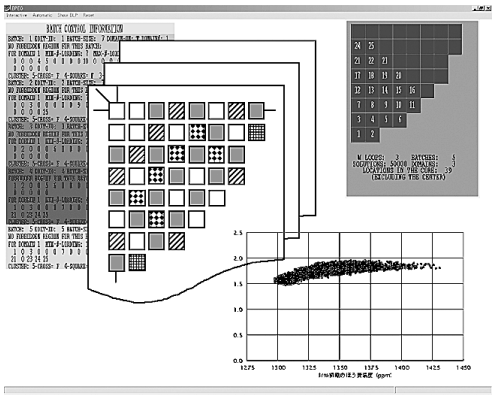

Development of PWR Fuel Loading Pattern Search Tool (Pearls™)

DAISUKE SATO*1

1. Introduction

In the Pressurized Water Reactor (PWR), annually about one third of the fuel assemblies are discharged, and the others are reloaded with new fuel assemblies. The best arrangement of new fuel assemblies and burnt fuel assemblies is searched for in the core design from the viewpoints of safety and economy.

This procedure is called the Loading Pattern (LP) search. In the LP search, the quarter symmetry pattern is usually employed to make the power distribution uniform. In such quarter symmetry cases, the number of LPs of a typical PWR that has 157 fuel assemblies in full core becomes astronomical about 10^{46}.

In the reload core design, it is necessary to decide the best LP in a limited time permitted to the nuclear design. In practical design, the designer is trying to search for the best LP based on his current experience with trial and error, although the requirements to be taken into account in core design will become more and complicated in the feature in accordance with the introduction of high burn-up fuel and MOX fuel etc.

Thus, PWR fuel loading pattern search tool (Pearls™)[1][2] has been developed so that an objectively wide-ranging search with considering a variety of design requirements can be achieved.

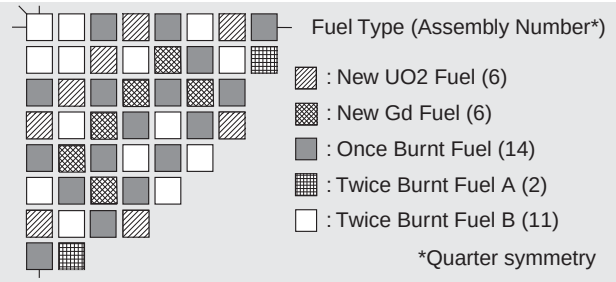

Fig. 1 Example of typical PWR group fuel (Batch) and group fuel loading pattern (BLP)
This figure shows the concept of Batch and BLP in Pearls™.

2. Pearls™ Method and Process

The procedure of a LP search contains the following 3 steps, (1) generating LPs by the relocation of burnt fuel assemblies and the new fuel assemblies, (2) performing the core characteristics calculation such as power distribution and critical soluble boron concentration, and (3) selecting the best LP from the viewpoint of safety and economy requirements. In Perls™ shifts the focus of LP search to step 1: the methodology of assembly shuffling and pattern generation.

The new fuel assemblies and burnt fuel assemblies assumed to be treated in several kinds of group fuel called "batch" according to their nuclear characteristics (**Fig. 1**). It is the most important in LP search to search for the location of the new fuel batch and the highly burnt fuel batch. This kind of batch loading pattern (BLP) grossly determines the major characteristics of the core.

In practical designs, designers try to make the coarse BLPs refined to individual assemblies manually. There are too many possible BLPs to investigate all of them. Besides, each BLP has a large number of its derived LPs. It is impossible for designers to track the individual LP consisting of many assemblies.

In Perls™, all possible BLPs are enumerated with satisfying the requirements. After selecting some of the BLPs according to the theory describing in the next paragraph, the BLPs are made to several new BLPs with using finer batches than previous batches. This procedure is called "Branching." After the some branching, the batches become individual assemblies providing real LPs. The branching process is carried out with the Branch & Bound (B&B) method with mixed the integer linear programming method. At that time, some design requirements can be considered, too.

When a batch is split into finer batches or become an individual assembly, a large number of daughter BLPs or LPs are generated as an integer permutation problem. In Perls™, this discrete integer problem is treated as a continuous real problem by assuming that the distinct assemblies could be arbitrarily taken apart and reassembled as a mixture.

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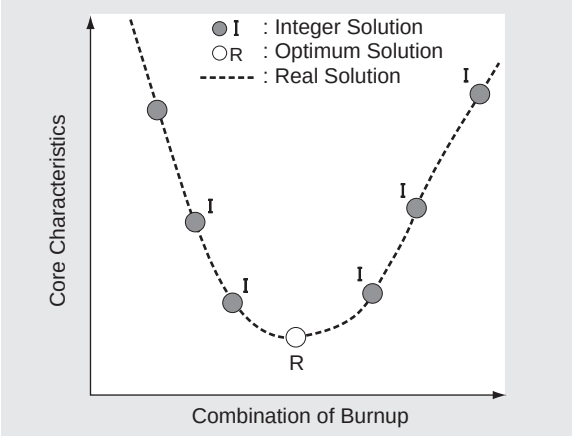

Fig. 2 Relation between fuel loading pattern (combination of burnup) and core characteristics
This figure shows the concept of the B&B method with mixed integer linear programming to the LP search in Pearls™.

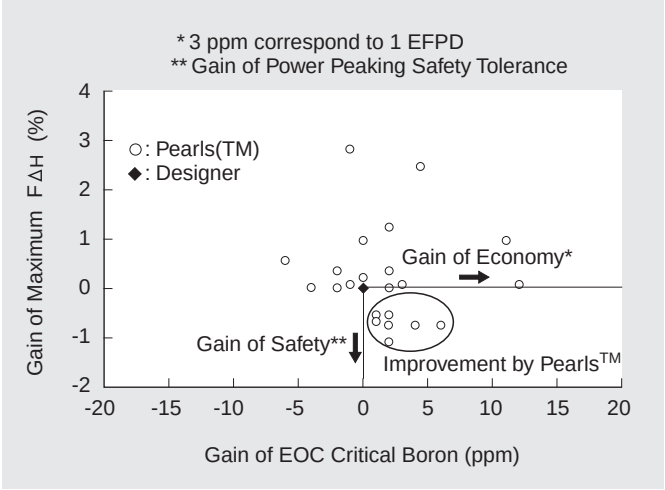

Fig. 3 Application results of Pearls™ for typical PWR
This figure shows the results of Pearls™ applying for reload core design.

The continuous real problem can be easily solved (**Fig. 2**). The best real solution always bounds the best integer solution. If the best real solution of the BLP is not acceptable, there is no need to branch and track all the daughter patterns. This means the whole BLP branches are investigated. Only surviving BLPs of which real solution is acceptable will be tracked further.

Furthermore, the mixed integer linear program can treat any design requirements that related to a linear combination of assembly average power, assembly average burnup and critical boron concentration. Thus, candidates are easily searched for and an effort to evaluate against useless BLPs was excluded by applying the B&B mixed integer linear programming method. Pearls™ makes LP search very efficient.

3. Pearls™ Application as Example

Pearls™ is applied to a typical PWR, and the result of LP search is shown in **Fig. 3**. The maximum local peaking factor ($F_{\Delta H}$) was assumed to be an index of safety and the critical boron concentration was assumed to be an index of economy. The Pearls™ LPs were compared with designer's results.

From this Fig. 3, it is found that Pearls™ can find equal or superior LPs compared with the designer's one from the viewpoint of the safety and economy, and the validity and the effectiveness of Pearls™ were confirmed.

4. Conclusion

PWR fuel loading pattern search tool (Pearls™) has been developed. The Pearls™ enabled an efficient LP search by using the B&B mixed with integer linear programming method that solves the combination problem for searching the optimal solution from an astronomical combination.

By applying Pearls™ to PWR LP search, it was possible to treat the design requirements complicated with the introduction of high burn-up fuel and MOX fuel etc, and in the viewpoint of the economy and safety, an excellent LPs can be decided efficiently in a limited time. As a result, it leads to the operating rate improvement by shortening the period of reload core design and contributes to the society as effective use for the limited fuel resource.

By using Pearls™ features that the design requirements can be easily treated, and considering the thermal hydraulics and fuel integrity evaluation on reload core design, the reload core design will be possible to improve the ability of reactor. Moreover, the best pattern search method used in Pearls™ can also be applied to the other fields, and the examinations are scheduled to the other field.

Note: Pearls™ is developed in Westinghouse Electric Company (WH) with the participation of Mitsubishi Heavy Industries (MHI) and Shanghai Nuclear Engineering Research and Design Institute (SNERDI), based on joint development projects of WH/MHI and WH/SNERDI respectively.

References

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