Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Technical Challenges for a Dual-Cooling Fuel Structural Components

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1. Introduction

This paper introduces mechanical component issues of a new concept PWR fuel, which is named as a "Dual-Cooling Fuel". The key feature of the dual-cooling fuel is readily discriminated by its annular cross-section of a fuel rod. So to speak, the fuel rod has an internal coolant passage in addition to an external one so that a fuel rod consists of coaxial inner and outer cladding tubes in which donut-shaped pellets are stacked. An intrinsic purpose of this shape is to increase the surface area of heat transfer which results in a reduction of the fuel temperature. The important effects of this idea are to enhance the fuel safety and to achieve a power uprating.

This idea has been recently studied at Massachusetts Institute of Technology (MIT) for about 3-4 years [1-3]. They picked up a conventional 17×17 PWR fuel of the Westinghouse type as a candidate and changed it into a 13×13 array fuel with increasing the outer diameter and making an additional internal flow passage. They found that the power uprating can be achieved by 50% with upgrading some necessary components of a nuclear power plant. Fuel performance, safety analysis and pellet fabrication were dealt with in their study but the fuel mechanical components have not been considered.

PWR fuel development division of Korea Atomic Energy Research Institute (KAERI) recently started a new project of developing a above-mentioned fuel technology through a National R&D Program by the Ministry of Science and Technology. One of the relevant projects is to develop a design technology of the major structural components of a double-cooling fuel. As for the components, fuel rod supporting structure, top and bottom end pieces, guide thimbles and instrumentation tube were chosen. Differently than the MIT's works, the dual-cooling fuel components have to be compatible with the OPR 1000 system without replacing the reactor internals. Therefore, many challenging problems have to be tackled in this project. This paper describes some of the key issues that should be resolved.

2. Tasks of Challenge for a Dual-Cooling Fuel Structure

2.1 Fuel Rods

Although a fuel rod is not a structural component of a dual-cooling fuel, the shape, dimension and configuration of a fuel rod is the very beginning point to determine the structural components. Since there exists an internal passage of coolant flow, the outer diameter of a fuel rod must be larger than that of a conventional solid fuel rod. This implies that a gap between fuel rods becomes smaller than that of a conventional fuel reflecting the constraint of the compatibility, i.e. the outer dimension of the cross section of a dual-cooling fuel assembly should be the same as that of the conventional fuel assembly as schematically illustrated in Fig. 1.

Change of fuel rod dimension and corresponding gap decrease influence not only geometrical and mechanical but also thermohydraulic conditions of the structural components such as dimensions, alignment, mechanical strength and characteristics, flow-induced vibration behaviour, pressure drop and so forth.

Fabrication method will also be one of the critical concerns. The most difficult problem may occur in the welding method between the end cap and the cladding. Since it is readily anticipated that the thermal and irradiation growth of the inner and outer claddings would be different, uneven stresses will be produced on the end cap welding location. A precise design and/or a challenging idea must be necessary on this matter. Besides this, a plenum spring, an insertion method of the pellets and a control of co-axiality of the inner and outer claddings are also of concern.

2.2 Fuel Rod Supporting Structure

The most challenging task in our work may arise in the fuel rod supporting structure of a dual-cooling fuel. Since the gap between the fuel rods decreases due to a larger fuel rod diameter, it is most important to check the applicability of the shape and feature of conventional spacer grids in the beginning stage. This is primarily concerned since the grid strap thickness as well as the formation of the springs and dimples are directly influenced by the gap. Even, a tolerance of the strap thickness can be critical for the applicability. The strap thickness also affects the strength of the grid structure, the pressure drop, the mechanical characteristics of the springs and dimples and the fabrication.

If a conventional concept of the grid structure (i.e., crossed straps to form cells with springs and dimples) cannot be applicable, a completely new concept is compulsory for supporting the fuel rods. Some important functions to be concerned are i) supporting method of fuel rods; ii) spacing method between fuel rods; iii) accommodation of fuel rod growth; iv) impact performance; v) thermohydraulic performance and vi) fabrication performance.

2.3 Top and Bottom End Pieces

Since a fuel rod has an internal flow passage in addition to an outer one, it is necessary to develop the shape, pattern and size of the flow holes of the top and bottom end pieces to perform intended direction and amount of the flow. In a conventional fuel case, for instance, the location of the holes of the bottom end piece does not coincide with that of the fuel rods lest they should drop down into the holes even though the supporting force of the fuel rods is completely lost. However, this may not be accepted in the case of a dual-cooling fuel rod since the flow into the internal passage could not be easily developed. Besides the flow concern, pressure drop and mechanical strength are other design constraints that are influenced by the flow holes.

Since the internal flow passage is a key feature of the dual-cooling fuel rod, any blockage of the internal flow passage should be strictly prohibited. Therefore, debris filtering is another important requirement of the bottom end piece. It can be achieved by adopting the conventional remedies such as to apply an additional grid onto the bottom end piece or other methods to trap the debris at the flow holes. Pressure drop caused by these methods will become a constraint of opposite side.

On the other hand, a holddown spring may be altered in the top end piece if the fuel assembly weight, volume and flow force are changed in the dual-cooling fuel.

2.4 Guide Thimbles and Instrumentation Tube

The outer diameter and array of the dual-cooling fuel rods also affect the dimension of the guide thimbles and instrumentation tube. Also, to comply with the compatibility condition with an OPR 1000 internal system, the location and inner diameter of the guide thimble and instrumentation tube should correspond to the geometry of the control rod assembly and in-core instrumentation probes. The gap (space) between a guide thimble (or an instrumentation tube) and the surrounding fuel rods should be appropriately blocked from the thermohydraulic concerns. It may produce a very sophisticated problem if the thicknesses of them are strictly controlled.

From the viewpoint of the mechanical buckling, better strength may well obtained as the tubes are thicker. To the contrary, a thicker tube may cause poor neutron economy. Besides, the joint and connection parts are influenced by the thicknesses of the guide thimbles and instrumentation tube. From the fabrication viewpoint, it may readily be anticipated that the dimple formation on the instrumentation tube becomes difficult if it is thicker. To make a dashpot in the lower region of a guide thimble also depends on the thickness.

3. Concluding Remarks

A new national project is now launched to develop a dual-cooling fuel at KAERI for future PWR fuel technology. Although this has been previously studied at MIT, a lot of challenging works have to be tackled since one of the most important targets of our dual-cooling fuel is to achieve a compatibility with the existing OPR 1000 reactor internal system, which is the very different from what has been done at MIT. From a preliminary study of the structural components, a fuel rod supporting structure will be the most difficult component. Other than that, top and bottom end pieces, guide thimbles and instrumentation tube are included in the mechanical components to be developed.

ACKNOWLEDGEMENT

This project has been carried out under the Nuclear R&D Program by MoST.

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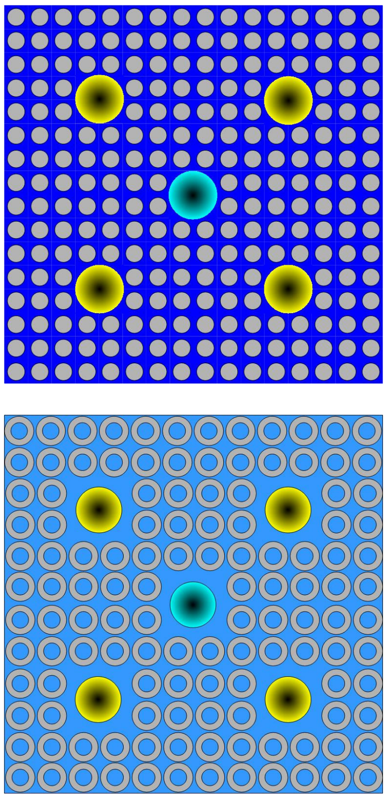

Fig. 1. Schematic of the fuel assembly cross-section of (a) conventional 16×16 and (b) dual-cooling fuel for OPR 1000.