revista tecnologia e sociedade

Revista Tecnologia e Sociedade
ISSN: 1984-3526

https://periodicos.utfpr.edu.br/rts

UK nuclear energy system study from 1956 to 2035

Carlos Eduardo Velasquez Cabrera
carlosvelcab@hotmail.com
Universidade Federal de Minas Gerais – Belo Horizonte, Minhas Gerais, Brasil.

Fidéllis B. G. L. e Estanislau
fidellis01@hotmail.com
Universidade Federal de Minas Gerais – Belo Horizonte, Minhas Gerais, Brasil.

Antonella Lombardi Costa
antonella@nuclear.ufmg.br
Universidade Federal de Minas Gerais – Belo Horizonte, Minhas Gerais, Brasil.

Maria Auxiliadora F. Veloso
mdora@nuclear.ufmg.br
Universidade Federal de Minas Gerais – Belo Horizonte, Minhas Gerais, Brasil.

Claubia Pereira
claubia@nuclear.ufmg.br
Universidade Federal de Minas Gerais – Belo Horizonte, Minhas Gerais, Brasil.

ABSTRACT

The first nuclear reactor built in 1947 had a research purpose, but the first commercial reactor power station was built nine years later at Windscale, England. After that, 45 reactors were built until 1995 for electricity production. Currently, 30 of them are permanently shutdown and 15 are still operational which comprises around 19% of the United Kingdom (UK) energy matrix. Despite the last reactor built in 1995 was a PWR - SIZEWELL-B connected to the grid 23 years ago, the UK government plan to build new generation plants to supply 19 GWe until 2025 and aims to have an additional 16 GWe until 2023. Nevertheless, half of the current capacity should be retired by 2025 and the rest of the AGR generation until 2030. Therefore, the UK nuclear energy system is modeled taking into consideration the retirement and construction of different reactors. The results show the UK nuclear energy system and the reactor transition from old AGRs to a new generation of nuclear reactors. Also, economic features and spent fuel produced due to the nuclear activity up to 2035 are presented.

KEYWORDS: Nuclear energy. Fuel cycle. Fuel cost. Investment. Modelling.

CABRERA, C. E. V. UK Nuclear Energy System Study from 1956 to 2035. **R. Tecnol. Soc.,** Curitiba, v. 15, n. 37, p. 360-370, jul./set. 2019.

INTRODUCTION

The world's first commercial nuclear reactor was built at Calder Hall 1 in the United Kingdom by 1956. The original nuclear policy in the UK promised a nuclear power programme between 5-6 GW of net capacity until 1965, which originated the Gas Cooled Reactor (GCR) generation, the model called Magnox. After that, around 1963 begins the era of the Advanced Gas-cooled Reactor (AGR) design, where the Windscale AGR was the first of its kind [1, 2]. In addition, two Fast Breeder Reactors (FBR) were built from 1962 to 1994, Dounreay DFR and PFR, without succeed. In the early 1990s, a new policy of nuclear energy promoting a new fleet of PWRs encouraged the government, but the plans were abandoned due to the lack of support. Despite the nuclear waste problem, the UK had a serious energy crisis in 2006 and with Tony Blair in the command, the discussion about the nuclear programme to avoid CO2 emissions, and the major contribution of nuclear energy as a part of the energy supply mix has resumed [3].

The aim of this work is to simulate the contribution of the nuclear energy system from 1956 to the near future, 2035. Therefore, this work seeks to simulate the energy contribution of 43 out of the 45 nuclear reactors connected to the grid. The two reactors excluded to the contribution were the FBR reactors due to the fact of their low energy contribution to the electricity production share [2]. Besides, it develops the transition from the shutdown of 15 reactors to the new generation of reactors separated in two groups of Advanced Light Water Reactor (ALWR). The ALWR-1 represents the European Pressurized Reactor (EPR) and the ALWR-2 represents the Advanced Boiling Water Reactor (ABWR).

METHODOLOGY

The UK nuclear energy system has been simulated from the beginning of the nuclear programme up to 2035. Nevertheless, the two FBR were not considered and for the increase of electricity share, two types of LWR reactors were considered: EPR and ABWR. Therefore, 43 nuclear reactors were simulated until 1995 due to the exclusion of the two FBR. The 43 nuclear reactors were classified in eight different types of reactors according to the power and reactor features and the planning reactors were classified in two different reactors according to their features. The categories were:

1. GCR- MAGNOX-I: Hunterston (A-1, A-2); Berkeley (1, 2); Bradwell (1,2)
2. GCR- MAGNOX-II: Dungeness (A-1, A-2); Hinkley Point (A-1, A-2); Oldbury (A-1, A-2); Sizewell (A-1, A-2); Trawsfynydd (1, 2)
3. GCR- MAGNOX-III: Calder Hall (1,2,3,4); Chapelcross (1, 2, 3, 4)
4. GCR- MAGNOX-IV: Wylfa (1, 2)
5. SGHWR: Winfrith SGHWR
6. AGR – 0: Windscale AGR
7. AGR: Dungemess (B-1, B-2); Hartlepool (A-1, A-2), Heysham (A-1, A-2, B-1, B-2); Hinkley Point (B-1, B-2); Hunterston (B-1, B-2), Torness (1, 2)
8. PWR: Sizewell B

9. ALWR1 (EPR & AP1000): Hinkley Point (C1, C2); Sizewell (C1, C2); Moorside (1, 2, 3)
10. ALWR2 (ABWR): Wylfa Newydd (1, 2); Oldbury (C1, C2)

The average parameters for each of the categories presented above are shown in Table 1. The operation factor and load factor were an average along the lifetime of the corresponding reactors. Besides, the table also shows the sum of electricity production (TW.h) for all the reactors in each category during their respectively lifetime as well as the type of fuel considered for each reactor. Furthermore, the consideration for the ALWR1 and ALWR2 were: UOX nuclear fuel and a load factor of 80% for both of them and a nuclear capacity of 1650 MW and 1000 MW, respectively.

Table 1. Main features of the 43 UK reactors modelled in Message

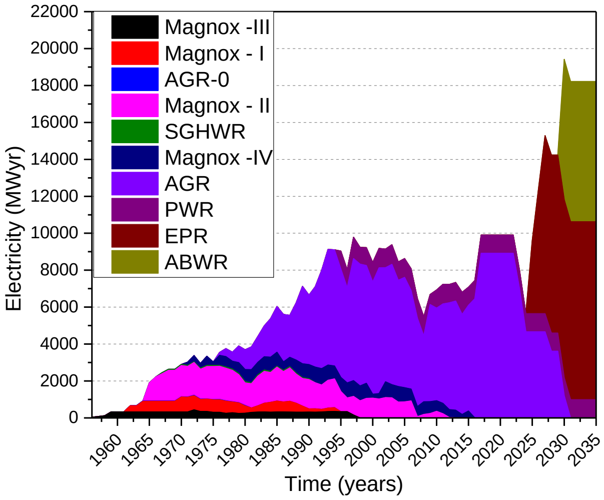
Reactor	Electricity sum of each one (TW.h)	Average Gross Capacity (MWe)	Average Net Capacity (MWe)	Operation Factor (%)	Load Factor (%)	Fuel Type
Magnox-I	154.24	161.67	146.00	87.02	68.40	UOX-NatU
Magnox-II	521.26	241.40	273.00	87.50	75.64	UOX-NatU
Magnox-III	112.96	60.00	35.00	60.00	81.20	UOX-NatU
Magnox-IV	235.75	535.00	550.00	82.40	70.05	UOX-NatU
SGHWR	10.96	318.00	100.00	60.90	60.70	UOX-NatU
AGR-0	3.26	36.00	32.00	56.80	59.80	UOX
AGR	1553.44	650.86	619.93	74.70	68.54	UOX
PWR	164.56	1250.00	1188.00	86.20	83.70	UOX

The burnup of each reactor type, the prices, costs, fuel costs, uranium price, the thermal efficiency, and other data are obtained from different sources [4-11].

RESULTS

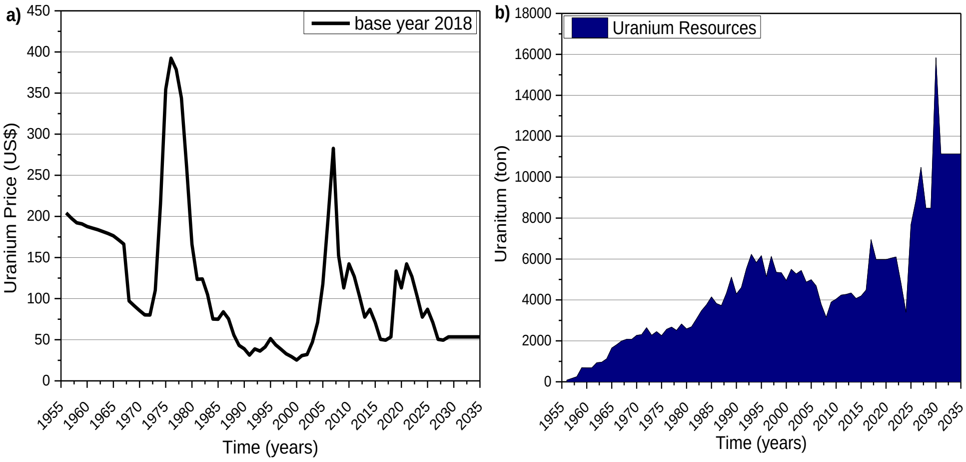
The electricity production by the different types of nuclear reactors are shown in Figure 1, each color represents the electricity production by reactor technology. The base year is 2018 and the model goes until 2035, which complete 40 years of operational PWR-Sizewell B. The period from 1955 to 2018 simulated the energy supply by 8 different reactor technologies. The period from 2019 to 2035 represents the transition of the nuclear energy program from the old reactors to the new generation fleet (16 GW) to be built by 2030. The beginning and the retirement of the different Magnox technology and the amount of electricity produced by them are shown in Figure 1. The transition from AGR to the new reactor fleet begins in 2025 for the EPR and 2030 for the ABWR, the late year represent the retirement of the AGR fleet.

Figure 1. Nuclear electricity production by reactor feature



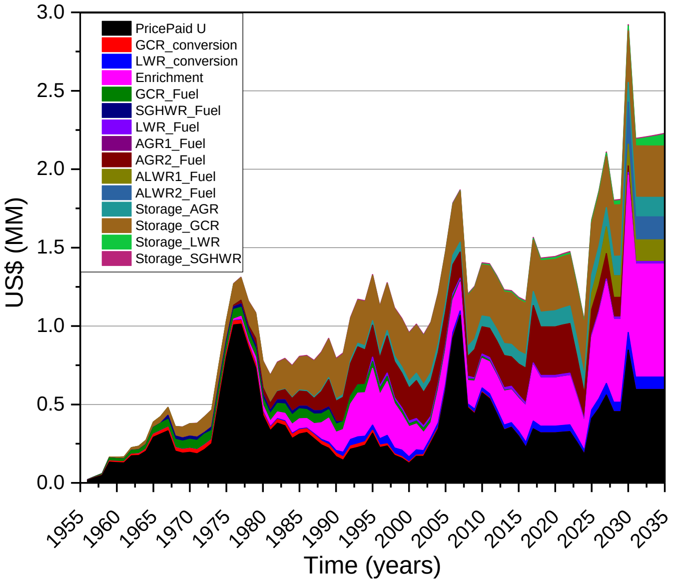
The United Kingdom is a country without uranium resources, which makes them dependent on the uranium market price. The uranium price in the market from 1955 to 2035 is shown in Figure 2a. As the variations on the market price are unknown, the price was assumed to be constant from 2018 to the last year tabulated. In addition, the uranium required to supply the needs of the country to supply the nuclear reactors with fuel is presented in Figure 2b. The increase in the uranium needs is due to the new capacity installation of the EPR and ABWR technology which also needs enriched uranium demanding a high amount of natural uranium.

Figure 2. (a) Uranium price by year and (b) uranium needed to supply the nuclear reactor



The nuclear fuel cycle expenditures for each step, from uranium price to the spent fuel storage, are shown in Figure 3. On the beginning of the UK nuclear program there was no need of enrichment because the GCR (MAGNOX) used natural uranium. Nonetheless, in 1963 a new reactor technology called AGR begins to be tested using the same gas cooled technology, but with the difference that it needed enriched uranium. The installed capacity of the AGR fleet begins in 1976, which demanded the enrichment technology to supply the reactors.

Figure 3. Nuclear fuel cycle cost by step



The high investment in the nuclear reactor technologies and lack of resources depends entirely on the uranium market price. The amount of nuclear fuel production needed by reactor technology is shown in Figure 4. On the one hand, the fuel for the GCR and the SGHWR passed through two processes, conversion and then fuel fabrication. On the other hand, the AGR-0, AGR, PWR, EPR, and ABWR needed to pass through the conversion process, separative work unit, enrichment, and fuel conversion. These last processes demand a higher amount of uranium due to enrichment processes that produce large amounts of depleted uranium. Enriched uranium begins to be produced from the beginning of the Windscale AGR to the ABWR, which is the last technology introduced into the system. Depleted uranium accumulation during the use of LWR reactors should be considered due to the large quantities of the by-product generated (Figure 5).

Figure 4. Nuclear fuel by reactor technology

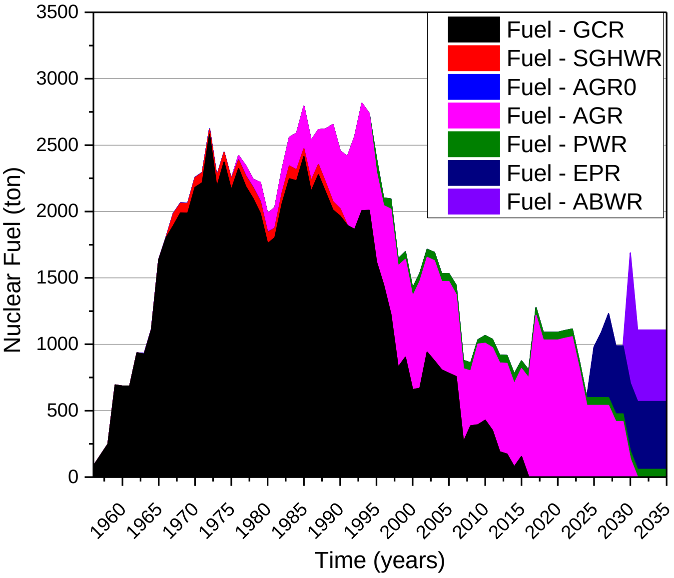
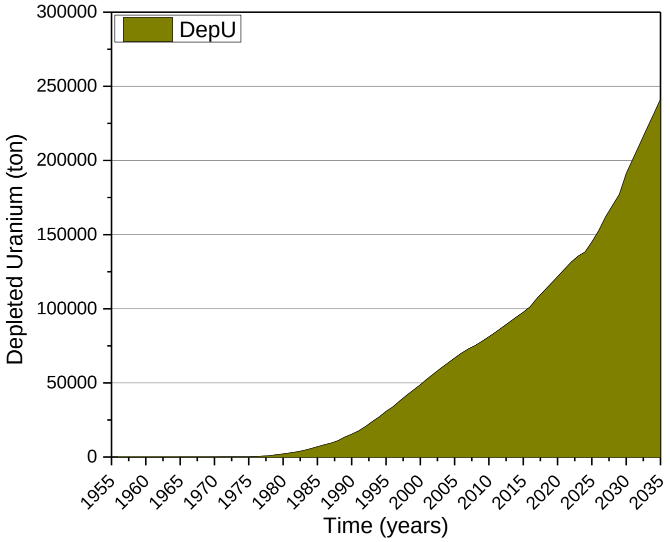


Figure 5. Depleted uranium accumulation



The use of nuclear power produces high amounts of nuclear waste. The spent fuel production after the nuclear activity of each type of reactor is shown in Figure 6. The term SF at the beginning means spent fuel pool and the IS term means interim storage. On the one hand, the spent fuel pool storage generally considers 5 years of cooling inside a spent fuel pool. On the other hand, the intermediate storage is a temporary solution that plays an important role in the management of spent fuel after the 5 years on the spent fuel pool. The highest production of spent fuel is produced by the 26 GCR reactors using natural uranium as nuclear fuel. The second one is produced by the AGR technology with 15 reactors. The third one is the ISLWR which considers the activity of the light water reactors (PWR, EPR, ABWR). Finally, the levelized cost per type of reactor build is shown in Figure 7a. The most expensive reactors are the Magnox-I and the SGWHR, both of them have a high consumption of nuclear fuel and have low power, which made them more expensive than the others. The nuclear investment in nuclear power plants (NPP) is shown in Figure 7b. The major investment would be the 16 GW of ALWR reactors planned to build between 2025 and 2030. The second highest investment was for the AGR reactors due to the construction time and decommission in the decade between 2015 and 2025.

Figure 6. Nuclear Spent fuel produced by nuclear reactor activity

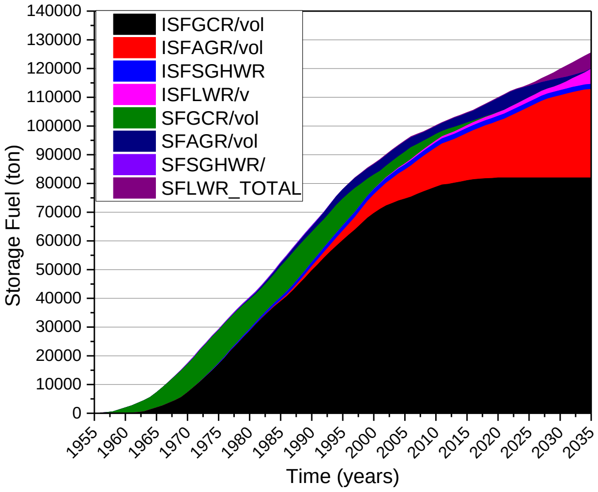
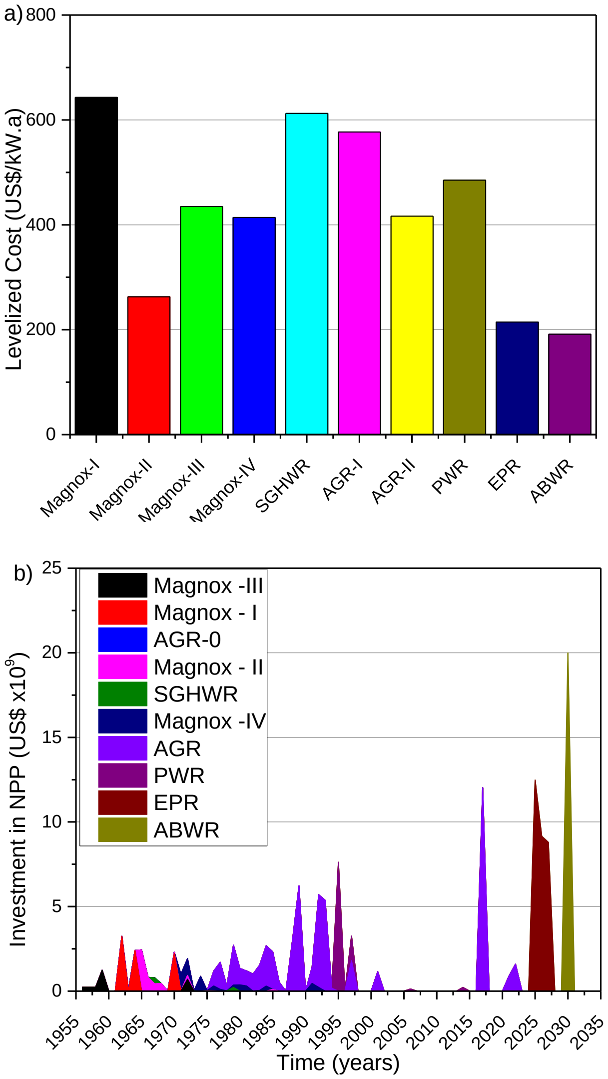


Figure 7. a) Levelized cost and b) Investment in nuclear power plants



CONCLUSIONS

To model the UK's nuclear energy program has been simulated 10 different kinds of reactors from the eldest ones to the future ones. The highest amount of spent fuel is for the GCR reactors due to their fuel cycle and natural uranium needs. The more expensive reactors are the first of their kinds such as the Magnox-I, SGHWR, and AGR-I. The highest investments are for the construction of the new nuclear power plants. The highest amount of spent nuclear fuel is for the GCR due to their high nuclear fuel cycle consumption. The amount of nuclear waste accumulated turns on the UK nuclear program to recycle the plutonium produced for military and electricity generation purposes. The nuclear fuel cycle for the GCR is cheaper than the AGR and LWR, nonetheless, the energy production is lower than the reactors that need enrichment. Assuming the prices of natural uranium were around US$55/kg the most expensive process would be the enrichment for the future reactors. Also, another disadvantage of the implementation of enrichment is the need for a higher amount of natural uranium to enrich the nuclear fuel to 2.7 to 5%, which produces a lot of depleted uranium.

Thereby, this work contribute to show the expenses of the UK's nuclear program during their lifetime. This is an initial work to have a vision of the evolution in investment and nuclear fuel cost of one of the eldest nuclear programs in the world.

Estudo do sistema de energia nuclear do Reino Unido de 1956 a 2035

ABSTRACT

O primeiro reator nuclear construído em 1947 teve um objetivo de pesquisa, mas a primeira usina de reator comercial foi construída nove anos depois em Windscale, na Inglaterra. Depois disso, 45 reatores foram construídos até 1995 para a produção de eletricidade. Actualmente, 30 deles estão permanentemente encerrados e 15 continuam operacionais, o que representa cerca de 19% da matriz energética do Reino Unido. Apesar do último reator construído em 1995 foi um PWR - SIZEWELL-B conectado à rede há 23 anos, o governo do Reino Unido planeja construir novas usinas de geração para fornecer 19 GWe até 2025 e pretende ter um adicional de 16 GWe até 2023. metade da capacidade atual deve ser desativada até 2025 e o restante da geração da AGR até 2030. Portanto, o sistema de energia nuclear do Reino Unido é modelado levando-se em consideração a desativação e a construção de diferentes reatores. Os resultados mostram o sistema de energia nuclear do Reino Unido e a transição do reator de antigos AGRs para uma nova geração de reatores nucleares. Além disso, características econômicas e combustível irradiado produzido devido à atividade nuclear até 2035 são apresentados.

KEYWORDS: Energia nuclear. Ciclo de combustível. Custo de combustível. Investimento. Modelagem.

ACKNOLEDGEMENT

The authors are grateful to the Brazilian research funding agencies, CNEN – Comissão Nacional de Energia Nuclear (Brazil), CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico (Brazil), CAPES – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Brazil) and FAPEMIG – Fundação de Amparo à Pesquisa do Estado de Minas Gerais (MG/Brazil), for the support.

REFERENCES

World Nuclear Association. **Nuclear Power in the United Kingdom**. 2018. http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx.

IAEA. **Power Reactor Information System (PRIS)**. 2018. https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=GB.

The Guardian News. **Nuclear power in the UK** – a history. 2018. https://www.theguardian.com/environment/2013/oct/21/nuclear-power-in-the-uk-a-history.

Peter Lloyd Jones, **The economics of nuclear power programs in the united kingdom**. The Macmillan Press LTD, London and Basingstoke, 1984.

G. Greenhalgh. **The Future of Nuclear Power**. Graham & Trotman, London, 1988.

Thomas Telford. **Water Chemistry of Nuclear Reactors Systems 8**: Proceedings of the Conference Organized by the British Nuclear Energy Society and Held in Bournemouth. British Nuclear Energy Society, International Atomic Energy Agency, UK, 2000.

Jamal T. Manassah. **Alternative Energy Sources**: Kuwait Foundation for the Advancement of Sciences. Academic Press, London, 1981.

Robert E. Masterson. **Nuclear Engineering Fundamentals**: A practical Perspective. CRC Press, 2017.

Yassin A. Hassan, Robin A. Chaplin. **Nuclear Energy Materials and Reactors** – Volume I. EOLSS, United Nations Educational Scientific and Cultural Organization, Oxford, UK, 2010.

Marian Radetzki. **Uranium**: A strategic Source of Energy. Croom Helm; London, 1981

UX Consulting. **Nuclear Fuel Training Seminar**. 2018. https://www.uxc.com/p/prices/UxCPrices.aspx.

Erik Nonbol**. Description of the Advanced Gas Cooled Type of Reactor (AGR)**. Riso National Laboratory, Roskilde, Denmark,1996.

Recebido: 22 fev. 2019.

Aprovado: 26 jun. 2019.

DOI: 10.3895/rts.v15n37.9647

Como citar: CABRERA, C. E. V. UK Nuclear Energy System Study from 1956 to 2035. **R. Tecnol. Soc.,** Curitiba, v. 15, n. 37, p. 360-370, jul./set. 2019. Disponível em: <https://periodicos.utfpr.edu.br/rts/article/view/9647>. Acesso em: XXX.

Correspondência:

Carlos Eduardo Velasquez Cabrera

Departamento de Engenharia Nuclear - Universidade Federal de Minas Gerais Av. Antonio Carlos, 6627 campus UFMG 31.270-901 Belo Horizonte, MG-Brazil