Current Status and Future Plans for US Tritium Production

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Tritium Production Enterprise: Background

- Tritium is required for the US nuclear weapons stockpile
- Tritium has a 12.3 year half-life and must be replenished
- 1988: DOE ceased production of tritium at SRS
- 1988-1992: The US considered the use of dedicated reactors for tritium production
  - Heavy water reactors (HWRs)
  - High temperature gas-cooled reactors (HTGRs)
  - Light water reactors (LWRs)
- 1995-1998: The US considered dual-use facilities
  - Commercial LWRs
  - Accelerators
- 1995: PNNL selected by DOE to be Design Authority for Commercial Light Water Reactor irradiation demonstration

L Reactor at SRS

Tritium Production Enterprise: Background

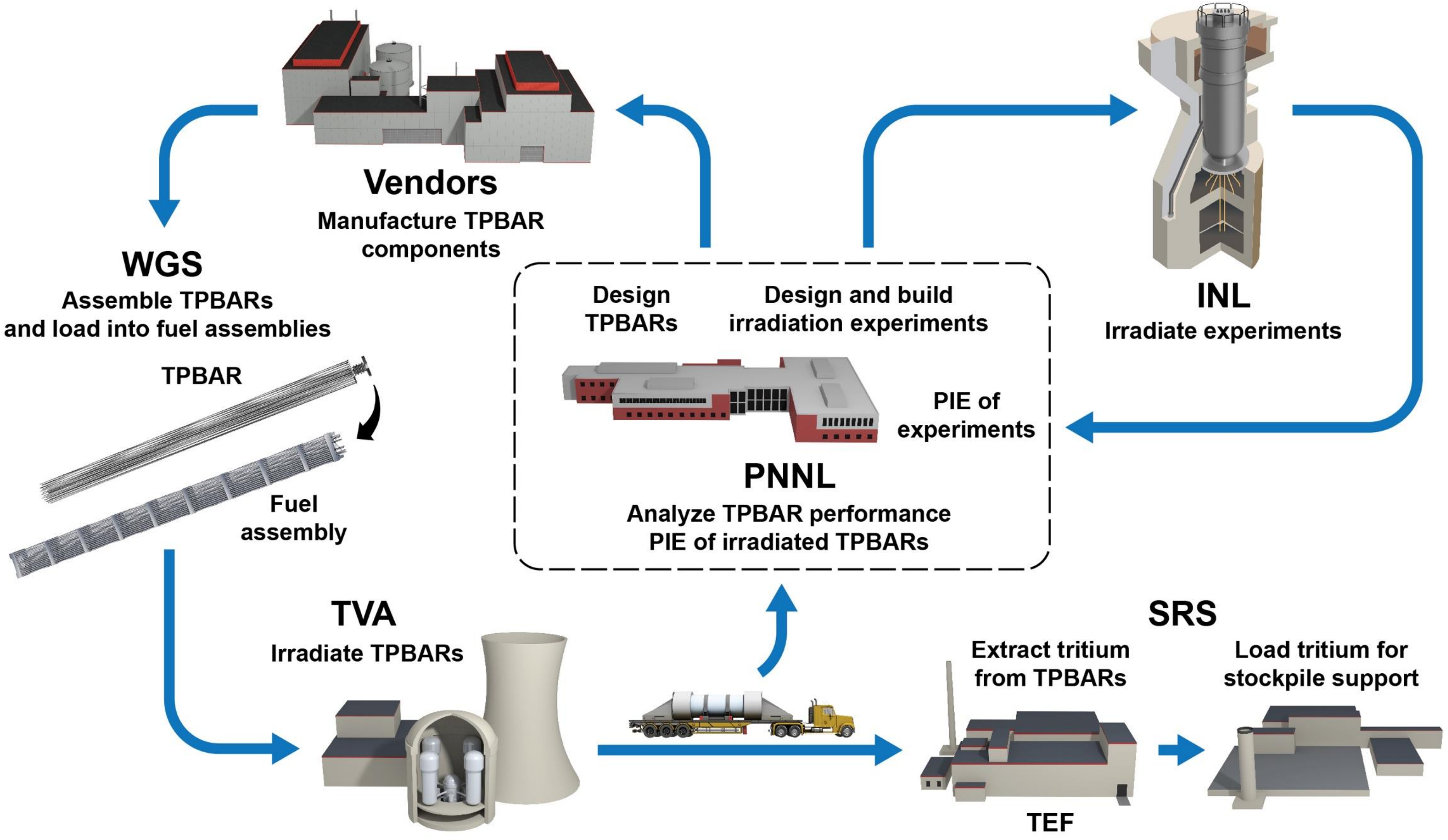
- 1995 – 1997: Lead Test Assembly (32 Tritium-Producing Burnable Absorber Rods, TPBARs) designed and built at PNNL for irradiation in TVA Watts Bar Nuclear Unit 1
- 1999: Post-irradiation examination of LTA
- 2000: The Commercial Light Water Reactor tritium program was selected by DOE over accelerators for production
- 2001 – 2003: Design and manufacturing scale-up for production TPBARs
- 2003 – present: Irradiation of 1st through 15th production cores at WBN1
- 2019: License amendment for 1792 TPBARs in WBN2 approved by NRC
- 2020 – present: Irradiation of 1st through 4th production cores at WBN2
- 2024: WBN license amendment to increase TPBAR limit to 2496 per unit approved by NRC

Watts Bar Nuclear Plant
Spring City, TN

TPBAR Irradiation History

WBN1 Cycle	WBN2 Cycle	TPBAR Quantity	TPBAR Design	Cycle Start	Cycle End
2		32	LTA	Fall 1997	Spring 1999
6		240	Production	Fall 2003	Spring 2005
7		240	Production	Spring 2005	Fall 2006
8		240	Production	Fall 2006	Spring 2008
9		368	Mark 9.2	Spring 2008	Fall 2009
10		240	Mark 9.2	Fall 2009	Spring 2011
11		544	Mark 9.2	Spring 2011	Fall 2012
12		544	Mark 9.2	Fall 2012	Spring 2014
13		704	Mark 9.2	Spring 2014	Fall 2015
14		704	Mark 9.2	Fall 2015	Spring 2017
15		1104	Mark 9.2	Spring 2017	Fall 2018
16		1584	Mark 9.2	Fall 2018	Spring 2020
17		1792	Mark 9.2	Spring 2020	Fall 2021
	4	544	Mark 9.2	Fall 2020	Spring 2022
18		1792	Mark 9.2	Fall 2021	Spring 2023
	5	1104	Mark 9.2	Spring 2022	Fall 2023
19		1792	Mark 9.2	Spring 2023	Fall 2024
	6	1680	Mark 9.2	Fall 2023	Spring 2025
20		1792	Mark 9.2	Fall 2024	Spring 2026
	7	1728	Mark 9.2	Spring 2025	Fall 2026
21		1824	Mark 9.2	Spring 2026	Fall 2027
	8	1920	Mark 9.2	Fall 2026	Spring 2028

NNSA Tritium Modernization Program



INL = Idaho National Laboratory
PIE = post-irradiation examination
PNNL = Pacific Northwest National Laboratory

SRS = Savannah River Site
TEF = Tritium Extraction Facility
TPBAR = tritium-producing burnable absorber rod

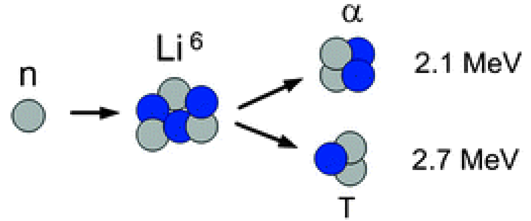
TVA = Tennessee Valley Authority
WGS = Westinghouse Government Services

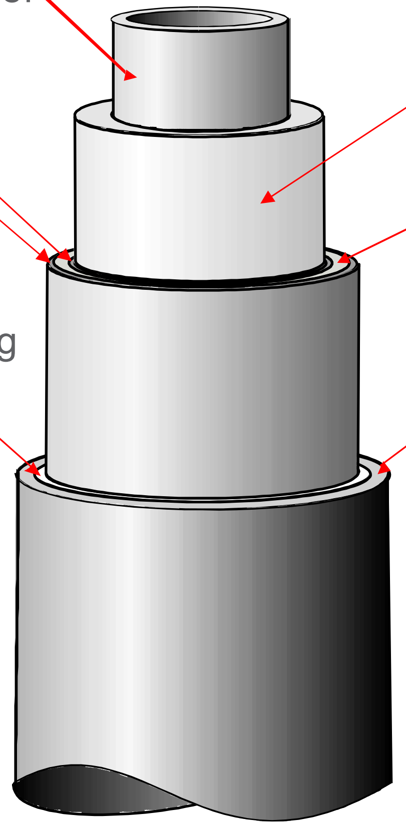
Watts Bar Nuclear

- Westinghouse PWR Design
  - 3459 MWt, ~1100 MWe
  - Four-loop, Ice condenser containment
  - 193 Westinghouse 17x17 fuel assemblies
- Two units at the plant
  - Unit 1 used for tritium production since Cycle 6
    - Construction began in 1973
    - Operation began in 1996
    - Currently in Cycle 20
    - 40-year license expires in 2035
  - Unit 2 used for tritium production since Cycle 4
    - Construction began in 1973
    - Construction halted in 1988
    - Construction resumed in 2007
    - Operation began in August 2016
    - Currently in Cycle 7
    - 40-year license expires in 2055
- Operate on an ~18 month fuel cycle
  - Outages offset by six months between the two units

TPBAR Design Fundamentals

- TPBARs replace burnable absorber rods normally used in Westinghouse PWRs (WABAs)
  - WABA reaction:
    - $^{10}B + {}^{1}n_{th} \rightarrow {}^{4}He + {}^{7}Li$
  - TPBAR reaction:
    - $^{6}Li + {}^{1}n_{th} \rightarrow {}^{3}H + {}^{4}He$
  - TPBARs introduce more negative reactivity than WABAs
- TPBARs are safety-related basic components licensed per 10 CFR 50 requirements
  - All TPBAR-related design, procurement and manufacturing conforms to 10 CFR 50, Appendix B quality assurance requirements
- Each TPBAR produces, on average, 0.95 g of tritium per cycle
- Current production planning basis is 1920 g tritium per unit per cycle

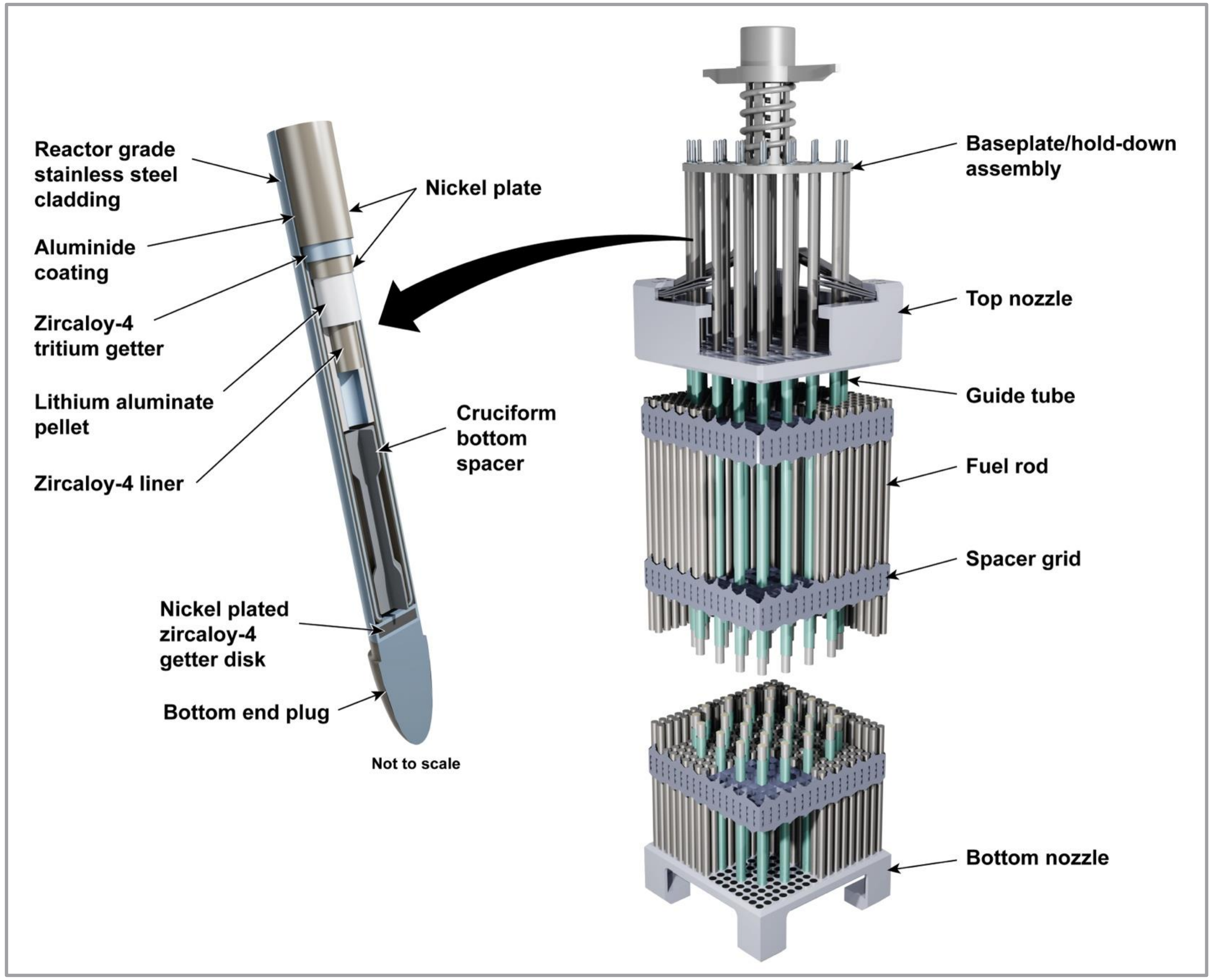




Not to scale

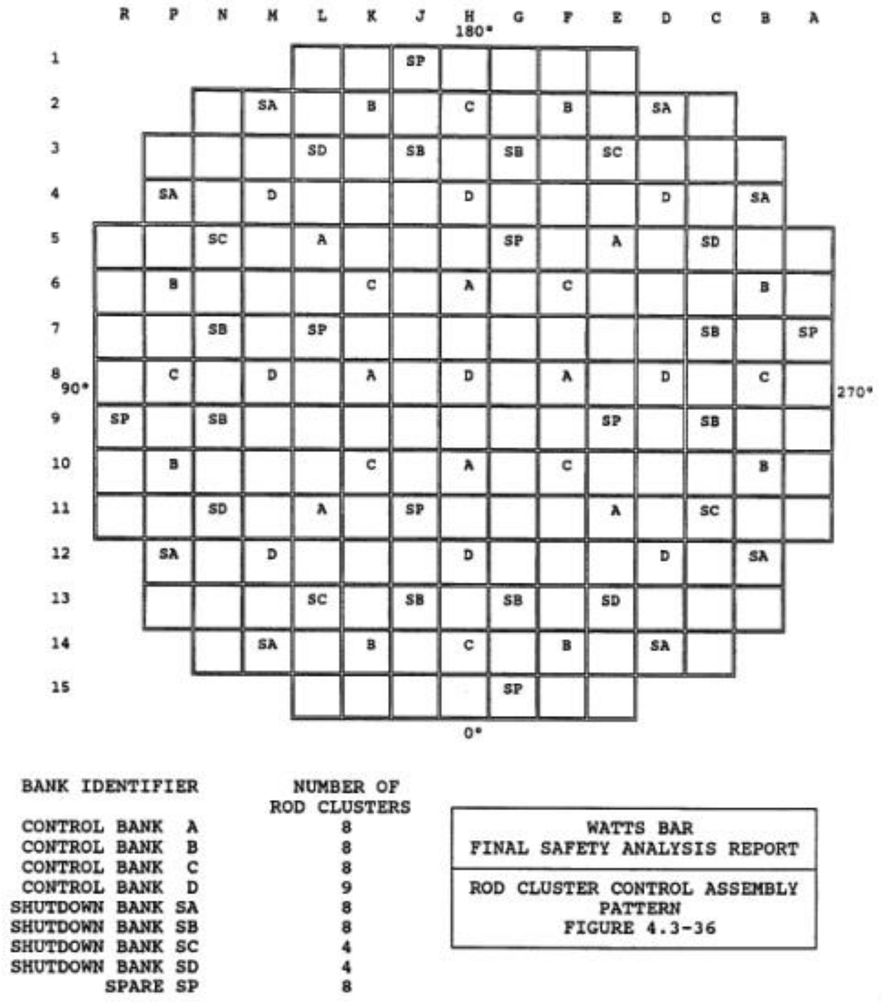
TPBAR Design Fundamentals

- Up to 24 TPBARs are attached to a hold-down assembly (multiples of four in symmetric locations) and inserted into a fresh fuel assembly
  - Hold-down assembly is loaded into fresh fuel assembly at the fuel fabrication plant and shipped to the reactor in the fuel assemblies
  - TPBARs reside in the fuel assembly guide tubes
  - Empty guide tubes have a thimble plug to regulate coolant flow
- After irradiation for one cycle, the hold-down assembly is removed from the fuel assembly, the TPBARs are removed from the hold-down assembly, and the TPBARs are shipped in a spent fuel cask to the Savannah River Site for tritium extraction



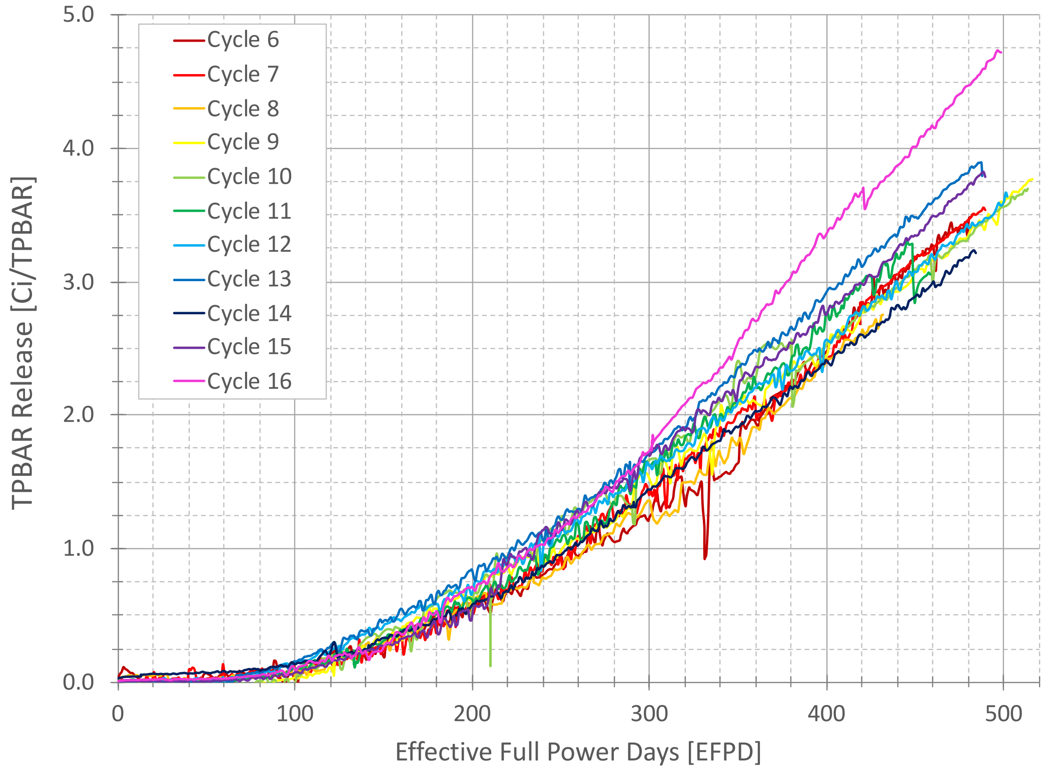
TPBAR and Core Design Considerations

- Tritium production is optimized while maintaining the reactor's energy goals for the cycle
  - Fuel enrichment is higher than a core design without TPBARs
  - More fresh fuel assemblies are required each cycle than a core design without TPBARs
  - NNSA covers the cost of the additional ^{235}U and fresh fuel assemblies
- Placement of TPBARs is constrained by several factors
  - TPBARs are only inserted in fresh fuel assemblies
  - TPBARs cannot be inserted in fuel assemblies with control rods or secondary sources
  - Core design must be symmetric by quadrant
  - Radial power misprediction limits
  - Axial power tilt limits
- Other design considerations
  - WBN fuel must be US-flagged (unobligated)
  - Fuel enrichment is currently limited to 4.95% ^{235}U
  - TPBAR and core design must accommodate a bounding cycle length of 550 EFPD at 3459 MW_t
  - Deleterious effects of fast neutron flux on pressure vessel lifetime must be avoided
  - Core design must meet all steady-state and design-basis accident criteria
  - Individual TPBAR maximum tritium production limited to 1.2 g, including all uncertainty



Operational Impacts

- The tritium concentration in the WBN primary coolant is measured multiple times per week
  - PNNL uses these data, in conjunction with water movement data, to attribute tritium permeation to TPBARs (i.e., measured tritium minus non-TPBAR sources) during and after each cycle
- NNSA operational investments at WBN
  - Construction of additional dilution water capacity to maintain primary coolant tritium concentration within operational limits
  - Construction of a 500,000 gallon (1.9 x 10^6 liter) tank to help manage tritiated water
- The negative reactivity provided by TPBARs results in an atypical soluble boron injection profile over the course of the cycle compared to other PWRs
- The Watts Bar Nuclear plant has one spent fuel pool serving both units, so TPBAR consolidation and shipping operations must be carefully coordinated with other plant activities
  - Motivation for design, construction and licensing of a higher-capacity cask to minimize the number of required shipments



Planning Scenarios for Future Tritium Production

- Tritium Incremental Limit Extension (TILE)
  - TPBAR design analyses were refined to reduce excessive conservatism, resulting in potential to increase production limit from 1.2 to 1.6 g per TPBAR
  - No change to the TPBAR design was required
  - TVA is currently performing additional site-specific analyses to support implementation
  - Following these analyses, TVA will determine whether a license amendment is needed for implementation
- Performing scoping TPBAR and core design analyses along with advanced materials development to evaluate tritium production feasibility while following emerging nuclear industry trends to reduce costs and improve uranium utilization
  - 24-month cycles
  - LEU+ fuel (>5% enriched in U-235)
- Also studying feasibility of 12-month cycles as a contingency if sprint production is required

Summary

- Tritium is produced for US defense needs by irradiating Tritium-Producing Burnable Absorber Rods (TPBARs) in the Watts Bar Nuclear commercial power plant
- Over 16,000 TPBARs have been irradiated safely at WBN since 2003
- PNNL is the Design Authority for TPBARs and leads R&D efforts on TPBAR materials manufacturing and irradiation performance
- WGS is responsible for procuring TPBAR components, assembling TPBARs and loading them into fresh fuel for the two WBN reactors
- TPBARs are irradiated for one cycle in each of the two reactors at WBN before being consolidated from once-burned fuel assemblies by TVA and shipped to SRS for extraction
- Planning scenarios, including TPBAR and scoping core designs, are being evaluated to position NNSA to respond to possible reactor operations changes such as 12-month cycles, 24-month cycles, LEU+ fuel, etc.
- Following the recent approval of a license amendment request to increase TPBAR quantities to 2496, a move to TPBAR quantities above the previous limit of 1792 is under way, ultimately leading to steady-state production at 1920 g/unit/cycle for the foreseeable future
  - At a TPBAR production limit of 1.2 g, and average production of about 0.95 g/TPBAR, 1920 g/unit/cycle equates to ~2024 TPBARs
  - If the TPBAR production limit is increased to 1.6 g, TPBAR quantities could be reduced for the same total tritium production, leading to a savings in TPBAR and fuel costs