Annals of Nuclear Energy, Vol. 6, pp 511 to 514
© Pergamon Press Ltd. 1979. Printed in Great Britain

0306-4549 79 1001-0511S02.00 0

EFFECT OF THE LOSS OF COOLANT ON THE RESONANCE ESCAPE PROBABILITY

C. NOTARI and A. M. LERNER
Comision Nacional de Energia Atomica, Buenos Aires, Argentina

(Received 27 February 1979)

Abstract In the analysis of the loss of coolant accident in natural uranium reactors of the Atucha or Candu type, the influence of the coolant voiding on the resonance escape probability appears to be of great importance.

In this paper we study this effect on the resonance absorption, analyzing its behaviour vs coolant density. We use the codes COCAP and WIMS,* in which the shadowing among pins in the cluster, or the Dancoff effect, is taken into account with different models.

In COCAP, the Dancoff factor calculation based on Carlvik's method shows a remarkable dependency on the coolant density, and its values at very low densities lead to an overestimation of the cell reactivity. It is shown that the inclusion of a Bell factor in the definition of the cluster effective surface improves the agreement with experimental results.

1. INTRODUCTION

In a simple representation of the multiplication factor in a reactor cell, we write:

$$k_\infty = \eta f \epsilon p \tag{1}$$

and we can analyse the effect of voiding the coolant on each factor.

We verify that the change of the resonance escape probability p, with coolant density δ, is very important and that its behaviour determines that of k_∞. It may be useful to sketch the methods used in COCAP (Rossen, 1974) and WIMS (Askew *et al.*, 1966) to calculate the resonance integrals which are directly related to the resonance escape probability p.

In COCAP, the resonance integral is calculated with the well known formula (we omit the temperature dependency):

$$I = A + B\sqrt{S_{eff}/M}, \tag{2}$$

where A and B are Hellstrand's coefficients.

For cluster-type fuel elements the effective surface is obtained calculating the Dancoff correction, $(1 - C)$, with Carlvik's method (1964):

$$S_{eff} = S_{geom}(1 - C). \tag{3}$$

In WIMS, the resonance integral of the heterogeneous system is calculated by an extension of the equivalence theorems to cluster geometry. In each particular problem, the parameters relating the heterogeneous system to the equivalent homogeneous one are calculated.

The Dancoff factor is not used here, but it is possible to infer it from the results.

We have calculated with both codes the reactivity variation as a function of coolant density for the Atucha reactor cell (Fig. 1), in order to simulate a loss of coolant accident. The coolant density was decreased at constant temperature. It is shown that an expression such as (2), with the definition of effective surface given in (3), does not lead to a good representation of experimental results on air cooled CANDU cells, and that it is necessary to take the Bell factor and its change with coolant density into account when the effective surface is defined.

2. COMPARISON WITH EXPERIMENTAL RESULTS

We have simulated some of the loss of coolant experiences in CANDU 28-rods fuel assemblies (Griffiths, 1971) and COCAP and WIMS and we have obtained the results shown in Table 1. The calculations were performed using the measured material buckling as geometrical buckling, so that the resulting reactivity is a measure of the discrepancy between calculations and measurements. As can be seen, COCAP fits the results for D_2O cooled cells satisfactorily, while this is not so for the air cooled ones where the reactivity is considerably overestimated. This fact shows that COCAP's model fails at very low coolant densities.

* We have used WIMS D version of this code.

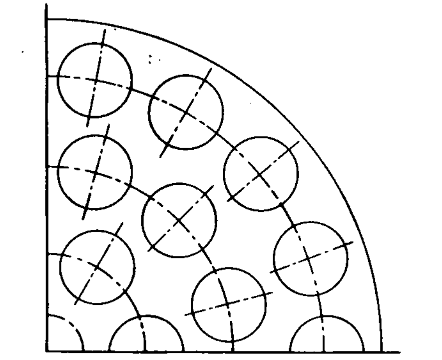

Fig. 1. The Atucha fuel element. Rod radius = 0.54 cm, cladding radius = 0.595 cm, tube radius (internal) = 5.41 cm. Pin centre radii: 1.60 cm (6 pins), 3.03 cm (12 pins), 4.51 cm (17 pins).

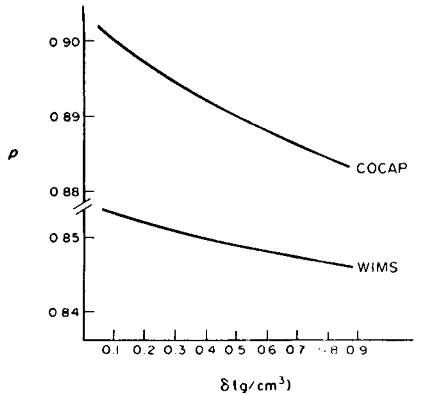

Fig. 2. Resonance escape probability vs coolant density for the Atucha cell.

WIMS' results are rather worse for the lower pitches and improve for the last two. In this case the results for the D_2O and air cooled cells are completely equivalent except for the lowest pitch; thus WIMS does not show the different behaviour between air and D_2O coolant found in COCAP.

Another difference is that in almost all the cases, COCAP overestimates the reactivity and WIMS underestimates it.

3. THE P-FACTOR

The behaviour of the four factors for the Atucha reactor cell was analyzed as a function of coolant density. It was concluded that p is the factor having the greatest variation. This is strictly so for COCAP, but not so much for WIMS which shows a non negligible dependency of ϵ with δ.

The results are shown in Fig. 2. WIMS predicts a smoother variation than COCAP. As the resonance escape probability is calculated by means of the resonance integrals, and in these quantities the δ-dependency is given through the Dancoff factor, we have plotted in Fig. 3 the Dancoff factor calculated with both codes for the Atucha cell. Again, COCAP's values decrease faster than WIMS' when δ tends to zero.

In order to draw a conclusion about this discrepancy, we have calculated the Dancoff coefficients as a function of the coolant macroscopic cross section Σ for the Swedish D_2O cooled Marviken reactor. In Fig. 4 we compare the results obtained with COCAP, WIMS and Leslie's method (1965). An excellent agreement between COCAP's and Leslie's results is achieved, while WIMS' values exhibit a considerably different behaviour.

The coincidence between the two different methods, that used by Leslie and the code COCAP, suggests that this calculation is correct and we look for another δ-dependent factor affecting the resonance escape probability.

Table 1. Reactivity values for the loss of coolant experiments in Candu 28-rod cells

	COCAP		WIMS	
Pitch (cm)	D_2O ρ (‰)	Air ρ (‰)	D_2O ρ (‰)	Air ρ (‰)
24	0.1078	10.1947	−1.5265	1.5596
26	−0.6825	3.6506	−3.8930	3.7848
28	0.4871	3.2055	−3.2703	−3.2998
30	2.6110	4.3309	−1.4320	−1.6036
32	2.8462	4.7344	−1.6322	−1.2374

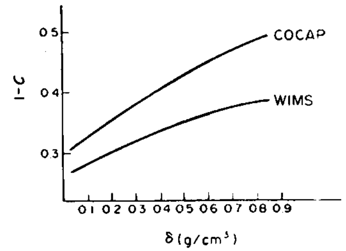

Fig. 3. Dancoff factor vs coolant density for the Atucha cell.

Table 2. Reactivity values for the loss of coolant experiments in Candu 28-rod cells, with the Bell correction

	COCAP	
Pitch (cm)	D_2O ρ (‰)	Air ρ (‰)
24	−4.5749	4.0017
26	−4.5067	−1.3928
28	−2.7327	−1.0384
30	−0.1712	0.7062
32	−0.5281	1.5388

4. THE EFFECTIVE SURFACE AND THE BELL FACTOR

According to the formulation of the equivalence theorems, the heterogeneous-system resonance integral can be put in terms of an homogeneous-equivalent one:

$$I_{hetero} = I_{homo}(\sigma_e),$$

where $\sigma_e = 1/N\bar{l}$, N being the resonance absorber number density and $\bar{l}$ the system mean chord.

Leslie *et al.* (1965) showed that the validity of this equivalence can be extended from isolated rods to infinite lattices and clusters as well, using the expression:

$$I_{hetero} = I_{homo}(a\sigma_e),$$

where a is the coolant-density dependent Bell factor.

The same authors studied the behaviour of a with coolant density, giving an analytic formula for infinite lattices and a plot of the Bell factor vs Σ for the 37-rod SGHW cluster.

This correction can be introduced in COCAP's formalism as follows:

$$I = A + B\sqrt{a \cdot S_{ef}/M}.$$

In this way, we introduce another δ-dependent factor. If we suppose that Leslie's a values calculated for the SGHW cell can be used for the CANDU cell under study and we adopt the values $a = 1.125$ ($\Sigma = 0.37$) and $a = 1.2$ ($\Sigma = 0$) for the D_2O cooled and air cooled cells, respectively, we can recalculate the cases of Table 1. The results are shown in Table 2. The agreement with experimental results is better for the air cooled cells and rather worse for the low pitches of the D_2O cases.

It would be interesting to calculate the Bell factor for this cell and analyse its behaviour with δ for different geometries.

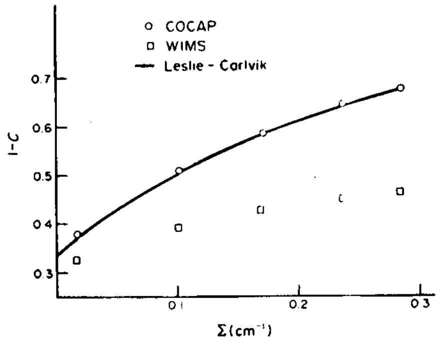

Fig. 4. Dancoff factor vs coolant cross section for the Marviken cell.

5. CONCLUSIONS

We have observed that the representation of the cluster resonance integral by means of the formula $I = A + B\sqrt{S_{ef}/M}$ does not lead to a satisfactory simulation of the loss of coolant experimental results in 28-rod CANDU cells when the classical definition $S_{ef} = S_{geom}(1 - C)$ is used. Even though the calculations can be directly fitted with the experimental results, we intend to justify this by introducing the Bell factor as a correction of the effective surface as the equivalence theorems suggest.

The dependency of the Bell factor on coolant density tends to improve COCAP's agreement with experimental results for air cooled cells, although a check of the a values used for CANDU cells is still needed.

With respect to WIMS' results, the behaviour of the Dancoff factor with δ is not clear (Fig. 3); nevertheless we observe that this code gives a similar fitting for D_2O and air cooled cells.

It must be also taken into account that although we have restricted our analysis to the p-factor, this is not the only one which varies with coolant density. Moreover, in COCAP its variation is decisive but in WIMS we find that ϵ's variation is of similar importance. The dependency of ηf on δ is almost negligible in both codes.

Leakage is another parameter affected by the loss of coolant which has not been considered here.

REFERENCES

Askew J. *et al.* (1966) *J. Br. nucl. Energy Soc.* **5**, 564.
Carlvik I. (1964) *3rd Geneva Conf. Proc.*; **2**, 681.
Griffiths J. (1971) *AECL-3739*.
Leslie D. C. *et al.* (1965) *Nucl. Sci. Engng* **22**, 78. **23**, 82.
Rossen J. (1974) Unpublished *CNEA* report

Annals of Nuclear Energy, Vol. 6, pp. 515 to 516
Pergamon Press Ltd. 1979. Printed in Great Britain

BOOK REVIEWS

Public Regulation of Site Selection for Nuclear Power Plants, ERNEST D. KLEMA and ROBERT L. WEST. Research Paper R2, Resources for the Future, Washington, D.C.

This volume consists of a comprehensive bibliography of articles concerned with nuclear power plant site selection, regulation and present procedures and reform proposals. Each of the many articles listed is adequately summarized with sufficient detail to enable readers to select easily and quickly any topic which may be of interest. The bibliography is the first stage of an investigation which will hopefully identify and evaluate feasible alternatives to the present procedures for nuclear power plant site selection. A central theme in the evaluation is the possibility of selecting alternative procedures which will eventually reduce the long time required for obtaining approvals and licenses for nuclear plant sites.

The volume is divided into four parts:

Part 1 contains literature associated with the process of power plant siting as carried out by the various utilities in the U.S. It includes reports on actual siting procedures and describes the analytical tools used for site assessment. Papers are included which consider the range of factors taken into account in any site assessment.

Part 2 deals with the public regulation of siting. Literature is included which describes the licensing process carried out by the U.S. Nuclear Regulatory Commission under the terms of the Federal Government. Regulatory objectives bearing on nuclear site approvals have changed significantly over the past 30 years and articles are cited which describe the changes which have occurred. Other articles cover local government, State, and Federal agency regulations. A few articles are cited which cover siting practices in countries other than the U.S. The volume could have been improved if this section had been expanded and made more comprehensive. Special prominence is given in this section to the description of experiences obtained in pursuing new public objectives for environmental protection.

Part 3 contains articles on some aspects of the present criticism of public regulation which are likely to influence judgements on any proposals for the reform of siting procedures. The main topics which were critical of present regulatory experience were that regulatory structure and practice are unresponsive to the public interest; that regulatory decision making is insufficiently accessible to public scrutiny and participation; and that present procedures encourage and protect inefficient practices. This section also quotes some influential legal decisions which have been instrumental in forming regulatory practices. Some case studies are cited of regulatory experience outside the electrical industry which have or are likely to influence regulatory reform.

Finally, Part 4 quotes selected proposals and analyses of recommendations for regulatory reform of nuclear plant siting procedures in the U.S. An array of reform proposals are cited which contain distinct suggestions which have given rise to widespread comment and discussion. The literature shows substantial agreement in detail of many reform proposals and reflects clear dissatisfaction with the present regulatory processes.

The bibliography will be a most useful reference for workers in the area of nuclear plant licensing and regulation. It provides a most comprehensive survey of the literature on siting within the U.S.

Assistant Director of J. SHAW
Nucleonics Laboratory
Queen Mary College
University of London

Management of Low Level Radioactive Waste, Volumes 1 and 2, edited by MELVIN W. CARTER, A. ALAN MOGHISSI and BERND KAHN. Pergamon Press.

This book, published in two volumes, is based on the papers presented at a Symposium on Management of low level radioactive wastes, which was held in Atlanta, Georgia, U.S.A on 23 27 May, 1977. All the papers included have been reviewed and edited. A total of 70 papers are presented in the two volumes in 10 chapters covering a wide range of topics. Without doubt this collection of papers specifies the current state of knowledge in the area of low level waste management.

The present U.S. Nuclear Regulatory Commission management programme for low level waste, long term considerations and transportation problems are covered in an introductory chapter. The generation and source of low level wastes are dealt with in a number of papers covering in detail such topics as the origin and characteristics of nontransuranic waste from the nuclear fuel cycle, sources of waste from light water reactors, solid wastes generated in a large commercial reprocessing plant, decontamination of nuclear plants, carbon 14 production in reactors and fusion fuel cycle wastes.

Cost benefit is dealt with in Chapter 3 and two papers are cited which describe risk assessments of radioactive waste management and cost-benefit analyses studies of low level waste management.

The subject of volume reduction of low level wastes is currently an important topic and in Chapter 4 a number of papers describe the problems associated with present methods. The options available, the operation of a fluidised bed system, a BWR radwaste system and a cyclone incinerator are all described in some detail.

Chapters 5 and 6 include problems associated with liquid, solid and gaseous waste treatment systems. A wide range of topics is covered which include a review of liquid waste management at Los Alamos, removal of plutonium and uranium from process streams using ultrafiltration membranes, ion exchange techniques for removal of technetium, incineration techniques, gas processing systems and the design and operation of liquid waste treatment systems. Other papers deal with solidification processes for liquid wastes and the operating costs for nuclear power plant waste systems.

Waste disposal technology and land burial case histories are dealt with in Chapters 7 and 8. They include problems