Nuclear-powered Shipping

Louis Kissinger, Brad Ellis, and Adam Pichman
Course: NPRE 458; Advisor: Magdi Ragheb

February 22, 2019

Abstract

Nuclear power was analyzed as an alternative to fossil fuel combustion for propulsion of large boats. In particular, ...

Contents

1 Introduction

Introduction

If you wanna cite Alekseev put [1]

If you wanna cite Carlton put [2]

[3]

[4]

[5]

If you wanna cite Hirdaris put [6]

If you wanna cite Jacobs put [7]

If you wanna cite Holtec put [8]

2 Background and State of the Art

Background and state of the art

3 Conceptual Design

3.1 Naval concept

3.1.1 Oceanic tug boat

3.1.2 Offshore power plant and coastal tug boat

3.2 Reactor concept

3.2.1 Core concept

3.2.2 Neutronics analysis

The following analysis determines the enrichment required to reach $k_\infty = 1$:

$$k_\infty = \eta f = 1 \tag{1}$$

$$= \nu \frac{\sigma_f^F}{\sigma_a^F} \frac{\Sigma_a^F}{\Sigma_a} \tag{2}$$

Approximate values of these parameters are given in table 1.

Table 1: Approximate values of nuclear properties germaine to equation 2, [9]

Parameter	Value	Unit
ν	2.4	-
σ_f, 235	1.2	barns
σ_a, 238	0.1	barns

The macroscopic cross section is by definition $\Sigma = N\sigma = \frac{\rho N_{av}}{A}\omega$. Equation 2 then reduces to:

$$1 = \nu \frac{{}^{235}\sigma_f}{{}^{235}\sigma_a} \frac{\frac{\omega}{235} {}^{235}\sigma_a}{\frac{1-\omega}{238} {}^{238}\sigma_a} \tag{3}$$

$$= \nu \frac{{}^{235}\sigma_f}{{}^{238}\sigma_a} \frac{238\omega}{235(1-\omega)} \tag{4}$$

Upon defining a new variable $\xi = \nu \frac{^{235}\sigma_f}{^{238}\sigma_a}$, we find:

$$\frac{1}{\xi} = \frac{238\omega}{235(1-\omega)} \tag{5}$$

$$\omega = \frac{235}{238\xi + 235} < 1 \tag{6}$$

Upon inserting the tabulated values for these cross sections, we find $\xi = 4.2$ and $\omega = 0.0336 = 3.4\%$. The bulk of the reactor can thus be fueled without HEU.

If the fuel is UO_2, then the mass of Uranium per mass of fuel is:

$$\frac{m_U}{m_{UO2}} = \frac{238(1-\omega) + 235\omega}{238(1-\omega) + 235\omega + 32} \tag{7}$$

$$= 0.8817 \frac{grams}{gram} \tag{8}$$

$$n_{235} = \omega m_u \frac{N_{av}}{235} \tag{9}$$

$$= 7.906 \times 10^{20} \tag{10}$$

If we **assume that $\frac{3}{4}$ of the fissions occur in** U_{235}, then the total fissile atoms per gram of fuel is 1.05×10^{21}.

We can now determine the required mass of Uranium to produce a certain amount of energy. The core's power is related to the fission rate by a factor of 200 MeV per fission. We will **assume a core power of 1.75 GWth** for this analysis. This value roughly corresponds to 60 MWe for typical values of efficiency, which is close to the power output of the reactors we seek to imitate. The fission rate in our reactor is then $1.75 \times 10^9 \frac{Joules}{sec} \times \frac{1MeV}{1.6\times10^{-13}} \times \frac{1Fission}{200MeV} = 5.5 \times 10^{19} \frac{fissions}{second}$.

In an **assumed 2-year refueling cycle** we would then need $5.5 \times 10^{19} \frac{fissions}{second} \times \frac{3.15\times10^7 s}{y} = 1.723 \times 10^{27}$ fissile atoms.

Returning to our value of fissile atoms per gram of UO_2, we can find the mass of Uranium required to power our core for two years. This number is $5.5 \times 10^{19} \frac{fissions}{second} \times \frac{6.3\times10^7 s}{2years} = 3.5 \times 10^{27}$

3.2.3 Thermal analysis

3.2.4 Materials analysis

3.2.5 Alternatives

Conceptual design

4 Conclusions

Conclusions

5 Acknowledgements

Thanks to the Illinois NPRE department for their tireless work educating us. In particular, we would like to thank Professor Ragheb for his guidance and mentorship and Professor Stubbins for instructing the Senior Design course.

References

[1] P. ALEKSEEV, N. E. KUKHARKIN, Y. N. UDYANSKII, T. D. SHCHEPETINA, I. A. BELOV, S. A. SUBBOTIN, A. A. D. A. A. SEDOV, M. M. KASHKA, and V. V. BASHAEV, "ADVANCED NUCLEAR POWER SYSTEMS WITH MICROPELLETED FUEL FOR NUCLEAR-POWERED SHIPS," *Atomic Energy Voll 99 No. 1* (2005).

[2] J. CARLTON, R. SMART, and V. JENKINS, "The nuclear propulsion of merchant ships: Aspects of engineering, science and technology," *Journal of Marine Engineering and Technology* (2011).

[3] J. GRAVINA, J. BLAKE, A. SHENOI, S. TURNOCK, and S. HIRDARIS, "CONCEPTS FOR A MODULAR NUCLEAR POWERED CONTAINERSHIP," (2013).

[4] W. SHI HAN and T. LIU, "A new marine propulsion system," (2003).

[5] M. HUSSAIN, F. REITSMA, M. H. SUBKI, and H. KIUCHI, "Advances in Small Modular Reactor Technology Developments," (2018).

[6] S. HIRDARIS, Y. CHENG, P. SHALLCROSS, J. BONAFOUX, D. CARLSON, B. PRINCE, and G. SARRIS, "Considerations on the potential use of Nuclear Small Modular Reactor (SMR) technology for merchant marine propulsion," (2013).

[7] J. JACOBS, "Nuclear Short Sea Shipping: The integration of a Helium cooled reactor in a 800 TEU Container Feeder," (2007).

[8] J. R. RUSSELL, "Holtec International Response to the DOE RFI," (2017).

[9] JAEA, "Japan Atomic Energy Agency Nuclear Data Center," (2018).