Assessment of the Lattice Characteristics for DCA using WIMS-D5

B.J. Min, W.Y. Kim, Y.A. Kim and K. J. Ryu
Korea Atomic Energy Research Institute
P.O. Box 105, Yusong, Taejon 305-600, Korea

S.K. Oh
Ajou University
Sna5 Wonchun-Dong Paldal-Gu Suwon 442-749, Korea

ABSTRACT

An investigation on the effect of the lattice characteristics for a Deuterium Critical Assembly (DCA) in JNC (Japan Nuclear Cycle Development Institute) has been performed. The DCA, the heavy water moderated and light water cooled pressure-tube type research facility, was designed not only for the core physics research, but also for the development of the core-related technology for the Advanced Thermal Reactor (ATR). The core structure of the ATR is highly heterogeneous and is separated from the heavy water moderator by a calandria tube. Therefore, neutron behavior is quite complicated and sensitive to a change of the core structure.

In this study, the assessment of the core physics characteristics such as the multiplication factor and the void coefficient for the DCA was conducted using the WIMS-D5 code and the results were compared with those of both the experimental data and WIMS-AECL.

1. INTRODUCTION

Since the neutron behavior of the DCA lattice is similar to that of the CANDU lattice, the feasibility study is performed with the experimental data of DCA using the analysis of the CANDU lattice characteristics. Regarding this, the assessment for the core physics characteristics of the DCA has been conducted using the WIMS-D5 code.

The DCA lattice characteristics such as the local power peaking factor (LPF), infinite multiplication factor, and coolant void reactivity are calculated by WIMS-AECL and WIMS-D5 codes with ENDF/B-6 nuclear data library. As the coolant void reactivity is an important parameter for the reactor design of a CANDU reactor, it is required to estimate the void reactivity accurately due to its positive void reactivity.

However, the measurement of void reactivity is limited to the fresh uranium fuel, it is required to extend the measurement to the irradiated fuel. At present, computational benchmark calculations are used as an alternative not only to verify the experimental results, but also to provide reliability of the void reactivity measurement in the stage of nuclear design and analysis.

In this study, the assessment of the lattice code is performed by the experimental data of the void reactivity at 0, 30, 70, 87 and 100 % void fractions, respectively. Four types of fuels (1.2w/o UO_2, 1.5w/o UO_2, 5SPu, 8Spu) with a 22.5 cm lattice pitch are selected for this study. In all four types of the fuels, the effective multiplication factors increase as the void fraction increases. The effective multiplication factors of WIMS-AECL are larger than those of WIMS-D5 for both the uranium fuels and 0.54PuO_2-UO_2 fuels. In the meanwhile, the coolant void reactivity of the core loaded with the plutonium fuel gave a greater negative value compared to that of the uranium fuel because of spectrum hardening due to the large void fraction.

2. CODE ASSESSMENT

A cluster composed of 28 UO_2 fuel pins with Al clad are arranged in a square lattice of 97 cells at a 22.5 cm pitch. Each cluster consists of three concentric layers of fuel pins; counting from the center outward, there are four pins in the first, eight in the second and sixteen in the third layer. The lattice consists of coolant, an Al pressure, an air gap, an Al calandria tube and a moderator. The heavy water used as the moderator is of 99.5 mol/o purity. The effective void fraction of the experimental coolant is changed from zero to unity with three intermediate fractions of 0.3, 0.7 and 0.87. The important safety parameters, such as infinite & effective multiplication factors and coolant void reactivity, are analyzed with WIMS-AECL and WIMS-D5 codes.

WIMS-D5 lattice code is released by OECD/NEA Data Bank and the WIMS-D library update (WLUP) is based on ENDF/B-VI consisting of 69 and 172 energy groups, respectively. WIMS-AECL code is improved using ENDF/B-VI library of 89 energy groups by AECL for CANDU reactors on the basis of WINFRITH for 20 years.

In this study, two kinds of core configurations are selected; (i) loaded with 1.2wt% enriched UO_2 fuel assemblies and (ii) loaded with 5Spu and 1.2wt% enriched UO_2 fuel assemblies. Lattice calculations are performed by the WIMS-AECL code and WIMD-D5 code. The effective multiplication factors and coolant void reactivities are calculated by using the measured bucklings and the transport and benoist theories are applied to compare the capability of these two codes, WIMS-D5 and WIMS-AECL.

3. RESULTS AND DISCUSSION

3.1. Infinite Multiplication Factor (K_{inf})

The infinite multiplication factors are calculated with WIMS-D5 and WIMS-AECL codes with various coolant void fractions for the 1.2 wt% UO_2 and 0.54 wt% PuO_2-UO_2 fuels, respectively. In Figure 1, the infinite multiplication factors increase as the coolant void fractions increase. However, the infinite multiplication factor decreases slightly at a 70% void fraction for the 1.2 wt% UO_2 fuel and 0.54 wt% PuO_2-UO_2 fuel. It seems that the boron insertion at a 70% void fraction causes a decrease in the infinite multiplication factor.

3.2. Effective Multiplication Factor (K_{eff})

The effective multiplication factors are calculated by using the measured buckling at DCA with the transport and benoist theories with the aim to compare the capability of WIMS-D5 and WIMS-AECL codes. As to the effective multiplication factors for the two types fuels, such as the 1.2 wt% UO_2 and 0.54 wt% PuO_2-UO_2 fuels, the results of WIMS-D5 code is closer to the experimental value, 1.0, than those of WIMS-AECL code as shown in Figures 2 and 3. In the sensitivity study, the results of WIMS-AECL show that the benoist theory is closer to the measured value than those of the transport theory. In terms of the energy group, the results of WIMS-D5 with 172 energy groups are in better agreement than those of 69 energy groups with the measured value. At a 100% void fraction, the results of both cases agreed well with the experimental value.

3.3. Coolant Void Reactivity

While the coolant void reactivity is positive in CANDU reactors, the void reactivity is negative due to the small lattice pitch and light water coolant in DCA critical reactor. The coolant void reactivity is calculated with various void fractions as shown in Figures 4 and 5.

In the Figures, the coolant void reactivity is more negative as the void fraction increases. The void reactivity of the core loaded with 0.54 wt% PuO_2-UO_2 fuels is more negative than that of the 1.2 wt% UO_2 fuel due to spectrum hardening. The void reactivity of the plutonium fuel cluster has a larger negative value than that of the uranium fuel because of the large plutonium cross-section. Since ^{239}Pu and

^{241}Pu have a giant resonance at a 0.3-eV energy, the plutonium fuel reduces void reactivity more effectively than the uranium fuel does.

Regarding the energy group, the difference of the coolant void reactivity between 69 and 172 energy groups is insignificant in the calculation of WIMS-D5 code. However, the void reactivity results of WIMS-AECL code are closer to the experimental value than those of WIMS-D5 code. As to the sensitivity of the methodology, the void reactivity using the benoist option inside WIMS-AECL agreed well with experimental value rather than that of the transport option. As for the two types of fuels, while the coolant void reactivity is similar to the measured value at a small void fraction for the 1.2 wt% UO_2 fuel, the 0.54 wt% PuO_2-UO_2 fuel agreed better with experimental data at a large void fraction.

However, since there are relatively large discrepancies at a 70% void fraction, it is required not only to conduct a reanalysis of the experimental data, but also to perform a code-to code validation between MCNP and WIMS-AECL codes in a future study

4. CONCLUSION

In this study, the infinite and effective multiplication factors and the coolant void reactivity are investigated by a comparison study between WIMS-D5 and WIMS-AECL codes using the experimental data of DCA. The conclusions of the present study are summarized as follows:

(1) The infinite multiplication factors are calculated by using WIMS-D5 and WIMS-AECL codes with various coolant void fractions for the 1.2 wt% UO_2 and 0.54 wt% PuO_2-UO_2 fuels. The results show that the infinite multiplication factors increase slightly as the coolant void fraction increase.

(2) The effective multiplication factors are calculated by using the measured buckling at DCA with the transport and benoist theories with the aim to compare the capability of WIMS-D5 and WIMS-AECL codes. As for the two types fuels, 1.2 wt% UO_2 and 0.54 wt% PuO_2-UO_2 fuels, WIMS-D5 code is closer to the experimental value, 1.0, than those of WIMS-AECL code. In the sensitivity study of WIMS-AECL code, the benoist theory is closer to the measured value than the transport theory. In terms of the energy group, the 172 energy groups are in better agreement than 69 energy groups.

(3) The coolant void reactivity becomes more negative due to spectrum hardening as the void fraction increases. In the sensitivity study, the difference of the coolant void reactivity between 69 and 172 energy groups was small. The benoist option is more proper rather than the transport option in WIMS-AECL code. While the coolant void reactivity is similar to the measured value at a small void fraction for the 1.2 wt% UO_2 fuel, the 0.54 wt% PuO_2-UO_2 fuel agreed better with the experimental data at a large void fraction.

(4) The void reactivity of the plutonium fuel cluster is a larger negative value than that of the uranium fuel because of the large plutonium cross-section. Since ^{239}Pu and ^{241}Pu have a giant resonance at a 0.3-eV energy, the plutonium fuel reduces the void reactivity more effectively than the uranium fuel does.

In conclusion, WIMS-D5 code with 69& 172 energy groups and WIMS-AECL code with 89 energy groups are validated by the measured data of DCA. For the effective multiplication factors, there is a good agreement between the experimental data and WIMS-D5 code with 172 energy groups. However, for the coolant void reactivity, there is a relatively close correlation between the measured value and WIMS-AECL with the benoist theory. Therefore, for the systematical validation of WIMS-D5 code, it is required not only to conduct a reanalysis of the experimental data, but also to perform a code-to code validation between MCNP and WIMS-AECL codes in a further study.

ACKNOWLEDGEMENT

This work has been carried out under the Nuclear Research and Development Program of Korea Ministry of Science and Technology.

REFERENCES

1. DONNELLY J.V., "WIMS-CRNL: A User's Manual for the Chalk River Version of WIMS", AECL-8955, Atomic Energy of Canada Limited, 1986.

2. KOWATA Y. and FUKUMURA N., "Study on Coolant Void Reactivity of Pressure-Tube-Type Heavy Water Lattice by the Substitution Method", *Nucl. Sci. Eng.*, **99**, pp.299-312 (1988)

3. AIHARA N. et al. "Axial Dependence of Partial Void Reactivity in a Light Water Cooled, Heavy Water Moderated, Pressure Tube Type Reactor", *Nucl. Sci. Eng.* **109**, 158 (1991)

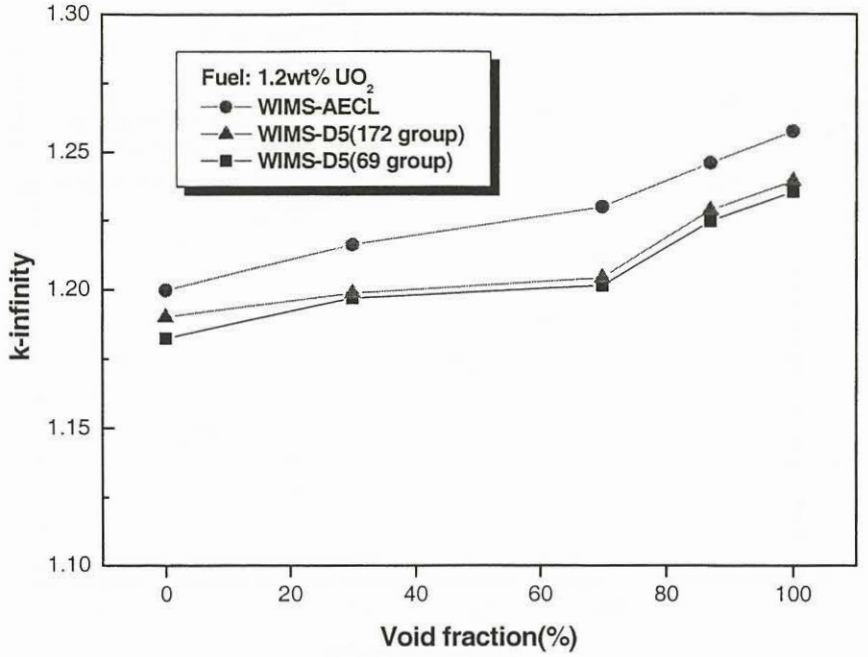
4. HACHIYA Y. et al., "Lattice Parameter Measurements on Cluster-Type Fuel for Advanced Thermal Reactor", *J. Nucl. Sci. & Tech.* **13**(11), 618 (1976)

5. WAKABAYASHI T. and HACHIYA Y., "Thermal Neutron Behavior in Cluster-Type Plutonium Fuel Lattices", *Nucl. Sci. Eng.* **63**, 292 (1977)

6. SHIBA K., "Substitution Measurements on 28-Fuel-rod Critical Clusters in D_2O and Their Analysis by the Second Order Perturbation Method", *Nucl. Sci. Eng.* **65**, 492 (1978)

7. MIN B.J., KIM S.Y., RYU S.J. and SUK H.C., "Analysis of Experimental Data", Proceedings of the Korean Nuclear Society Spring Meeting, Korea, May 2000.

8. M.J. Halsall and C.J. Tauman, "WIMS-D: A Neutronics Code for Standard Lattice Physics Analysis," AEA Technology, 1986.



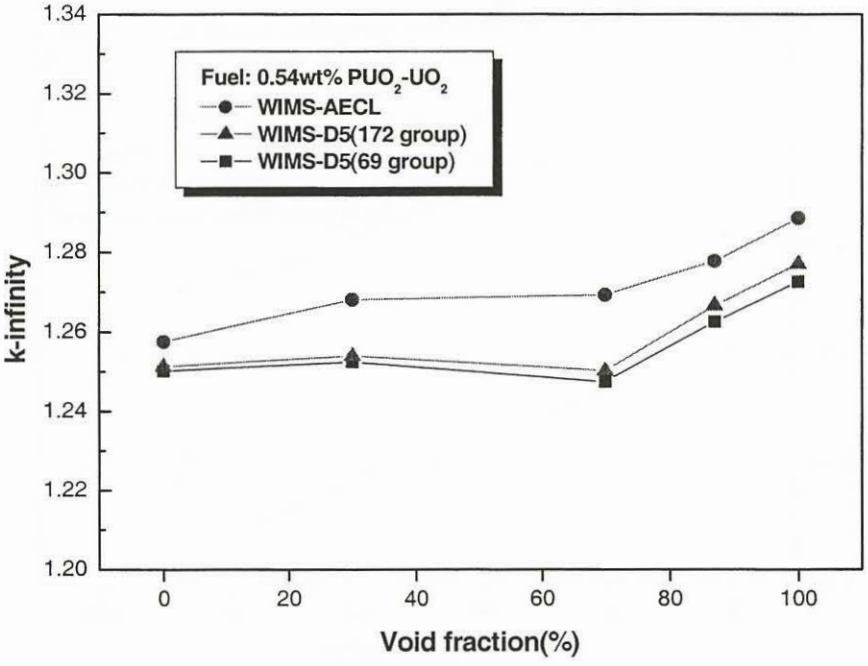
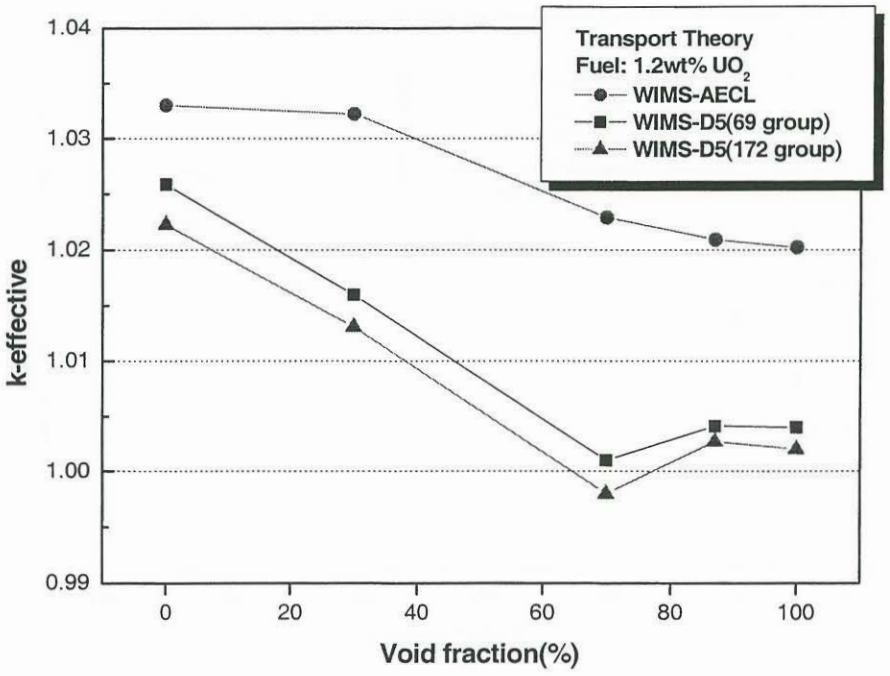


FIGURE 1. THE INFINITE MULTIPLICATION FACTOR DUE TO COOLNAT VOID FRACTIONS



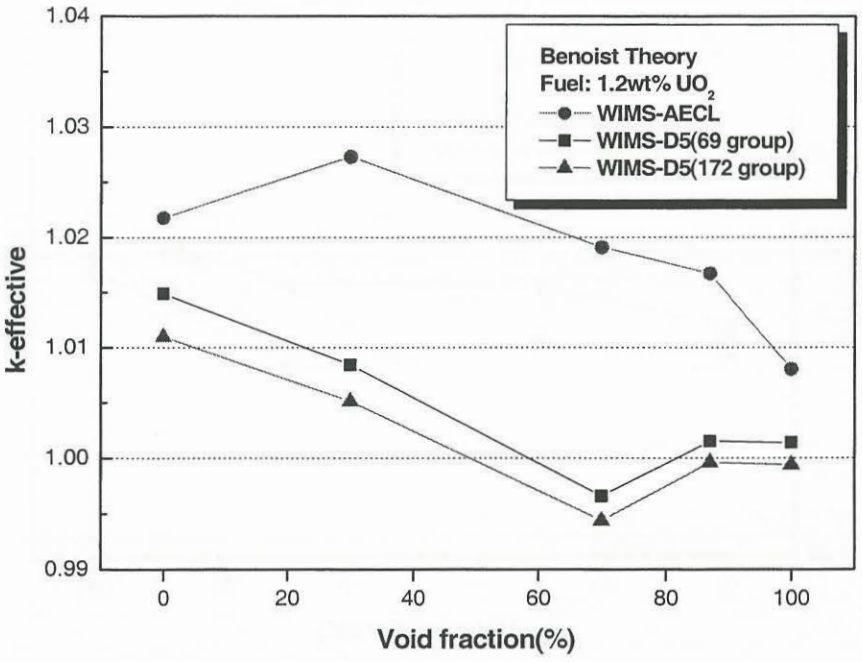


FIGURE 2. EFFECTIVE MULTIPLICATION FACTOR DUE TO COOLNAT VOID FRACTIONS FOR 1.2 wt% UO_2 FUEL

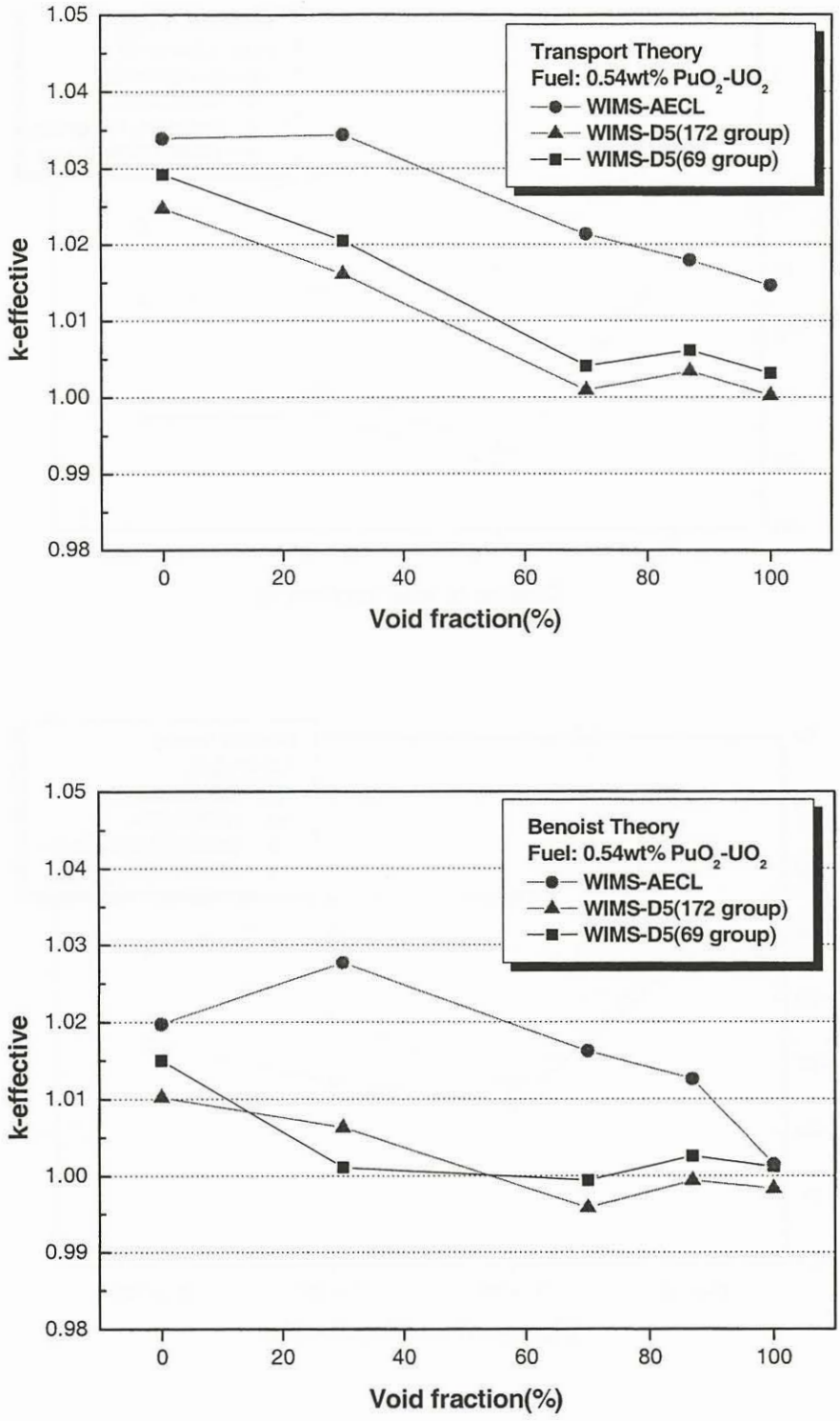


FIGURE 3. EFFECTIVE MULTIPLICATION FACTOR DUE TO COOLNAT VOID FRACTIONS FOR 0.54 wt% PuO_2-UO_2 FUEL

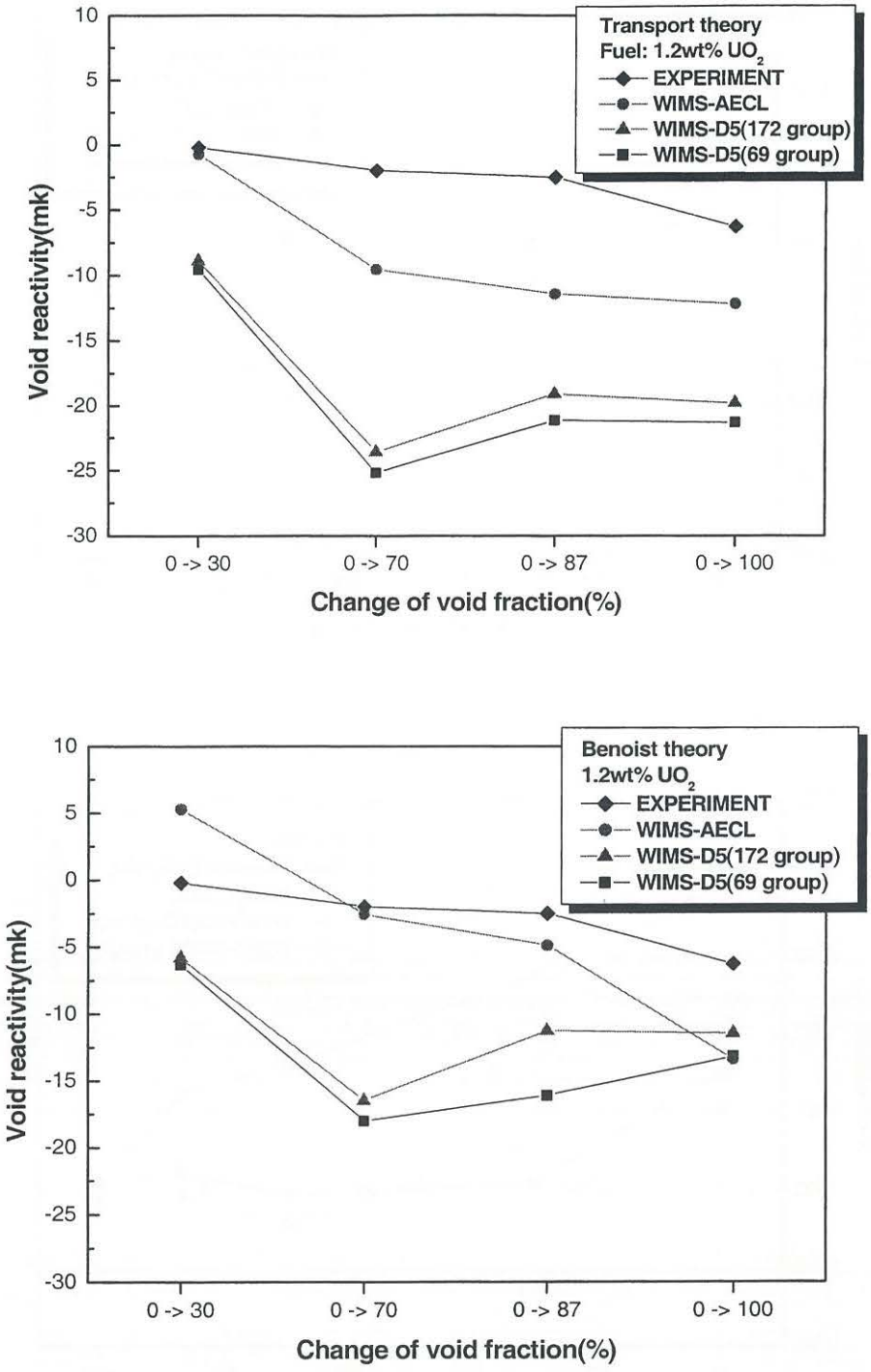
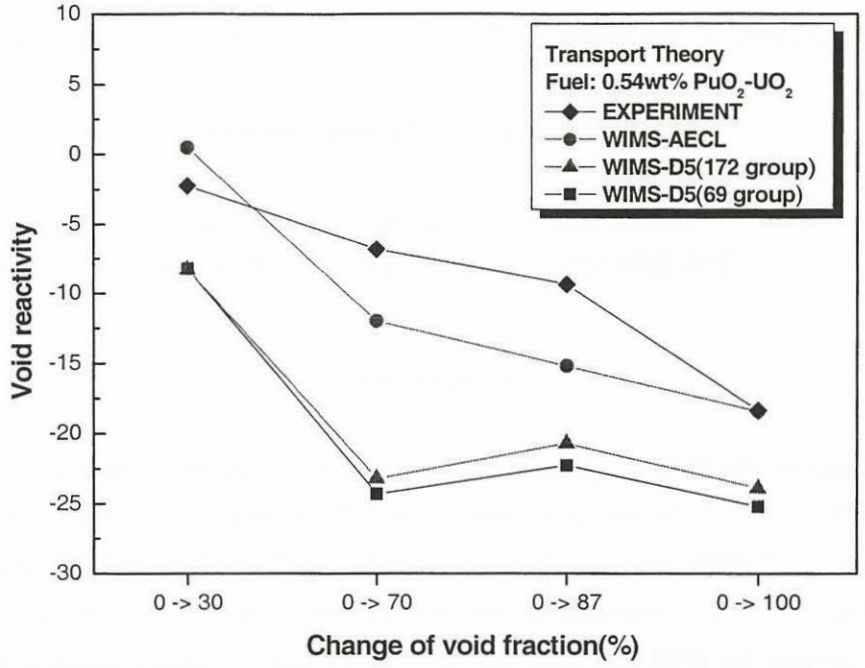


FIGURE 4. THE COOLANT VOID REACTIVITY DUE TO COOLANT VOID FRACTIONS FOR 1.2 wt% UO_2 FUEL



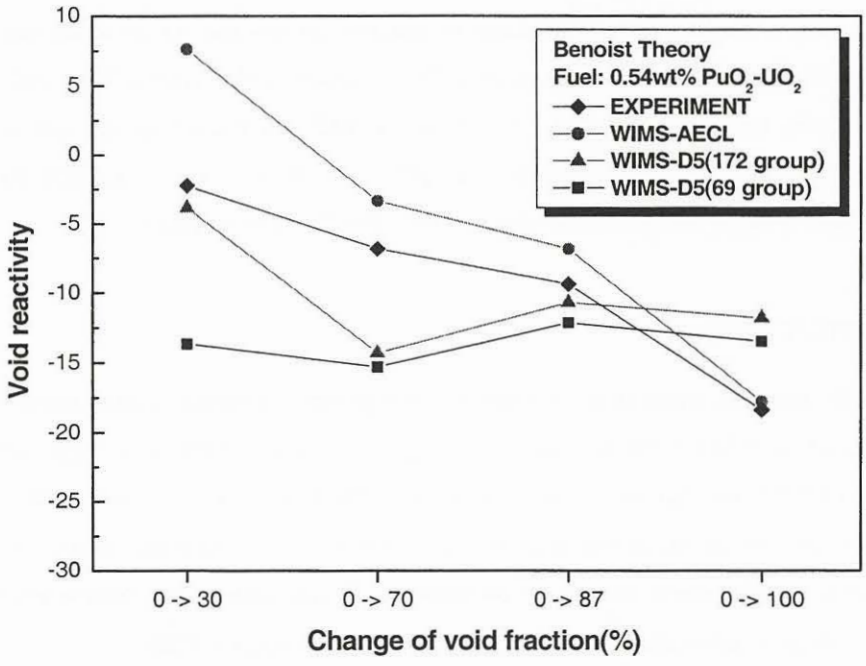


FIGURE 5. THE COOLANT VOID REACTIVITY DUE TO COOLANT VOID FRACTIONS 0.54 wt% PuO_2-UO_2 FUEL