

# Technical Considerations and Capabilities of a Near-Term Deployable Traveling Wave Reactor Core

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## INTRODUCTION

Traveling wave reactors (TWRs) are high-burnup nuclear reactors designed to operate indefinitely using fertile material such as natural or depleted uranium (DU), light-water reactor (LWR) waste, or thorium as reload fuel [1]. After an initial partial loading of fissile fuel, the TWR will operate for decades without needing reprocessing or further enrichment, until the lifetime of major structural components is reached. Then, the core can regain criticality without requiring separations of actinides or fission products in another reactor building. Fundamental concepts relevant to near-term development of TWRs are discussed, as well as the traditional physical constraints considered for rapid deployment of a TWR. Finally, the fuel cycle capabilities of a TWR satisfying these constraints are discussed.

## REQUIRED MINIMUM BURNUP

The minimum burnup required for traditionally-designed fast reactor assemblies to allow a propagating wave on fertile material is calculated as upwards of 32% fissions per initial metal atom (FIMA), which roughly corresponds to 300 MWd/kg in U-238 fuel. On DU reload fuel, this burnup level will correspond to structural doses above 550 displacements per atom (DPA). Previous fast reactors have irradiated structural material to 200 DPA, and some of the ferritic-martensitic steels show promise of reaching the required dose.

For advanced assembly designs and less conventional core configurations, a minimum burnup below 20% FIMA and doses below 300 DPA are possible, but these would likely require a development period on the order of a decade.

## PHYSICAL CONSTRAINTS

The TerraPower near-term TWR core design effort focuses on one of many possible TWR configurations. It rigorously accounts for the following physical constraints:

1. *Cladding strain limit* – Fuel Cladding Mechanical Interaction and other forces must not

deform the cladding beyond coolability and integrity limits.

2. *Assembly distortion limit* – Assembly distortions must not cause excessive withdrawal and insertion loads.
3. *Coolability limit* – Fuel centerline temperatures and cladding temperatures must be maintained below design limits to mitigate rapid expansion and/or Fuel Cladding Chemical Interaction.
4. *Major component dose limit* – Irradiation-induced embrittlement of fuel assemblies and major structural components must not substantially degrade handling and transient response.
5. *Excess reactivity limit* – The TWR must remain redundantly controllable at all times.
6. *Thermal striping limit* – Cyclic loading of the upper internal structure caused by rapid turbulent mixing of different temperature coolant must be prevented from causing high-cycle fatigue and potential failure.

These physical constraints and others are tightly coupled to many aspects of the near-term TWR design. Purely neutronic studies, e.g., [2], that do not clearly consider these limits may fall short of adequately assessing a given reactor design.

## CALCULATION TOOLS

For core analysis, TerraPower employs a proprietary database-driven data management system that couples simulation and analysis tools. The neutronics kernel options include MCNPXT (a heavily modified descendent of MCNPX [3]) for very high-fidelity computations and the MC\*\*2-2/DIF3D/REBUS-3[4] suite of codes with new features added for rapid design exploration computations. Both kernels have been developed to account for coupled fuel performance that has been deemed important for TWR analysis, including:

- Axial expansion of fuel
- Sodium bond removal
- Fission gas removal

Mechanical analysis of the core is accomplished using various commercial Finite-Element Analysis (FEA) structural and Computational Fluid Dynamics (CFD) codes. A full 3-D metallic fuel performance FEA code is under development to supplement the 1-D mechanistic fuel model (FEAST [5]) currently in use.

## IGNITION

Bringing a TWR from a beginning of life (BOL) state with fresh fissile material to an equilibrium state running on converted fissile nuclides with the smallest amount of BOL fissile inventory requires sophisticated fuel management design, known as ignition. Guiding the ignition effort are physics studies made possible by the neutron excess concept [6], which mathematically determines how much fissile material is required to sustain a wave. This theoretical work provides a guide for initial design as well as a metric of success for any given transitional shuffling plan.

## FUEL CYCLE PERFORMANCE

The enrichment of the initial 5 MT of fissile fuel loaded in a core of a 500 MWe TWR leaves 1020 MT of DU tails. A LWR with an average burnup of 60 MWd/kg, normalized to 500 MWe, can start up with substantially less fissile material, but requires an incoming natural uranium feed of 250 kg/day. The equilibrium cycle of this TerraPower near-term TWR core (with 22% FIMA average discharge burnup) requires an incoming DU feed of feed of 5 kg/day, requiring no separative work units (SWUs) and producing no tails. Figure 1 shows these mass and SWU flows. Thus, the core can operate for over 500 years on the tails produced in the enrichment of the initial core, whereas the LWR must continually produce

more tails as more uranium is mined and enriched. Of course, no reactor can be designed to last for 500 years, but the fuel assemblies in one retiring TWR can be used in a new plant. It is clear that the TWR drastically improves the sustainability of nuclear as an energy resource.

## REFERENCES

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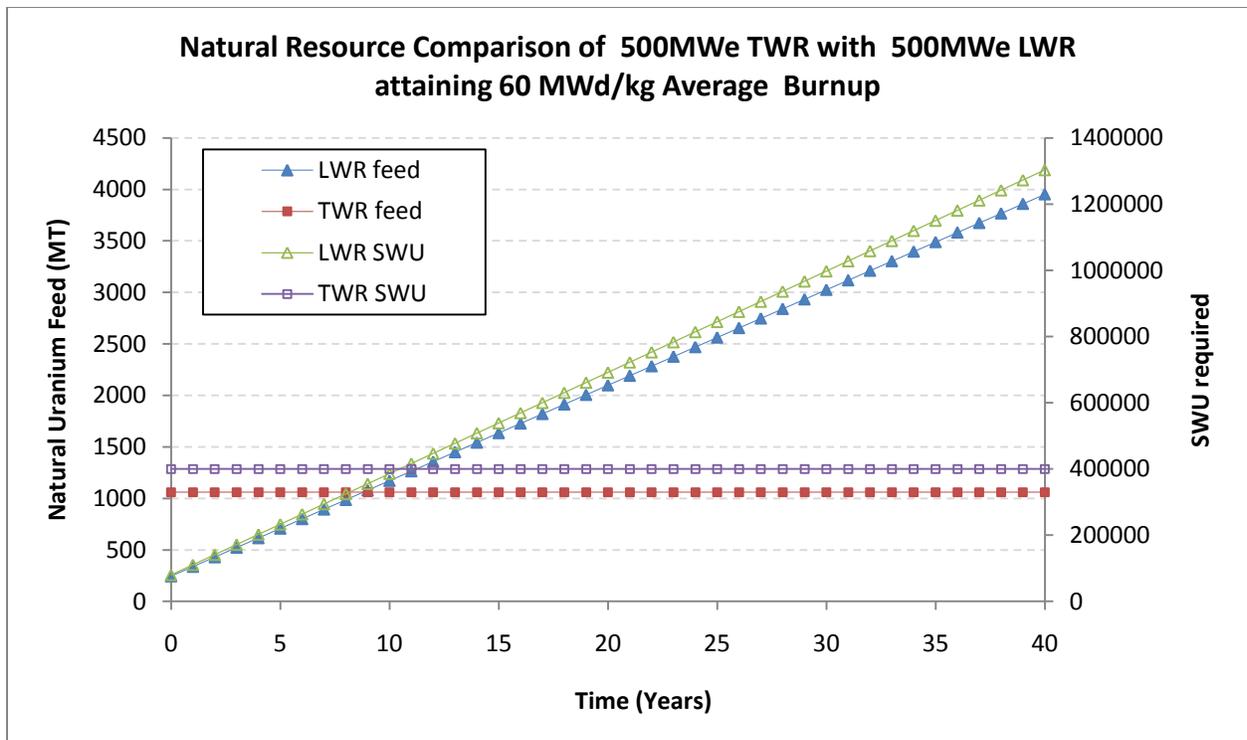


Fig. 1. Required initial and incoming feed uranium and separative work units required for 40 years of operation of a early-deployment 500 MWe TWR compared to an LWR normalized to 500 MWe. The TWR feed curve has no slope because tails from the initial core loading have not been consumed until year 500, at which point the slope becomes imperceptibly positive. The TWR SWU curve is always flat.