Nuclear Fission Reactor Generations Safety Evolution Analysis

Análisis de la Evolución de las Generaciones de Reactores de Fisión Nuclear

E. L. Ayala[1]

[1]*GIE Grupo de Investigación de Energías "Energy Research Group", Universidad Politécnica Salesiana, Cuenca, Ecuador*
E-mail: eayala@ups.edu.ec

Abstract

Nowadays, there is a debate about how reliable nuclear power is in terms of safety. Some countries are banning its proliferation while others support the construction of new nuclear power plants. There are multiple risks of its implementation not only for the environment but also for public health. In this paper it is analyzed the evolution of nuclear fission reactors safety features through generations for security improvements. It is included information about how nuclear power plants guaranty safeness and what the real risks are when producing nuclear power. Moreover, some accidents in the past are described as well as radioactive waste management. Finally, some standards and attributes for energy production are also presented. The aim of this analysis is to provide different perspectives from technical to social implications of nuclear power to offer a clear understanding of nuclear waste hazards. The focus is not only on the role of international regulations but also on past accidents that have led to develop nuclear fission reactor generations. In this work, it is explained the importance of supporting nuclear power nonproliferation until real solutions are found for nuclear radioactivity threat.

***Index terms*— Nuclear Fission Reactor, Nuclear Generations, Safety, Radioactive Waste.**

Resumen

Hoy en día, existe un debate sobre qué tan confiable es la energía nuclear en términos de seguridad. Algunos países están prohibiendo su proliferación, mientras que otros apoyan la construcción de nuevas centrales nucleares. Existen múltiples riesgos de su implementación no solo para el medio ambiente sino también para la salud pública. En este artículo se analiza la evolución de las características de seguridad de los reactores de fisión nuclear a través de generaciones para mejorar la confiabilidad. Se incluye información sobre cómo las plantas de energía nuclear garantizan la seguridad y cuáles son los riesgos reales al producir energía nuclear. Además, se describen algunos accidentes en el pasado, así como la gestión de residuos radiactivos. Finalmente, también se presentan algunos estándares y atributos para la producción de energía. El objetivo de este análisis es proporcionar diferentes perspectivas de las implicaciones técnicas de la energía nuclear para ofrecer una comprensión clara de los peligros de los desechos nucleares. La atención se centra no solo en el papel de las regulaciones internacionales, sino también en los accidentes pasados que han llevado al desarrollo de generaciones de reactores de fisión nuclear. En este trabajo, se explica la importancia de apoyar la no proliferación de la energía nuclear hasta que se encuentren soluciones reales para la amenaza de la radioactividad nuclear.

***Palabras clave*— Reactor de Fisión Nuclear, Generaciones Nucleares, Seguridad, Residuos Radiactivos.**

Recibido: 02-10-2018, Aprobado tras revisión: 16-01-2019
Forma sugerida de citación: Ayala, E. (2019). "Nuclear Fission Reactor Generations Safety Evolution Analysis". Revista Técnica ***"energía".*** No. 15, Issue II, Pp. 22-29
ISSN On-line: 2602-8492 - ISSN Impreso: 1390-5074

1. INTRODUCTION

Historically, nuclear energy career started after the first nuclear weapon was development in United States in 1945 leading a new controversial strategy for energy production. Scientists studied nuclear fission where heavy nucleus are separated into lighter nucleus and fusion reactions where two nucleus are combined into a heavier ones. They replicated fission by using raw materials such as: Uranium-235, Plutonium-239, Plutonium-241 and Uranium-233 [1]. The first prototypes of Nuclear Power Plants (NPP) were developed in USA. In 1951 the first nuclear reactor was used to produce electricity in an isolated facility in Idaho. Soon after, in 1954 the first NPP was connected to a Soviet Union electric grid. As a result, the era of nuclear energy began [2] [3].

NPPs usually consist of multiple stations with individual reactors working in parallel. It allows continues energy production while other stations can be shut off for maintenance [4]. First of all, each station generates electricity by fission reaction produced inside the reactor when an incoming neutron is launched to a Uranium-235 atom which releases two free more neutrons and the Uranium become in Krypton-97 and Barium-137 fission fragments [5]. Fusion is the opposite reaction that produces energy by adding different atoms creating a new one. For example, when the atom of Deuterium and Tritium are launched they form helium which is very stable. This method is still being researched for energy production since the scientific community is interested in developing more efficient energy sources [6].

Inside the NPP, the Nuclear Fission Reactor (NFR) is the core of nuclear power where fission occurs. When fission starts, decomposition of matter releases considerable amounts of heat that is usually captured by water (or another fluid) and quickly transformed into steam. Consequently, the fluid moves into a close loop passing through electric turbines transforming the kinetic forces into electricity. Then, the fluid is cooled using different coolants through a heat exchanger systems and then the cold fluid is returned again into the cycle. That is why most of NPPs have big cooling towers [5].

Inside the NFR there are multiple rods of Uranium or another chosen active material forming an array [7]. Between them are disposed rods named "poison" which are heavy matter for fission control [8]. When the rods are introduced very deeply the energy released is reduced. On the other hand, when the poison is not located properly it could produce over fission reaction. If this process fails, the result is called "melting of the core" where fission destroys the container of the NFR which is usually built using different concrete layers plus thermic insulation materials in order to prevent the scape of radioactive fluids. As a result, manipulation of high temperatures, radioactive byproducts, kinetic forces and electricity involves some hazards that are considered for a proper NPP design and licensing [9].

Nowadays, many countries recognize the classification of NPPs by generations. The purpose is to find the best method for controlling nuclear power generation and preventing catastrophes in case of accidents or attacks. The scientific community is still reviewing the standards, however other methods are been researched to provide the mechanisms for a safe nuclear energy production [6] [7] [10]. At the moment there are principally four generations of NPP referring to security and operational standards [8]. They are implemented in order to improve safety performance.

Even though multiple improvements have been developed in nuclear stations, there is a controversial discussion about how reliable fission reaction is since many disasters have occurred in the past. The aim of this work is to analyze the advantages and disadvantages of nuclear energy based on the nuclear fission reactor generations safety evolution. In the second section of this work it is presented the nuclear power plants attributes that are usually considered for a new design. In the third section it is described the nuclear fission reactor generations and characteristics as well as the time line. The fourth section presents the hazards of nuclear stations based on historical events, present-day threats and future problems. Finally, fifth section analyses the current and future scenario for nuclear energy based on the presented information. Radioactive waste management is also presented to understand how nuclear stations are dealing with these unavoidable by-products. Statistical data is analyzed in contrast with political, economic, environmental and social implications for supporting the non-proliferation of nuclear energy.

2. NUCLEAR POWER PLANTS ATTRIBUTES

Over the last few decades there are multiple debates about the proliferation of nuclear power. In Europe for instance Germany has promoted shutting down their nuclear fission reactor by the end of 2022 [11]. Some countries such as India and China on the other hand seek for new NPPs implementations [12]. Another important benefit is the reduction of carbon emissions to the environment as the Environmental Protection Agency (EPA) promotes [13].

There are economic implications that promote the proliferation of nuclear power since its implementation and operation is considerable low cost compared with other energy sources. Because of this international interest, there are some organizations that regulate and provide recommendations for nuclear energy safety. For instance, the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) seek for a peaceful use of nuclear energy [14]. This is because the closeness between nuclear energy and nuclear weapons. For this reason, many countries create their own standards and regulations for NPP facilities leading political implications. Moreover, because of the environmental threat, some legislations also influence the law as well as the engineering aspects for the design [15].

When planning a NPP construction, there are social, economic and technical implications for the proposed design. Those implications are usually described by authors from different perspectives, for instance: social, environmental, technical and economic considerations are usually discussed. Governments often organize different commissions that are required to apply guidelines in order to attain the best possible design [9]. For instance, S. Goldberg and R. Rosner describe some of the following attributes for a NPP design and implementation [8]:

2.1. Cost Effectiveness

It refers to the capacity of replacing fossil fuels with renewable energy as well as the methods involved. For instance, investment, times and life-cost cycle of the plant are important factors in order to guaranty competitive kilowatt hour cost for consumers. Generally, nuclear energy is not considered entirely renewable because it requires other sources for fueling the reactor. Rokhshad Hejazi states that nuclear energy is an important solution to reduce carbon emissions besides that economic advantages over governments and the environment [14]. Moreover, the energy can be considered renewable if uranium extraction can be also conceived unlimited. For instance, Claude Degueldre states that uranium extraction using parsimony in sea water could be carried indefinitely [7].

2.2. Safety

Nuclear Energy is considered a critical contaminant. On one hand, the manipulation of active materials implies the generation of radioactive waste. On the other hand, when an accident occurs in a NPP, a lot of radiation can be released to the environment.

2.2.1 Fission Reactor Accidents

During fission reaction, the core of the reactor can reach high temperatures (480°C to 950°C) in order to generate electricity [8]. Therefore, a cooling system must be implemented for lowering the extreme temperature in the reactor. However, if the cooling systems fails, the temperatures can reach critical temperature similar to core of the sun (where nuclear fusion of hydrogen nuclei produces helium and huge amounts of energy). The extreme heat can melt the structure of the reactor releasing radioactive byproducts. This type of accident is one of the most dangerous because environmental impact is irreversible and can occur at any moment if safety protocols fail (usually when cooling the reactor). That is one important reason for some governments to prohibit nuclear energy proliferation [9].

2.2.2 Radioactive Waste

Another problem that NPPs face is nuclear waste. When it is not properly disposed, it may affect health of people and damaging different ecosystems making the area inhabitable for almost any live form.

2.2.3 Security and nonproliferation

This factor is related with the demand of NPP around the world. Nowadays the scientific communities as well as different organizations are promoting the nonproliferation of nuclear energy because of the hazards of double use of this technology for producing nuclear weapons since NPP is the first step to reach nuclear weapons. In this context, potential terrorist or military attracts represent a risk to be considered in the design of the NPP.

2.2.4 Grid Appropriateness

NPPs must be connected to the grid which allows to provide extra energy. However, it implies an investment related with security, control and monitoring systems. The purpose is to maintain the NPP connected to the grid and generate as much power as possible and maintain the levels of frequency and voltage stable. For instance, grid connection can produce faults that affect entire countries representing millions of dollars in losses [16].

2.2.5 Commercialization roadmap

This factor relates with roads availability for NPPs construction and operation. That means the considerations for the development of regions or cities have to be considered in order to do not affect the expansion of territories preserving the area where the NPP will be located.

2.2.6 The fuel cycle:

It is also important to consider that the fuel for a reactor cycle is a critical element in determining the safety protocols for a specific design. For example, the thermodynamics in NPP is usually controlled by the reaction itself but also by external systems. There are some different methods to transmit the steam to the turbine.

3. NUCLEAR FISSION REACTOR GENERATIONS

In order to classify the existing NPP systems around the world, it was necessary to standardize and categorize the NPP into generations. Nowadays, there are four generations running on around the world. Most of them are controlled by organizations as The Academy’s Committee on International Security Studies (CISS), the more recently, the Academy’s Global Nuclear Future (GNF) Initiative—under the guidance of CISS—is examining the safety, security, and non-proliferation implications of global spread for nuclear energy [8]. There are basically four generations that describe the NPP evolution.

3.1 Generation I

Generation one is basically a prototype of NPP which was conceived for experiments. For long time many different NPP were built around the world. All of those are considered Generation I because they basically do not follow any international specifications. On the other hand, NPPs are the result of nuclear weapons development. This is because the prototypes are required in order to obtain the necessary materials to experiment with fission and attain energy. The first NPP generation one appears in United States in 1950 and the last one operated in United Kingdom in 2010 [8].

The safety issues of this generation are related to the lack of security protocols when fission is conducted. After the fission heats up the water, the molecules vibrate very fast producing steam. In Generation I and some Generation II NPPs the steam was directly conducted to the turbine and then to the generator. In this NPPs there were no heat exchanger and the steam produced by fission was directly released to the environment implying radioactive pollution dispersed by wind. There is a debate about how much of this radioactivity remains in water and soil, but it is understood that even if it was dispersed it still exist active. For this reason, in new designs the heat exchanger is incorporated in order to guaranty the safety of the system.

Moreover, the system can be easily tested, monitored and controlled. When the steam is cooled to be returned to the cycle again, that prevents to overheat the materials and the consequently destruction of the reactor core [17].

3.2 Generation II

These types of reactors were developed for commercial purposes only. They were improved versions of previous generation designed to obtain more power. They were economically more reliable with a typical life time of 40 years. Those Reactors include Pressurized Water Reactors (PWR), Canada Deuterium Uranium reactors (CANDU), Boiling Water Reactors (BWR) and Advanced Gas-cooled Reactors (AGR). Those are the basic examples for this kind of technology. Most of the NPP around the world are using this technology because it was developed with commercial purposes. Moreover, the lifetime of generation one is each time finished and replaced by Generation two. However, for new NPP there is a new option called Generation III [8].

3.3 Generation III

This generation was developed during the last two decades. This technology implies the same commercial purposes of Generation II but includes some advantages. The portability is one of the main reasons for choosing this technology. Any power plant in the world using a different fuel than the nuclear can be easily replaced with Generation III. The safety and reliability of those systems are very high compared with the generation two NPP. That is why the new NPP around the world are been built following this new standard. The life time of these plants are around 60 years of operation and could be easily increased with the correct maintenance. Those new reactors are regulated by NRC. The first-Generation III reactor were built in Westinghouse producing 600 MW using an ABWR and being tested by NRC. It was built and went outline in Japan in 1996. However, today there are other Generation III power plants working around the world. Only a total of five generation power plants are in service around the world. No third-generation power plants are working in United States [8].

3.4 Generation III +

Significant changes in the design were added later in NPPs. In United States in 1990s the NRC was the responsible to certify the design and construction of the first generation III+. Some other countries also adopted this standard, but they are not officially considered in this category. There are significant changes in the protocols. The most relevant change is the implementation of new passive safety features which means that the reactor is not likely to suffer any problem due to human mistakes. The Generation III+ NPPs are basically working in Canada, United States, Europe, Japan and China [8] [18].

Canada is an example of Generation III+ power plants certificated; similarly, some countries have adapted new politics about the use of NPP. In Canada there are some NPPs operating in Quebec, Ontario and New Brunswick. The Canadian Nuclear Safety Commission (CNSC) regulates their operation. After the use of the fuel or active material, the remaining waste is disposed in water pools used as a shield for between 5 to 10 years. These pools are specially designed to support earthquakes and terrorist attacks. Not only the disposition of nuclear waste is regulated but also the security in the generation itself is also reinforced. They focused mainly in the contention of radiation, cooling the fuel and the control of the reactor. The systems are monitored continuously. The CNSC utilizes some of the following safety backups including [19]:

- Shout-off rods that are inserted automatically between the fuels or active material rods in the reactor to prevent overheating.
- Cooling the reactor by introducing frozen liquid or "poison" to immediately stop the nuclear reaction.

Those security back-ups are continuously tested by operators and they can perform any activity with or without human intervention. The systems also do not require external power intervention to guaranty the protection.

The CNSC states that for controlling the cool system in the NPP, it is also important to cool the fuel using different mechanisms even if the plant is not operating. The CNSC also states that heat transport systems bring the heat produced by the reactor to the steam generators. This system is made up of very robust pipes, filled with heavy water which is a rare type of water found in nature. Pipes and other components are maintained and inspected regularly and replaced if necessary. Inspections include measuring pipe wear, tear and identifying any microscopic cracks or changes to prevent lines collapse [19].

United States is researching the possibility of using spheres containing active component and poison to have a more complex nuclear fission. These spheres will be also covered by an extra layer of a special material that will contain the radioactive components in case of accidents. Also, the temperature achieved by these spheres will be much lower compared with the traditional generation two and three core reactors [18].

3.5 Generation IV

This technology is still under research. The objective of this generation is to reduce cost, increase life time of the reactor and also improve safety and sustainability. Sodium fast reactor has become the principal founded project since it employs liquid sodium coolant achieving higher power density at lower pressure. This system promises to generate from 1000 to 1500 MW with long core life up to 20 years without refueling.

Many countries are founding this research including Canada, USA, China, France, Japan, Russia, South Korea, South Africa, Switzerland, and the EU. Non-active members include Brazil, Argentina, Australia and United Kingdoms.

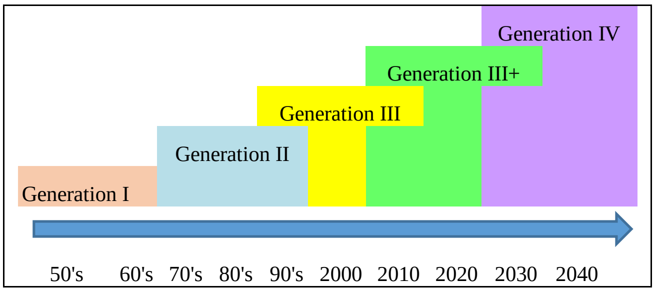

Figure 1. Nuclear fission reactors evolution

Technologies under research such us: Molten salt reactor (MSR), Sodium-cooled fast reactor (SFR), Supercritical water-cooled reactor (SCWR), and Very high-temperature gas reactor (VHTR) [20]. Fig. 1 shows the evolution of NFRs generations along a timeline.

4. NUCLEAR POWER PLANT HAZARDS

In the past years most of NPPs accidents have occurred when poisoning rods have been manipulated incorrectly producing explosions or melting. Safety violations also have been reported as well as structure failures due to natural disasters. Deficient instrumentation also has been detected allowing radiation to be released to the environment.

4.1. Nuclear Power Plant Accidents

According to Jakub Sierchuła there are about 449 nuclear reactors for electricity generation around the world and more than 60% of these are PWRs [21]. Even though they follow safe standards, the risk of accidents is always present since they have occurred in the past causing significant humanitarian, environmental and economic disasters around the world. As a result, some countries are banning nuclear energy completely or at least the non-proliferation [11]. Scientists are researching for options that imply nuclear energy safe generation by improving the current standards and protocols. In order to attain safe technology, different accidents around the world have studied in order to manage a more precise fission control.

When measuring the balance of a nuclear disaster, the IAEA introduced a seven-level scale. For instance, there have been registered only two level seven events in history. One occurred in 1986 in northern Ukrainian Soviet Socialist Republic, Soviet Union and the other one was in 2011 in Fukushima Daiichi, Japan. In both cases, information was not clear about the incidents. Hence, some authors state that there are governments hiding the information related to the real implications of nuclear energy production [22].

Other minor disasters have been reported around the World including United States where at least one incident per year has been detected. The most significant disaster was in Pennsylvania in 1979 when a meltdown occurred in a NFR releasing radioactivity to the atmosphere and the nearby rivers [15]. People exposed to radiation presented chromosomes anomalies after some time. However, some governments are encouraging still people to believe that this information is not scientifically proved. This problem is still under investigation because of the number of cases of cancer reported due to radioactivity. However, it seems that some governments promote the proliferation of Nuclear Power Plants while others ban them completely.

The issue is because this NPP was working without the respectively permissions and using falsification as a method to pass the inspections. Moreover, the NPP in Japan was designed to support earthquakes and more accidents. However, when the tsunami hit the shore of Japan, all the backup safety systems failed at the same time. That means that not even the lack of a correct design but also the risk was well know before the accident many investigations revealed. In addition, third generation power plants are designed to work for at least 40 years [8]. But this was not the case in Japan. All this controversy reaffirms the idea that Nuclear Power is not only a technical issue but also it implies the appropriate regulation, the government control and intervention, the international certification and control, but more than that the Nuclear Power should be considered as the last resource to generate energy in a country until the completely safety of the system is assumed.

It is important to note that in the catastrophe in Japan in Kashiwazaki, the radioactivity released to the ocean was about 0.6 liters - 280 Becquerel which is very dangerous and was transferred to different places [23]. On Wednesday, 18 July 2007, at Unit 7, radioactive iodine was detected and at that time some workers of the company were already exposed to high levels of radioactivity. The leakages in the reactor number two were about 0.9 liters - 16,000 Bq. For those reasons, the Committee of Nuclear Security in Japan then decided that the NPP will be closed and a deep investigation was opened after finding that the reasons for the fault in the reactor was due to problems in the backup design. Although the facilities are more secure now, the future impact as well as the implications in the present of the habitants of the near communities is still unknown. The total impact of this disaster is still under investigation [24].

Fukushima is a very important item in the nuclear history because after this accident, many countries as Germany, Italy, and Switzerland announced the prohibition of Nuclear Energy production within their territories. Those countries allege that this is not a question of technical issues but is also a question of guaranty the health of the people and the environment [10].

4.2. Nuclear Waste Environmental Implications

Nuclear waste is all residual components that contains radioactivity. It could be produced by: decomposition of active materials such as Plutonium or Uranium, materials used for their manipulation or active mineral extraction. The production of these by-products usually is regulated by government agencies. There are many issues about the disposition of nuclear waste around the world. For instance, environmental protection organizations have found some companies discarding barrels with radioactive waste into the ocean with low protection. This practice was justified because it was considered that sea water will dilute the radioactive components. However, this affirmation is not proved to be safe for humans and the marine environment.

When nuclear waste is confined appropriately, the risk of contamination is very low. However, control agencies have to periodically verify these disposals and their radiation levels. On the other hand, when an accident occurs in a NPP, the radiation levels and propagation depend on many different factors such as the presence of wind, rivers, sea, pressure, temperature and even the magnitude of the accident. Some companies provide information about radioactive levels close to the NPPs. For instance, in Japan the government require the NPPs to measure radioactivity exposition levels and inform it to the citizens.

However, in the case of Pennsylvania NPP accident, they were also required to measure these levels but when the accident occurred, the measured level was considered normal meaning those devices or the information presented where manipulated somehow.

According to the IAEA in the published: Radioactive Waste Safety Standards (RADWASS) radioactive waste is classified into five principal categories [25]:

4.2.1 Uranium tailings

heavy metals left over during mining process. This is not considered as radioactive hazard.

4.2.2 Low Level Waste

Also known as Low Level Radioactive Waste (LLW) includes all elements used for radioactive components manipulation as well as nuclear fuel cycle of energy generation. Requires shielding during transportation and is usually buried.

4.2.3 Intermediate Level Waste

Also known as Intermediate-level radioactive waste (ILW) includes all elements used for energy production and chemical processes where the radioactive components are solidified in concrete or bitumen before disposed properly. Cooling is not required however proper area designation is required.

4.2.3 High Level Waste

Also known as high-level radioactive waste (HLW) usually once the fuel rods that have been used for a fission cycle into a nuclear reactor finishes the process, it is removed and disposed. This is the most radioactive element after fission occurs and accounts 95% of all the radioactive byproducts of nuclear energy generation around the world.

4.2.4 Transuranic Waste

It refeers to all transuranic components usually used for nuclear weapons manufature. They are usually disposed into confinated military facilities. Governments have been investigating about the best possible scenarios for high level waste considered long-term nuclear waste. However, because of the risks all of those ideas represent only few have been implemented. These options can be seen in Table I. International agreements have made important progresses in banning some hazardous disposals options. Not only for the environmental treat but also for people health compromise. For instance, Tc-99 long-lived fission products could remain radioactive for 220,000 years and I-129 about 15.7 million years [25].

When humans are exposed to ionizing radiation, it is able to penetrate very deep in the body producing destruction of the gens and chromosomes. The symptoms are fever, diarrhea and headache very similar to the consumption of poisonous food. Then, depending of the amount of exposition the symptoms could last for few days before the person dies. However, in small quantities the mutation of the genes produces modification of the DNA structure in long term. This mutation is even transmitted to the following generations and irreversible [10]. It is also important to note that people are constantly exposed to radioactivity, a very common example is the isotope of radon 222Rn that induces cancer in people and is present in some building materials [26].

Table 1. Waste disposal options

Waste Disposal Option	Description	Countries Involved
Near-surface disposal	Currently in use. LLW disposed at ground levels or inside caverns deep below the surface	Czech Republic, Finland, France, Japan, Netherlands, Spain, Sweden, UK, and USA.
Deep geological disposal	Currently in use from 250 m to 5000 m depths.	France, Sweden, Finland, and the USA, UK and Canada
Long-term on ground storage	Project currently conceived only as interim measure	France, Netherlands, Switzerland, UK, and USA
Disposal in outer space	Abandoned project because high cost which consisted launching HLW to the deep space.	USA
Rock-melting	Banned project because international agreements. For heat generated HLW to be injected as a fluid in solid isolated massive rocks.	Russia, UK, and USA
Disposal at subduction zones	Banned project because international agreements. HLW to be located in subduction (places where a section of Earth descends beneath another one)	USA
Sea disposal	Banned project because international agreements. Some countries implemented this method in the past dropping LLW and ILW.	Belgium, France, Germany, Italy, Japan, Netherlands, Russia, South Korea, Switzerland, UK, and USA
Sub seabed disposal	Banned project because international agreements. LLW, ILW and HLW to be set beneath deep ocean floor.	Sweden and UK
Disposal in ice sheets	Banned project because international agreements. For HLW mainly where it is disposed in extreme cold isolated places and buried in ice	USA
Deep well injection	Implemented in Russia injecting LLW and ILW in liquid form deep wells where the waste gets trapped underground.	Russia and USA

5. NUCLEAR ENERGY GENERATIONS EVOLUTION ANALISYS

Nuclear energy generations evolution responds different factors that has lead the development of safer and more reliable production. According to the World Nuclear Association, about 11% of the world´s electricity is produce in NPPs [27]. This is a significant amount of energy considering the rapid growth of renewable energies. Nuclear stations fife time is another important consideration for new generation development. The embrittlement of reactor materials forces to decommission NPPs every 40 to 60 years [28].

For this reason, the implementation of more reactors around the world implies a nuclear waste over production. Environmentally this is an issue that has not faced a permanent solution nowadays. The proliferation of nuclear stations increases risks of spreading radioactivity worldwide in case of emergencies. That is why the nuclear scientific community renews the safety standards continuously.

From Generation I to Generation IV, there are important progresses in safety measurements. These improvements respond to international and politic influences for supporting nuclear energy proliferation. Moreover, there are countries that have low natural resources such as Belgium where about 50% of the total energy is generated by nuclear stations [27]. Generally, these countries rely on their work force and that implies high energy consumption. This reality demands more technological improvements for new nuclear energy implementations since the population energy demand increases every year [29]. In other words, nuclear energy generations evolution responds not only to necessity of improving methods for energy production but also responds to the global energy demand. Considering this form of energy is relatively inexpensive compared with other sources, many countries have decided to improve the conditions for its implementation.

On the other hand, countries such as Germany have proposed to change their energy production policy. They are transitioning from nuclear to more reliable renewable energies. In the case of Germany this is part of a program named Energiewende (energy transition) [27]. Other countries have signed an agreement for the peaceful use of nuclear energy. However, most of the developed countries have refused to sign that treaty since some possess nuclear weapons [30].

The more nuclear stations around the world, the more nuclear waste is produce and the more risks for nuclear weapons development. Moreover, nuclear power plant facilities represent a permanent treat of accidents or terrorist attacks. These evidences probe that even though nuclear energy is supporting the development of nations, the real cost and its permanent dangers should be considered to decide which source of energy must be selected worldwide. Until now, nuclear energy generations evolution is still attempting to find temporary solutions to the mentioned problems.

CONCLUSIONS

Even though nuclear power has proved to be an efficient mechanism for energy production, radioactive waste generation and military double use of nuclear power facilities are international concerns. These issues have encouraged some governments to ban its proliferation. Low, medium and high-level waste management are not able to offer a permanent solution for present civilization and future generations. Moreover, some accidents have revealed the vulnerability of nuclear power plant facilities. Radioactive waste generation cannot be avoided for nuclear energy production. Most of international organizations establish environmental priority and some governments prioritize the economic benefits of low costed energy production.

After some nuclear accidents and findings of the effects of radiation on living organism have led in many improvements' requirements for future facilities, these progresses are mainly focused in reinforcing safety protocols leading the evolution of nuclear power plants from generation I to IV. However, in generation III+ and IV. there is still a risk of accidents caused for extreme circumstances where facilities are not able to manage emergencies such as natural disasters or terrorist attacks.

There have been some important progresses in nuclear waste management. For instance, governments have prohibited damping any type of nuclear waste into the oceans, the Antarctic or any other geological formations. Even though these efforts have shown some results, it has not been developed an efficient method to manage nuclear waste and the 449 fission reactors around the world continue producing dangerous by-products. It must be clear for future implementations that it is urgent to find a permanent solution for nuclear waste. Meanwhile, it must be granted the non-proliferation of nuclear energy worldwide.

ACKNOWLEDGMENTS

I would like to take the opportunity to thank Professor Jagdish Patra for inspiring me to follow the research path during my master´s studies in Australia.

REFERENCES

[1] B. Viswanathan, Energy sources : fundamentals of chemical conversion processes and applications., Saint Louis: Elsevier Science, 2016.

[2] R. L. Murray and K. E. Holbert, "Chapter 8 - The history of nuclear energy," in *Nuclear Energy*, Boston, Butterworth-Heinemann, 2015, pp. 109-121.

[3] S. Şahin and H. M. Şahin, "1.20 Nuclear energy," in *Comprehensive Energy Systems*, I. Dincer, Ed., Elsevier, 2018, pp. 795-849.

[4] M. Modarres, T. Zhou and M. Massoud, "Advances in multi-unit nuclear power plant probabilistic risk assessment," in *Reliability Engineering & System Safety*, vol. 157, 2017, pp. 87-100.

[5] S. Şahin and Y. Wu, "3.14 Fission energy production," in *Comprehensive Energy Systems*, Elsevier, 2018, pp. 590-637.

[6] T. Koyanagi et al, "Recent progress in the development of SiC composites for nuclear fusion applications," *Journal of Nuclear Materials,* 2018.

[7] D. Claude, "Uranium as a renewable for nuclear energy," *Progress in Nuclear Energy,* vol. Volume 94, pp. 174-186, 2017.

[8] S. Golberg and R. Rosner, "Nuclear reactors: generation to generation," *Cambridge, MA: American Academy of Arts and Sciences,* vol. 2, pp. 1-3, 2011.

[9] D. P. Amber, "Extending life by half [nuclear power plant relicensing]," *IEEE Spectrum,* vol. 38, no. 11, pp. 48-51, 2001.

[10] J. Deutch et al, "The future of nuclear power," *Massachusetts Institute of Technology Report of Nuclear Power,* 2003.

[11] K. Bruninx, D. Madzharov, E. Delarue and W. D'haeseleer, "Impact of the german nuclear phase-out on europe's electricity generation," *2012 9th International Conference on the European Energy Market,* pp. 1-10, 2012.

[12] S. Jain, "Inevitability of nuclear power in the asian region," *Energy Procedia,* vol. 7, pp. 5-20, 2011.

[13] S. William, "EPA's clean power plan: what to do about nuclear power?," *The Electricity Journal,* vol. 28, no. 2, pp. 10-16, 2015.

[14] H. Rokhshad, "Nuclear energy: sense or nonsense for environmental challenges," *International Journal of Sustainable Built Environment,* vol. 9, no. 2, pp. 693-700, 2017.

[15] R. P, "Engineering development and environmental law," *Engineering Management Journal,* vol. 10, no. 2, pp. 85-87, 2000.

[16] D. C. Smith, "Power cuts: risks and alternatives to the current transmission system,," *Refocus,* vol. 4, no. 6, pp. 22-25, 2003.

[17] D. A. Berkowitz and A. M. Squires,, "Nuclear power and radionuclides in the environment," *Power Generation and Environmental Change,* pp. 21-21, 2003.

[18] M. J, "Evolution of nuclear fission reactors: third generation and beyond," *Energy Conversion and Management,* vol. 51, no. 9, pp. 1774-1780, 2010.

[19] C. N. S. Commission, "Nuclear power plant safety systems," 2018. [Online]. [Accessed 25 June 2018].

[20] W. N. Association, "Generation IV nuclear reactors," 2018. [Online]. Available: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-reactors.aspx. [Accessed 2 June 2018].

[21] S. J, "Analysis of reactivity changes during the operation of a nuclear power plant," *2018 International Interdisciplinary PhD Workshop (IIPhDW),* pp. 61-66, 2018.

[22] S. Ho, J. Looi, A. Chuah, A. Leong and N. Pang, "“I can live with nuclear energy if…”: exploring public perceptions of nuclear energy in Singapore," vol. 120, Singapore, 2018, pp. 436-447.

[23] A. Hasegawa et al, "Health effects of radiation and other health problems in the aftermath of nuclear accidents, with an emphasis on Fukushima," *The Lancet,* vol. 386, no. 9992, pp. 479-488, 2015.

[24] M. Nishikawa, T. Kato, T. Homma and S. Takahara, "Changes in risk perceptions before and after nuclear accidents: Evidence from Japan," *Environmental Science & Policy,* vol. 55, no. Part 1, pp. 11-19, 2016.

[25] I. A. E. Agency, "IAEA Regulatory control of nuclear power plants," October 2000. [Online]. Available: https://www.iaea.org/ns/tutorials/regcontrol/legis/legis1121.htm?w=1radioactive+waste+safety+standards. [Accessed 23 June 2018].

[26] F. Del Claro, S. Paschuk, J. Corrêa, V. Denyak, J. Kappke, A. Perna, M. Martins, T. Santos, Z. Rocha and S. H.R, "Radioisotopes present in building materials of workplaces," *Radiation Physics and Chemistry,* vol. 140, pp. 141-145, 2017.

[27] W. N. Association, "Nuclear Power in the World Today," [Online]. Available: http://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx. [Accessed 7 January 2019].

[28] D. Abbott, "Is Nuclear Power Globally Scalable? [Point of View]," *Proceedings of the IEEE,* vol. 99, no. 10, pp. 1611-1617, 2011.

[29] Energy Information Administration, “eia Beta International,” [Online]. Available: https://www.eia.gov/beta/international/. [Accessed 8 January 2019].

[30] R. Gladstone, “"A Treaty Is Reached to Ban Nuclear Arms. Now Comes the Hard Part",” *New York Times,* p. 2017, 9 August 2017.

Edy Leonardo Ayala Cruz.- He was born in Cuenca, Ecuador in 1987. He obtained his Bachelor degree of Electronic Engineer from Universidad Politécnica Salesiana, Ecuador in 2011; his Master degree of Electrical and Electronics Engineering Science from Swinburne University of Technology, Australia in 2015. His field research involves electronic sensors, electrical safety, renewable energies and intelligent systems.