remain in a state of rest or inactivity.

Latent I and II includes all countries with a score between 26-39, meaning that they are capable of acquiring or developing required capabilities to build nuclear weapons within a short amount of time but whose capabilities are not obvious, visible or active yet.

Finally, Limited Capabilities includes all countries with a score between 0-25, with capabilities that are limited so they don't have the potential to transit from peaceful use of nuclear technology to manufacturing nuclear weapons in a short amount of time.
Japan (49), Iran (54), South-Korea (49), Germany (49) and South-Africa (46) were ranked into Dormant. Canada (29) and Saudi-Arabia (27) were ranked into Latent I and II.
Ghana, with a score of 8, was ranked into Limited Capabilities.

Aim of the Weaponization Score Index, as demonstrated within this thesis, is to enable a fast and efficient ranking of all countries that consider developing a nuclear program; already started planning one or have a stable civilian nuclear program. Furthermore, it establishes transparence on what capabilities, required for dual-use of nuclear technology a country already possesses and allows to keep a clear overview of those countries' progressing.

Final step of this paper was, after having confirmed how quick a country with the required capabilities can transit into bomb work, to bring possible solutions to thicken the line between peaceful uses of nuclear technology and weaponization. From all drivers selected for the Weaponization Score Index's elaboration, four drivers, *Human resource development, Sites and supporting facilities, Nuclear fuel cycle and Legal framework* were of particular importance to either facilitate a country's transition or prevent a country from misusing its acquired nuclear technology.

Human resource development, essential to develop a successful civilian nuclear program, includes all nuclear related training and educations programs required to train highly-qualified personal in nuclear technology matters. However, one main issue of this component is that scientific knowledge, once acquired, can be misused to military ends, as it was proven with Pakistan's case. To secure and reinforce the framework in which scientific knowledge is passed through and prevent from potential misuse, a possible solution would be for Intelligence communities of a country that welcomes foreign students, experts, trainees within a specific training/education program, to execute a specific background check of individuals coming from countries classified as Dormant or Latent, according to the Weaponization Score Index. Besides, the creation of an accessible register including all students, experts and trainees coming from the above-mentioned countries would establish transparence and enable responsible authorities to better keep track of their evolution. In addition, all trainees, students, experts shall sign a legally-binding declaration at the beginning of their nuclear related education/trainee program, stating that they won't misuse the acquired scientific knowledge, otherwise they will be sanctioned.

The second driver, Sites and supporting facilities as well as Nuclear fuel cycle proved to be essential requirements for a country to develop a successful civilian nuclear program. However, main issues of these components are that, despite reinforced Safeguards inspections of nuclear facilities, the eventuality for a country to reconfigure enrichment facilities in order to produce HEU or misuse reprocessing facilities to acquire plutonium remain existent. Besides, in a context of globalization, access to nuclear material and technology is made available, which overburdens the IAEA inspectors and increases potential nuclear proliferation. To dampen the potential risk of a country accessing required material to produce nuclear weapons, the Additional Protocol, established to allocate IAEA inspectors expanded rights of access to locations and information in the member States, should be ratified by all states possessing nuclear facilities.

On the basis of the Weaponization Sore Index, all countries classified under "Dormant" or "Latent" should open their military facilities to IAEA inspections in order to prevent misuses of nuclear technology. Furthermore, the number of enrichment plants per country should be limited by means of a centralized enrichment facilities' system, so that IAEA inspectors get a better overview of where facilities are situated and can complete their inspections in due form; The construction of reprocessing plants should only be granted if the country is in capacity to demonstrate that reprocessing would benefit him economically. Finally, the road of proliferation resistance as a system designing technologies (SMR) and using other nuclear fuel (thorium) which minimize potential proliferation risks, should be considered.

One last aspect which was deepened within the second chapter of this Thesis is the nuclear legal framework's scope. As stated previously, to have community access to nuclear material, technical expertise, design and to develop a successful civilian nuclear power program, countries have to be members of several legal agreements. Two main elements of the nuclear legal framework are the Non-Proliferation Treaty, which confers the right to non-nuclear-weapon states parties to access nuclear material, knowledge and expertise in exchange of their disclaimer to acquire nuclear weapons and the NSG Guidelines, whose aim is to ensure that nuclear trade only contributes to develop peaceful uses of nuclear technology. However, issues such as the Security Council's lack of action against potential threats to international security and peace, the non-legally binding aspect of the NSG Guidelines and the limitation of the NPT regime in regard to countries that withdraw from the Treaty to develop their own military nuclear program (North-Korea) were raised. To reinforce the legal framework in which nuclear technology is set, all parties to the NPT should sign a legally-binding declaration, which stipulates that, if they tended to withdraw from the Treaty, they would renounce to their rights of using acquired nuclear materials, facilities while being parties to the Treaty. Concerning the Security Council's actions, it should not only reinforce the solution of the legally-binding declaration mentioned above, as the potential withdrawal of countries from the NPT represents a threat to international peace and security, but also establish automatic sanctions for each country violating its obligations.

Finally, the NSG Guidelines should be made legally-binding to all Member States or amended to not only implement bilateral inspection rights for IAEA inspectors to control exported uranium and other nuclear items, but also to prevent illicit trafficking of nuclear related equipment, technical expertise and knowledge.

Though the mentioned solutions are more recommendations, they should, nevertheless, be taken into serious consideration, since the actual context of globalization and energy transition enables countries to gain access to all required components to develop their own nuclear program.

In the future, the Weaponization Score Index, further elaborated and transformed in a computerized mathematical model, could be an efficient tool in facilitating institutions' work to monitor the technical evolutions of a given country.

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