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RESEARCH OF NUCLEAR WASTE MANAGEMENT AND TECHNOECONOMICAL ANALYSES

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Furkan DEMİRKOPARAN

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M.Sc. THESIS EXAMINATION RESULT FORM

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RESEARCH OF NUCLEAR WASTE MANAGEMENT AND TECHNOECONOMICAL ANALYSES

ABSTRACT

In short, nuclear energy is the energy generated from the large amount of heat generated by the disintegration of the atom. Fission and fusion reactions when obtaining nuclear energy appear as two types of reactions. Turkey's increasing nuclear energy technology, in this field is trying to catch by following the more developed countries. Turkey, which does not have any energy-generating nuclear reactors other than TR-1 and TR-2 research reactors for nuclear energy technology, has signed protocols with Russia and Japan to commission Akkuyu with the Russians. The TR-2 reactor, the last working reactor in Turkey, was operated in 2009 for purely educational purposes with special permission, and there was not even any contamination in the area.

Of course, nuclear waste will occur after the fuel rods to be used during the acquisition of nuclear energy. Waste management and disposal is another important issue in nuclear power plants. Because the recycling of nuclear waste is very important for preventing environmental lysis such as global warming.

After energy is produced in nuclear power plants, two types of waste occur. These are low-level waste sourcing and high-level waste. Low-level waste can be easily processed and disposed. High-activity fuels are used fuel rods from the reactor core. These used fuel rods are stored in pools near the reactor. These used fuels contain 97% of the materials of value in terms of nuclear fuel. Two methods are used in the world: open and closed cycles for used nuclear fuels. In the open cycle, where used fuels are considered waste, the process of burying the waste directly underground is applied. The method by which used fuels are reprocessed is a closed loop method. Radioactive useful materials in used fuel are re-inserted into the nuclear cycle, while the remaining waste is glazed and buried in the ground. The most preferred method in the world is open cycle method. This is because this method is much more economical than the closed cycle method.

In this study, general and up-to-date information on nuclear power, radioactivity and nuclear power plants in Turkey and around the world will be given. Nuclear studies in Turkey will be examined in a comparative manner; fuel types, fuel reserves and availability of these reserves, costs and recommendations for storage or disposal of nuclear waste in more appropriate ways

Keywords: Nuclear, Disposal, Radioactivity, Energy, Storage, Uranium, Thorium

NÜKLEER ATIK YÖNETİMİNİN ARAŞTIRILMASI VE TEKNOEKONOMİK ANALİZLERİ

ÖZ

Kısaca nükleer enerji, atomun parçalanması sonucu ortaya çıkan çok miktarda ısıdan elde edilen enerjidir. Nükleer enerji elde ederken fisyon ve füzyon reaksiyonları, iki tip reaksiyon türü olarak karşımıza çıkmaktadır. Türkiye'de günden güne yükselen nükleer enerji teknolojisini, bu alanda daha gelişmiş olan ülkeleri takip ederek yakalamaya çalışmaktadır. Nükleer enerji teknolojisi için TR-1 ve TR-2 araştırma reaktörleri dışında herhangi enerji üreten nükleer reaktör bulundurmayan Türkiye, bu alanda çalışmalarına Rusya ve Japonya ile protokoller imzalayarak Akkuyu Nükleer A.Ş şirketini Ruslarla beraber devreye sokmuştur. Türkiye'de en son çalışan reaktör olan TR-2 reaktörü, özel bir izinle tamamen eğitim amaçlı 2009 yılında çalıştırılmış, alanda herhangi bir kontaminasyon dahi kalmamıştır.

Nükleer enerji elde edinmesi esnasında kullanılacak yakıt çubuklarının ardından pek tabii ki nükleer atıklar meydana gelecektir. Atık yönetimi ve bertarafı da nükleer santrallerde bir diğer önemli konudur. Zira nükleer atıkların geri dönüşümü, küresel ısınma gibi çevreye zarar verecek durumların önüne geçilmesi için oldukça önemlidir.

Nükleer santrallerde enerji üretildikten sonra iki tip atık meydana gelmektedir. Bunlar düşük seviyeli atıklar ve yüksek seviyeli atıklar olarak karşımıza çıkmaktadır. Düşük seviyeli atıklar kolaylıkla işlenebilir ve imha edilebilir. Yüksek aktiviteli yakıtlar ise reaktör çekirdeğinden çıkan kullanılmış yakıt çubuklarıdır. Bu kullanılmış yakıt çubukları reaktör yakınındaki havuzlarda depolanır. Bu kullanılmış yakıtlar %97 oranında nükleer yakıt açısından değerli maddeler ihtiva etmektedir. Dünyada kullanılmış nükleer yakıtlar için açık ve kapalı çevrim olmak üzere iki metot kullanılır. Kullanılmış yakıtların atık olarak kabul edildiği açık çevrimde, atıklara direk yer altına gömülme işlemi uygulanır. Kullanılmış yakıtların yeniden işleme sokulduğu metot ise kapalı çevrim metodudur. Kullanılmış yakıt içerisindeki radyoaktif yararlı maddeler tekrardan santral çevrimine sokulur, kalan atıklar ise camlaştırılarak toprağa gömülür. Dünyada en çok tercih edilen metot açık çevrim metodudur. Bunun nedeni, bu metodun kapalı çevrim metoduna oranla çok daha ekonomik olmasıdır.

Bu çalışmada, Türkiye'deki ve dünyadaki nükleer enerji, radyoaktivite ve nükleer santrallerle ilgili genel ve güncel bilgiler verilecektir. Türkiye'deki nükleer çalışmalar karşılaştırılmalı bir şekilde incelenecek; yakıt türleri, yakıt rezervleri ve bu rezervlerin kullanılabilirliği, maliyetleri ve nükleer atıkların daha uygun yöntemlerle depolanmasına ya da bertaraf edilmesine dair öneriler sunulacaktır.

Anahtar Kelimeler: Nükleer, Atık, Radyoaktivite, Enerji, Depolama, Uranyum, Toryum

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NOMENCLATURE

β: Beta rays.

k: the ratio of the number of neutrons entering the reaction.

A: number of nucleons

Z: number of charges

E_T: Amount of total energy, J

m: mass, g

c: speed of light, m/s

Q: necessary energy emitted or cause a reaction by a nuclear reaction,W

ρ: linear momentum, kg.m/sec

υ: speed, m/sec

Fc: Coulomb's force, N

q: amount of the charge

Ɛ: permittivity of free space

Ŋ: amount of particle per cubic centimeter

ȷ: the number current intensity per unit time passing any unit is perpendicular to the flow direction

N_O: total target area

R: the collision's number

Σ_t: Macroscopic total cross-section

O_{a0}: The cross-section at υ_0, generally assumpted as 2200m/s

Ld.: diffusion distance, mm

Ly.: deceleration distance, mm

M: the distance the neutron folds before cooling, mm

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CHAPTER 1 INTRODUCTION

Turkey has a history of about 50 years of efforts to build a nuclear power plant, but the legal framework was created in 2007 with the adoption of law 5710. In this sense, the type, model and fuel to be used is of serious importance. Turkey, which has no experience in nuclear power plant technology yet, must follow more developed countries in this field. As a matter of fact, the plant to be established by ROSATOM, a Russian company, will be Turkey's first nuclear power plant.

Nuclear waste and their storage are another important issue in nuclear power plants. Low and high levels of waste are emerging from nuclear power plants. Low-level waste is easily processed and destroyed. High-adliable wastes are used fuel bundles that come out of the reactor protection. Used fuels are stored in pools near the reactor and left to cool down. It contains 97% of nuclear fuel-valued substances in used fuels. Two methods are used for used nuclear fuels, open and closed cycle slots around the world. Used in open cycle, lit waste is accepted and buried underground. In the closed cycle, these burnt fuels are reprocessed and valuable materials are separated. The remaining waste is glassed and then buried underground. Because it is economical, the most open cycle is used in the world. Used fuels can be kept in storage pools for many years. The fuel cycle, which is most suitable for Turkey, has been discussed in thesis.

In this thesis study, general and up-to-date information about the energy situation in Turkey and the world and nuclear power plants were given, and nuclear studies in Turkey were examined in a comparative manner; recommendations for the availability, cost and storage of waste in more appropriate ways are presented.

Nuclear energy occurs the nuclear reactions between atoms. As a result of nuclear reactions, a large amount of heat energy is generated according to the chemical reactions. As a result of combustion of 1 kg uranium, 0.87g uranium is converted into energy. This mass releases approximately 7.8×10^{13} J/kg of energy. This seems relatively small. However, the energy generated by the burning of fossil fuels by 1 kg is 5×10^{7} J/kg. In other words, nuclear fuel provides 1.5×10^{6} times more energy than fossil fuels [1].

In today's nuclear reactors, uranium is used as fuel. Although plutonium-blended fuels are used, this fuel is also caused by the reaction of the U-238 with neutrons. So, plutonium is an artificially produced element that is not found in nature. The much-talked-about Thorium mine is not yet used as commercial fuel. Thorium will need a little more time and advanced technology to be used as fuel. India and South Africa continue to work on this issue.

The uranium used in nuclear reactors releases energy as a result of fission. Fission means core division. Uranium 235 isotope is divided when it swallows neutrons. For this reason, the U-238, which cannot be divided by slow neutrons, is enriched with U-235 to create fuel. Otherwise, uranium is not used as fuel. 99.7% of the uranium found in nature consists of U-238 isotope and 0.7% isotope. In light aqueous reactors, uranium must be enriched by 3-5% in terms of U-235 in order to be used as fuel.

An *atomic particle* is the smallest building block of matter. the atom is composed of nucleus and electrons on the peripheral orbit. Inside the nucleus, there are uncharged neutrons and positively charged protons. Around the nucleus, negatively charged electrons are light, protons and neutrons are heavier than electrons. Protons are 1836 times heavier than electrons, and neutrons are 1839 times heavier than electrons. A typical atomic model is presented Figure 1.1

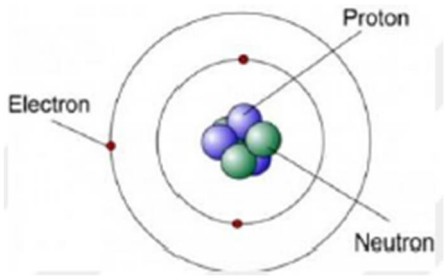

Figure 1.1 A typical atomic model.

109 elements found in nature are shown according to proton numbers in a system called periodic table. The uranium element, with a proton number of 92, is one of the heaviest elements in nature. The weight of an atom is the sum of the number of protons and neutrons in that atom. For example, the U-238 representation means it has 92 protons and 146 neutrons.

Atoms with the same atomic number but different mass number are called *isotope atoms.* The chemical properties of isotope atoms are identical. But their physical properties are different. Atoms are stable by a certain number of neutrons and protons. If neutrons are above or below a certain number; the atom is become unstable.

Unstable atoms become stable by throwing out particles or energy. Unstable atoms are called *beam-enabled* or *radioactive* atoms [2].

Uranium and Hydrogen isotopes are the most important isotopes in nuclear energy. Uranium has isotopes with weight ratios of 233, 235, 237, 238. The atomic number of each element is Z=92 and has the same chemical properties. But their core composition is different. Isotopes are shown according to their atomic weights. Uranium U-235 with atomic weight of 235. Hydrogen has three different isotopes: H-1, H-2 and H-3. These are 1H (Hydrogen), 2H (Deuterium) and 3H (Tritium), respectively. All three isotopes have one proton. The hydrogen in the water we use in h-1-day life is the atom used in heavy water used in H-2 CANDU reactors, and H-3 is the more unstable tritium atom. In CANDU type reactors, heavy water (^2H_2O) is used instead of normal water (H_2O) used in other reactors [3].

Fertile substances are substances that cannot be spontaneously disintegrated by thermal neutrons. However, these substances can be converted into divisible matter by neutron absorption and subsequent core transformations [4].

Isotopes, which can be easily divided when bombarded with slow neutrons, are called fisil isotopes.

The only *fissile* isotope found in nature is u-235. Other fissile isotopes are U-233, Pu-239 and Pu-241 isotopes, but they are not found in nature. They're caused by nuclear reactions. For example, the Th-232 needs to react for the formation of the U-233.

Thorium alone cannot be treated as a nuclear fuel. Thorium can only act as a fuel by forming the U-233 in a reaction. This is because thorium is a fertile isotope. The equation of how the U-233 isotope is obtained from thorium is also shown in Figure 1.2.

$$^{232}_{90}\mathrm{Th} + \mathrm{n} \rightarrow {}^{233}_{90}\mathrm{Th} \xrightarrow{\beta^-} {}^{233}_{91}\mathrm{Pa} \xrightarrow{\beta^-} {}^{233}_{92}\mathrm{U} \quad (1.1)$$

Figure 1.2 Obtaining U-233 isotope from Th [5].

The type of energy emitted by energy packets called waves, particles, or photons is called radiation. *Radiation* is transported by rapid particles and electromagnetic waveform to transition to stable structure of natural or artificial radioactive nuclei [6]. A radioactive material emits energy and particles too small to be seen with the eye. In 1896, Henry Becquerel discovered that uranium salts emitted X-ray-like rays, while the Curie family conducted some work on the radioactivity of uranium [7].

Examples of electromagnetic radiation are X and gamma rays. The energies and frequencies of these rays are higher than visible light. The measure of whether an element is stable or not is the radioactivity of that element. Unstable radioactive atoms tend to become stable by throwing energy and particles under the laws of nature [8].

When talking about radiation, three basic energy emissions, basically alpha, beta and gamma, should also be mentioned. Alpha radiation is a weak radioactive radiation. Alpha radiation, composed of + charged particles, can be stopped even by a piece of paper. Beta radiation is made up of electrons. A thin aluminum sheet is enough to stop these electrons. Gamma radiation is composed of energy waves moving at the speed of light [9].

Half-life is the time it takes for half the atoms that make up that radioactive material to become another element. The half-life of known radioactive materials can be as short as a millionth of a second, or as long as millions of years. Radioactive after a half-life the amount of matter is halved, the second half of life is passed, a quarter of the initial amount is reached, and after three half-lifetimes have passed, only 1/8 of the initial amount remains, and the process continues in this way [10].

Some radioactive isotopes and their half-life are given as Table 1.1 below.

Isotope	Half-Life
Neutron	614 s
Tritium (H-3)	12.33 y
Carbon-14	5715 y
Nitrogen-16	7.13 s
Sodium-24	14.96 h
Phosphorus-32	14.28 d
Potassium-40	1.25×10^9 y
Argon-41	1.82 h
Cobalt-60	5.271 y
Krypton-85	10.73 y
Strontium-90	29.1 y
Technetium-99m	6.01 h
Iodine-129	1.7×10^7 y
Iodine-131	8.021 d
Xenon-135	9.10 h
Cesium-137	30.2 y
Radon-222	3.823 d
Radium-226	1599 y
Uranium-235	7.04×10^8 y
Uranium-238	4.47×10^9 y
Plutonium-239	2.410×10^4 y

Table 1.1 Some radioactive isotopes and their half-life [11].

People are exposed to radiation every day due to cosmic rays from the atmosphere, concrete structures, air and food, and technological instruments. There are some units which are used for *radiation dose*. These are given below with Table 1.2.

TERM	UNIT		CONVERTION
	Classic System	SI Unit	
ACTIVITY	Curie, Ci	Becquerel, Bq	1Ci= 3,7 x 10^7 Bq 1Ci= 37GBq
TELEPORTATION LEVEL	Röntgen, R	Coulomb/kilogram C/kg	1 C/kg= 3876R
ABSORBED DOZE	Radiation Absorbed Dose, rad	Gray,Gr	1Gr=100rad
DOZE EQUIVALENT	Röntgen Equivalent Man, rem	Sievert, Sv	1Sv=100rem

Table 1.2 Radiation units [12].

The effective dose for those working in nuclear power plants or radiology departments of hospitals cannot exceed 20 mSv for five consecutive years and 50 mSv in any given year. The annual equivalent dose limit for the hand, foot or skin is 500 mSv. This ratio is 150 mSv for the eye lens. The equivalent dose of 1 cm square area exposed to the highest radiation dose for the skin is considered to be the average skin equivalent dose regardless of the dose taken by other areas [13].

1.1 Nuclear Energy

When nuclear energy is called, Uranium is the most important element fort his topic. Uranium is explored in 1789 and after this exploration, in 1934, the atom splitted. After the atomic fragmentation, it was noticed that a large energy was noticed. Nuclear energy is an energy that occurs after fragmentation of the atom and consequently a large amount of heat energy is revealed. There are two types of nuclear reaction which are fission and fusion reactions.

The *fission* reaction is the reaction of a neutron to be absorbed by hitting the nucleus of a heavy element atom and consequently, the bombarded atom becomes unstable and divides into at least two smaller different cores. Otto Hann and Fritz Strassmann first saw the fission reaction by bombing a neutron with the U-235 atom in December 17 ,1939 [14].

In Figure 1.3 an example of fission reaction is shown.

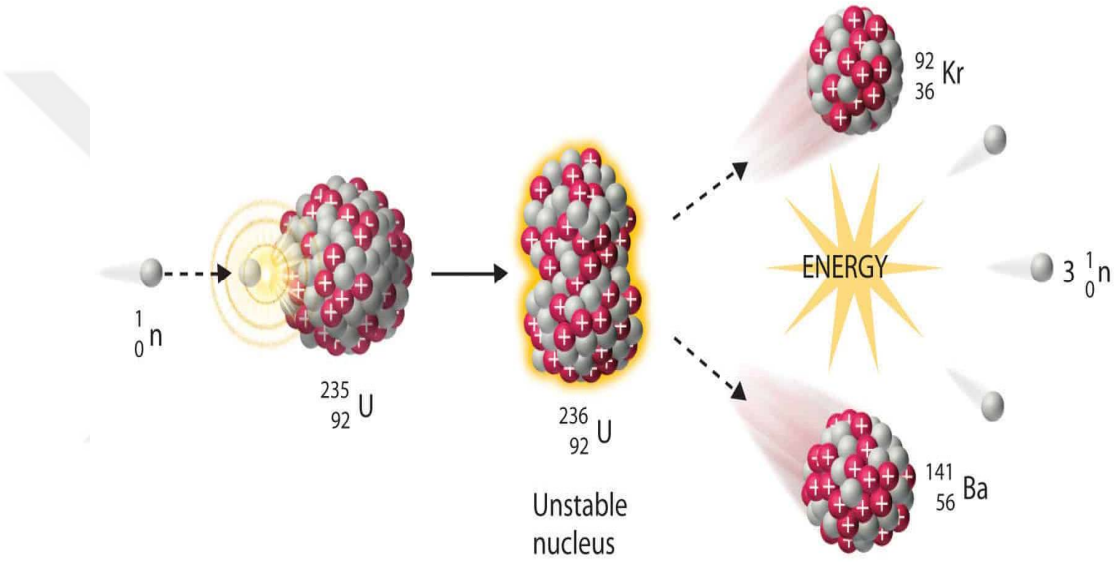

Figure1.3 An example of fission reaction [15].

The atoms that occur after the fission reaction are called fission products. A huge amount of those atoms has radioactive properties. As mentioned before, fission reaction is a core reaction. According to a chemical reaction, approximately one million times more energy is revealed as a result of core reaction.

The equation of nuclear fission reaction is given below.

$$^{235}U_{92} + {}^{1}n_{0} \rightarrow {}^{141}Ba_{56} + {}^{92}Kr_{36} + 3{}^{1}n_{0} \quad (1.2)$$

In addition to the neutron in reaction, the two neutrons are seen on the products part of the core reaction. Therefore, it is possible that the core can be continued in a self-chained manner. In a typical fission reaction, more than one neutron is released from a nucleus that divides it. As these released neutrons continue to collide with other neighboring nuclei, specific nuclear fission reactions, known as *nuclear chain*

reactions, occur. As a result of the reaction, between the mass number 72 and 160 amu, 88 basic fission products may occur, and more than 1200 different fission products may occur as a result.

As an example of the energy occurred after the reaction is given below.

Bombardment of ^{235}U with the slow neutron

$$^{235}U_{92} + {}^{1}n_{0} \rightarrow (^{236}U) \rightarrow {}^{95}Mo_{42} + {}^{139}La_{57} + 2{}^{1}n_{0} + 7\beta^{-} + Q \quad (1.3)$$

In the Table 1.3, masses are given before reaction and after reaction.

Mass Before Fission Reaction		**Mass After Fission Reaction**	
$^{235}U_{92}$	235.043923amu	$^{95}Mo_{42}$	95.905841amu
		$^{139}La_{57}$	138.906348amu
		$2{}^{1}n_{0}$	2.017330amu
		$7\beta^{-}$	0.003840amu
TOTAL	236.052588amu	TOTAL	235.837331amu

Table 1.3 Masses before and after reaction

β- Beta rays.

Energy released per fission reaction;

(236.052588amu-235.837331amu) *931.5MeV/amu = 0.21526amu * 931.5MeV/amu= 200.5MeV [16].

Mega Electron Volt (MeV) equals to $1.6022*10^{-13}$ J [17].

165.5MeV ~ Kinetic energy of fission products

7MeV ~ Gamma rays.

6MeV ~ Kinetic energy of the neutrons.

7MeV ~ Energy from fission products.

6MeV ~ Gamma rays from fission products.

9MeV ~ Anti-neutronios from fission product [18].

The total mass of fragmentation products is the kinetic energy of the lost mass products in terms of delivery according to $E= mc^2$ when the mass of the first nucleus is smaller [19].

When enriched uranium is bombarded with neutrons, the nucleus division occurs. Division products try to escape from the environment with kinetic energy, and thus nuclear energy occurs in the form of heat energy. 2 or 3 neutrons occur as a result of each fission. The resulting neutrons react immediately with fissile isotopes, re-dividing. With this division, new fissions emerge. This cycle continues to grow.

The neutrons emerging as the product of the fission reaction are absorbed by the atomic nuclei that capable of making other fission in the reaction cycle and react to them. This event is repeated continuously. It is called *Nuclear Chain Reaction.* This event is carried out under control in nuclear power plants. It is impossible to lose control and turn nuclear fuel into a nuclear bomb. In Figure 1.4, chain reaction can be seen.

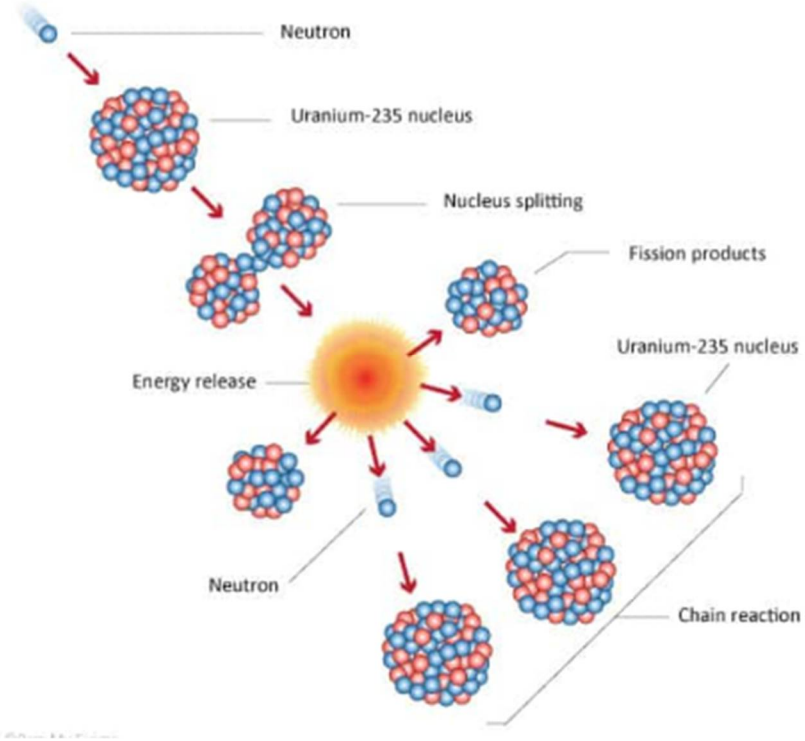

Figure 1.4 Chain reaction [20]

Critical mass is an important for fission chain reaction, it is the minimum explosive mass that is suitable to circulate and can sustain itself in the fission reaction, which is initiated in the fission without leaving the neutrons out of the nuclear explosive [21].

We said that there was a neutron that hit ^{235}U in a fission reaction and more than one neutron in the products section of the fission reaction. The number of neutrons from the reaction is indicated by the k symbol, which is the ratio of the number of neutrons entering the reaction.

$$k = \frac{\text{the number of neutrons in production at the end of the reaction}}{\text{the number of neutrons in production in the first production of the reaction}}$$

If k > 1, nuclear chain reaction continues [22].

All of the neutrons occurring in a fission reaction can be used to initiate other fission reactions. In this way, more neutrons that remain free will cause more fission and this way the fission chain is formed. However, the energy (1MeV) or velocity (~ 107m/s) of the neutrons exposed in the fission reaction are too high to cause more fission reaction of ^{235}U. For this reason, these neutrons must be slowed down less than 1eV [23].

Certain materials are used to reduce the neutron flow and concentration in the system. These materials absorb neutrons. These materials can be shown as an example of cadmium and boron cores. These materials have a cross-section of neutron capture that is 10 times more than ^{235}U. The rods obtained from these materials are immersed in the nuclear reactor to slow down or stop the nuclear chain reaction. When the reaction is requested to be restarted or accelerated, the rods are removed [24].

Fusion reaction is a combination of two light radioactive atomic nuclei, bringing together a heavier atomic nucleus. As a result of this reaction, a very large temperature occurs. Reactions in the sun are treated as a fusion reaction.

This reaction is also called nuclear fusion because it emits very high energy. It is the reactionary fusion reactions that take place in the sun. In this context, the sun is also considered as a source of nuclear energy. In fusion reactions, a greater energy is released compared to fission reactions. There is no nuclear power plant in the World

yet that operates on the principle of fusion reactions. Today, the relevant studies of this are still ongoing. It is not possible for scientists to commercialize a nuclear power plant that can work with fusion reaction principle in the near future. The basic fusion reaction is shown in Figure 1.5.

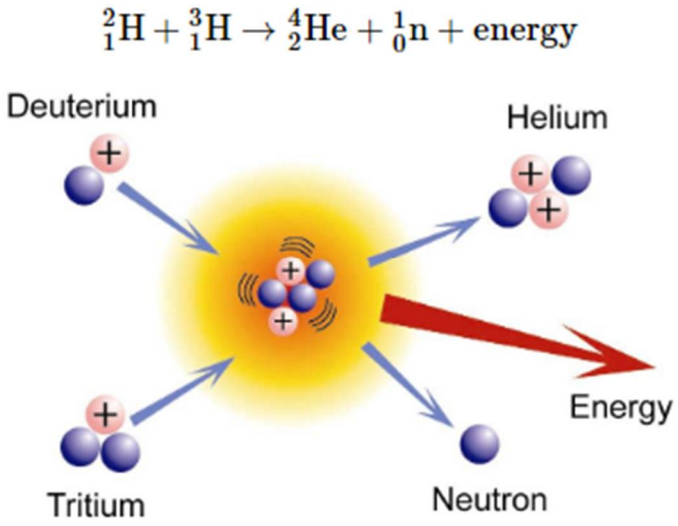

Figure 1.5 The basic fusion reaction [25].

Useful fusion reactions are divided to two basic sections that are D-D (Deuterium-Deuterium and D-T (Deuterium-Tritium) reactions. These are demonstrated below.

$^{2}H_{1} + ^{2}H_{1} \rightarrow {}^{3}H_{1} + {}^{1}H_{1} + 4.03MeV$

D-D reactions

$^{2}H_{1} + ^{2}H_{1} \rightarrow {}^{3}He_{1} + {}^{1}n_{0} + 3.27MeV$

D-T reaction

$^{6}Li_{3} + {}^{1}n_{0} \rightarrow {}^{4}He_{2} + 4.8MeV$

1.2 Nuclear Raw Materials

As a source of nuclear fuel, uranium fuel UO_2 is used in almost all reactors. The issue of the reactor will be discussed later in the thesis. Processing and turning uranium into a fuel bar is much lower cost and more advantageous than other resources.

Pu-239 (Pu-241) is another radioactive element that can be used as fuel. Plutonium is not an element that can be found purely in nature alone. Plutonium is obtained as a result of chain nuclear reactions in nuclear reactors. If there is no uranium element, there can be no mention of plutonium. In addition, plutonium must be converted into a fuel called MOX (Mix-Oxide) in order to be used as fuel. The MOX system will be examined later in the thesis.

Thorium-232 is another substance that can be used as fuel. Thorium is not yet used in any commercial reactor. However, thorium-232 is expected to be an important fuel source in the future by the scientific community. Since thorium alone is not a fisil element, it must be mixed with a fissile element. At this time Thorium does not appear to be economical and not enough technological progress has been achieved.

Uranium was discovered by Martin Klaproth in 1789. Uranium is a radioactive element, which was discovered by Henry Becquerel in 1896 after a number of experiments. In the periodic table, it is an element that with atomic number 92, mass number 238 and specific weight of approximately 19. It's not free in nature. Although it is easily oxygenated, it combines with various elements to form uranium minerals. Only 3 uranium isotopes occur naturally: U-234, U-235 and U-238 [26].

Uranium is usually found in rocks, soil and water in low-level areas. It is also found in the sea and oceans. It is found in the form of different isotopes in nature. Uranium-238, Uranium-235 and Uranium-234 are natural uranium isotopes. 99.28% of uranium in nature consists of U-238, 0.71% u-235 and 0.0054% U-234. Artificial uranium isotopes in the reactor after the U-235 and Th-232 reactions are U-236, U-233 and U-232 [27].

Most common uranium ore is shown in Figure 1.6



Figure 1.6 Most common uranium ore- uraninite [28].

Uranium is used in nuclear power as plant fuel, in uranyl acetate analytical applications, armout plating, ship and aircraft constructions, in order to give color to the ceramics, production reactors; plutonium in the production of hydrogen bombs, to make nuclear explosives.

Although the U-238 constitutes almost all of the uranium in nature, it cannot be used as nuclear fuel alone because it is not a fissile substance. The element that is literally used as nuclear fuel is Uranium-235.

In the Figure 1.7, distribution of uranium production by country is shown.

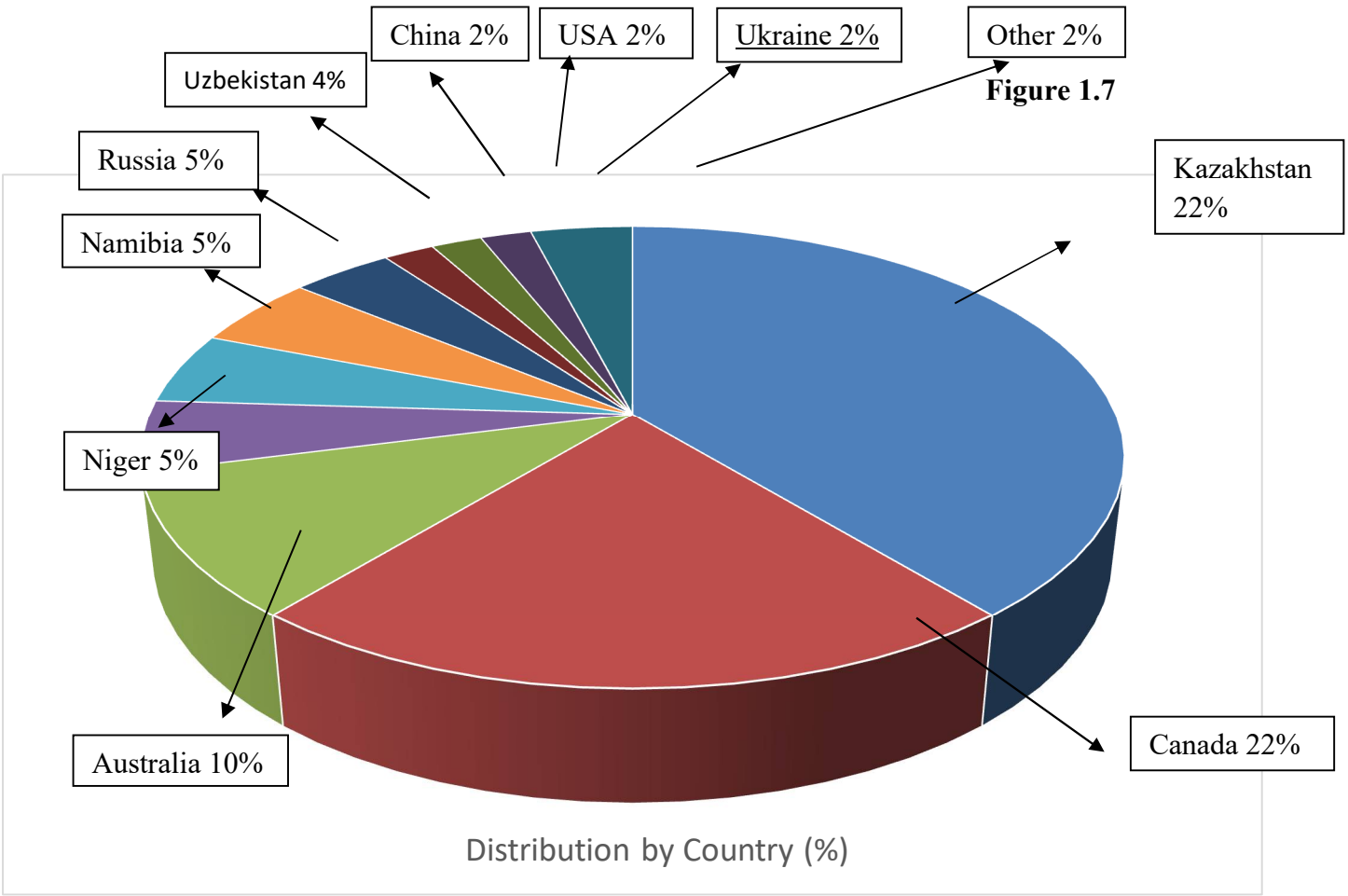

Figure 1.7 Distribution of Uranium production by country [29].

Like uranium, *plutonium* is a heavy element, with atomic number 94. Plutonium is an element that can be used as fuel in nuclear reactors and to fuel nuclear bombs. The most widely used isotope is plutonium-239, which can easily make fission. Half-life is approximately 24,000 years. One of the most important isotopes of plutonium with 14 more isotopes is plutonium-238, although it is known to have a half-life of approximately 87.7 years, it is mostly used in nuclear batteries. Some of the other important isotopes are plutonium-240 (6.6 years half-life), plutonium-241 (14.4 years half-life) and plutonium-242 (374.000 years half-life). Today, plutonium-238 is used as a power source for the American spacecraft, which is approaching 30 [30].

The element plutonium is named after the ninth planet (recently removed from planetary status) from pluto and roman underground deity. American chemist Glenn Seaborg and his friends Joseph Kennedy, Arthur Wahl and Edwin McMillan produced this element at the University of California in 1941. The discovery of plutonium was kept secret until 1948 because it was used to make bombs. In 1951, Seaborg and

McMillan were awarded the Nobel Prize in Chemistry for their work on plutonium [31].

A PWR (Pressure Water Reactor) nuclear reactor with a power of 1000 MWe produces approximately 27 tons of used fuel annually. This used fuel contains 0.9% of plutonium. About 70% of this plutonium contains a fissile isotope. In other words, it can be used as fuel. In order to reuse energy production in used nuclear fuel, it must undergo reprocessing (Reprocess) and recycling as mentioned in the later sections [32].

The formation of plutonium has been shown in Figure 1.8, a nuclear reactor with uranium fuel.

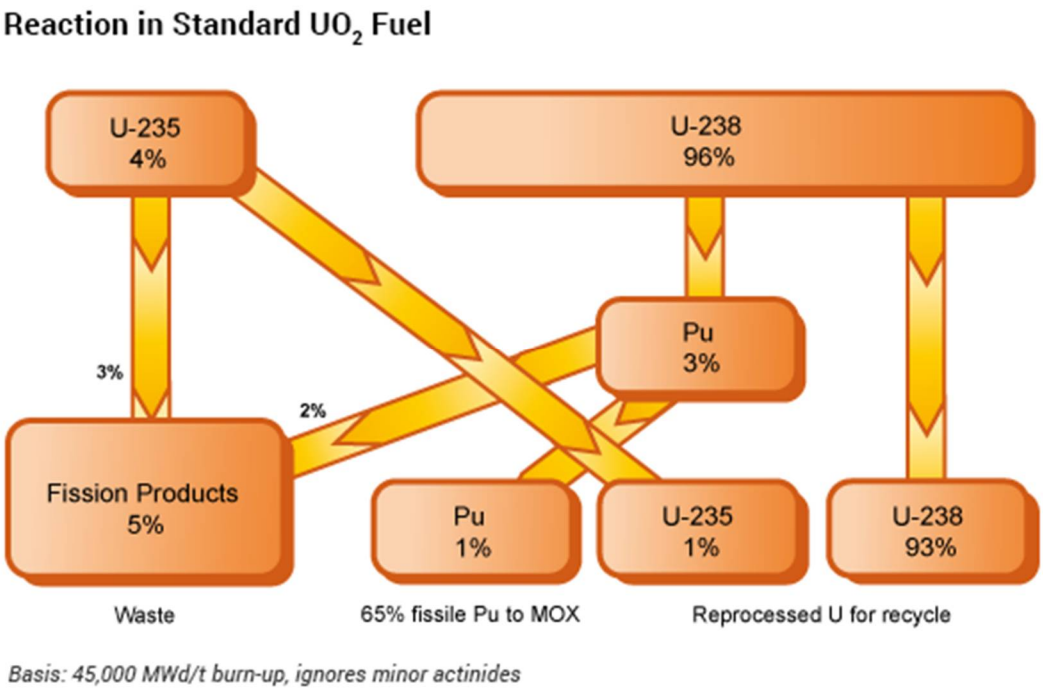

Figure 1.8 The formation of plutonium in a nuclear reactor with fuel of uranium [33].

Thorium is a chemical element with atomic number 90 that can be spontaneously found in nature. The chemical symbol is "Th", which was discovered by Norwegian scientist Morten Thrane Esmark in 1828. Thorium is found in sands that are three times more natural than uranium and are usually monazite (rare earth metals containing phosphate minerals). Of thorium, which has 6 isotopes in nature, only Th-232 is stable compared to others. Others (^{230}Th, ^{229}Th, ^{228}Th, ^{234}Th and ^{227}Th) are unstable isotopes. The half-life

of the Th-232 is approximately 1.4×10^{10} years and close to the earth's age (4.5×10^{9} years.).

Almost 100% of thorium in nature is Th-232. Th-232 is a fertile isotope. It means that it doesn't react with low-energy neutrons. However, it can react with fast neutrons with energy greater than 1 MeV. Thorium must be mixed with a fisil substance in order to be used as fuel.

The idea of using thorium as nuclear fuel dates back to the beginning of developments in nuclear energy. In 1944, a meeting on different nuclear reactor designs in the United States also discussed the development of reactor designs using thorium. With the discovery of new natural uranium deposits, the sources of uranium became as limited as predicted, and research on thorium gradually lost its importance. As of 2002, however, uranium extracted from the ground every year can only meet half of the annual requirements of the world's nuclear reactors. Thorium is about three times more abundant in nature than uranium. Turkey ranks sixth when assessed for the abundance of thorium resources in the World [34].

There are three different ways to use thorium as a fuel in a nuclear reactor. One of them is that, Th-232 is mixed with U-235. In this mixture, thorium is added to a certain amount of uranium (U-235 and U-238 mixture) known as fresh fuel and fuel is obtained. The second one of them is that Th-232 is mixed with Pu-239 (mixed Pu-241). Plutonium cannot be found in nature spontaneously. It occurs the result of combustion reaction of Uranium. This plutonium is separated from used nuclear fuel. Mixing of this plutonium with thorium can be used as a nuclear fuel. The third one is that mixing of Th-232, U-233. Uranium-233 cannot be found in nature alone. U-233 is obtained from the result of combustion of Th-232 in the reactor. In this case, in order to make such a mixture, it is necessary to first obtain fuel with the first or second row mixture and then separate the resulting U-233.

What makes thorium valuable is that it's not just that. Abundant in nature compared to uranium and produces radioactive waste that lasts less than uranium. Thorium fuel cycle research reactors have been used by Germany, India, Canada, Japan, China, the Netherlands, Belgium, Norway, Russia, Brazil, the UK and the United States, and some countries are continuing to do so [35].

CHAPTER 2 NUCLEAR REACTORS AND NUCLEAR PROCESSES

2.1 Nuclear Reactors

Although there is sufficient core division to operate nuclear reactors, other components are needed to build a functional reactor. The world's first use of reactors began in 1942. Since then, various rectors have been tried and designed. Different engines were used. Power, security, economy, etc. have created different choices. Reactors were originally used for military vehicles, submarines and ships. In the following period, it was used for commercial and electricity generation purposes. There are also reactors used for education and research purposes.

Since the main topic of our study is nuclear commercial power reactors, other reactors have not been emphasized. Commercial reactors are also classified according to a number of features. They work with fast neutrons and thermal neutrons, as mentioned in the names of fast reactors and thermal reactors. Fast productive reactors (FBR) have not yet been brought to the desired economic and commercial level. For this reason, the current commercial reactors are thermal reactors. Thermal reactors are mentioned in this thesis.

Another classification criterion is the type of fuel used. Depending on fuel use, they can be divided into three main sections: (1) CANDU type reactors using natural uranium are not enriched; (2) Less enriched reactors, enriched by 3-5%; (3) 10% or higher are enriched.

By obtaining nuclear reactor types, light Water Reactors are the most common types of reactors in the world. Approximately 92% of the world's existing reactors are "Light Water Reactors" and the remaining 8% are other reactors. Light water reactors are divided into two parts among themselves. These are the "Compressed Water Reactor (PWR) and the Boiling Water Reactor (BWR).

Pressurized Water Reactor (PWR): Pressurized water reactors are reactors that use 3-5% enriched uranium, using light water as a slower and refrigerant at 15 Mpa pressure and 320 C. PWR is the most widely used reactor in the World.

Boiling Water Reactor (BWR): It operates at lower pressure and temperature than PWR. The coolant water starts to boil at low pressure in the reactor. The resulting

steam is sent directly to the turbine. Since BWR does not have steam generators, they are designed to be simpler than PWR. BWR has two water cycles. The water circulating in the first cycle carries the heat generated in the reactor to the turbine, and in the second cycle, the water from the sea and the energy from the turbine are lost and the steam is recycled into the water again.

VVER (Voda-Vodyanoı Energetichesky Reactor): VVER reactors are pressure water reactors developed by the Russians. The Russian acronym VVER means energy reactor that is cooled and slowed by water. Unlike PRGEs in VVER reactors, steam generators are placed horizontally.

CANDU (Canada Deuterium Uranium): These reactors are pressurized, heavy water-fired and natural uranium-powered reactors (Pressurized Heavy Water Reactor, PHWR). You do not need to enrich uranium as fuel. However, in order to use heavy water as a refrigerant and decelerator, it is necessary to separate the heavy water which is less than 1% in sea water and obtain 99% pure heavy water. This requires a separate process. The fuel is placed horizontally in short bundles. There is no need to shut down the power plant during the fuel exchange process, the reactor has a fuel loading machine at its heart.

RBMK (Reactor BolshoI Moschnosti Kanalynyi): RBMK is also a Russian-produced BFF. The Chernobyl disaster occurred at an RBMK-type plant. RBMK uses water as a cooler. It also uses graphite as a decelerator. Such reactors are planned to be shut down in the future for safety reasons.

GCR/AGR (Advanced/Gas Cooled Reactor): Gas-cooled reactors are commercially used in the UK only. There are two different types: MAGNOX (fuel is magnesium-oxide) and AGR. AGR is MAGNOX'S advanced design. In AGR, the refrigerant is CO2, decelerator graphite and fuel-enriched uranium.

FBR (Fast Breeder Reactor): Fast productive reactors that have not yet been commercial. No decelerators are used, and sodium is used as a refrigerant. These reactors are designed to produce more Pu-239s than the U-235 consumed, so it's called a productive reactor. Neutrons that emerge after division and then flickers are caused by rapid neutrons. The resulting neutrons are used to convert the U-238 to pu-239

while providing energy production on the one hand. If this technology can develop, uranium mines and used nuclear fuels will be used much more efficiently

Advanced Reactors: Generation 4, also called 4. Generation reactors are still in the design phase. It is not expected to be operational before the middle of 2020. Such reactors are planned to have a closed fuel cycle. As fuel, long-lasting actinites are considered. In this way, fission products are expected to be only from high-level waste, and reuse of these wastes is more likely than low-level waste. A total of 7 designs are planned as a 4th generation reactor. 4 or 5 of these designs are thought to be accelerated neutron reactors. It is envisaged to use fluoride or liquid metal coolers. That's why these reactors will run at low pressure. Two of the reactors designed handle gas cooling method. Almost all of the designed reactors are expected to operate at higher temperatures than today's water-cooled reactors [36].

Floating Nuclear Power Plants: ROSATOM, Russia's largest company working on atomic energy, has established a subsidiary to develop a number of reactors to generate power on ships. Its purpose is to build more than 200 nuclear reactors, as well as floating nuclear power plants ranging from 70-600Mwe. These barges, which are intended to be installed in pairs on a large barge, will anchor in a coastal settlement or industrial zone or where necessary for desalination. These barges, which have a power of 40Mwe as icebreakers in remote Siberia, ensure that the cost of electricity is much lower than the alternatives [37].

2.1.1 Lifetime of Nuclear Reactors

Nuclear power plants are usually designed on the capacity to operate for 30 or 40 years. However, in systems, the plant life can be extended with supporting technological improvements and investments in components. In the United States, the vast majority of nearly 150 reactors are licensed to operate for 40-60 years. Extending the life of a nuclear power plant requires considerable capital.

Some components in the reactor (reactor components will be processed in the thesis) lose their function due to some reasons such as wear, corrosion or fatigue and reduce reactor efficiency. For this reason, some components in the plant need to be replaced. Steam generators are the first components that need to be replaced after a certain time. Although it has a certain cost, its change can extend the life of the reactor to 60 years.

Otherwise, the reactor life span remains around 30 years. It's easier to replace small components as they get older. In CANDU type reactors, it is known that after the reactor has performed an operation for around 30 years, a number of facilities have been exchanged for compressed tubes.

Another issue is obsolesceon. In older reactors, instruments and control systems are controlled analoguely. Thirdly, with the aging of the materials, the materials can be deteriorated by neutron radiation and high temperatures. Such problems are very important for reliability and security. In order to protect the security margins, periodic security inspections are carried out in the old facilities in accordance with international security rules.

One of the most important issues is knowledge management on this entire cycle, from design to construction and operation, to commissioning and dismantling reactors. This information management is broad and important enough to spread over many years, involve a few generations of engineers or form consortiums. Issues such as software, plant safety, nuclear waste, operators and human health are covered within the scope of this information management. Information management is of interest to all people, not just employees [38].

Types and distribution of reactors operating in the world is shown in Figure 3.1 with date of January 2017.

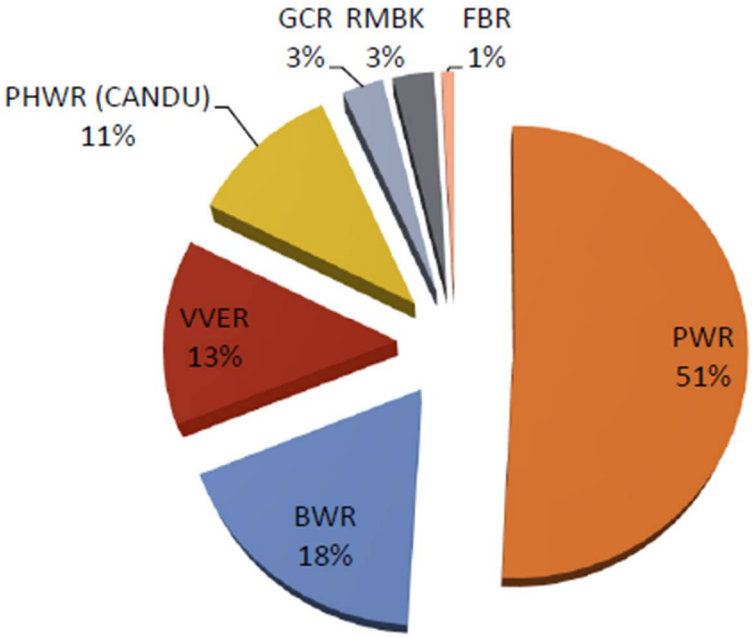

Figure 2.1 Types and distributions of reactors operating in the World [39].

On the other hand, nuclear power reactor materials are shown in Table 2.1 below

	Pressurized Water (PWR)	**Boiling Water (BWR)**	**Naturel U Heavy Water (CANDU)**	**High Temp. Gas Cooled (HTGR)**	**Liquid Metal Fast Breeder (LMFBR)**
Fuel Form	Uo_2	Uo_2	Uo_2	Uc, Thc_2	Uo_2, Puo_2
Enrichment	3% U-235	2.5% U-235	0.7% U-235	93% U-235	15 Wt % Pu-239
Moderator	Water	Water	Heavy Water	Graphite	None
Coolant	Water	Water	Heavy Water	Helium Gas	Liquid Sodium
Cladding	Zircaloy	Zircaloy	Zircaloy	Graphite	Stainless Steel

Control	B_4C Or Ag-In-Cd Rods	B_4C Crosses	Moderator Level	B_4C Rods	Tantalum or B_4C Rods
Vessel	Steel	Steel	Steel	Prestressed Concrete	Steel

Table 2.1 Nuclear power reactor materials [40].

2.2 The Main Components of a Nuclear Reactor

- **Fuel**: It is the material that nuclear energy is revealed. It is produced in the form of tiny tuffities called fuel pellets (as much as cigarette butts). Pellets are usually placed in thin pipes made of zirconium. These pipes, which are about 3.5-4 meters tall and 1 cm in diameter, are called fuel rods. The fuel rods are placed in 7x7, 14x14 or 17x17 square bundles or hexagonal-shaped fuel bundles. These bundles are placed in the reactor container (reactor core) depending on the type of reactor. Almost all commercial reactors use uranium. Figure 3.2 is also shown small UO_2 fuels and fuel bar to fit into the palm.



Figure 3.2 Fuel pellets and fuel rod.

- **Cooler**: It is the liquid or gas used to remove the heat that occurs in the reactor core. The refrigerant prevents the fuel from melting. Most commercial reactors use water. The features the cooler should have are the fact that it does not swallow neutrons, is cheap and abundant, does not cause rusting, can carry energy comfortably.

- **Control Rods:** It adjusts the production rate of energy and is used to completely stop energy production. They are made of materials such as cadmium, silver, indium, boron and hafnium that can swallow neutrons. After placing the fuel bundles in it, the control rods are pulled up to increase the power. To reduce power, it is lowered downwards. Thus, more neutrons swallow and the power of the reactor decreases.
- **Inhibitor:** Neutrons are split in two quickly and slowly. The energy of fast neutrons is above 1keV. The energy of neutrons resulting in the fission is approximately 2MeV on average. Their energies and speeds are too high. However, slow neutrons are more likely to react, so these rapid neutrons are slowed down with different substances (Water, CO2, Graphite).
- **Other Auxiliary Systems:** The residential columns and plates are available for the fuel to stand properly. In addition, the guide tubes placed inside the reactor also provide the movement of control rods. The surrounding area of the fuel area is surrounded by reflector. The reflector is used to re-project neutrons trying to get out of the reactor into the reactor. There is also a pressurer and steam generator, only in compressed water reactors.

2.3 Nuclear Processes

2.3.1 Transmutation of Elements

When transmutation of elements is approached**,** Nuclear reactions can be written as follows by using a general equation;

Nuclear reactions can be written as follows by using a general equation;

$$^{A1}\alpha_{Z1} + {}^{A2}X_{Z2} \rightarrow {}^{A3}Y_{Z3} + {}^{A4}b_{Z4} \quad (2.1)$$

All reactions in the universe obey the four basic rules set out below:

(1) Conservation of nucleons: $A_1 + A_2 = A_3 + A_4$ (2.2)

(2) Conservation of charge: $Z_1 + Z_2 = Z_3 + Z_4$ (2.3)

(3) Conservation of momentum

(4) Conservation of total energy

Rutherford carried out the process of converting one element to another, called transformation, in England in 1919. In Figure 3.3, Rutherford's Experiment is shown. According to the equation below, he bombarded nitrogen atoms with particles from radioactive sources to produce an oxygen isotope and one proton [41].

$$^{4}He_{2} + {}^{14}N_{7} \rightarrow {}^{18}O_{7} + {}^{1}H_{1} \qquad (2.4)$$

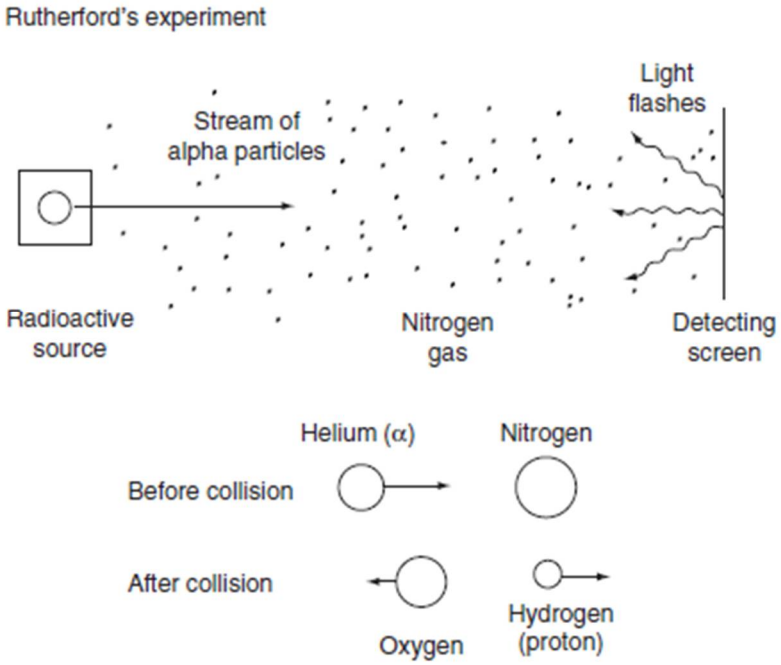

Figure 2.3 Rutherford's experiment [42].

Values A are found to be a total of 18 on both sides of the equation. Likewise, it is clear that the sum of Z values is 9 on both sides. Due to electrical thrust force between the same charged particles, it is difficult to enter a positively charged part into the nitrogen core. Therefore, the particle that will enter the core must have a few MeV energies.

2.3.2 Energy Conservation

In physics and chemistry, conservation of total energy remains constant in an isolated system. By obtaining in a chemical or nuclear reaction, in other words, sum of the reactant energies must be equal to the sum of the product energies.

$$\Sigma_{REACTANT}\, E_T = \Sigma_{PRODUCT}\, E_T \qquad (2.5)$$

Let's obtain X(a,b)Y reaction, as conservation of energy rule is simply;

$${}^{X}E_T + {}^{a}E_T \rightarrow {}^{b}E_T + {}^{Y}E_T \quad (2.6)$$

As is known, the total energy is the sum of the potential energy (rest mass energy), E_0, and the kinetic energy, E_K, so the expression is written as;

$${}^{X}E_0 + {}^{X}E_K + {}^{a}E_0 + {}^{a}E_K = {}^{Y}E_0 + {}^{Y}E_K + {}^{b}E_0 + {}^{b}E_K \quad (2.7)$$

Or, we can write it in terms of energy-mass;

$$M_X c^2 + {}^{X}E_K + m_a c^2 + {}^{a}E_K = m_b c^2 + {}^{b}E_K + M_Y c^2 + {}^{Y}E_K \quad (2.8)$$

It ıs know that, generally, target nucleus X is stationary. That is why the kinetic energy of target nucleus is zero.

The reaction energy conservation allows us to calculate the necessary energy emitted or cause a reaction by a nuclear reaction. We will call it as Q. Therefore, to rearrange the Equation XX provides us to the definition of Q values.

$$Q = [(M_X + m_a) - (m_b + M_Y)]\, c^2 = ({}^{b}E_K + {}^{Y}E_K) - ({}^{X}E_K + {}^{a}E_K)$$

So ;

$$Q = \Sigma_{reactants} M\, c^2 - \Sigma_{products} M\, c^2 = \Sigma_{products} E_K - \Sigma_{reactants} E_K \quad (2.9)$$

The utility of examining these two formulas together is that Q can be calculated if the masses are known. After that, combined kinetic energy can be obtained.

If there is producing energy in a reaction, it is called exothermic. On the other hand, a reaction requires an input energy to occur, it is called endothermic. The Q value provides us to make a decision that the reaction is endothermic or exothermic. How the decision is found out is given below.

If Q >, reaction is exothermic, alias exoergic

If Q <, reaction is endothermic, alias endoergic.

It is seeking that exoergic reactions that are fission and fusion to supply power sources. Because, it is known that radioactive decay is occurred spontaneously without energy input. It is surmised that all decay reactions are exoergic.

2.3.3 Momentum Conservation

Above calculations, (section 3.1 and 3.2) only tell us the total kinetic energy of the products but it tells us nothing about what the speeds are. Which is why there is need to apply the momentum conservation rule. By applying the momentum conservation rule that mass, m, speed, υ, and linear momentum ρ;

$$\rho = m\upsilon \tag{2.10}$$

Let's obtain a very slow neutron. It strikes a hydrogen atom which is at rest, it can be assumed the initial momentum is zero. If the final momentum is zero, it means that the hydrogen and γ-ray have to go into splinters with equal magnitudes of momentum $\rho_D = \rho_\gamma$. It can be written that $\rho_\gamma = m\ c^2$ if it is considered the mass an effective value, related to the γ energy E_γ by the Einsteins's formula $E=m\ c^2$. Thereby,

$$\rho_\gamma = E\gamma/\ c \tag{2.11}$$

2.3.4 Rate of Reactions

When any two particles are close together, the interaction between them depends on the nature of the force. If they are electrically charged, they obey the Coulomb's rule

$$Fc = \frac{q_1 q_2}{4\mathcal{E}\pi r^2} \tag{2.12}$$

q: amount of the charge

Ɛ: permittivity of free space

12 r: the distance of separation of centers

Regardless the distance, there will be some interaction between the particles. But, if two particles are electrically neutral, there will be no influence until they close to each other. The distance is small ($\approx 10^{-10}$m). The special force between the electrically charged particles are even more limited ($\approx 10^{-15}$m).

Although it is not seen the nucleii, it is imagined that they are spheres with a certain radius. To estimate this radius, there is a need to probe with a proton, an electron or γ-ray. However, the answer will be depended on the projectile used and its speed, so it is necessary to specify the visible radius and cross-sectional area for a reaction [43].

A series of imaginary experiments can be done to clarify the idea of cross-section. As shown in the Figure 2.4, a tube of 1 cm^2 area containing only one target particle is

considered. A single bullet is injected parallel to the tube axis, but the exact position is not specified. It is clear that the ratio of the target area of the collision chance, indicated by Sigma and called microscopic section, to the area of the tube is 1 cm^2 (see Figure 2.4 A)

Now, let's inject a continuos velocity υ particles into the empty tube (see Figure 2.4 B). Over a period of 1 second, each of the particles moved along the distance of υ cm (see Figure 2.4 C). They all sweep in the volume (1 cm^2) (υ cm) = υ cm^3 column in a column at a point at which it is watched every second. If there are η particles per cubic centimeter, the number current intensity per unit time passing any unit is perpendicular to the flow direction ηυ called ȷ.

ȷ= ηυ (see Figure 2.4 B-C) …. (2.13)

Lastly in Figure 2.4 D, it will be completed each unit volume of the tube with N pieces targets, each of ares seen by gaining (it is supoosed that the targets do not into the sides of each other). If the attention is given to the unit volume, there can be seen a total target area of N_O. This product is labeled Σ (capital sigma), which is the macroscopic section that refers to the large-scale characteristics of the medium. It is seen the Figure 2.4 given below [44].

Figure 2.4 Particle collisions.

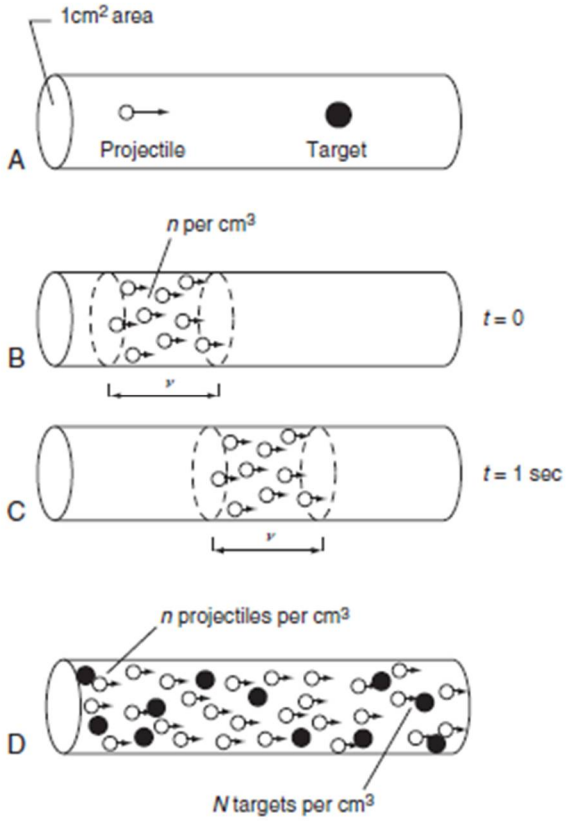

Figure 2.4 Particle collisions.

$$\Sigma = N_O \tag{2.14}$$

Again, the stream of projectiles are injected in a period of 1 second, the number of passing through projectiles the target volume is ηυ, and the probability of each colliding with the target atom, Ʊ, the collision's number that can be defined as reaction per unit volume R is given as;

$$R=(\eta\upsilon) \text{ x } (N_O) \tag{2.15}$$

2.3.5 Particle Attenuation

Visualize a stream of particles in the common velocity and direction, which is allowed to hit the plane surface of a substance, as in Figure 3.5. Collisions with target atoms in the material a process labeled attenuation, which will continuously remove projectiles from the stream, thereby reducing distance and strength. If the current density happening on the object at position z=0 is labeled j_0 current of those that do not have any collisions penetrating to depth z is given by;

$$J = J_0 e^{-\Sigma_t x} \quad (2.16)$$

Σ_t: Macroscopic total cross-section

To understand the relationship between the parameters on the equation given above, the Figure 3.4 is given below can be analyzed.

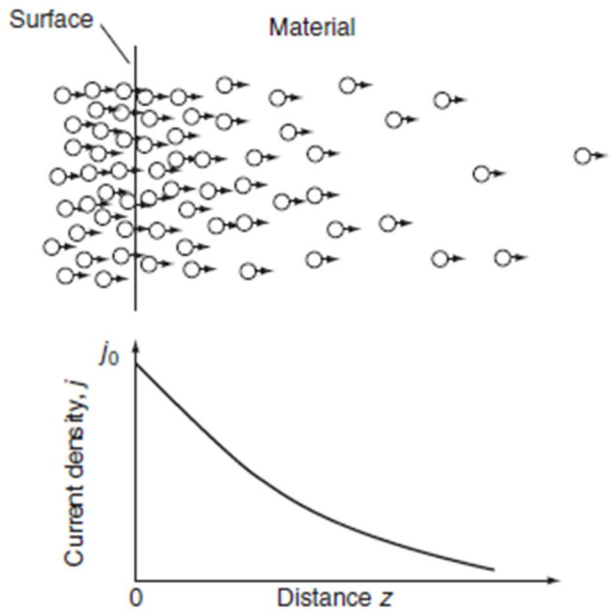

Figure 2.5 Relationship between the parameters on the equation (2.16) [45].

2.3.6 Neutron Cross-Sections

The cross section of Neutron absorption is largely dependent on the isotope and Neutron energy in the bombardment in materials. For making a consistent comparison and use, the cross-section is usually preferred as 0.0253eV, corresponding to Neutron speed 2200m/s.

In Figure 3.6 which is given below, shows capture cross-section O_y values for a number of isotopes at that energy level. There are two types of absorption cross-section and energy dependence to each Other. The first one is quoted 1/υ, where O_a diversifies inversely with Neutron speed.

$$Ơ_a(\upsilon) = Ơ_{a0}\,\upsilon_0 / \upsilon \qquad (2.17)$$

$Ơ_{a0}$: The cross-section at υ_0, generally assumpted as 2200m/s.

The second one is resonance. It means that very strong absorption at a certain level Neutron energies.

Isotope	σ_s (barns)	σ_γ (barns)	Other σ (barns)
H-1	20.49	0.3326	
H-2	3.39	0.000519	
Li-6	0.75	0.0385	$\sigma_\alpha = 940$
Li-7	0.97	0.0454	
Be-9	6.151	0.0076	
B-10	2.23	0.5	$\sigma_\alpha = 3837$
B-11	4.84	0.0055	
C-12	4.746	0.00353	
C-13	4.19	0.00137	
N-14	10.05	0.075	$\sigma_p = 1.83$
N-15	4.59	2.4×10^{-5}	
O-16	3.761	0.00019	
O-17	3.61	0.000538	$\sigma_\alpha = 0.235$
O-18		0.00016	
Na-23	3.025	0.53	
Al-27	1.413	0.231	
Mn-55	2.2	13.3	
Co-59	6.0	20.4	
Nb-93	6.37	1.15	
Xe-135		2.65×10^6	
Au-197	7.84	98.65	
Th-232		7.37	$\sigma_f < 2.5 \times 10^{-6}$
U-233	12.8	45.5	$\sigma_f = 529.1$
U-235	14.3	98.3	$\sigma_f = 582.6$
U-238	9.38	2.68	$\sigma_f = 4 \times 10^{-6}$, $\sigma_\alpha = 1.3 \times 10^{-6}$
Pu-239	7.6	269.3	$\sigma_f = 748.1$
Pu-241	9.0	358.2	$\sigma_f = 1011.1$

Data source: Mughabghab et al., 1981 (http://ie.lbl.gov/ngdata/sig.htm).

Figure 2.6 Some isotopes selected thermal neutron cross-section at 0.0253eV.

2.3.7 Neutron Migration

If the cross-sectional surface area increases, total leakage will also increase. Total leakage can be defined as ly + 1h. In addition, the distance the neutron folds before cooling increases, the leakage also increases. This distance is called M, migration distance. M is depended on diffusion distance, Ld, and deceleration distance, Ly.

Diffusion distance is that before cooling a thermal neutron , its average distance that it travels. The deceleration distance is a distance that a fast neutron slowers to the thermal energy level. Therefore;

$$M = (L_d^2 + L_y^2)^{1/2} \quad (2.18)$$

There are some similarities between chemical and nuclear reactions in terms of equations and in the requirements on conservation of energy and moment of particles and situation of electrically charged. If nuclei are bombarded with the electrically charged particles or neutrons, new nuclei and particles will occur. Their final energies can be easily found from mass differences, and final velocities can be also easily found from conservation of momentum. Neutrons with nuclei interaction for the cross section is the measure of the chance of collision Neutron flows and macroscopic cross section affect directly to the reaction rates. The non-colliding particle density decreases exponentially if there is a flow of particles in the environment. Although scattering cross-sectional areas are generally fixed, neutron absorption cross-sections may differ greatly with target isotope and neutron energy. Although scattering section areas are stable overall, neutron absorption sections may vary greatly with target isotope and neutron energy. It is observed that a neutron slows easily as a result of colliding with light cores. Accordingly, they migrate from where they came from. As soon as neutron reaches thermal energy, it continues to disintegrate.

2.2. Nuclear Fuel Cycle

Nuclear fuel cycle; search, extraction and processing of uranium, exposure to reaction, storage and re-processing of radioactive uranium used, processing and disposal of waste spawned after reuse is the entire process of completing the life of the reactor. Nuclear power plants, like thermal power plants, are machines that convert heat energy into mechanical and then electrical energy. Various coals are used as fuel in coal plants. There are two types of fuel cycle that has been using all over the world. These are open fuel cycle and closed fuel cycle.

In the open fuel cycle, the fuels produced by coming out of the mine and processed are considered waste after they are burned in the reactor. Used fuels left to cool for many years in storage pools are stored temporarily to be immersed in underground. However, today, the still burial process has not yet been done by any country. In the closed fuel cycle, used fuels from the reactor are sent to the facilities for reprocessing. Used fuels are disassembled in the reprocessing plant and the uranium and plutonium, which can be used in fuel, are separated. The remaining high-activity waste is glassed and sent to store. Closed fuel cycle costs 10% more than open cycle. High-tech and very large facilities are needed to make closed cycle. France and Japan are the countries that make the largest investment in reprocessing facilities in the world. The given Figure 2.7 below, it can be seen open and closed fuel cycle together.

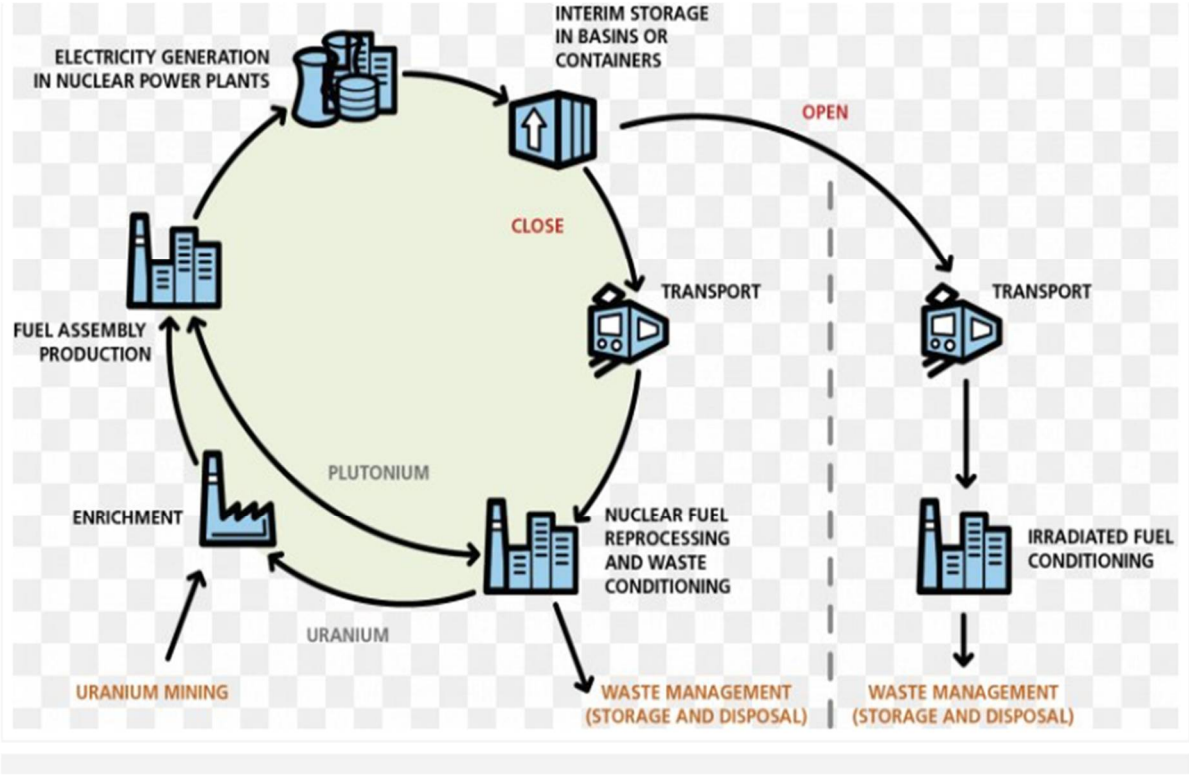

Figure 2.7 Open and closed cycle

2.2.1 Open (Single Pass) Fuel Cycle

As seen in Figure 2.7 the difference between open and closed fuel cycles is about the method of the used fuel. The fuel used in nuclear power plants in the open fuel cycle is considered nuclear waste and is expected to be sent to final underground waste storage facilities after being held for a certain period of time. Since high-tech and expensive facilities such as open (single-pass) cycle, re-processing plant and mineral-sourced uranium prices are very low today, as it is seen as the most economical nuclear fuel cycle method. Therefore, many countries, especially the United States, use this method. Only 20% of used fuels from nuclear power plants around the world are sent to re-processing facilities according to closed fuel cycle principles, while 80% of the world's nuclear power plants are exposed open (single pass) in accordance with the principles of open fuel cycle waste. This means that 80% of the world is used open fuel cycle.

In addition to the advantages of open fuel cycle being cheap, there are some unpreferred aspects. One of them is that some valuable materials found in burnt fuel - such as unburned uranium and newly formed plutonium - are sent underground as nuclear waste without being evaluated. Another aspect of the unpreferred is that the

amount of high-level waste to be sent underground is larger than the closed fuel cycle. In closed fuel cycle, the volume of waste to be sent is very low because useful cores are regained.

2.2.2 Closed Fuel Cycle

In terms of sustainability of nuclear energy, the closed fuel cycle is an advanced cycle. In the closed fuel cycle, the radiotoxicity of final waste is reduced, while sustainability and resource use are aimed at increasing. As research and development work is currently underway, different fuel cycles are emerging and below what they depend on [46]:

- Fuel Reprocessing
- Advanced Nuclear Reactors

2.3 Facilities in the Open Fuel Cycle

-*Uranium Mine*: Small amounts of uranium are located almost everywhere like rock, soil, water and etc. It has been discovered that it has high access in a small number of regions around the world. There are three major methods to get the uranium. These are open mining, underground mining and In-Situ mining.

In the open mining, it is done in places where uranium is close to the earth (70-80 meters). The taken uranium sprouts are loaded into trucks and taken to the treatment facilities near the mine. If uranium is deeper, underground mining is preferred. 100 meters long holes are drilled on the ground in underground mining, these holes are ventilated, and a stack is created below by dynamite at the bottom. Uranium ore is brought to the surface with special tools. In this method, water and energy are needed in a lot of fortunes. In Situ Mining is an easy method with less cost. As shown in Figure3.8, holes are drilled where the mine is and acid and alkaline solutions are sent down through these holes. Uranium, which melts through the solution, is brought to the surface with the help of pipes. Then, in the increment plant, uranium and solution are separated. Uranium is left at the facility for use, and the solution is sent back to the In-Situ system. The disadvantage of this method is that there is a possibility of damaging groundwater. In mining, measures are kept at a high level.

Uranium mine levels are measured and delivered to the incremental facility by trucks. The first shredding process is performed. The uranium, which becomes small pieces, is then milled in the wet grinding section and brought to the consistency of mud. It is then converted into a solution of uranium sulfuric acid, subject to oxidation and acidification. After the solution becomes solvent extract, gas ammonia is added and ammonium diuranitis sediment is formed. Ammonium diuranitis is filtered into yellow dough and heated at 700 C, creating uranium oxide (U_3O_8) in yellow powder. This powder is called a yellow cake in the language of nuclear fuel. Yellow cake is filled into 200-liter barrels and sent to conversion facilities [47].

2.3.1 Conversion and Enrichment Facilities

Conversion facilities are available in the USA, France, UK and Russia. The powdered yellow cake conversion plant is converted into "Uranium Hexafluoride (UF_6)". First, the particles in the yellow pie are cleaned. The yellow cake is converted to UF_4 and then UF_6 by two methods, wet or dry. The conversion step is basically shown in the Table 2.2 given below.

Step-1	Step-2	Step-3	Step-4
			
Yellow Cake (U_3O_8)	Conversion Facility	Uranium Tetrafluoride (UF_4)	Uranium Hexafluoride (UF_6)

Table 2.2 Conversion steps.

In the wet method, ammonium Diuranite occurs after sediment, first the uranyl nitrate solution is obtained. Uranium Dioxide (UO_2) powder is created by reducing ammonium Diuranite. In the solid method, UO_2 is obtained by making direct reduction. UO_2 consists of UF_4 known as green salt with hydrogenated flouring. UF_4 gas is reacting with fluoride, creating liquid UF_4. The resulting UF_6 is left to cool for

5-6 days. After cooling, it becomes solid crystal. 14-ton solid UF_6 barrels are sent to enrichment facilities.

99.3% of the uranium found in the natural environment is U-238 isotope and 0.7% U-235 isotope. The U-238 is fertile isotope and cannot be used as fuel in today's commercial reactors. The U-235 ratio must be around 3-5% for use of uranium as fuel.

The enrichment of Uranium was first built for military purposes in the world, and then commercial enrichment facilities were established in order to produce fuel to power reactors.

Enrichment of Uranium can be also carried out a lot of methods, which are named below;

- Gas diffusion method .
- Gas centrifuge method.
- Technique of nozzle (aerodynamic) method .
- Isotope decomposition with laser.
- EMIS (electromagnetic isotope decomposition).
- Thermal diffusion.
- Chemical change for isotope separation.
- Ion Exchange method.
- Method of plasma decomposition [48].

Uranium enrichment ratios by usage areas are given with the Table 2.3 below

Enrichment Ratio	Usage Area
No Enrichment (Natural Uranium) 0%	CANDU Type Reactor Fuel
0,9-2% Enrichment	New Type CANDU Reactor Fuel
3-5% Enrichment	PWR-BWR Type Reactor Fuel
5-20% Enrichment	Civil/Military Research Reactors
20% and Above Enrichment	Nuclear Weapons, Aircraft Carrier, Fast Neutron Reactors, Submarines

Table 2.3 Uranium enrichment ratios by usage areas.

Although there are several methods of uranium enrichment, only two of them have been commercialized. These are; Centenary Sorting and Gas Published Parsing methods. Recently, the conversion of gas-dissipating facilities into centrifugal separation facilities has also been brought up. This method spends 10 times less energy than gas-despairing and consists of fewer stages.

Methods of uranium enrichments are given with the Table 2.4 below

Supply source	2000	2010	2015	2020
Diffusion	50%	25%	0%	0%
Centrifuge	40%	65%	100%	93%
Laser	0%	0%	0%	3%
Conversion from Old Weapons	10%	10%	0%	4%

Table 2.4 Methods of uranium enrichments.

Uranium enrichment methods used by countries are given with the Table 2.5 below.

Country	Location	Technology
China	Lanzhou	Centrifuge
	Shaanxi	
France	Tricastin (closed in 2012)	Gas diffusion
Germany	Gronau	Centrifuge
Japan	Rokkasho-Mura	Centrifuge
Netherlands	Almelo	Centrifuge
Russia	Angarsk	Centrifuge
	Ekaterinburg	Centrifuge
	Krasnoyarsk	
	Seversk	

UK	Capenhurst	Centrifuge
USA	Paducah (closed in 2013)	Gas diffusion

Table 2.5 Uranium enrichment methods used by countries.[49]

2.3.2 Uranium Mining in Turkey

Pioneering laboratory studies were carried out as a result of uranium searches conducted in Turkey in the past. During these technological studies, yellow cake production from the found uranium ore was also carried out. The pilot facilities established by the MTA in 1974 in the ores of Köprübaşı (Manisa) were operating between 1974 and 1982, and approximately 1200 kg of yellow cake was produced from the uranium ores extracted in the Köprübaşı and Fakılı (Usak) region and delivered to TAEK in 1996. After the search by the MTA in Yozgat-Sorgun region, the business in the mine of Temrezli village, which has been licensed, Anatolia Energy Ltd. Sti. studies have been made for the acquisition of uranium in a basic environment with the on-site recovery method (licic). As a result of feasibility studies in the region, it is aimed to produce approximately 4,000 tons of U_3O_8 with solution mining technology at the facility, which is planned to be operational for about 10 years. Solution mining is a closed system and within this method, uranium solution is taken to the processing of the product for the acquisition method is monitored. In solution mining technology, underground layers containing uranium ore are given solutions with the help of wells. The solution to underground layers makes the uranium ore in these layers mobile. Uranium taken into the solution is brought to the surface with the help of pumps from the wells in the field. The solution pumped to the surface is sent to the process facility and concentrated uranium oxide is obtained in this facility [50].

Nuclear power plants are in the process of establishing in Turkey, and the energy deficit in the coming years will make it mandatory to increase nuclear power plants. 19,736 tons (U_3O_8) uranium reserves have been identified in the studies carried out by the General Directorate of MTA to date. However, it is not clear how much of the beds can be produced as the exact feasibility studies are not carried out. In order to provide some of the raw materials we will use from our own sources, existing reserves need to

be increased. In the world markets, uranium prices range from 30-130 USD/kg according to the conditions of the day. In times of crisis, new resources must already be found to avoid being affected by expensive raw materials [51].

2.3.3 Nuclear Fuel Fabrication

The uranium mine is enriched in enrichment facilities, solid UF_6 is brought in the barrels and these barrels are sent to fuel manufacturing facilities. Solid UF_6 is processed and powdered Uranium Dioxide (UO_2) is converted. The UO_2 is then converted into pellets with a diameter of 9 mm and a length of around 1.3cm and cooked at high temperature and converted into a solid structure.

Pellets are filled into fuel rods, each about 3.5-4 meters long and approximately 1 cm in diameter. Then approximately 200-250 pieces of these fuel rods come together to form fuel bundles. Fuel bundles can vary according to different designs. PWR also used fuel bundles from about 500 kg.

The fuel bundles produced are usually transported to nuclear power plants by trucks from the highway. It is also transported by railway, sea route and very rarely by air. Because the radio activity of fresh fuels is not very high, they do not need special protection armor when transporting. Fuels coming to the power plant are placed in their reactor shelter. PWR's are generally fresh fuel loading every 18-24 months. For this process, the plant must be closed. During fuel loading, burnt fuels are removed and replaced and replaced and replaced and replaced. When the power plant is closed, all other parts are reviewed, and maintenance is carried out. This maintenance process takes about 3-6 weeks. However, there is no need to close the reactor for fuel replacement in CANDU reactors. Everything is done with automatic devices.

It is seen the Figure 2.8 given below, PWR type reactor fuel barrets

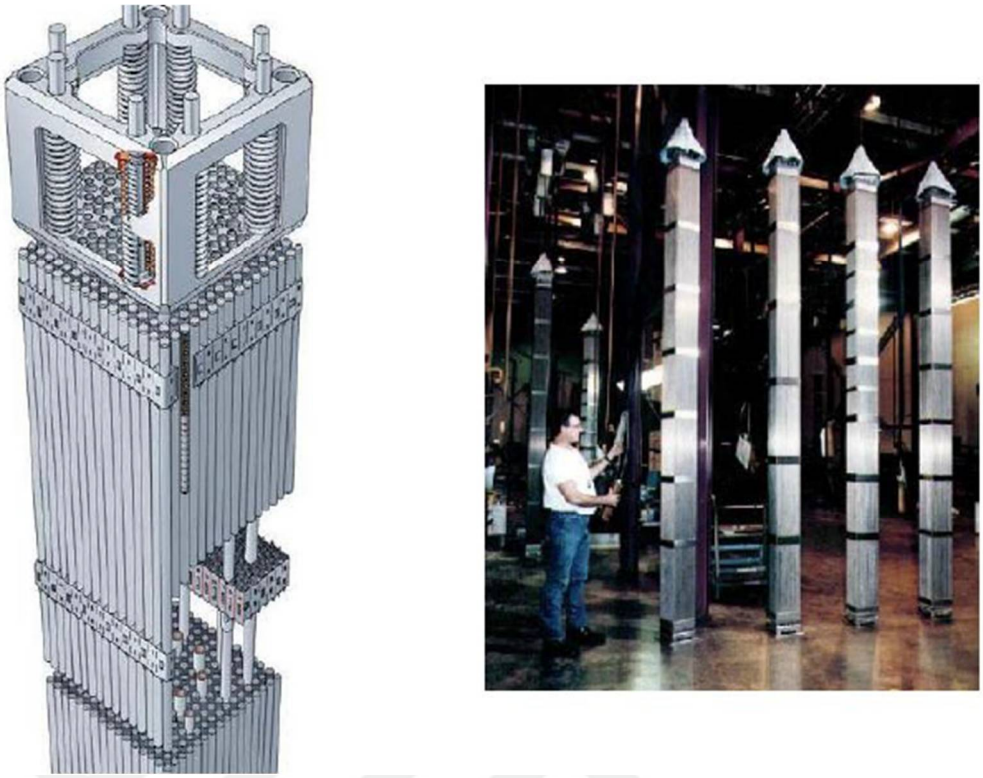

Figure 2.8 PWR type reactor fuel barrets.

It is seen the Figure 2.9 given below, VVER type reactor fuel barrets which will be used in our country.



Figure 2.9 VVER type reactor fuel barrets.

CHAPTER 3 USED NUCLEAR FUEL (UNF) AND WASTE

After the necessary fuels are burned and energy is produced in nuclear power plants, radioactive fuel is produced in different ways. These wastes usually occur during fuel manufacturing, during the uranium mining phase, when the reactor is operated, used fuel is processed and the reclaimed waste is reloaded into the reactor. In addition, power plants are not the only source of radioactive waste. Radioactive drugs, industry and industrial products used in the field of medicine constitute a significant amount of waste. In addition, a significant amount of radioactive waste is produced as a result of nuclear weapons programs.

Nuclear waste is the result of a chemical reaction containing radioactive chemical elements. At the end of this process, the waste sits as a byproduct of the chemical reaction. On the other hand, Carbon-14, Potassium-40, Uranium-238 and Thorium-232 are naturally emerging isotopes as the largest source of waste. If these wastes are subjected to concentration and highly enriched, they are treated as nuclear waste. Nuclear waste is collected under 4 main headings as low, medium and high level waste depending on amount of radioactivity.

- High Level Waste (HLW): The type of waste that occurs as a result of reprocessing and contains most of the fission products.
- Transuranic waste: Generally, plutonium isotopes with constantation in excess of 10^{-9}Ci/g. Transuranic waste is occured during the reprocess-recycling step and producing nuclear weapons.
- Low Level Waste (LLW): It is usually a type of waste that has constantation under 10^{-9}Ci/g. Waste that requires low armour or no armoring is required but still contains hazardous materials.

LLW includes:

- Materials used to process high radioactive parts.
- Medical materials used for therapeutic purposes or to diagnose the diseas such as x-rays.
- Some materials that is capable of doing α, β, χ emissions.

- Producing plastics for industry
- Some agricultural products [52].

- Mine Waste: This type of waste occurs during uranium mining. They have low concentration.

As mentioned earlier, the stage of removing used fuels from the reactor is expressed as the back end. Fuel bundles from the reactor are called used fuel, because they are not in a state of waste that does not work. These bundles are the same as fresh fuels that have not been burned in appearance. 5% of uranium pellets in fuel rods are burnt. These products are called "Used Nuclear Fuel (UNF) instead of the waste because they contain fuel-rich substances. In countries where the closed cycle is, UNFs are decomposed in reprocessing facilities and converted into Mixed Oxide Fuel (MOX).

3.1 Reprocess and Recycling

Reprocess is the process of separating used nuclear fuels into components. These components are used to be used to consists of uranium, fission products and plutonium. Various physical and chemical methods are used to reprocess. Reprocessing is sometimes carried out for preparation purposes prior to the final burial process. This process also reduces the volume and radiotoxide of the waste to be buried. This approach to used fuel management has not yet been implemented by many countries, but is preferred by some European countries (Belgium, France, Germany and Switzerland), India, China, Japan and Russia.

Reprocessing reduces the need for natural uranium by 10-15% through the recovery of plutonium during the operation process and its use in MOX fuel production. The separation of uranium and plutonium from other isotopes is commercially carried out using a chemical process called PUREX (Plutonium Uranium EXtraction). Fission products and minor actuators fall into the high-level waste class. Other residues are the metallic structures of the fuel depot that are called shells and endpoints. Reprocessing facilities were in very few countries because they were large, complex and expensive facilities

In the Figure 3.1, it is seen that the including of used nuclear fuel.

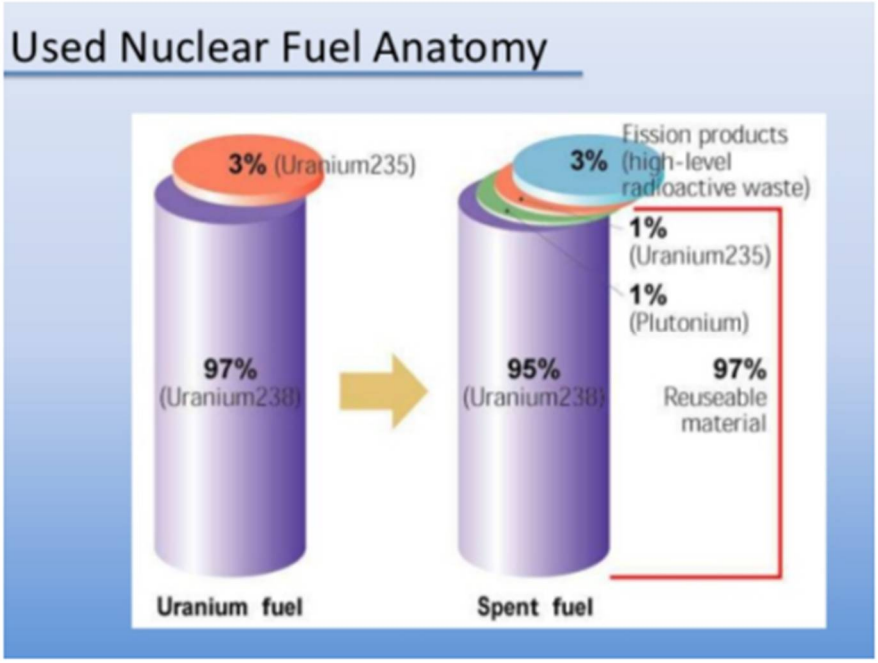

Figure 3.1 Including of used nuclear fuel [53].

On the other hand, it is seen the Figure 3.2 given below, there is recycle facility in France.

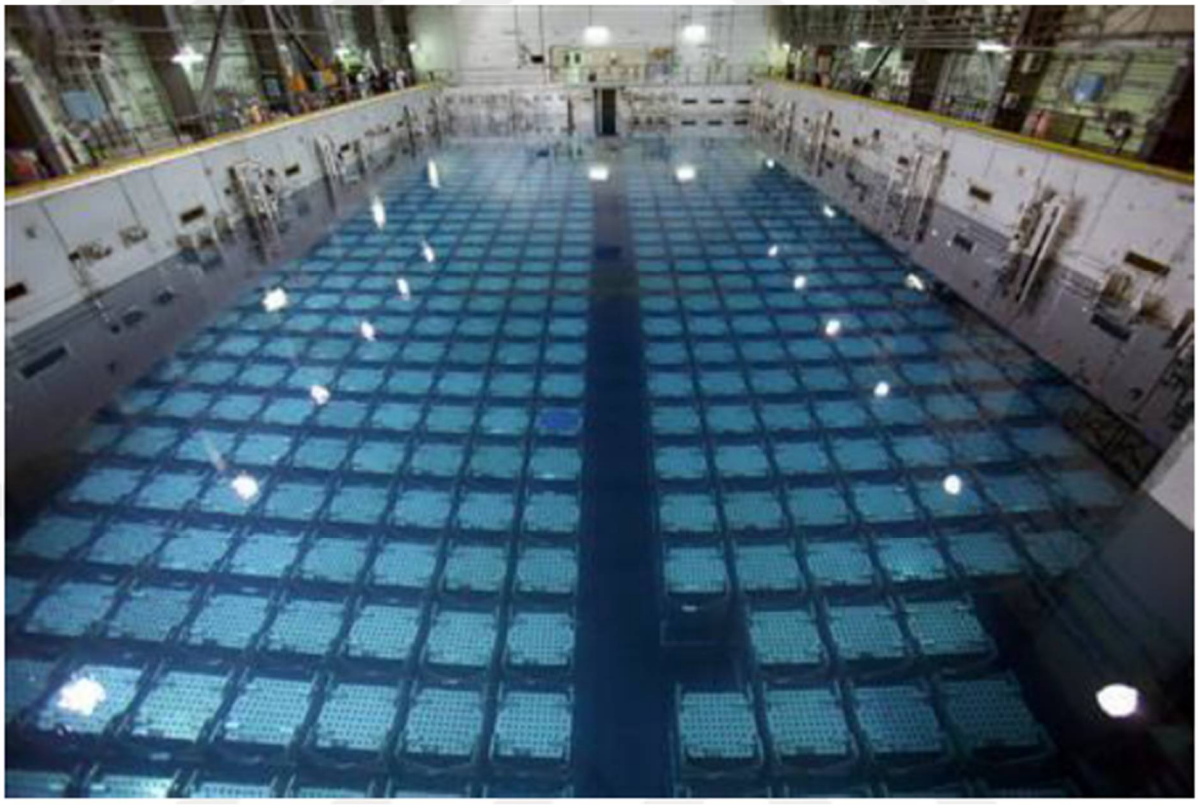

Figure .2 The biggest reprocess and recycle facility in the world in France [54].

Used fuel from a transport barrel is transferred to the pools for further decay and cooling. After adequate cooling and decay, the mechanical cutting machines integrated into the system and the fuel rods are cut into 3 cm long parts. These parts fall into compartments with nitric acid to dissolve UO_2 and separate zirconium alloy shells surrounding the fuel bar. Then a watery solution from the pre-filtering process continues to render the solver. This extraction process is called PUREX.

The solvent in the recovery of plutonium and uranium with PUREX is the diluted organic compound Tributyl Phosphate (TBF). The separation of used fuel into components is shown in Figure 5.3 The resulting uranium has a U-235 content that is denser than natural uranium. Uranium can be set aside or reenriched by isotope separation processing. The resulting plutonium is converted into a suitable oxide for combining with uranium oxide, which will form a mixed oxide (MOX) containing all or part of the reactor fuel.

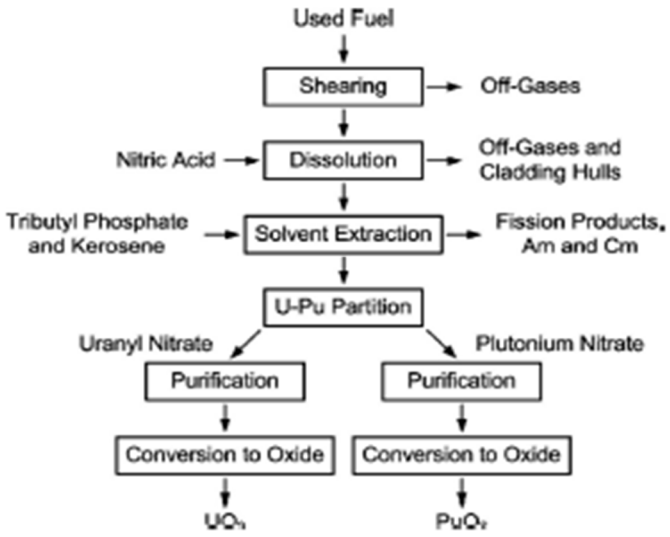

Figure 3.3 Simplified diagram of PUREX nuclear fuel reprocessing process [55].

Countries such as France, Germany, Britain, Russia, Canada and Japan have active reprocessing facilities. An important feature of reprocessing is that the recycled plutonium is a nuclear weapons material. Because of concerns about nuclear weapons, Carter, who was then us prime minister, argued that the reprocessing process should be abandoned in 1977, which was banned, but then in 1981, President Reagan lifted

the ban. But the uncertainties still persisted. The United States is currently on hold its place in the still storage on Yucca mountain. Because of the tons of used fuel to be buried, 95% of the fuel can be used.

On the other hand, the concern of armaments seems to be a barrier to reprocessing. With the technology developing in the future, these uncertainties will become clear. MOX fuel produced is currently available in FBrs. The commercialization of FBR reactors will be in the 2050s. More Pu-239s are produced in FBrs and these reactors and closed cycle facilities are expected to become widespread [56].

3.2 Disposal of Nuclear Waste

Radioactive waste occurs in different areas of practice such as medicine, industry, research in different areas of activity, physical and chemical situations. The half-life of radioactive waste varies depending on the type of element but can be from several years to centuries. Radioactive waste is classified within different criteria. Many countries have developed a different waste classification system depending on the characteristics required by waste management to be implemented. Waste is processed and disposed of as required by their classrooms.

The approach in the facilities for the long-term storage of radioactive waste is to concentrate radioactive waste and to store them in closed environments such as concrete, asphalt and glass, which are defined as matrix. Radioactive waste should be stored for different periods depending on the half-life and other characteristics of radionuclides in them.

Storage facilities for radioactive waste can be collected in roughly two groups; close surface storage facilities and deep storage facilities.

Studies are carried out all over the world in order not to affect the environment and human health of radioactive waste and to protect people and the environment in the most effective way. To this end, the inventory of radioactive waste and waste final disposal facilities is regulated and stored in conditions that allow future generations to be clearly informed and easily access waste records.

Basic safety criteria for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (United Convention on Used

Fuel and Radioactive Waste Management) by the International Atomic Energy Agency (IAEA); waste safety is guaranteed internationally by determining from technical and administrative perspectives. The legal regulation on Radioactive Waste Management and Storage facilities in Turkey is article 4 of the Turkish Atomic Energy Authority Law No. 2690. Article (f) and "Radiation Safety Regulation" 8. It is located in the paragraph (c) of the article. Within the framework of the specified legal powers, low and medium radioactive waste (LILW) processing and temporary storage facility has been established within the TAEK Çekmece Nuclear Research and Training Center and continues to operate [57].

3.2.1 Disposal of Low-Level Waste

The disposal of low and high-activity waste is carried out in different ways. As mentioned earlier, low or medium-level waste is solid, such as gloves and clothes coming out of power plants or hospitals; liquids used in disinfectant. These wastes are expected to decrease in activity by holding them in a controlled manner in the facilities. They are then sent to low-level operating facilities. Solid, liquid and gas-shaped waste spills are processed by compression, burning and other methods in these facilities and their volumes are reduced and filled into barrels.

Waste is first filled into green barrels and kept in waste processing facilities. They are then subjected to a number of operations. Solid waste is reduced by approximately 1/150 by burning and compression methods. Liquid waste is reduced by approximately 1/500 by evaporation and drying methods. As a result of the operations, the sludged liquid or compressed solids left in the middle are mixed with cement and plastic in yellow barrels and turned into fixed barrels. Processed yellow waste barrels are audited and their radioactive activity and density are measured. After approval, 8 waste barrels are placed in large transport containers of 1.6mx3.2mx1.3m and covered up. They are sent by land or train to the final storage facility. They're stored here for up to 500 years of hold. Many substances in waste fall to the level of natural radiation within 100 years. The remaining 20% of the content is radiation rates after about 500 years, and natural radiation levels. Transport barrels are stored about 12 meters below the ground using systems that will not leak water. It is cemented and covered with soil in the top layer.

3.2.2 Disposal of High-Level Waste

High-level waste varies for indoor or open cycle. In the open cycle, all KNNs coming out of the reactor are considered waste and, in the form of a fuel bundle, are first stored in pools at the power plant site or in dry storage barrels at the power plant site to cool down. These are temporary storage methods. It is then buried in a land allocated for final storage, covered very firmly. This embedding happens again to prevent these fuels from coming to earth.

In the closed cycle, UNFs are sent to the reprocessing facility after cooling in pools for about 5-10 years. Here, Plutonium and Uranium within UNFs are decomposed. All that remains is high activity fisyon products. This waste cannot be cemented and deppered like low-level waste. For this reason, a stronger method of protection, the way to the glazing path is reached. High-level waste strapped to steel barrels is sent to final storage facilities.

There are basically two ways currently applied in almost all countries for the storage of high-level nuclear waste: storage pools and dry storage facilities. These two methods are temporary storage systems, not a definitive solution for waste. But no country has ever buried its waste 500-1500 meters below the ground. Because countries with nuclear programs think that the valuable elements within the UNFs can operate at a later time. Because it's very difficult, even if it's not impossible to re-remove a UNF that's being stored in the final. For years, the United States, which built a final storage facility on Yucca mountain and opposes closed cycle, has decided to stop it for final storage.

Temporary storage pools are pools with a depth of approximately 8-9 meters inside the reactor building. As soon as the UNFs exit the reactor, they are placed vertically in these pools. It covers up to 4 meters of water on the bundles. This water is both cooling and a powerful armouring task. In this way, as seen in Figure 3.4, there is no serious radiation radiation around the pool.

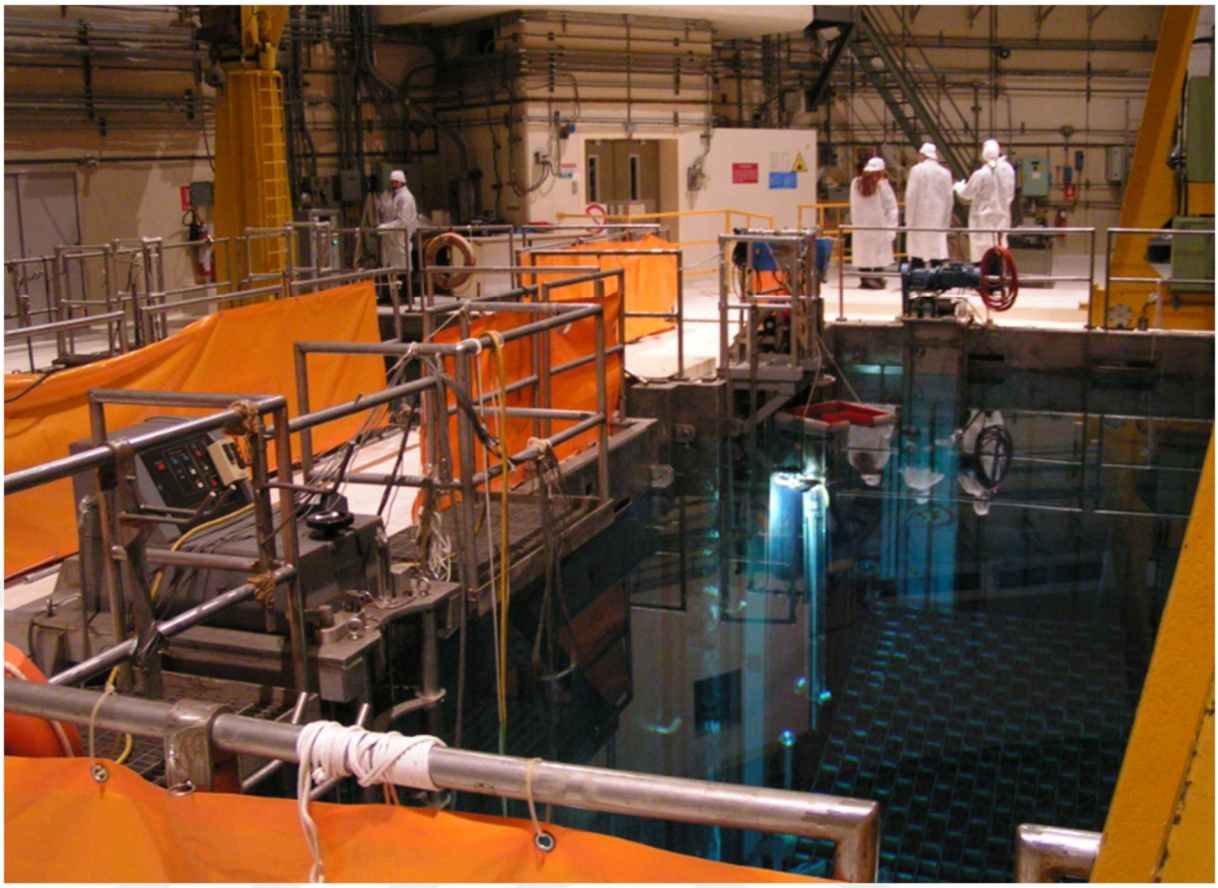

Figure 3.4 Used nuclear fuel pool and workers [58].

Other temporary storage form is a way to store in barrels in warehouses built within the power plant site or privately allocated nearby. This storage shape, called dry storage, allows natural air circulation to cool waste. The cost of dry storage shown in Figure 3.5 is higher than wet storage.



Figure 3.5 Dry storage facility [59].

To summarize, the waste from the nuclear plant can be stored in four basic ways. The first and second storage methods are temporary methods and will require continuous maintenance. On the third road, valuable materials in UNF will not be available and will leave a huge volume of waste. For example, a reactor with a power of 1200 MW comes from a reactor in a year, approximately 30 tons of UNF, or 3-4 m^3 UNF in volume. However, approximately 1 ton of waste will be produced in the final method of glassing and final burial. But the most difficult and costly way is the last. The ways of disposal of the wastes are listed below.

1. Pools filled with UNF bundles or dry storage on-ground.
2. Over-the-ground storage facility filled with glazed waste.
3. Permanent burial of UNF bundles 500-1500 meters underground.
4. Ultimately buried deep in the ground of glassed waste.

When thermal power plant waste sits generally with a nuclear power plant, it is quite clear that the nuclear power plant is both cheaper and greener than the thermal power plant.

A thermal power plant with a power of 1000 MW requires 3 million tons of fuel per year, while as a result 7 million tons of carbon and sulfur dioxide gas waste and 150-200 thousand tons of ash waste are produced released into the annual atmosphere.

If a nuclear power plant with a 1000 MW power is considered, the annual fuel requirement is only 25 tons. Again, 1 ton of radioactive waste is produced, which is glazed by reprocessing.

The processing of waste is considered the final stage of the fuel cycle. Fuel cycle and some of the amount of nuclear waste are needed to produce 3-4% enriched uranium fuel for a year, according to information tailored on the World Nuclear Organization's website. The amount of UF_6 to be obtained within this ore will be around 200 tons. UF_6 remains about 20 tons after being enriched at its enrichment facility. The UF_6, which has enriched around 20 tons, is converted into fuel at a fuel plant for an average of 25 tons, which burns an average of 5,000 days in the reactor.

Finally, in Figure 3.6, all stages of the mining, processing, fueling and burial of uranium were shown and a summary was presented.

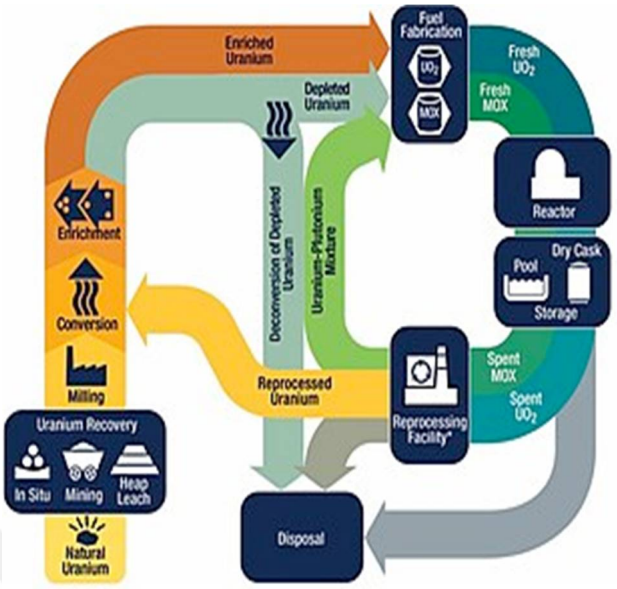

Figure 3.6 Nuclear fuel cycle with details [60].

3.3 Waste Management and Future of Waste Management in Turkey

At the end of the power generation, products and waste will be produced in different ways to be stored from the nuclear plant. These are, respectively; used nuclear fuel rods, radiation liquid waste and low-level solid radiation products such as gloves and clothing. Again, these wastes can be separated between themselves as low, medium and high radioactive.

Low levels of radioactive liquid and solid waste from power plants have almost the same characteristics as radioactive waste in hospitals. These wastes; Gas and steam as well as some particles, gloves used by the staff, clothes, such as solid liquids and liquids in that area. The safe transportation of these wastes and its temporary and final liquidation are carried out by the Turkish Atomic Energy Authority. Radioactive waste in hospitals is also taken and destroyed by TAEK by special vehicles.

The method used for the disposal of gas waste is the filtration system. Radioisotopes, which are short-lived, are also kept in warehouses for a while to reduce their activity.

Liquid waste produced in medicine is usually short-lived. These wastes are released into the environment such as normal liquid waste, taking into account the maximum permitted limit and the IAEA's release limits are also taken into account. However, if

the liquid is long semi-lasting and moderately active, it is first passed through chemical applications and then converted into a small volume by evaporation or ion exchange method. The resulting radioactive concentrate is cemented and placed in the barrels and thus rendered harmless.

Solid waste; by burning or compressing. After cremated waste is burned, the remaining ash is cemented and rendered harmless. Compressible waste is compressed and cemented with a powerful press machine. The unburned and uncompressed solids are cemented directly and placed in the barrels. These wastes placed in barrels are stored in temporary warehouses according to their radioactive activity.

All of these described storing applies to temporary storage. An final form of storage means burying it underground in today's conditions. Low and medium-level waste is kept in temporary warehouses for a while and then buried in the ground at superficial depth and stored in a final way. High-activity waste should be buried at least 500 m below the ground.

As mentioned earlier, no country has ever storing high activity used fuels in the final way as there is reprocessing.

There is only low and moderate radioactive waste in Turkey. Most of these wastes occur during medical and industrial studies. TAEK law no. 2690. Article: TAEK has the duties, powers and responsibilities to take or take the necessary measures to securely process, transport, temporary and continuous storage of radioactive waste from nuclear facilities and radioisotope laboratories. Within this framework, "Çekmece Nuclear Research and Education Center-(ÇNAEM)" was established. The ÇNAEM is responsible for making medium and low-level waste harmless. The waste processing plant was established in 1989. The wastes, which are cemented and filled into barrels, are stored in temporary warehouses at this facility and are under supervision. There is no designated location for final storage in Turkey yet [61].

On the basis of the liquidation of high-activity wastes. İf we store the used fuels of the four reactors to be established in Mersin in an Olympic pool of 25m x 50m, it is needed to know the size of the fuel rods and fuel bundles in the reactor to calculate how many years this pool will be filled. The dimensions of the fuel-related materials of the VVER-1200 reactor are given in Table 3.1. Operations were made using this table.

The VVER fuel beam used in the reactor is shown in Figure 3.7. These coming bundles are stored upright in the pool.

Type of Material	Dimension
The Lengt of the Fuel Bar	365,8 cm
Outer Diameter	0,9499 cm
Cage Thickness	1,260 cm
The Number of Fuel Rods in Every Fuel Beam	312
The Number of Fuel Beam	163
One Side of a Fuel Beam	15 cm
The Shape of a Fuel Beam	Hexagon
The Distance Between Two Fuel Rods (Pitch)	1,5 cm

Table 3.1 The dimensions of the fuel-related materials of the VVER-1200.

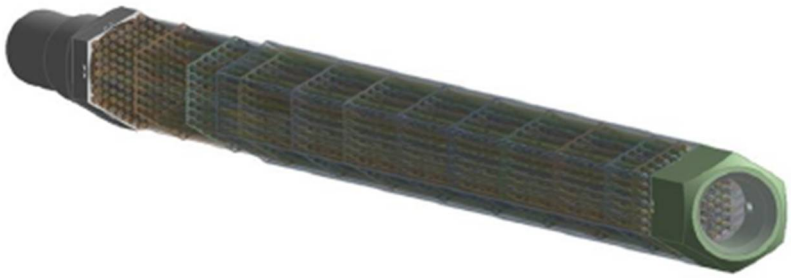

Figure 3.7 VVER fuel beam [62].

Used nuclear fuels are stored in a pool One side of the hexagonal fuel hole is 15cm. Approximately 1 cm distance should be left between each fuel hole. If the gap is taken into account, one edge can be considered 15.5 cm. The vertical area of the hexagonal with an edge of 15.5 cm is 624.18cm^2. We can store the fuel in an Olympic pool. A standard Olympic pool size is 25mx50m. The pool area is also 12.500.000 cm^2.

$$\frac{12500000}{624,18} = 20032$$

According to these calculations, an Olympic pool can store approximately 20.000 fuel bundles. The depth of the pools should be around 8-9 meters. Fuel bundles are 4 meters in length. Approximately 4-5 meters of water, which will remain on the bundles, acts as an armor against radiation.

The refueling period of VVER reactors is 18 months. In 18 months, a third of the used fuel comes out. This means that 1/4 fuel beam is extracted each year. In total, about a quarter of the 163 descriptors are 41 fuel bundles. An average of 41 fuel beams come out of a VVER reactor each year.

If the Akkuyu nuclear plant puts all four units into operation, a total of 164 fuel beams will be released from four units each year. Since an Olympic pool can store 20,000 fuel pots, this pool will only fill up after 20000/164 = 121 years later.

As the above calculations suggest, the volume of used nuclear fuels is quite small. However, this does not mean that nuclear waste is destroyed. This form of storage is ultimately temporary. In these pools, fuel bundles that are held after a long time are either reprocessed as mentioned earlier or buried 500 m below the ground so that they will never go up again. This is the most reasonable way to appear under current circumstances. However, no country, including the United States, has buried used fuelunderground. Because future technology can offer better methods.

It can store used fuels in Turkey for many years in a pool at the power plant site. This process is very safe and healthy. However, it requires an additional cost of maintenance. Due to future uncertainties, space selection work must already be started for final storage.

Our country, which began nuclear power plant operations in the 1970s, has not taken a serious step in this field for political and economic reasons. Ground surveys, uranium and thorium exploration were completed in the 1980s. In 2004, nuclear energy was again on the agenda. Hilmi Guler, the former minister of energy, who stepped up the work in 2005, announced that the foundation of the first plant would be laid in 2007 and the "Nuclear Energy Act" was passed in 2007. However, President Ahmet Necdet Sezer vetoed the law on the grounds that it was unconstitutional. Later, the law was

sent back to parliament and the law on the establishment and operation of nuclear safe power plant number of 5710 was adopted. The relevant regulations were issued in 2008. Thus, the legal framework is drawn.

In 2009, nuclear power plant tenders were cancelled due to inadequate demand and inappropriate conditions, according to a report in the Sabah newspaper. Thus, four nuclear power plant auctions were cancelled in the history of Turkey. These are tenders made in 1979, 1985, 2000 and 2009 respectively [63].

As a result of the tender in 2010, The Russian Nuclear Company Ros Atom of mersin Akkuyu Power Plant tender was won. In the same year, an intergovernmental treaty was signed between Russia and Turkey.

Sinop is the second nuclear power plant planned to be established in Turkey. Work for the Sinop plant began in 2008 and relations with Japanese companies were carried out. But these talks have been suspended following the Fukushima nuclear accident. Then, in May 2013, a deal was reached with Mitsubishi heavy industries (MHI) and Areva, a France-Japanese consortium. A total of four units are planned to be made of 4600 MWe, each with 1150 MWe power, from the pressure water reactor of type 1 atmea. The first unit was decided to start in late 2017 [64].

The planned third nuclear power plant has been decided to establish the İğneada position of Kirklareli. In November 2014, negotiations and agreements were reached with China's Nuclear Technology Corporation (SNPTC) and Westinghouse. The date of construction of this plant has not yet been specified. Mersin and Sinop will be the first, and then the construction of the plant in İğneada will be gradually started.

The cities Turkey plans to build a nuclear power plant, plant types, capacities, start and operating date are shown in detail in Table 3.2. Turkey is working to launch at least 2 nuclear reactors by 2023.

	Type	MWe	Date of start	Operating date
Mersin-Akkuyu 1	VVER-1200	1200	End of 2016	2023
Mersin-Akkuyu 2 Mersin-Akkuyu 3	VVER-1200	1200	2017 2018	2023 2024
Mersin-Akkuyu 4	VVER-1200	1200	2019	2025
Sinop 1 Sinop 2 Sinop 3	Atmeal	1150	2017 2018 ?	2023 2024 ?
Sinop 4	Atmeal	1150	?	?
Kırklareli-İğneada1-4	AP1000x2 CAP1400x2	2x1250 2x1400	?	?

Table 3.2 Plant types, capacities, start and operating date in Turkey.

3.3.1 Mersin- Akkuyu Nuclear Power Plant

The Akkuyu project is of great importance for the energy diversity and the closure of the energy deficit. Within the scope of this power plant treaty, 4 units will be established, each with 1200 MWe power, within the power area of Akkuyu in Gülnar district of Mersin. Thus, Turkey will have a power plant with an average installed power of 4800 MWe. The first two units at the plant will be operational in 2023 and the other two units in 2024 and 2025, the official company said. Akkuyu N.G.S. Elektrik A.Ş. is responsible for the plant.

The Ministry of Energy estimates that our country's installed power in 2023 will be around 110.000-130.000 MW and electricity generation will be 500 billion-kWh. Our country imports all of the natural gas and liquid fuels it uses for electricity generation.

In addition, approximately 30% of the coal used is imported. On the other hand, due to low efficiency in renewable energy sources and the lack of work sufficiently

economically, the desired electricity generation will not be realized. For these reasons, nuclear energy is becoming more imperative than an alternative. The electrical energy that akkuyu nuclear power plant will generate in one year is;

See:

According to Turkey's 2019 data, electricity generation is approximately 290.9 million MWh. A reactor with a power of 1200 MWe will produce in a year when it operates at 90% efficiency (capacity factor)

amount of electricity;

$$365 \text{ days} \times 24 \text{ hours} \times 0.90 \text{ efficiency} \times 1200 \times 10^6 W = 9.46 \times 10^9 kWh$$

Since a unit in Akkuyu will generate an average of 9.5 billion kWh of electricity per year, approximately 40 billion kWh of electricity will be generated when all four units are operational. In addition, if the plant in Sinop is operational, this value will double, meaning 80 billion kWh of electricity will be produced. 80 billion kWh corresponds to 25% of Turkey's current electricity generation.

As previously stated by accounts, a reactor unit in Akkuyu produces 9.4608 billion kWh of electricity annually. On the question of how many nuclear reactors would be needed if Turkey had only produced electricity using nuclear reactors, it was concluded that 31 reactors were sufficient as a result of the following calculation.

$$\frac{290{,}9x10\text{^}9kWh}{9{,}4608x10\text{^}9kWh} \approx 31$$

Assuming an average of 4 units will be installed in a power plant area, an average of 7.5 plants will be established. Even these small calculations show how much power nuclear plants provide. The area where akkuyu nuclear power plant will be established is approximately 15km^2, which is 55 times smaller than Atatürk Dam, which has an area of 817 km^2. The plant will also provide approximately twice as much power as the installed power of this dam. As you can see from here, there is no need for massive areas for the nuclear power plant. This is seen as an important and great advantage.

3.3.2 Sinop and Other Planned Nuclear Power Plants

After Turkey's first nuclear power plant was designated as ANS, it was decided to install new plants in new locations. ANS will be established by the Russians and operated for 15 years. From this point of view, an outbound plant is established in the

first place in the operating-maintenance-fuel area. The energy sector can suffer in a possible intergovernmental problem. As a matter of fact, on November 24, 2015, relations between the two countries were strained due to the Russian plane that Turkey had shot down on the grounds of border violations, and the nuclear power plant project was negatively affected by this tension. After the incident, the plant project was suspended for a long time. For these reasons, there must be alternatives to nuclear power plants in order to maintain energy. As an alternative to Mersin Akkuyu, two separate plants with The Japanese and China or The Americans were planned to be established in Sinop Inceburun and in the region of İğneada in Kırklareli.

Work was initiated for the Sinop Nuclear Power Plant and on May 3, 2013, an intergovernmental nuclear power plant treaty was signed between Japan and Turkey. Under this agreement, Turkey will become a shareholder of 49% and will design the plant, Mitsubishi Heavy Industries (MHI). One of the most important purposes of the Sinop plant is the production of the plant with domestic facilities and the priority of the possible goods and services. For this purpose, MHI performed a preliminary feasibility study.

All reactor types and properties planned to be used in Sinop have been previously stated.

The third plant planned to be established in Turkey is planned to be installed in the district of İğneada in Kirklareli. However, no serious work has yet been done on this project. Negotiations are currently underway with American company Westinghouse and Chinese companies for this plant. It seems possible to be involved in other companies in future processes.

All reactor types and properties planned to be used in Kirklareli have been previously stated.

The establishment period of nuclear power plants is constantly delayed for many reasons. Turkey's first priority will be the completion of Mersin Akkuyu Power Plant.

CHAPTER 4 ECONOMICAL ASSESMENTS

4.1 World Nuclear Economy

The type of power plant to be installed depends on many factors. For example, in a country where the number of sunny days is very small, no solar power plants are installed. Because the cost will be more than production, it won't make sense. The establishment of the plants depends on a variety of factors as Table 4.1 shows that the capacity factor, the initial investment cost, is local or dependent on the outside. Nuclear Power Plants look attractive with an 85-90% capacity factor and an average unit production cost of 5cent/kWh. But the initial cost of investment and the security concerns that exist in the public eye are the obstacles to nuclear. However, the initial investment cost is almost the same as thermal power plants.

Power Plant Type	Local/ Foreing-Dependant	Capacity Factor(%)	Initial Invesment Cost ($/kW)	Unit Energy Production Cost(Cent/kW)
Thermal Power Plant with Natural Gas	Foreing-Dependant	85-90	500-1.300	3.6-10.6
Thermal Power Plant with Lignite	Local	50-85	2000-3000	4.6-12
Thermal Power Plant with Imported Coal	Foreign-Dependant	50-85	1900-2600	2.7-3.5
Hydroelectric Power Plant	Local	30-45	2500-5000	3.0-8.2
Nuclear Power Plant	Local/Foreing Dependant	85-95	2500-5000	3.0-8.2
Wind Energy Power Plant (h: 30m, υ:8,5m/s)	Local	25-45	1200-2500	5.1-14.6
Geothermal Power Plant	Local	80-90	1700-4000	3.3-4

Solar Powered Power Plant(Fotovoltaic Battery)	Local	20-25	4000-8000	12.3-24.5
Biomass Power Plant	Local	80-90	2000-3500	4.8-8.0

Table 4.1 Investment factors in power plant [65].

Once the initial investment costs are taken into consideration, nuclear power plants become much more attractive. Because nuclear power plants with maintenance-operating costs of 0.78 cents/kWh and fuel costs of 1 cent/kWh are far less cost than thermal power plants and are less operational-maintenance costs than non-fuel renewable energies. The maintenance and fuel costs of other power plants can be examined from Table 4.2

Power plant type	**Cost of Business-Maintenance($/MWh)**	**Fuel cost ($/MWh)**
Thermal Power Plant with Natural Gas	4.15	36.09
Thermal Power Plant with Lignite	14.95	18.39
Thermal Power Plant with Imported Coal	14.13	19.65
Hydroelectric Power Plant	2.03	0
Nuclear Power Plant	7.8	10
Wind Energy Power plant	12	0
Geothermal Energy Power Plant	18	0
Fotovoltaic Battery	16	0

Table 4.2 Cost of business-maintenance for power plants [66].

Energy production costs for a nuclear power plant are generally examined in 3 parts and expressed in kWh.

Capital Cost can be listed as materials, land allocation, loan interest and construction expenses. Operating and Maintenance costs include Insurance, taxes and consumables. These expenses continue during the operation of the plant. Nuclear Fuel and Assembly Manufacturing Cost includes the enrichment of fuel, the liquidation of used fuels.

Nuclear power plants have very high capital costs and but low fuel costs compared to other power-generating power plants. U.S. spends $0.001/kWh to cover fuel disposal only.

Factors that directly affect the cost of electricity fuel are the plant's heat efficiency (ηth), fuel expense FC ($/kg) and the combustion rate of fuel (B) [67].

The equation of fuel cost is;

$$ef = FC / (\eta th.B) \quad (7.1)$$

Uranium is a mine that can be bought and sold and marketed. The most traded uranium is natural uranium. Natural uranium is uranium containing 0.71% U-235. This concentrate is taken for use in CANDU reactors or by countries with uranium enrichment facilities.

The second uranium traded is uranium, which is enriched by around 3-5%(lightly rich uranium). This is called uranium oxide (UO2). Black and brown are powdered substances. It is the main fuel of light water reactors.

Another commercial uranium is 20% enriched uranium. This fuel is used in research reactors. Uranium, which is higher than this rate, cannot be commercially purchased and sold. Because wealth over 20% is the beginning of nuclear weapons.

By 2020, the price of natural uranium is approximately $69/kg. By 2020, the price of enriched uranium is approximately $1.000/kg [68].

In the light of the information given, the distribution of the cost rates of the nuclear power plant is shown in the Table 4.3 below on the basis of percentage language.

Cost Titles	Cost Rate (%)
Uranium	5
Investment	60
Production of Fuel	3
Decommisioning	16
Operation and Maintenance	4
Waste Management	5
Enrichment	1
Recycling	1

Table 4.3 Distribution of the cost rates of a nuclear power plant.

The total cost of a four-unit nuclear power plant is said to be around $20 billion. This is initially the recommended cost for Akkuyu. However, as the financial balance changed at times, no clear cost is currently laid out. According to the latest reports, the cost is said to have increased by 57 billion Turkish liras. However, these sources have not been made with any official explanation. Within approximately 10 years of establishing nuclear power plants, it pays off costs and goes by land.

4.2 Turkey Nuclear Economy

According to the Akkuyu Nuclear Power Plant treaty, Turkey will buy 70% of the electricity produced by the first and second units, 30% of the others, at 12.35 cents/kWh (excluding VAT) for 15 years [69].

The investment cost, called the first cost of each plant to be installed, is the most important factor. The initial investment costs of nuclear plants range from $2500-5000/kW. The initial investment cost for the VVER-1200 type reactor, which will be established in Turkey, is set at $2933/kW based on VVER-1150. This cost can be considered $3000/kW considering economic fluctuations [70].

So, the initial investment cost of a power plant of 4800 MW is around $14 billion. Turkey spends around $3 billion on Akkuyu as investment costs up to 2016.

In light of the information obtained from the internet address of Akkuyu Nuclear Corporation, the most important cost after the initial investment costs is the fuel cost. Turkey will also supply the fuel from the Russian company because it does not have an enrichment facility. The fuel to be used in Akkuyu will be 3-5% lightly enriched uranium. The annual fuel cost of the Akkuyu Nuclear Power Plant is described as an average of $360 million. Approximately $40 billion of electricity will be generated annually with $360 million in fuel. 8 billion m^3 natural gas is used to generate 40 billion kWh of electricity. The cost of 8 billion m^3 of natural gas is about $3.6 billion

In the Table 4.4 below, the amount and prices of fuel from the nuclear power plant and natural gas plant are clearly seen.

	Amount of Fuel	**Price of Fuel**	**Production of Electric per Year**
Nuclear Power Plant	120 Tons of Uranium	$360 million	40 billion kWh
Natural Gas Power Plant	8 billion m^3 Natural Gas	$3.6 billion	40 billion kWh

Table 4.4 Nuclear and Natural gas power plants fuel price and amounts for Turkey.

Based on the information in Table 7.4, it is possible to say that a natural gas plant that will generate 80 billion kWh of electricity can be built with the money to be paid in 6 years. When Akkuyu is built, it will be able to generate electricity in one year at a cost of 10 times less fuel than the natural gas plant.

As long as the plant is in operation, the most important cost will be the cost of operating and maintenance. This cost will also be based on the VVER-1150 reactor, which will be around $16.8/MWh.

The project company will pay 0.15 cents/kWh to the used fuel and radioactive fuel management account as part of the electricity sales agreement obtained by TEIAS. Under the agreement, the company is also responsible for the waste, and used fuels can be transported to Russia and processed from new facilities there. For UNF stored in a waste warehouse and its disposal, the increase in production costs per kWh is around 10%.

Fuel cycle costs are in the range of $4-11/MWh and average $9.34/MWh. This range is the total numbers for both the front and the back end. The preliminary stage of the fuel cycle is approximately $7.8/MWh. If the back end is added approximately $1.54/MWh, the total is $9.34/MWh. Fuel costs in the Akkuyu treaty are also in line with these calculations. If the Akkuyu nuclear power plant is charged with annual electricity generation of 40 billion kWh, the cost for annual waste will be $370.36 million.

The final cost of the nuclear plant is the cost of decommissioning. These reactors must be removed and removed from operation after its establishment and revisions (approximately 100 years). According to the nuclear agreements between Turkey and Russia, all decommissioning and dismantling operations will be carried out by the authorized Russian company. Ros Atom will pay 0.15 cents/kWh in an account for decommissioning as well as the cost of waste. The cost of unemployment accounts for approximately 9% to 15% of the initial costs of a nuclear power plant. If Akkuyu's initial investment cost is accepted at $14 billion, the cost of decommissioning will be about $1.5 billion. The U.S. discloses these costs by 0.1 to 0.2 cents/kWh in 2016 [71].

4.3 Economical Management of UNF and High Activity Nuclear Waste

As mentioned earlier in this study, approximately 95.5% of the used nuclear fuel from the reactor consists of uranium, 0.9% plutonium, 3.5% light isotopes, and 0.1% of other heavy isotopes, such as Neptune, Americanium and curium. Only about 5% of the original fresh fuel has changed, and about a fifth of that change is Pu, which is a valuable element for nuclear energy production and is not found in nature. When the used nuclear fuel comes out of the reactor, it's terminally anti-radioactive. Over time, radio activity decreases. In an average of 40-50 years, the value drops to one thousandth of the time it leaves the reactor. But on the other hand, it remains a potential danger to man and the environment. It is almost impossible to distinguish nuclear fuel, which is used with fresh fuel from appearance. The outer structures are the same. 96.4% of used nuclear fuel is made up of substances that can be used as fuel again. It is possible to obtain U and Pu separately with a number of chemical processes. The remaining 3.6% is the part responsible for most radio activity of used nuclear fuel. Chemical processing of used nuclear fuel involves many economic uncertainties. In addition, the reclaimed Pu is a potential nuclear weapons material. For this reason,

many countries, especially the United States, have not adopted the path of recovery industrially.

All of the nuclear fuel used because of this unadopted condition is considered waste and treated as high-activity nuclear waste status, although it contains 96.4% available material. Therefore, it is planned to be liquidated in accordance with this classification.

When it comes to used nuclear fuel, chemical separation methods alone are inadequate. Almost everything must be done by remote control method in heavily armored process areas. This is reflected as a very serious factor in the cost. With recovery, the need for fresh fuel can be reduced by 40%. Although used nuclear fuel processing may seem a requirement, it is undeniable that the event has very serious cost dimensions.

Processing of used nuclear fuel contains many economic uncertainties. All of the processing facilities available are based on a design based on the retribution of U and Pu separately and purely. This thesis argues that such an approach is unnecessary in civilized technology. The use of Saf Pu as nuclear weapons material raises a question mark in the handling of the UNF for peaceful methods. At this point, China stands out as a leading technology to the world. China does not establish any recovery facilities, but re-process UNF in a different type of reactor. These reactors, which are custom designed, are called Defense Reactors.

As uranium reserves decrease and consequently, as Uranium prices increase, as energy requirements and prices increase, UNF will become a reserve. In the following years, it is inevitable to think and address UNF as a reserve, not a waste. Many countries, especially the United States, are in no hurry to bury UNF underground. As a result, burying thousands of tons of UNF, which is valued at 96% and has the potential to be much more valuable in the future, requires a serious workforce, appropriate geological structure and cost.

CHAPTER 5 CONCLUSION AND DISCUSSIONS

In this thesis study, the work of Turkey, which has been trying to establish a nuclear power plant for more than 50 years, has been examined. Research has been carried out on the development, cost and waste of Akkuyu Nuclear Power Plant, Turkey's first important step in the field of nuclear technology; other power plants planned to be installed, the country's uranium and thorium resources were also provided. With this thesis, analyses have been made about Turkey's nuclear future and recommendations have been presented.

There has been a negative mood about nuclear energy in recent years. In particular, there have been reports that the United States has not been building new power plants for a long time, saying that the world has given up nuclear and that some countries are shutting down nuclear power plants. However, to say that nuclear power has been abandoned through this news is due to a serious lack of information. Instead of making a new plant thanks to evolving technologies, the life span of an existing plant can be extended for about 40 years. This application costs much cheaper than building a new power plant. That's what nuclear giants' countries like the U.S. and China are currently doing.

Nuclear energy is an energy with advantages and disadvantages, such as many types of energy. With a small amount of uranium, the main fuel of nuclear plants, a large amount of energy can be provided. Fuel transport is easy. Nuclear plants have virtually no effects, such as greenhouse gas essays and acid rain. Nuclear energy studies have a long experience and scientific basis. Fuel costs are low in the face of energy costs. These advantages make nuclear energy attractive.

On the other hand, nuclear plants have disadvantages such as the problem of high-activity waste, radioactive materials that can be released to the environment after a serious accident, emergency control systems, the high cost of establishment. International barriers and sanctions also make it difficult for governments to invest in this area.

For the first nuclear power plant to establish, Turkey has selected the VVER-1200 (AES-2006) reactor, an improved version of the VVER-1000 reactor produced by the Russians. The VVER-1200 will be a reactor with active security systems and high

efficiency. Russia has announced that it will operate the first power plant of the VVER-1200 at the end of 2016 and is currently in the process of establishing 10 reactors around the world. There is also a 15-year experience from the VVER-1000. TAEK (Turkish Atomic Energy Association) is requesting a licensed and construction of this reactor from Russia as a condition. Determination of the safety of the plant is specified during the licensing. VVER-1200 reactors are established in Russia with construction licenses. The selected reactor is the most widely used "Light Water Pressure Water Reactor (PWR)" which is the most used in the world and has the most experience. The establishment of akkuyu area will also allow the refrigerant water to be taken from the sea and in addition, water towers will not be built.

Akkuyu Nuclear Power Plant will be installed in an area 55 times smaller than the Ataturk dam. The area that will cover when building power plants should also be taken into account. It's not the structures where everything disappears around nuclear power plants, as they think in society. On the contrary, they are power plants where there are beaches where people can swim right on the banks of the nuclear power plant. The Vandellos Nuclear Power Plant, which is still in operation in Spain, can be cited as an example.

Another benefit that the nuclear plant will provide to the country is the operation of uranium and thorium resources on our country's soil. Thus, both domestic resources will be activated, and fuel gains will be made. Because the uranium we import will cost ten times more. Although the thorium source is not currently used as fuel, it is estimated that it will be used soon and work in this area is ongoing. In this thesis study, uranium and thorium sources and plutonium fuel caused by the burning of uranium in the reactor were examined in detail.

Building a nuclear power plant has become more of an alternative for Turkey than an alternative. Hydroelectric resources were largely used, dozens of thermal and natural gas plants were established. Unfortunately, our country has become dependent on the outside with the energy provided by natural gas and imported coal. With the installation of nuclear power plant, Turkey will make improvements in the field of technology and will be able to use its own uranium resources in a future process.

According to the agreements of the Akkuyu plant, the Russian company will run the plant for 15 years and then leave it to be experienced Turkish engineers.

Akkuyu Nuclear Power Plant will be an important experience for other power plants to be installed. Akkuyu costs about $20 billion. Investment costs account for the majority of this figure. Uranium fuel, enriched between 3-5%, will be covered by the Russian company. About 2500 personnel will work in Akkuyu in the first place and contribute to the country's economy. Students studying nuclear in Russia and other countries by the State of the Republic of Turkey sent on scholarships will also help the nationalization of the project by working at Akkuyu Nuclear Power Plant when they return to the country. According to the contract, Turkey will receive electricity from 12.5-15 cents/kW. This figure appears to be a fairly affordable price compared to current electricity prices.

According to our calculations, when used fuels from the four reactors to be installed in Akkuyu are stored in the form of a fuel bundle, an Olympic pool is only filled in 121 years. However, the life span of a reactor is now up to 60 years. It can be revised to 100 years. During this time, if the used fuels in the pool are reprocessed, the size of the waste will shrink by 1/25. If their fuel can only be stored in the form of sticks, not in the form of a bunch, it will take up to 200 years to fill the pool. But used fuels cannot be used in the form of sticks with the current technology. This method will be much more advantageous after some improvements have been made recently. Storage in pools is done safely in all countries. This path appears to be the safest and logical way until studies on final storage and recycling are developed. The only disadvantage of this process is continuous maintenance.

America has long halted its project to land the nuclear waste it has been running and has declared that it will not allocate any budgets. Waste collection has been extended to 1998, 2010 and 2020, respectively. There is no fuel buried in the final storage area on Mount Yucca so far because the recycling of used fuels is very attractive and advantageous. But reconversion facilities are a business that includes advanced technology and cost.

Turkey started the first work in the field of nuclear power plants with Akkuyu and in second place-initiated negotiations for the Sinop Nuclear Plant. Although some

disagreements come out from time to time and the project is suspended, the Sinop Nuclear Power Plant is still on the agenda as an up-to-date issue. After Sinop, the planned third plant will be installed in the Fortylareli İğneada position. In order to carry out fuel production, enrichment and recycling, Turkey must establish the three plants mentioned and have sufficient experience.

Turkey is not yet a country that can make a nuclear breakthrough. To solve the waste problem in Turkey, there is currently no need for a high-tech system. The changing economic order, the economic crises and fluctuations on which the world is on the brink of a recovery also have a negative impact on the idea of establishing a recovery facility. The situation can be summarized with numeric data as follows. Turkey's electricity production in 2019 is approximately 290 billion kWh. If we meet all of this electricity from a reactor with a power of 1200 MWe, approximately 32 reactors are required (VVERs have the capacity to generate 1200 MWe of electricity and VVER type reactor will be used in Turkey). The waste, which will come out of 32 nuclear reactors in total, can only fill 1.5 pools of Olympic sizes with a depth of 9 meters. The suggestion of this thesis is to work on the defense-type reactor and put the waste back into the cycle in the later processes, and to keep waste in pools of Olympic length and 9 meters depth until this technology is.

As a result, Turkey will establish its first nuclear power plant in Akkuyu. This plant is a light water-pressure reactor (PWR) of the VVER 1200 developed by the Russians. The plant will be established in the form of a 15-year build-operate transfer and after 15 years the operator operation will be transferred to Turkey. The fuel to be used is 3-5% lightly enriched uranium. At the same time, uranium extraction efforts have been started in Turkey and domestic fuel will be provided. The plant will cost about $20 billion, all inclusive, and Turkey will buy electricity at 12.5-15 cents/kW. Low and medium-to-moderate waste from the plant will be easily disposed of by TAEK. These wastes are the equivalent of waste from hospitals. Used fuels are considered as high-activity wastes. These will be stored in the pools within the Akkuyu plant. The total waste from Akkuyu will only fill an Olympic pool in 121 years. However, since the life of the plant will be 100 with the revision, the UNFs that will come out of Akkuyu will not be able to fill an Olympic pool adequately. These wastes will be left to be cooled and stored in pools for about 20-30 years. There is no treaty or work on whether

used fuels should be processed. Turkey will address this issue in the future. However, it will be the most appropriate way to reprocess and obtain new fuels for used waste, thus reducing the amount of waste.

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APPENDICES

Appendix A: Nuclear Energy Histroy Chronology.

Appendix B: Nuclear Energy Dictionary.

Appendix A- Nuclear Energy Histroy Chronology.

1895: Wilhelm Roentgen discovered x-rays.

1896: Henry Becquerel discovered radioactivity.

1898: Marie Curie discovered Polonium and Radium, radioactive cores.

1899: Rutherford discovered two different radiations called alpha and beta.

1900: Fredrick Soddy discovered that radioactive qualifiers spontaneously disrupted, calling it isotope.

1905: Albert Einstein published his article on special relativity with the Formula $E=mc^2$.

1913: Bohr published the theory of atomic structure that established the relationship between nuclear and quantum.

1917: Einstein published the theory of Quantum. This theory revealed for the first time the concept of light photons.

1919: Rutherford bombarded nitrogen gas with alpha, and oxygen isotopes and protons emerged. Thus, the presence of protons in the core was proved. This reaction also went down in history as the first nuclear reaction.

1923: Broglie discovered that electrons were both waves and particles.

1925: Heisenberg,MaxBorn and then Schrödinger formulates quantum mechanics.

1927: Heisenberg explained the principle of uncertainty. Accordingly, it is not possible to find both the location and speed of an item at the same time.

1932: Chadwick discovered neutrons by sending alpha rays over the berilyum leaf.

1938: German physicists Otto Hahn and Fritz Strassmann began a series of experiments that paved the way for an atomic bomb related to the fission.

1940: Neptunium was discovered.

1941: Plutonium was discovered and it was reported that it could be used as an atomic bomb in its element. U.S. president Roosvelt has launched efforts to build an atomic bomb with the Manhattan project.

1942: Robert Oppenheimer was appointed head of the Manhattan scientific projects. Work has begun in Oak Ridge, Tennessee.

1945: U-235 natural uranium separation was carried out for the first time. The first atomic bomb trial was conducted in New Mexico on July 16 (Tirinity). On August 6th, a Uranium bomb named Little Boy in Hiroshima, A plutonium bomb named Shiman man was detonated on Nagazaki. More than 100,000 people died in Hiroshima and 74,000 in Nagazaki.

1946: The UN Atomic Energy Commission convened for the first time.

1949: USSR Joe 1 detonated a plutonium bomb on Semipalatinisk (Kazakhstan).

1951: EBR I experimentally prolific reactor produced enough electricity to burn four 150 Watt bulbs at the Idaho National Engineering laboratory.

1952: United States and the USSR conducted hydrogen and atomic bomb trials.

1954: America's first submarine, the USS Nautilus, was submerged.

1995: The first patent for nuclear reactors was submitted to the Atomic Energy commission by the American patent office.

1956: The first 5MW power plant for electricity generation entered operation in Obinsk, Russia.

1957: The Treaty of Rome, which constitutes the European Atomic Energy Society and the Evrupa Economic Community, was signed. Dresden-I, the first private sector nuclear plant, was built in the United States.

1958: Italy began the construction of a 200 MW plant called Latina.

France has opened a reprocessing plant for the first time.

1959: U.S. nuclear weapons study had significant results such as missiles.

1962: CANDU reactors developed.

1966: Countries such as the United States, China, Japan, Switzerland and France made progress in the construction of nuclear power plants and weapons.

1968: Nuclear Disarmament Treaty (NDT) was signed.

1973: Oil Crisis emerged, and demand for nuclear increased dramatically.

1977: Plutonium pellets were used for the energy of the Voyager 2 spacecraft.

1983: The United States began work to finalize the storage of high-level waste.

1986: Chernobyl accident occurred.

1990: France opened its MOX manufacturing plant, but was able to operate five years later.

1991: The world's first 3rd generation advanced-designed reactor was founded in Japan (Kashiwazaki Kariwa-6).

1995: 178 countries that signed the 1995 NDT renewed the treaty.

2007: Turkey began agreements with Russia for the nuclear power plant.

2010: Iran experienced a nuclear fuel enrichment crisis.

2011: There was a major accident at Japan's Fukushima Daichi nuclear power plant.

2015: Countries such as Jordan, Egypt, Algeria, Bangladesh, Bolivia, Indonesia, Vietnam, Ghana, Argentina have signed contracts with Russian and American nuclear companies to build nuclear plants.

2016: Finland, together with Russia, began work to establish a VVER 1200 type reactor.

Appendix B- Nuclear Energy Dictionary

Heavy Water: It is water with deuterium isotopes instead of hydrogen atoms.

Heavy Water Reactor: It is a type of reactor that uses heavy water as a slowing.

Acute Irritation: Short-term and high-level teleportation

Bombardment: Particles sent repeatedly on an item.

Multiplying Coefficient (k): The ratio of neutrons produced over a certain time period is the number of neutrons that are evaded or peeled. Ideal value is 1.

Dose Equivalent: The value (H) dose equivalent unit (H) that occurs as a result of the collision of a tissue at a certain point is sievert (Sv).

H=D.Q.N 1 Sv = 100 rem

Fertile: Substances that can not be self-divided, need fisil matter to be divided.

Fissile Item: Self-dividing matter, which reacts spontaneously or with neutrons.

Fission: Heavy cores are divided into two or three parts, thus exposing energy. Core division.

Fusion: Core fusion. Two lighter substances are transformed into a heavier substance.

Light Water: It's the water we use in everyday life.

Fast Neutron: Neutrons with more than 0.1 MeV

Radiation: It is the spread of energy in the form of electromagnetic waves or particles.

Short-Lived Waste: Radioactive activity is a waste that halves as a result of a certain inspection and has a half life span of about 30 years.

Control Rod: They are the bars that are placed in the heart of the reactor to control the chain reaction. It is usually made of elements such as Boron, Cadmium and Zirconium.

Nuclear Fuel: Fissile relapse is substances used to produce energy in the reactor.

Nuclear Poison: It is the substance that can reduce reactivation due to the effective cross-section of very high neutron absorption.

Pellet: The latest version of nuclear fuels being introduced into cigarette butts. These pellets are placed in nuclear fuel rods.

Reactor Core: It is the part that contains fuel elements and produces energy.

Leak Beam: Harmful radiation that radiates through welding armor.

X Rays: The waves are beams other than gamma rays, which are made up of photons and are much lower than the eye.

Fuel Cycle: The stages of nuclear fuel processing.

Fuel Bar: It is a rod-shaped fuel element in the reactor, which uses natural uranium as fuel.

Inhibitors: Reactor elamans, which are usually made up of water or graphite, are the reactor elamans that are used to slow down the rapid neutrons that occur in chain reactions in the reactor.

Enrichment: The process of increasing the fisil matter at the isotope ratio of an element.

Chain Reaction: U-238 is a new fisil ingredient by grabbing neutrons from productive cores.