# An Optimized Refueling Outage for Pressurized Light Water Reactor Plants

Jeong-Ki Hwang*, In-Yong Kim, Tack-Sang Choi
*NSSS Division, KEPCO Engineering and Construction Company, INC.*
*1045 Daeduk-daero Youseong-gu Daejon 305-353*
**Corresponding author: hjk@kepco-enc.com*

## 1. Introduction

The goal of the optimization of the refueling outage duration is to establish no more than 17 calendar days as a normal refueling operation in a pressurized light water reactor(PWR) plant in accordance with the Utility Requirement Document[1,2]. It follows that the efforts for reducing the refueling outage duration has been made in nuclear power plants. With various efforts for shortening the refueling outage duration and for increasing the operating and equipment reliability, the utilization factor for nuclear power plants in Korea is above 10% higher than that of the world-wide average in the year of 2008[3]. In this paper, various refueling method and equipment are presented, which are directly related to the reduction of the refueling outage duration.

## 2. Refueling Process and Improved Refueling Equipment

In this section the refueling method, upgrade of fuel handling equipment, permanent reactor cavity seal assembly and integrated head assembly are described.

### *2.1 Refueling Process*

There are two ways to replace fuel assemblies in a PWR plant; one is the full core offload that all fuel assemblies are withdrawn from the reactor and move to the spent fuel storage pool in the fuel building and then the fuel assemblies are reloaded to the reactor, the other is the in-core shuffling that most of the fuel assemblies are relocated in the reactor. It is known that some countries adopt the in-core shuffling. In Korea the full core offload shall be currently applied for an inspection of fuel assemblies reloaded [4]. If a refueling machine has an apparatus of the fuel inspection, the in-core shuffling may be applied to the fuel relocation in the reactor. Further detailed and specific technical review is necessary to apply the in-core shuffling. A refueling sequence comparison between full core offload and in-core shuffling is shown in Figure 1.

### *2.2 Upgrade of Fuel Handling Equipment*

Performance upgrade of the fuel handling equipment is one of the ways to shorten the refueling outage duration. The fuel handling equipment consists of a refueling machine, a spent fuel handling machine and a fuel transfer system. The speed of the refueling machine and the spent fuel handling machine can be increased up to two times without interfering fuel integrity. The upending and travelling time of the fuel cavity in the fuel transfer system should be optimized so that the refueling machine and the spent fuel handling machine have no time to be idled while they have fuel assemblies. Also the function of an automatic mode and offset operation is added to save the operating time of the refueling machine. The performance upgrade of the fuel handling equipment applies to many nuclear plants in the world. In Korea it applies to all PWR plants which are under construction and in operation.

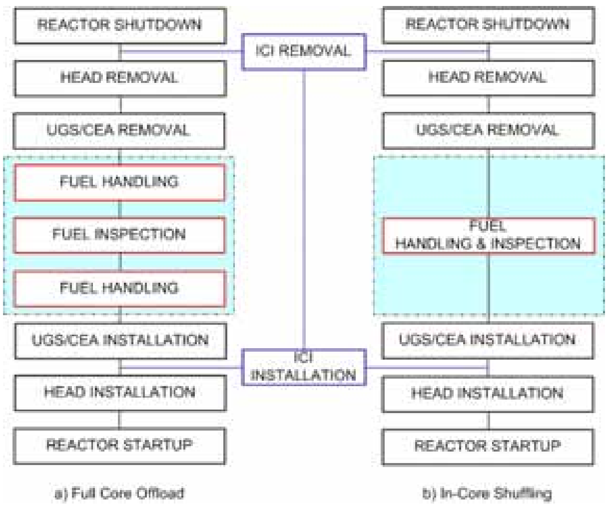


Fig. 1. A refueling sequence comparison between Full Core Offload and In-Core Shuffling

The fuel transferring performances for the fuel handling equipment are shown in Table I; the previous value is those of the normal fuel transfer before being upgraded and the upgraded value is those of the tests after being upgraded. Nowadays the new fuel handling equipment can transfer more than 6 bundles per hour. This can be saved by more than 2 days of the critical path during the refueling outage.

Table I: A comparison of fuel transferring performance

| Plants | Fuel Transferring Performance (fuel assemblies/hour) | |
|---|---|---|
| | Previous | Upgraded |
| Ulchin #3 | 2.5 ~ 3.0 | 6.94 |
| Yonggwang #4 | 2.5 ~ 3.0 | 6.25 |
| Yonggwang #2 | 2.5 | 6.46 |

### *2.3 Permanent Reactor Cavity Seal Assembly*

A reactor cavity seal assembly is designed to connect the reactor vessel seal ledge to the embedment ring in the refueling pool floor to permit filling of the refueling pool for fuel handling activities. Generally it is a removable type with large seals more than 50 mm in diameter. In 1984, the Haddam Neck plant experienced a failure of the refueling cavity water seal with the refueling cavity flooded in preparation for refueling. The refueling cavity water level decreased to the level of the reactor vessel flange which flooded the containment. If a similar seal failure were to occur at a plant during fuel transfer, fuel assemblies could be uncovered and could result in high radiation exposure to plant personnel, possible fuel cladding failure, and release of radioactive material [5]. In order to prevent the reactor cavity from flooding, a reactor cavity seal assembly having permanent steel seals was proposed, which is called a permanent reactor cavity seal assembly. A permanent reactor cavity seal assembly is a fixed structure and has two steel flexures which are welded to the seal ledge of the reactor vessel and the embedment ring of the refueling pool floor, respectively. The permanent reactor cavity seal assembly for OPR1000 is shown in Figure 2.

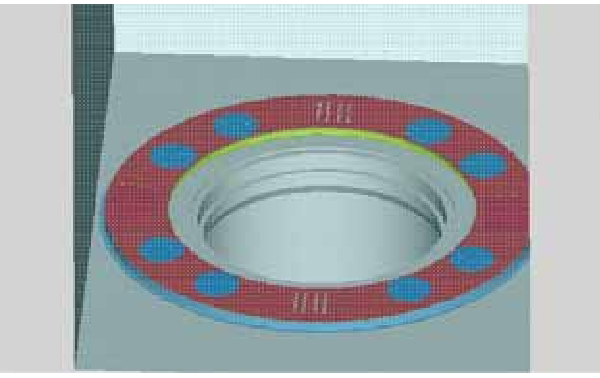

Fig. 2. The permanent reactor cavity seal assembly with refueling water for OPR1000

The permanent reactor cavity seal assembly was installed in Shinkori Units 1 & 2 and will be installed in other PWR plants under construction and in operation in Korea. The advantages of its application in comparison with the reactor cavity seal assembly in OPR1000 are; 1) the critical path during the refueling outage is shortened by the range of 5.5 to 10.5 hours, 2) the man power is saved by a minimum of 80%, 3) the radiation exposure of the personnel can be reduced by a minimum of 67%, and 4) the possibility of massive flooding in the reactor cavity is fundamentally excluded.

### *2.4 Integrated Head Assembly*

A great contribution to shorting the refueling outage duration is an integrated head assembly which is a process oriented one. The integrated head assembly consists of the structurally integrated equipment necessary for the handling and storage of the reactor vessel closure head, and additional equipment to perform functions for control element drive motor cooling, head area cable supporting, missile shielding, and seismic loads transmitting to refueling pool wall. All those equipment are assembled together and moved to the reactor vessel closure head storage stand in the operating floor as a single structure during the refueling outage.

The integrated head assembly was installed in Shinkori Units 1 & 2 and will be installed in other PWR plants under construction and in operation in Korea. The advantages of its application in comparison with the conventional head assembly in OPR1000 are; 1) the working day is shortened by approximately 4.5 days including 2.5 days of the critical path during the refueling outage, and 2) the radiation exposure of the personnel can be reduced by approximately 32%.

## 3. Conclusions

To increase the utilization factor by reducing the refueling outage duration for PWR plants, the followings were reviewed. 1) It is necessary to consider the in-core shuffling process. 2) The performance upgrade of the fuel handling equipment can save 2 days of the critical path. 3) The application of the permanent reactor cavity seal assembly can reduce 5.5 hours of the critical path. 4) The application of the integrated head assembly reactor cavity seal assembly can reduce 2.5 days of the critical path. 5) Shortening the refueling outage duration accompanies with the retrenching manpower and the radiation exposure.

## REFERENCES

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