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PRESSURE-VESSEL FLUENCE REDUCTION THROUGH SELECTIVE FUEL-ASSEMBLY REPLACEMENT*

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The nil-ductility transition temperature (RT_{NDT}) of a PWR pressure vessel (PV) increases during its lifetime due to neutron-induced radiation damage. If during a pressurized thermal shock (PTS) event the PV is cooled below its RT_{NDT} and then repressurized, the vessel may undergo brittle fracture.[1] For several operating reactors it may be necessary to reduce this neutron-induced vessel damage in order to maintain the vessel RT_{NDT} below the range of concern. In this study we consider the potential fluence (and hence damage) reduction achievable by selective replacement of peripheral fuel assemblies with assemblies in which the fuel rods have been replaced by stainless steel rods.

The fluence reductions obtained by assembly replacement are due to the increased distance and shielding between the core and PV. Since the same power output is demanded from a smaller number of assemblies, the fluence reductions are achieved at the expense of an increase in the core power peaking (or equivalently a loss of margin) in the core interior.

Calculations have been performed for three PWR core/PV geometries: a 133-fuel assembly (FA) Combustion Engineering (CE) reactor; a 157-FA Westinghouse (W) reactor; and a 177-FA Babcock and Wilcox (B&W) reactor.[2] The calculations were performed using the DOT-3.5[3] discrete ordinates transport code in (r-θ) geometry, together with a 16-group, region-dependent cross section library based on the DLC-37/EPR (ENDF/B-IV) library.[4]

The assembly replacement (AR) patterns considered for the 177-FA B&W configuration are shown Figure 1. The selection of the assemblies to be removed was based on their location relative to the peak-wall fluence (PWF) location and/or the location of longitudinal welds in the PV shells which overlap the active core.

The resultant end-of-life (EOL) PWF's and weld fluences, relative to the PWF for the case with no assemblies removed (AR-1), are given in Table 1. Estimates for the power peaking penalties associated with each pattern are also included. The results for patterns AR-2 through 4 assume that the given pattern is implemented immediately, and applies for the remaining vessel life of $\sim$ 27 Effective-Full-Power-Years. In addition, we show results for two cases where patterns AR-2 through 4 are assumed to apply for only portions of the remaining life. These latter cases represent an attempt to optimize the fluence reduction azimuthally, while minimizing the accompanying power peaking penalties.

The results show that reductions in PWF of from $\sim$ 18% to a factor of $\sim$ 4 are achievable with selective assembly replacement. Maximum reductions in the weld fluences are similar, with the exception that the minimum reduction obtained is a factor of $\sim$ 2. This is due to the specific location of the welds relative to the removed assemblies. The increases in power peaking range from $\sim$ 13 - 30%. It is important to note that these power peaking increases do not account for any power flattening that might be achieved by, for example, a judicious use of lumped burnable poisons.

While similar results were obtained for the CE and W configurations, the effectiveness of assembly replacement is strongly dependent on the shape of the azimuthal fluence at the PV, and the locations of the peak and of important welds. For these reactors the azimuthal fluence shape varies by factors of 2-6 (as compared to ~ 30% for B&W); consequently somewhat larger reductions were achieved with the removal of fewer assemblies. Increases in power peaking were also similar, ranging between ~ 8 and 40%.

The results of this study demonstrate that considerable fluence reductions can be obtained by selective replacement of peripheral fuel assemblies with assemblies containing stainless steel rods. These reductions are achieved at the expense of increased power peaking, or loss of available margin. Because of these penalties, as well as other considerations, assembly replacement is expected to be utilized only in extreme situations.

References

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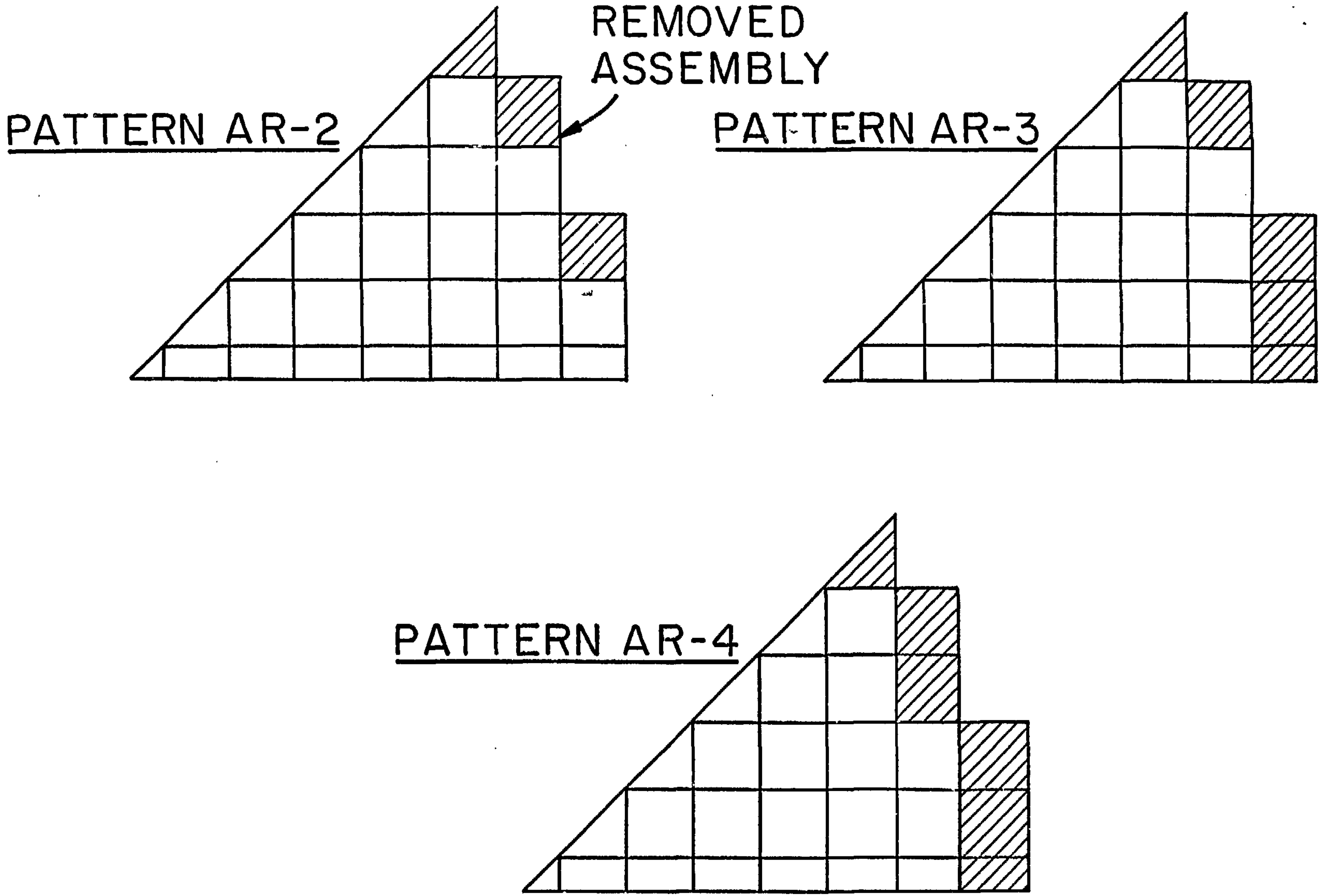

Figure 1. Assembly Removal Patterns for 177-FA Reactor

TABLE-1

177-FA REACTOR ASSEMBLY REPLACEMENT (AR) EOL VESSEL (>1.0 MeV) FLUENCE REDUCTION

Peripheral Assembly Configuration	Peak Wall Fluence†	Weld Seam @ 19°†	Weld Seam @ 22°††	Weld Seam @45°†	ΔP(%)
Base Case (AR-1) (4.0, 28.0, 0,0,0)*	1.0	0.883	0.130	0.810	0.0
Case (AR-2) (4.0, 1.1, 26.9,0,0)	0.824	0.434	0.065	0.276	12.7
Case (AR-3) (4.0, 1.1, 0, 26.9, 0)	0.374	0.355	0.060	0.283	22.1
Case (AR-4) (4.0, 1.1, 0,0,26.9)	0.273	0.249	0.038	0.268	29.2
Case (AR-5) (4.0, 1.1, 3.1, 17.6, 6.2)	0.346	0.340	0.055	0.279	22.7**
Case (AR-6) (4.0, 1.1, 9.3, 17.6, 0)	0.447	0.382	0.062	0.281	18.9**

† Axial factor is 1.0.

†† Axial factor is 0.16.

* (I,J,K,L,M) Read as I EFPY in pattern with equilibrium EOL source, J EFPY in pattern with present low-leakage source, K EFPY in pattern AR-2, L EFPY in pattern AR-3 and M EFPY in pattern AR-4; present accumulated exposure = 5.1 EFPY

** Exposure weighted over remaining 26.9 EFPY.