IMPROVEMENT OF INPUT PARAMETERS FOR THE ESTIMATION OF FUEL ROD TEMPERATURE IN DRY TRANSPORT CASK

J.C. Lee, K.S. Bang, J.H. Ku, K.S. Seo, D.K. Min, and S.G. Ro

Spent Fuel Management Technology Research Team
Korea Atomic Energy Research Institute
P.O.Box 105, Yusong, Taejon 305-600, Korea

SUMMARY

A typical PWR spent fuel bundle has a 17x17 rod array, and an analysis requires a very long computation time and a vast amount of memory. Therefore, we applied the lumped fuel bundle analysis approach with the homogenized method to estimate the fuel cladding temperature efficiently. Thermal analysis results for lumped fuel bundles showed an excessive radiative heat transfer, and we applied an emissivity modification factor to compensate for this radiation effect. The value of the factor decreased as the number of the rods in the homogenized array decreased. For the lumped 8x8 array, the best emissivity modification factor was shown to be 0.40. The rod emissivity of 0.8 is generally recommended to be used in COBRA-SFS[D. R. Rector et al.] calculations. Therefore, we can use the modified rod emissivity of 0.32 for lumped 8x8 array. There are good agreements between the results from lumped 8x8 array bundle and the results from real 17x17 array bundle. By homogenization, we can increase the computational speed substantially, as well as reduce the requirements on computer memory and space.

INTRODUCTION

All shipping casks for transporting spent fuels should be evaluated for their thermal integrity in accordance with the transport regulations prescribed in the IAEA regulations[IAEA 1985a and 1985b] and domestic atomic laws. One of the most important objectives in dry spent fuel transport cask design is to remove the decay heat from the fuel bundle and maintain the peak clad temperature below the allowable value. The objective of this study is to improve the input parameters for thermal analysis of fuel bundles in a dry transport cask using the COBRA-SFS code.

DESCRIPTION OF COBRA-SFS CODE

The COBRA-SFS code is a lumped-parameter, finite-difference computer code that predicts the flow and temperature distributions in spent fuel storage, transportation systems and fuel assemblies under mixed and/or natural convection conditions. The code provides finite-difference solutions to equations governing the conservation of mass, momentum, and energy for incompressible flows. Analyses are conducted with a subchannel approach in which the flow areas of assemblies or storage systems are divided transversely and axially into discrete control volumes. These conservation equations are then solved using an iterative implicit method. The energy equations for the coolant, rod cladding, fuel, and structural members are solved implicitly by iteration, simultaneously in a plane. Axial conduction in the structural members is considered. A nonparticipating media, gray body radiation heat transfer model allows for two-dimensional radiant heat exchange among all solid members in a given enclosure and is iteratively coupled to the rod and the wall energy equations.

The code RADGEN[D. R. Rector] is an ancillary radiation exchange factor generator for COBRA-SFS that uses these exchange factors to describe the net energy transferred from one surface to any other surfaces in an enclosure. RADGEN has the capability to handle the rod patterns of a square and triangular pitch, as well as open channel geometries.

IMPROVEMENT OF INPUT PARAMETERS FOR COBRA-SFS

Typical PWR spent fuel bundle has a 17x17 rod array. And the analysis requires a very long computation time, and a vast amount of memory and disk space. Therefore, the PWR bundles with 17x17 rod array are reduced to smaller ones by homogenization. Homogenization is a process which reduces larger fuel bundles, i.e., 17x17 bundles, which are the typical PWR fuel design nowadays, into smaller bundles, i.e, 8x8.

In the process of fuel bundle homogenization, the following important parameters should be considered as significant. The lumped fuel bundles have the same volumetric energy generation rate, total fuel cross-sectional area, axial fuel length and pitch to diameter ratio as the real 17x17 fuel bundle. These parameters will keep the total energy power and the geometric configuration.

Lumped Fuel Bundle Analysis

A three-dimensional model of the PWR single bundle is applied in this analysis. A cross section of the analysis model is shown in Figure 1. The decay heat from the fuel bundle is considered to be 1.75 kW and the fuel basket temperature is assumed to 150 ℃. In this analysis model, various rod arrays are considered from the lumped 4x4 array to the 17x17 array.

Thermal analyses were carried out in cases of convection-only, and convection and radiation, in order to evaluate the dominant heat transfer effect. Heat transfer from the rods and walls to the coolant is prescribed using the film coefficient of the form Nu=3.66[Kays, W. M., and M. E. Crawford]. The emissivity values for the fuel cladding and stainless basket are selected to be 0.8[Peterson. C.] and 0.3[Siegel R. and J. R. Howell]. The results are shown in Figure 2. For convection-only, the peak clad temperature does not change with lumped array sizes. This is expected, since homogenization should yield the same peak clad temperature as the original bundle. Hence, the homogenization process is adequate for the convection-only case. For convection and radiation, however, the peak clad temperature is a function of the lumped array size. The smaller the lumped bundle size, the lower the peak clad temperature and, hence, the higher the radiative heat transfer. In dry spent fuel cask thermal calculation, the radiation heat transfer is a dominant factor. For a 17x17 bundle, radiation reduces the peak clad temperature from 530 ℃ (convection-only) to 300 ℃ (convection and radiation).

For the small lumped bundle, fuel rods are less densely spaced and so radiation from one rod is less shielded by its surrounding neighbors. This decreased shielding by the surrounding fuel rods increases radiative heat transfer from the center hot rod to its neighboring rods and subsequently to the bundle wall. Hence, measures must be taken to compensate for the abnormal temperature decrement in the lumped fuel bundle.

Methods to Compensate for the Excess Radiative Heat Transfer

The reduced shielding in the lumped model tends to decrease the peak cladding temperature. Hence, the ways must be found to compensate for the excess radiation heat exchange by reducing the effective emissivity. To achieve this goal, a radiation modification factor is introduced to adjust the rod emissivity.

In COBRA-SFS, we take the peak temperature of the 17x17 array as the standard value under convection and radiation. We then calculate the peak clad temperature for the lumped array under the same physical conditions, except with a modified rod emissivity. If the temperature is different from the standard value, we adjust the rod emissivity and iterate until the two temperatures are equal. Finally, the rod emissivity modification factor is obtained for this lumped array. The rod modification factor is a function of several factors, but the most significant factor is a function of the lumped array size. A study to determine the modification factor is performed and the result is illustrated in Figure 3 using COBRA-SFS/RADGEN.

Verification of the Homogenization Procedure

In this study, we demonstrate that the homogenization procedure is applicable independent of the wall temperature. To do so, we will examine results at wall temperatures of 50, 100, 150, 200 and 250℃ using COBRA-SFS. Figure 4 shows the peak clad temperature as a function of the bundle wall temperature. For bundle wall temperatures ranging from 50 to 250℃, the peak clad temperature deviates by no more than 3 ℃ for arrays lumped to as small as 8x8. Hence, the homogenization procedure(geometry adjustment and the radiation modification factor) is adequate in representing the 17x17 arrays of the real fuel bundle by the lumped smaller arrays.

APPLICATION OF IMPROVED INPUT PARAMETER

Thermal analysis was carried out with the improved input parameters to verify the reliability of lumped fuel bundle analysis. We applied the improved input parameters to the analysis of KSC-4 spent fuel shipping cask. The cask was designed to transport 4 PWR spent fuel assemblies with a burn-up of 38,000 MWD/MTU and 3 years cooling time. The decay heat from the 4 PWR fuel bundles is about 7 kW. Figure 5 shows a cross section of the KSC-4 cask analysis model. To verify the radiation modification for lumped fuel bundles, two cases of 8x8 and 17x17 array bundles are considered in this analysis. A rod emissivity of 0.8 is considered for the 17x17 array and 0.32 is considered for the 8x8 array.

A comparison of the analysis results between the 8x8 and 17x17 arrays is shown in Table 1. There are good agreements between the two results, and it is shown that the lumped bundle analysis is successfully applied to estimate the fuel cladding temperature. The 8x8 lumped fuel bundle problem requires less than 300 CPU seconds, but about 3,000 CPU seconds is required for 17x17 bundle problem.

CONCLUSION

A bundle lumping approach was developed that makes it feasible for small computers to simulate bundles with large arrays. The analysis results for a lumped fuel bundles show an excessive radiative heat transfer due to the diminished shielding by the rods in the lumped fuel array. The effect is compensated by the emissivity modification factor. The modification factor decreases as the number of rods in the homogenized array decreases.

A rod emissivity of 0.8 is generally recommended to be used in COBRA-SFS calculations for 17x17 array bundle but the best emissivity factor is shown to be 0.32 for lumped 8x8 array bundle. Thermal analysis was carried out using the improved input parameters to verify the reliability of the bundle lumping method. The results showed very good agreement, and the bundle lumping approach is successfully established to estimate the fuel cladding temperature. By homogenization, we can increase computation speed substantially, as well as reduce the requirements on computer memory and space.

REFERENCES

D. R. Rector et al., "COBRA-SFS : A Thermal Hydraulic Analysis Computer Code," PNL-6049, Vol.II, UC-85, 1986.

D. R. Rector, "RADGEN : A Radiation Exchange Factor Generator for Rod Bundles," PNL-6342, UC-85, 1987.

IAEA Safety Series No. 6, "Regulations for the Safe Transport of Radiative Material," 1985a.

IAEA Safety Series No. 37, "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material," 3rd, 1985b.

Kays, W. M., and M. E. Crawford, "Convection Heat and Mass Transfer," McGraw-Hill Inc., New York, 1980.

Peterson. C., "Literature Search on Some Properties of Zircaloy-4 at High Temperatures," AECL-5101, Atomic Energy of Canada, LTD, 1972.

Siegel. R. and J. R. Howell, "Thermal Radiation Heat Transfer," 1st Ed. McGraw Hill, 1972.

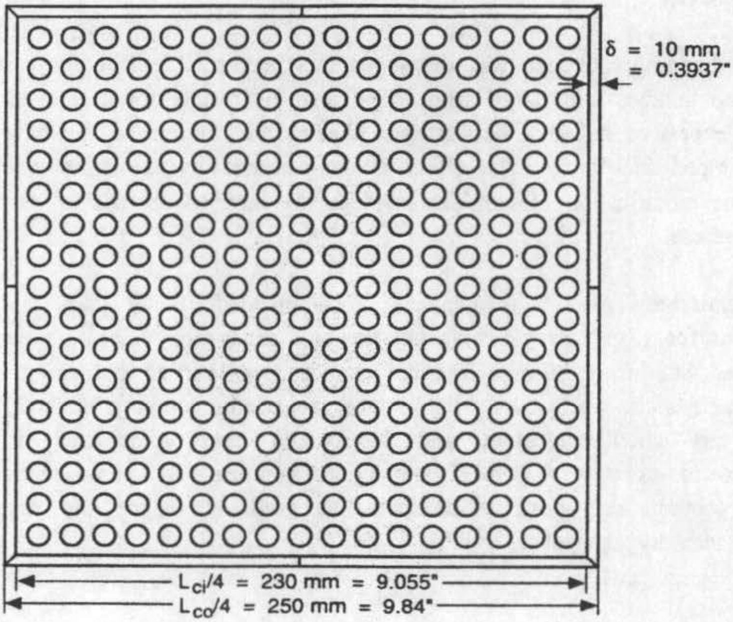

Figure 1. Thermal Analysis Model for 17x17 Array Bundle.

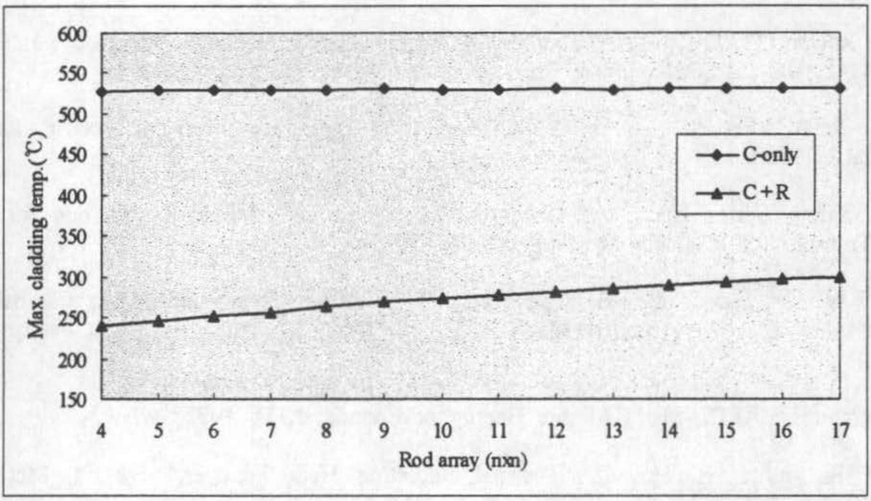

Figure 2. Maximum Cladding Temperature as a Function of Rod Array.

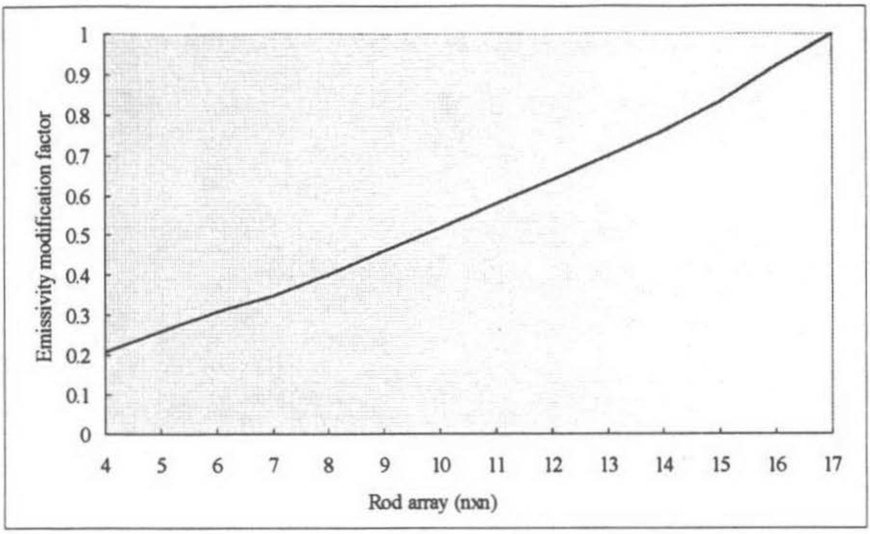

Figure 3. Emissivity Modification Factor as a Function of Rod Array.

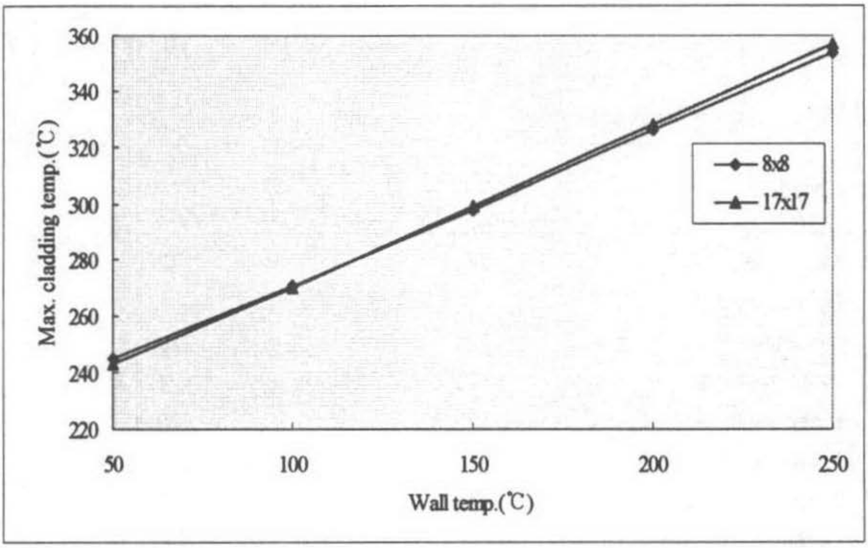

Figure 4. Maximum Cladding Temperature as a Function of Wall Temperature.

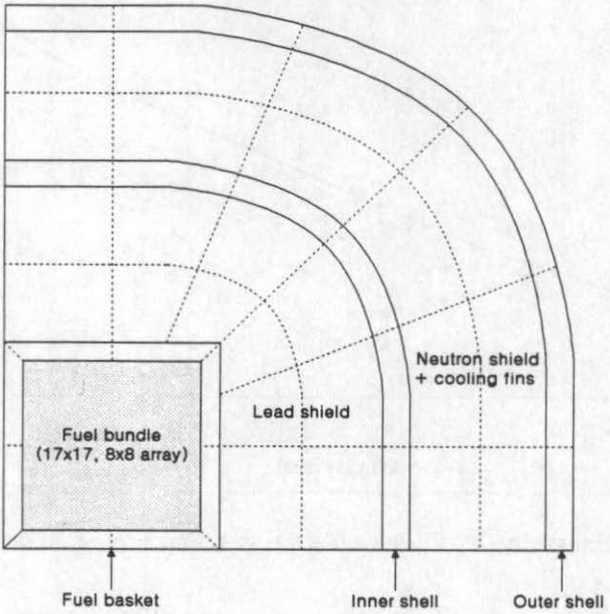

Figure 5. Thermal Analysis Model for KSC-4 Cask.

Table 1. Summarized Results of Thermal Analysis for KSC-4 Cask

Location	Calculated temperatures (℃)	
	8x8 lumped array bundle	17x17 array bundle
Max. fuel cladding	284	287
Basket wall		
- Inner wall	227	228
- Outer wall	123	124
Inner shell	120	120
Lead shield	118	118
Neutron shield	99	99
Outer shell	83	83