

4A Typical Control Rod Patterns and Associated Power Distribution for Lungmen NPS

4A.1 Introduction

This appendix contains a simulation of an equilibrium cycle. The control rod patterns used are just one example of a set of control rod patterns which could be used to provide the radial and axial power shaping needed to meet the Technical Specifications.

The basic control rod strategy for this case is provided in Table 4A-1.

4A.2 Power Distribution Strategy

A basic operating principle (Haling) used to minimize power peaking throughout an operating cycle has been developed and is applied to boiling water reactors (Reference 4A-1). The main concept is that “for any given set of end-of-cycle conditions, the power peaking factor is maintained at a minimum value when the power shape does not change during the operating cycle.”

4A.3 Results of Core Simulation Studies

Table 4A-2 itemizes the exposure steps and their related figure numbers. The detailed data presented demonstrates that this design can be operated throughout this cycle with adequate margins to allow for operating flexibility. Significant margin exists relative to the MAPLHGR limit (Section 6.3). The variation of the minimum critical power ratio (MCPR) with cycle exposure is shown in Figure 4A-14. Given that the Operating Limit MPCR (OLMCPR) is 1.31 (see Table 15.0-1), the margin to the OLMCPR variance with cycle exposure is shown in Figure 4A-14.

4A.4 References

- 4A-1 J. A. Woolley, *Three-Dimensional BWR Core Simulator*, NEDO-20953A, January 1977.

Table 4A-1 Basic Control Rod Strategy

The basic control rod strategy for this case consists of a single control rod pattern using only deeply inserted rods to compensate for excess reactivity located adjacent to low reactivity fuel. Axially zoned fuel flattens the core axial power distribution, eliminating the need for shallow control rods. Insertion of the deep blades next to low reactivity fuel, combined with a slowly varying hot excess reactivity, minimizes control rod motion.

The core is operated at 85% of rated core flow from the beginning of the cycle until the core is critical with all control rods withdrawn. Then the core flow is gradually increased to 111% of rated core flow, maintaining criticality while extending the cycle burnup.

Table 4A-2 Incremental Exposure Steps and Related Figure Numbers

Incremental Exposure (GWd/Mt)	Simulation	Figure Numbers
10.2	All-Rods-Out Haling 85% Flow	4A-1a through 4A-1e
10.5	All-Rods-Out Haling 100% Flow	4A-2a through 4A-2e
10.7	All-Rods-Out Haling 111% Flow	4A-3a through 4A-3e
0.2	Stepwise Rod Pattern	4A-4a through 4A-4e
1.1	Stepwise Rod Pattern	4A-5a through 4A-5e
2.2	Stepwise Rod Pattern and Control Rod Sequence Exchange	4A-6a through 4A-6h
3.3	Stepwise Rod Pattern	4A-7a through 4A-7e
4.4	Stepwise Rod Pattern and Control Rod Sequence Exchange	4A-8a through 4A-8h
5.5	Stepwise Rod Pattern	4A-9a through 4A-9e
6.6	Stepwise Rod Pattern and Control Rod Sequence Exchange	4A-10a through 4A-10h
7.7	Stepwise Rod Pattern	4A-11a through 4A-11e
8.8	Stepwise Rod Pattern and Control Rod Sequence Exchange	4A-12a through 4A-12h
9.9	Stepwise Rod Pattern	4A-13a through 4A-13e

Figure 4A-1a Summary of Haling Condition — 85% Core Flow

(Proprietary information provided in a separate proprietary volume.)

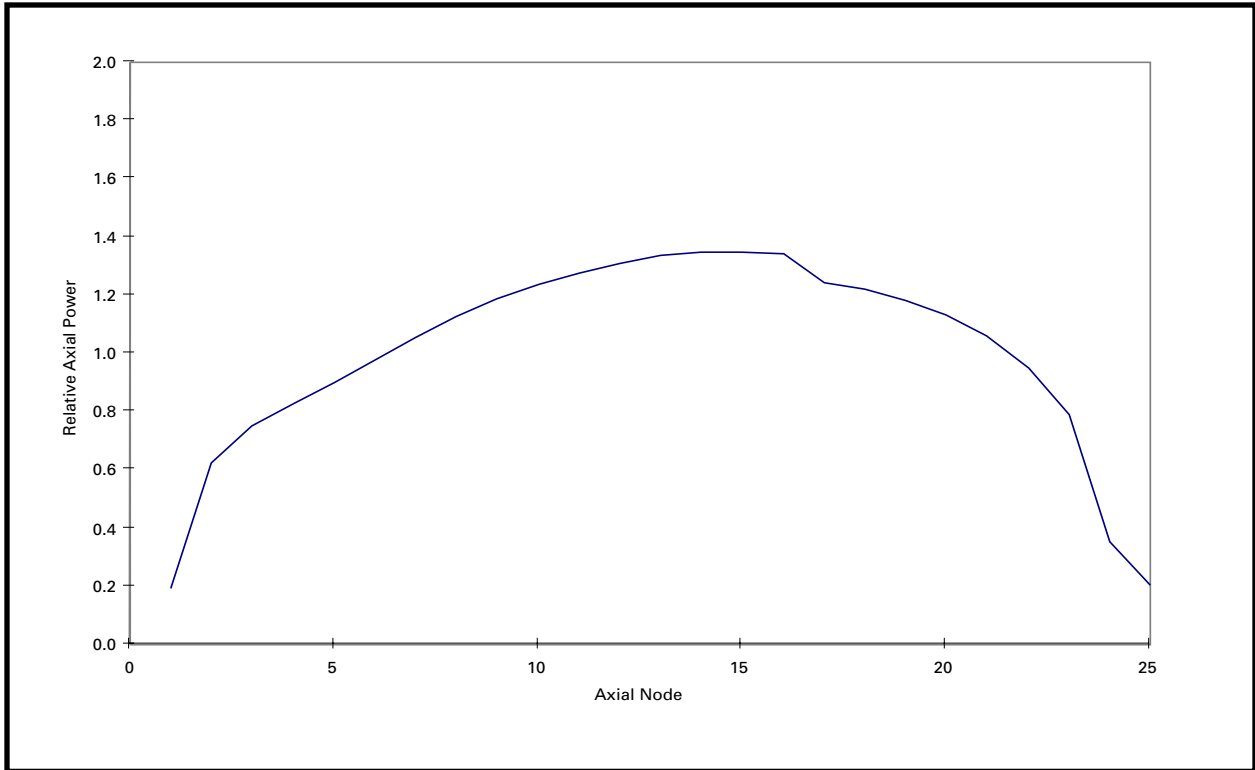


Figure 4A-1b Relative Axial Power at 10.2 GWd/MT Cycle Exposure (Haling at 85% Core Flow)

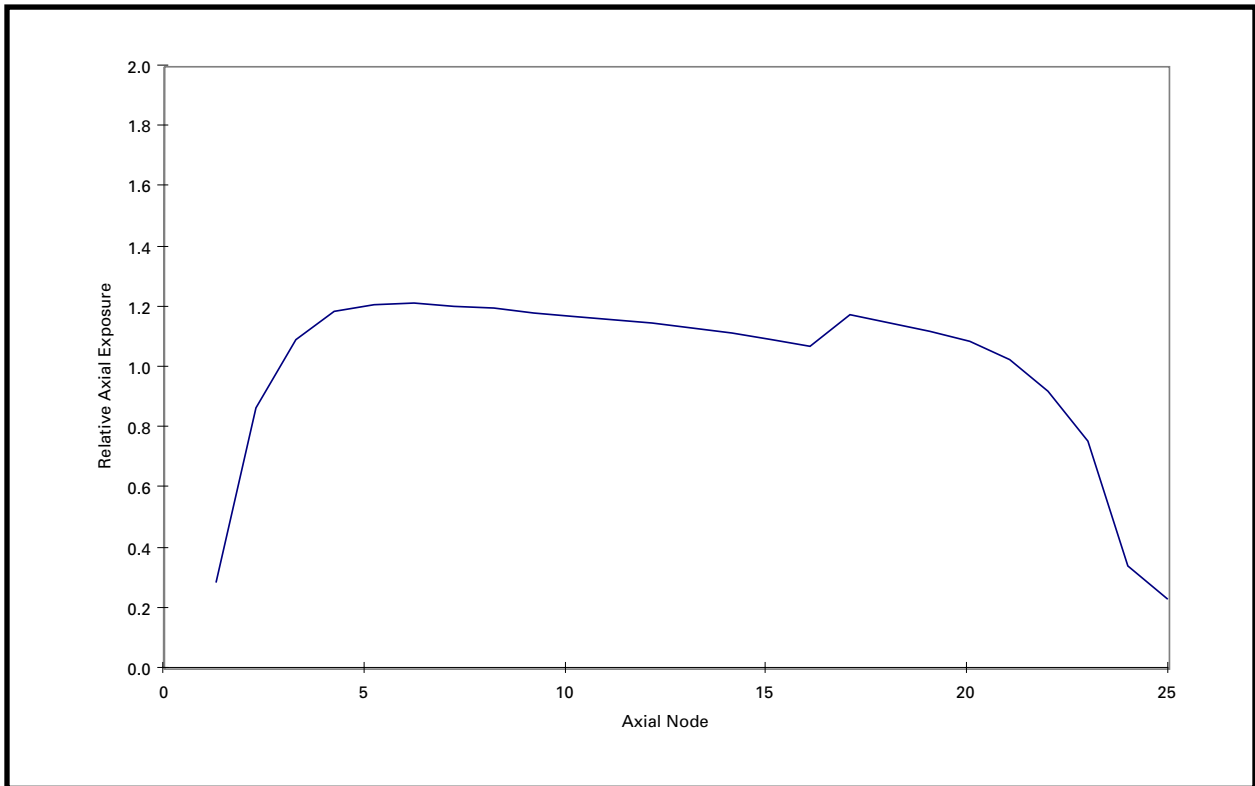


Figure 4A-1c Relative Axial Exposure at 10.2 GWd/MT Cycle Exposure (Haling at 85% Core Flow)

**Figure 4A-1d Integrated Power per Bundle at 10.2 GWd/MT Cycle Exposure
(Haling at 85% Core Flow)**

(Proprietary information provided in a separate proprietary volume.)

**Figure 4A-1e Average Bundle Exposure at 10.2 GWd/MT Cycle Exposure (Haling
at 85% Core Flow)**

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-2a Summary of Haling Condition — 100% Rated Core Flow

(Proprietary information provided in a separate proprietary volume.)

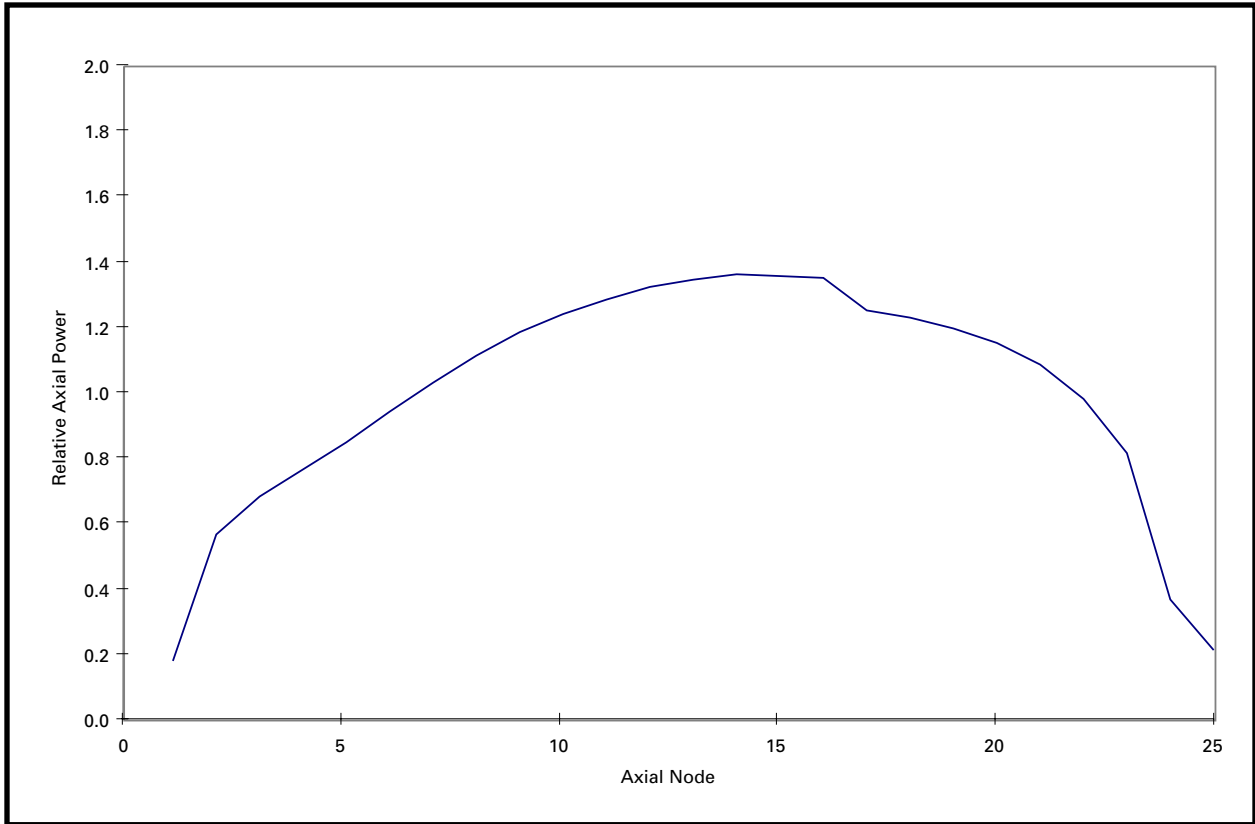


Figure 4A-2b Relative Axial Power at 10.5 GWd/MT Cycle Exposure (Haling at 100% Core Flow)

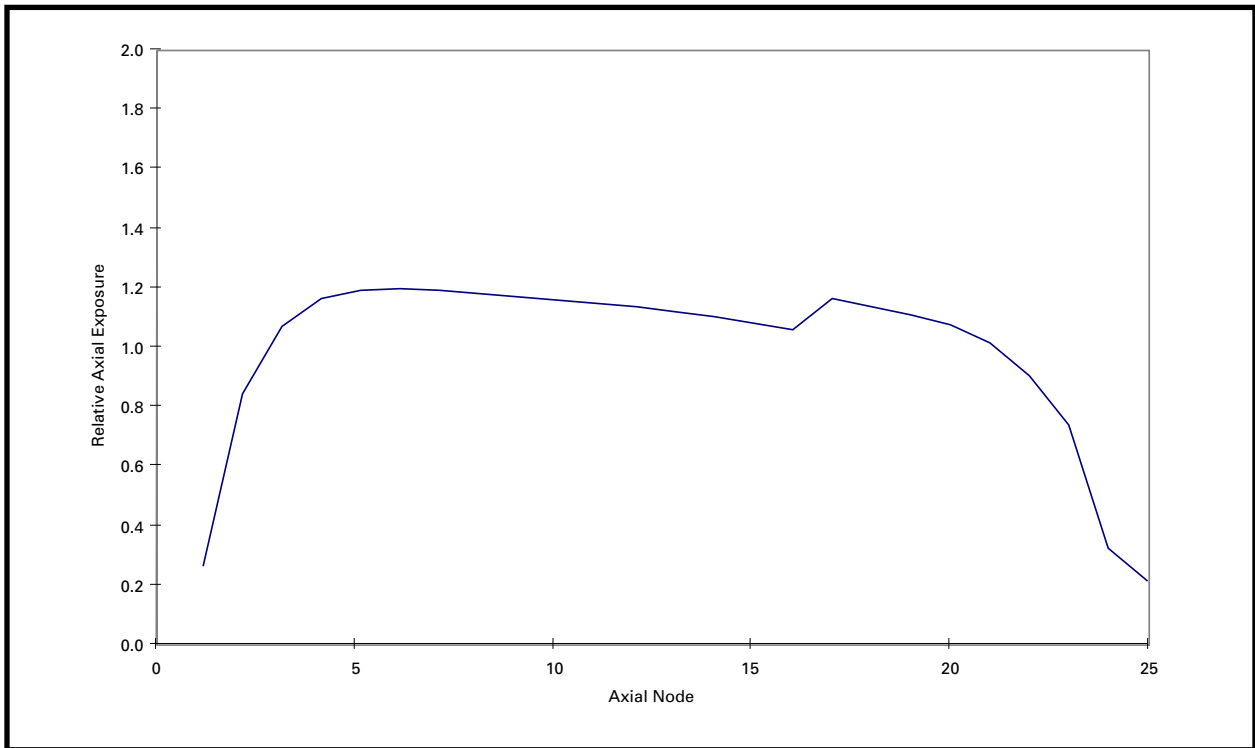


Figure 4A-2c Relative Axial Exposure at 10.5 GWd/MT Cycle Exposure (Haling at 100% Core Flow)

Figure 4A-2d Integrated Power Bundle at 10.5 GWd/MT Cycle Exposure (Haling at 100% Core Flow)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-2e Average Bundle Exposure at 10.5 GWd/MT Cycle Exposure (Haling at 100% Core Flow)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-3a Summary of Haling Condition — 111% Rated Core Flow

(Proprietary information provided in a separate proprietary volume.)

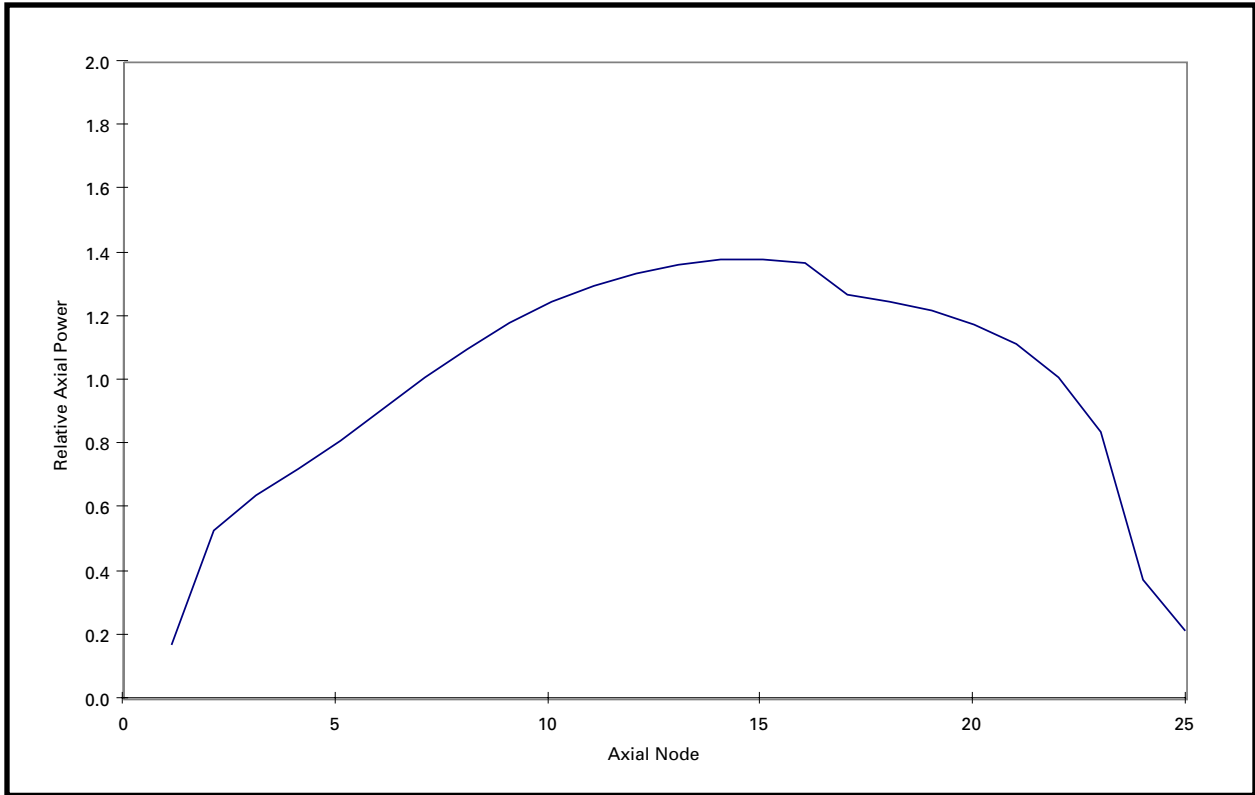


Figure 4A-3b Relative Axial Power at 10.7 GWd/MT Cycle Exposure (Haling at 111% Core Flow)

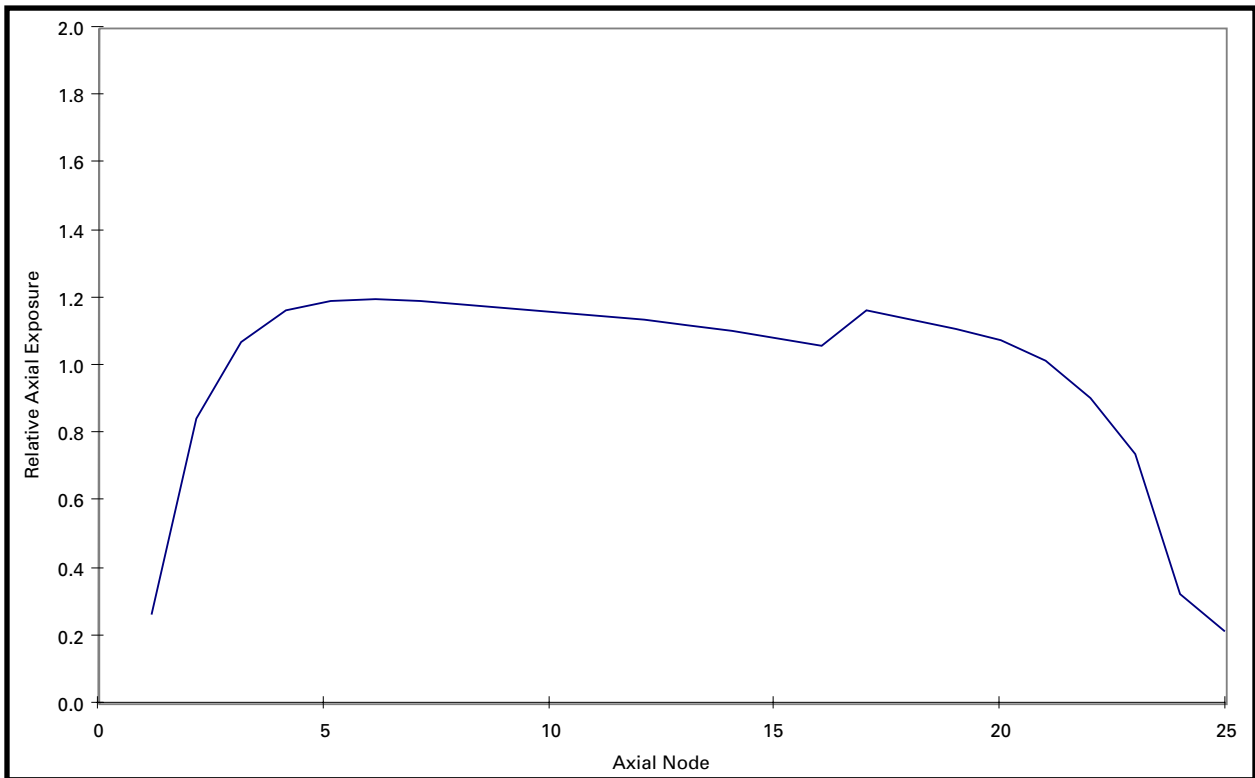


Figure 4A-3c Relative Axial Exposure at 10.7 GWd/MT Cycle Exposure (Haling at 111% Core Flow)

**Figure 4A-3d Integrated Power per Bundle at 10.7 GWd/MT Cycle Exposure
(Haling at 111% Core Flow)**

(Proprietary information provided in a separate proprietary volume.)

**Figure 4A-3e Average Bundle Exposure at 10.7 GWd/MT Cycle Exposure (Haling
at 111% Core Flow)**

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-4a Summary of 0.2 GWd/MT Condition

(Proprietary information provided in a separate proprietary volume.)

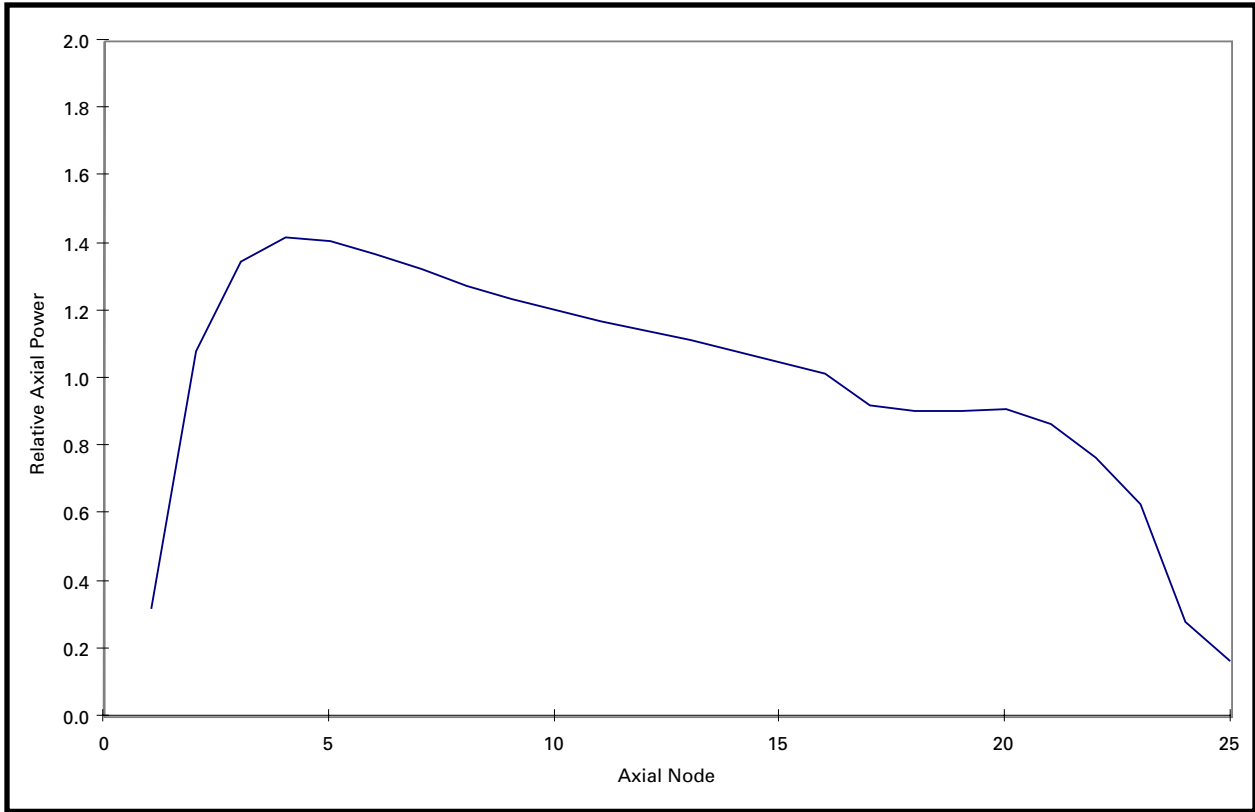


Figure 4A-4b Relative Axial Power at 0.2 GWd/MT Cycle Exposure

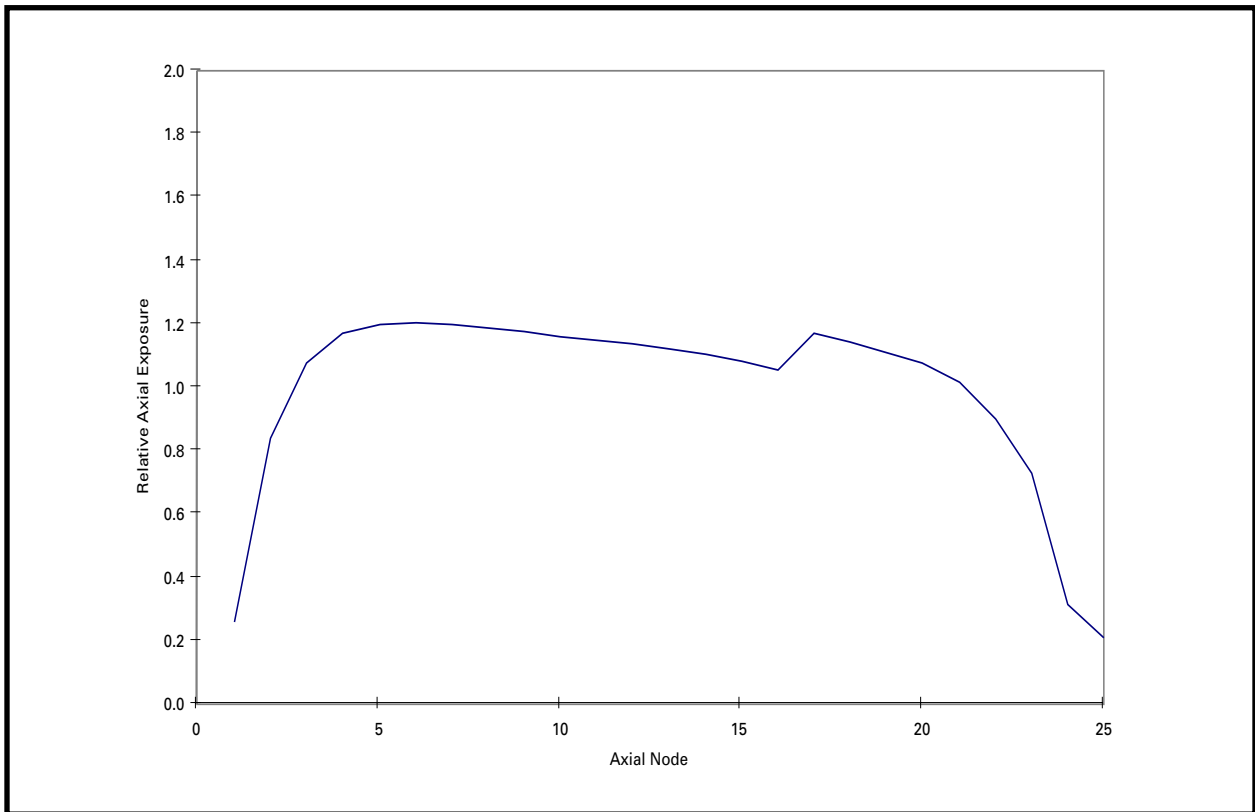


Figure 4A-4c Relative Axial Exposure at 0.2 GWd/MT Cycle Exposure

Figure 4A-4d Integrated Power per Bundle at 0.2 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-4e Average Bundle Exposure at 0.2 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-5a Summary of 1.1 GWd/MT Condition

(Proprietary information provided in a separate proprietary volume.)

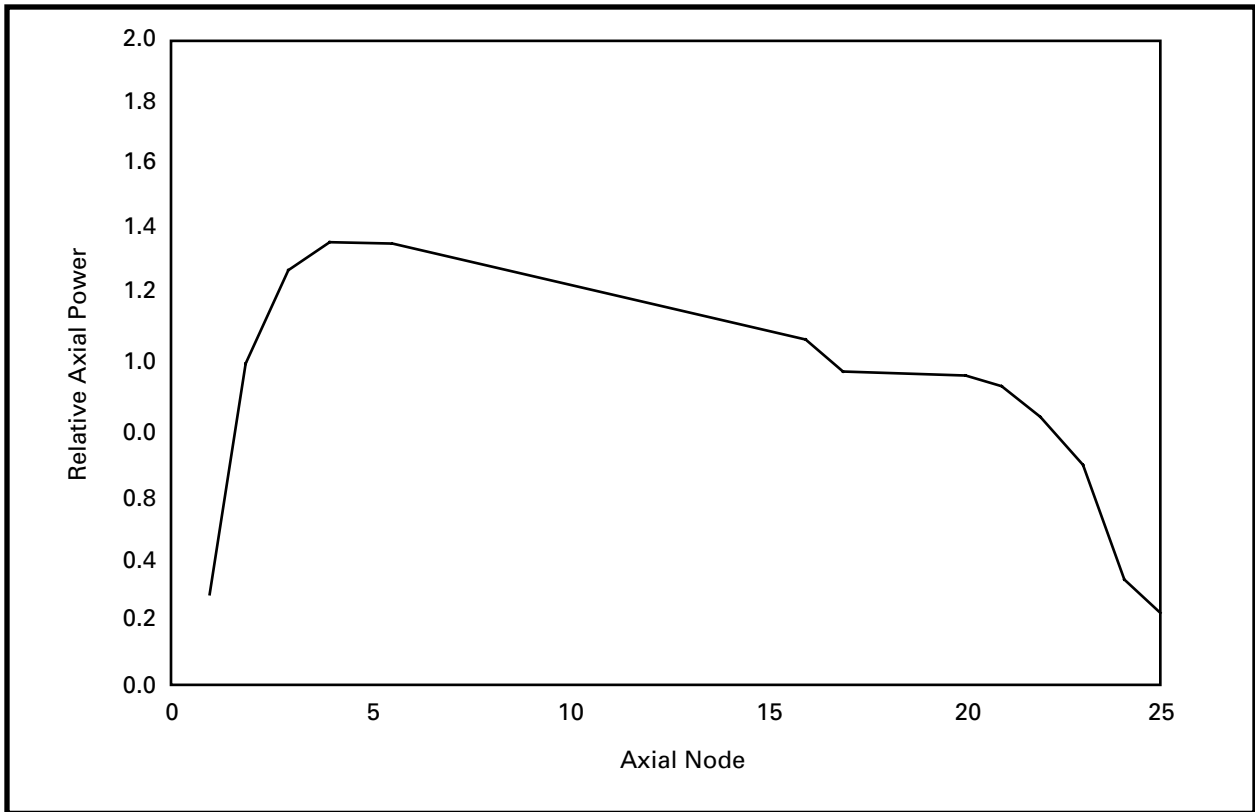


Figure 4A-5b Relative Axial Power at 1.1 GWd/MT Cycle Exposure

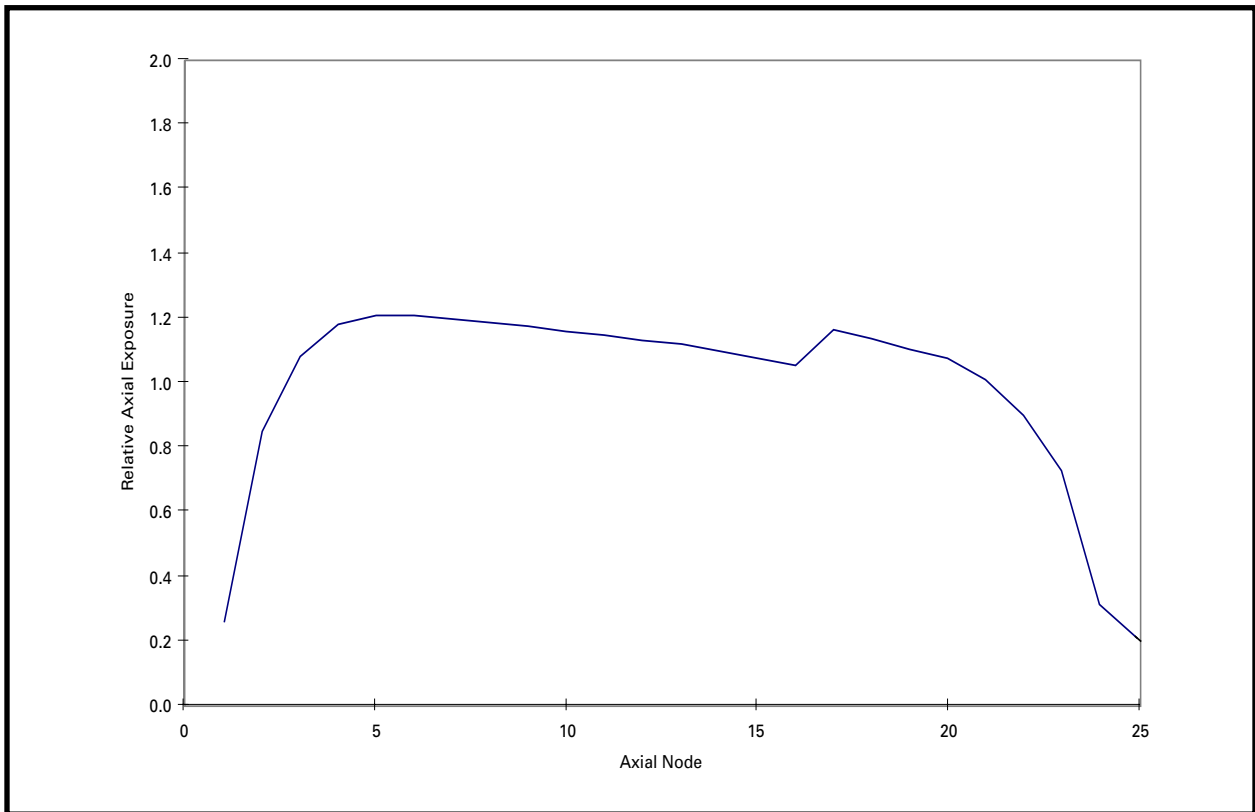


Figure 4A-5c Relative Axial Exposure at 1.1 GWd/MT Cycle Exposure

Figure 4A-5d Integrated Power per Bundle at 1.1 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-5e Average Bundle Exposure at 1.1 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-6a Summary of 2.2 GWd/MT Condition (before rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-6b Summary of 2.2 GWd/MT Condition (after rod sequence exchange)
(Proprietary information provided in a separate proprietary volume.)

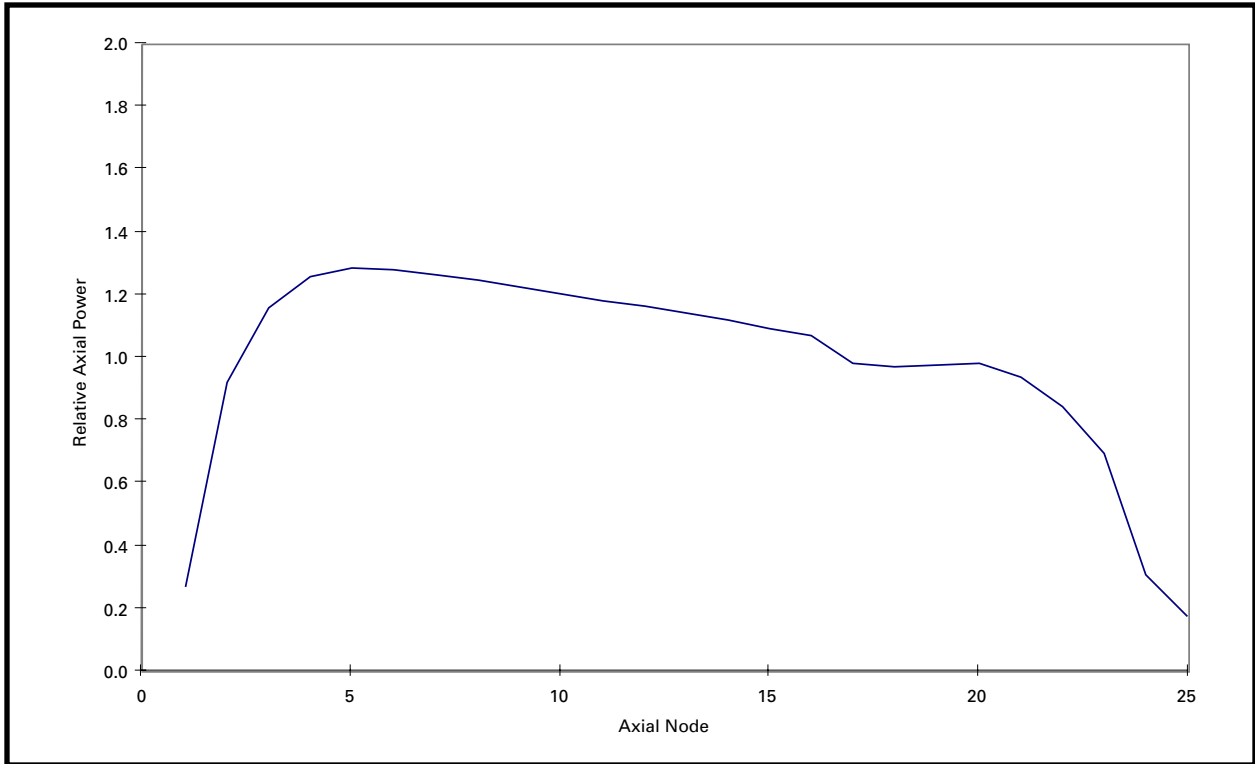


Figure 4A-6c Relative Axial Power at 2.2 GWd/MT Cycle Exposure (before rod sequence exchange)

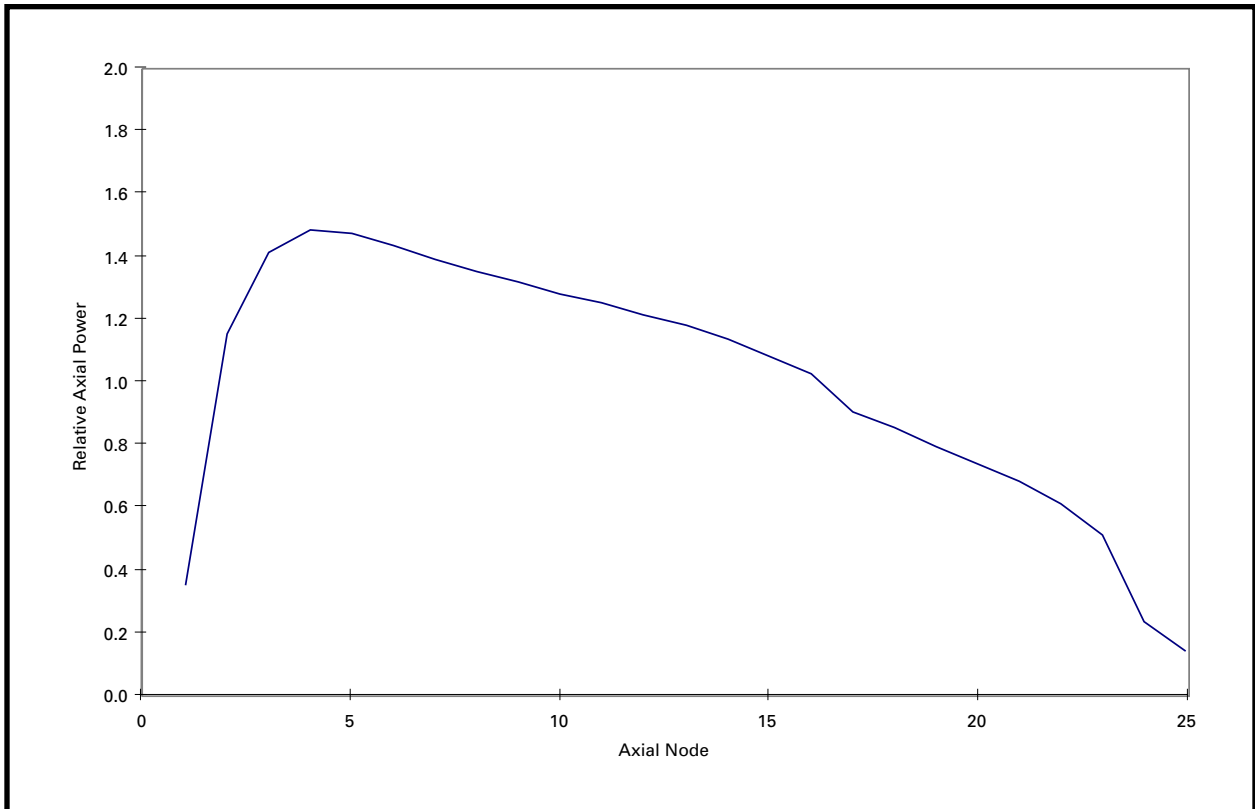


Figure 4A-6d Relative Axial Power at 2.2 GWd/MT Cycle Exposure (after rod sequence exchange)

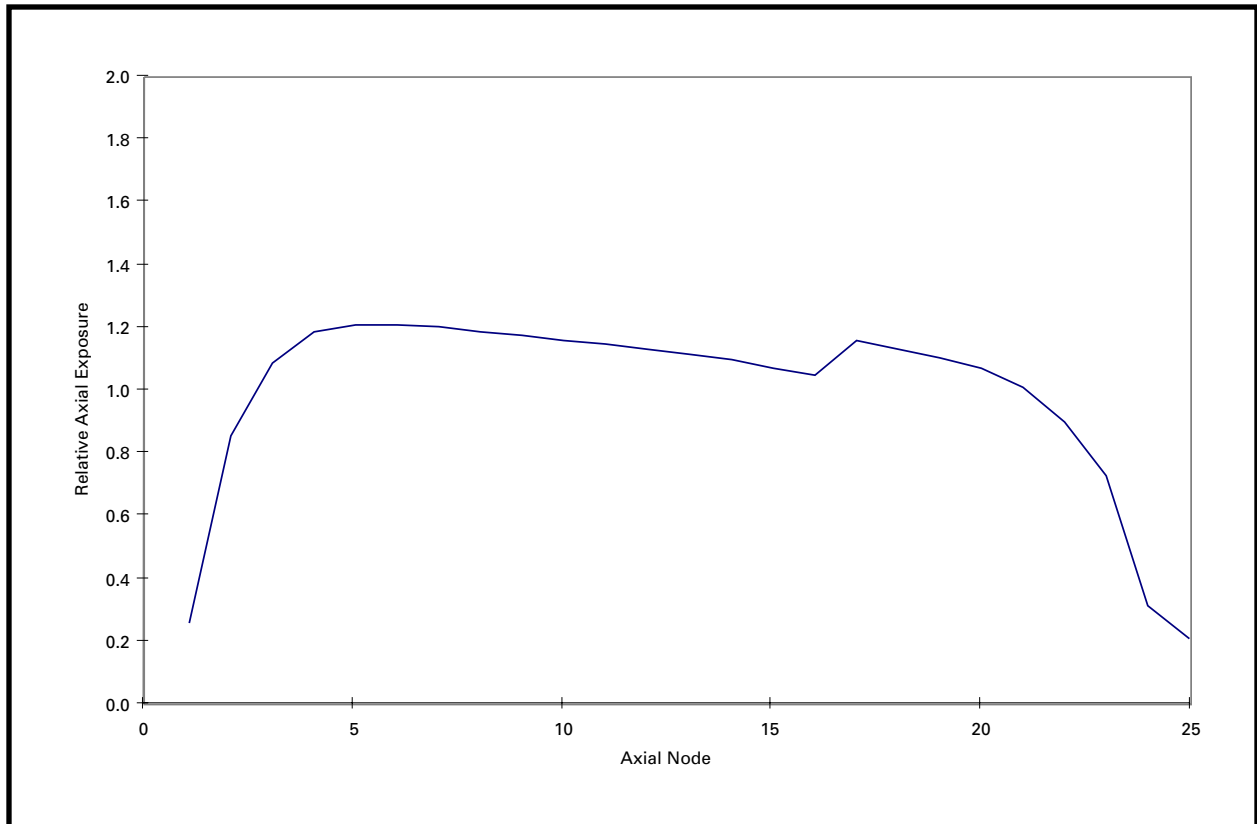


Figure 4A-6e Relative Axial Exposure at 2.2 GWd/MT Cycle Exposure

Figure 4A-6f Integrated Power per Bundle at 2.2 GWd/MT Cycle Exposure (before rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-6g Integrated Power per Bundle at 2.2 GWd/MT Cycle Exposure (after rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-6h Average Bundle Exposure at 2.2 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-7a Summary of 3.3 GWd/MT Condition

(Proprietary information provided in a separate proprietary volume.)

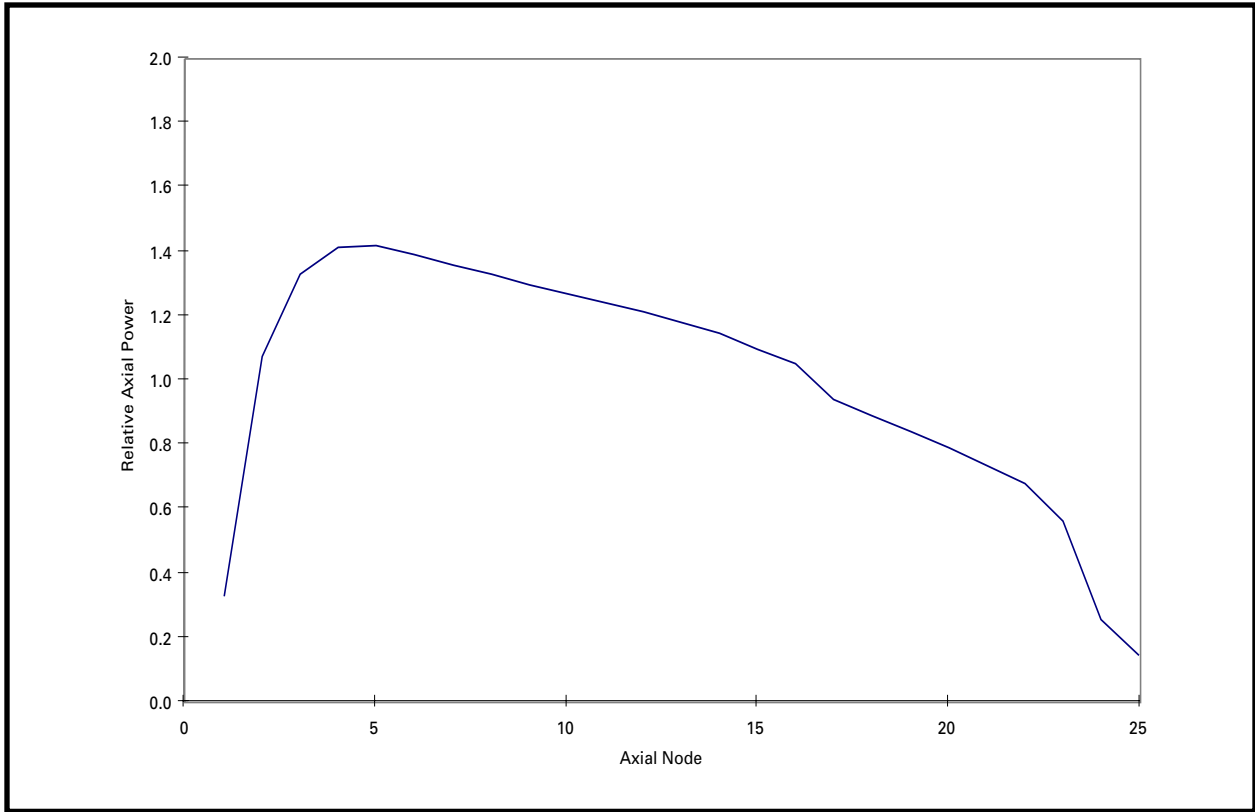


Figure 4A-7b Relative Axial Power at 3.3 GWd/MT Cycle Exposure

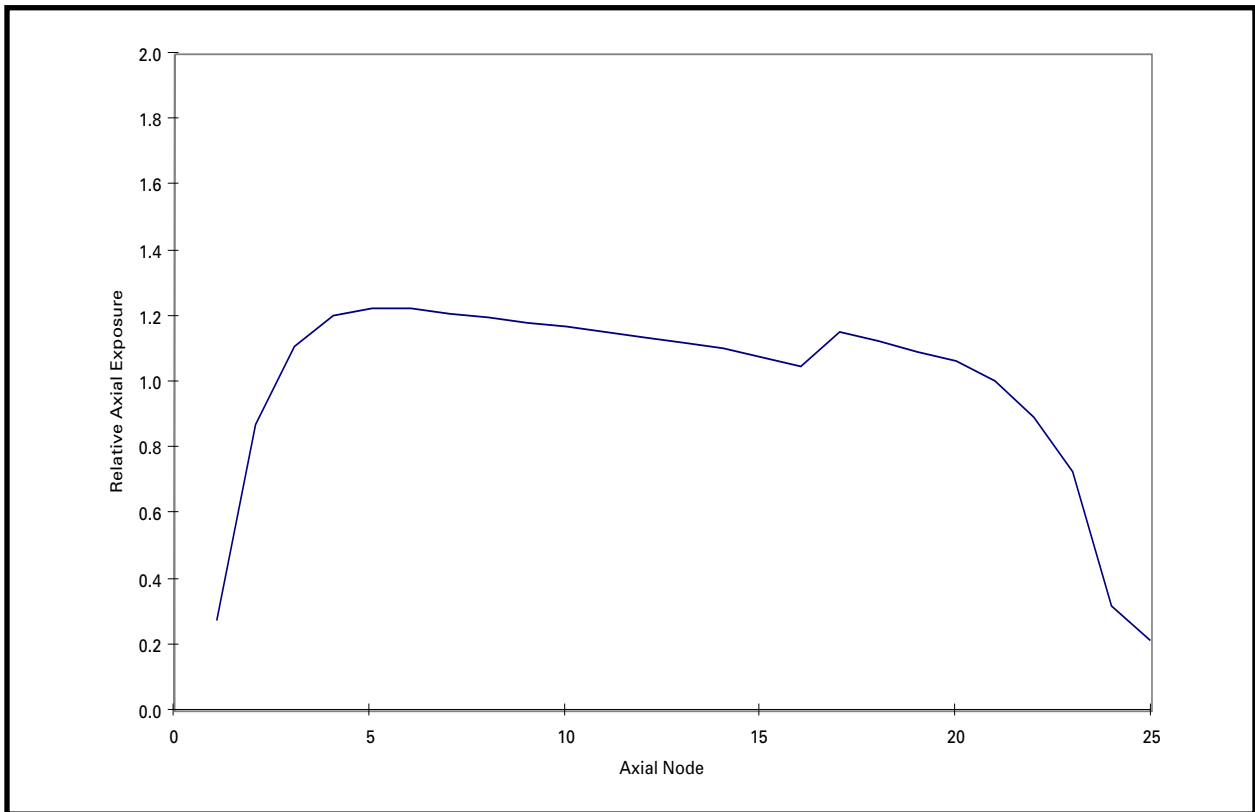


Figure 4A-7c Relative Axial Exposure at 3.3 GWd/MT Cycle Exposure

Figure 4A-7d Integrated Power per Bundle at 3.3 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-7e Average Bundle Exposure at 3.3 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-8a Summary of 4.4 GWd/MT Condition (before rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-8b Summary of 4.4 GWd/MT Condition (after rod sequence exchange)
(Proprietary information provided in a separate proprietary volume.)]

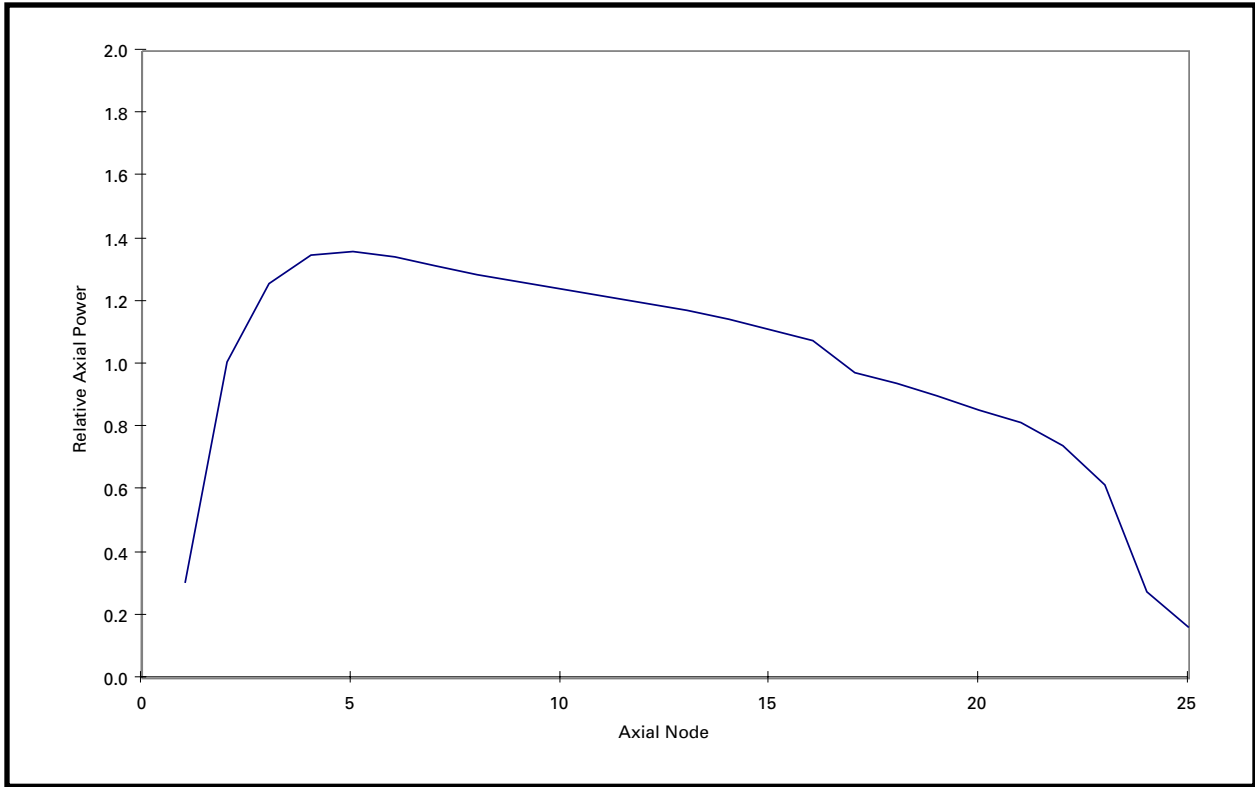


Figure 4A-8c Relative Axial Power at 4.4 GWd/MT Cycle Exposure (before rod sequence exchange)

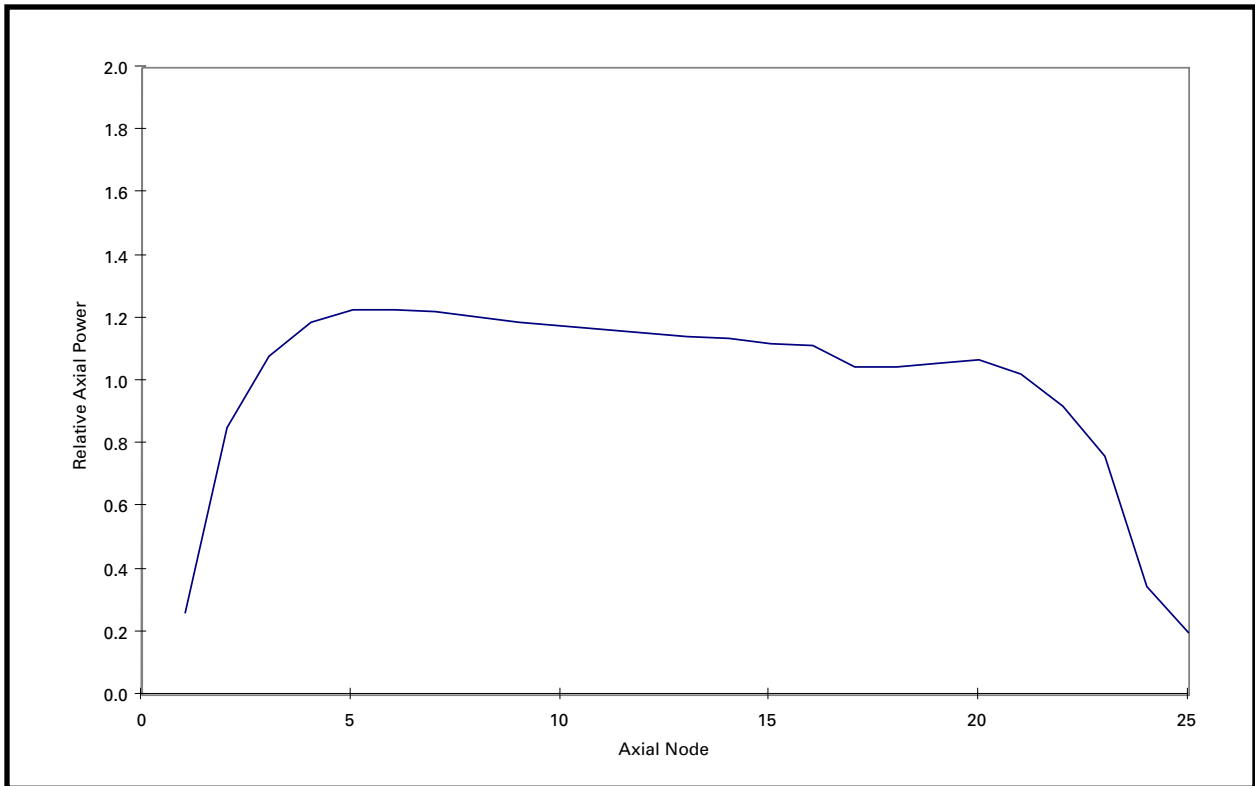


Figure 4A-8d Relative Axial Power at 4.4 GWd/MT Cycle Exposure (after rod sequence exchange)

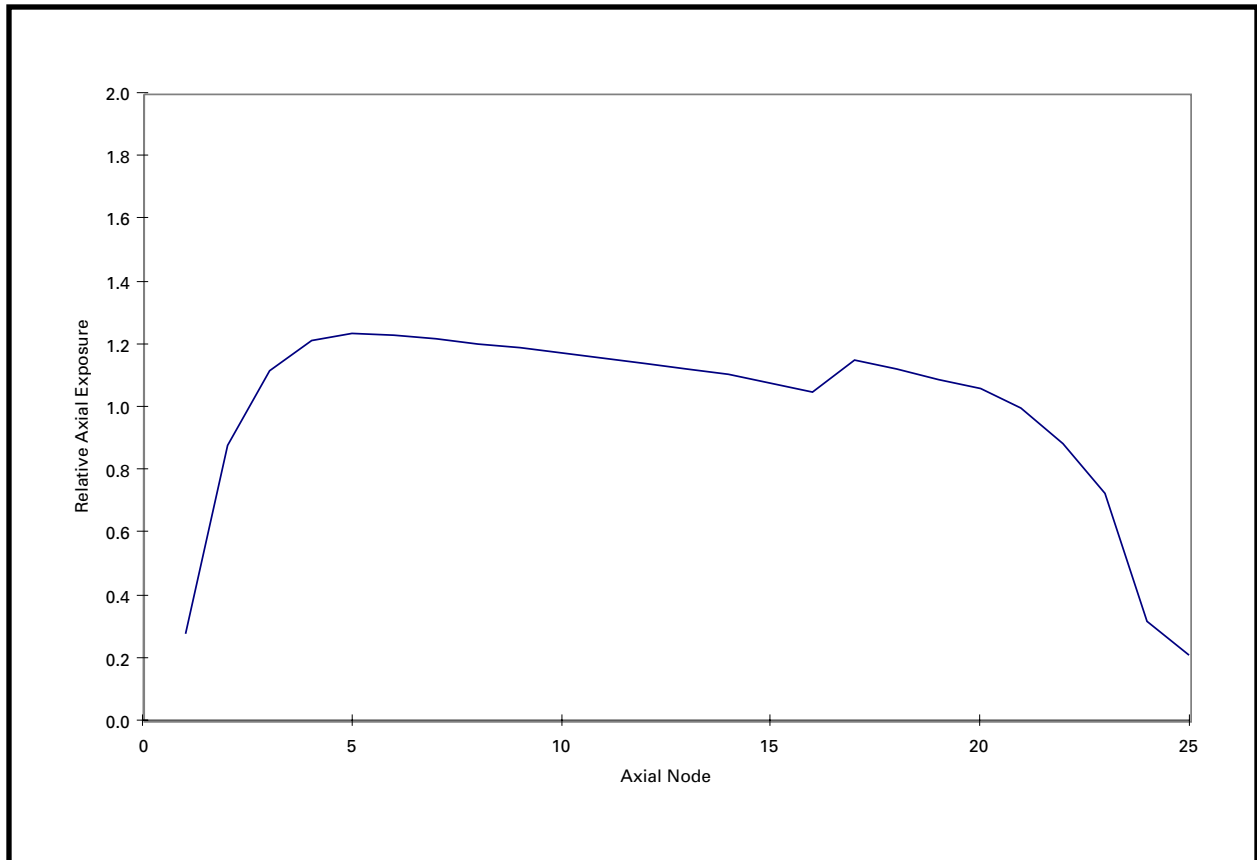


Figure 4A-8e Relative Axial Exposure at 4.4 GWd/MT Cycle Exposure

Figure 4A-8f Integrated Power Bundle at 4.4 GWd/MT Cycle Exposure (before rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-8g Integrated Power per Bundle at 4.4 GWd/MT Cycle Exposure (after rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-8h Average Bundle Exposure at 4.4 GWd/MT Cycle Exposure
(Proprietary information provided in a separate proprietary volume.)

Figure 4A-9a Summary of 5.5 GWd/MT Condition

(Proprietary information provided in a separate proprietary volume.)

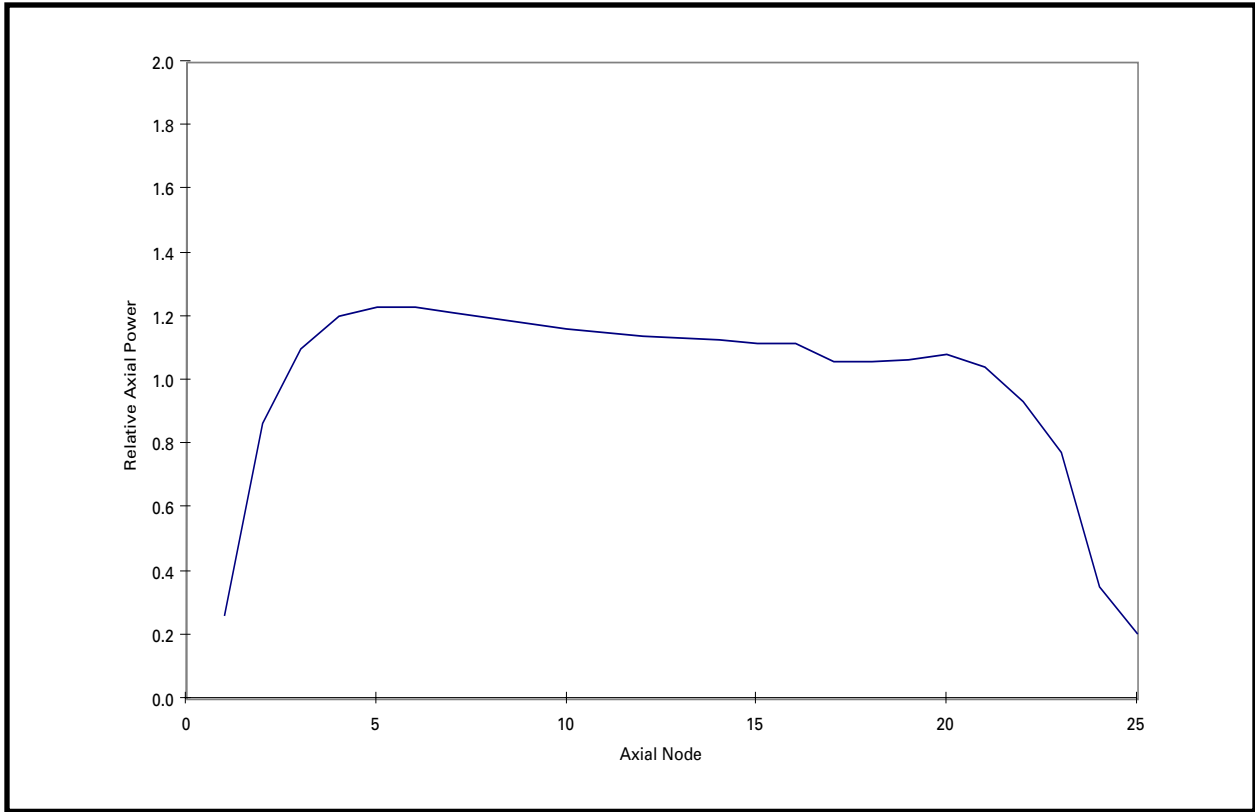


Figure 4A-9b Relative Axial Power at 5.5 GWd/MT Cycle Exposure

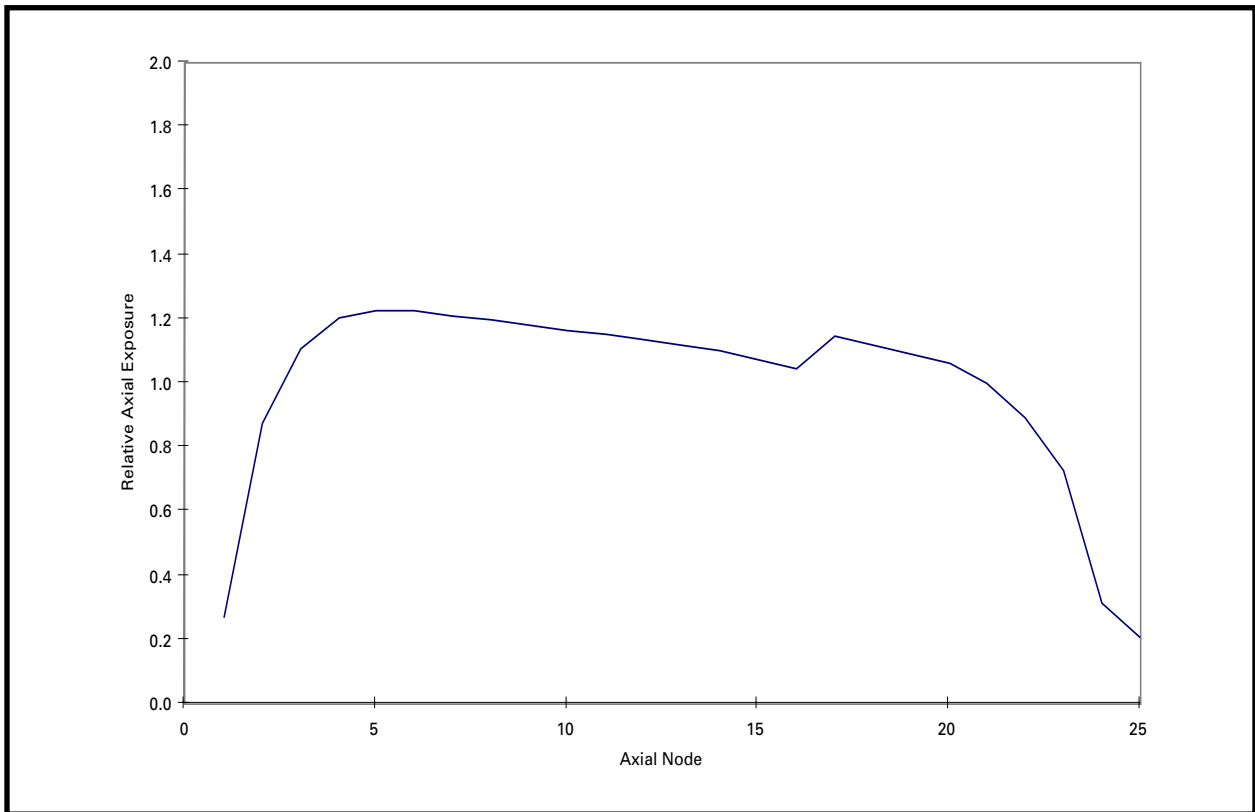


Figure 4A-9c Relative Axial Exposure at 5.5 GWd/MT Cycle Exposure

Figure 4A-9d Integrated Power per Bundle at 5.5 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-9e Average Bundle Exposure at 5.5 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-10a Summary of 6.6 GWd/MT Condition (before rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-10b Summary of 6.6 GWd/MT Condition (after rod sequence exchange)
(Proprietary information provided in a separate proprietary volume.)

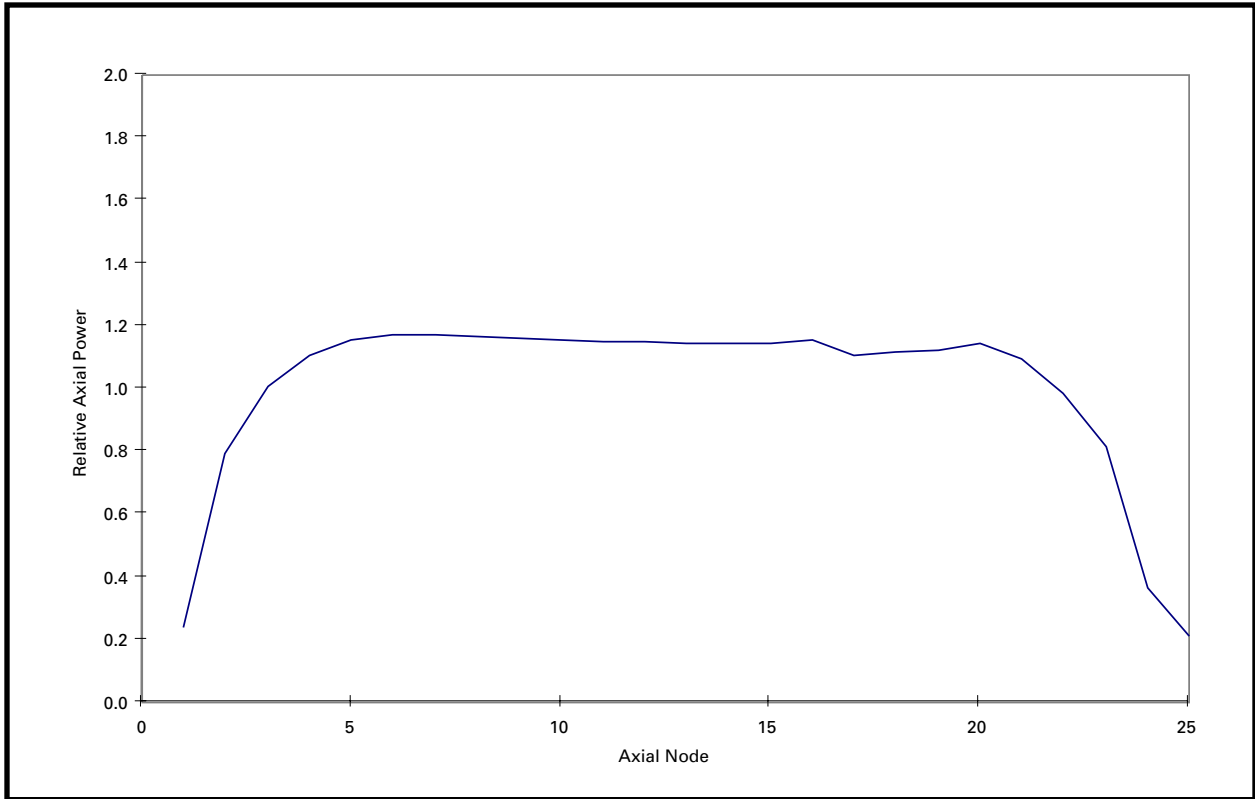


Figure 4A-10c Relative Axial Power at 6.6 GWd/MT Cycle Exposure (before rod sequence exchange)

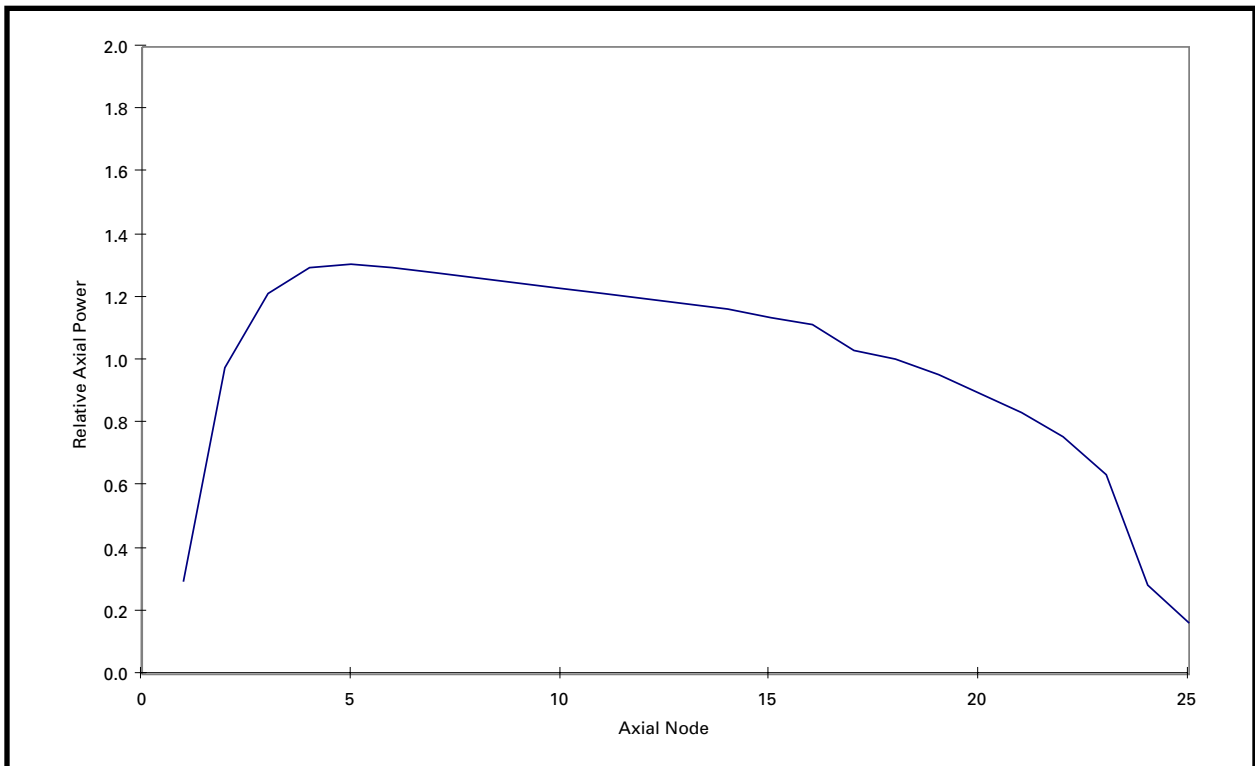


Figure 4A-10d Relative Axial Power at 6.6 GWd/MT Cycle Exposure (after rod sequence exchange)

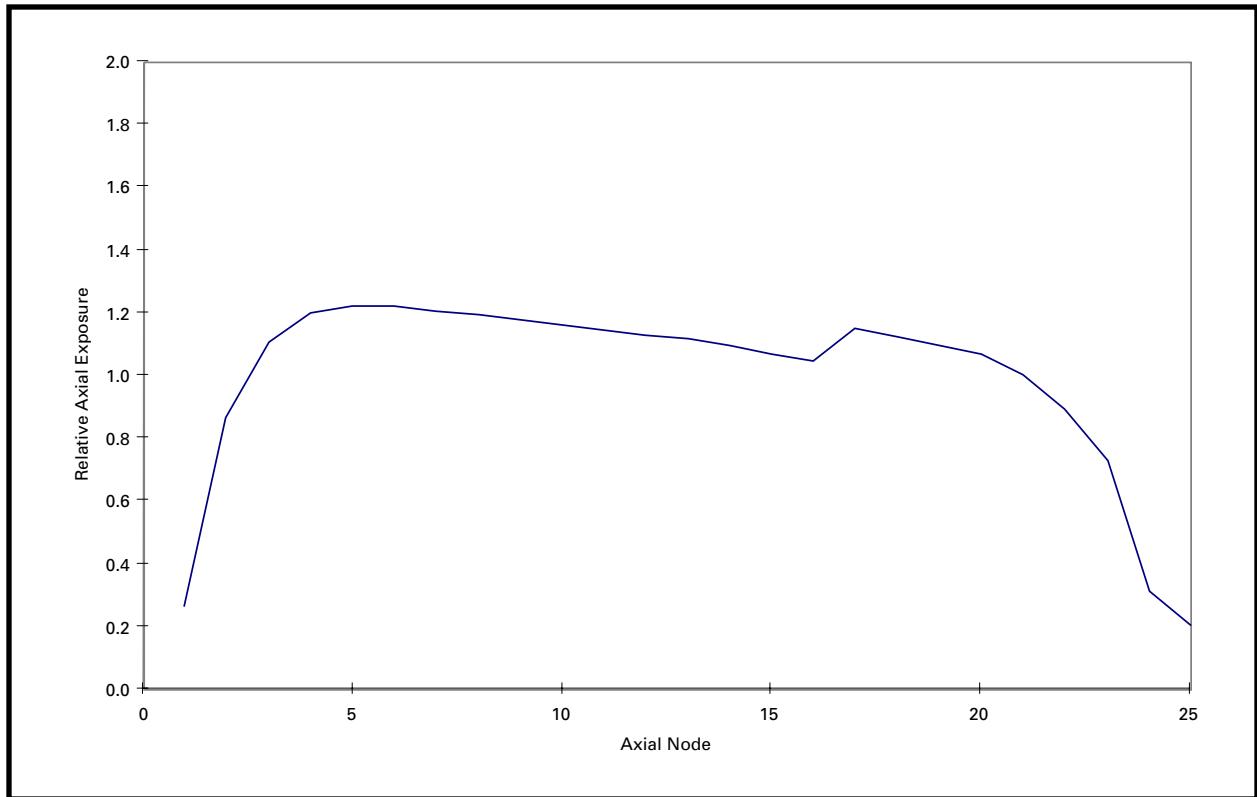


Figure 4A-10e Relative Axial Exposure at 6.6 GWd/MT Cycle Exposure

**Figure 4A-10f Integrated Power per Bundle at 6.6 GWd/MT Cycle Exposure
(before rod sequence exchange)**

(Proprietary information provided in a separate proprietary volume.)

**Figure 4A-10g Integrated Power per Bundle at 6.6 GWd/MT Cycle Exposure (after
rod sequence exchange)**

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-10h Average Bundle Exposure at 6.6 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-11a Summary of 7.7 GWd/MT Condition
(Proprietary information provided in a separate proprietary volume.)

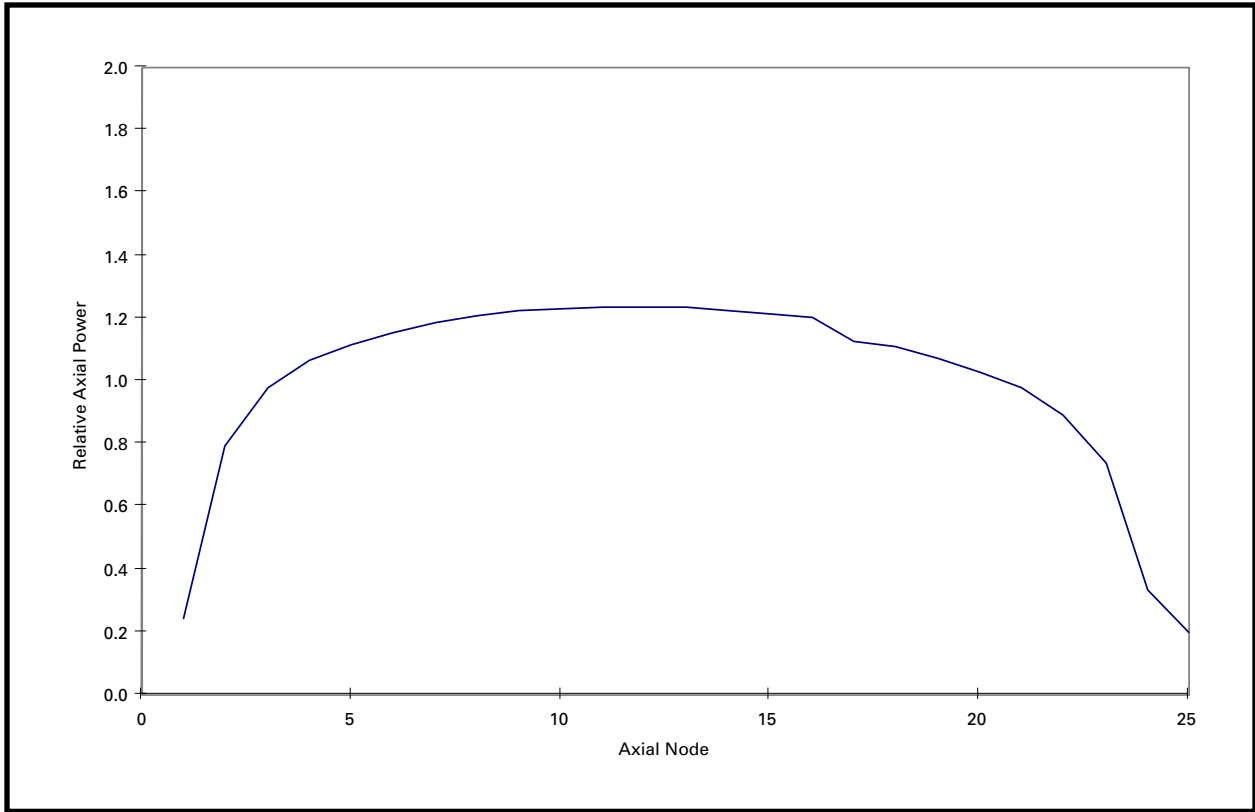


Figure 4A-11b Relative Axial Power at 7.7 GWd/MT Cycle Exposure

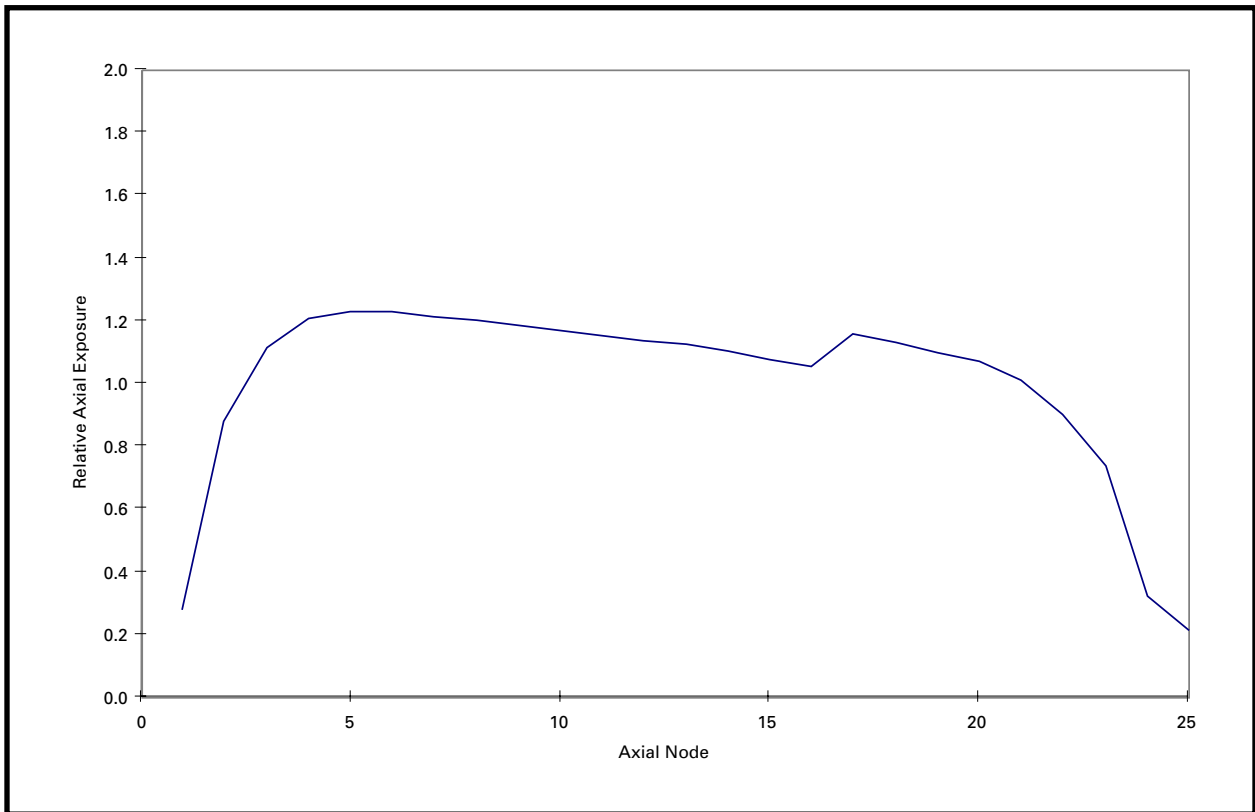


Figure 4A-11c Relative Axial Exposure at 7.7 GWd/MT Cycle Exposure

Figure 4A-11d Integrated Power per Bundle at 7.7 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-11e Average Bundle Exposure at 7.7 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-12a Summary of 8.8 GWd/MT Condition (before rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)]

Figure 4A-12b Summary of 8.8 GWd/MT Condition (after rod sequence exchange)

(Proprietary information provided in a separate proprietary volume.)

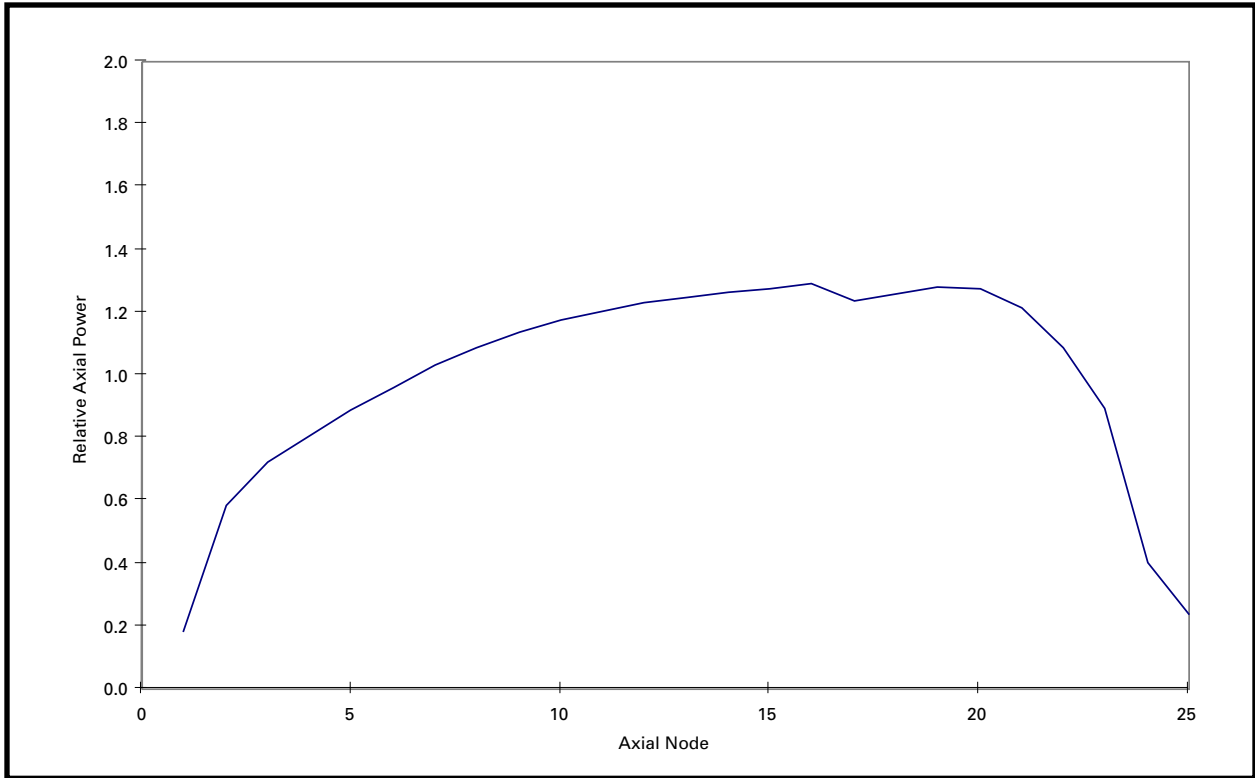


Figure 4A-12c Relative Axial Power at 8.8 GWd/MT Cycle Exposure (before rod sequence exchange)

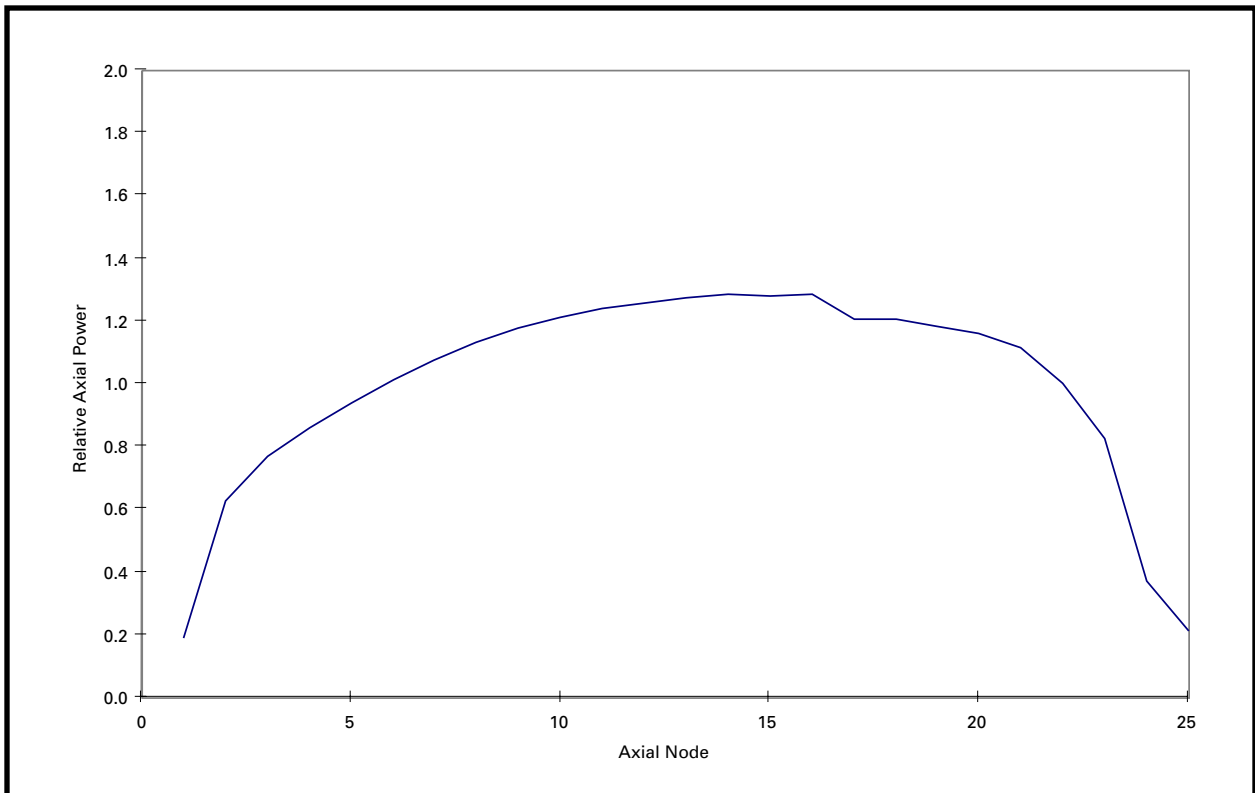


Figure 4A-12d Relative Axial Power at 8.8 GWd/MT Cycle Exposure (after rod sequence exchange)

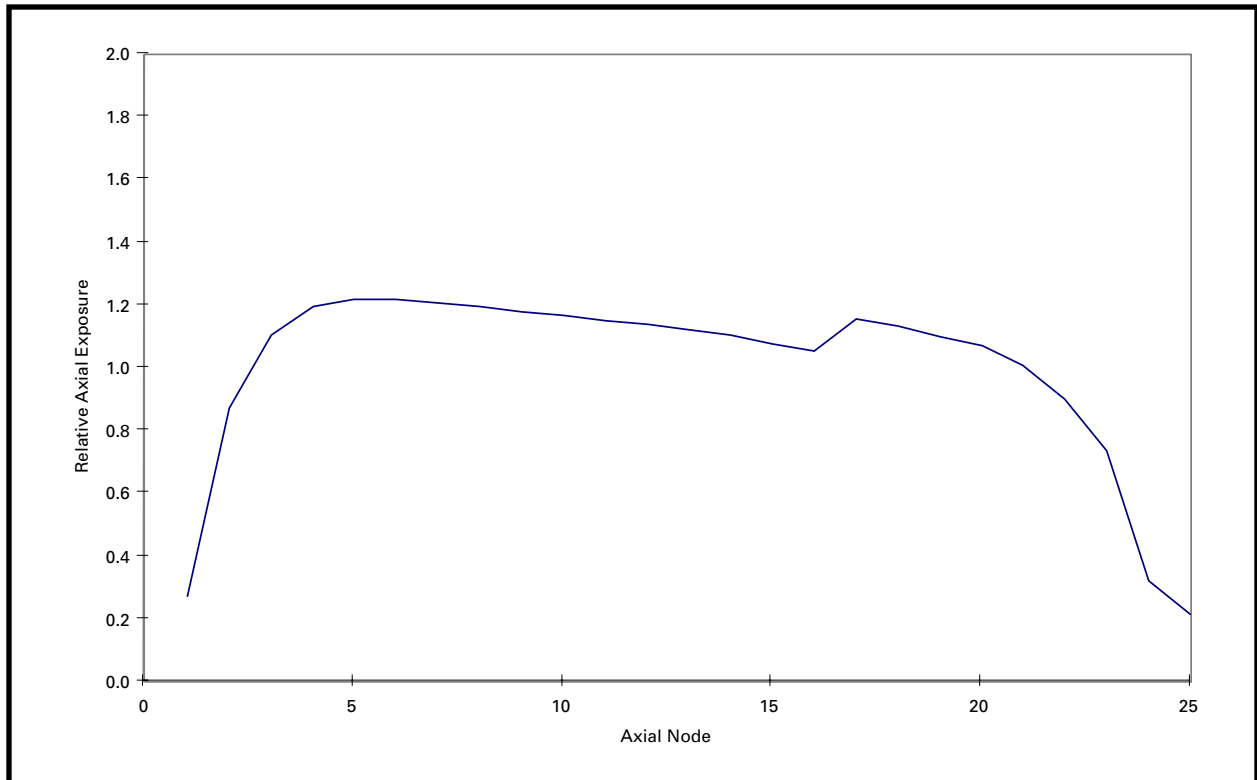


Figure 4A-12e Relative Axial Exposure at 8.8 GWd/MT Cycle Exposure

**Figure 4A-12f Integrated Power per Bundle at 8.8 GWd/MT Cycle Exposure
(before rod sequence exchange)**

(Proprietary information provided in a separate proprietary volume.)

**Figure 4A-12g Integrated Power per Bundle at 8.8 GWd/MT Cycle Exposure (after
rod sequence exchange)**

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-12h Average Bundle Exposure at 8.8 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-13a Summary of 9.9 GWd/MT Condition
(Proprietary information provided in a separate proprietary volume.)

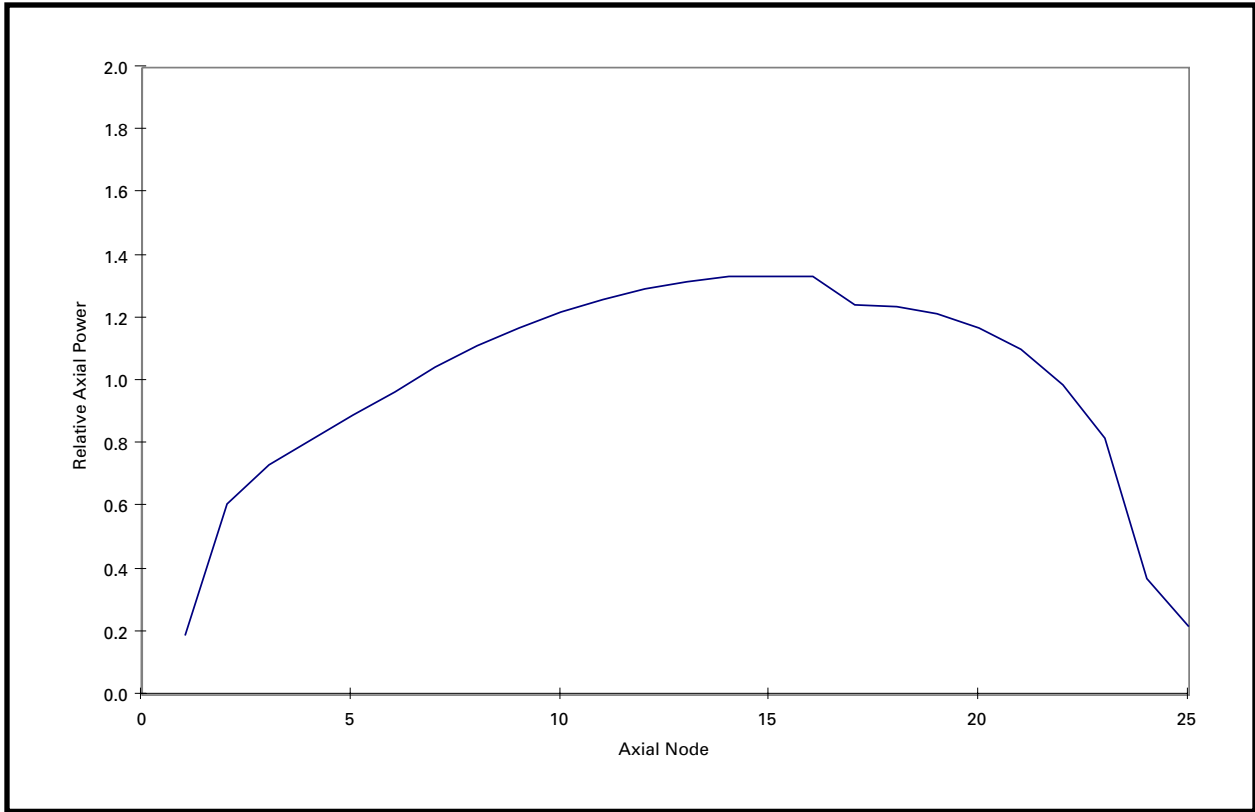


Figure 4A-13b Relative Axial Power at 9.9 GWd/MT Cycle Exposure

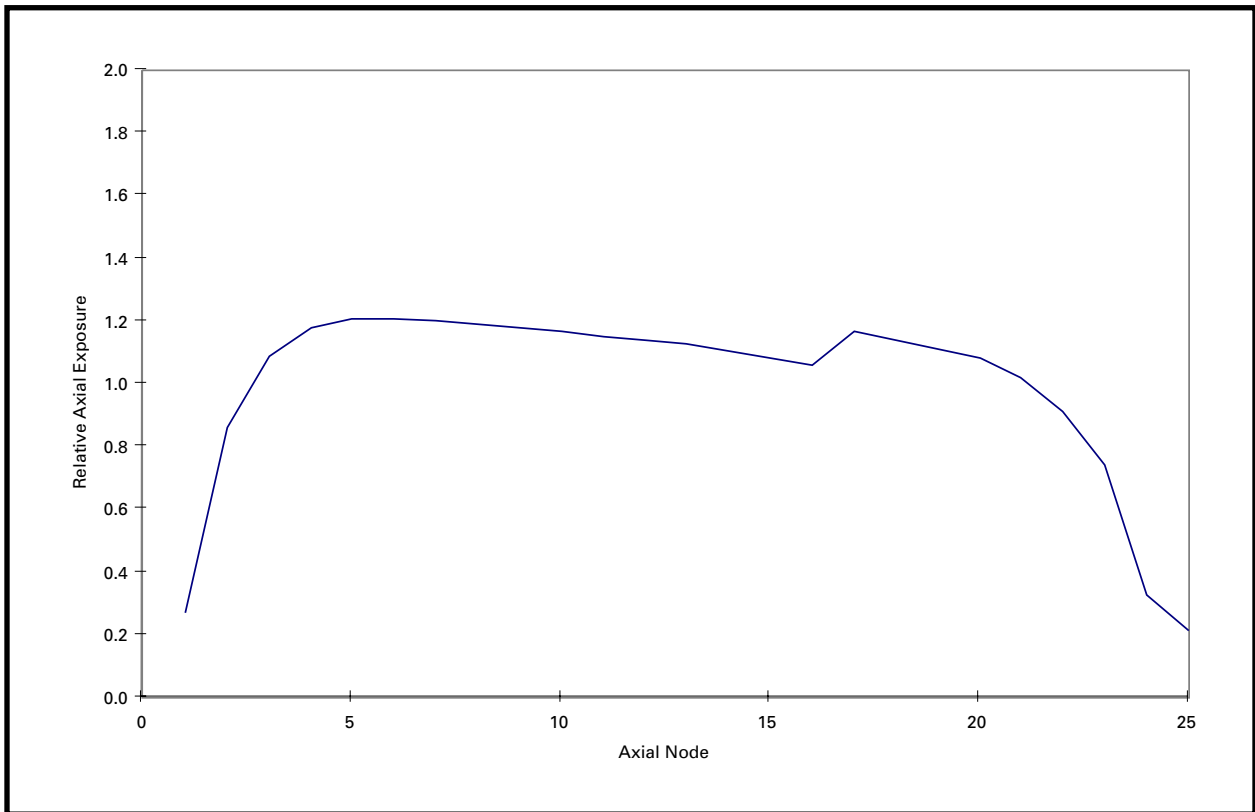


Figure 4A-13c Relative Axial Exposure at 9.9 GWd/MT Exposure

Figure 4A-13d Integrated Power per Bundle at 9.9 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

Figure 4A-13e Average Bundle Exposure at 9.9 GWd/MT Cycle Exposure

(Proprietary information provided in a separate proprietary volume.)

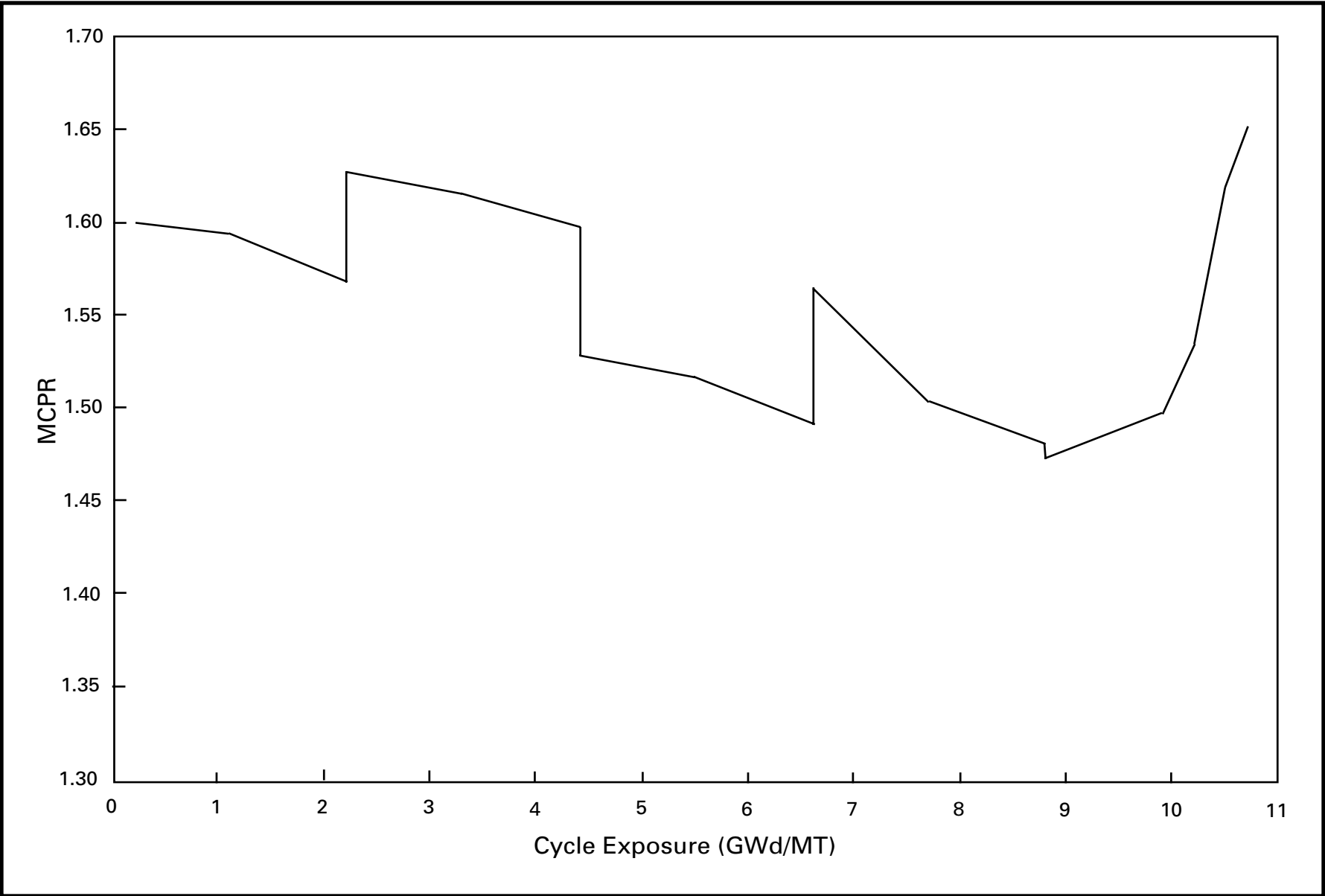


Figure 4A-14 Minimum Critical Power Ratio (MCPR) as a Function of Cycle Exposure (Four Rod Sequence Exchanges)