

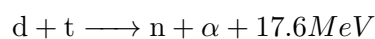
CONTENTS

1 Placeholder: Snippets from Report	1
1.1 Theory	1
1.2 Major Breeder Blanket Architectures	2
1.2.1 Liquid Breeder Concepts	2
1.2.2 Solid Breeder Concepts	2
2 Introduction	5
3 Theory	5
3.1 Fundamentals of Nuclear Fusion	5
3.2 Neutron Transport and Interactions	5
3.2.1 Scattering Interactions	5
3.2.2 Absorption Interactions	5
3.3 Tritium Breeding and Neutron Multiplication	5
4 Literature Review	5
4.1 The D-T Reaction and the Tritium Fuel Imperative	5
4.2 Breeder Blanket: Concept, Function, and Evolution	5
4.3 The Role of Neutron Multipliers	5
4.3.1 Beryllium Neutron Multipliers	5
4.3.2 Lead Neutron Multipliers	5
4.4 Major Breeder Blanket Architectures	5
4.4.1 Solid Breeder Concepts	5
4.4.2 Liquid Breeder Concepts	5
4.5 Neutronics Modelling and the Research Gap	5
5 Methodology	5
5.1 Modelling Neutron Transport: From Boltzmann to Monte Carlo	5
5.2 Computational Workflow and Toolchain	5
5.3 Simulation Strategy: Model Choices and Parameter Sweep Strategies	5
6 Results	5
6.1 Material Composition / Enrichment Results	5
6.2 Geometry Sweep Results	5
6.3 Design Agnosticity (Is this portable to all tokamaks?)	5
7 Discussion	5
7.1 TBR Optimisation Strategies	5
7.2 Consequences to Other Critical Criteria	5
7.3 Model Limitations	5
7.4 Next Steps	5
8 Conclusion	5

1. PLACEHOLDER: SNIPPETS FROM REPORT

1.1. Theory

For terrestrial power generation, the most promising reaction is that between the two heavy isotopes of hydrogen, deuterium (d) and tritium (t) [1, 2]:



This D-T reaction is the primary focus of mainstream fusion research, as it has a fusion cross-section significantly higher than other candidate reactions (such as D-D or D- ^3He) (Fig. 1) [2]. This is mainly due to the stability of the final products linking to a higher Q value output [3].

Another important reason for D-T is the comparatively lower required input energy / temperature. To initiate fusion, the positively charged nuclei must be given enough kinetic energy to overcome their mutual electrostatic repulsion, known as the Coulomb barrier. This barrier will increase if the reactants have a more positive charge and so more electrostatic repulsion. This can exclude cycles like D- ^3He as the required temperatures/energies are already high enough (hotter than the core of the sun). In Magnetic Confinement Fusion (MCF) devices, such as the **tokamak** [4], this is achieved by heating the D-T gas into a plasma state at temperatures exceeding 100 million Kelvin. The hot plasma is then confined by powerful magnetic fields, preventing it from touching the reactor walls. The 17.6 MeV of energy released is partitioned between the two products: the alpha particle (α , a helium nucleus) carries 3.5 MeV, while the neutron (n) carries 14.1 MeV [2].

1.2. Major Breeder Blanket Architectures

Blanket designs are broadly divided into two categories—liquid and solid—based on the phase of the lithium-bearing breeder material.

1.2.1. Liquid Breeder Concepts

Liquid breeders (LBs) are attractive because the breeding medium can simultaneously function as the coolant, simplifying the design and allowing for continuous tritium extraction outside the reactor [5].

1.2.1.1. Lithium-Lead (Li-Pb):

This is one of the most mature concepts, typically using the eutectic alloy $\text{Li}_{17}\text{Pb}_{83}$ [6, 7]. The lead acts as both a neutron multiplier and the primary component of the alloy, while the eutectic composition provides a low melting point, which is crucial for circulation [6]. This concept is the basis for the **Dual-Cooled Lithium-Lead (DCLL)** blanket, a primary candidate for the European DEMO reactor [8, 9]. A key challenge for all liquid metal blankets is magnetohydrodynamics (MHD), where the strong magnetic fields of the tokamak induce currents in the flowing metal, creating a drag force that inhibits circulation [9].

1.2.1.2. Molten Salts:

An alternative LB concept uses molten fluorine or chlorine salts. The most prominent example is **FLiBe (2 LiF · BeF₂)**, which advantageously combines the breeder (LiF) and multiplier (BeF₂) into a single, low-conductivity fluid [5]. This is the reference design for the **Affordable Robust Compact (ARC)** reactor concept from MIT [10, 11, 12]. A wide variety of other salt compositions, including $\text{LiF} \cdot \text{PbF}_2$ and novel chlorine-based salts, are also under investigation to optimise breeding, temperature, and material compatibility [13, 14].

1.2.2. Solid Breeder Concepts

REFERENCES

1. Paris MW and Chadwick MB. A lost detail in D-T fusion history. *Physics Today*. 2023 Oct 1; 76:10–11. DOI: 10.1063/PT.3.5317. Available from: <https://pubs.aip.org/physicstoday/article/76/10/10/2912725/A-lost-detail-in-D-T-fusion-history> [Accessed on: 2025 Oct 14]
2. Heckrotte W and Hiskes J. Some factors in the choice of D-D, D-T or D- ^3He mirror fusion power systems. *Nuclear Fusion*. 1971 Oct; 11:471–84. DOI: 10.1088/0029-5515/11/5/009. Available from: <https://doi.org/10.1088/0029-5515/11/5/009> [Accessed on: 2025 Oct 8]
3. Lilley J. *Nuclear Physics: Principles and Applications*. Manchester Physics Series. John Wiley and Sons, 2008
4. Wesson J. *Tokamaks*. 4th. Oxford University Press, 2011

5. Tas H, Malang S, Reiter F, and Sannier J. Liquid breeder materials. *Journal of Nuclear Materials*. 1988 Jul; 155-157:178–87. DOI: 10.1016/0022-3115(88)90239-5. Available from: <https://linkinghub.elsevier.com/retrieve/pii/0022311588902395> [Accessed on: 2025 Oct 8]
6. Mas de les Valls E, Sedano LA, Batet L, Ricipito I, Aiello A, Gastaldi O, et al. Lead–lithium eutectic material database for nuclear fusion technology. *Journal of Nuclear Materials. Heavy Liquid Metal Cooled Reactors and Related Technologies* 2008 Jun 15; 376:353–7. DOI: 10.1016/j.jnucmat.2008.02.016. Available from: <https://www.sciencedirect.com/science/article/pii/S0022311508000809> [Accessed on: 2025 Oct 8]
7. Wu Y. Overview of liquid lithium lead breeder blanket program in China. *Fusion Engineering and Design*. 2011 Oct; 86:2343–6. DOI: 10.1016/j.fusengdes.2010.12.046. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0920379610005818> [Accessed on: 2025 Oct 7]
8. Fernández-Bergeruelo I, Palermo I, Ugorri F, Rapisarda D, González M, Alguacil J, et al. Progress in design and experimental activities for the development of an advanced breeding blanket. *Nuclear Fusion*. 2024 May 1; 64:1–16. DOI: 10.1088/1741-4326/ad37ca. Available from: <https://iopscience.iop.org/article/10.1088/1741-4326/ad37ca> [Accessed on: 2025 Oct 7]
9. Malang S, Deckers H, Fischer U, John H, Meyder R, Norajitra P, et al. Self-cooled blanket concepts using Pb-7Li as liquid breeder and coolant. *Fusion Engineering and Design*. 1991 Apr 2; 14:373–99. DOI: 10.1016/0920-3796(91)90020-Q. Available from: <https://www.sciencedirect.com/science/article/pii/092037969190020Q> [Accessed on: 2025 Oct 14]
10. Sorbom B, Ball J, Palmer T, Mangiarotti F, Sierchio J, Bonoli P, et al. ARC: A compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets. *Fusion Engineering and Design*. 2015 Nov; 100:378–405. DOI: 10.1016/j.fusengdes.2015.07.008. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0920379615302337> [Accessed on: 2025 Oct 8]
11. Bocci B, Hartwig Z, Segantin S, Testoni R, Whyte D, and Zucchetti M. ARC reactor materials: Activation analysis and optimization. *Fusion Engineering and Design*. 2020 May 1; 154:1–8. DOI: 10.1016/j.fusengdes.2020.111539. Available from: <https://www.sciencedirect.com/science/article/pii/S0920379620300879> [Accessed on: 2025 Oct 9]
12. Segantin S, Testoni R, Hartwig Z, Whyte D, and Zucchetti M. Optimization of tritium breeding ratio in ARC reactor. *Fusion Engineering and Design*. 2020 May; 154:1–5. DOI: 10.1016/j.fusengdes.2020.111531. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S092037962030079X> [Accessed on: 2025 Oct 8]
13. Segantin S, Testoni R, and Zucchetti M. Neutronic comparison of liquid breeders for ARC-like reactor blankets. *Fusion Engineering and Design*. 2020 Nov; 160:1–10. DOI: 10.1016/j.fusengdes.2020.112013. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0920379620305615> [Accessed on: 2025 Oct 8]
14. Bohm TD and Lindley BA. Initial Neutronics Investigation of a Chlorine Salt–Based Breeder Blanket. *Fusion Science and Technology*. 2023 Nov 17; 79:995–1007. DOI: 10.1080/15361055.2022.2136923. Available from: <https://www.tandfonline.com/doi/full/10.1080/15361055.2022.2136923> [Accessed on: 2025 Oct 8]

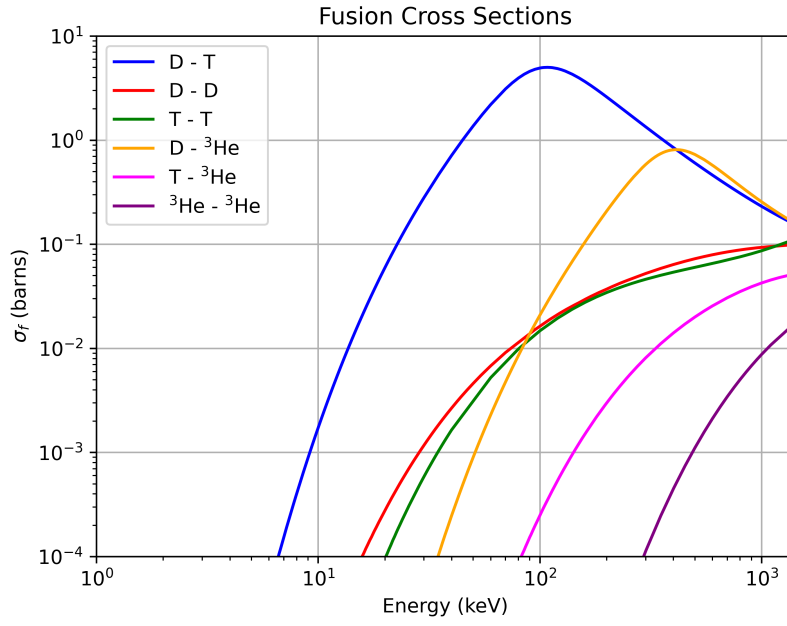


Figure 1: A comparison of fusion reaction reactivities total cross section σ as a function of ion temperature (keV) for the D-T, D-D, and D- ^3He fuel cycles. The D-T reaction's cross section peaks at a lower temperature and is significantly larger than the alternatives, making it the most accessible reaction for current and near-term fusion devices.

2. INTRODUCTION

3. THEORY

3.1. Fundamentals of Nuclear Fusion

3.2. Neutron Transport and Interactions

3.2.1. *Scattering Interactions*

3.2.2. *Absorption Interactions*

3.3. Tritium Breeding and Neutron Multiplication

4. LITERATURE REVIEW

4.1. The D-T Reaction and the Tritium Fuel Imperative

4.2. Breeder Blanket: Concept, Function, and Evolution

4.3. The Role of Neutron Multipliers

4.3.1. *Beryllium Neutron Multipliers*

4.3.2. *Lead Neutron Multipliers*

4.4. Major Breeder Blanket Architectures

4.4.1. *Solid Breeder Concepts*

4.4.2. *Liquid Breeder Concepts*

4.5. Neutronics Modelling and the Research Gap

5. METHODOLOGY

5.1. Modelling Neutron Transport: From Boltzmann to Monte Carlo

5.2. Computational Workflow and Toolchain

5.3. Simulation Strategy: Model Choices and Parameter Sweep Strategies

6. RESULTS

6.1. Material Composition / Enrichment Results

6.2. Geometry Sweep Results

6.3. Design Agnosticity (Is this portable to all tokamaks?)

7. DISCUSSION

7.1. TBR Optimisation Strategies

7.2. Consequences to Other Critical Criteria

7.3. Model Limitations

7.4. Next Steps

8. CONCLUSION

REFERENCES

1. Paris MW and Chadwick MB. A lost detail in D-T fusion history. *Physics Today*. 2023 Oct 1; 76:10–11. DOI: 10.1063/PT.3.5317. Available from: <https://pubs.aip.org/physicstoday/article/76/10/10/2912725/A-lost-detail-in-D-T-fusion-history> [Accessed on: 2025 Oct 14]

2. Heckrotte W and Hiskes J. Some factors in the choice of D-D, D-T or D-3He mirror fusion power systems. *Nuclear Fusion*. 1971 Oct; 11:471–84. DOI: 10.1088/0029-5515/11/5/009. Available from: <https://doi.org/10.1088/0029-5515/11/5/009> [Accessed on: 2025 Oct 8]
3. Lilley J. *Nuclear Physics: Principles and Applications*. Manchester Physics Series. John Wiley and Sons, 2008
4. Wesson J. *Tokamaks*. 4th. Oxford University Press, 2011
5. Tas H, Malang S, Reiter F, and Sannier J. Liquid breeder materials. *Journal of Nuclear Materials*. 1988 Jul; 155-157:178–87. DOI: 10.1016/0022-3115(88)90239-5. Available from: <https://linkinghub.elsevier.com/retrieve/pii/0022311588902395> [Accessed on: 2025 Oct 8]
6. Mas de les Valls E, Sedano LA, Batet L, Ricapito I, Aiello A, Gastaldi O, et al. Lead–lithium eutectic material database for nuclear fusion technology. *Journal of Nuclear Materials. Heavy Liquid Metal Cooled Reactors and Related Technologies* 2008 Jun 15; 376:353–7. DOI: 10.1016/j.jnucmat.2008.02.016. Available from: <https://www.sciencedirect.com/science/article/pii/S0022311508000809> [Accessed on: 2025 Oct 8]
7. Wu Y. Overview of liquid lithium lead breeder blanket program in China. *Fusion Engineering and Design*. 2011 Oct; 86:2343–6. DOI: 10.1016/j.fusengdes.2010.12.046. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0920379610005818> [Accessed on: 2025 Oct 7]
8. Fernández-Berceruelo I, Palermo I, Urgorri F, Rapisarda D, González M, Alguacil J, et al. Progress in design and experimental activities for the development of an advanced breeding blanket. *Nuclear Fusion*. 2024 May 1; 64:1–16. DOI: 10.1088/1741-4326/ad37ca. Available from: <https://iopscience.iop.org/article/10.1088/1741-4326/ad37ca> [Accessed on: 2025 Oct 7]
9. Malang S, Deckers H, Fischer U, John H, Meyder R, Norajitra P, et al. Self-cooled blanket concepts using Pb-7Li as liquid breeder and coolant. *Fusion Engineering and Design*. 1991 Apr 2; 14:373–99. DOI: 10.1016/0920-3796(91)90020-Q. Available from: <https://www.sciencedirect.com/science/article/pii/092037969190020Q> [Accessed on: 2025 Oct 14]
10. Sorbom B, Ball J, Palmer T, Mangiarotti F, Sierchio J, Bonoli P, et al. ARC: A compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets. *Fusion Engineering and Design*. 2015 Nov; 100:378–405. DOI: 10.1016/j.fusengdes.2015.07.008. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0920379615302337> [Accessed on: 2025 Oct 8]
11. Bocci B, Hartwig Z, Segantin S, Testoni R, Whyte D, and Zucchetti M. ARC reactor materials: Activation analysis and optimization. *Fusion Engineering and Design*. 2020 May 1; 154:1–8. DOI: 10.1016/j.fusengdes.2020.111539. Available from: <https://www.sciencedirect.com/science/article/pii/S0920379620300879> [Accessed on: 2025 Oct 9]
12. Segantin S, Testoni R, Hartwig Z, Whyte D, and Zucchetti M. Optimization of tritium breeding ratio in ARC reactor. *Fusion Engineering and Design*. 2020 May; 154:1–5. DOI: 10.1016/j.fusengdes.2020.111531. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S092037962030079X> [Accessed on: 2025 Oct 8]
13. Segantin S, Testoni R, and Zucchetti M. Neutronic comparison of liquid breeders for ARC-like reactor blankets. *Fusion Engineering and Design*. 2020 Nov; 160:1–10. DOI: 10.1016/j.fusengdes.2020.112013. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0920379620305615> [Accessed on: 2025 Oct 8]
14. Bohm TD and Lindley BA. Initial Neutronics Investigation of a Chlorine Salt–Based Breeder Blanket. *Fusion Science and Technology*. 2023 Nov 17; 79:995–1007. DOI: 10.1080/15361055.2022.2136923. Available from: <https://www.tandfonline.com/doi/full/10.1080/15361055.2022.2136923> [Accessed on: 2025 Oct 8]