MECHANICAL DESIGN OF THE STRUCTURAL COMPONENTS OF A DUAL COOLED FUEL

H.-K. Kim[1], J.-Y. Kim[1], Y.-H. Lee[1], K.-H. Yoon[1], K.-H. Lee[1], H.-S. Kang[1]
[1]LWR Fuel Technology Division, Korea Atomic Energy Research Institute, Daejeon, 305-353 KOREA
E-mail of corresponding author: hkkim1@kaeri.re.kr

ABSTRACT

A feature of dual cooled fuel is that the fuel rod consists of two coaxial tubes of different diameters and donut shaped UO_2 pellets stacked between the tubes. Reactor coolant flows inside and outside the fuel rod so that heat can be extracted from the rod more efficiently. This enables a considerable amount of power uprate. To maximize its economic benefit, it was our target to develop a dual cooled fuel for an existing power plant, the OPR-1000. To this end, structural components of the fuel assembly were designed such that the fuel assembly is compatible with the reactor internals as well as non-fuel bearing core components. Intrinsic difficulty arose from the fuel rod dimension. The diameter of the outer tube of the fuel rod was determined as 15.9 mm (9.5 mm for conventional fuel). The thickness of the tube, 0.87 mm was determined using the theory of elastic buckling. In turn, spacer grids and top/bottom end pieces were designed by incorporating the increased diameter and internal flow passage of a dual cooled fuel rod. Additional outer guide tubes were also designed to decrease the difference between the fuel rod gap, and the fuel rod and guide tube gap. The mechanical design criteria of the components should be checked. It is shown that a dual cooled fuel assembly for the OPR-1000 can be designed without violating the mechanical design criteria, and even has better strength compared with a conventional assembly.

INTRODUCTION

From the viewpoint of economy and safety enhancement of an existing nuclear power plant operation, a fuel with longer burnup and/or power uprate is demanded. In fact, the former has been widely brought into focus rather than the latter. Materials of the fuel pellets and cladding tubes have been the major research subjects in developing the fuels for larger burnup. Recently, fuel for a power uprating has been studied by the MIT, USA with collaborative works of major fuel vendors. They studied an '*internally and externally cooled annular fuel*', which is termed '*dual cooled fuel*' in this paper. Its basic idea was to enlarge the heat transfer area of a fuel rod by using coaxial inner and outer cladding tubes. Actually, this innovative concept dates back to the mid 60's [1]. Almost all the subjects were covered in this research such as thermal hydraulics, safety analysis, mechanical behaviors, reactor physics, manufacturability of pellets, thermo-mechanical and irradiation performances, and even economic benefits of using dual cooled fuel [2]. The candidate fuel assembly design was based on the Westinghouse type LWR (light water reactor) 17X17 array fuels and changed the number and location of guide tubes for control rods. They also needed a replacement of the major components of the primary system. Also, the structural components of the dual cooled fuel were not considered in this study.

Due to the peculiar feature of a dual cooled fuel, i.e. increasing the heat transfer area through two coaxial fuel cladding tubes, the outer diameter of the outer cladding tube will be considerably increased from that of the conventional fuel rod. The thickness of the outer tube should be increased correspondingly from a stability standpoint. If it is intended that the dual cooled fuel be used in an existing plant without changing the reactor internal structures and non fuel bearing core components, the increase in the outer diameter of a fuel rod significantly affects the fuel rod array (must be reduced) as well as the structural components of the fuel assembly such as the spacer grid, top and bottom end pieces, and the guide tubes. There are a lot of challenging issues in their mechanical design correspondingly, the resolutions of which are the very purpose of the present research. For the reactor system for our dual cooled fuel, the OPR-1000 system (Korean Standard Nuclear Power System) was selected. The crucial mechanical design issues for a fuel rod and structural components of a fuel assembly are listed as follows. This paper presents their resolutions.

1) Fuel rod cladding thickness
    - Concern of elastic buckling corresponding to the increased diameter especially for the outer tube
2) Spacer grid assembly
    - Formation and contact force of springs and dimples due to the dimension, weight, and array changes of the fuel rods

   - Mechanical strength corresponding to the reduced number of straps
3) Top and bottom end pieces
   - Pattern and size of the flow holes incorporating the flow passage through the fuel rods, especially for the inner cladding tubes
   - Mechanical strength corresponding to the changed pattern and area of the flow holes
4) Guide tubes
   - Concern of flow area around the guide tubes due to the changed fuel rod diameter and array
   - Mechanical strength corresponding to the change of the tube cross section

MECHANICAL DESIGN OF FUEL ROD CLADDING THICKNESS

The characteristic dimension of a cladding tube of the conventional OPR-1000 fuel is 9.5 mm in diameter, 0.57 mm in thickness and 4069.74 mm in length (nominal values). It was decided that the tube would be used as an inner cladding of a dual cooled fuel. Also, the length was not changed, while the diameter of the outer cladding tube was determined as 15.9 mm (nominal) from the thermal-hydraulics design. This is considerably increased from the conventional tube diameter by around 67%. Determining the outer cladding's thickness is a critical issue since it directly affects the UO_2 amount inside a fuel rod and resultantly the fuel to moderator ratio, which is a critical parameter in nuclear design and fuel performance.

However, such a large diameter has not been used for commercial fuel rods thus far. Little reference data exists. The parameter, t/D (thickness to diameter ratio) has been generally used in the tube design. It was found that t/D = 0.058-0.067 was used for the commercial LWR fuels [3]. However, it resulted in a considerable shortage of UO_2 if the ratio was adopted. It was inevitable to reduce the ratio but how much to reduce and which criterion to apply were definitely new tasks. Structural stability and integrity were taken into consideration. The tube thickness should be sufficiently large to prevent the fuel rod from instantaneous and permanent deformations. Thus, possible deformation types of fuel cladding tube were studied such as elastic buckling, plastic deformation, creep collapse, diametral shrinkage, dimpling and axial wrinkling.

The occurrence of elastic buckling and plastic deformation were brought into focus for the criteria of thickness determination since those were regarded critical for this particular case of dual cooled fuel. Elastic buckling of a tube is an instantaneous collapse occurring when the external pressure exceeds a critical value (termed "critical buckling pressure"). Griffin's [4] and Morgan's [5] works can be consulted. Their theories and derivations of the formulae have already been investigated [6]. Thus, only the resultant formulae are reproduced here with the designation of $p_{cr}{}^{G}$ and $p_{cr}{}^{M}$ for Griffin's and Morgan's formula, respectively.

$$p_{cr}^{G} = \frac{\eta E_s}{4(1-\mu^2)}\left(\frac{t}{r}\right)^3 \text{ and } p_{cr}^{M} = \frac{\xi E}{4(1-\nu^2)}\left(\frac{t}{r}\right)^3 \tag{1}$$

where, t and r are the thickness and mean radius of a cladding tube, respectively. Also, E and ν are the elastic modulus and Poisson ratio, respectively, and η and ξ are defined as

$$\eta = 1 - \frac{1-\dfrac{E_t}{E_s}}{1+\dfrac{(1-4\mu^2)E_t}{3E_s}} \; ; \; \mu = \frac{1}{2} - \left(\frac{1}{2} - \nu\right)\frac{E_s}{E} \; ; \; \xi = \frac{E_s}{E}\frac{1-\nu^2}{1-\nu'^2}\left(\frac{1}{4} + \frac{3}{4}\frac{E_t}{E_s}\right)\frac{E_s}{E} \; ; \; \nu' = \frac{1}{2} - \frac{1}{5}\frac{E_s}{E} \; . \tag{2}$$

In Eq. (2), E_t and E_s are the tangential modulus and secant modulus, respectively. It is readily derived that both $p_{cr}{}^{G}$ and $p_{cr}{}^{M}$ are deduced to be the same as Eq. (3) if $Es = Et = E$ (i.e., the material is perfectly linear) and ν = 0.3 (for Morgan's formula in particular). In addition, Eq. (4) is generally used as a formula of critical buckling pressure for a nuclear fuel rod [7], designated as $p_{cr,el}$, which is more conservative expression of Eq. (3) since t and r are replaced with t_{min} (minimum thickness) and $r_{m,max}$ (maximum mean radius), respectively. Eq. (4)

$$p_{cr} = \frac{E}{4(1-\nu^2)}\left(\frac{t}{r}\right)^3 \tag{3}$$

$$p_{cr,el} = \frac{E}{4(1-\nu^2)}\left(\frac{t_{\min}}{r_{m,\max}}\right)^3 . \tag{4}$$

Besides the elastic buckling, a formula of plastic deformation has been given as follows [7].

$$p_{cr,pl} = \frac{2t_{\min}\sigma_{ys}}{D_o - t_{\min}} \tag{5}$$

where, D_o and σ_{ys} are the outer diameter and yield strength of the tube, respectively.

The safety factor of the elastic buckling (S_{el}) and that of the plastic deformation (S_{pl}) are then obtained as follows.

$$S_{el} = \frac{p_{cr,el}}{p_D} \text{, and } S_{pl} = \frac{p_{cr,pl}}{p_D} \tag{6}$$

where, p_D is a design pressure, i.e. the pressure difference between the external and internal pressures of a fuel rod. Finally, the minimum thickness is to be determined such that $S_{el} > 1$ and $S_{pl} > 1$.

Fig. 1 shows the S_{el} and S_{pl} in terms of the minimum thickness to outer diameter ratio when p_D = 10.5 MPa (assuming 15.5 and 5.0 MPa for the external and internal pressures, respectively).

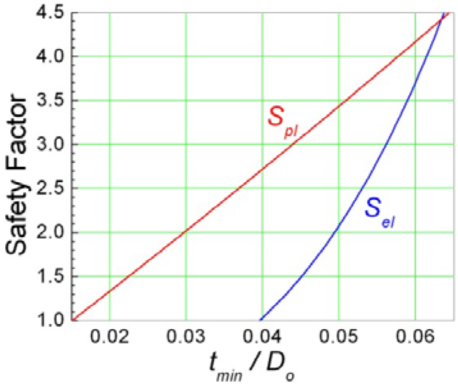


Fig.1: Safety factors of the elastic buckling (S_{el}) and plastic deformation (S_{pl}) with respect to the minimum thickness to outer diameter ratio of a fuel rod cladding tube (at the design pressure of 10.5 MPa)

According to Fig. 1, it is shown that the use of elastic buckling formula will provide a more conservative result than the plastic deformation. Therefore, the thickness of outer cladding tube of a dual cooled fuel is to be designed based on the elastic buckling. If a safety factor of 1.0 is assumed, t_{min}/D_o = 0.04 and the thickness is evaluated as 0.63 mm. However, this is acceptable as long as the formula (Eq. (4)) is valid under an actual condition. So to speak, the formula has been derived theoretically [4,5] so it may be necessary to investigate the validness of the formula. For the purpose of it, an experiment was carried out to check the conservatism of the formula and its uncertainty was analyzed independently. These were presented elsewhere [6,8]. The essence of the results are reproduced here.

From the experiment with zircaloy-4 tubes of 13.12 mm diameter and 0.38 mm thickness under the environment of 350°C and p_D = 2.27-9.44 MPa, the elastic buckling formula (Eq. (4)) underestimated the actual buckling pressure by around 18.2% [6]. In turn, the tolerances of the diameter and thickness, and the measuring uncertainties of the elastic modulus and Poisson’s ratio, which constitute Eq. (4), have been considered for the uncertainty analysis [8]. It was found that a safety factor of at least around 1.6 should be necessary from the uncertainty analysis. This depends on the thickness and diameter values.

Consequently, the thickness of the outer cladding tube of our dual cooled fuel was determined to be 0.87 mm (nominal) after compromising with the thermal-hydraulic, thermo-mechanical, and neutronic analyses, which can be found in the reference [9]. This implies that t/D = 0.055, which is slightly smaller than the conventional fuel case (i.e., 0.058-0.067). The corresponding safety factor was evaluated as 2.33 from the viewpoint of elastic buckling occurrence.

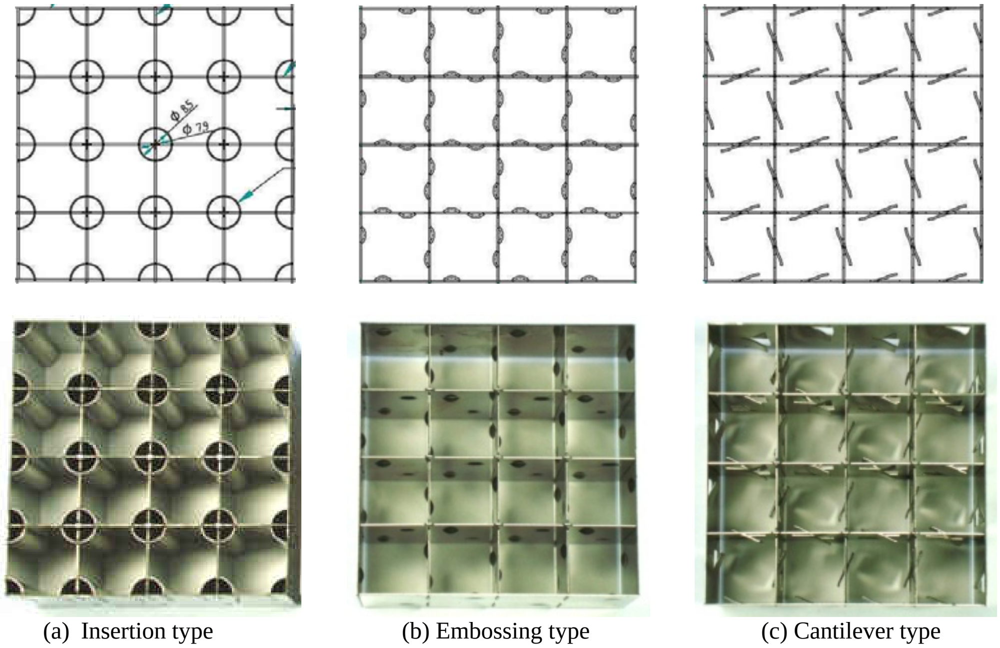
On the other hand, the plastic deformation was considered for the inner cladding tube. As mentioned, a conventional cladding of a solid fuel rod was adopted for the inner cladding, i.e. 9.5 mm and 0.57 mm for the diameter and thickness, respectively. Then, $p_{cr,pl}$ was obtained as 35.34 MPa with t_{min} = 0.49 mm (=0.57–0.08) and σ_{ys} = 324.92 MPa (Zircaloy-4 at 350^{o}C). The corresponding safety factor was 3.37, which is much larger than that of the elastic buckling as stated.

MECHANICAL DESIGN OF STRUCTURAL COMPONENTS OF FUEL ASSEMBLY

Spacer Grid Assembly

In general, fuel rods are supported by the springs and dimples of a spacer grid assembly, which consists of perpendicularly crossed thin strips. Each fuel rod is inserted into a square cavity constituted by the crossed strips, called a ‘cell’. In each cell, part of a strip is protruded to form the springs and dimples that are in contact with the fuel rods. Therefore, the distance between the fuel rod and strip surfaces should be enough to form the springs/dimples. The friction force between the springs/dimples and fuel rod’s surface should be sufficient to prevent a fuel rod from dropping down but less than that affords the irradiation growth of a fuel rod to prevent bowing. To sustain a positive contact (positive contact force) between them during a fuel life would be necessary to alleviate fretting wear failure.

In the case of a conventional cylindrical fuel, the springs and dimples are usually located at the center of the cell width. For instance, the smallest distance between the conventional fuel rod and spring/dimple is around 3.0 mm since the diameter of a conventional rod is 9.5 mm with a pitch of 12.8 mm. The grid strip thickness is 0.46 mm so even the smallest distance between the fuel rod surface and spring/dimple is greater than the strip thickness. However, this is not the case of the dual cooled fuel. Fuel rod pitch was evaluated as 17.1 mm in the case of the dual cooled fuel of a 12X12 array with a fuel rod diameter of 15.9 mm. As a result, the smallest distance was evaluated as 0.38 mm, which is even smaller than the strip thickness. This implies that the springs and dimples cannot be located at the center of the cell width.



(a) Insertion type (b) Embossing type (c) Cantilever type

Fig.2: Candidate designs of a spacer grid for a dual cooled fuel and fabricated mockup specimens

Under this circumstance a possible way is to move the springs and dimples toward the cell corners. Fig. 2 shows three candidate designs of the spacer grids (insertion, embossing and cantilever types) together with the mockup specimens of a 4X4 array. Characterization tests were carried out with the specimens, and the results are provided in Fig. 3. It was found that the stiffness of the cantilever type has the lowest value (68.9 N/mm) when compared with that of the embossing (1327.1 N/mm) and insertion type (1806.1 N/mm). All types show a good linearity with respect to the applied displacement. It was found that the contact forces of all types are larger than the minimum required force, 7 N, when a dual cooled fuel rod is inserted.

Therefore, it is concluded that all the developed types can be used as the candidates of a spacer grid spring for our dual cooled fuel. However, a fuel rod insertion test showed that the insertion type spring was too stiff. Also, the embossing type spring is preferably used as a dimple rather than a spring. Thus a combination of the cantilever type spring with the embossing type dimple was suggested for the dual cooled fuel assembly.

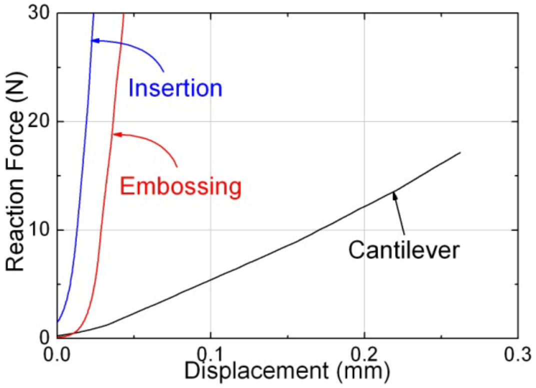


Fig.3: Characteristic results of each type of grid spring

Besides the conventional spacer grid type mentioned above, a completely new concept of a fuel rod supporting structure was also developed. It is composed of two (upper and lower) *horizontally* oriented straps with holes for clamping fuel rods as well as for coolant flow and a truss of thin wires between them. The truss structure was used for reinforcing the buckling and impact strengths in the lateral direction. This is called a "*perforated plate support with truss structure*", the schematic and mockup specimen of which are illustrated in Fig. 4. It may be used both for the mid grids and bottom grid.

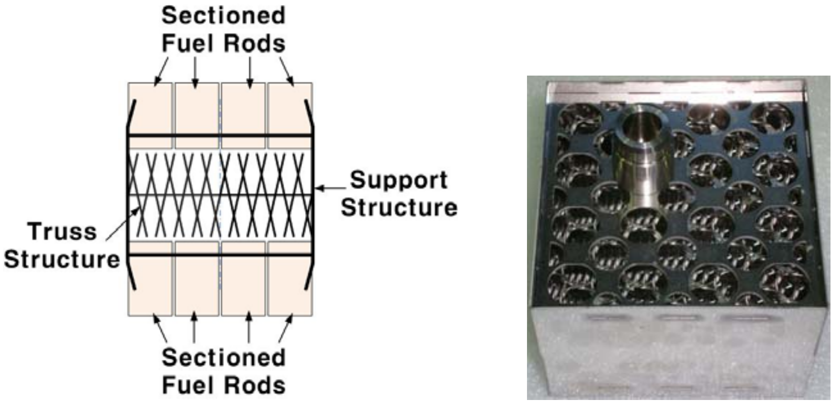


Fig.4:.Schematic and mockup specimen of the perforated plate support with truss structure

If used for mid grids, fuel rods are to be divided into more than two pieces. Fuel rod sectioning has not been commercially shaped thus far. However, it may give another positive aspect to the dual cooled fuel rod, i.e. to alleviate the inner tube's vibration. Since the inner cladding cannot be supported along its full length, an excessive vibration may be a concern of a dual cooled fuel. The perforated horizontal plates can take a role of inner cladding support as well as outer cladding support. Thus the idea of horizontally aligned plates and sectioned fuel rods will be a strong candidate for a supporting structure of dual cooled fuel rods.

On the other hand, the truss structure may have a debris-filtering capability. Conventionally, a bottom end piece with small holes and/or a debris filtering grid, a so-called protective grid, has been being used to prevent a fuel assembly from debris-induced failure. The debris protective grid usually located just above the bottom end piece so that the debris that passes through the flow holes of the bottom end piece can be trapped inside the protective grid. On this matter, the truss of thin wires is expected to take a role of debris capturing since the cavities between the wound wires are small enough to capture the debris efficiently. This feature can be used not only for dual cooled fuel but also for conventional fuel. These innovative concepts of a sectioned fuel rod and truss reinforced plate type grid have been applied for US patents [10-12].

Top and Bottom End Pieces

To maintain the geometrical compatibility with the OPR-1000 reactor internals, the shape and dimension of the interfacing parts of the top/bottom end pieces should not be changed from those of conventional fuel. The simplest solution is to directly use the conventional top and bottom end pieces for our dual cooled fuel. However, a problem arises in the flow hole size and pattern. In a conventional fuel, it has been designed such that the flow holes of the top and bottom end pieces are located between the fuel rods to prevent the rods from being escaped out through the holes in any case. This is also for the coolant flow to be directed between the fuel rods to extract heat more efficiently.

However, the holes at the fuel rod locations may be strongly necessary for a dual cooled fuel since a sufficient coolant flow through the internal flow passage is highly required. Thus the design was carried out such that the outside dimension of the top/bottom end pieces was maintained but the flow holes were modified, i.e. the size and pattern of the flow holes were changed. As a result, two different candidates were designed for each top and bottom end piece. As for the top end piece, a diamond and “X” like pattern (termed “type D and type X”, respectively) were designed, and the unit hole shapes of a circle and a rounded square (termed “type C and type S”, respectively) were designed for the bottom end piece. Figs. 5 and 6 show each pattern for the top and bottom end pieces, respectively together with a view of overlapping the conventional end pieces onto the dual cooled fuel rod array.

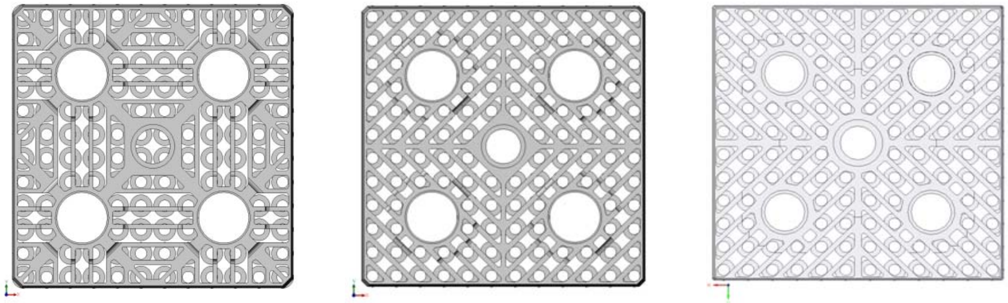

(a) Conventional (b) Type D (c) Type X

Fig.5: Flow hole pattern of the top end piece

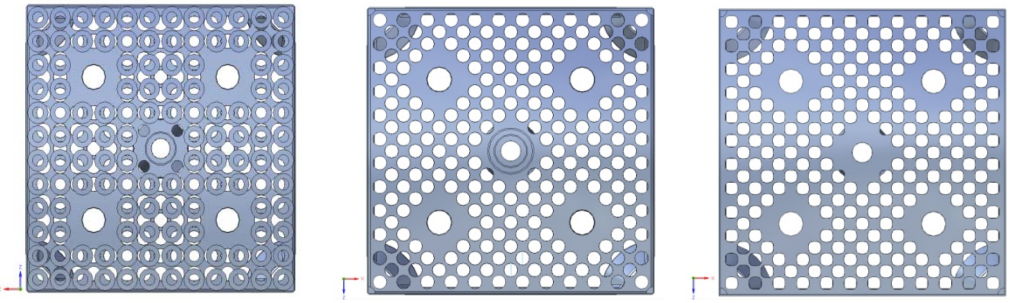

(a) Conventional (b) Type C (c) Type S

Fig.6: Flow hole pattern of the bottom end piece

Due to the additional flow hole at the fuel rod locations, the total flow area was increased relative to the conventional top and bottom end pieces. The increased ratios were 5.7% (Type D) and 6.6% (Type X) for the top end piece, and 9.4% (Type C) and 2.6% (Type S) for the bottom end piece. Another associated concern was the reduction of mechanical strength caused by the increase of flow area, even though the pressure drop decreased positively. Finite element analysis was conducted using ABAQUS [13]. The applied parametric values were: E (elastic modulus) = 193 GPa, ν (Poisson’s ratio) = 0.29, σ_{ys} (yield strength) = 215 MPa for the mechanical properties of type 304 stainless steel [14]. A quarter of the top/bottom end pieces was modeled with 10-node quadratic tetrahedron elements and actual boundary conditions.

The most severe load exerted to the top and bottom end pieces is 22.24 kN in the case of the fuel assembly handling (lift-up load). The Tresca stresses were obtained after using a stress linearization process according to the ASME NB-3200 [15]. In turn, these were compared with the stress intensity limits. Table 1 provides the results. As shown, every Tresca stress is far below the stress intensity limits. Thus it is soundly concluded that the newly designed flow holes and their patterns of the top and bottom end pieces sufficiently satisfy the strength criteria and improve the pressure drop.

Table 1: Tresca stresses of the top and bottom end pieces for a dual cooled fuel for the OPR-1000 (unit: MPa)

Component	Classification	Tresca stress	Stress intensity limits
Top end piece			
- Type D	P_m	5.02-10.15	215
	$P_m + P_b$	3.53-16.60	322.5
- Type X	P_m	4.58-10.17	215
	$P_m + P_b$	2.59-15.08	322.5
Bottom end piece			
- Type C	P_m	16.05-61.46	215
	$P_m + P_b$	13.56-127.38	322.5
- Type S	P_m	15.63-61.44	215
	$P_m + P_b$	13.69-128.78	322.5

P_m: primary membrane stress, P_b: primary bending stress

Guide Tubes

There are five guide tubes in a conventional fuel for the OPR-1000. The center guide tube is for the instrumentation and the others are for the control rods. It is necessary to maintain their shape and dimension for our dual cooled fuel in order not to change the control rod assemblies and instrumentation probes. This is important since the control rod drop time is critical for the nuclear power safety and directly depends on the gap between the control rods and guide tubes. However, to use conventional guide tubes alone for dual cooled fuel causes a hydraulic issue due to the considerable differences of the gap between the fuel rods and that between the fuel rod and guide tube. In other words, more coolant will flow around the guide tubes than around the fuel rods since the gap between the guide tubes and fuel rods is much larger than that between the adjacent fuel rods.

As a simple method to resolve this, an additional tube of larger diameter was applied outside the conventional tube (i.e., coaxial dual tubes were formed). The dimension of the additional outer tube was determined considering a hydraulic diameter. The target value of the hydraulic diameter of a guide tube of the dual cooled fuel was around 9.0 mm since that of the conventional fuel and the dual cooled fuel rod was 9.56 and 8.11 mm, respectively. As a result, the outer diameter of the outer tube was determined to be 33.50 mm with a thickness of 1.0 mm to achieve a hydraulic diameter of 9.0 mm. Fig. 7 shows a plan view of a 12X12 array including dual guide tubes.

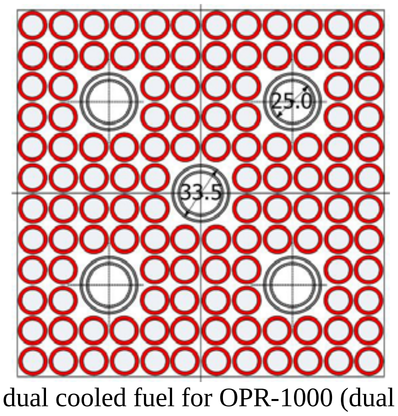


Fig.7: Plan view of 12X12 dual cooled fuel for OPR-1000 (dual guide tubes are illustrated)

The criterion of the control rod drop time was automatically satisfied since a conventional guide tube was still used for the control rod insertion. It is readily anticipated that the bending stiffness and buckling strength can also be satisfied since the area moment of inertia is increased by around 2.5 times due to the additional outer tube.

However, a detailed analysis was carried out to evaluate the bending stiffness and buckling strength using ABAQUS [13] again since the deformation sequence during horizontal bending will be somewhat sophisticated. If a horizontal load is applied to the dual guide tube, the outer guide tube will withstand the load at first. In turn, the outer tube will contact the inner tube as the load increases. After the contact, both the outer and inner tubes will withstand the load. As a result, it was found that the bending stiffness and buckling strength were increased by 2.87 and 3.47 times from those of a conventional guide tube, respectively.

CONCLUSION

To shape the dual cooled fuel for the OPR-1000, structural components of a fuel assembly, such as spacer grid, top and bottom end pieces, and guide tubes, were designed. A fundamental study on the cladding thickness was also done based on the elastic buckling theory, especially for the outer tube of the fuel rod. It was verified that a dual cooled fuel assembly can be designed without changing the reactor internal structures and control rods of the OPR-1000 based on the following results.

1) A conventional spacer grid type can be used through moving the location of the springs and dimples to and near the cell corners. A new concept of the *perforated plate support with truss structure* is also developed which uses segmented fuel rods.
2) Flow hole patterns of the top and bottom end pieces are modified such that the flow is directed to the fuel rod locations. The flow area is increased to mitigate the pressure drop but the structural strength is satisfied.
3) An additional outer tube is designed to surround the conventional guide tubes to adjust the hydraulic diameters of fuel rod and guide tube. This increases the bending stiffness and buckling strength of a fuel skeleton so the dual cooled fuel assembly will be much more robust compared with a conventional assembly.

ACKNOWLEGMENTS

This work was supported by Nuclear R&D Program of National Research Foundation grant funded by the Ministry of Education, Science and Technology of Korea.

REFERENCES

[1] Lackey, M.E., “Multi-region neutronic fuel element”, *US Patent 3,215,607*, 1965.

[2] Kazimi, M.S., et al., “High performance fuel design for next generation PWRs: Final report”, *MIT-NFC-PR-082*, 2006.

[3] Nuclear Engineering International, Sep. 2006, pp.32-36.

[4] Griffin, D.S., “Deformation and collapse of fuel rod cladding due to external pressure”, *WAPD-TM-591*, 1967.

[5] Morgan, R., “Report on external collapsing pressure of ELK River reactor fuel element tubing”, *ACNP 64-509*, 1964.

[6] Kim, H.-K., et al., “A study on the structural integrity issues of a dual cooled fuel rod”, *Proc. TopFuel 2009*, Paris, Sep. 2009, paper no. 2080.

[7] KAERI & Kraftwerk Union, “Fuel Design Report for 17X17 Assembly”, 1987.

[8] Kim, H.-K., Kim, J.-Y., Yoon, K.-H., “Mechanical design issues and resolutions of a dual cooled fuel for the OPR-1000”, *Nuclear Engineering and Design*, Vol.241, 2011, pp.2119-2127.

[9] Chun, T.-H., et al., “A potential of dual cooled annular fuel for OPR-1000 power uprate”, *Proc. TopFuel 2009*, Paris, Sep. 2009, paper no. 2185.

[10] Yoon, K.-H., et al., “Intermediate end plug assembly for segmented fuel rod and segmented fuel rod having the same”, *US Patent Application 12/420,874*, 2009.

[11] Yoon, K.-H., et al., “Perforated plate for dual-cooled segmented fuel rod”, *US Patent Application 12/421,829*, 2009.

[12] Yoon, K.-H., et al., “Truss-reinforced spacer grid and method of manufacturing the same”, *US Patent Application 12/849,431*, 2009.

[13] Simulia Co., “ABAQUS/explicit User’s Manual Ver. 6.8”, 2009.

[14] http://www.matweb.com.

[15] American Society of Mechanical Engineers, “ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, Class 1 Components Rules for Construction of Nuclear Facility Components”, 2007.