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# Evaluation of the insertion of a transmutation layer in the ARC compact reactor

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## 1. Introduction

Power production from nuclear fusion is widely investigated for an always-available, environmentally benign, and well-distributed energy solution. Fusion power can also provide power on demand on a utility scale, making it an excellent complement to intermittent renewables and battery storage. With this in mind, many countries are investing in studies in the area to develop large projects, such as the ITER (International Thermonuclear Experimental Reactor) project being built in France by investment from the European Union, India, Japan, China, Russia, South Korea, and the USA. ITER is based on Tokamak technology and is being investigated by the Department of Nuclear Engineering (DEN/UFMG). One of the works developed by DEN was the insertion of a transmutation layer in a hybrid fusion-fission system based on Tokamak, to induce transuranic transmutation using neutrons originating from the fusion reaction, through fission reactions [1]. The Tokamak is a magnetic confinement reactor, which has a structure formed by a toroidal field together with a poloidal field generated by the plasma current. These reactors, in turn, are large scale, approximately 24 m high and 28 m in diameter, and have a high installation cost [2].

However, studies are being conducted seeking technologies for a compact, robust, and affordable reactor that aims to reduce the size, cost, and complexity of an installation. One promising fusion reactor under design at the Massachusetts Institute of Technology (MIT) is the Affordable Robust Compact (ARC) reactor. The ARC is a conceptual design of the spherical tokamak reactor, which can function as a demonstration fusion plant for power generation and a fusion nuclear science facility (FNSF) for integrated materials. In addition, it performs component irradiation tests using the same Deuterium-Tritium (D-T) fusion reaction as the ITER reactor, whose neutrons produced are 14.1 MeV. The ARC study uses high-temperature superconductors (HTS), which allow for large magnetic fields in the shaft and ultimately reduce the size of the reactor [3]. The use of high temperature superconductors in reactors has brought nuclear fusion within reach, allowing a decrease in the size and cost of fusion reactors, this advancement is called the accelerated route [4].

The ARC project is of conceptual point of a nuclear fusion science facility/pilot plant that demonstrates the advantages of a compact high-field design using rare earth barium copper oxide superconducting magnets (REBCO HTS), which have gaskets to allow disassembly, and lower hybrid current drive (LHCD). The project was executed as a continuation of the conceptual design of Vulcan, a tokamak to study the physics of plasma-material interaction (PMI) that also uses the dismountable REBCO and high-field side LHCD [5][6]. It is emphasized that the ARC represents one of many possible configurations of compact high-field design. Therefore, this work seeks to compare the properties of the ITER reactor with the ARC reactor. Furthermore, to investigate the possibility of inserting a transmutation layer in the ARC compact reactor, which has an optimized geometry smaller than the Tokamak reactor from the ITER project.

## 2. Methodology

The use of high temperature superconductors (HTS) in reactors provides large scale magnetic fields on the shaft and reduces the size of the reactor. This property can provide access to the high plasma gain $Q_P$ and allow net electrical gain $Q_L > 1$, which is the available energy released by fusion reactions that can be used to generate electrical energy. The diagram, illustrated in Figure 1, shows the accelerated route, in which it is observed where the ARC reactor is located in relation to the ITER in relation to the fixed aspect A, q and in relation to the confinement factor H = 1. There is a large discrepancy between the projects, in which the volumes are 880 for ITER, 140 for ARC and 12 for SPARC [8].

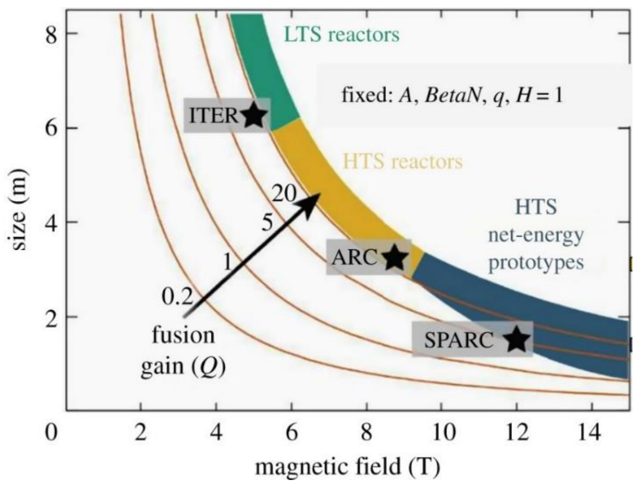


Figure 1. Magnetic field size diagram illustrating the three areas of low temperature superconductors (LTS), HTS reactors and HTS net energy prototypes, plotted for a fixed aspect ratio *A*, *q* e confinement factor *H = 1*. [8].

The characteristics of the ARC project will be investigated and compared with the studies carried out at DEN/UFMG about the Tokamak since it has already been modeled. Table I presents a comparison with some parameters used in the ARC project system and the hybrid system based on Tokamak. It is observed that the ARC reactor has smaller dimensions, with greater magnetic field and fusion power than the Tokamak hybrid reactor. The differences in design properties and geometry point to the need to study the application of the same methodology used in Tokamak, to propose the insertion of a transmutation layer in the ARC compact reactor [1][3].

Table I: Comparison of ARC [3] and Tokamak [1] system parameters.

| **Parameters** | **ARC** | **Tokamak** |
|---|---|---|
| Major radius, $R_0$ (m) | 3.3 | 6.2 |
| Minor radius, r (m) | 1.13 | 2 |
| Fusion power (MW) | 525 | 250–500 |
| Plasma elongation, k | 1.84 | 1.85 |
| Toroidal magnetic field (T) | 9.2 | 5.3 |
| Plasma current, $I_p$ (MA) | 7.8 | 15 |
| Fission power (MW) | - | 3000 |
| Type of plasma | D-T | D–T |
| Volume plasma chamber ($m^3$) | 141 | 837 |

## 3. Expected results

The different properties of the ITER and ARC projects allow us to observe what is the possibility of inserting the transmutation layer in the compact reactor and whether this layer can be in a similar place to the one studied for the Tokamak reactor. These different properties indicate that it will be necessary to study the insertion of the transmutation layer in the ARC model. Furthermore, it is expected to find out the most suitable location within the ARC, considering the dimensions of the components and the neutron flux over them, as well as better results in the investigation of the neutron flux in the inserted transmutation layer.

## 4. Conclusions

In this work, it is expected that the feasibility of inserting a transmutation layer in an ARC reactor will be advantageous in terms of engineering and financially due to the smaller dimensions of the project and provide opportunities for advances in the area.

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## References

[1] Velasquez, Carlos E., et al. "Fusion–fission hybrid systems for transmutation." *Journal of Fusion Energy* 35.3 (2016): 505-512.
[2] Shimomura, Y., and W. Spears. "Review of the ITER project." *IEEE Transactions on Applied Superconductivity* 14.2 (2004): 1369-1375.
[3] Sorbom, B. N., et al. "ARC: A compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets." *Fusion Engineering and Design* 100 (2015): 378-405.
[4] Windsor, Colin. "Can the development of fusion energy be accelerated? An introduction to the proceedings." (2019): 20170446.
[5] Olynyk, G. M., et al. "Vulcan: a steady-state tokamak for reactor-relevant plasma–material interaction science." *Fusion Engineering and Design* 87.3 (2012): 224-233.
[6] Maeda, Hideaki, and Yoshinori Yanagisawa. "Recent developments in high-temperature superconducting magnet technology." *IEEE Transactions on applied superconductivity* 24.3 (2013): 1-12.
[7] Bruzzone, Pierluigi, et al. "High temperature superconductors for fusion magnets." *Nuclear Fusion* 58.10 (2018): 103001.
[8] Whyte, Dennis. "Small, modular and economically attractive fusion enabled by high temperature superconductors." *Philosophical Transactions of the Royal Society A* 377.2141 (2019): 20180354.
[9] Crow, Raym. "The case for institutional repositories: a SPARC position paper." (2002).