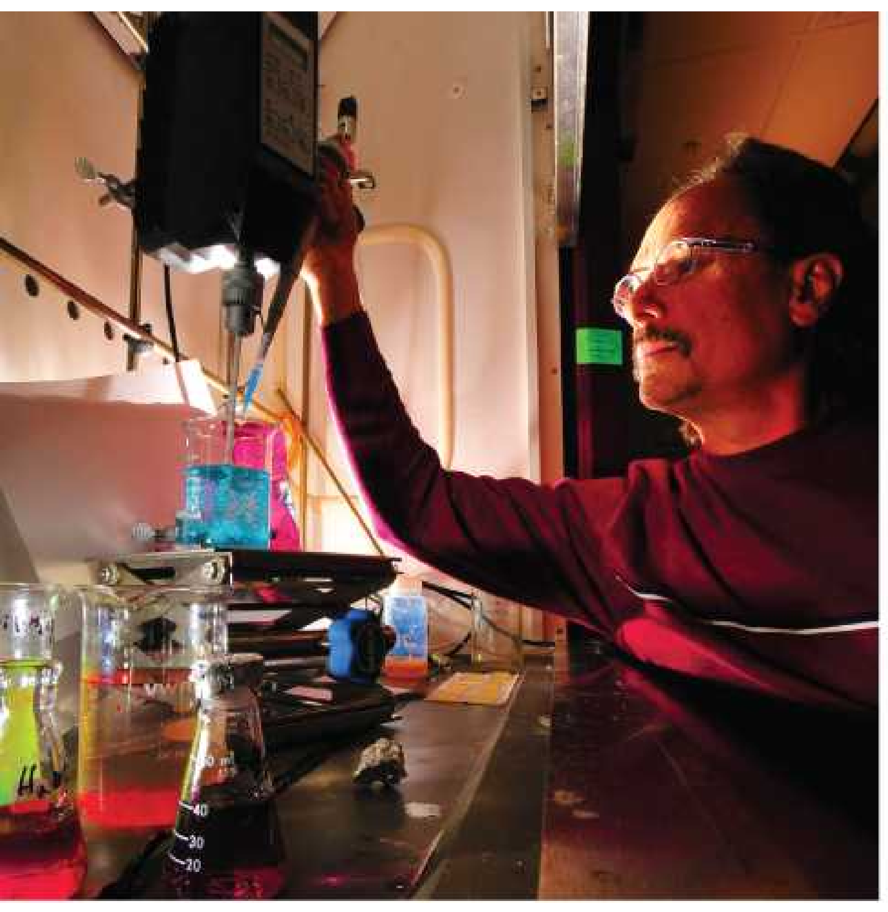
SAND2017-7748C



Reactor Modeling for Proliferation Pathway Studies

Alex Salazar
University of California, Berkeley, PhD Nuclear Engineering, 2018
Kenneth O Reil, Matthew R Sternat, Org. 1384
Sandia National Laboratories/NM, U.S. Department of Energy

ABSTRACT

As part of a proliferation pathway study for standing wave reactors, the nuclide inventory of the TerraPower prototype TWR is analyzed at various points of operation within several regions of interest. The plutonium quality is evaluated in the natural uranium breeder region over time for various compositions of the driver fuel. When employing a low power output, it is found that no significant quantity of fissile Pu can accumulate in the core blanket for the duration of the reactor lifetime. However, the implications of using more fertile depleted uranium in the breeder must still be explored.

INTRODUCTION

Standing wave reactors are attractive options for emerging nuclear energy nations as they are low-cost, capable of breeding their own fissile material, and able to operate over long periods of time. These reactors operate by surrounding enriched driver assemblies with a breeder containing fertile material. Over time, fissile nuclides generated in the breeder are moved inward to replenish the driver and sustain criticality, excluding the need for reprocessing or enrichment. However, the same fissile material that is generated as fuel can also be susceptible to diversion for misuse. While the exact manner in which diversion can occur can be examined in a separate study, a “Safeguards by Design” approach can be implemented to model the time dependence under which significant quantities of fissile material can be generated in such a reactor. This project will simulate the inventory of significant materials in a standing wave reactor and discuss the implications for safeguardability.

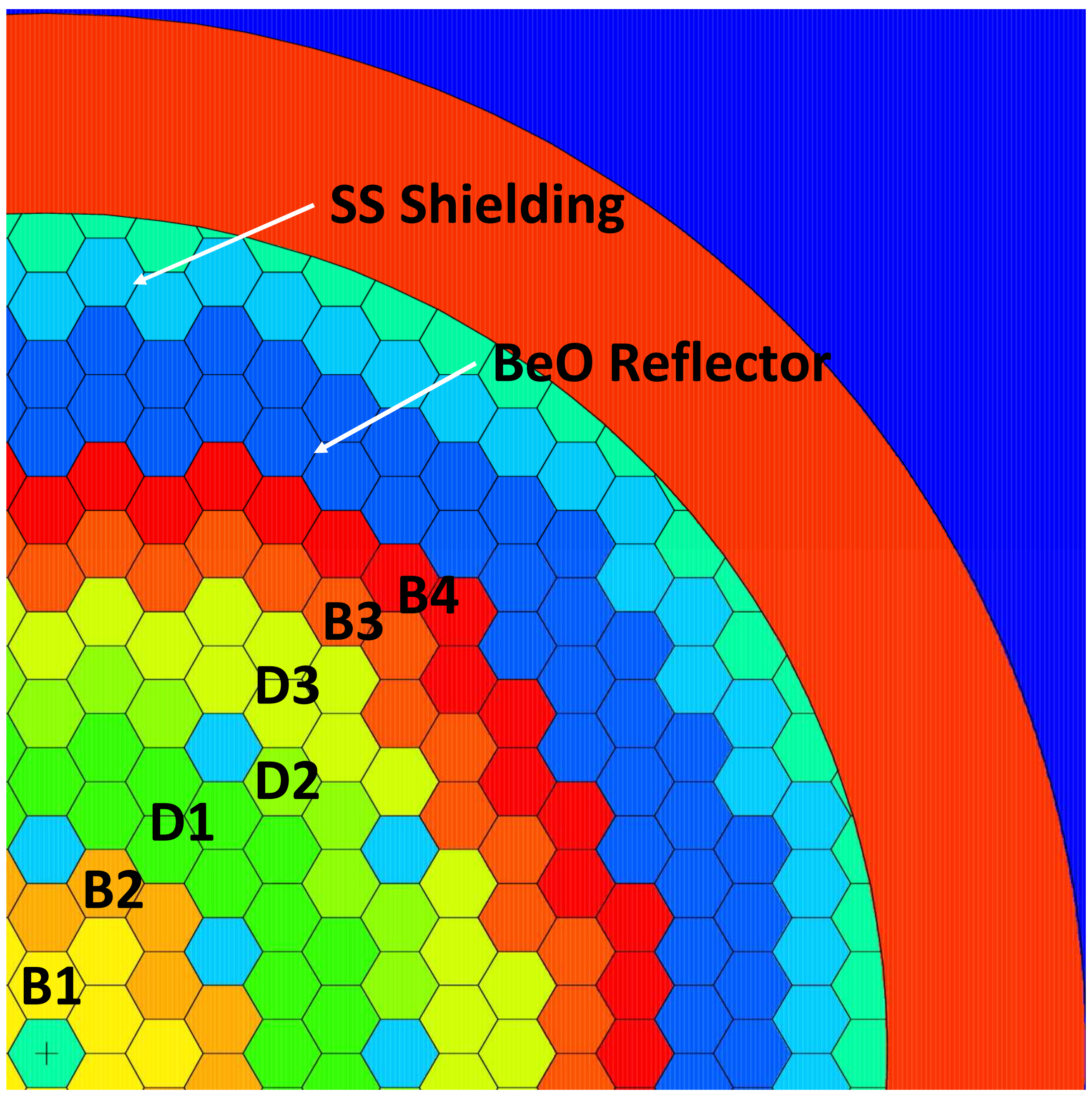


Fig. 1: Diagram of TWR-P core model colored by regions of interest.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-NA0003525.

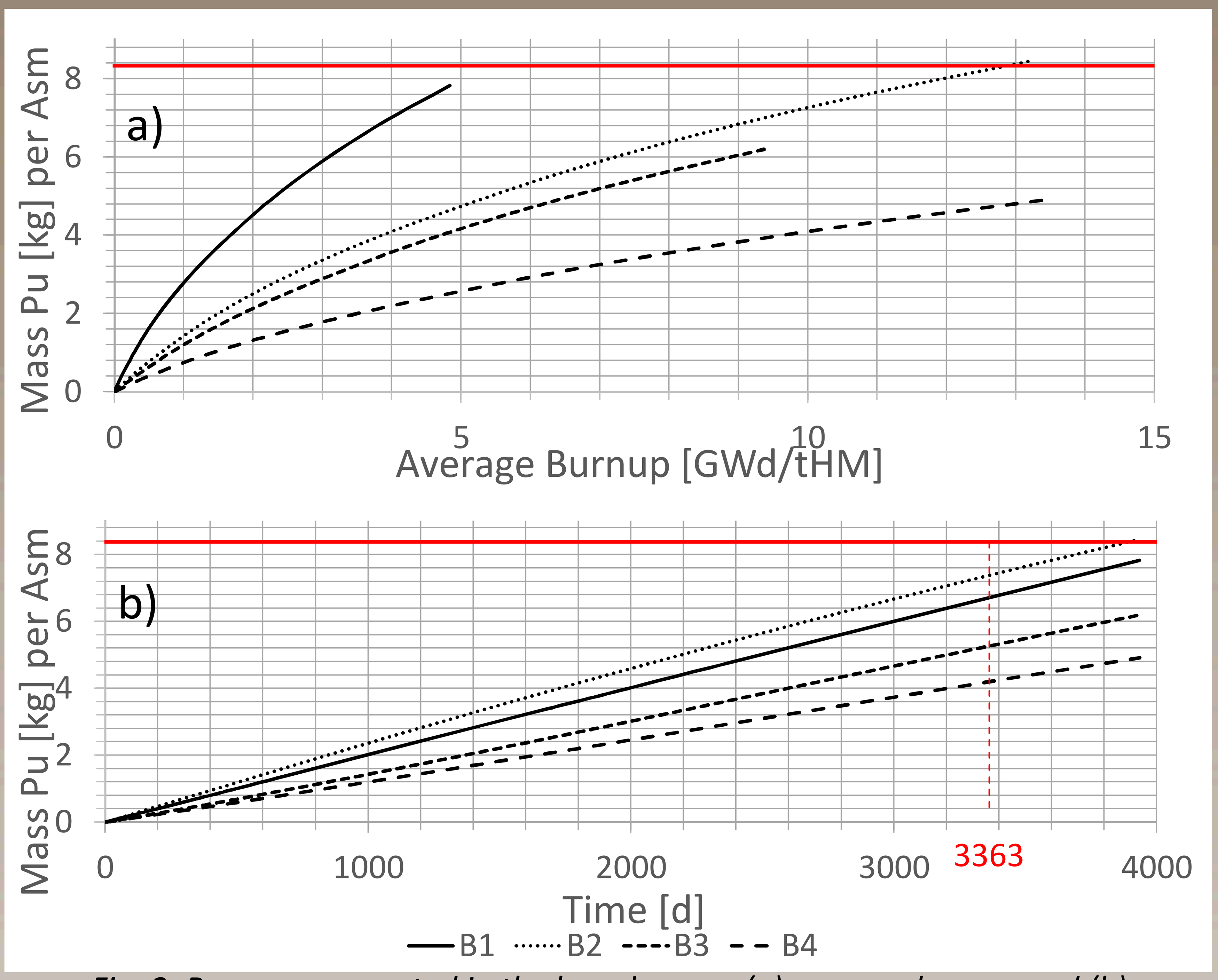


Fig. 2: Pu mass generated in the breeder over (a) average burnup and (b) operating time, with SQ and EOL marked in red.

METHODS

The MCNP6.1.1 code [1] was employed for the full-core neutron transport analysis. The design was guided by the standard assembly parameters for the TerraPower prototype traveling wave reactor (TWR-P),[2] although the control, test, and safety assemblies were not included for conservatism (Fig. 1). The metallic fuel is alloyed with 10 wt% Zr and cooled by liquid sodium. BeO comprises the reflector and stainless steel is used for shielding.

Two sets of calculations were performed based on the enrichments of the driver fuel: one at 15.75 wt% as the maximum suggested by the manufacturer, and 20 wt% to represent the IAEA lower bound on HEU. The blanket material was chosen to be natural uranium (0.711 wt% U-235). Altogether, 27 MTU is loaded into three driver (D) regions and 29 MTU into four breeder (B) regions (Fig. 1).

The CINDER depletion module was utilized to evaluate nuclide inventories at successive burnup steps over the reactor lifetime. Perl scripts were written to organize the burnup data on an assembly basis by the specified driver and breeder regions. Power was kept low at 600 MWt to ensure adequate burnup fidelity over ~10 years.

The IAEA significant quantity (SQ) of 8 kg is used for Pu mass. Plutonium quality is determined based on tiers of Pu-240 content meant to signify reactor grade (>19%), fuel grade (≤7-19%), weapons grade (<7%),[ref. 3] and super weapons grade (<2%) quantities.[4] For uranium enriched below 20 wt%, the 75 kg U-235 SQ is adhered to.

RESULTS

The manufacturer's suggested fuel enrichment was not adequate to sustain criticality for a significant period of time in the simulation. For the HEU driver fuel, criticality is sustained for 9.2 years. Within this period, a maximum of ~7.5 kg Pu/assembly, which is just below the SQ, is generated before reshuffling is required to continue chain reactions (Fig. 2). The Pu-240 content ranges from 3-12 wt%, which implies fuel grade quality (Fig. 3). This content appears to rise steadily as opposed to reaching an asymptotic limit. In Fig. 4, the IAEA SQ for U-235 is not surpassed in any area of the core on an assembly basis.

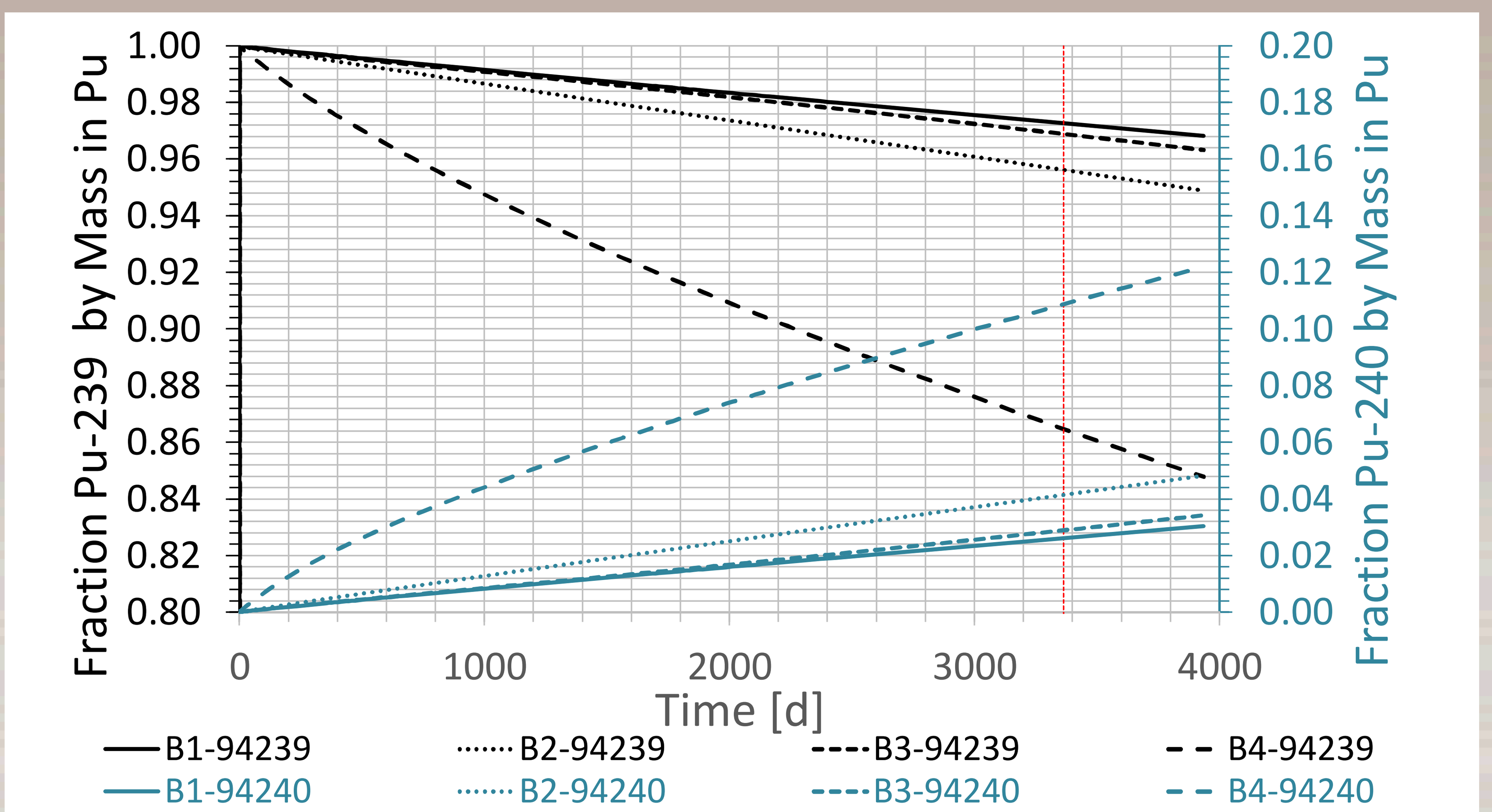


Fig. 3: Mass fractions of Pu-239 (left) and Pu-240 (right) in the breeder regions.

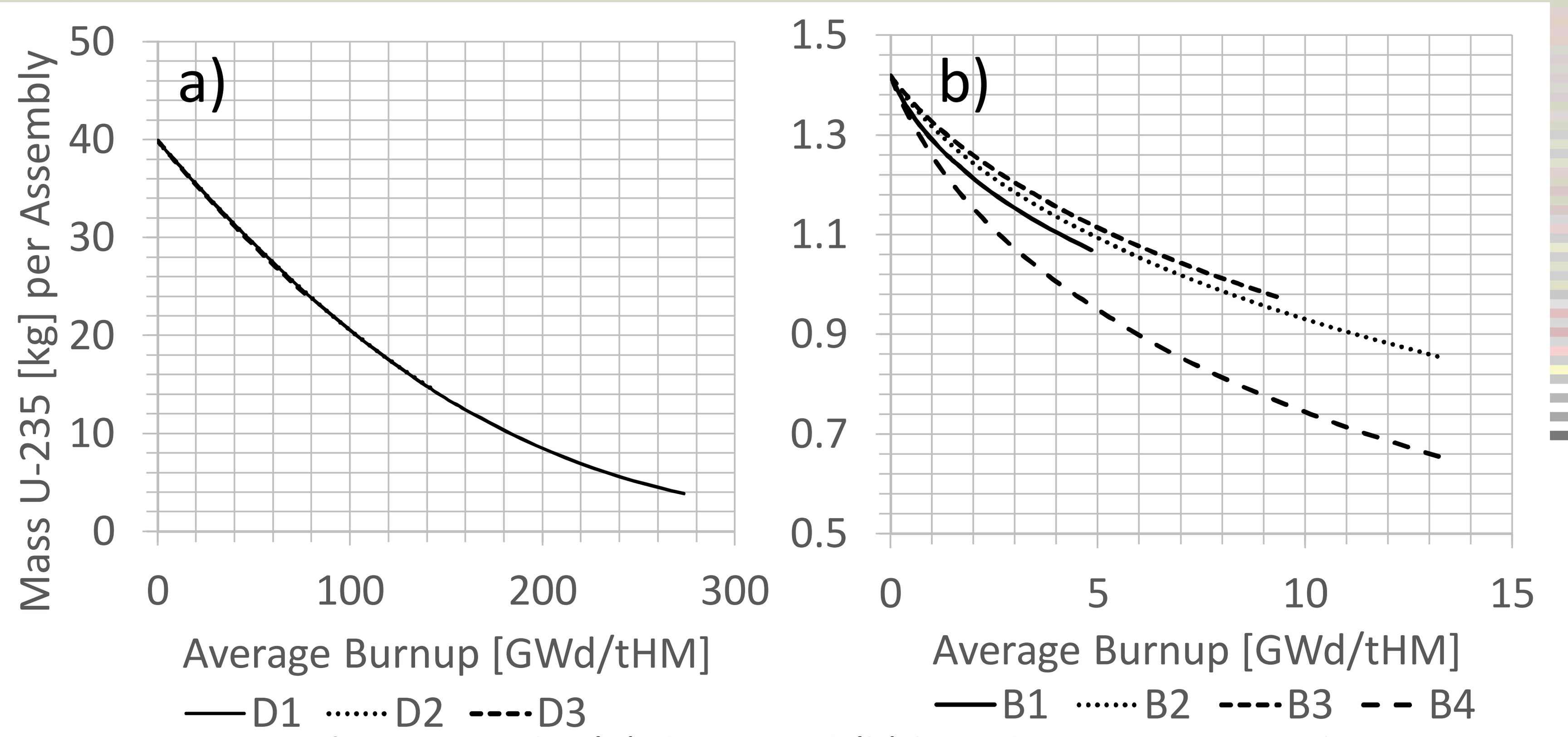


Fig. 4: Mass of U-235 in the (a) driver and (b) breeder over average burnup.

DISCUSSION

Results for the TWR-P simulation indicate that significant Pu production may be plausible given more favorable reactor operating conditions or configurations. Further studies are needed using depleted uranium or Th as the fertile breeder materials to assess their effects on inventory, along with different power levels in the burnup calculations. Studies are continuing on modeling the various stages and layouts of the standing wave design.

REFERENCES

[1] T. Goorley, "MCNP6.1.1-Beta Release Notes," LA-UR-14-24680 (2014).
[2] H. Pavel et al, "TerraPower, LLC traveling wave reactor development program overview," Nuc Eng & Tec 45.6, 731-744 (2013).
[3] United States Department of Energy, "Plutonium: the First 50 Years," DOE/DP-0137 (1996).
[4] J. C. Mark, F. von Hippel, and E. Lyman, "Explosive properties of reactor-grade plutonium," Sci & Global Sec 17.2-3, 170-185 (2009).

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.