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Master Thesis

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Critical analysis of important aspects of the decommissioning process for an American and a Spanish nuclear power plant

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Abstract

The decommissioning of nuclear power plants is the driving motivation for the present work. However, decommissioning or dismantling of nuclear power plants is a wide topic and it is carried out in different ways in every country.

Various factors like experience in previous decommissioning processes, own interpretation of regulations or different management teams lead to distinct decommissioning processes. However, the diverse strategies reach the goals stablished by the international organisms.

Although there is a global organization called “International Atomic Energy Agency (IAEA)”, which *“promotes nuclear safety and nuclear security standards and their implementation”* [1], every country applies its own procedures or laws based on the directions from IAEA.

As a consequence, this work encompasses the analysis of some important aspects of the decommissioning of two nuclear power plants: Vandellòs 1 (located in Spain) and San Onofre (located in USA). The topics analysed are the following ones:

- Decommissioning strategy
- Impact on staffing and socio-economic factors
- Phases of decommissioning
- The decommissioning management team
- Waste management

Preface

This work will examine and analyse how two different nuclear power plants (Vandellòs 1 and San Onofre) have developed some important aspects of decommissioning.

The first section will introduce the topic taking the motivation of this work into consideration. Furthermore, the reason for carrying out a thesis about nuclear energy will be discussed, as well as why to focus on the decommissioning process. Finally, the contributions of my thesis for future decommissioning processes will be pointed out.

In the second section, a theoretical overview of the necessary elements to understand the main concept of *“decommissioning of nuclear power plants”* will be presented. It is important to acquaint the reader with the context, in order to ease the later comprehension of the topic. In general terms, the theoretical introduction will be based on the following concepts:

- Nuclear plant
- Nuclear energy in the world
- Nuclear energy in Spain
- Nuclear energy in USA
- Conclusions of nuclear energy in Spain and USA
- Decommissioning

The third section is the most important part of this thesis. Here the critical analysis of each decommissioning process at Vandellòs 1 and San Onofre is carried out.

The procedure is structured according to the following: firstly the general regulations about the topic are presented. The source can be the IAEA (International Atomic Energy Agency), the “Handbook of Nuclear Engineering from Don Gabriel Cacuci” [2] or any other accurate source. Secondly, the real situations from Vandellòs 1 and San Onofre are explained. Those are, of course, related to the theory that has been exposed before. Finally, a detailed analysis comparing the real situation from each plant with the general principles will be made too. The final conclusions will be very valuable because it will be possible to see the different approaches among countries. Many factors like experience, control authorities or history of nuclear energy, among others, will be considered for the final conclusions. Those will add value to all the research that has been done previously.

The last section will summarize the analysis and insights of this thesis in a condensed manner.

Declaration

I hereby declare that I have prepared the present thesis independently and without the help of third parties. Thoughts and citations, which I have taken directly or indirectly from other sources, are properly identified. This thesis did not exist in the same or similar form before and has not been published so far.

I agree that this thesis may be available for the public at the Department of Nuclear Engineering.

Munich, 12th April, 2018

Joan Sabaté Francés

Content

1. Introduction

1.1. Motivation and Background

The main reason about the development of this work is the **great utility of a comparative analysis from important aspects of the decommissioning process**. Indeed, there are international regulations promoted by the **IAEA** (International Atomic Energy Agency) regarding how to carry out the decommissioning in the nuclear power plants, but every country adapts the regulations in different ways. Because of that, it is **very useful to analyse if those countries have followed the general patterns or directions issued by the main organisms**. Moreover, the way that each country has applied its requirements can be as a starting point for improving the processes in other countries.

In the case of this thesis, two decommissioning examples have been chosen in order to carry out the analysis. One of those is Vandellòs 1, a nuclear power plant in Spain. The second example is San Onofre, situated in USA.

Regarding the **background of decommissioning processes** in the world, it is well-known that in the **USA** the **first shutdown** of a nuclear power plant was executed already by the 1960 (Vallecitos). In **Spain**, the first shutdown was in **1990** with Vandellòs 1. Another important information is that in the USA nearly thirty reactors have been dismantled since 1964, whilst in Spain only three reactors have been shut down in the past.

This last information shows that the **experience in decommissioning processes in the USA is bigger than in Spain**. However, both countries have their own organisms which regulate the nuclear energy and nowadays both have already carried out a decommissioning of a nuclear power plant. The US Nuclear Regulatory Commission (**US NRC**) in the case of the USA and the **CSN** (Consejo de Seguridad Nuclear) in the case of Spain. Moreover, there is a common and international organism called the "International Atomic Energy Agency (**IAEA**)" where the regulations come from.

Consequently, that shows that **each country has already enough background in decommissioning but there is a lack of exchanging information between countries that could help to improve the expertise from both sides**. As a consequence, this thesis will analyse some important aspects of decommissioning carried out at Vandellòs 1 and San Onofre based on a common theoretical framework and it will serve as a **starting point for promoting the sharing of decommissioning experiences in the future**.

2. Theoretical Overview

2.1. Nuclear Plant

2.1.1. What is a Nuclear Plant

With a nuclear power plant it is possible to obtain electrical energy from nuclear energy.

Regarding the operation of a nuclear power plant, it works as follows:

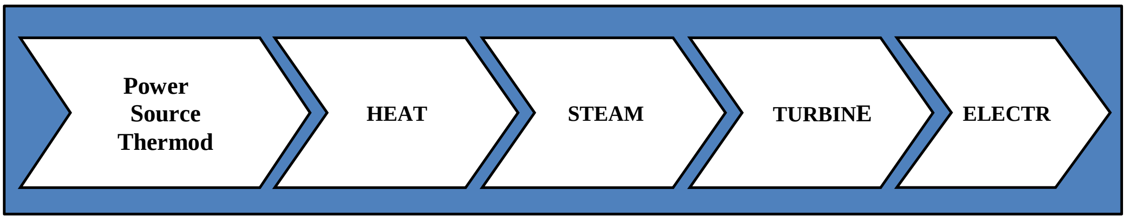

Illustration 1. General Operation of a Nuclear Power Plant

On the other hand, there are different types of electrical installations depending on the energy source:

a) Nuclear Power Plant: *It uses the heat released in the nuclear fission reactions of certain atoms.*
b) Thermal Power Plant: *It uses the heat released in the combustion of one or more fossil fuels (coal, natural gas, fuel,..).*
c) Thermoelectric Solar Plants: *It uses the energy from the solar radiation.*

[3]

2.1.2. Basic operation of a nuclear power plant

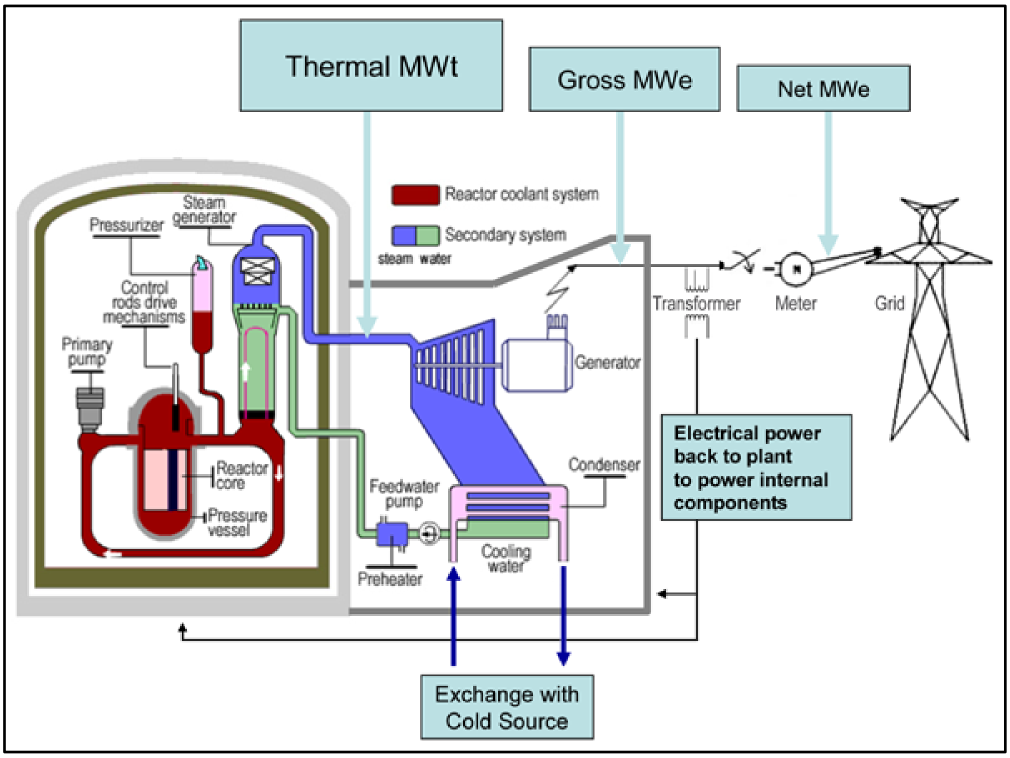

Illustration 2. Example of a nuclear power plant operation [4]

A nuclear reactor generates the thermal energy that the nuclear power plant uses to generate electrical energy. Thus, chain fission reactions are produced in a controlled way inside the reactor. It is important to know that the element that fissures (the nuclear fuel) is natural uranium or enriched uranium. As a note: *enriched uranium is natural uranium with a higher uranium-235 isotope ratio*.

Moreover, a nuclear power plant has other facilities that are very important for its operation. Those are the steam turbine, the alternator, two or three circuits (primary, secondary and tertiary) and one or several cooling towers of the condensing fluid (usually water). Its total efficiency is about 30-40%.

[3]

2.1.3. Nuclear Chain Reactions

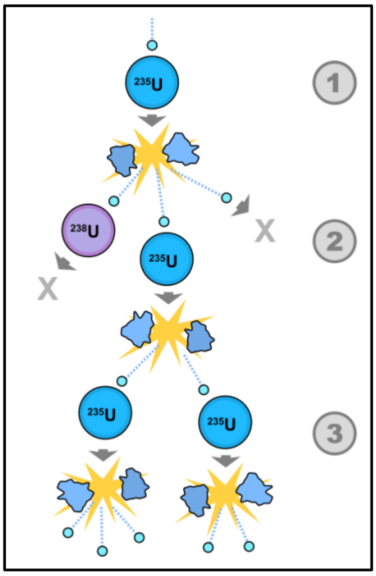

Illustration 3. Possible nuclear fission chain reaction [5]

It is necessary that the nuclear reactions are chain reactions. Otherwise, it is not possible to achieve that the obtained energy is greater than the used energy.

The energy is obtained from the nucleus of atoms by means of its division (**nuclear fission**). The chain reaction starts by bombarding an atom with a neutron. After the beginning of the reaction, the chain reaction is controlled by the control rods and the neutron moderator.

It is known that the atoms possess internal links that join their sub particles (electrons, neutrons and protons). After the division, the links break and release the internal energy bonding that joined the separated particles.

At the **beginning** of the reaction, **a lot of energy** is needed to start the nuclear chain reaction. However, **once the reaction is already started**, it is **not necessary** to contribute with **loads of energy** to maintain it. Finally a moment where the obtained energy is greater than the used energy is reached

Those chain reactions are produced in the core of the nuclear reactor. After this process, a circuit of tubes (in which a fluid called coolant circulates) is responsible for transporting the heat (thermal energy) of the tank.

[3]

2.1.4. Activation of the turbines of the nuclear power plant

After obtaining the heat from the nuclear reactions, the temperature of the water is augmented until it boils. Thus, the water becomes steam at a very high pressure.

Thanks to the steam, the turbine blades start to move and, in this way, the **thermal energy** is transformed **into mechanical ene**rgy. Thus, the turbine is connected to an electric generator (or alternator) that makes the transformation from **mechanical energy to electrical energy** possible.

[3]

2.1.5. Nuclear Reactor

The nuclear reactor is the site where nuclear fission reactions are generated. In short, **it produces heat** (thermal energy).

[3]

2.1.6. Types of Nuclear Reactors

a) **Pressurized water reactor (PWR and VVER):** "*They use high pressure water for producing steam for the steam generators. They have three circuits". [3]*

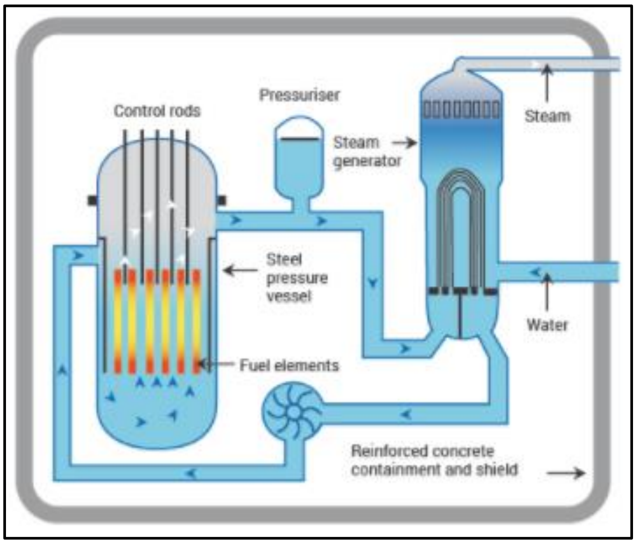

Illustration 4. Pressurized Water Reactor (PWR) [1]

b) **Boiling water reactor (BWR):** "*The water boils, generating steam directly in the reactor core. They have only two circuits". [3]*

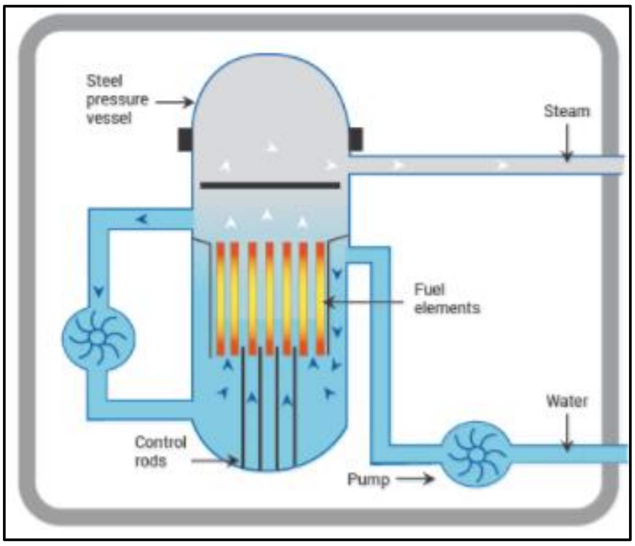

Illustration 5. Boiling Water Reactor (BWR) [1]

c) **Pressurized Heavy Water Reactor (PHWR):** "*Uses high pressure heavy water as a neutron moderator and as a refrigerant*". *[3]*

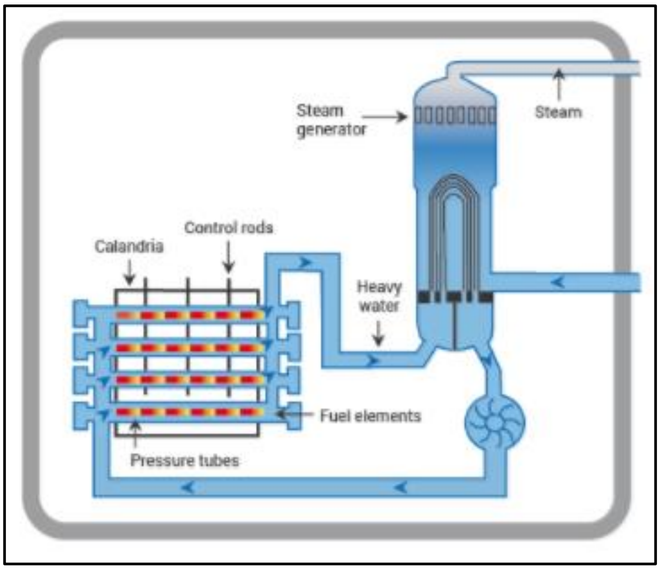

Illustration 6. Pressurized Heavy Water Reactor (PHWR) [1]

d) **Gas reactor (GCR: AGR and Magnox):** "*They use graphite as moderator of neutrons and carbon dioxide in gaseous state as refrigerant*". *[3]*

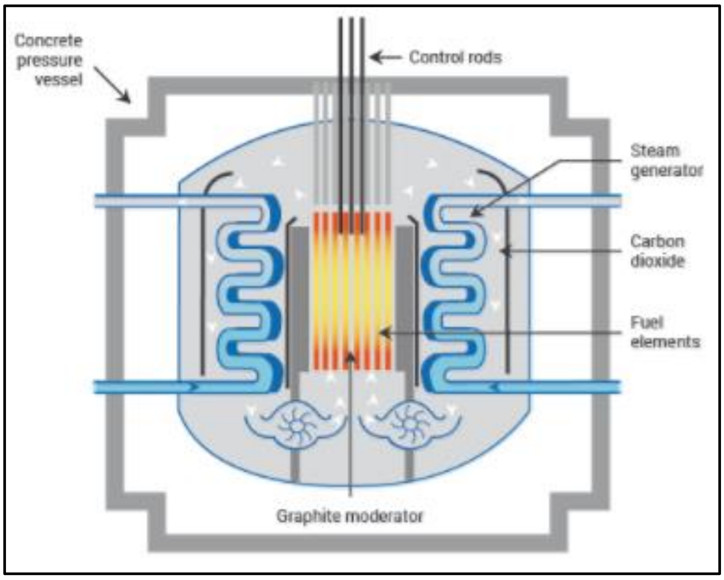

Illustration 7. Advanced Gas-cooled Reactor (AGR) [1]

e) **Reactor moderated by graphite and cooled by light water (LGR and RBMK):** "*Russian models. The "light water" is normal water*". *[3]*

f) **Fast Reactor (LBR, or LMFBR):** "*Does not decelerate the neutrons of the chain reaction and refrigerates with liquid sodium. They are in the prototype and research phase*". *[3]*

2.2. Nuclear Energy in the world

Here a **brief timeline about the progresses in the nuclear energy** is introduced:

- **1895 - 1945:** Development of the science of atomic radiation, atomic change and nuclear fission.
- **1939 - 1945:** Development focused on the atomic bomb.
- **1945 - Onwards:** Development focused on making profit of this energy for naval propulsion and electricity.
- **Since 1956:** Development focused on nuclear power plants.

[6]

2.3. Nuclear Energy in Spain

2.3.1. Important figures

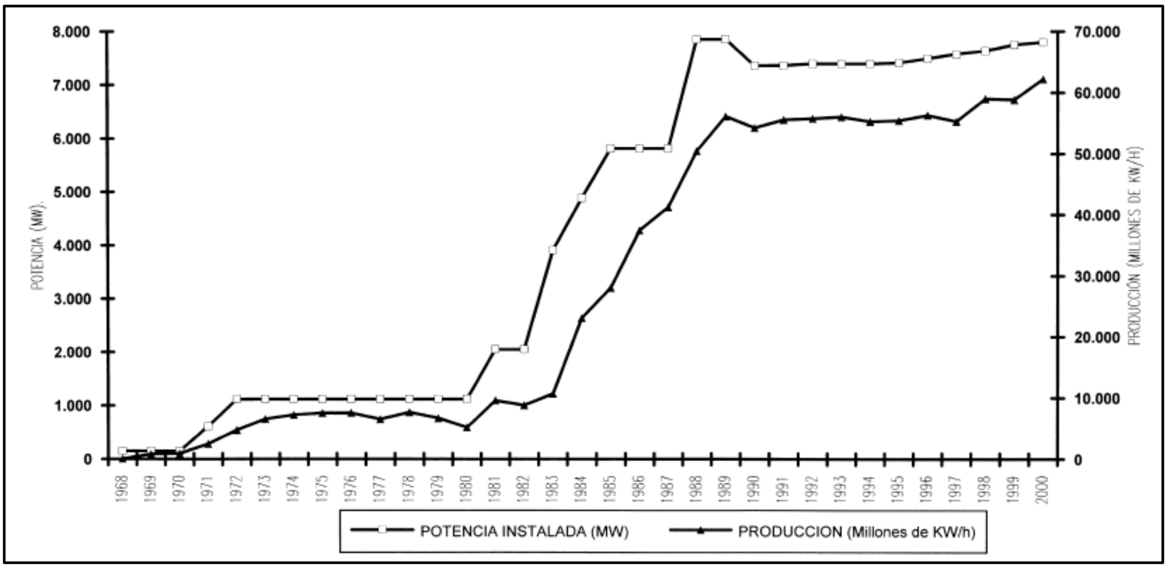

Illustration 8. Production of nuclear energy in Spain 1968-2000 (kwh) [1]

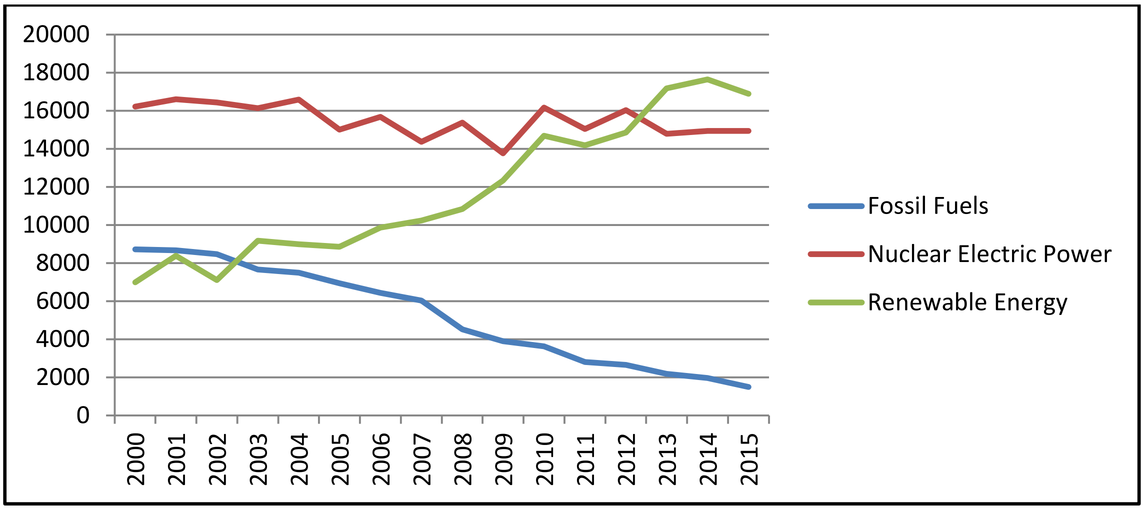

Illustration 9. Production of energy in Spain 2000-2015 (ktep) [7]

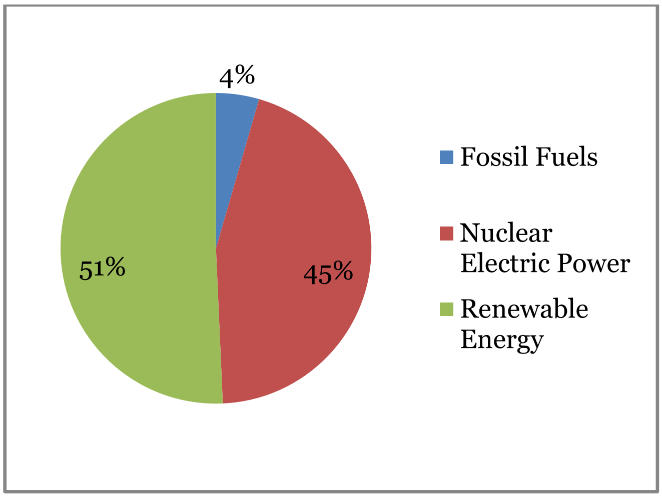

Illustration 10. Production of energy in Spain (2015) [8]

2.3.2. History of Nuclear Energy in Spain

Timeline:

1947: a commission is created at the superior council of scientific investigations. Its purpose is to discuss about topics of "**Physics of higher technical interest for the country**".

Mid 1947: the embassy of United States in Spain donates a wide collection of American magazines which are specialised in nuclear fission and its applications (civil and military) to the "Laboratory and research office of the navy". After this fact, the possibility of an international collaboration is considered.

September 1948: creation of **JIA** ("Junta de Investigaciones Atómicas").

1948-1951: development of JIA. On the one hand, the JIA promoted the training abroad of the first Spanish specialists in nuclear field. On the other hand, the first uranium prospections are initiated in Spain.

1963: This year was very important for the future development of the nuclear energy in Spain. The **law of nuclear energy** is promulgated and the previous authorization for the **first Spanish nuclear power plant** (Almonacid de **Zorita**, in Guadalajara) is accepted. Some years later it was called "**José Cabrera**".

July 1965: The building of **Zorita** is started.

July 1968: **Zorita** nuclear power plant (José Cabrera) is synchronized and supplies energy for the **first time**.

1971: Another nuclear power plant is completely built and supplies energy for the first time. That is Santa María de **Garoña**.

1972: Another nuclear power plant is completely built and supplies energy for the first time. That is **Vandellós I**.

October 1989: A **fire** destroys different facilities of **Vandellós I**.

1990: It is decided to close **Vandellós I** and start with the **decommissioning process**.

It is important to know that those three nuclear power plants (José Cabrera, Santa María de Garoña and Vandellòs I) are known as plants of "**first generation**". They represented a total power of **1220 MW**.

After these beginnings with nuclear energy in Spain, it is decided to build new power plants because of the increasing on the demand of energy. Those new nuclear power plants will contribute with an additional nuclear power of **6500 MW**. Those will be considered as the "**second generation**".

1981: Another nuclear power plant is completely built and supplies energy for the first time. That is "**Almaraz**".

1983: two more nuclear power plants are installed and start working. Those are "**Ascó**" and the second group of "**Almaraz**".

1984: "**Cofrentes**" starts to work.

1985: The second nuclear reactor of "**Ascó**" starts to work.

1987: "**Vandellós II**" starts to work.

1989: "**Trillo I**" starts to work.

[9]

2.3.3. Actuality of Nuclear Energy in Spain

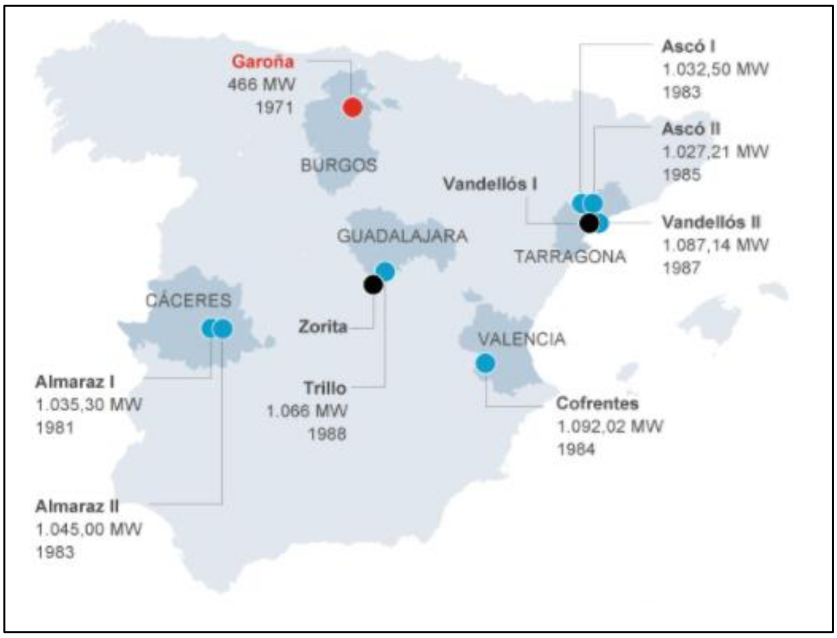

Illustration 11. Actual stand from nuclear power plants in Spain (2017) [10]

Little explanation about the colours of the circles showed in the picture:

Red: future decommissioning.
Black: stopped or in decommissioning process.
Blue: working nuclear power plant.

Plant	Electrical Power (MW)	Reactor	Starting year	
Zorita (José Cabrera)	160	PWR	1968	First Generation
Garoña	466	BWR	1971	
Vandellòs I	500	GCR	1972	
Almaraz I	1035,30	PWR	1981	Second Generation
Ascó I	1032,50	PWR	1983	
Almaraz II	1045	PWR	1983	
Cofrentes	1092,02	BWR	1984	
Ascó II	1027,21	PWR	1985	
Vandellòs II	1087,14	PWR	1987	
Trillo	1066	PWR	1989	

Table 1. Review from all nuclear plants in Spain (1968-2017) [7]

One of the **conclusions** extracted from the information about the nuclear power plants which exist in Spain, is that all the plants from the first and the second generation are located in the **middle-north of the Iberian Peninsula**. That is because of the **lower seismic incidence** and also because of the situation of **rivers** Tajo and Ebro.

Moreover, those nuclear plants are located in places where there is not a high population density, but they are **close to communities where a big amount of electricity is required** (Madrid, Barcelona or Valencia).

2.4. Nuclear Energy in USA

2.4.1. Important figures

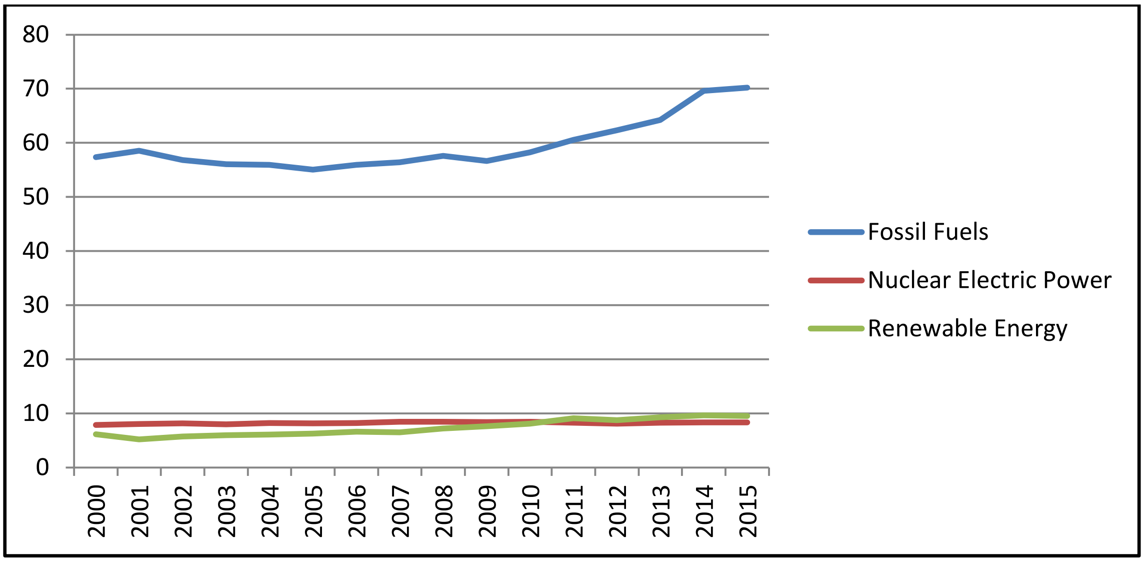

Illustration 12. Production of energy in USA (quad btu) [11]

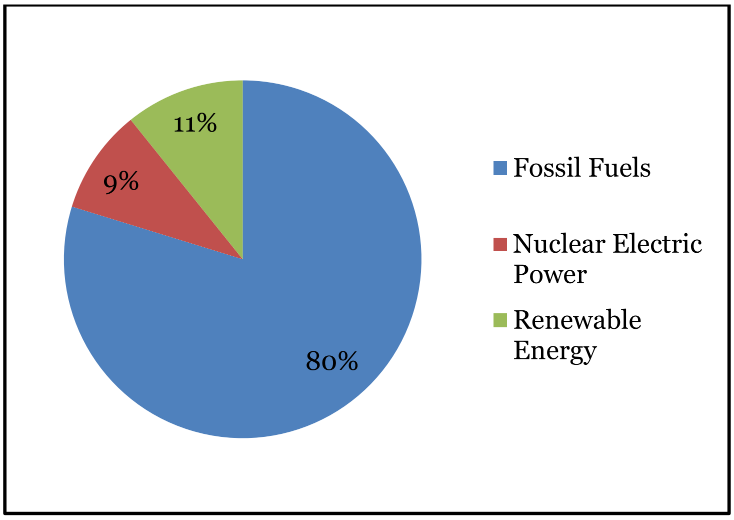

Illustration 13. Production of energy in USA in 2015 [11]

2.4.2. History of Nuclear Energy in USA

Timeline:

Post-World War II:

- The Atomic Energy Commission is created to look for peaceful options for the nuclear materials that USA used in the war. [12]

- **US Navy** starts to look for projects in nuclear electricity generation. [12]

April 1957: **First atomic power generator** producing electricity (SM-1 Nuclear Reactor in Fort Belvoir, Virginia). [13]

May 1958: **First commercial nuclear power plant** in USA (Shippingport Atomic Power Station). [13]

1979: **Three Mile Island accident**. There were no people injured nor anyone exposed to radiation. Many orders were cancelled and the construction of future nuclear plants went down. [14]

1986: **Chernobyl accident**. That produced discussions about the safety of nuclear power and raised the number of opposing people to nuclear energy. [12]

1989: **Shippingport's Decommissioning**. By this time, there were already 109 nuclear reactors generating electricity in USA. [12]

2017: 61 commercial nuclear power plants with **99 nuclear reactors are operating in the USA**. Those are situated in thirty US states. [15]

2.4.3. Actuality of Nuclear Energy in USA

First of all, the actuality of nuclear energy in the USA will be introduced with a table that includes all the nuclear plants operating right now in the USA:

Reactor	State	Type	MW
Arkansas Nuclear One 1	Arkansas	PWR	834
Arkansas Nuclear One 2	Arkansas	PWR	986
Beaver Valley 1	Pennsylvania	PWR	920
Beaver Valley 2	Pennsylvania	PWR	914
Braidwood 1	Illinois	PWR	1,178
Braidwood 2	Illinois	PWR	1,152
Browns Ferry 1	Alabama	BWR	1,101
Browns Ferry 2	Alabama	BWR	1,104
Browns Ferry 3	Alabama	BWR	1,105
Brunswick 1	North Carolina	BWR	938

Brunswick 2	North Carolina	BWR	932
Byron 1	Illinois	PWR	1,164
Byron 2	Illinois	PWR	1,136
Callaway	Missouri	PWR	1,190
Calvert Cliffs 1	Maryland	PWR	866
Calvert Cliffs 2	Maryland	PWR	861
Catawba 1	South Carolina	PWR	1,140
Catawba 2	South Carolina	PWR	1,150
Clinton	Illinois	BWR	1,065
Columbia 2	Washington	BWR	1,158
Comanche Peak 1	Texas	PWR	1,205
Comanche Peak 2	Texas	PWR	1,195
Cooper	Nebraska	BWR	764
Davis Besse	Ohio	PWR	894
Diablo Canyon 1	California	PWR	1,122
Diablo Canyon 2	California	PWR	1,118
Donald C. Cook 1	Michigan	PWR	1,009
Donald C. Cook 2	Michigan	PWR	1,060
Dresden 2	Illinois	BWR	902
Dresden 3	Illinois	BWR	895
Duane Arnold	Iowa	BWR	601
Edwin I. Hatch 1	Georgia	BWR	876
Edwin I. Hatch 2	Georgia	BWR	883
Fermi 2	Michigan	BWR	1,124
Grand Gulf 1	Mississippi	BWR	1,401
H.B. Robinson 2	South Carolina	PWR	741
Hope Creek 1	New Jersey	BWR	1,172
Indian Point 2	New York	PWR	1,020
Indian Point 3	New York	PWR	1,035
James A. Fitzpatrick	New York	BWR	837
Joseph M. Farley 1	Alabama	PWR	874
Joseph M. Farley 2	Alabama	PWR	883
La Salle 1	Illinois	BWR	1,135
La Salle 2	Illinois	BWR	1,136
Limerick 1	Pennsylvania	BWR	1,120
Limerick 2	Pennsylvania	BWR	1,122
McGuire 1	North Carolina	PWR	1,158
McGuire 2	North Carolina	PWR	1,158
Millstone 2	Connecticut	PWR	868

Millstone 3	Connecticut	PWR	1,220
Monticello	Minnesota	BWR	647
Nine Mile Point 1	New York	BWR	637
Nine Mile Point 2	New York	BWR	1,287
North Anna 1	Virginia	PWR	948
North Anna 2	Virginia	PWR	944
Oconee 1	South Carolina	PWR	847
Oconee 2	South Carolina	PWR	848
Oconee 3	South Carolina	PWR	859
Oyster Creek 1	New Jersey	BWR	608
Palisades	Michigan	PWR	784
Palo Verde 1	Arizona	PWR	1,311
Palo Verde 2	Arizona	PWR	1,314
Palo Verde 3	Arizona	PWR	1,312
Peach Bottom 2	Pennsylvania	BWR	1,308
Peach Bottom 3	Pennsylvania	BWR	1,309
Perry 1	Ohio	BWR	1,240
Pilgrim 1	Massachusetts	BWR	682
Point Beach 1	Wisconsin	PWR	598
Point Beach 2	Wisconsin	PWR	598
Prairie Island 1	Minnesota	PWR	521
Prairie Island 2	Minnesota	PWR	519
Quad Cities 1	Illinois	BWR	908
Quad Cities 2	Illinois	BWR	911
R.E. Ginna	New York	PWR	582
River Bend 1	Louisiana	BWR	968
Salem 1	New Jersey	PWR	1,170
Salem 2	New Jersey	PWR	1,158
Seabrook 1	New Hampshire	PWR	1,248
Sequoyah 1	Tennessee	PWR	1,152
Sequoyah 2	Tennessee	PWR	1,126
Shearon Harris 1	North Carolina	PWR	928
South Texas Project 1	Texas	PWR	1,280
South Texas Project 2	Texas	PWR	1,280
St. Lucie 1	Florida	PWR	981
St. Lucie 2	Florida	PWR	987
Surry 1	Virginia	PWR	838
Surry 2	Virginia	PWR	838
Susquehanna 1	Pennsylvania	BWR	1,260

Susquehanna 2	Pennsylvania	BWR	1,260
Three Mile Island 1	Pennsylvania	PWR	803
Turkey Point 3	Florida	PWR	802
Turkey Point 4	Florida	PWR	802
V.C. Summer	South Carolina	PWR	971
Vogtle 1	Georgia	PWR	1,150
Vogtle 2	Georgia	PWR	1,152
Waterford 3	Louisiana	PWR	1,160
Watts Bar 1	Tennessee	PWR	1,123
Watts Bar 2	Tennessee	PWR	1,122
Wolf Creek 1	Kansas	PWR	1,175
Total (99 units)			**99,678**

Table 2. US Operating Nuclear Reactors (2017) [16]

After analysing this information from the Table 2 and further sources of information, the following facts about the actual nuclear energy in the USA can be concluded:

- USA has the **largest production of nuclear power in the world**. [14]
- In the year **2017**, **USA** has **99 nuclear reactors**, which produced **99678 MW**.
- USA is building two new reactors. Those are expected to start working by 2020.
- Nowadays there are 65 pressurized water reactors (PWRs) and 34 boiling water reactors (BWRs) in the USA.

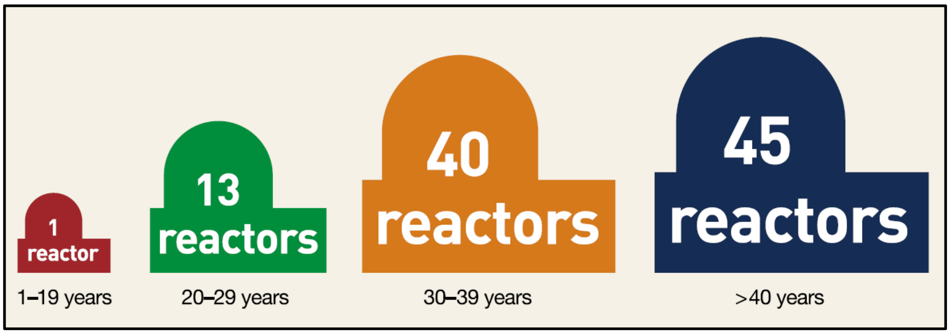

Illustration 14. Actual situation of nuclear reactors in USA (2017) [17]

From Illustration 14 it can be extracted that **almost all the US nuclear energy comes from reactors that have been initiated more than 30 years ago**.

In the next illustrations, the **general overview of all the nuclear plants existing in the USA** (2017) is presented. Moreover, a map of the USA is included, which helps to determine the location factors.

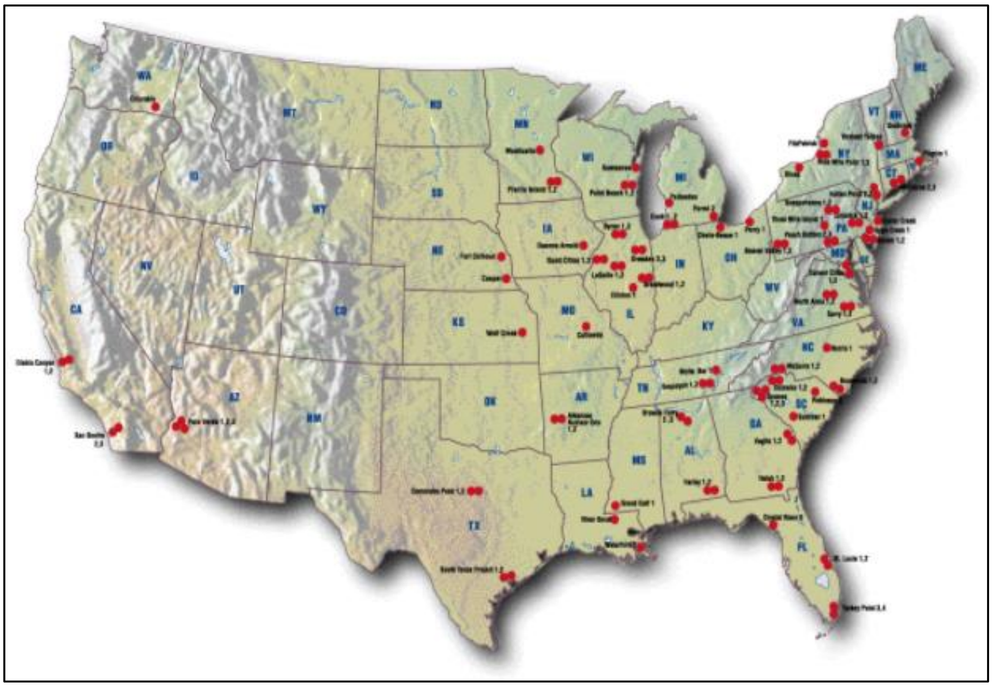

Illustration 15. Locations of nuclear power plants in the USA [14]

Illustration 16. General view of the USA [18]

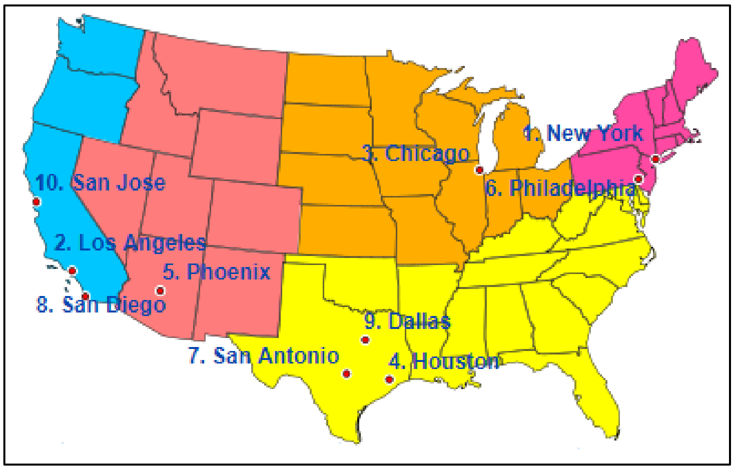

Illustration 17. The ten most populous cities of the USA [19]

After analysing both pictures, the following facts about the criteria for building the nuclear power plants can be concluded:

- **State laws**, **geography** and **population** are the main factors for locating a nuclear power plant.

- In the case of state laws, it is seen that, for example, California, Hawaii, Illinois, Minnesota, West Virginia and others, have problems with the government related to the installation of nuclear power plants. **According to the Illustration 15, there are not many plants in those places**.

- Referring to the **geography** (or topography), it is well-known that all nuclear reactors require **water** to operate. Because of that, most nuclear plants in the USA are built close to rivers or the ocean, but also in places with a large amount of space **without seismic risks**.

- Finally, it is very important to know the **expected population growth** (or actual population) when fixing a location. That is directly related with the demand for power. For example, in the case of the USA, **most of the nuclear plants are located near the most populous cities** (see Illustration 15 and Illustration 17).

2.5. Conclusions of Nuclear Energy Spain and USA

In this section, **the information about the Nuclear Energy in Spain and USA** (chapter 2.3 and chapter 2.4) will be summarized.

Starting with the case of Spain, according to the Illustration 9, a **decrease of the production of fossil fuels is observed in Spain from the year 2000 until now**. Contrarily, the **production of renewable energy has increased** until now, reaching an annual production of 17000 ktep in 2015. Regarding the **nuclear electric power, it has been very stable** between 2000 and 2015, producing approximately about 16000 ktep per year.

Furthermore, focusing on the Illustration 10, can be observed that in the year 2015 **almost half of the production of energy in Spain comes from the nuclear power**. That means that it is still a very important source of energy for Spain, although **renewable energy is growing** and it was 51 % in 2015.

Regarding the history of nuclear energy in Spain, it has to be remarked that the **first Spanish power plant** started to work in **1963** (Zorita, José Cabrera) and the **first decommissioning process** in Spain was in **1990** (Vandellòs 1).

On the other hand, focusing on the **actuality of nuclear energy in Spain**, it is found that **seven nuclear power plants** are working in 2017. Two nuclear power plants are stopped or in decommissioning process and, finally, one nuclear power plant is waiting for future decommissioning. The total energy provided by the seven working plants is **7385,17 MW**.

In the second place, the **case of the USA** will be examined**.**

Focusing on the first graphic, the Illustration 12, the **production of fossil fuels has increased in the USA from the year 2000 until the year 2015**. Moreover, during these years the fossil fuels have represented by far the **main type of energy produced in the USA**. Indeed, the production of fossil fuels has kept from 60 to 70 quad btu between 2000 and 2015 while the production of nuclear electric power and renewable energy has been stable between 2000 and 2015 with values close to 10 quad btu.

As a consequence, observing the Illustration 13, it can be perceived that in 2015, **80 % of the production of energy in the USA was coming from fossil fuels**. Consequently, the **nuclear energy power** represented **only 9 % of the total production**. That confirms the tendency introduced before and the huge importance of fossil fuels in the USA.

About the **history of the nuclear energy in the USA**, there are some important dates that are necessary to take into account. Those are, for example, when the **first commercial nuclear power plant** started to work in **May 1958**. Moreover, **by the 1989** already **109 nuclear reactors** were generating electricity in the USA.

Nowadays, there are **99 reactors** operating in the USA. That means a production of **99.678 MW**. In addition, it is also interesting to know that at least 85 of the 99 reactors have more than 30 years.

Finally it is necessary to **contrast the information from Vandellòs 1 and San Onofre**.

Starting with the evolution of the energy production between 2000 and 2015, it can be observed that in **Spain** there has been a **clear decreasing of the fossil fuels until 2015**, **while in the USA it has increased**. Besides, the production of fossil fuels in **Spain** in 2015 represents **4%** of the total production, whilst 80% in the **USA.** That confirms the importance of fossil fuels in the USA.

A curious data about the actuality is that in **Spain** there are **7 nuclear reactors working**, whilst in **USA** there are **99 reactors**. Furthermore, the total power generated by the reactors is **7385, 17 MW and 99678 MW respectively**. However, the power from Spain represents almost the half of the total production, while in USA this amount is only 9% from the total production. Consequently, **it is deduced that the quantity of energy needed in USA is much higher than in Spain**, and for sure they will export part of it. Only as information, the population of Spain is 46, 528 million and in USA is 324, 3 million.

Regarding the history of nuclear energy both in Spain and the USA, it is observed that **the nuclear energy arrived before to USA**. There, the US Navy started to investigate about nuclear energy already in the post-World War II. Consequently, in **1958** they turned on the **first commercial nuclear power plant**. Indeed, **Spain started its path to nuclear energy in 1947 thanks to the USA**. In this year, the embassy of the USA donated a research laboratory to Spain. Later, in **1963,** Spain could turn on its **first nuclear power plant**.

Finally, focusing on the factors for placing the nuclear power plants, **both in Spain and the USA, it is perceived that the one and the other follow the same patterns considering state laws, geography and population**. Thus, they try to locate the plants in areas without seismic risks and close to water, they avoid placing them in states with unstable regulations and most of them are located near the most populous cities.

2.6. Decommissioning

2.6.1. What is Decommissioning

Generally, it is well-known that all power plants (coal, gas and nuclear) have a closing date after which they cannot operate anymore.

"Decommissioning refers to the administrative and technical actions taken to remove all or some of the regulatory controls from an authorized facility so the facility and its site can be reused. Decommissioning includes activities such as planning, physical and radiological characterization, facility and site decontamination, dismantling, and materials management". [20]

Focusing on the life expectancy of nuclear plants, the **early nuclear plants** will be differentiated from the **newer nuclear plants**. The first ones, were designed for a life of 30 years approximately. On the other hand, the second ones have a life expectancy of 40 to 60 years of operating life.[21]

Decommissioning of nuclear power plants:

- It is necessary to consider it already during the designing (before construction) of nuclear power plants.

- The facility's initial authorization includes a decommissioning plan that demonstrates that the decommissioning is possible and costs can be paid.

- Later in the final shutdown, a final decommissioning plan is prepared with important topics like safety, radiation protection, environmental impacts and management of materials.

- A decommissioning project includes a complex and multidisciplinary process of planning and implementing. Moreover, it involves technical and non-technical aspects. In the same way, a proper management is fundamental.

[20]

2.6.2. Decommissioning Strategies

a) **Immediate Dismantling (or Early Site Release/'Decon' in the US):**

"This option allows for the facility to be removed from regulatory control relatively soon after shutdown or termination of regulated activities. Final dismantling or decontamination activities can begin within a few months or years, depending on the facility. Following removal from regulatory control, the site is then available for re-use". [22]

b) **Safe Enclosure ('Safstor') or deferred dismantling:**

"This option postpones the final removal of controls for a longer period, usually in the order of 40 to 60 years. The facility is placed into a safe storage configuration until the eventual dismantling and decontamination activities occur after residual radioactivity has decayed. There is a risk in this case of regulatory change which could increase costs unpredictably". [22]

c) **Entombment (or 'Entomb'):**

"This option entails placing the facility into a condition that will allow the remaining on-site radioactive material to remain on-site without ever removing it totally. This option usually involves reducing the size of the area where the radioactive material is located and then encasing the facility in a long-lived structure such as concrete, that will last for a period of time to ensure the remaining radioactivity is no longer of concern". [22]

2.6.3. Decommissioning in Spain

First of all, a **brief introduction will be presented where the normal shut down process of a nuclear power plant in Spain is outlined**.

- Firstly, it is well-known that nuclear power plants are obliged (before its operation) to fulfil different authorizations for ensuring the security during its operation. [23]

- Once the operation of the nuclear power plant is finished, it is still subject to a control system due to the fact that the residual radioactivity is dangerous. Moreover, the inactive installation can be a risk for the environment. [23]

- The responsibles for the decommissioning projects have to present the security informs to the respective authorities. There, all the potential risks during the decommissioning will be exposed and the procedures and protections for avoiding them will be shown. In the case of Spain, this organism is "Consejo de Seguridad Nuclear (CSN)". [23]

- Some responsibilities from the CSN:

    - Assuring the nuclear security and the radiological protection.
    - Evaluating the security of the decommissioning projects and report to the government for accepting or refusing the authorizations.
    - Inspection and control of nuclear facilities during its operation. For the last, they normally have a resident inspector in each plant.
    - In the last stage of the decommissioning process, they evaluate the quantity of radioactivity in the place and decide how to proceed. [23]

- After the decommissioning permission is accepted, another organism starts to work. This is "Empresa Nacional de Residuos Radioactivos" (ENRESA). The owners and operators from the plant, transfer the control to ENRESA. One of the main tasks of this organism is the management of the whole decommissioning and the long-term management of radioactive waste. It was created in 1984 by the Spanish government [24] [25]

After this brief introduction about the steps before to the start of the decommissioning, a **general summary of the actual nuclear plants under decommissioning in Spain will be shown**.

	Type	Net MW	First power	Shutdown	Years of operation
Vandellòs 1	UNGG	480	1972	1990	18
Jose Cabrera (Zorita)	PWR	142	1968	2006	38
Santa Maria de Garoña	BWR	446	1971	2012	41

Table 3. Actual shutdown reactors in Spain (2017) [24]

After that, the **reason for each shutdown will briefly be explained**:

- **Vandellòs 1:** It was closed after a turbine fire. The estimated budget of the repairs was quite high and it was decided to shut down the nuclear plant. This case will be explained more in depth in the following sections.
- **José Cabrera (Zorita):** It was closed after 38 years of operation.
- **Santa Maria de Garoña:** It was closed after 41 years of operation.

[24]

This confirms what is said in [26]. Thus, in the case of nuclear power plants of occidental design (USA and some European including Spanish ones), it is expected to have a design life of 40 years. However, this quantity can be exceeded if they have the acceptance from the respective authorities.

2.6.4. Decommissioning in the USA

In a similar way to the prior section, a **brief introduction about the normal shut down process of a nuclear power plant in the USA will be presented.**

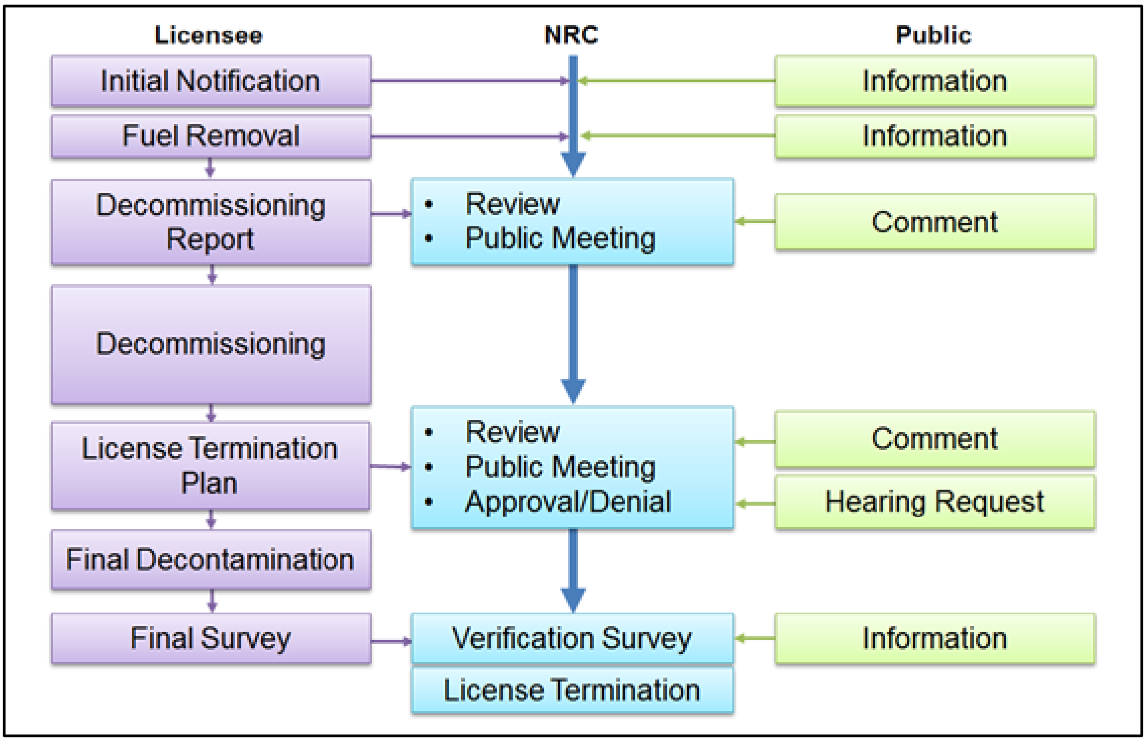

Illustration 18. Reactor Decommissioning Process [27]

1.) The beginning of the decommissioning process occurs when the licensee decides to cease operations.

2.) A written notification is submitted to NRC (U.S. Nuclear Regulatory Commission). Moreover, the licensee has to notify to NRC when the fuel has been extracted from the reactor vessel.

3.) Up to two years after cessation of operations, the licensee is obliged to hand in a PSDAR (Post-Shutdown Decommissioning Activities Report). The PSDAR includes the following:

    - *Description and schedule of the planned decommissioning activities.*
    - *Expected costs.*
    - *Environmental Impact statements (EISs).*

4.) The PSDAR is not approved by the NRC.

5.) After 90 days from the reception of the PSDAR at the NRC, the licensee can start the decommissioning activities.

6.) The licensee must notify any changes in the decommissioning process which are not listed in the PSDAR.

7.) Power reactors have to hand in an application for termination of its license. This application includes a "License Termination Plan (LTP). The NRC has to approve it.

8.) The NRC will inspect the licensee during decommissioning operations to make sure that the LTP is being fulfilled.

9.) The decommissioning process has to be completed up to 60 years from the cessation of operations.

10.) Once the decommissioning activities have been finished, the licensee will hand in a radiation survey report.

[28]

After the brief introduction about the normal decommissioning process in the USA**, some more information about the NRC (U.S. Nuclear Regulatory Commission)** will be presented.

In the case of USA, the U.S. Nuclear Regulatory Commission (NRC) is responsible for the decommissioning of nuclear facilities. [29]

This includes the process of safely removing the facility and reducing the residual radioactivity until a situation is achieved where either the property can be released for unrestricted use or under specified restricted conditions. [29]

However, sometimes the NRC shares its responsibility with the State governors. Those agreements enable the individual States to manage the decommissioning of materials facilities inside their borders. The states with this status receive the name of "Agreement States". [29]

As a consequence, in those states which are not considered as "Agreement States", the Office of Nuclear Materials Safety and Safeguards (NMSS) and the NRC's regional offices monitor the regulations over the decommissioning processes. [29]

Regarding the actual state of shut down of nuclear reactors in the USA, the following table provides actual information:

Reactor Name	Type	MWt	Location	Shutdown	Status
Big Rock Point	BWR	240	Charlevoix, MI	29/08/97	DECON Completed, ISFSI only
Bonus	BWR	50	Punta Higuera, PR	1/06/68	ENTOMB
Crystal River	PWR	2568	Florida	5/2/13	SAFSTOR
CVTR	PHWR	65	Parr, SC	1/01/67	SAFSTOR
Dresden 1	BWR	700	Morris, IL	31/10/78	SAFSTOR
Elk River	BWR	58	Elk River, MN	1/02/68	DECON Completed
Fermi 1	FNR	200	Newport, MI	22/09/72	SAFSTOR
Fort Calhoun	PWR	c1428	Blair, NE	24/10/2016	SAFSTOR
Fort St. Vrain	HTR	842	Platteville, CO	18/08/89	DECON Completed, ISFSI only
Connecticut Yankee	PWR	1,825	Haddam Neck, CT	5/12/96	DECON Completed, ISFSI only
Hallam	SCGMR	256	Hallam, NE	1/09/64	ENTOMB
Humboldt Bay	BWR	200	Eureka, CA	2/07/76	DECON in Progress
Indian Point 1	PWR	615	Buchanan, NY	31/10/74	SAFSTOR
Kewaunee	PWR	1772	Carlton, WI	7/5/13	SAFSTOR
LaCrosse	BWR	165	Genoa, WI	30/04/87	SAFSTOR
Maine Yankee	PWR	2,700	Wiscasset, ME	6/12/96	DECON Completed, ISFSI only
Millstone 1	BWR	2,011	Waterford, CT	21/07/98	SAFSTOR
NS Savannah	PWR	74	Baltimore, MD	1/11/70	SAFSTOR
Pathfinder	BWR	190	Sioux Falls, SD	16/09/67	DECON Completed
Peach Bottom 1	HTR	115	Peach Bottom, PA	31/10/74	SAFSTOR
Piqua	OCMR	46	Piqua, OH	1/01/66	ENTOMB
Rancho Seco	PWR	2,772	Herald, CA	7/06/89	DECON Completed, ISFSI only
San Onofre 1	PWR	1,347	San Clemente, CA	30/11/92	DECON completed, ISFSI
San Onofre 2	PWR	3,438	San Clemente, CA	7/6/13	SAFSTOR
San Onofre 3	PWR	3,438	San Clemente, CA	7/6/13	SAFSTOR
Saxton	PWR	24	Saxton, PA	1/05/72	DECON Completed
Shippingport	PWR	236	Shippingport, PA	1/01/82	DECON Completed
Shoreham	BWR	2,436	Wading River, NY	28/06/89	DECON Completed
Sturgis FNPP	PWR	10	Fort Belvoir, VA	1976	SAFSTOR
Three Mile Island 2	PWR	2,770	Middletown, PA	28/03/79	SAFSTOR: Post defueling monitored storage
Trojan	PWR	3,411	Ranier, OR	9/11/92	DECON Completed, ISFSI only
Vallecitos (GE VBWR)	BWR	50	Pleasanton, CA	9/12/63	SAFSTOR
Vermont Yankee	BWR	1593	Vernon, VT	29/12/14	SAFSTOR
Yankee Rowe	PWR	600	Franklin Co., MA	1/10/91	DECON Completed, ISFSI only
Zion 1	PWR	3,250	Zion, IL	21/02/97	DECON in progress
Zion 2	PWR	3,250	Zion, IL	19/09/96	DECON in progress
Total: 35					

Illustration 19. Shutdown Power Reactors 2017 [30]

2.6.5. Decommissioning Plan

This section will connect the entire introduction with the following section.

Thus, through the "**Critical Analysis of Important Aspects**", some topics that are normally included in a decommission plan for nuclear power plants will be presented, analysed and compared.

Because of that, the main goal of this section is to introduce what a decommissioning plan is and highlight its characteristics.

Here are some advices extracted from [2]:

- *"Planning for decommissioning is an essential prerequisite to ensure that decommissioning activities can be accomplished in a safe, timely, and effective manner".* [2]

- *"Licensee is responsible for this planning".* [2]

- *"The regulatory body provides guidance in this respect, and reviews and approves the decommissioning plan before the start of decommissioning activities".* [2]

- *"Successful decommissioning depends on careful and organized planning including clear identification of the objectives of the decommissioning process".* [2]

- *"The end states are derived from the objectives of the organization charged with completing the work and are in compliance with the requirements by the regulatory body and other competent authorities".* [2]

- *"When the timing of the final shutdown of a plant is known, the licensee should initiate detailed studies and finalize proposals for decommissioning".* [2]

- *"Once a strategy has been developed, the decommissioning plan is prepared for each nuclear facility".* [2]

- *"The extent of such plans and their content and degree of detail required may be different, depending on the complexity and hazard potential of the nuclear facility and on regulations".* [2]

Typical contents of a final decommissioning plan: [2]

Section	Contents
Introduction	• Objectives, scope, goals to be achieved
Facility description	• Physical description of the site and the facility and its operational history • Radioactive and toxic material inventory
Decommissioning	• Objectives, decommissioning alternatives strategy • Selection and justification of the preferred option
Project management	• Resources • Organization and responsibilities • Review and monitoring arrangements • Training and qualification • Reporting and records • Risk management
Decommissioning activities	• Decontamination and dismantling activities • Waste management • Maintenance programs
Safety assessment	• Dose prediction for tasks, demoristration of ALARA for task risk and uncertainty analyses • Operating rules and instructions
Environmental impact assessment	• Demonstration of compliance with environmental standards and criteria
Quality assurance program	• Setting up a QA (quality assurance) / QC (quality control) program • Verification of compliance with established QA requirements
Radiation protection and safety program	• Radiation monitoring and protection systems • Physical security and materials control • Emergency arrangements • Management of safety • Justification of safety for workers, general population and environment
Continued surveillance and maintenance	• Development of surveillance and maintenance programs
Final radiation survey	• Demonstration of compliance with the clean-up criteria
Costs	• Cost estimate • Provision of funds

Table 4. Contents of a decommissioning plan [2]

3. Critical Analysis of Important Aspects

3.1. Introduction

First of all, the two nuclear plants the decommissioning analysis of important aspects is based on will be described. Both are currently in the process of decommissioning.

3.1.1. Vandellòs 1

Vandellòs 1 is placed in **Vandellós i l'Hospitalet de l'Infant (Tarragona)**. It started to work in **1972** with the licensee of the Hispano-French company of Nuclear Energy (**HIFRENSA**). It stopped its activity in **1989** after 17 years of operation. [31]

Referring to the technical characteristics of the nuclear power plant, it was a **GCR** (graphite-natural uranium) plant and it was cooled by gas. The power owned by the nuclear plant was **480 MWt**. [31]

After its stop in 1989, **HIFRENSA** was responsible for the conditioning activities between **1991 and 1997**. This work consisted in the unloading of the reactor core and the elimination of the fuel of the place and the management of the waste.

ENRESA was responsible between **1998 and 2003** for the decommissioning of the nuclear power plant of Vandellòs 1. In 2003 they reached the level 2 of decommissioning (OIEA), removing all the buildings, systems and equipment outside from the reactor. [31]

At this time, the reactor was sealed and it will be kept in this way for 25 years. After this time, the total decommissioning will be done with better security conditions and economical costs. This period of 25 years is called "**Latency period**". [31] [32]

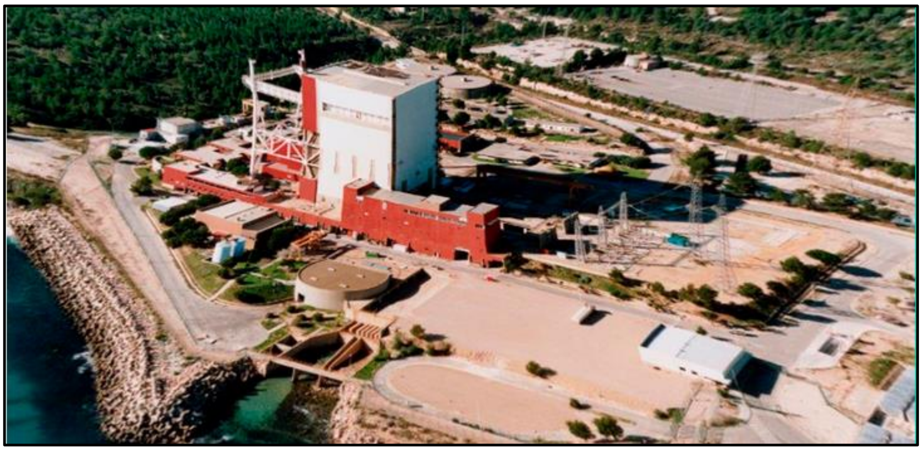

Illustration 20. Vandellòs 1 during its activity [31]

Illustration 21. Vandellòs 1 after the reactor sealing [31]

The main reason for closing it was the incident that occured on October 19, 1989. On this date, a fire broke out in the plant because of a mechanical effect. [32]
The turbine building had not connection to radioactive components. After the rupture of lubrication pipes, a huge oil spill came in a very short time and then the fire was produced. After that, successive system failures appeared. [32]

This turbine fire caused an expensive repair of the plant. [21]

Based on the INES Scale, this incident was rated with level 3 (important incident, Defence in depth). [32]

After mentioning the **INES Scale**, a short explanation will introduce its meaning:

The INES Scale is an instrument for estimating the gravity of a nuclear and radiological event. Actually that is called "**International Nuclear Events Scale**". [33]

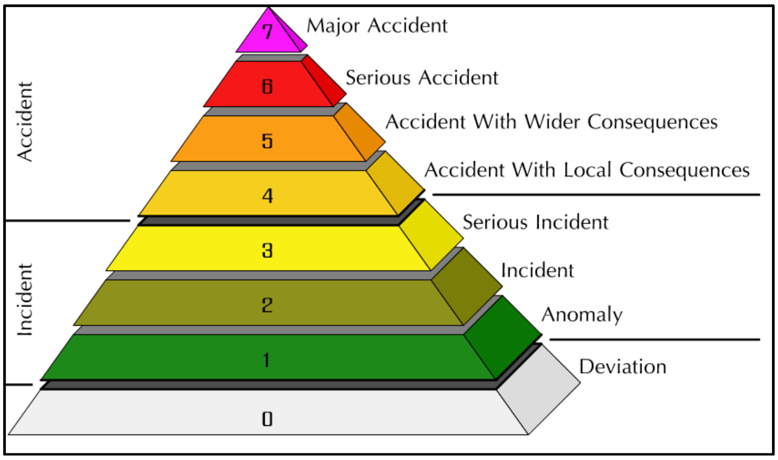

Illustration 22. INES Scale [34]

Moreover, INES considers three areas of impact:

a) **People and the environment:** *"considers the radiation doses to people close to the location of the event and the widespread, unplanned release of radioactive material from an installation".* [35]

b) **Radiological Barriers and Control:** *"covers events without any direct impact on people or the environment and only applies inside major facilities. It covers unplanned high radiation levels and spread of significant quantities of radioactive materials confined within the installation"*. [35]

c) **Defence-in-Depth:** *"covers events without any direct impact on people or the environment, but for which the range of measures put in place to prevent accidents did not function as intended"*. [35]

3.1.2. San Onofre

Firstly, **the analysed decommissioning aspects from San Onofre will refer to the Unit 2 and Unit 3**. Unit 1 is not considered due to the fact that the decommissioning process was started in 1992 and is almost finished now.

The San Onofre Nuclear Generating Station (**SONGS**) is placed on the **Pacific coast of California, concretely in the north-western corner of San Diego County**, south of San Clemente. Its units 2 & 3 were retired from service on **7th June 2013**. That was decided by Southern California Edison (SCE). [36]

SONGS is owned mostly by Southern California Edison (SCE). It holds 78,2 % ownership. SCE is also the Licensee of the nuclear power plant. [36]

It is important to say that when SONGS was fully functional, it employed about 2000 people. [37]

SONGS was formed by 3 units.

The first unit, **Unit 1**, worked from **1968 to 1992**. [38].

On the other hand, **Unit 2** started in 1983 and **Unit 3** started in 1984. After 20 years of working, some upgrades were made for both units, in 2009 and 2010. Unfortunately, both reactors had to be **shut down in January 2012**. The main reason was premature wear found on over 3000 tubes in the steam generators that had been installed in 2010 and 2011. [36] However, this incident was not included in the INES Scale, since no accident (nuclear or radiological success) happened.

The power owned by **Unit 2 and Unit 3** was **1070 MW and 1080 MW**, respectively. [39]

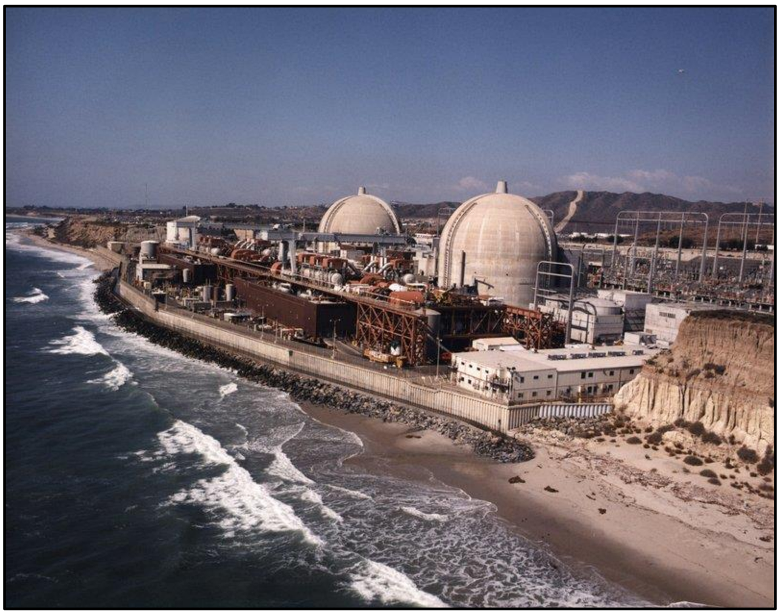

Illustration 23. San Onofre Nuclear Power Plant [40]

3.1.3. Analysis and Conclusions

	Vandellòs I	San Onofre (Unit 2 and Unit 3)
Start to work	1992	Unit 2 → 1983 Unit 3 → 1984
Stop of activity	1989	Both 2013
Reactor type	GCR (graphite natural uranium)	PWR
Power generation	480 MW	Unit 2 → 1070 MW Unit 3 → 1080 MW
Decommission responsible	ENRESA (surveillance from CSN)	SCE (surveillance from US NRC)
Decommissioning time	1989-2028 → 40 years	Approximately 20 years
Reason for closing	Fire (level 3)	Premature wear found on over 3000 tubes
Licensee during operation	HIFRENSA	SCE (Southern California Edison)

3.2. Decommissioning strategy

Starting from the definition of the International Atomic Energy Agency (IAEA), there are three options for decommissioning. Those have been previously introduced in section 2.6. but will be reminded now:

- **Immediate Dismantling (or Early Site Release/'Decon' in the US):**
  "This option allows for the facility to be removed from regulatory control relatively soon after shutdown or termination of regulated activities. Final dismantling or decontamination activities can begin within a few months or years, depending on the facility. Following removal from regulatory control, the site is then available for re-use". [22]

- **Safe Enclosure ('Safstor') or deferred dismantling:**
  "This option postpones the final removal of controls for a longer period, usually in the order of 40 to 60 years. The facility is placed into a safe storage configuration until the eventual dismantling and decontamination activities occur after residual radioactivity has decayed. There is a risk in this case of regulatory change which could increase costs unpredictably". [22]

- **Entombment (or 'Entomb'):**
  "This option entails placing the facility into a condition that will allow the remaining on-site radioactive material to remain on-site without ever removing it totally. This option usually involves reducing the size of the area where the radioactive material is located and then encasing the facility in a long-lived structure such as concrete, that will last for a period of time to ensure the remaining radioactivity is no longer of concern". [22]

3.2.1. Decommissioning strategy at Vandellòs 1

The decommissioning from Vandellòs 1 is classified as **Safe Enclosure ("Safstor")** or **deferred**. Moreover, its strategy is based in **three levels**. In the following review of the levels of decommissioning, it is proven that the decommissioning of Vandellòs 1 follows the "Safstor" strategy:

The **first level** starts after the Ministerial Order of July 1990 which confirms the final shutdown of the plant. Then, between **1991 and 1997** HIFRENSA carry out with all the conditioning activities, such as unloading the reactor core and removal of fuel from the site, among others. [41]

The **second level** starts in **February 1998** and finishes in **June 2003**. ENRESA is responsible for the accomplishment of it. Generally, the main goal of this level is the decommissioning of structures and preparation for the latency period. Moreover the level is divided in **two phases**:
The **first phase** starts between **February 1998 and February 1999**. [42] At this time, the conditioning of the space for disassembly is carried out and the unnecessary conventional structures were removed. [43]

On the **second phase** (**March 1999 until June 2003**), the conventional radioactive waste materials are separated. In this way, it is assured that all the structures were decontaminated. [42] [43]

Finally, the **third level** will be carried out around **2028**, after the latency period. That will be focused on the removal of the concrete pressure vessel and all the internal structures. [43]

In the following table the former explanations are summed up:

1990	1991	1994	1997	1998
Ministerial Order for final shutdown, setting the conditions for maintaining the plant in safe shutdown.	Start of Hifrensa's Stage 1 dismantling.	Submission by Enresa of the Dismantling and Decommissioning Plan for Vandellós 1.	End of Stage 1 tasks.	Approval of the Dismantling and Decommissioning Plan for the plant. Transfer to Enresa of the ownership of the plant. Start of Stage 2 dismantling.

1999	2000	2001	2002	2003
Approval by the Nuclear Safety Council of the Dismantling Plan for Radioactive Parts and start of work.	Confinement and sealing of the concrete pressure vessel.	Start of shipments of cleared materials to recycling plants. Assembly of the weather proof protective structure for the concrete pressure vessel. Submission to the Nuclear Safety Council of the regulatory documentation for the dormancy period.	Approval by the Nuclear Safety Council of the surface clearance and combined clearance methodology. End of the dismantling of the reactor external structures.	End of Stage 2 dismantling of the Vandellòs nuclear power plant.

Table 5. Timeline Decommissioning Vandellòs 1

3.2.2. Decommissioning strategy at San Onofre

As we can read in the picture below, San Onofre follows a decommissioning strategy called "**DECON**".

Type of Site:	Power Reactor Facility
Location:	San Clemente, CA
License No.:	NPF-10 & NPF-15
Docket No.:	50-361 & 50-362
License Status:	DECON
Project Manager:	Marlayna Vaaler

Illustration 24. Site Identification San Onofre Units 2 and 3 [44]

The process of decommissioning for San Onofre starts on the **7th June 2013**, when Southern California Edison (SCE) decides to retire Units 2 and 3 at the San Onofre. [44]

Estimated date for closure → **December 31, 2031** [44]

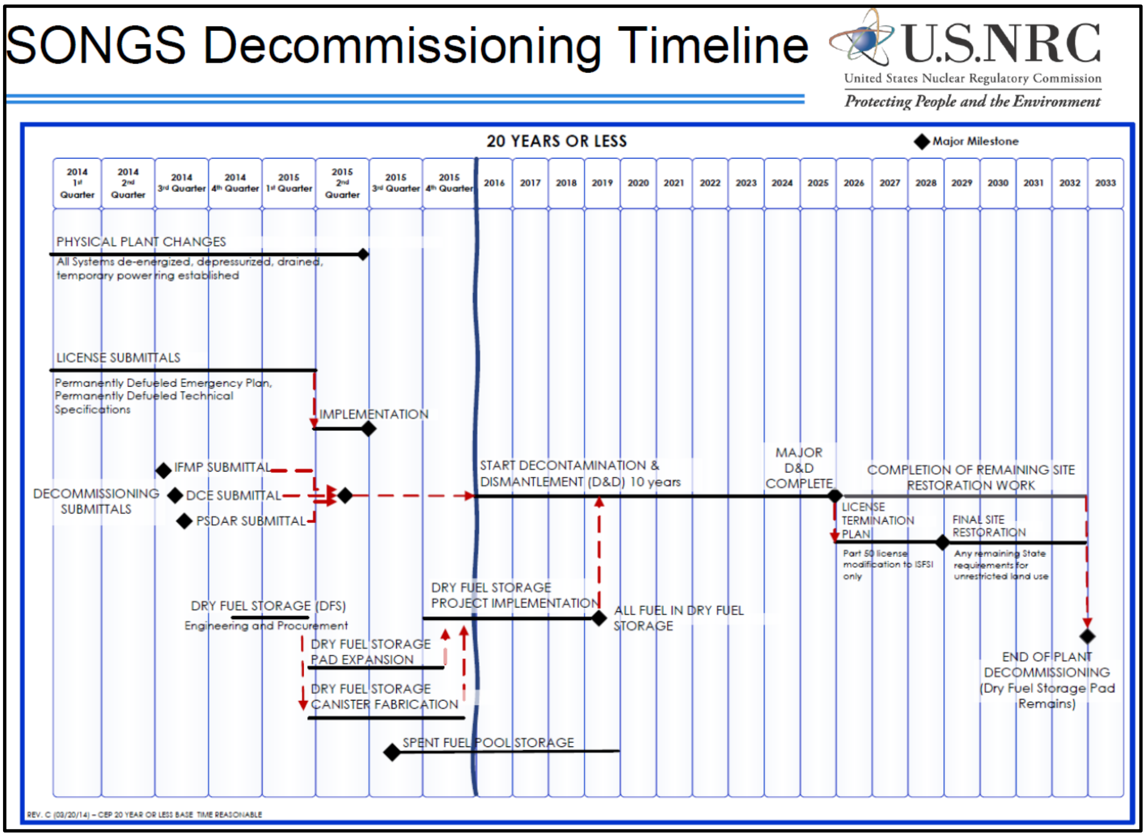

Illustration 25. SONGS Decommissioning Timeline [44]

Dates	Milestone Description
07/06/2013	Announcement of Cessation of Operations
22/06/2014	Required NRC Submittal – PSDAR, IFMP, DCE
30/06/2015	Cold and Dark Achieved
30/06/2015	Implement Permanently Defueled Technical Specifications
30/06/2015	Implement Permanently Defueled Emergency Plan
01/01/2016	Start of Decontamination and Dismantlement
01/06/2019	All Spent Fuel Transferred to Dry Storage
30/12/2028	Start of License Termination Submittal and Final Site Restoration
30/12/2032	License Termination During Demolition
24/06/2050	Independent Spent Fuel Storage Installation Part 50 License Termination
17/03/2051	Independent Spent Fuel Storage Installation Demolition
02/02/2052	Final Site Restoration and Easement Termination
2024-2049	Spent Fuel Transfer Window to Department of Energy (DOE)

Illustration 26. Key Milestone Dates San Onofre [44]

3.2.3. Analysis and Conclusions

First of all, the case of **Vandellòs 1** will be analysed. It has followed a decommissioning strategy called " **SAFSTOR**". It has been divided in 3 levels:

1989: Shutdown of Vandellós 1

a) **Level 1** (1991-1997) → *Conditioning activities*.

b) **Level 2** (1998-2003) → *Decommissioning of structures and preparation for the latency period*.

c) **Latency Period** (2003-2028).

d) **Level 3** (Around year 2028) → *Decommissioning of reactor box*.

[41]

The information extracted from the IAEA, says the following about SAFSTOR strategy:

- *"Facility is placed into long-term storage"*. [45]
- *"Dismantling is deferred from 10 to 60 years"*. [45]
- *"Systems are drained, waste removed and areas secured"*. [45]
- *"Allows decay of radionuclides"*. [45]
- *"Lose current work force knowledge"*. [45]
- *"Portions of the site may be used for other purposes"*. [45]
- *"Option if waste disposal or spent fuel management facilities are not available"*. [45]
- *"Allows for the collection of funds"*. [45]
- *"Work force reduced until dismantling begins"*. [45]
- *"Spent fuel may be an issue"*. [45]
- *"May be the preferred option if multiple facilities are on-site"*. [45]
- *"Sometimes called Safe Storage or Safe Enclosure"*. [45]

After presenting those principles of SAFSTOR from the IAEA, some of them will be examined to see if those are fulfilled at Vandellòs 1:

Regarding the first feature "**facility is placed into long-term storage**", that happens in Vandellòs 1. For example, the unreleased parts (reactor box) are placed during 25 years (latency period) during which time the radiological activity decays. That would fulfil also "**allows decay of radionuclides**".

On the other hand it is introduced the fact that "**dismantling is deferred from 10 to 60 years**". That is true at Vandellòs 1 due to the fact that starting with the conditioning activities (1991) and finishing with the final dismantling (about 2028), almost 40 years have passed.

"**Systems are drained, waste removed and areas secured**". During the level 2 of the decommissioning, the decommissioning report [41] states that all the structures, systems and component except the reactor box are dismantled and released.

Moreover, the **decay of radionuclides** is fulfilled during the latency period.

Regarding the "**lose of current work force knowledge"**, in the following section (3.3.1. Impact on staffing and socio-economic factors at Vandellòs 1), it is said that during the operational phase 400 people were employed at the nuclear plant and 110 from them continued working for the decommissioning process. Of course, there was a huge loss of knowledge that ENRESA solved with a lot of trainings for the old and new people (a more detailed explanation will be covered in the section 3.3 Impact on staffing and socio-economic factors).
In the same way, this fact is also related with "**work force reduced until dismantling begins**". Indeed, analysing the Illustration 28 from the section 3.3.1, it can be seen how the workforce varies depending on the phases of the decommissioning.

Additionally, many infrastructures were removed, adapted or built for the decommissioning. Actually, the decommissioning report of ENRESA [41] presents examples like *"the control room was replaced with a new surveillance post*" or "*during 1998, various infrastructures of logistical interest for the decommissioning process were adapted"*. That would be related with the fact of "**portions of the site may be used for other purposes**".

In the second place, the case of San Onofre will be analysed. It has followed a decommissioning strategy called "DECON".

As it has been already explained in the previous section 3.2, the DECON option consists in **removing all the equipment**, structures and systems that contain radioactive contaminants from the facility **as soon as possible**. Moreover, they are decontaminated as soon as possible, in order to finish the license after the operational phase. [46]

A brief review considering the main milestones occurred at San Onofre:

- **June 2013** → SCE decides to retire Unit 2 and Unit 3 at San Onofre.
- **January 2016** → Start of decommissioning process.
- **2032** → End of plant decommissioning.
- **2052** → Final site restoration.

The information extracted from the IAEA, says the following about DECON strategy:

- *"All radioactivity above specified levels is removed".* [45]
- *"Allows clearance or unrestricted use".* [45]
- *"Normally begins very soon after shutdown (2-5 years)".* [45]
- *"Allows use of current work force".* [45]
- *"Work force remains relatively stable during period".* [45]
- *"Does not allow for significant decay of radionuclides".* [45]
- *"Waste and spent fuel management facilities must be available".* [45]
- *"Funding must be available to complete the activities".* [45]
- *"Preferred option if resources are available".* [45]

Starting with the principles of DECON presented by the IAEA, some of them will be examined in order to verify if those were fulfilled at San Onofre.

In the case of San Onofre, it is true that "**all radioactivity above specified levels is removed**". Thus, as [36] indicates, "*spent fuel would be held on-site in dry casks indefinitely, while Low Level Radioactive Waste would be disposed in Texas and Utah*". Those are information from SCE in August 2014.

Referring to the feature "**allows clearance or unrestricted use**", according to the information exposed in [47], " *Once San Onofre's license has been terminated and the NRC has released the site for unrestricted use, the area can be used in any way permissible by federal, state and local laws*". As a consequence, the final purpose of the decommissioning in San Onofre is releasing the place for any other use.

A further characteristic from IAEA (DECON strategy) which is fulfilled in San Onofre is that the "**decommissioning process begins very soon after shutdown**", since the shutdown was in 2013 and the process has already started in 2016.

Besides, another feature from DECON would be "**allows use of current work force**". In the same way as in Vandellòs 1, some workers who were already working there during the operational phase from San Onofre, continued there for the decommissioning. This will be further explained in the following section 3.3.2 and with Table 9.

Moreover, the topic "**waste and spent fuel management facilities must be available**" is in the section 3.6.2 better explained.

Finally, extracting the information listed in [47] with date of February 2016, "**funding is assured for carrying out the activities"**. Thus, "*Decommissioning San Onofre is expected to cost $4.4 billion. The project is paid for with trust funds that were established early during the plant's operations. Based on forecasted escalation, the trust funds are fully funded*".

To sum up, and as a conclusion from this section focused on the "decommissioning strategy", it is important to say that **each nuclear plant (Vandellòs 1 and San Onofre) has chosen its respective strategy regarding different factors**. Some of them are listed below:

- Regulations of the government in the respective country.
- Development and availability of a system for the waste management.
- Influence of the hazards.
- Funding.
- Characteristics of the facility.
- Knowledge and experience of the staff.
- Future utility of the place.
- Kind of nuclear waste and type of facility.
- Impact in the society and economy of the site.

3.3. Impact on staffing and socio-economic factors

It is well-known that the quantity of workers of the nuclear plant decreases during the decommissioning period compared to the operational phase. However, the number of new employees increases related with the decommissioning process. [48]

It is important to know that the dismantling and the preparatory process, last about ten years. This means that the solutions for the workers can be predicted in advance. For example, some workers can be changed to other centres and others sent on early retirement. [48]

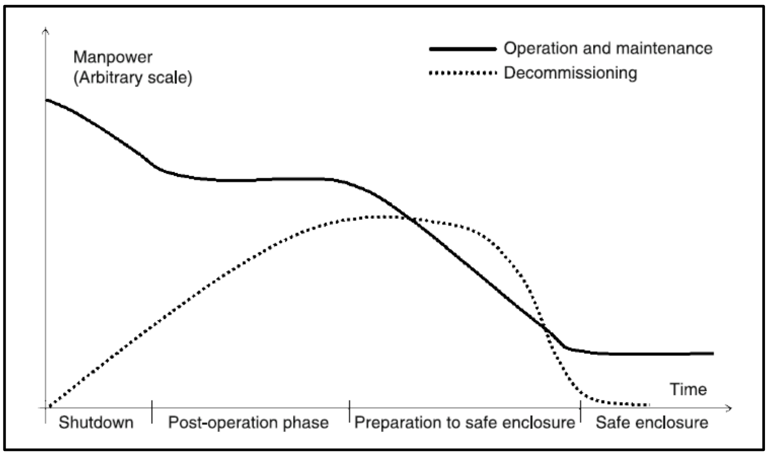

Illustration 27. Profile of staff reduction during decommissioning [2]

Moreover, these four points are very important regarding the **impact on staffing**: [49]

- "Staff reduction profile".
- "Use of operating staff to undertake decommissioning project tasks".
- "Sharing key resources among plants".
- "Policies for choosing what work will be put out to contract".

Regarding the **kind of staff** that we could have, there are two options:

a) **"Maintaining a high number of operational staff"**:
With this option, it is necessary to train the workers in new skills and reorientation of attitudes. [48]

b) **"Use of an outside contractor"**:
That may have a negative impact on the local workforce. [48]

Regarding the general topic about "Impact on Staffing", here we have a very close example from a recent closing of a nuclear power plant called "Garoña" in Spain:

- Initial staff (operational phase): 227 workers. [50]

- Licensee is Nuclenor (Iberdrola and Endesa). [50]

- From those 227 workers, the nuclear power plant will take 119 workers for the dismantling process, 55 workers will be relocated to other nuclear power plants from Iberdrola or Endesa, and about 30 workers will leave pre-retired. Besides, 13 workers have rejected the relocation offer. [51]

- Moreover, the pre-retired workers will have to teach those workers who will occupy the other positions. [51]

On the other hand, we have the **socio-economic factors** that can have impacts in the surrounding area. It is necessary to consider the following three different phases in the whole decommissioning process:

a) Permanent shutdown:

It is clear that after the shutdown, a **loss of employment** takes place (direct and indirect) and consequently a loss of income. [52]

Regarding the **direct loss of employment**, it is produced because of the ceasing of activity at the nuclear power plant. It could also lead to a demographic slump in the area of the plant (migratory effect on the opposite direction to implementation of facility). [52]

Focusing on **indirect loss of employment**, it is clearly known that it comes from the activities directly linked to the facility (auxiliary companies, refuelling work,..). [52]

b) Decommissioning Period

That's a **new impulse for the area**, through the activity related with the decommissioning. It reactivates the local economy through the hiring of direct workers to work at the decommissioning and from the contracting of companies in the area. [52]

On the other hand, the **revenues that the local administrations receive because of the decommissioning** are very important too: licenses and permits, compensations for waste storage, agreements for promoting the area after the decommissioning and others. [52]

c) Post-Closure

The post-closure phase is considered the **end of the activity**. From this point, it is time to **look for other economic incentives** for the area because the nuclear installation has already disappeared. [52]

Normally, the most adapted measure is the training of people and the preparation of companies and entrepreneurs in the area. [52]

However, it is obvious that the final release of the site can be used for different activities. Moreover, there is an advantage with the already existing infrastructures (electricity lines, water supplies, cooling systems and others). [52]

3.3.1. Impact on staffing and socio-economic factors at Vandellòs 1

Important facts:

- 1998: The decommissioning plan is approved and starts.
- Number of workers at operational phase: 400 workers.
- Number of workers employed for the decommissioning: 110 workers. Those workers had to be trained.
- The other workers were retired or relocated to other nuclear plants (290 workers).
- However, during the dismantling period (1998-2003), a total of 2700 workers belonging to 63 companies were employed there. [53]

In the following tables and illustrations, some cities that are in the surrounding area from Vandellòs 1 will be additionally considered, because no other source than [54] could be found providing more focused information.

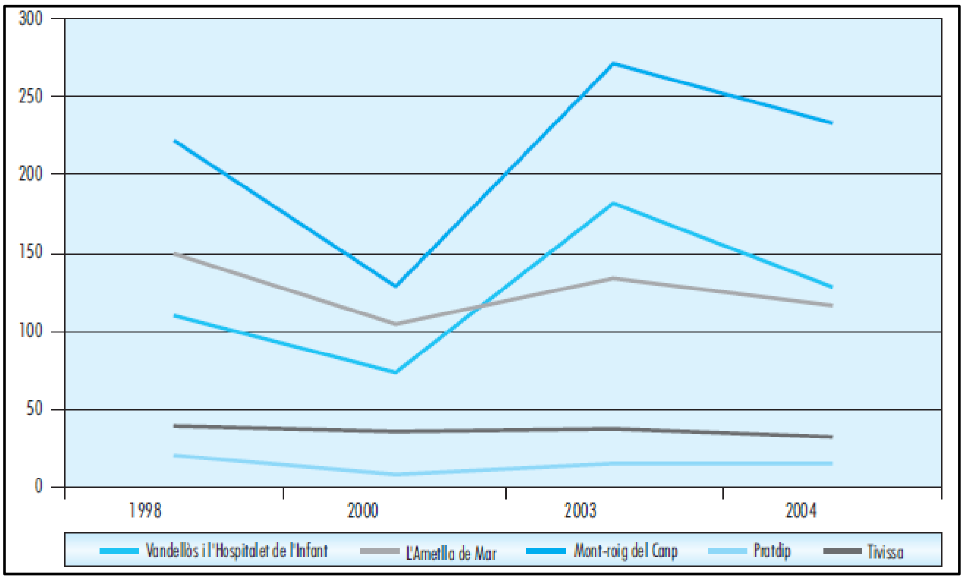

Illustration 28. Staff evolution during decommissioning Vandellòs 1 [54]

In the following illustrations a map with the location of the different cities listed in Illustration 28 is presented.

→ Vandellòs 1 nuclear power plant

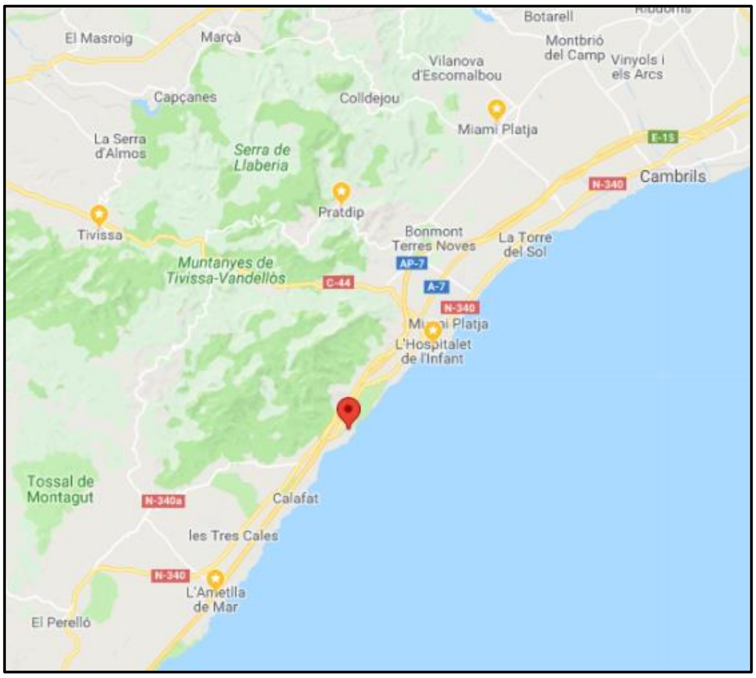

Illustration 29. Location of the different cities

Illustration 30. Location of the different cities

Illustration 29 and Illustration 30 support the better understanding of the following tables.

The Table 6 shows the **population in the cities** near Vandellòs 1.

City	Population (2016)
Vandellòs i l'Hospitalet de l'Infant	6.143
L'Ametlla de Mar	7.102
Mont-roig del Camp	11.521
Pratdip	691
Tivissa	1684

Table 6. Population of cities

The Table 7 shows the evolution in the **number of companies** which have been grounded between 1998 and 2002.

City	Number of companies		
	1998	2000	2002
Vandellòs i l'Hospitalet de l'Infant	261	286	291
L'Ametlla de Mar	337	371	402
Mont-roig del Camp	529	710	715
Pratdip	25	31	28
Tivissa	87	93	83

Table 7. Number of companies in surrounding área [54]

Moreover here is an important information extracted from [52]:

	Local	Provincial	Remainder	Total
Employees (September 2003)	194	-	112	306
Companies (November 1999)	40	48	38	126

Table 8. Data on employment in decommissioning Vandellòs 1 [52]

Another information that it has been extracted from [52]:

"*In the case of Vandellòs 1 nuclear power plant, where the transition period between the permanent shutdown and the start of decommissioning works has taken ten years, the direct loss of employment has meant the disappearance of almost 300 jobs in a community of some 4000 inhabitants. Local administrations during this transition period were involved directly in the decommissioning project, satisfying all the information requirements*". [52]

Regarding the **new activities from a nuclear power plant after decommissioning (post-closure)**, in Vandellòs 1 one can find many different examples.

On the one hand, Vandellòs 1, after its decommissioning, has established a location for the **performance of research programmes and for the training of people** who will be in charge of future decommissioning projects. Thus, ENRESA signed a collaboration with the Rovira i Virgili University on behalf of the new research and development centre. [41]

That will be called "**Mestral Technology Centre**". At this one, three main activities will be carried out:

1. *"Management of the latency period"*. [41]
2. *"Research into technologies, materials and procedures for future decommissioning projects"*. [41]
3. Training of future professionals.

[41]

3.3.2. Impact on staffing and socio-economic factors at San Onofre

As it can be read at San Onofre Economic Impact Study [55], those are the main figures of the decommissioning process:

San Onofre Staffing			
Phase	**Core Staffing**	**Contract Employees**	**Comments**
During Operation	2200	500	Higher employment and more "permanent" jobs
Decommissioning	375	100	Lower employment and more "temporary"jobs

Table 9. San Onofre Staffing during decommissioning [55]

As it can be seen at the chart, staffing was reduced during 2013 about 400 workers. However, transition plans are going to ensure the proper closing of the nuclear power plant. Human Resources will work hardly for a fair transition plan too. The support of contractors will be evaluated on a case-by-case basis. [56]

Here an extract from the Post Shutdown Activities Report written by SCE [46] is presented, which shows a lot of information given in the section 3.3:

*"The primary socioeconomic impacts of decommissioning are related to **staffing changes and decreasing tax revenues**. Impacts related to the decision to permanently cease operations are outside the scope of this evaluation. SCE determined the **staff reduction impacts** from the decision to be **minimal**. The staff reductions represent 0.04 percent and 0.03 percent of San Diego County's and Orange County's workforces, respectively".* [46]

"Any impacts will be deferred somewhat due to the employment of temporary staff necessary to accomplish the various decommissioning activities". [46]

*"Similarly, **SONGS** is located in San Diego County and its property assessment is a relatively **small portion of** San Diego County's total **tax collections**. Historically, SONGS' contribution to the county property tax collections has been consistently **less than 1 percent**. SONGS' tax obligations will be reduced due to decommissioning, but SCE and SONGS will continue to contribute to county tax revenues".* [46]

*"It is anticipated that **there will be limited or no changes or impacts to the local community and socioeconomic conditions** and less impact than would be expected generically where other nuclear facilities have a higher relative impact on the job market or tax base. Thus, SONGS' impacts are bounded by those considered in the GEIS in which the NRC generically determined socioeconomic impacts to be SMALL".* [46]

3.3.3. Analysis and Conclusions

The **"Impact on staffing and socio-economic factors" at Vandellòs 1 is more accurately analysed than at San Onofre.** That is because the decommissioning from Vandellòs 1 is almost done and the one from San Onofre started about one year ago. However, the analysis of San Onofre will be based on forecasts.

Firstly, **the situation of Vandellòs 1 will be analysed**. As a reminder, the main milestones from its decommissioning will be presented:

1989: Shutdown of Vandellós 1

a) **Level 1** (1991-1997) → *Conditioning activities*.
b) **Level 2** (1998-2003) → *Decommissioning of structures and preparation for the latency period*.
c) **Latency Period** (2003-2028).
d) **Level 3** (Around year 2028) → *Decommissioning of reactor box*.

Starting with the variance of the quantity of workers between operational and decommissioning phase, it is found that **many topics presented previously at the beginning of the section 3.3. are reflected**.

For example, "**the staff reduction profile**" it is reflected in Table 8 and Illustration 28. Regarding the first one, the table shows that by 2003 more than 300 workers were employed, while during the operational phase more than 400 workers were employed. Moreover, the Illustration 28 reflects the evolution of the unemployed people in

Vandellòs and surroundings. As it can be seen, depending on the phases of the decommissioning process, the quantity of employed or unemployed workers increases or decreases. In addition, cities like Tivissa which are quite far from the nuclear plant, are less influenced by the demand of workers at the decommissioning process of Vandellòs 1.

Another example is related to one of the four points presented in the section 3.3. That is the "**use of operating staff to undertake decommissioning project tasks**". As it is said in the section 3.3.1, after the shutdown of Vandellòs 1, 100 workers from the 400 workers from the operational phase, were employed and continued to work for the tasks of decommissioning.

Moreover, the fact of "**sharing key resources among plants**" was also carried out in Vandellòs 1. Thus, as it can be read in the section 3.3.1, "*the other workers were retired or relocated to other nuclear plants (290 workers)*".

Regarding the analysis of the **socio-economic factors** at Vandellòs 1, the Illustration 28 could justify the three different phases that can be distinguished in the decommissioning process. As a reminder, those are:

a) Permanent shutdown.

b) Decommissioning period.

c) Post-closure.

As it can be seen in Illustration 28, the **evolution of unemployed people between 1998 and 2004 is not stable and depends on the time**, at least for Vandellòs i l'Hospitalet de l'Infant, l'Ametlla de Mar and Mont-roig del Camp. Those are the **cities closer to the nuclear power plant** and, because of that, the changes on it affect more these places. Thus, at the **beginning of 1998** (coinciding with the start of Level 2 of decommissioning), the **unemployement figures are high**, but then already in **2000 low** and then by **2003** they **increase again**.

Based on this, a correlation between the different phases in the decommissioning and the process presented before can be established. In the **permanent shutdown** a **loss of employment** (direct and indirect) takes place, around **1989**. However, during the **decommissioning period**, there is a new impulse in the area, increasing **the amount of employed people and companies**. That would be around **1999** in the case of Vandellòs 1. Finally, the **post closure** means the end of the activity and it is time to look for other incentives. For Vandellòs 1, this last stage would be around **2003** and later in **2028**.

Regarding the **post-closure stage from the decommissioning, in Vandellòs 1** a clear example of research for other economic incentives is found. As it is presented in the section 3.3.1, the "**Mestral Technology Centre**" will be created. That will be a center for researching and training people, related to nuclear plants and nuclear energy.

Finally, analysing Table 6, Table 7 and Illustration 28 together, it can be concluded that in **the three first cities with more population the influence of the decommissioning of Vandellòs 1 can be better noticed**. Thus, the evolution of **unemployed people** varies depending on the phase of decommissioning and the **quantity of companies** which are grounded increases from 1998 until 2003 in Vandellòs i l'Hospitalet de l'Infant, l'Ametlla de Mar and Montroig del Camp.

Secondly, the **case of San Onofre** will be analysed. As a reminder, the main milestones from its decommissioning will be presented:

- **June 2013** → SCE decides to retire Unit 2 and Unit 3 at San Onofre.
- **January 2016** → Start of decommissioning process.
- **2032** → End of plant decommissioning.
- **2052** → Final site restoration.

Starting with the information from the Illustration 27, it can be assured that the **profile of staff** occurred at San Onofre during the decommissioning have been, like in Vandellòs 1, represented by the Illustration. Thus, **operation and maintenance** have a tendency of **decreasing** through the time, while **decommissioning workforce increase** from the shutdown until the preparation to safe enclosure.

Moreover, focusing on the topic of "**staff reduction profile**", at San Onofre it occurs too. For example, taking the Table 9 into account, a reduction of 400 contract employees is seen between the operation phase and the decommissioning phase. In the same way, it is found that there are "**policies for choosing what work will be put out to contract**". Thus, in the Table 9 appears that during the operation phase there is *higher employment and more "**permanent**" jobs* while during the decommissioning phase there is *lower employment and more "**temporary**" jobs*.

On the other hand, referring to the **socio-economic factors**, those are the main conclusions about San Onofre (it is important to remind that the conclusions are based in recent or forecasted studies and it could change in some years):

Considering the workforce, "**staff reduction impacts will be minimal**". That is because the staff reductions represent about 0.04 percent of San Diego County's workforces. Moreover, the nuclear plant taxes are a small portion of San Diego's tax collections and SCE (owner of San Onofre) will continue paying taxes because it has other businesses.

Because of that, and in the same way that is assured in section 3.3.2,"*there will be limited or no changes or impacts to the local community and socio economic conditions".*

As a **conclusion** from both **Vandellòs 1 and San Onofre**, they have followed more or less the same strategy regarding the Staff. That is the first approach "*The Licensee performs the decommissioning with in-house resources supplemented by specialist contractors as needed*".

That means that it is used the staff that already existed in the nuclear plant but also a huge amount of hired people. Consequently, the **Licensee is in day to day control of the facility, processes and activities**.

It is important to say that the management of decommissioning at Vandellòs 1 and San Onofre try to have the **minimum amount of the workers that already existed** in operating phase, because that is very expensive to maintain. They have to train these people for the new changing situations because they are not specialists in everything. This requires also training in new skills and reorientation of attitudes towards a project completion outlook.

However, is also important to guarantee future relocation of staff to other plants or projects (as we can read in Vandellòs 1).

3.4. Phases of decommissioning

The **final goal** of the decommissioning of a nuclear power plant is to ensure that the future activities carried out in the place of the nuclear power plant, do **not** have any **risk neither for the health of the people nor for the environment**. [23]

As it is said in the document [23], the strategy and the schedule for achieving the closing or final phase of a nuclear power plant depends on different factors related to each country or even to each power plant.

This explanation can be transferred for the phases of decommissioning, namely, in each situation or power plant; **one can adapt and modify the phases of decommissioning in order to satisfy the decommissioning process in the best way**.

It is important to **distinguish the decommissioning state from the operational state**.

That is the start point from which our analysis will be guided:

Decommissioning state	Operations state
Temporary design life of structures to assist dismantling	Permanent design of structures for operation
Safety management systems based on decommissioning tasks	Safety management systems on operating management facility
Control based on as-built structures	Control based on drawings
Reduced safety risks but changing situation	Significant safety risks but permanent and routine
Management of changing situation during decommissioning	Management of steady state during operation
Reduced administrative infrastructure	Steady state administration infrastructure
Retraining staff for new activities	Routine training and refresher training
Visible end of employment – refocus their work objective	Permanent employment with routine objectives
New or developing regulations/regulatory requirements	Established and developed regulations for operation

Table 10. Differences betweeen decommissioning and operational states [2]

The table below presents the **general process of decommissioning established by IAEA** and in the following it will be analysed how each country has adapted it.

FACILITY STAGE	DECOMMISSIONING ACTIVITY
Design, Construction & Start-up Phase	• Initial decommissioning plan
Operating Phase	• Update decommissioning plan • Finalize safe enclosure plan • Prepare shutdown plan
Transition Phase	• Source term reduction • Waste conditioning • Prepare site • Preparation plan
Preparation Phase	• Site preparation • Initial dismantling
Deferred Dismantling Period	• Update final decommissioning plan • Surveillance & maintenance
Decontamination & Dismantling Phase	• Decontamination • Dismantling activities
Final Phase	• Final survey • License termination

Table 11. Overall Decommissioning Process by IAEA [57]

On the one hand, the **division of phases that has implemented the United States Nuclear Regulatory Commission (US NRC) will be presented**:

<u>*Phase 1: Initial Activities (Before Clean-up)*</u>

- *"Written certification of permanent cessation of operations to the NRC within 30 days"*. [58]

- *"Written certification when radioactive nuclear fuel is permanently removed from the reactor vessel"*. [58]

- *"Within 2 years after submitting the certificate of permanent cessation → the licensee must submit a post-shutdown decommissioning activities report to NRC (planned decommissioning activities, schedule and expected costs)"*. [58]

<u>*Phase 2: Major Decommissioning Activities (During Cleanup)*</u>

- *"Ninety days after the NRC receives planning report → The owner can begin major decommissioning activities (permanent removal of major components as reactor vessel, steam generators, large piping systems, pumps and valves)"*. [58]

- *"It is chosen a decommissioning strategy"*. [58]

<u>*Phase 3: License Termination Activities (After Cleanup)*</u>

- *"The owner is required to submit a license termination plan within 2 years of the expected license termination"*. [58]

- *"The license termination report (LTP) requires NRC approval of a license amendment"*. [58]

[58]

Table 12. Phases of decommissioning by US NRC [58]

On the other hand, the different **phases of decommissioning which are used for decommissioning in Spain** will be presented:

<u>*Phase 1: Closing under surveillance*</u>

- *"It is removed fuel elements, control rods and contaminated liquids. Moreover, the primary circuit is kept as it was during the operation phase but the opened systems are closed"*. [23]

- *"The containment building is maintained in operating situation for avoiding any release of radioactive material. It is also very important to control the inner atmosphere of the containment (humidity, radioactivity and temperature)"*. [23]

<u>*Phase 2: Partial and conditional release of the site*</u>

- *"The primary circuit is reduced to its minimum size and the most easily removable parts are removed. Moreover the primary circuit (barrier against contamination) is better sealed and, if it is necessary, it is added a biological shield"*. [23]

- *"After having decontaminated until acceptable levels, the containment building and ventilation systems can be modified or eliminated. The areas and buildings which are not radiological can be reconverted for other* *uses. In the same way, the materials which are not contaminated or enough decontaminated can be reused outside the nuclear area".* [23]

<u>*Phase 3: Total and unconditional release of the site*</u>

- *"All the materials and elements from the nuclear power plant which have still some levels of radioactivity are removed from the area. The remaining elements must have contamination levels below the authorized limits".* [23]

- *"The place is totally dismantled".* [23]

[23]

<table>
<tr><th>Phase 1</th><th>Phase 2</th><th>Phase 3</th></tr>
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Table 13. Phases of decommissioning by CSN [23]

3.4.1. Phases of decommissioning at Vandellòs 1

Regarding the phases of decommissioning that were carried out at Vandellòs 1, **the decommissioning report from ENRESA [41] indicates the following information**:

<u>***1989: Shutdown of Vandellòs 1***</u>

<u>***Level 1: 1991 – 1997 (Conditioning activities)***</u>

During this period, the reactor core was unloaded, the fuel was removed and the wastes were removed or stored in the graphite silos. At the same time, some initial disassembly tasks were carried out.

<u>***Level 2: February 1998 – June 2003 (Decommissioning of structures and preparation for the latency period)***</u>

During this period, all the structures, systems and components were dismantled, except the reactor box. Moreover, most of the site was released and the rest was left as a regulated zone. Finally, the reactor box was confined and covered by a new structure.

At the end of this level, the unreleased parts of the site were prepared to remain under surveillance for 25 years. That is known as "Latency Period". During this period, the radiological activity decays about 5% level of the initial level.

Level 3: from 2028 (Decommissioning of reactor box)

After the latency period, the reactor box and all the internal elements will be removed and finally the entire site will be released.

[41]

3.4.2. Phases of decommissioning at San Onofre

In the case of San Onofre, firstly the main milestones about the decommissioning process will be introduced:

- **June 2013** → SCE decides to retire Unit 2 and Unit 3 at San Onofre.
- **January 2016** → Start of decommissioning process.
- **2032** → End of plant decommissioning.
- **2052** → Final site restoration.

As it can be seen, the **decommissioning process** of San Onofre started **very little time ago**. As a consequence, all that has been found related to the phases at San Onofre are timelines, key milestones and documents related to phases, however, everything related to forecasts.

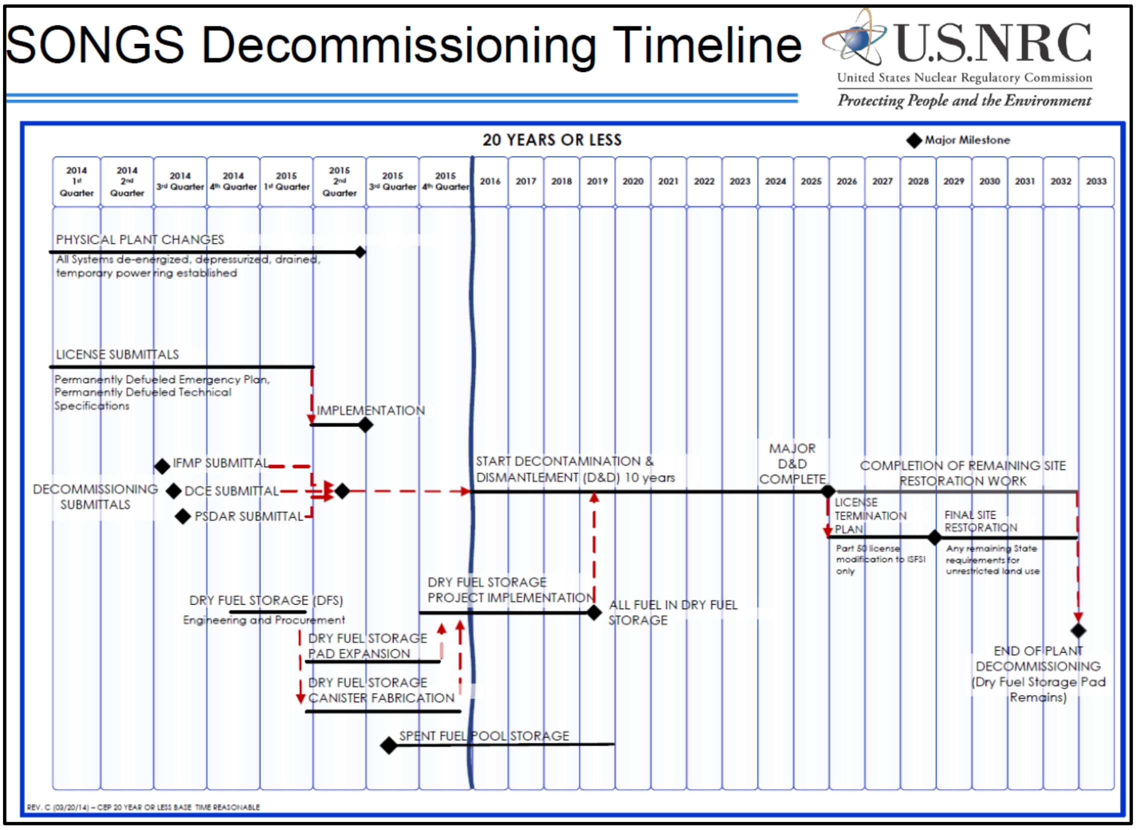

Illustration 31. SONGS Decommissioning Timeline [44]

Dates	Milestone Description
07/06/2013	Announcement of Cessation of Operations
22/06/2014	Required NRC Submittal – PSDAR, IFMP, DCE
30/06/2015	Cold and Dark Achieved
30/06/2015	Implement Permanently Defueled Technical Specifications
30/06/2015	Implement Permanently Defueled Emergency Plan
01/01/2016	Start of Decontamination and Dismantlement
01/06/2019	All Spent Fuel Transferred to Dry Storage
30/12/2028	Start of License Termination Submittal and Final Site Restoration
30/12/2032	License Termination During Demolition
24/06/2050	Independent Spent Fuel Storage Installation Part 50 License Termination
17/03/2051	Independent Spent Fuel Storage Installation Demolition
02/02/2052	Final Site Restoration and Easement Termination
2024-2049	Spent Fuel Transfer Window to Department of Energy (DOE)

Illustration 32. Key Milestone Dates San Onofre [44]

Finally a **presentation performed by Thomas J. Palmisano** (vice president and chief nuclear officer at the San Onofre Nuclear Generating Station) has been found. It was realised in **2014, after the shutdown of San Onofre and prior to the beginning of the decommissioning**. From this presentation, the following information can be extracted: [59]

- ***Phase 1:*** *"includes the initial activities, starting on the effective date of permanent cessation of operations. Its duration is about 2 years"*. [59]

- ***Phase 2:*** *"encompasses activities during the storage period or during major decommissioning activities. Its duration is variable but maximum 58 after shutdown"*. [59]

- ***Phase 3:*** *"consists of the rest the activities the licensee undertakes to terminate the license. This phase must be complete within 60 years of ceasing operation"*. [59]

Moreover, the following illustration is one of the slides from Thomas Palmisano, where each phase is explained more in detail:

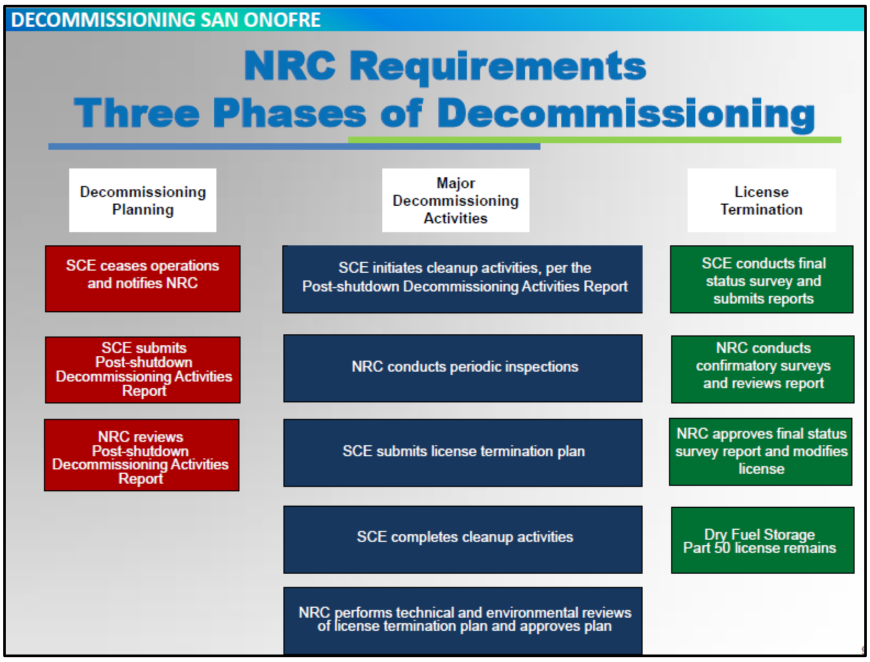

Illustration 33. Phases of decommissioning (by Thomas Palmisano in 2014) [59]

3.4.3. Analysis and Conclusions

First of all, the **difference between decommissioning state and operational state** will be analysed. After searching information in many sources such as decommissioning reports, **some examples that fulfil the characteristics of decommissioning state (based on Table 10)** have been found:

Regarding to **Vandellòs 1**:

1. *Temporary design life structures:*

- *"The electrical systems were modified, this including the installation of a new distribution arrangement adapted to the needs of the decommissioning process"* [41]
- *"A materials declassification and cutting workshop was set up in an enclosure adjacent to the reactor building"* [41]
- *"Adaptation of the medical service, especially adapted to the decommissioning works"* [41]

As it can be seen, those are not facilities for a long time. Those are built only to satisfy the provisional needs for a certain period of decommissioning.

2. *Safety Management systems based on decommissioning tasks*

- *"Control Room was replaced with a new Surveillance Post"* [41]

A facility for surveillance during the decommissioning was built.

3. *Reduced administrative infrastructure*

- *"The Administration offices were taken to the easternmost area of the site, in order to separate works activities from purely administrative tasks"* [41]

During decommissioning it is very important to centralize each kind of activity in order to be more effective. In this case, the management of Vandellòs 1 tried to reduce the administrative infrastructure for a short time.

4. *Retraining staff for new activities*

- "Including the acquisition of new equipment and the setting up and training of the 41-strong fire brigade" [41]

As it has been said before, the decommissioning process is a period of time where a lot of different tasks have to be carried out and a huge quantity of different expertise is required. Because of that, the people working on it or the hired people have to attend constantly new trainings to know how to deal with the changing work. On the other side, in the operational state, people attend training as a routine and the changes are smoother.

5. *New or developing regulations/regulatory requirements*

- "Weighing device was installed (final radiological control prior to the exit of the materials from the facility)" [41]

According as new situations in the decommissioning process happen, measures or regulations are set up. Contrarily, in the operations state everything is more standard.

Regarding to **San Onofre**:

1. *Safety Management systems based on decommissioning tasks*

- "Shipping casks and other equipment necessary to conduct decommissioning activities will be designed and procured" [60] [46,60]

As it has been said before, during the decommissioning state, the safety management systems are focused in the activities of dismantling. Here the focus lies in the casks and necessary equipment for fulfilling the required safety levels.

2. *New or developing regulations/regulatory requirements*

- "Appropriate radiation protection and contamination control measures will be employed to manage these activities" [60]
- "Surveys will be conducted to establish the contamination and radiation levels throughout the plant" [60]

- "Monitoring walls were installed around the plant to monitor for radionuclides" [60]

As presented before in the example of Vandellòs 1, new procedures or measures are installed during all the process of decommissioning based on the needs that have to be fulfilled.

After the comparison and analysis between the decommissioning state and the operations state, the following step will be referred to the study of the phases of decommissioning of both Vandellòs 1 and San Onofre. It will be checked if those fulfil the requirements exposed by the IAEA (Table 11) and the CSN (Spain) or US NRC (USA) respectively.

First, the case of **Vandellòs 1** will be examined. Vandellòs 1 is located in Spain and, because of that, it is under the surveillance from **CSN** and it follows regulations from **IAEA**. As a reminder, those are the phases carried out in Vandellòs 1:

- **1989** → Shutdown of Vandellòs 1.
- **1991 – 1997** → Level 1. Conditioning activities.
- **1998 – 2003** → Level 2. Decommissioning of structures and preparation for the latency period.
- **From 2028** → Level 3. Decommissioning of reactor box.

Regarding to the IAEA (Table 11), the division of phases executed at Vandellòs 1 is quite similar to those presented in the table:

For sure, that the management already thought about decommissioning before starting the operation of the plant in 1972, that would be during the "**Design, Construction and Start-up Phase**". The "**operating phase**" for Vandellòs 1 was between **1972** and **1989**. It finished with the fire which occurred in the turbine-alternator. Because of the fact that the **ending of the operation was not planned**, the preparation of the shutdown lasted still 2 years until 1991. Thus, in July 1990 the Ministry of Industry and Energy issued a Ministerial Order for shutdown.

In **1991** the "**transition phase**" started and it lasted **until 1997**. As IAEA and the decommissioning report from ENRESA say, this period was mainly for conditioning the site and removing the waste. As it is read in the decommissioning report from ENRESA [41], "*the work performed during this period included the unloading of the reactor core and the removal of the fuel from the site, the conditioning of the operating wastes,..*". That is the same as indicated in the table from IAEA.

Later in **1998** the "**preparation phase**" started and it lasted **until 2003**. The decommissioning report from ENRESA [41] calls this phase as "**Level 2**" but the explanations are the same as exposed by IAEA. That is *"Decommissioning of structures and preparation for the latency period"*.

In this way, **in 2003 the latency period starts which will last until 2008**. In terms of IAEA, that would be the "**deferred dismantling period**" and in its explanations says *"surveillance and maintenance"*. That is the same as in decommissioning report from ENRESA [41]: *"the unreleased parts of the site remain under the responsibility and surveillance".*

Finally in **2028** it will be carried out the phase of "**decontamination and dismantling phase**" according to IAEA. In the decommissioning report from ENRESA [41] this phase is called "**Level 3**". Moreover, the "**final phase**" to certify that the site is already released is always necessary.

In conclusion, it is quite clear that the management of ENRESA followed the procedures and instructions given by IAEA.

Now it will be analysed if the management of ENRESA followed also the instructions established by **CSN** (Consejo de Seguridad Nuclear) [23].

The CSN establishes 3 levels during the decommissioning process:

- **Phase 1:** Closing under surveillance.
- **Phase 2:** Partial and conditional release of the site.
- **Phase 3:** Total and unconditional release of the site.

Comparing the information from the decommissioning report from ENRESA [41] and the regulations from CSN exposed in the section 3.4.1, it can be concluded that the directions are quite similar. Based on information from CSN, Vandellòs 1 was dismantled until the level 1 in a short time (5 years), then a waiting period (latency period) was settled having the nuclear plant closed with surveillance and, finally, in 2028, the dismantling until the level 3 will be continued. That will last about 40 years in total.

In conclusion, it is possible to affirm that the management of ENRESA followed also the procedures and instructions given by CSN.

Secondly, the case of **San Onofre** will be examined. San Onofre is located in the **USA** and, because of that, it is under the surveillance from **US NRC** and it follows also regulations from **IAEA**.

It is important to know that San Onofre finished its activity at Unit 2 and Unit 3 last June 2013. 2 years later, in 2016, the decommissioning process started. Because of that, what will be analysed is based on forecasts.

As a reminder, **those are the phases designed for San Onofre, which were presented by Thomas J. Palmisano** (vice president and chief nuclear officer at the San Onofre Nuclear Generating Station):

- ***Phase 1:*** *"includes the initial activities, starting on the effective date of permanent cessation of operations. Its duration is about 2 years".* [59]

- ***<u>Phase 2:</u>*** *"encompasses activities during the storage period or during major decommissioning activities. Its duration is variable but maximum 58 after shutdown".* [59]

- ***<u>Phase 3:</u>*** *"consists of the rest the activities the licensee undertakes to terminate the license. This phase must be complete within 60 years of ceasing operation".* [59]

Moreover, the Illustration 33 explains each phase more in depth.

Starting with the analysis based on the IAEA (Table 11), the **phases established by IAEA and those established by the management from San Onofre decommissioning plant** (South California Edison, SCE) could be connected as follows:

The so called "**operating phase**" (IAEA) would be the operating phase at San Onofre, until the cessation of operations, concretely in 2013. In this time, several tasks like preparing and updating the shutdown plan are carried out.

Later, between **2013** and **2016**, the "**transition phase**" and the "**preparation phase**" could be put together. In the case of IAEA, they say that those phases have responsibilities like "*waste conditioning, preparing of the site, initial dismantling,..*" and that is the same what is assumed in "**phase 1**" by San Onofre: *"initial activities, shutdown of the plant,…"*.

As it can be seen in the section 3.4.2, the decommissioning of San Onofre is following a **DECON** strategy. That means that **there is not any "latency period"** due to the fact that the priority is an "early site release". Because of that, **it will be ignored the phase of "deferred dismantling period"** (IAEA).

After that, it could be spoken about the "**decontamination and dismantling phase**" (IAEA), having mainly activities like *"decontamination and dismantling activities"*. In the case of San Onofre, that would be "**phase** 2" (between **2016** and **2032**) and, as it is said, that would be "**major decommissioning activities**".

Finally, by **2032**, the "**final phase**" (IAEA) or the "**phase 3**" (San Onofre) will be reached. According to IAEA, this phase is focused on *"final survey and license termination"*. That is very similar to the explanations from San Onofre: *"consists of the rest of the activities the licensee undertakes to terminate the license"*.

In conclusion, it is possible to affirm that the management of San Onofre followed also the procedures and instructions given by IAEA. Of course, not exactly, but they have taken into account the general orders.

Now, it will be analysed if the management of **San Onofre** followed the instructions established by **US NRC** (United States Nuclear Regulatory Commission) [23].

The US NRC establishes 3 phases during the decommissioning process:

- **Phase 1:** initial activities (Before Clean-up).

- **Phase 2:** major decommissioning activities (During Clean-up).
- **Phase 3:** license termination activities (After Clean-up).

Starting with **phase 1** from **US NRC**, it refers to initial activities like shutdown, fuel removal, certificate of permanent cessation among others. That goes in the same way from "**phase 1**" (**San Onofre**).

Furthermore, **phase 2** from **US NRC** refers to *"major decommissioning activities"*. Here the strategy of decommissioning is chosen and the biggest tasks regarding the decommissioning are carried out. Of course, that would be also the "**phase 2**" from San Onofre.

Finally, **phase 3** from **US NRC** refers to *"license termination activities*". That means that responsibilities such as *"the owner (San Onofre) is required to submit a license termination plan"* or NRC is going to conduct a survey to check if everything is right for releasing the place. In the case of the phases established at San Onofre, the "**phase 3**" is focused in the same things: *"consists of the rest the activities the licensee undertakes to terminate the license".*

As a general conclusion, it can be concluded that the management of San Onofre decommissioning (South California Edison, SCE) and the management of Vandellòs 1 (ENRESA) have followed the instructions and regulations exposed by IAEA (International Atomic Energy Agency) and from US NRC (United States Nuclear Regulatory Commission) and CSN (Consejo de Seguridad Nuclear) respectively.

In fact, those 2 last organisms control that all the actions carried out by the responsibles of the decommissioning (ENRESA and SCE) fulfil the requirements.

3.5. The decommissioning management team

In this section **how each nuclear plant (Vandellòs 1 and San Onofre) was lead** will be analysed and discussed. First of all, the main characteristics about managing the decommissioning and operating phases from nuclear plants and also the possible organisational charts that a nuclear plant can possess will be introduced. Moreover, the importance of the training for the proper operation of the management team will be highlighted.

Later, in 3.5.1 and 3.5.2 the real situation from Vandellòs 1 and San Onofre will be presented, regarding the decommissioning management team.

Finally, a respective analysis and conclusions taking into account all the sections will be done.

In the decommissioning team it is necessary to have **staff with all the required skills, qualifications and experience**. However, it is also relevant having a **suitable supervisory structure** which leads the whole process.

At the beginning of the project, it is recommended to include experienced people in the decommissioning team. Those who were working at the facility during the operation phase because they have knowledge of the plant and its history. Thus, **experienced staff always has preference**.

Regarding **training programs**, that is an essential topic to ensure that all the staff owns the requirements for participating on the decommissioning tasks. Furthermore, this training helps the decommissioning staff to carry out its task according to the **present requirements of technology**.

Focusing on the role of the **DPM** (Decommissioning Project Manager), this person shares the responsibility for **managing, building and planning the decommissioning project** with the licensee. The DPM normally **recruits** the decommissioning management team **and defines the responsibilities** to each section of the organization. He or she **decides which tasks** will be derived for **external** organizations.

In this way, we can see below **two different structures from a management team** in decommissioning. On the first figure, the licensee performs most of all decommissioning tasks using in-house resources. On the second figure, the licensee hires an outside organization to carry out most of the work and the licensee is focused on management activities.

[2]

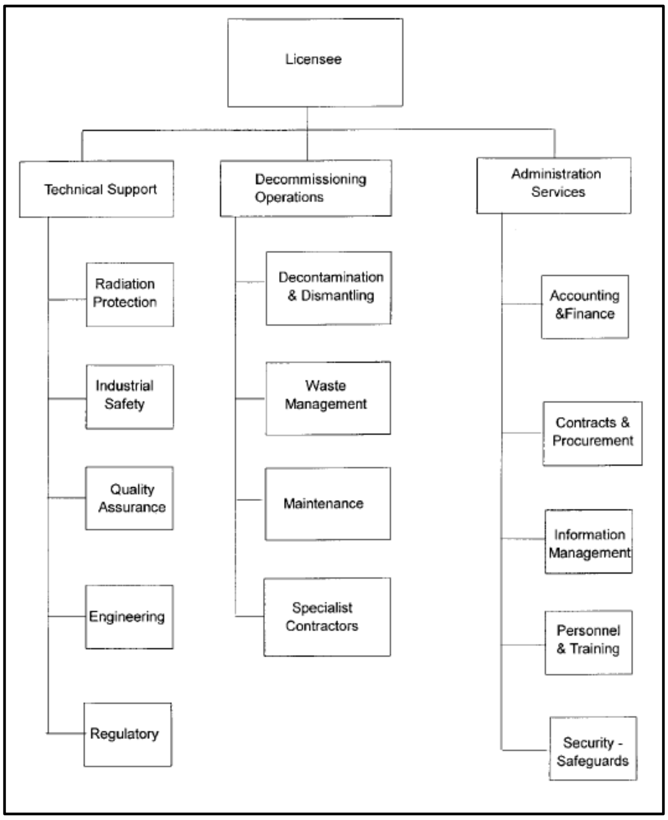

Illustration 34. Licensee performing decommissioning organization [2]

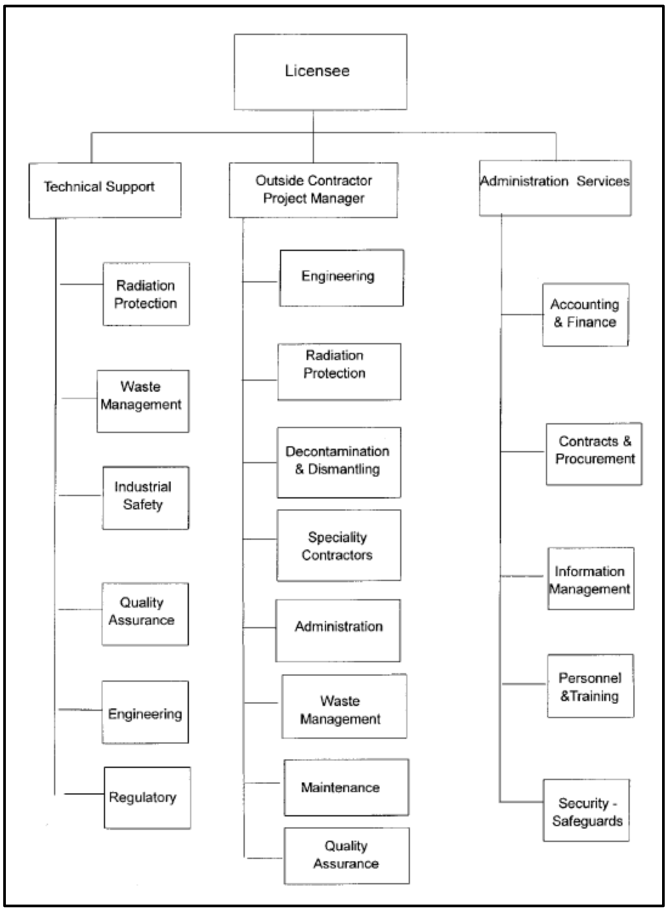

Illustration 35. Licensee with outside contractor performing decommissioning [2]

3.5.1. The decommissioning management team at Vandellòs 1

Vandellòs 1 nuclear power plant **was owned by HIFRENSA** (Hispano-Francesa de la Energía Nuclear, S.A.). It **started its operation in 1972**. Some years later, in **1989**, the nuclear power plant was **closed down** because of a fire. In **July 1990**, the Ministry of Industry and Energy obliged HIFRENSA to keep the plant in the safe **shutdown** mode, undertake the first level of decommissioning and **transfer the ownership to ENRESA** (Empresa Nacional de Residuos Radiactivos S.A.). [41]

In the following paragraph extracted from the web of **Enresa**, we can find a **general approach about the mentioned company**: [25]

"The Spanish Parliament created Enresa in 1984 as a public, non-profit organisation responsible for the management of radioactive waste. Enresa was created to perform an essential public service: collecting, treating, conditioning, storing and disposing of the radioactive waste produced throughout the Spanish State". [25]

"Therefore, the task of Enresa is to protect people and the environment from radioactive waste. It is also included the dismantling of nuclear and radioactive facilities, as well as the environmental restoration of uranium mines". [25]

In the following Illustration 36, Illustration 37 and Illustration 38 the management and control relations stablished between ENRESA, CSN and the government of Spain are shown:

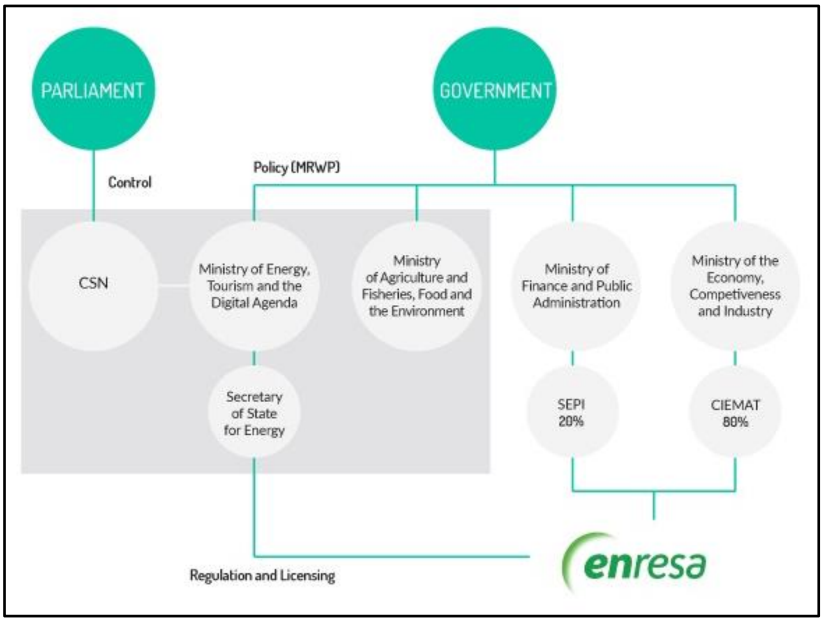

Illustration 36. Organisational Chart of Institutional Control at ENRESA [61]

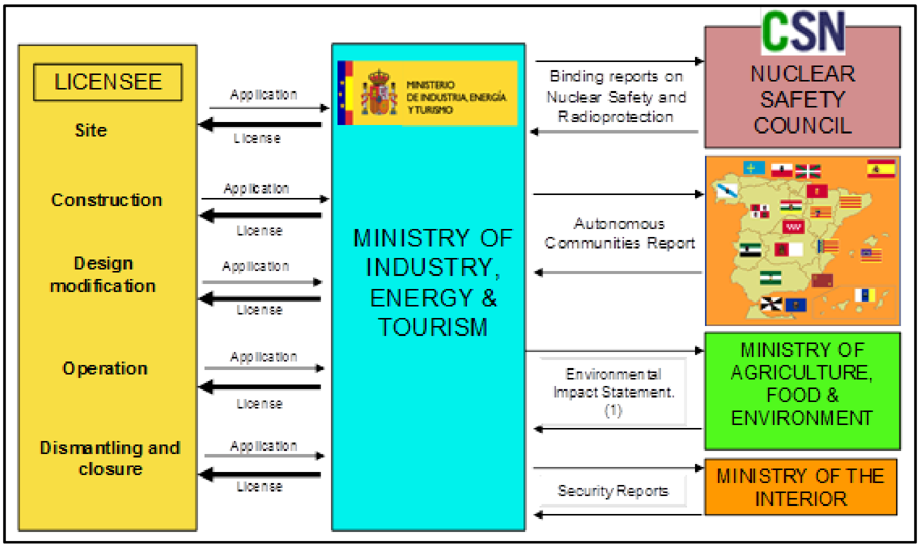

Illustration 37. Management chart of nuclear plants in Spain [62]

Illustration 38. Organizational Flowchart (ENRESA) for decommissioning [41]

In the paragraph below some facts about **the Training that was carried out at Vandellòs 1** are presented:

The implementation of the training plan was made by Enresa. Thus, it took into account providing all the workers with the necessary know-how to guarantee their safety and to accomplish the requirements.

As a curiosity, during the level 2 of decommissioning, Enresa organized 1537 courses which were attended by approximately 7800 people.

These courses were obligatory both for contractor company workers and for those having already experience at the plant. Moreover, the recycling courses were very important because they periodically involved workers of all levels of responsibility.

[41]

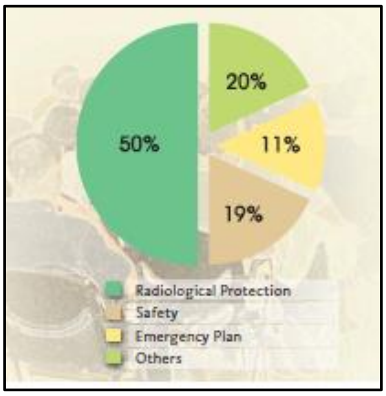

Illustration 39. Training by subject áreas [41]

3.5.2. The decommissioning management team at San Onofre

In the **USA**, the **Nuclear Regulatory Commission** (**NRC**) is the main regulator of the nuclear power industry. Thus, it is in charge of transportation, storage, and disposal of nuclear materials and waste, and decommissioning of nuclear facilities. [63]

Moreover, the San Onofre Nuclear Generating Station is operated and owned (78.2%) by the **Southern California Edison Company** (**SCE**), who is also the Licensee. In this way, on June 7 **2013**, **SCE made public its announcement of closing** the Units 2 and 3 from SONGS. Later, in **January 2014**, SCE contracted the services from **EnergySolutions** in order to analyse the decommissioning alternatives and prepare all the documents that US NRC asks for. [60]

Finally, in **December 2016**, SCE announced the selection of the **AECOM / EnergySolutions** team, as the main contractor for the decommissioning of San Onofre nuclear power plant. As SCE President said: "*SCE will maintain strict oversight of the contractor and will continue to engage with the community and all stakeholders during decommissioning*". [64]

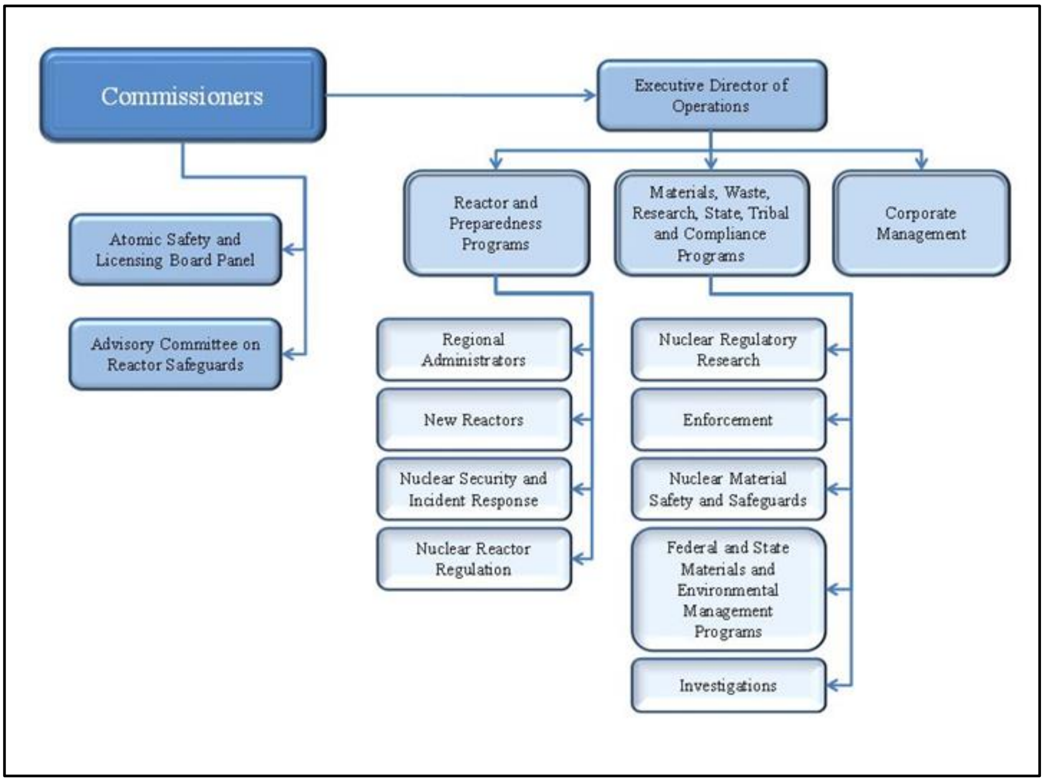

Illustration 40. Organizational chart of US Nuclear Regulatory Commission [63]

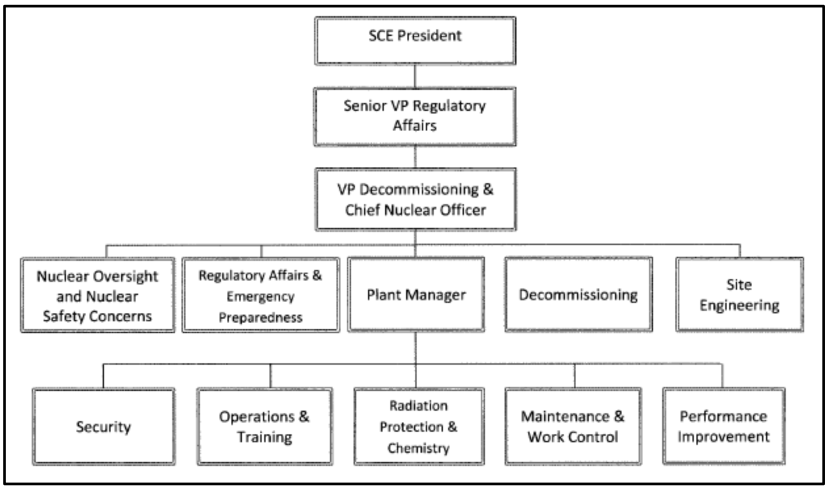

Illustration 41. Organizational Chart for decommissioning San Onofre (SCE) [65]

Regarding the main topic about the **Decommissioning Staff**, the following text summarizes the facts discussed in the previous theory paragraph (3.5) in relation to San Onofre:

*"**EnergySolutions** has assumed that the SONGS Units 2 and 3 decommissioning project will be performed in an efficiently planned and executed manner using **project personnel experienced in decommissioning**. This DCE (Decommissioning Cost Estimate) assumes that the decommissioning will be performed by a **highly experienced and qualified DGC** (Decommissioning General Contractor), with **oversight and management** of the decommissioning operations performed **by the Licensee staff**. It is also assumed that the Utility (Licensee) staff will be supplemented by a professional consulting engineering firm, particularly in the planning and preparation phase".*

*"**EnergySolutions analyzed the SONGS licensee staff** and developed a site-specific staffing plan. The SCE (Southern California Edison) existing salary structure was then used as the basis for calculating Utility (Licensee) staff labor costs. EnergySolutions used industry data to develop DGC (Decommissioning General Contractor) salary costs. Staffing levels, for both staffing plans and for each project period, are based on the Atomic Industrial Forum (AIF) guidelines and industry experience. The sizes of the staffs are varied in each period in accordance with the requirements of the work activities. **Staffing has been organized into the following departments or functional groups:"***

- *Decommissioning*
- *Engineering*
- *Maintenance and Work Control*
- *Operations*
- *Oversight and Nuclear Safety*
- *Radiation Protection and Chemistry*
- *Regulatory and Emergency Planning*
- *Safety and Human Performance*
- *Security Administration*
- *Security Guard Force*
- *Site Management and Administration*
- *Additional Staff for Spent Fuel Shipping*

- *DGC Staff*

[60]

3.5.3. Analysis and Conclusions

First of all, **the case of Vandellòs 1 will be examined according to the theory exposed in the section 3.5 and the real situation described in 3.5.1**.

As it has been said, **Vandellòs 1** was managed by **HIFRENSA** during its **operation phase**. The operation phase finished in 1989 and then, in **1990**, **ENRESA** took the responsibility for the nuclear plant in order to start with the decommissioning.

ENRESA owned a **very competitive staff** for carrying out the decommissioning process. As it can be seen in Illustration 38, it fulfils the requirements exposed in the section 3.5, having *"a staff with all the required skills, qualifications and experience"*. Moreover, *"a suitable supervisory structure which leads all the process" exists*. That would be the site management.

Furthermore, the section 3.5 speaks about the importance of the **training programs** for having a very competitive management team and staff. At **ENRESA**, according to the information presented above, *"during the level 2 of decommissioning, at least 1537 courses were organised"*.

Of course, some people were operators already working at Vandellòs 1 during the operation phase and the other were contracted workers which had to attend the mentioned trainings as well.

Regarding to the **structures from the management team**, in the case of Vandellòs 1, **ENRESA** (the licensee) was in charge of the decommissioning organization. That means that it performed almost all the decommissioning tasks using **a lot of in-house resources**. That is said above when "*the Ministry of Industry and Energy obliged HIFRENSA to transfer the ownership to ENRESA*" and it is confirmed observing the organizational flowchart from Illustration 38.

However, and this is very important, **ENRESA** is a *"public, non-profit organisation responsible for the management of radioactive waste"* and *"it was created by the Spanish Parliament in 1984"*. That means that it is constantly controlled, among others, by the **CSN** (Consejo de Seguridad Nuclear) and all the ministries from the Spanish government. This fact can be seen in the Illustration 36 and Illustration 37.

In conclusion, after the analysis of the management team from Vandellòs 1, taking the theoretical background from section 3.5 into account, it is possible to say that the supervision of the decommissioning process from Vandellòs 1 was carried out according to the recommendations presented by the Handbook of Nuclear Engineering (Don Gabriel Cacuci) [2].

On the other hand, the **case of San Onofre** will be examined according to the theory exposed in the section 3.5 from "Handbook of Nuclear Engineering – Don Gabriel Cacuci 2010" [2] and the real situation from San Onofre described in 3.5.2.

As it has been said, **San Onofre** was managed during its **operation phase** by **SCE** (Southern California Edison). The operation phase **finished in 2013** and then, in **2016**, the **decommissioning process** started. However in this case, as it can be read above, "*in December 2016, SCE announced the selection of the AECOM/Energy Solutions team, as the main contractor for the decommissioning of San Onofre nuclear power plant*" and it is also said *"SCE will maintain strict oversight of the contractor…*". That means, based on the theory from section 3.5, that San Onofre is following the **structure of a management team with outside contractor performing decommissioning** (Illustration 36). Thus, "*the licensee hires an outside organization to carry out most of the work and the licensee is focused on management stuff*".

Focusing on the **structure of management** of San Onofre decommissioning, based on the Illustration 41, it can be seen that all the position and roles are completely defined in the organizational chart to fulfil the requirement of "*is relevant having a suitable supervisory structure which leads all the process*". Also, it is presented that they will contract **external workers**: "*the licensee staff will be supplemented by a professional consulting engineering firm*".

Moreover, in the project of decommissioning of San Onofre, the **role of the DPM** (Decommissioning Project Manager) is also taken into account. This is in charge of managing, building and planning the decommissioning project with the licensee. Thus, in the section 3.5.2 it is presented as "*the decommissioning will be performed by a highly experienced and qualified DGC (Decommissioning General Contractor), with oversight and management of the decommissioning operations performed by the License staff*". **The role of DGC in San Onofre would be the equivalent to DPM**.

Referring to the topic of **trainings** for decommissioning, in the case of San Onofre **any information about the mentioned topic has not been found**.

Finally, and as a review, it is important to say that **SCE** (Southern California Edison) is **responsible for the decommissioning** of San Onofre, but it has selected **AECOM/Energy Solutions** as the **main contractor** for the decommissioning. However, **SCE is constantly supervising all the work**. In addition, SCE is observed and controlled by US NRC, which is the principal regulator of the nuclear power industry in the USA.

In conclusion, both Vandellòs 1 and San Onofre follow the directions established in the section 3.5 by [2].

3.6. Waste Management

In this section the **main points about waste management** that have to be taken into account **when managing the closure of a nuclear power plant** will be presented. Later, in 3.6.1 and 3.6.2 the reality about Vandellòs 1 and the forecast for San Onofre will be presented. Finally, following the same philosophy like in the other sections, an analysis comparing the theory with the real situations will be made.

According to [2], radioactive wastes are a very important topic of nuclear operations and, because of that, they have to be treated carefully. When the nuclear plants are nearly to the finishing their operating phases, all the work related with decommissioning becomes more important.

Normally **all the governments for each country try to share their experiences** and background on safety and technological aspects of decommissioning based on the experience with many types of nuclear facilities.

It is important to know that **the more facilities are planned to be shutdown, these tasks and assignments can support countries preparing**, planning and carrying out programs for the secure management of radioactive waste from dismantling operations.

Here there is a **classification of the wastes** that is important to take into account when planning the waste management plan:

- **Nonradioactive wastes (primarily concrete and rubble)**: largest share of total waste.

- **Very low-level radioactive waste:**
  "Depending on the nature of this waste, its activity and the relevant regulations, it can be either recycled or stored in packages in a dedicated facility without posting a danger to the public". [2]

- **Short-lived or low-medium-level activity waste**: smallest share.
  "This waste is governed by national regulations that dictate disposal procedures, in either a surface storage or interim storage facility before being sent to a medium – level long-lived waste storage centre". [2]

- There are also cases of **long lived or intermediate to high level wastes**:
  "These may be present in the Gas Graphite NPP`s or in the fuel cycle facilities (like reprocessing facilities) where spent fuel has been dissolved". [2]

Finally, it is relevant that all wastes from the decommissioning processes have to be sent to a **disposal facility**. If this possibility is not available, then the waste should be shipped to a **long-term centralized storage centre** or being stored on an **interim basis on-site**.

[2]

Moreover, the Handbook of Nuclear Engineering from Don Gabriel Cacuci [2] speaks about "waste management strategy". Here some instructions for reaching an excellent waste management plan are pointed out:

- *"Estimation of the **types of waste**, including physical and chemical characteristics, and the volume of each waste category"*. [2]
- *"Basis for the **restricted/unrestricted reuse** or recycling of equipment or materials from decommissioning"*. [2]
- *"Criteria for **segregating waste into various categories**"*. [2]
- *"**Plans and procedures** for handling, treating, conditioning, storing, and disposing of each category of radioactive, nonradioactive and hazardous wastes from decommissioning"*. [2]
- *"Procedures for **monitoring and recording radioactivity**, including the monitoring of cleared wastes before unrestricted release, as well as taking and analysing samples"*. [2]
- *"Requirements for **packaging and package** design for transport and disposal"*. [2]
- *"Identification of **adequate storage and disposal routes and sites**"*.
- *"Safety assessment of the waste management strategy"*. [2]
- *"Taking into account the **possible reuse and minimization of waste** through the use of waste-minimization and volume-reduction techniques"*. [2]

3.6.1. Waste Management at Vandellós 1

Here some **information about the waste management as it occurred in Vandellòs 1 during its decommissioning process** will be presented. It is important to know that Vandellòs 1 will be in Latency Period until 2028.

During the decommissioning from Vandellòs 1, a large amount of materials has been produced from both active and conventional areas. The main question is if they have to be recycled or stored as wastes.

ENRESA has assumed as one of the most important things during the decommissioning: *"the exhaustive control of all the materials from the site with a view to segregating those that had radiological implications from those others that were clean and might be reused"*.

Moreover, for ENRESA the segregation and decontamination techniques and the policy of recycling were essential. For example, at the **beginning 2000 tons** of radioactive wastes were forecasted and finally they **ended with 1763 tons**.

In the following figure, we have a general view of the destination of materials at the decommissioning of Vandellòs 1:

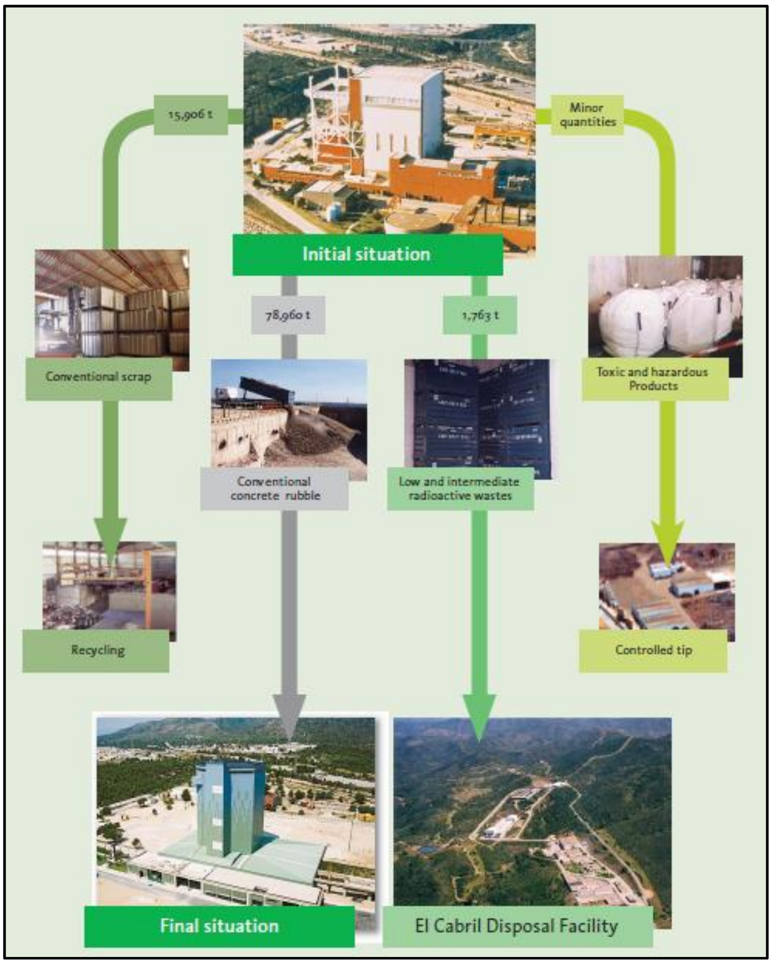

Illustration 42. Material's Destination Vandellòs 1 [41]

Related to the previous illustration, **15900 tons of non-contaminated materials** were generated, most of all were metallic materials (were recycled) and minor amounts of conventional wastes. The former were sent to authorised centres.

The approximate **78960 tons of conventional concrete rubble were reused for land restoration**.

In order to know the **suitable destination of each material**, ENRESA created a management system that established **up to five controls for all the materials from the active areas** that were candidates **for declassification**.

As declassification "*a technical and administrative activity in which the acceptable levels for materials and surfaces from active areas are certified*" is known.

Through the declassification plan, **ENRESA wants to reduce the maximum volume of radioactive wastes produced**. The plan is applied to both the materials from the dismantling of equipment and components and from the structures and wall facings of the buildings that previously housed them.

[41]

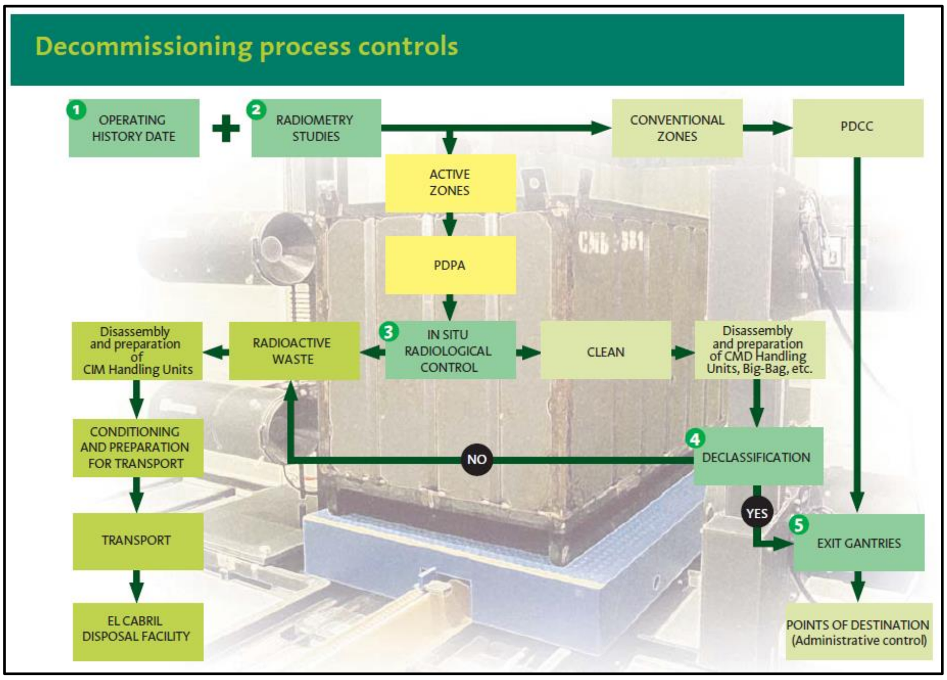

Illustration 43. Decommissioning process controls (up to 5 controls) [41]

3.6.2. Waste Management at San Onofre

Here some information about the **waste management planned for San Onofre during its decommissioning** will be presented. It is important to know that **San Onofre was closed in June 2013** and then its **decommissioning started in January 2016**. Because of that, the information available is not as precise as the one from Vandellòs 1. However it has been found a Post-Shutdown Decommissioning Activities Report (PSDAR) that can provide the data.

According to Southern California Edison (SCE) [60], **in the following paragraphs the planned procedures for the waste management** at San Onofre will be presented.

First of all they speak about the **objectives from the dismantling process** at San Onofre:

- *"The first objective is to* ***reduce radiation levels throughout the facility*** *to minimize personnel radiation exposure during dismantlement".*

- *"The second objective is to* ***clean as much material as possible to unrestricted use levels****, thereby allowing non-radiological demolition and disposal and* ***minimizing the quantities of material that must be disposed by costly burial as radioactive waste****".*

Moreover, SCE added that "*the decontamination / dismantlement of contaminated SSCs (structures, systems and components) may be accomplished by:* ***decontamination in place, decontamination and dismantlement, or dismantlement and disposal***".

*"**Material below the applicable radiological** limits may be **released for unrestricted disposition** (scrap, recycle, general disposal)".*

Regarding to the **low level radioactive waste** (LLRW), *"it will be processed in **accordance with plant procedures and existing commercial options**"*. Thus, *"**contaminated material** will be characterized and segregated for additional **onsite decontamination** or processing, **off-site processing** or **packaged for controlled disposal** at a low-level waste disposal facility"*. For example, *"contaminated concrete will be packaged and shipped to a low-level waste disposal facility"*.

One important thing about releasing space is *"contaminated concrete and structural steel components will be decontaminated and removed as required to **gain access to plant SSCs**"*.

On the other hand, regarding the managing of different types of waste, *"a **waste management plan will be developed consistent with regulatory requirements** for each waste type"*. For *example "LLRW (low level radioactive waste) classes B and C may be disposed of at the Waste Control Services (WCS) waste disposal site in Andrews County, Texas"*. Moreover, *"class A LLRW will be disposed at a licensed disposal site"*.

Finally, regarding the **waste management plan**, *"it will be **based on the evaluation of available methods and strategies** for processing, packaging, and transporting radioactive waste in conjunction with the available disposal facility and associated waste acceptance criteria"*.

[60]

3.6.3. Analysis and Conclusions

Once exposed the theory about waste management on decommissioning of nuclear power plants and once the different real situations of Vandellòs 1 and San Onofre have been presented, an **analysis for finding out if the procedures carried out in Spain and USA are in the direction of the instructions** indicated by Handbook of Nuclear Engineering – Don Gabriel Cacuci 2010 [2] will be carried out.

In the first place, the analysis will be focused in the information of **Vandellòs 1**.

Starting about the **experience of a country** like Spain in decommissioning processes, looking at the section 2.6.3 it is found that Vandellòs 1 was the first decommissioning in the history of Spain. Because of that, at this time, the management of the nuclear plant had to learn a lot for this new process.

Regarding to the **classification of the wastes** generated at Vandellòs 1, observing the Illustration 42 it is found that in the waste management plan the different types of wastes were taken into account. Thus, it can be seen in Illustration 42 *"conventional scrap"*, *"conventional concrete rubble"*, *"low and intermediate radioactive wastes*" and *"toxic and hazardous products"*. **Connecting this classification with the classification from the section 3.6**, the first and the second one would be "*nonradioactive wastes (primarily concrete and rubble)*", *"low and intermediate radioactive wastes"* would be *"very low-level"* and *"low-medium-level"* and, finally, *"toxic and hazardous products"* would be related to *"long lived or intermediate to high level wastes"*.

Illustration 42 shows that depending on the wastes, those are sent to a **disposal facility**, **long-term centralized storage centre** or are stored on an **interim basis on-site**. Thus, the conventional concrete rubble was reused for land restoration while the low and intermediate radioactive wastes were sent to "El Cabril Disposal Facility".

In the section 3.6 the "**plans and procedures for handling the generated wastes**" are discussed. In the case of Vandellòs 1, the Illustration 42 is a clear example of a plan for defining where each kind of waste has to be sent and the routes that have to be followed.

Furthermore, a very important point that is commented in the section above is "**the possible reuse and minimization of waste**". In the case of Vandellòs 1, it is said that *"ENRESA wants to reduce the maximum volume of radioactive wastes produced"*, so this philosophy was already implemented by ENRESA too.

Finally, in the section 3.6 the topic of "**monitoring and recording radioactivity**" is presented. That was also present during the decommissioning of Vandellòs 1 as it can be seen in the Illustration 43. Here it can be observed that up to 5 decommissioning process controls were carried out during the transport of the wastes. With this method, it was possible to know always the suitable destination for each material.

In general, all the recommendations or instructions presented in the section 3.6 were applied during the decommissioning of Vandellòs 1 and the decommissioning report from ENRESA [41] documented everything.

In the second place, the **analysis will be focused in the information of San Onofre.**

As it has been indicated before, the decommissioning of San Onofre started two years ago and all the information which has been found is based on forecasts and very recent reports. Thus, all the information extracted about San Onofre is based in the Post-Shutdown Decommissioning Activities Report issued by SCE.

Regarding the **experience that SCE** (Southern California Edison) or US NRC (US Nuclear Regulatory Commission) **has in decommissioning process**, **it is obviously higher than the experience of Spain**. Thus, according to the section 2.6.3 and 2.6.4, the first shutdown in **Spain** was in **1990** (Vandellòs 1) whilst in the **USA** it was in **1963** (Vallecitos). That shows that the background and experience of the USA must be higher.

Regarding the distinction of the **different types of wastes**, SCE distinguishes the materials "*below the applicable radiological limits*" and the "*low level radioactive waste (LLRW)*". Besides, in the LLRW, it differentiates class A, class B and class C.

Furthermore, SCE also takes into account what is presented in the section 3.6 about the **final location of the wastes**. In the section above it is distinguished *"disposal facility"*, *"long-term centralized storage centre"* and *"interim basis on-site"*. In the case of San Onofre, it is spoken that the contaminated material will be assigned between *"onsite decontamination"*, *"off-site processing"* or *"packaged for controlled disposal at a low-level waste disposal facility"*.

On the other hand, as it has been mentioned before, it is very important, according to the instructions from the section 3.6, the **"possible reuse and minimization of waste"**. Referring to San Onofre, it is also mentioned in the Post-Shutdown Activities Report (PSDAR). Thus, that is present in the two objectives presented by SCE. The **first objective** tries to **reduce radiation levels** at the facility and the **second objective** is more focused on *"minimizing the quantities of material that must be disposed by costly burial as radioactive waste"*.

Finally, as a resume, it is important to remark the last paragraph of the section 3.6.2 of San Onofre. Here it is said that the **management plan of San Onofre will be based on the available resources and strategies for processing, packaging, transporting, disposal facilities and others.** To sum up, that would include the instructions exposed above such as *"plans and procedures for managing wastes"*, *"monitoring and recording radioactivity"* and *"packaging and package"* among others.

In conclusion, the information analysed about San Onofre goes in the direction of the theory exposed in the first place but, it would be suitable and necessary to possess more data or reports about the decommissioning of San Onofre, in order to be able to carry out a more exhaustive analysis.

4. Conclusion and Outlook

This last chapter briefly summarises all the achievements in this thesis. It concludes with an outlook as a motivation for future work.

In general terms, as it was indicated in the abstract as well as in the introduction, the **main purpose of this thesis lies in the analysis of certain topics related to the decommissioning of nuclear power plants**. In this way, the analysis has been based on the theory from suitable sources of information and the real cases of decommissioning from **Vandellòs 1** (Spain) and **San Onofre** (USA). The **first one** started its decommissioning in **1991** and the **second one** in **2016**.

Generally, there is an **international organism** which regulates the nuclear safety and nuclear security standards and it is called **IAEA**. However, at the same time, **each country has its own organization which adapts the regulations from the IAEA**. In the case of **Spain**, that is the **CSN** (Consejo de Seguridad Nuclear) and, in the case of the **USA**, that is the **US NRC** (US Nuclear Regulatory Commission).

Consequently, through this thesis, it has been possible to understand better how each country (Spain or USA) has interpreted the international laws in specific cases like the decommissioning process of Vandellòs 1 or San Onofre.

Regarding the **procedure**, as mentioned before, at the beginning of the chapter a **general theory introduction** about the topic has been presented including the general regulations or recommendations from international books or organisms. Later, the **case at Vandellòs 1 and San Onofre** has been described. Finally, the **analysis comparing the theory with the specific aspect at each country has been made**.

After seeing the conclusions from the five analysed aspects *(decommissioning strategy, impact on staffing and socio-economic factors, phases of decommissioning, the decommissioning management team and waste management)*, it is possible to say that **both Spain and the USA have performed the decommissioning process in the direction indicated by the international organisms**. However, regarding many factors like previous experience in decommissioning, year of shutdown and start of decommissioning, strategy of decommissioning and laws of the country, each plant has designed its own plan.

Finally, it is important to strike that **more information about the decommissioning process from Vandellòs 1 has been found compared to San Onofre**. As it has been previously remarked, the decommissioning of the first one started in 1990 and it is well-known that there are more available reports and documents. Regarding the second one, it started in 2016 and most of the information are forecasts or plans.

As an outlook, deeper analysis could be made in every important aspect discussed in the chapter 3. Regarding the background of the author and the availability of sources, the investigation about each topic had more focus on **the management and not as much on the technical side**. However, this thesis can be a starting point for further investigations on each aspect. One of the **main problems** was that **most information about decommissioning processes is very confidential** and the institutions are not allowed to share it publically. Because of that, most of the obtained facts were papers and sources through internet or the library.

On the other hand**, it is very important that this thesis can serve as a motivation for a future** exchange of information between countries regarding the decommissioning processes. As it has been said, the international regulations are adapted in each country depending on internal laws and experience. However, **some processes can be more effective and it would be perfect to implement them in other places and save costs or improve security**.

List of Illustrations

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