**Registered Office**
Herrmann-Debrouxlaan 40
1160 Brussel – Belgium

**Foundation of Public Utility**
VAT BE 406.568.867

**Research Centres**
Boeretang 200
2400 Mol – Belgium

Chemin du Cyclotron 6
1348 Ottignies-Louvain-la-Neuve – Belgium

| Reference N° | Creation Date | |
|---|---|---|
| SCK CEN/54517938 | 2023-04-13 | |
| Alternative Reference N° | Revision | Version |
| N/A | 1.0 | 31 |
| ISC | Revision Status | |
| Public | Approved | |

# Economic model benchmark for fuel cycle codes.docx

| Authors* |
|---|
| Nerea Aguilera Gómez |

**Review information since previous revision***

| Name | Outcome | Date |
|---|---|---|
| Gert Van den Eynde | Reviewed | 2023-04-11 |
| Pablo Romojaro | Reviewed | 2023-04-12 |

**Approval information for current revision***

| Name | Outcome | Date |
|---|---|---|
| Gert Van den Eynde | Approved | 2023-04-13 |

**Change log***

| Revision | Version | Status | Date | Description of change |
|---|---|---|---|---|
| 1.0 | 31 | Approved | 2023-04-13 | |

**ISC motivation**
*ISC was automatically assigned.*

Exploring
a better tomorrow

ER-1249

# Economic model benchmark for fuel cycle codes

## ANICCA's economic model results for benchmark with JAEA

**Authors:** Nerea Aguilera-Gómez[1,2], Pablo Romojaro[1] and Iván Merino-Rodríguez[3]

**Affiliations:**

[1]Belgian Nuclear Research Centre (SCK CEN), Boeretang 200, 2400 Mol, Belgium.
[2]Universidad Politécnica de Madrid (UPM), José Gutiérrez Abascal, 2, 28006 Madrid, Spain
[3]Universidad Católica del Maule (UCM), Talca 3460000, Chile

Contract name:
Contract number:
Publication date: 2023-04-13

SCK CEN/54517938 Rev. 1.0

Stichting van Openbaar Nut - Fondation d'Utilité Publique - Foundation of Public Utility

**Registered Office:**
Avenue Herrmann Debroux 40 - 1160 Brussel – Belgium

**Research Centres:**
Boeretang 200 - 2400 Mol - Belgium
Chemin du Cyclotron 6 - 1348 Ottignies-Louvain-la-Neuve - Belgium

www.sckcen.be

# Table of content

Glossary of abbreviations 5
Abstract 6
Keywords 7
1. Introduction 8
2. Scenario description 8
3. Output description 9
4. Economic output 11
References 15

# Glossary of abbreviations

| | |
|---|---|
| ANICCA | Advanced Nuclear Inventory Cycle Code |
| CRAM | Chebyshev Rational Approximation Method |
| Dep U | Depleted Uranium |
| FP | Fission Products |
| HM | Heavy Metal |
| LCOE | Levelized Cost Of Electricity |
| MA | Minor Actinides |
| O&M | Operation and Maintenance |
| Pu | Plutonium |
| PWR | Pressurized Water Reactor |
| SWU | Separative Work Unit |
| $UF_6$ | Uranium Hexafluoride |
| $UO_2$ | Uranium Dioxide |
| $U_3O_8$ | Triuranium Octoxide |

# Abstract

The ANICCA code is a tool developed to simulate advanced fuel cycle scenarios. Recently, an economic module has been implemented in the code to be able to estimate the costs associated to the different fuel cycle scenario options. One of the key components of an economic calculation is the economics database used by the code, and the one currently implemented in ANICCA needs to be verified.

Since these codes often contain simplified models for reactor systems, front-end and back-end fuel cycle facilities, it is important to assess the impact of these simplifications on the physical parameters of interest in the simulation. Moreover, these codes are often used for the modeling of the impact of future, advanced nuclear systems, thus uncertainties exist on input data. Being able to translate these uncertainties into economic terms can be of great help to the industry, since decision making is not only based on science but also on economics. Therefore the development of the economic module in ANICCA is of special relevance.

In this report, a benchmark - defined in the framework of SCK CEN-JAEA collaboration - is presented and results are reported, with the objective of reaching a consensus on the references used for the calculation of costs in the different stages of the fuel cycle, and to verify that the economic models work properly. In future reports, a comparison between ANICCA and NMB economic modules will be performed, results from this scenario will be analyzed and sensitivities to economic model parameters will be studied.

## Keywords

Fuel cycle scenario; ANICCA; fuel cycle code; economic model; benchmark; spent fuel.

# 1. Introduction

In the nuclear fuel cycle context one of the current challenges is the characterization of spent nuclear fuel. Determining as accurately as possible related observables such as masses, radionuclide content, decay heat or radiation emission plays a very important role when carrying out any project related to nuclear waste management.

Currently in the field of nuclear energy, there are fuel cycle codes that allow simulating different scenarios combining technologies on demand (i.e., different reactor types, fuel compositions and storage options), one of them being ANICCA (1). ANICCA code is a tool developed to simulate advanced fuel cycle scenarios. In addition, an economic module has been implemented in the code to be able to estimate the costs associated to the different fuel cycle scenario options.

The use of these type of codes is associated with an uncertainty margin due to uncertainties in input data, or margins introduced by simplified models. These simplifications can reduce the complexity of the model and/or improve calculation time. The most important uncertainties are associated with technology, plant operation, numerical calculations and nuclear data (2). Being able to translate these uncertainties into economic terms can be of great help to the industry, since this can give a better idea on the impact of uncertainties in fuel cycle parameters, such as the dimensioning of deep geological repositories. Therefore the development of the economic module in ANICCA is of special relevance.

One of the key components of an economic calculation is the economics database used by the code, and the one currently implemented in ANICCA, based on Ref. (3), needs to be verified. Therefore, in the framework of the SCK CEN-JAEA collaboration agreement (4), a benchmark has been defined with the objective of reaching a consensus on the references used for the calculation of costs in the different stages of the fuel cycle, and to verify that the economic models work properly. The present report describes the scenario definition and the results obtained with ANICCA. This is part of a series of reports in which a comparison between ANICCA and NMB (5) economic modules will be compared, results from this scenario will be analyzed and sensitivities to economic model parameters will be studied.

# 2. Scenario description

In order to compare the economic module, a simplified scenario with a single LWR in an open cycle was defined. The scenario was defined using a single 60 year operation lifetime PWR reactor, with a 4.10% $^{235}$U enrichment and 45 MWd/kg$_{HM}$ of fuel burnup. The scenario specifications are given in *Table 1*. For storage and disposal time, spent fuel remains 10 years on an in-site pool at the nuclear power plant and is transferred afterwards to dry storage for 40 years. Final disposal will take place 50 years after the end of irradiation.

To carry out the irradiation process in ANICCA, a nuclear data library input with cross sections averaged in time and burnup, and representative for the reactor technology, fuel and burnup reached during irradiation, is needed. This library has been generated with the SCK CEN homemade burn-up code ALEPH2 (6) and the ENDF/B-VIII.0 nuclear data library (7). Independent fission yields are also taken from ENDF/B-VIII.0 and spontaneous fission yields and radioactive decay data from JEFF-3.1.1 (8). The irradiation process is based on solving the Bateman's equation using Chebyshev Rational Approximation Method (CRAM) (9).

*Table 1: Scenario specifications.*

| | |
|---|---|
| **Electric power** | 1 GW |
| **Thermal power** | 3 GW |
| **Operation load factor** | 90 % |
| **Reactor core mass** | 75 tons |
| **Enrichment** | 4.10 % |
| **Enrichment tail** | 0.30 % |
| **Fuel burnup** | 45 GWd/tHM |
| **Reactor life** | 60 years |
| **Wet storage** | 10 years |
| **Dry storage** | 40 years |

For the scenario several components are created to represent the whole fuel cycle in ANICCA. As shown in *Figure 1*, the simulation starts with a ***mine facility***, that gives as output natural uranium on demand according to irradiation requirements, that means that the mine will provide as much natural uranium as the irradiation facility needs, according to input specifications. Next, natural uranium obtained in mining is transported to the fuel ***fabrication facility*** on demand, and after a two-year-period uranium oxide ($UO_2$) fuel and a depleted uranium (Dep U) tail - 0.003 wt% $^{235}U$ - are obtained. Depleted uranium is stored in a pool but it is not considered in the back end of the cycle.

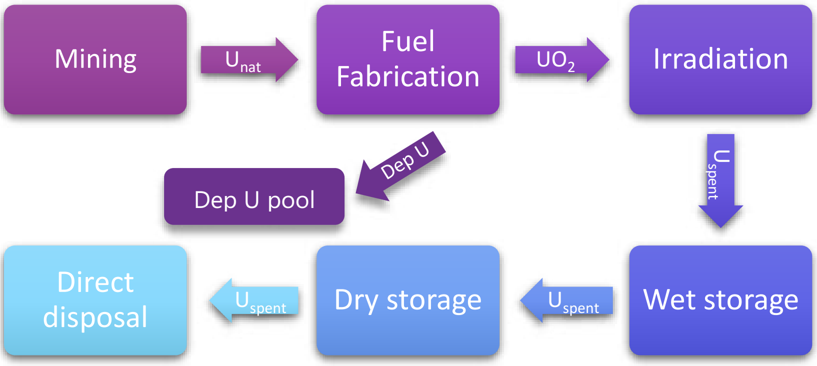

*Figure 1: Simulated fuel cycle scheme.*

At this point the fuel is moved to the ***irradiation facility***, a PWR reactor in this scenario, where the irradiation takes place following the parameters defined in *Table 1*. In ANICCA, spent fuel is obtained each irradiation cycle time. For this scenario, irradiation cycles of one year were defined. Then, spent fuel is moved to an on-site spent fuel pool for ten years, that will be **wet storage**. Although an extra facility for this is not required, it was represented on the diagram to describe mass flow throughout the cycle. The fourth facility is ***dry storage***, where spent fuel will remain forty years before being transferred to the ***final disposal facility***.

## 3. Output description

To ensure that both, the input and the code are working properly, mass conservation has been checked. On the one hand, total mass of natural uranium ($U_{nat}$) entering the fabrication facility is 12648 tons, matching the masses of HM contained in the form of generated products ($UO_2$ and Dep U). On the other hand, it can also be seen that all manufactured fuel is used in the reactor - mass of HM over spent fuel ($U_{spent}$) is equal to initial $UO_2$ -, which means that there is no stock of fresh fuel in the reactor left (*Table 2*).

*Table 2: Fabrication mass flow in tons.*

| $U_{nat}$ | $UO_2$ (HM) | Dep U | $U_{spent}$ |
|---|---|---|---|
| 12648 | 1368 | 11280 | 1368 |

At the beginning of the scenario, the fabrication facility produces **75 tons** of fuel as initial start-up to load the core. After that first load, this facility has a constant production rate of **21.9 tons** of fuel per year which is what is needed to simulate recurring fuel reloads in ANICCA. This trend in fuel manufacturing has been represented in separative work units (SWU) over time (*Figure 2*). This being said, the production of 21.9 tons of $UO_2$ in $^{235}U$ content to 4.10% enrichment and a tail of 0.03 wt% is equivalent to 120 SWU and the full core mass equals to 410 SWU. All this amounts to a cumulative value of 7477.5 SWU in the 60 years of plant operation.

To understand the mass flow in the backend of the fuel cycle for this scenario, it is important to know that reactor cycle time in ANICCA were set annually. Thus, every year 21.9 tons of spent fuel is removed from the reactor core. This means that during the first years the mass increases gradually. Moreover, since residence time in the pool is 10 years, it is from year 11 onwards when there is a balance between what gets in and out of the facility.

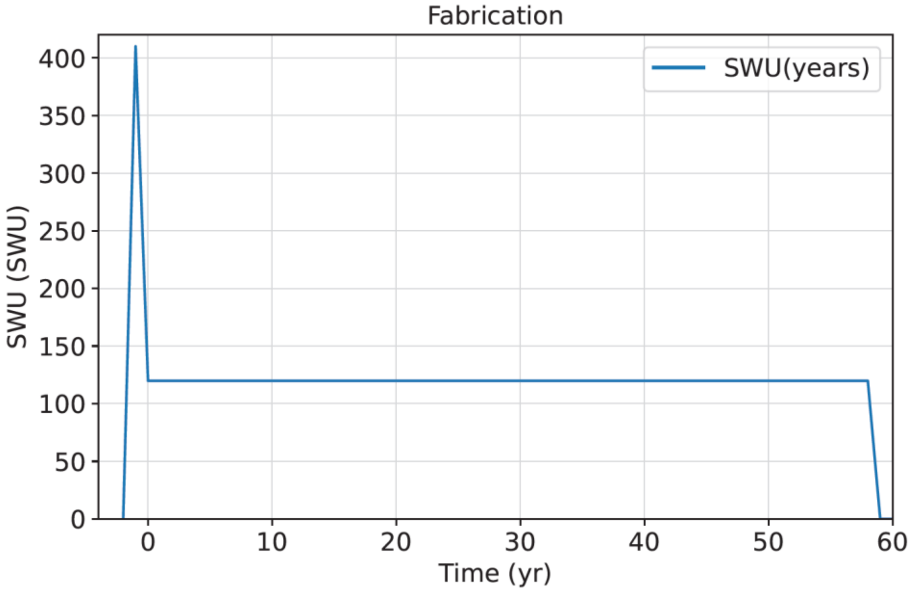

Figure 2: Separative Work Unit evolution.

Once the reactor shuts down after 60 years of operation, the core is entirely discharged, that means that 75 tons of spent fuel will be moved to wet storage. This abrupt increase in mass is visible in *Figure 3*. After that, spent fuel will no longer arrive and mass in the facility will decrease until the pool is emptied. The maximum mass in the dry storage is reached when the wet storage is emptied. In general, It can be seen that mass flow between facilities works properly as established in the scenario.

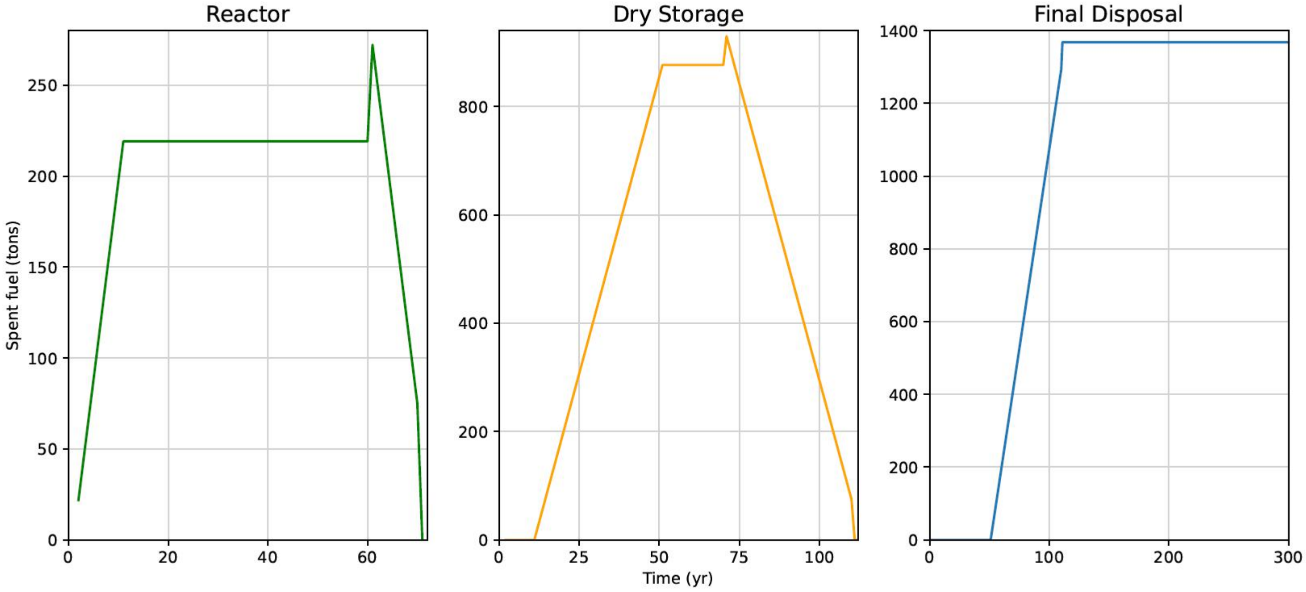

Figure 3: Spent fuel evolution in (left) Wet Storage, (center) Dry storage and (right) Final disposal.

Maximum masses of plutonium (Pu), fission products (FP) and minor actinides (MA) are also presented in *Table 3* since all of them will have an influence on radiotoxicity, decay heat and waste storage and are, therefore, important for the economic calculation.

Table 3: Maximum mass of plutonium, fission products and minor actinides in the simulation.

| Pu | FP | MA |
|---|---|---|
| 14.54 | 66.54 | 3.63 |

For both plutonium and fission products, maximum values are obtained at reactor shutdown; however, to get minor actinides' maximum value it will be necessary to wait for around 150 more years, in other words, the maximum value will be reached in the final disposal facility due to decay of some isotopes, such as $^{241}$Pu to $^{241}$Am. This information is crucial for radiological protection and temperature evolution in every storage stage.

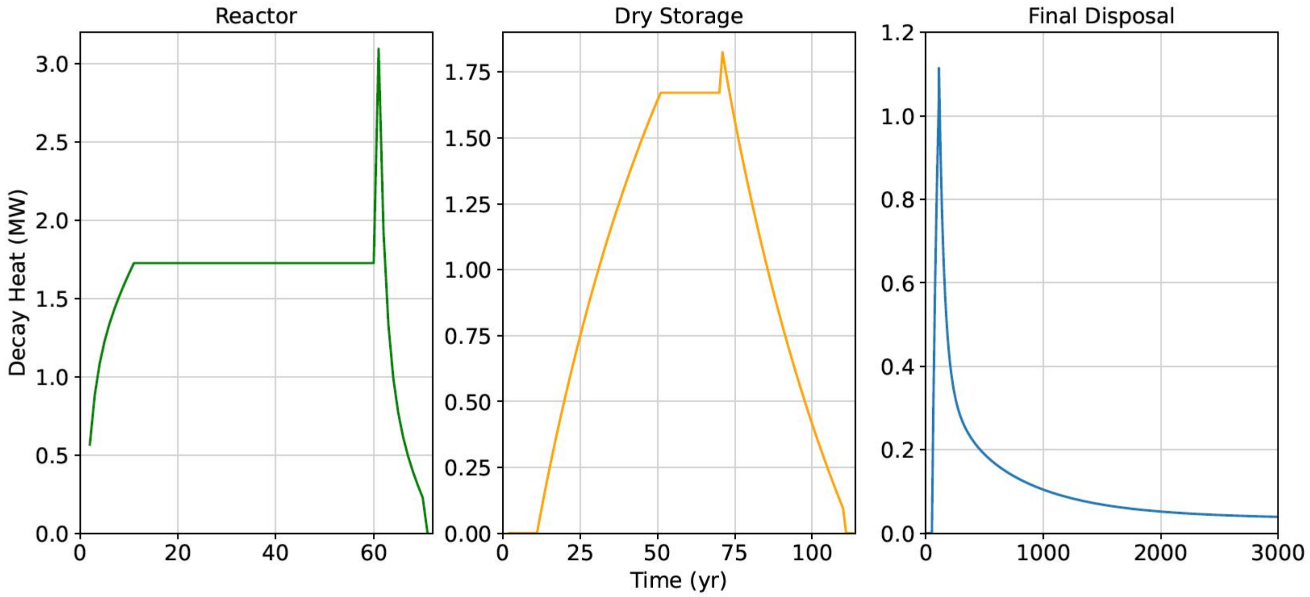

*Figure 4: Decay heat evolution in (left) Wet storage, (center) Dry storage and (right) Final disposal.*

Regarding decay heat and radiotoxicity data (*Figure 4* and *Figure 5*, respectively), it can be said that, for both, wet and dry storage, the trend follows spent fuel mass evolution in the facilities. They have a first stage of growth that corresponds to entry of material into storage. Then masses are constant for as many years as the residence time of the installation, thus, both variables are also constant. There is decay of short-lived and medium-lived fission products, however they are practically negligible comparing masses, because residence time in wet and dry storage is quite short. Moreover spent fuel is being sent to the facility at a constant rate, which makes observing these variations more complicated. Drastic reduction of masses during discharge in wet and dry storage is caused by spent fuel transfer between facilities, i.e. mass removal from the facilities.

Maximum values on each facility are different given that each storage has a different capacity, i.e., an imposed inventory associated with the residence time. Final disposal plot shows exponential decay, which is expected as long-term trend in spent fuel.

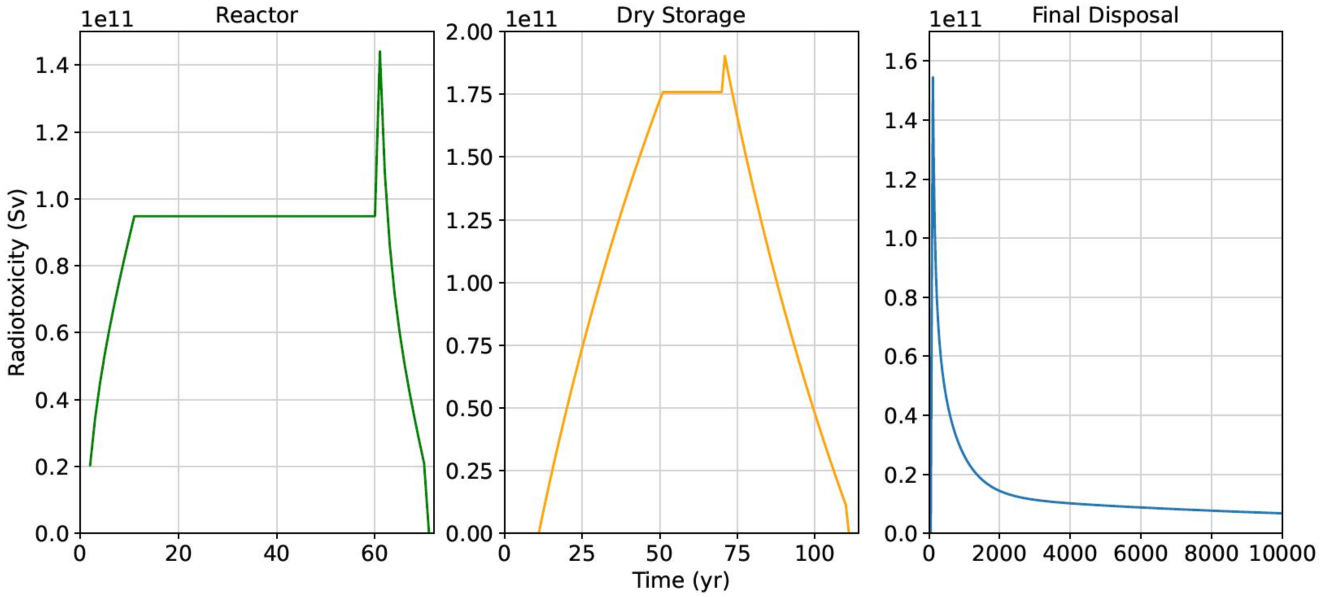

*Figure 5: Radiotoxicity evolution in (left) Wet storage, (center) Dry storage and (right) Final disposal.*

## 4. Economic output

ANICCA's **economic module** was developed to carry out a full cycle cost analysis. This study entails **construction**, **operation**, **shutdown** and **decommissioning costs** of different facilities as well as **waste management**. Additionally, initial investment, execution time, power and load factor of the plant are taken into consideration.

In order to run the economic module two inputs are required. ANICCA's "ecoutput" is one of them, where time, power and load factor history, masses of raw materials and by-products (fuels and irradiated materials) and material movements between facilities for each type of reactor present in the scenario, are given. Economic information is required in a different file. In this second file costs, dates and interest rates are specified. The analysis follows the recommendation of (10) and it divides the LCOE into four main cost blocks: **investment**, **operation and maintenance**, **fuel fabrication** and **backend**.

As it was agreed in the benchmark specifications, interest rate is set to 8% and construction time of the reactor is 6 years. Since it was not established beforehand, **payback period** was set at **30 years**. All used data is either from 2020 or updated to that same year USD dollar value (11), (12), (13), (14) and (15). All used costs have been selected by contrasting information from several sources. Moreover, as not all data could be obtained from the same reference, influence of each action and installation on the overall cost of the cycle has been taken into account. In addition, when costs were given in ranges, average values were selected.

*Table 4: Investment and Operation and maintenance costs.*

| **INVESTMENT COST** | | |
|---|---|---|
| **TECHNOLOGY** | **UNITS** | **BEST ESTIMATE** |
| Overnight (11) | $/kWe | 3606 |
| Loan rate | % | 8 |
| Construction interest | % | 8 |
| Construction time | years | 6 |
| Payback period | years | 30 |
| **O&M COSTS** | | |
| **TECHNOLOGY** | **UNITS** | **BEST ESTIMATE** |
| O&M (12) | $/kWe-yr | 73 |

Investment costs block (*Table 4*) covers overnight investment expressed in $/kWe, interest rates expressed in % and construction and reimbursement times expressed in years. Operation and maintenance costs are related to the overnight cost. It requires costs of the plant normal operation, but it does not include equipment repairs, therefore they are expressed in $/kWe-yr as seen in *Table 4*. For fuel fabrication block, all process will be accounted. Beginning with natural uranium purchase, and going through conversion, enrichment and fuel fabrication ($UO_2$). As it can be seen in *Table 5*, costs are in $ per kg of material at the end of the process ($/kg) and only enrichment will be given with different units, SWU.

*Table 5: Fuel costs.*

| **FUEL COSTS** | | |
|---|---|---|
| **TECHNOLOGY** | **UNITS** | **BEST ESTIMATE** |
| Raw uranium (13) | $\$/kgU_3O_8$ | 66 |
| Conversion (14) | $\$/kgUF_6$ | 22.3 |
| Enrichment (15) | SWU | 99.5 |
| Fabrication (3) | $\$/kgUO_2$ | 298 |

The last block, the backend block (presented in *Table 6*), includes waste storage, final disposal and plant decommissioning. There is no distinction between dry and wet storage in the economic module, hence both have same prices and their cost will be given in a single value. Costs in *Table 6* are divided in overnight investment and operation and maintenance, however on this scenario we provided fixed and **spent fuel costs**. On the one hand fixed costs are independent of the amount of spent fuel generated and are expressed in millions of dollars. On the other hand, variable costs, as their name specifies, rely on the mass of spent fuel to be stored, they are therefore expressed in $/kgHM and are expressed as spent fuel costs. To obtain those costs, two thirds of both (overnight investment and operation and maintenance) were added for fixed costs and one third for spent fuel. Decommissioning of the plant is typically interrelated with overnight costs and is hence given in % overnight.

Table 6: Backend costs.

| BACKEND | | |
|---|---|---|
| **TECHNOLOGY** | **UNITS** | **BEST ESTIMATE** |
| **Final Disposal** | | |
| Fixed cost (3) | M$ | 691 |
| Spent fuel (3) | $/kgHM | 259 |
| **Storage** | | |
| Fixed cost (9) | M$ | 263 |
| Spent fuel (3) | $/kgHM | 100 |
| **Decommissioning** (11) | overnight % | 15 |

With all this information, **3 different simulations** were carried out, each of them using a different construction interest plan that will only change investment budget. The first model assumes that the entire loan is obtained at the **beginning of construction**, the second model assumes that the loan is allocated **halfway through construction** and last model assumes that the loan is divided by **constructions years,** so interests will be set each year, making this option the most accurate one.

It should be noticed that not all data is obtained from the same source and that in this scenario the whole fuel cycle is represented. Therefore, it cannot be as accurate as other studies such as uranium resources and nuclear energy costs (16) or nuclear waste management (17) that use more updated, consistent and complete data.

Obtained costs are shown in *Table 7* for the 3 simulations described above. In the first column per model, data is displayed in $ per kWh, while the second column represents the percentage of each group. The first 6 rows are the categories in which costs were divided i.e., investment, operation and maintenance, fuel fabrication, final disposal, storage and decommissioning of the plant. On the last column **total levelized cost of electricity (LCOE)** is specified, which is the combination of all the previous rows.

Table 7: Economic output obtain with ANICCA with 8% Interest rate.

| 8% INTEREST RATE | | | | | | |
|---|---|---|---|---|---|---|
| | **Model 1 $/MWh** | **Model 1 (%)** | **Model 2 $/MWh** | **Model 2 (%)** | **Model 3 $/MWh** | **Model 3 (%)** |
| **Investment** | 32.21 | 64.2% | 25.57 | 58.8% | 26.81 | 59.9% |
| **O&M** | 9.25 | 18.4% | 9.25 | 21.3% | 9.25 | 20.7% |
| **Fuel fabrication** | 4.79 | 9.6% | 4.79 | 11.0% | 4.79 | 10.7% |
| **Final Disposal** | 2.21 | 4.4% | 2.21 | 5.1% | 2.21 | 4.9% |
| **Storage** | 0.56 | 1.1% | 0.56 | 1.3% | 0.56 | 1.2% |
| **Decommissioning** | 1.14 | 2.3% | 1.14 | 2.6% | 1.14 | 2.6% |
| **Total LCOE** | 50.17 | 100% | 43.52 | 100% | 44.75 | 100% |

In addition to these 3 simulations, two more scenarios with interest rates of 3% and 0.01% (0% interest rate cannot be calculated in ANICCA, due to the current implementation of the corresponding equation) were simulated to assess the impact of the interest rate on LCOE. Two extra tables (*Table 8* and *Table 9*) are presented with this information. Total levelized costs of electricity for both scenarios – 3% and 0.01% interest rate – decrease accordingly.

*Table 8: Economic output obtain with ANICCA with 3% Interest rate.*

| 3% INTEREST RATE | | | | | | |
|---|---|---|---|---|---|---|
| | **Model 1 $/MWh** | **Model 1 (%)** | **Model 2 $/MWh** | **Model 2 (%)** | **Model 3 $/MWh** | **Model 3 (%)** |
| **Investment** | 13.92 | 43.7% | 12.74 | 41.5% | 12.95 | 41.9% |
| **O&M** | 9.25 | 29.0% | 9.25 | 30.1% | 9.25 | 29.9% |
| **Fuel fabrication** | 4.79 | 15.0% | 4.79 | 15.6% | 4.79 | 15.5% |
| **Final Disposal** | 2.21 | 6.9% | 2.21 | 7.2% | 2.21 | 7.1% |
| **Storage** | 0.56 | 1.7% | 0.56 | 1.8% | 0.56 | 1.8% |
| **Decommissioning** | 1.14 | 3.6% | 1.14 | 3.7% | 1.14 | 3.7% |
| **Total LCOE** | 31.87 | 100% | 30.69 | 100% | 30.90 | 100% |

*Table 9: Economic output obtain with ANICCA with 0.01% Interest rate.*

| 0,01% Interest | | | | | | |
|---|---|---|---|---|---|---|
| | **Model 1 $/MWh** | **Model 1 (%)** | **Model 2 $/MWh** | **Model 2 (%)** | **Model 3 $/MWh** | **Model 3 (%)** |
| **Investment** | 7.63 | 29.8% | 7.63 | 29.8% | 7.63 | 29.8% |
| **O&M** | 9.25 | 36.2% | 9.25 | 36.2% | 9.25 | 36.2% |
| **Fuel fabrication** | 4.79 | 18.7% | 4.79 | 18.7% | 4.79 | 18.7% |
| **Final Disposal** | 2.21 | 8.6% | 2.21 | 8.6% | 2.21 | 8.6% |
| **Storage** | 0.56 | 2.2% | 0.56 | 2.2% | 0.56 | 2.2% |
| **Decommissioning** | 1.14 | 4.5% | 1.14 | 4.5% | 1.14 | 4.5% |
| **Total LCOE** | 25.59 | 100% | 25.58 | 100% | 25.58 | 100% |

# References

1. *The nuclear fuel cycle code ANICCA: Verification and a case study for the phase out of Belgian nuclear power with minor actinide transmutation.* **I. Merino Rodríguez, A. Hernández-Solís, N. Messaoudi, G. Van den Eynde.** s.l. : Nuclear Engineering and Technology, 2020, Vol. 52, pp. 2274-2284.

2. *Comparison of nuclear data uncertainties with other nuclear fuel cycle uncertainty sources.* **Aris V. Skarbeli, Rubén de Eusebio-Yebra, Pablo Romojaro, Francisco Álvarez-Velarde, Daniel Cano-Ott.** 12, s.l. : International Journal of Energy Research, 2021, Vol. 45, pp. 18292-18301.

3. **NEA.** *The Economics of the Back End of the Nuclear Fuel Cycle.* Paris : OECD Publishing, 2013.

4. **Eynde, K. Nishihara and G. Van den.** Collaboration JAEA - SCK CEN. s.l. : SCK CEN/37819593, 2020.

5. **Nakase, Masahiko.** NMB code: Fuel Cycle Integrator. [Online] [Cited: 4 12, 2023.] https://nmb-code.jp/.

6. *Advanced Method for Calculations of Core Burn-Up, Activation of Structural Materials, and Spallation Products Accumulation in Accelerator-Driven Systems.* **A. Stankovskiy, G. Van Den Eynde.** 2012, Science and Technology of Nuclear Installations, Vol. 2012, p. 12.

7. *ENDF/B-VIII.0: The 8th Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data.* **D.A. Brown, M.B. Chadwick, R. Capote, A.C. Kahler, A. Trkov, M.W. Herman, A.A. Sonzogni, Y. Danon, A.D. Carlson, M. Dunn, D.L. Smith, G.M. Hale, G. Arbanas, R. Arcilla, C.R. Bates, B. Beck, B. Becker, F. Brown, R.J. Casperson, J. Conlin, D.E. Cullen, M.-A.** 2018, Nuclear Data Sheets, Vol. 148, pp. 1-142.

8. **NEA.** *The JEFF-3.1.1 Nuclear Data Library.* Paris : OECD Publishing, 2009.

9. *Numerical methods for nuclear fuel burnup calculations.* **Pusa, M.** s.l. : VTT, 2013 .

10. **Forum, The Economic Modeling Working Group Of the Generation IV International.** *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems.* s.l. : OECD, 2007.

11. **IEA.** *Projected Costs of Generating Electricity.* IEA. Paris : IEA, 2020.

12. **U.S. Department of Energy.** *Advanced Fuel Cycle Cost Basis-2017 Edition.* U.S. Department of Energy (DOE) Office of Nuclear Energy (NE). s.l. : U.S. Department of Energy, 2017.

13. **Camero.** Camero. [Online] 2020. [Cited: March 13, 2023.] https://www.cameco.com/invest/markets/uranium-price.

14. **TradeTech.** TradeTech. [Online] August 20, 2021. [Cited: March 13, 2023.] https://sprott.com/media/4209/nmr210820.pdf.

15. **U.S. Department of Energy.** *Uranium Marketing Annual Report.* Washington, DC : Uranium Marketing Annual Report, 2021. p. 53.

16. **NEA.** *Uranium 2022: Resources, Production and Demand.* Paris : OECD Publishing, 2023.

17. **ENRESA.** *Versión inicial del 7º Plan General de Residuos Radiactivos.* 2022.

18. *Quantification of the differences introduced by nuclear fuel cycle simulators in advanced scenario studies.* **A.V. Skarbeli, I. Merino Rodríguez, F. Álvarez-Velarde, A. Hernández-Solís, G. Van den Eynde.** 2020, Annals of Nuclear Energy, Vol. 137, p. 9.