Optimized Core Loading Sequence for Ukraine WWER-1000 Reactors

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Abstract

In 2012, several Westinghouse WWER-1000 Fuel Assemblies (WFAs) experienced mechanical damage of the grids during loading at both South Ukraine 2 (SU2) and South Ukraine 3 (SU3). The grids were damaged due to high lateral loads exceeding their strength limit. The high lateral loads were caused by a combination of distortion and stiffness of the mixed core fuel assemblies and significant fuel assembly-to-fuel assembly interaction combined with the core loading sequence being used.

To prevent damage of the WFA grids during core loading, Westinghouse has developed a loading sequence technique and loading aides (smooth sided dummies and top nozzle loading guides) designed to minimize fuel assembly-to-fuel assembly interaction while maximizing the potential for successful loading (i.e., no fuel assembly damage and minimized loading time). The loading sequence technique accounts for cycle-specific core loading patterns and is based on previous Westinghouse WWER core loading experience and fundamental principles. The loading aids are developed to “open-up” the target core location or to provide guidance into a target core location. The Westinghouse optimized core loading sequence and smooth sided dummies were utilized during the successful loading of SU3 Cycle 25 mixed core in March 2015, with no instances of fuel assembly damage and yet still provided considerable time savings relative to the 2012 and 2013 SU3 reload campaigns.

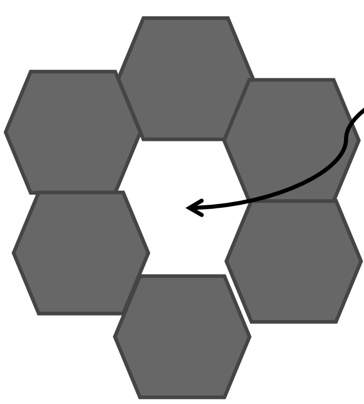

Figure 1. The schematic picture shows that distorted fuel assemblies present major loading challenges as the geometry of the open positions are no longer hexagonal.

1. Introduction and Background

In 2012, several Westinghouse WWER-1000 Fuel Assemblies (WFAs) experienced mechanical damage of the grids (scratches and rub marks, and even damage to some of the grids) during the reload at both South Ukraine 2 (SU2) and South Ukraine 3 (SU3). The grids were damaged due to high lateral loads exceeding their strength limit. The high lateral loads were caused by a combination of distortion and stiffness of the mixed core fuel assemblies and significant fuel assembly-to-fuel assembly interaction combined with the core loading sequence being used. It should be noted, however, that the integrity of all fuel rods was unaffected.

In contrast to other pressurized water reactor fuel geometries which use a square-lattice, the hexagonal-lattice WWER-1000 core is more exposed to mechanical contact between the fuel assemblies, particularly if the surrounding assemblies are distorted (see Figure 1). In the actual cores which have been experienced, the Westinghouse fuel assemblies were surrounded by co-resident competitor fuel assemblies with a significant amount of distortion and a high level of structural lateral stiffness. It can be understood that if a fuel assembly is loaded into (or pulled out of) position under such circumstances, significant mechanical interference would occur which could cause increased risk for damage to the grids.

It was realized that the existing axial trip limit specification of 150 kg for the refueling machine crane would not be sufficient to load the mixed core. Therefore, in order to facilitate core load-

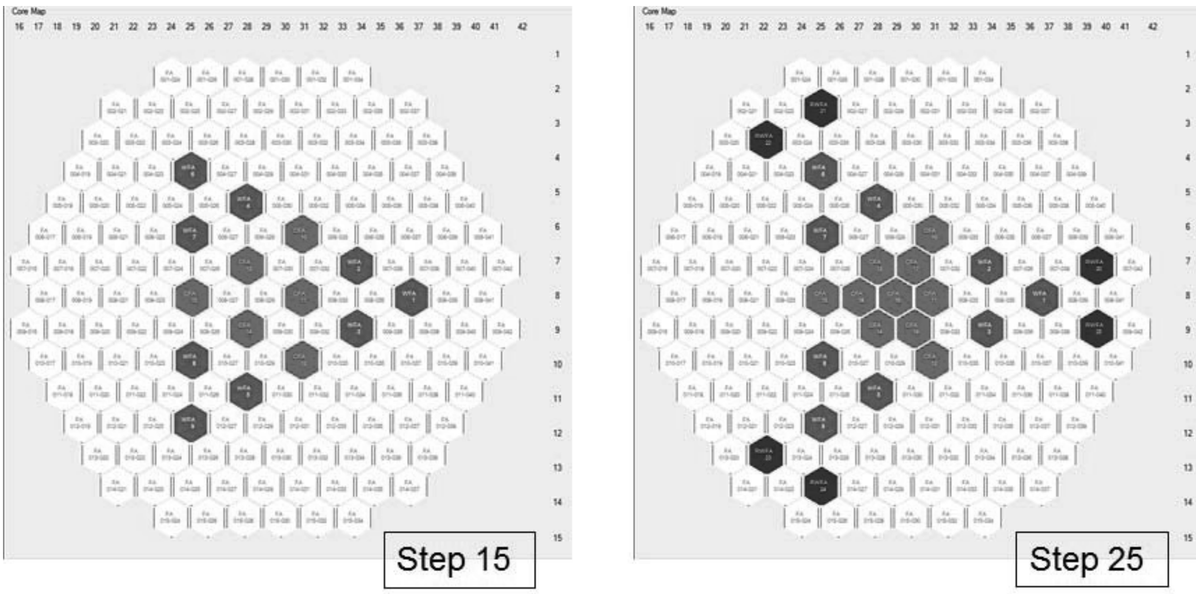

Figure 2. Use "open water" loading to largest extent possible.

ing and mitigate observed fuel handling issues, an enhanced WWER-1000 design, referred to as the Robust Westinghouse Fuel Assembly (RWFA), has been designed to withstand handling loads generated from an axial trip limit of 225 kg which was determined to be adequate to load and unload fuel from the reactor based on the current mixed core conditions and the improved core loading sequences developed by Westinghouse.

In addition to developing the RWFA, Westinghouse has developed a core loading sequence approach and loading aides (smooth sided dummies and top nozzle loading guides) designed to minimize fuel assembly-to-fuel assembly interaction while maximizing the potential for successful loading (i.e., no fuel assembly damage and minimized loading trip limits and time). These core loading enhancements are discussed further in this paper.

2. WWER-1000 Core Loading Enhancements

2.1. Optimized Core Loading Sequence

Based on the 2012 core loading experience at South Ukraine, it was realized that, due to the distortion and stiffness of the mixed core fuel assemblies, the core loading sequence (CLS) needed to be optimized to minimize the fuel assembly-to-fuel assembly interactions and maximize the potential for successful loading (i.e., no fuel assembly damage and minimal loading time impact). The CLS approach:

- is cycle-specific and is core loading plan (CLP) dependent.
- CLS is optimized for each CLP.
- considers assembly stiffness and strength as a major parameter.
- minimizes fuel assembly-to-fuel assembly interactions.
- maximizes the allowable refueling machine crane trip force limit that can be used.
- assumes smooth-sided dummies are available to open-up "crowded" core location/straighten-up a leaning assembly or guide a fuel assembly into its target core location if needed.

The CLS approach accounts for cycle-specific loading patterns and is based on previous Westinghouse WWER core loading experience and fundamental principles. The CLS approach uses "open water" loading to the largest extent possible (See Figure 2) and gives priority to locations with no neighbors or 3-symmetically spaced neighbors before developing "boxed" locations.

The CLS approach then stabilizes the core center in its intended position by building 3-legged bridges from the core center out to the shroud (See Figure 3) while loading lower stiffness fuel first and loading higher stiffness fuel last and closing rows with higher stiffness fuel.

Finally, during the last few loading steps when the core is almost full, the CLS approach tries to

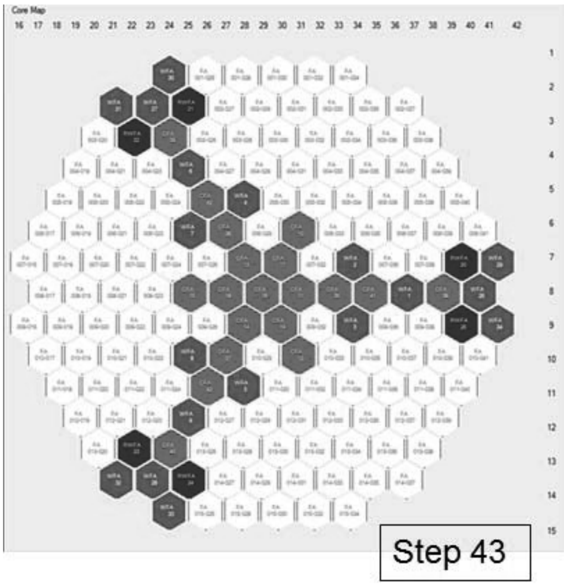

Figure 3. Build 3-legged bridges from core center.

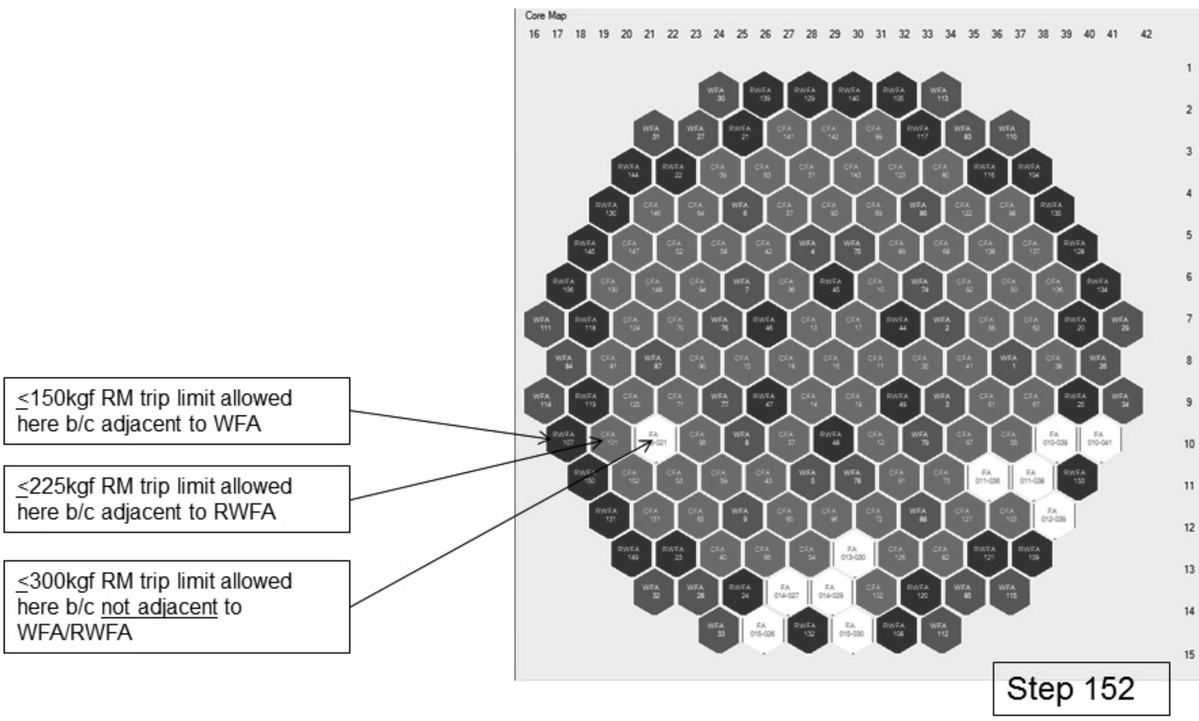

Figure 4. Build pockets where higher refueling machine trip limts can be used.

leave pockets of core locations where fuel with higher refueling machine trip limits can be used (See Figure 4).

This Westinghouse developed CLS approach has been used successfully at SU3 since 2013.

2.2. Loading Aides

The loading aids are designed to "open-up" the target core location or to provide guidance into a target core location.

Smooth Sided Dummies. Smooth sided dummies (SSDs) were introduced at South Ukraine after the 2012 core loading difficulties. The SSDs are based on a design that had been used successfully for several years in Temelin. The SSDs (See Figure 5) have several features which have proven to provide many benefits in the core loading process:

- Large lead-in chamfer on an extra stainless steel member attached to the bottom of the bottom nozzle.
- Six straight smooth sides which eliminate grid-to-grid interactions and minimize overall drag between assemblies.
- Standard top and bottom nozzle configuration and overall envelop of standard fuel assemblies.
- Same approximate buoyant weight of standard fuel assembly to minimize fuel loading machine handling issues.

If the top nozzle of a neighboring fuel assembly is out of position, th e SSD can be lowered into the target core location and push that assembly back toward its desired location, opening up the target core location and allowing the actual fuel assembly to be loaded in the following step. If bow or twist is present in loaded fuel assemblies, the SSD can move them in a straightening direction without tripping the fuel assembly handling tool and allow the targeted fuel assembly to be loaded within acceptable trip limits in the following step.

The SSD has proven to be a great tool to minimize loading issues during core reload and has advantages over using an actual fuel assembly dummy in that there are no grid-to-gird interfaces to overcome or cause hang-up, it has better anti-engagement/anti-snag features, and it provides lower friction and drag during core loading. SSDs were utilized during the successful loading of SU3 Cycle 25 mixed core in March 2015, with no instances of fuel assembly damage and considerable time savings relative to the 2012 and 2013 SU3 reload campaigns.

Top Nozzle Loading Guides. During the 2012 core loading at South Ukraine, there were a few instances of interaction between the bottom of the bottom nozzle of a fuel assembly that was being loaded into a target core location and the adaptor plate of the top nozzle of a neighboring WFA which made loading difficult (See Figure 6).

As a counter measure, Westinghouse developed a Top Nozzle Loading Guide (TNLG) that is de-

Figure 5. Smooth Sided Dummies Designed to Assist with Fuel Loading

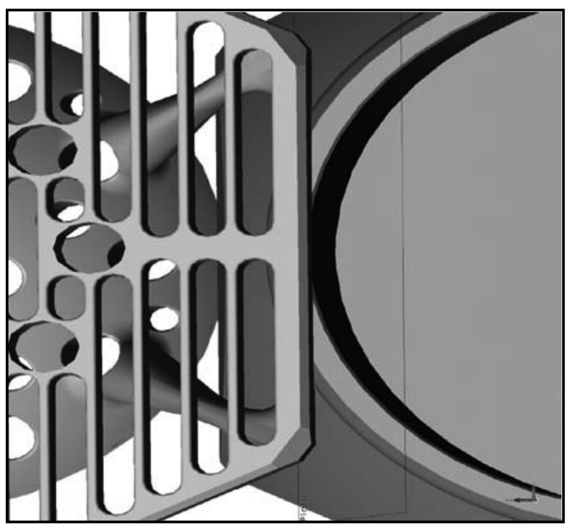

Figure 6. Interaction between the Bottom of the Bottom Nozzle and the Adaptor Plate of the Top Nozzle during Core Loading

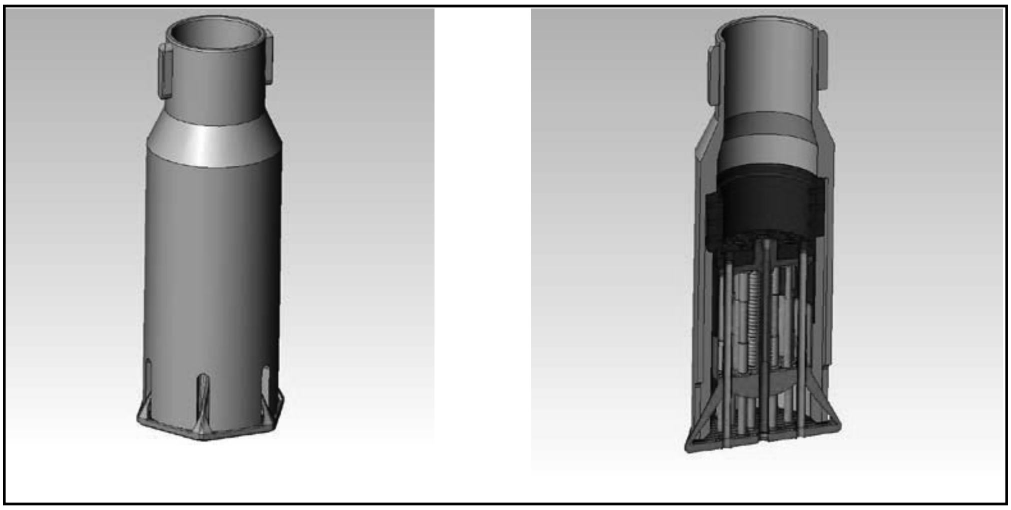

Figure 7. Top nozzle loading guide designed to assist with fuel loading

signed to fit over the top nozzle of the neighboring WFA (See Figure 7) to eliminate this hang-up condition. The TNLG has been design, manufactured, and qualified and is available for use for current WFA assemblies with top nozzle/bottom nozzle engagement problems.

3. Summary of WWER-1000 Core Loading Enhancements

Westinghouse, in addition to developing the RWFA design, has developed and implemented core loading enhancements for Ukraine WWER-1000 Reactors as a result of the core loading difficulties experience at South Ukraine in 2012. Westinghouse has developed a core loading sequence approach and loading aides (smooth sided dummies and top nozzle loading guides) designed to minimize fuel assembly-to-fuel assembly interaction while maximizing the potential for successful loading (i.e., no fuel assembly damage and minimized loading trip limits and time). The demonstration of the successful deployment of these enhancements during the SU3 2015 reload enables application of RWFA fuel in reload quantities and will help achieve Ukraine's energy independence objective.