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ATOMIC ENERGY
OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

COMPARISON OF ASSERT SUBCHANNEL CODE WITH MARVIKEN BUNDLE DATA

Comparaison des prédictions du code ASSERT avec les données de la grappe Marviken

A. TAHIR and M.B. CARVER

Presented at the 10th Simulation Symposium on Reactor Dynamics and Plant Control, St-John, New Brunswick
1984 April 9, 10

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

Chalk River, Ontario

April 1984 avril

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The work reported in this document was funded by the AECL-Ontario Hydro CANDEV program

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Comparaison des prédictions du code ASSERT avec les données de la grappe Marviken

Rapport présenté au 10^e symposium de simulation
concernant la dynamique des réacteurs et le contrôle des centrales,
tenu à St-Jean, Nouveau-Brunswick, les 9 et 10 avril 1984.

par

A. Tahir et M.B. Carver

Résumé

Dans ce rapport, les prédictions ASSERT sont comparées à la grappe Marviken de six barreaux et à la grappe de 36 + 1 barreaux. On présente les prédictions de deux expériences dans la grappe de 6 barreaux et de quatre expériences dans la grappe de 36 + 1 barreaux. Pour un faible sous-refroidissement d'entrée, les prédictions de vide sont en bon accord avec les données expérimentales. Dans le cas des sous-refroidissements d'entrée élevés, cependant, l'accord n'est pas aussi bon. Cela est dû au fait que dans les expériences de sous-refroidissement d'entrée élevé, le mélange turbulent en phase simple joue un rôle plus important pour déterminer les conditions d'écoulement dans la grappe.

Les travaux dont il est question dans ce document ont été
financés par le programme CANDEV de EACL et Ontario Hydro.

Laboratoires nucléaires de Chalk River
Chalk River, Ontario K0J 1J0

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ABSTRACT

In this paper ASSERT predictions are compared with the Marviken 6-rod bundle and 36+1 rod bundle. The predictions are presented for two experiments in the 6-rod bundle and four experiments in the 36+1 rod bundle. For low inlet subcooling, the void predictions are in good agreement with the experimental data. For high inlet subcooling, however, the agreement is not as good. This is attributed to the fact that in the high inlet subcooling experiments, single phase turbulent mixing plays a more important role in determining flow conditions in the bundle.

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COMPARISON OF ASSERT SUBCHANNEL CODE
WITH MARVIKEN BUNDLE DATA

by

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SUMMARY

The ASSERT[+] subchannel code was developed primarily to assess flow and phase distribution inside horizontal subchannels of CANDU reactor fuel bundles. ASSERT solves the non-equilibrium equations of two fluid flow in interconnected subchannels and incorporates models of various two phase mixing mechanisms. The code has been validated against two sets of air water experiments and heated boiling experiments with low inlet subcooling. For these particular experiments, the operating conditions were such that the flow was two phase for most of the test section. Single phase turbulent interchange for these conditions is insignificant in comparison to the two phase mixing.

In this paper ASSERT predictions are compared with the Marviken 6-rod Bundle and 36+1* rod bundle.

The void fraction was measured inside different rings of the bundle at different axial locations. ASSERT predictions are presented for two experiments in the 6-rod bundle and four experiments in the 36+1 rod bundle. For low inlet subcooling, the void predictions are in good agreement with the experimental data. For high inlet subcooling, however, the agreement is not as good. This is attributed to the fact that in the high inlet subcooling experiments, single phase turbulent mixing plays a more important role in determining flow conditions in the bundle.

1. Introduction

ASSERT[1] is an advanced subchannel code under development to provide more rigorous numerical simulation of flow and phase distribution in horizontal fuel bundles. To this end the equations of two fluid flow are solved in non-equilibrium form, permitting the phase to have unequal velocities and temperatures, unlike the equilibrium equations in the COBRA-IV code [2], which impose equal temperatures and velocities. Departure from mechanical

---

[+] ASSERT Advanced Solution of Subchannel Equations in Reactor Thermalhydraulics

*36+1 bundle refers to a bundle of thirty-seven rods where only thirty-six are heated.

equilibrium permits separation phenomena such as slip and gravitational drift to be modelled, while departure from thermal equilibrum permits mechanistic modelling of subcooled boiling.

An extensive validation program is being conducted as part of the ASSERT development, and code predictions have been compared to air-water experiments in connecting subchannels in both vertical and horizontal orientation[1]. However, no detailed experimental data on flow and phase distribution in horizontal bundles is yet available, so the code is being validated against a number of well documented experiments using vertical bundles. Comparisons with experiments with a heated 6-rod bundle with low inlet subcooling are given in [3] and in this paper further experiments with another 6-rod bundle [4] and a 36+1 bundle [5] are used for further validation.

In simulating flow in rod bundles, care must be taken to model each of the individual mechanisms contributing to flow exchange, so these mechanisms are reviewed here.

2. Mixing Mechanisms in Single Phase Flow

The comprehensive review by Rogers and Todreas [6], classified single phase mixing mechanisms as shown in Table 1.

TABLE 1

Mixing Mechanisms

	Natural Mechanisms	Forced Mechanisms
Molecular effects	Diffusion	
Non directional flow effects	Turbulent interchange	Flow scattering
Directional flow effects	Diversion cross flow	Flow sweeping

2.1 Natural Mechanisms

Natural mixing mechanisms consist of those processes which are operable in the absence of flow perturbers. These mechanisms are molecular diffusion, turbulent interchange and diversion cross flow.

2.1.1 Molecular Diffusion

Molecular diffusion is only important for very low Prandtl numbers such as in the case of liquid metals. Also it is important at low Reynold's number, less than 5000, and very narrow gaps, less than 0.25 mm, as discussed by

Singh [7]. These conditions are not typical in power reactors, and consequently this mechanism will not be modelled in ASSERT.

2.1.2 Turbulent Interchange

The salient feature of turbulent motion is the fact that the velocity and pressure at a fixed point do not remain constant with time even in steady flow, but undergo very irregular fluctuations of high frequencies.

These fluctuations affect the diffusion of scalar and vector quantities. In the study of mixing in rod bundles, the mechanism by which turbulence enchances diffusion between subchannels is given the name "turbulent interchange".

In single-phase, in the absence of other mixing mechanisms, the subchannel flows remain essentially constant in order to maintain approximately the same pressure level in each subchannel at any axial position. Thus there is momentum and energy transfer between subchannels but there is little or no mass transfer [8].

2.1.3 Diversion Cross Flow

Diversion cross flow is the directed flow between subchannels caused by pressure gradients normal to the major flow direction. These gradients may be induced by differences in subchannel geometries, gross variation of heat flux or the onset of boiling in one of the subchannels.

2.2 Forced Mixing

Forced mixing is that subchannel fluid interchange which is induced by the presence of structural elements or flow diverters in the bundle. These devices can serve simply to break up the flow in a random fashion, to which the designation "flow scattering" is applied, or else they may divert a portion of the flow in a preferred direction, which is called "flow sweeping". Flow scattering is associated with grid spacers, wart type spacers, axial or circumferential fins and bundle end plates. Flow sweeping is associated with helical wire-wrap spacers, helical fins, contoured grids and mixing vanes.

The relative importance of the mixing mechanisms on rod bundle performance is dependent on the bundles geometric characteristics. Turbulent interchange is the basic mechanism and occurs with all turbulent flows. For a sufficiently long bundle, in the absence of boiling and structural devices, turbulent interchange will be the only effective mechanism.

In the absence of mixing between the subchannels, non-uniform flow rate or non-uniform heat input would cause significantly different bulk coolant temperatures in different subchannels [9].

3. Mixing in Two Phase Flow

In addition to turbulent interchange and diversion cross flow there are two additional mixing mechanisms in two phase flow. A brief description of these two mechanisms is given below.

3.1 Void Drift

This mechanism accounts for the tendency of the vapour phase to shift to higher velocity channels. A number of ad hoc models have been proposed to explain this. One of the most promising methods of handling this effect invokes minimum entropy principles [10].

3.2 Buoyancy Drift

In horizontal channels, the void is pushed upward normal to the major flow direction due to the difference specific gravities between the two phases.

This mechanism plays a significant role in void distribution between horizontally oriented subchannels [1].

3.3 Mixing Models Used in ASSERT

Up to this stage of the ASSERT code development, attention has been focused on two phase mixing mechanisms, and models addressing diversion cross flow, void and buoyancy drift and two phase turbulent interchange have been implemented and tested [2,3]. So far no attention has been given to modelling single phase turbulent interchange. The only mechanism calculated for single phase conditions is the diversion cross flow. In future developments, single phase turbulent interchange will be implemented.

4. The Experiments

The experiments used in this validation were conducted by Nylund et al. and reported in [4,5]. Two bundles were tested, one with 6 rods [4] and one with 36+1 rods [5], both were uniformly heated with rods of 13.8 mm outer diameter and 4.4 m heated length. In the 36+1 bundle, an unheated centre rod of 20 mm diameter was used.

The void was measured with a multi beam gamma ray densitometer. By manipulating the beam in the radial direction it was possible to measure the void in different zones of the bundle. The 36+1 bundle were divided in three zones as shown in Fig. (1). The measurements were taken at several axial locations in the bundles.

Two detailed void measurements were given for the 6-rod bundle. The operating conditions are shown in Table 2 and 3.

TABLE 2

Experimental Conditions for the 6-Rod Bundle (FT-6)

Run No	Mass Flux $kg.m^{-2}.s^{-1}$	System Pressure Bar	Heat Flux $w.cm^{-2}$	Inlet Subcooling °C
13037	1111.2	49.7	62.2	1.2
13042	997.	49.6	98.0	1.2

TABLE 3

Operating Conditions for the 36+1 Rod Bundle

Run No	Mass Flux $kg.m^{-2}.s^{-1}$	System Pressure Bar	Heat Flux $w.cm^{-2}$	Inlet Subcooling °C
313013	1120.	49.7	42.9	4.6
313016	1208.	49.6	42.6	19.3
313018	1124.	49.7	64.3	3.7
313020	1159.	49.7	64.6	22.4

5. Computed Results

Both ASSERT and COBRA-IV [9] were used to simulate the experiments shown in Tables 2 and 3. ASSERT was used without tuning to fit any particular experiment. However, for COBRA-IV, different options were tested to choose the ones which give the best overall general agreement with the experimental results. The Levy subcooled void correlation and Armand modified void fraction correlation gave the best general agreement and they were used for the COBRA-IV simulation of the experiments. Specification of a correlation for subcooled boiling is not necessary in ASSERT as a mechanistic model is used.

For the 36+1 rod bundle the scatter in the measurements of zones 1 and 2, were too large for meaningful comparison, as shown in Fig. (2). The measurement in the remaining zones are more consistent as shown in Fig. (3). Here the comparisons reported are only bundle average, and zones 3 and 4 because of the low scatter in the experimental results.

ASSERT and COBRA-IV predictions are shown in Figs. 4 to 19. ASSERT predictions are in good agreement with experimental results especially for low inlet subcooling as shown in Figs. 4, 5, 6, 7, 8, 9, 10, 14, 15 and 16. In these cases the mixing between subchannels is dominated by two phase effects, and ASSERT predicts the void profiles considerably better than does COBRA. It is apparent from the 6-rod experiments that COBRA predicts very little difference in the void profile in the two zones, whereas ASSERT predicts the significant difference as observed in the experiment. This is attributed to the fact that COBRA-IV lacks a two phase mixing model and treats two phase mixing exactly in the same manner as single phase mixing, thus neglecting the mass exchange which can occur in two phase conditions.

For experiment 30316 (Figs. 11, 12, 13) subcooling was quite high, and a significant length of the bundle is in single phase. In these conditions the accuracy of the ASSERT prediction deteriorates, and understandably, the COBRA accuracy improves. The final experiment 30320 also has low subcooling but a higher heat flux, and the accuracy of the ASSERT predictions is intermediate. In none of the cases, however, do the ASSERT predictions show unreasonable discrepancies.

6. Conclusions

As part of a continuing program of validation, both ASSERT and COBRA were used to simulate the Marviken bundle experiments [4,5]. For low inlet subcooling, ASSERT predictions are in good agreement with the experimental results. For high inlet subcooling, however, the agreement is not as good. This is attributed to the fact that in high inlet subcooling experiments, single phase turbulent mixing plays a more important role in determining flow conditions in the boiling section of the bundle.

In the development of ASSERT, two phase mixing had been considered to be so dominant that single phase effects would be negligible. In all the comparisons completed hitherto this was, in fact, the case; the air water experiments had no single phase, and the heated bundle experiments used in previous comparisons had very low subcooling. Because of this new evidence however, provision of a single phase mixing model is planned in the future development of ASSERT.

ACKNOWLEDGEMENTS

The work reported in this document was funded by the AECL-Ontario Hydro CANDEV Program.

The authors wish to acknowledge the contributions of the ASSERT development team, R. Judd, J. Kiteley, G. Stewart and P. Thibeault.

Thanks are also due to Mrs. S. Baker for typing the manuscript.

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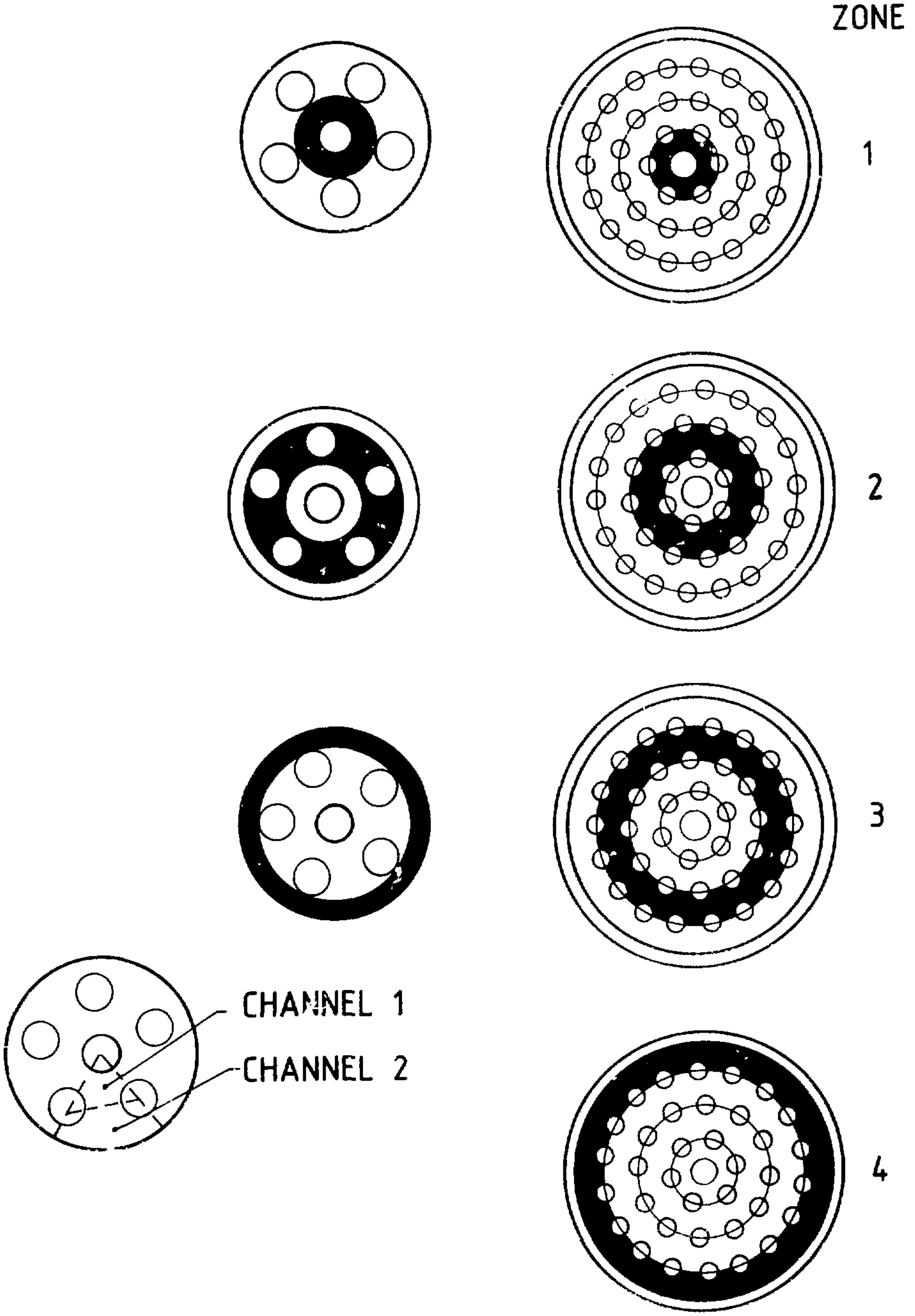


FIG. 1 MEASURING ZONES IN 6 AND 36 + 1 BUNDLES

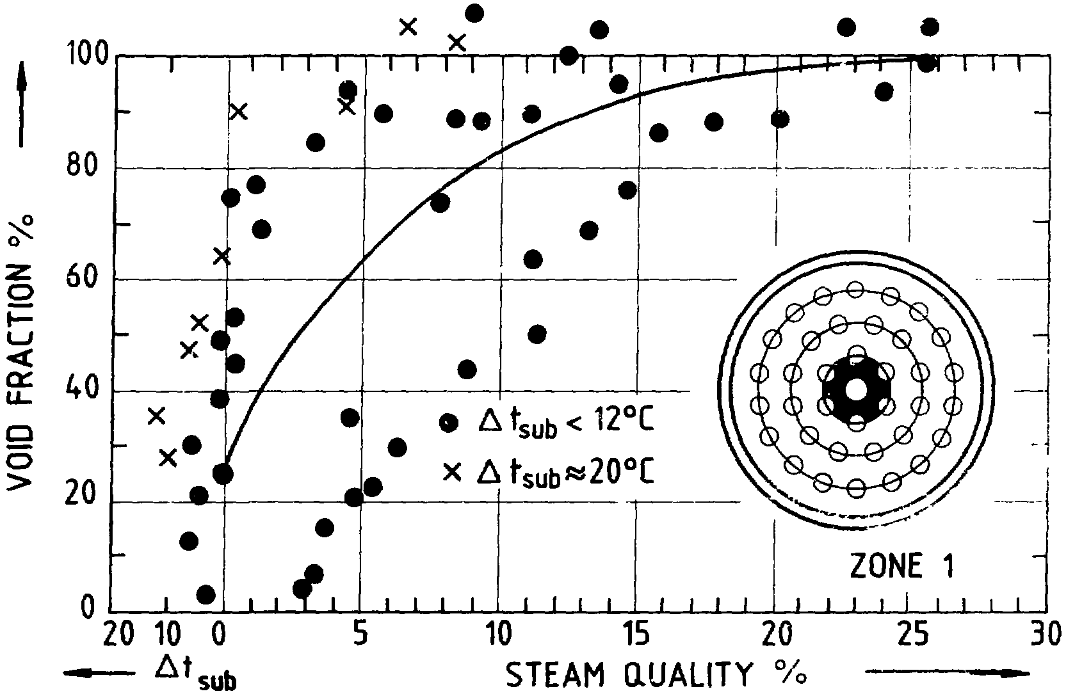


FIG. 2 SCATTER OF THE DATA IN THE INNER ZONE

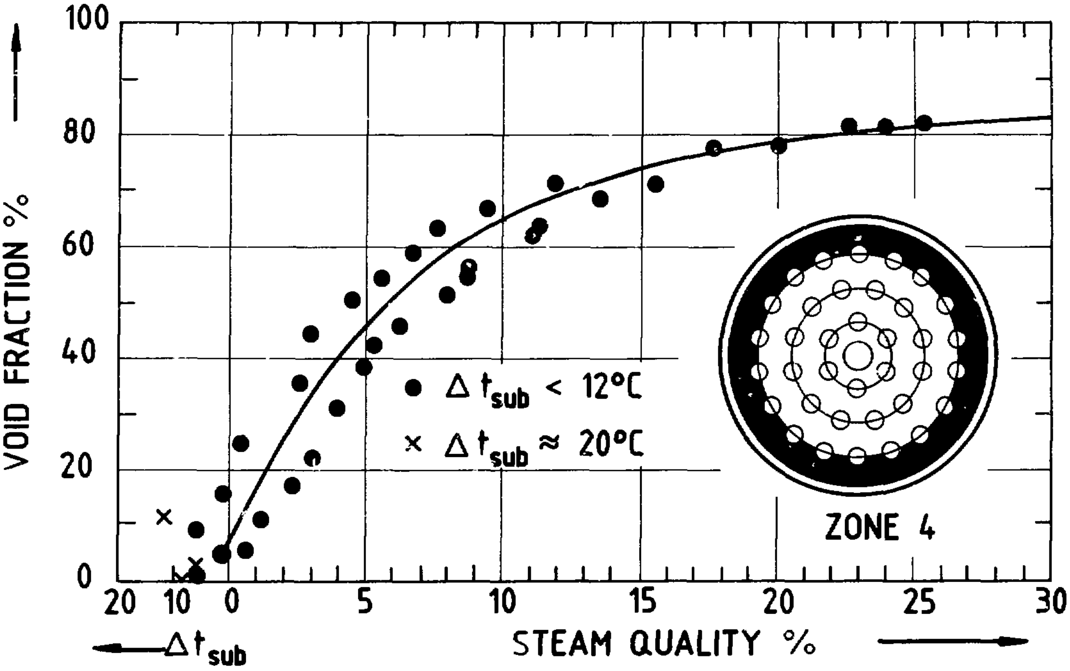
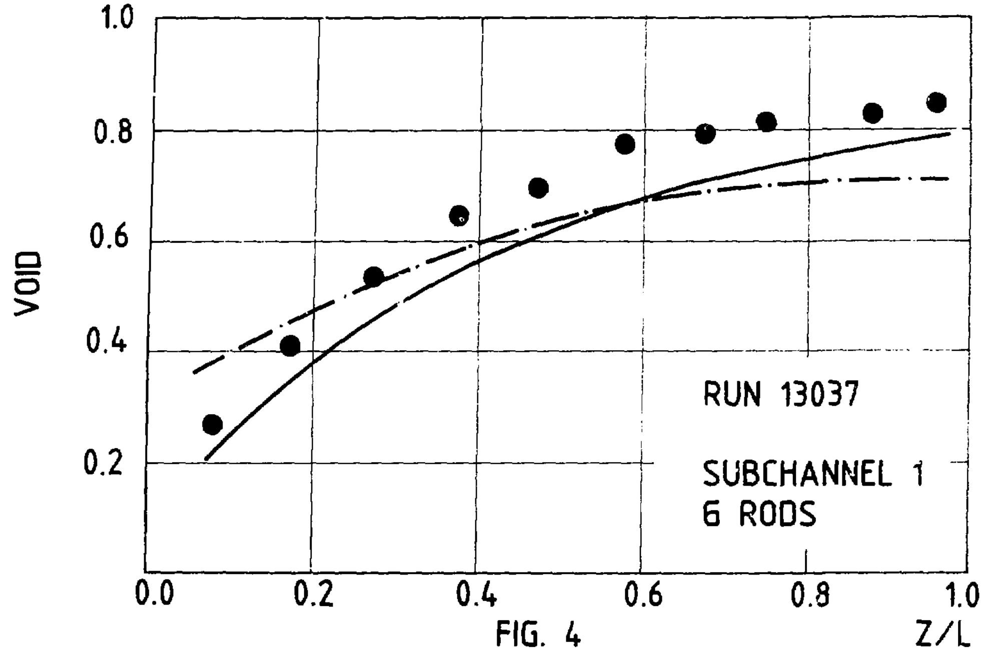


FIG. 3 SCATTER OF THE DATA IN THE OUTER ZONE



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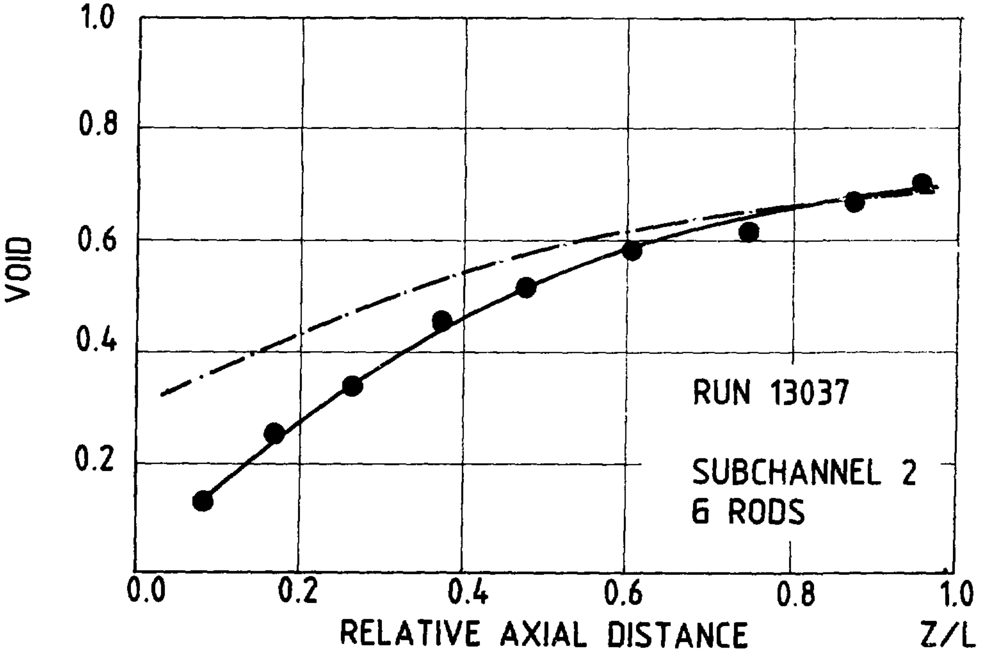
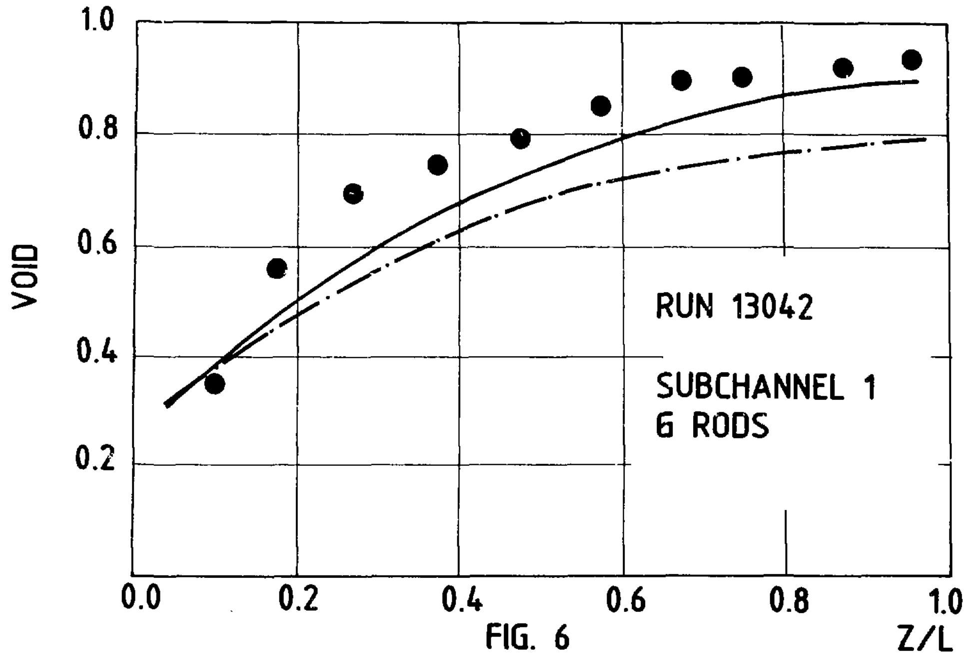


FIG. 5

● EXPERIMENT
— ASSERT
-·- COBRA-IV



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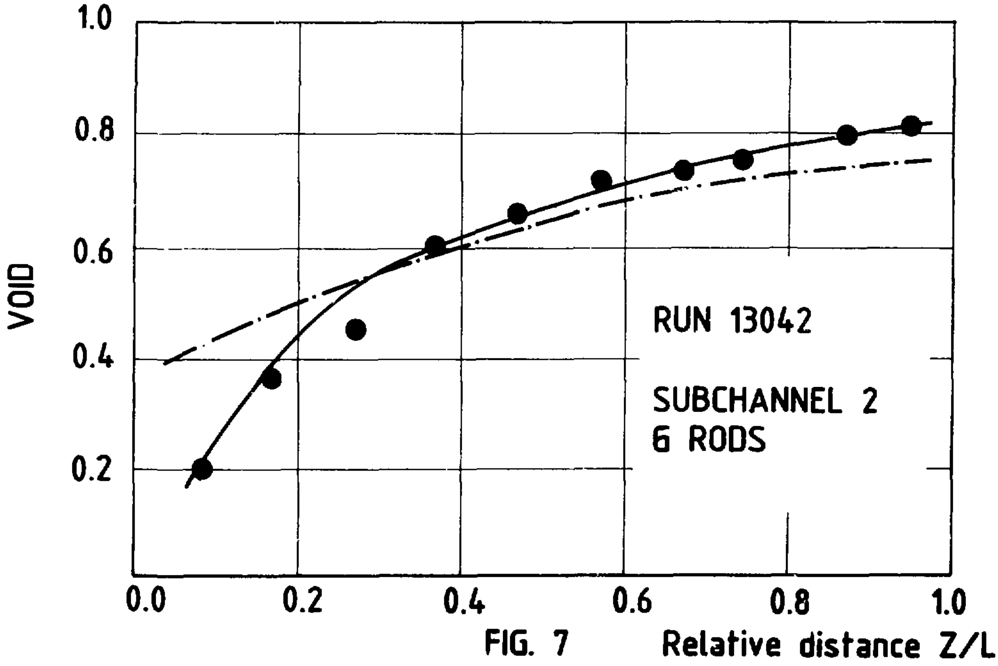

FIG. 7

● EXPERIMENT
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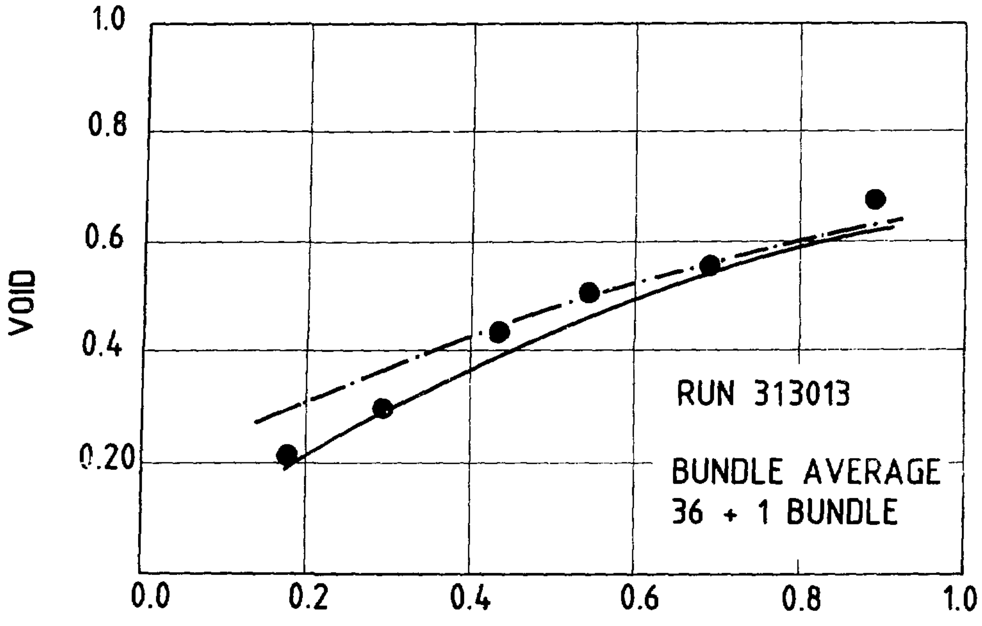
–·– COBRA-IV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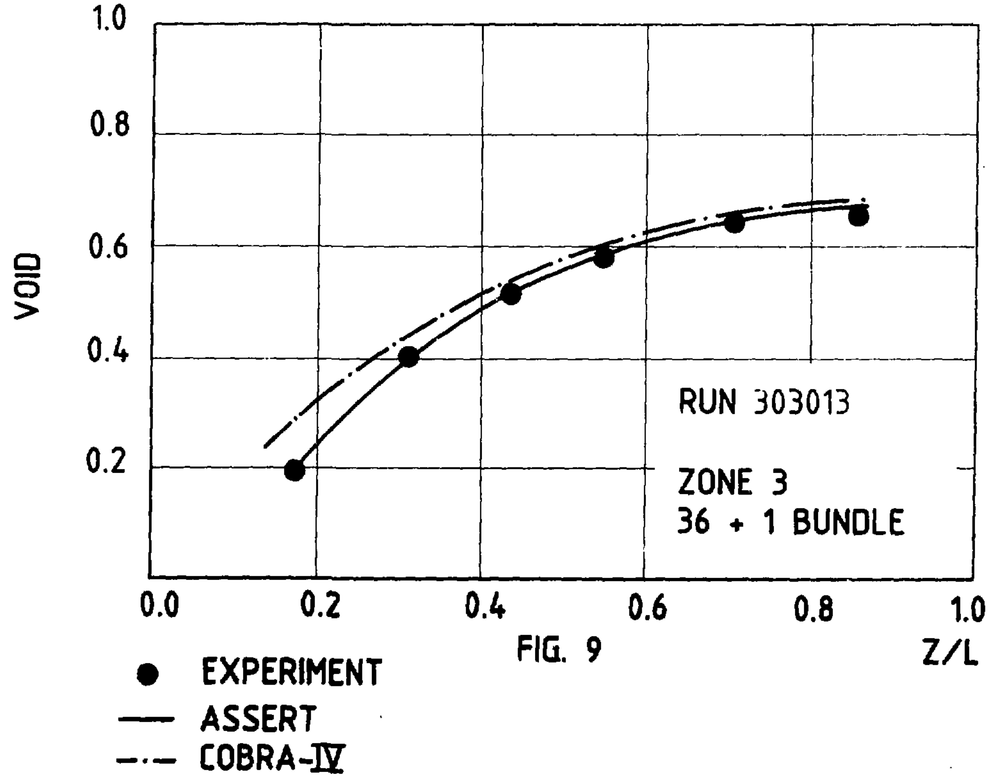
BUNDLE AVERAGE
36 + 1 BUNDLE

FIG. 8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● EXPERIMENT
—— ASSERT
—·— COBRA-IV

FIG. 9

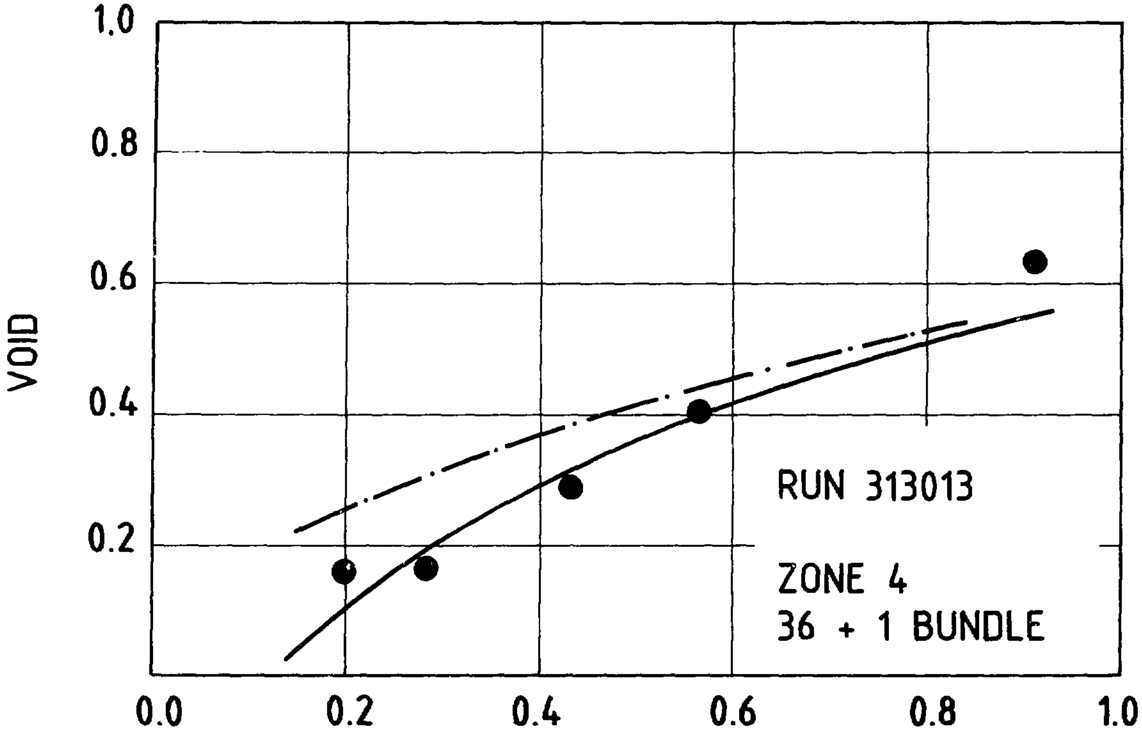
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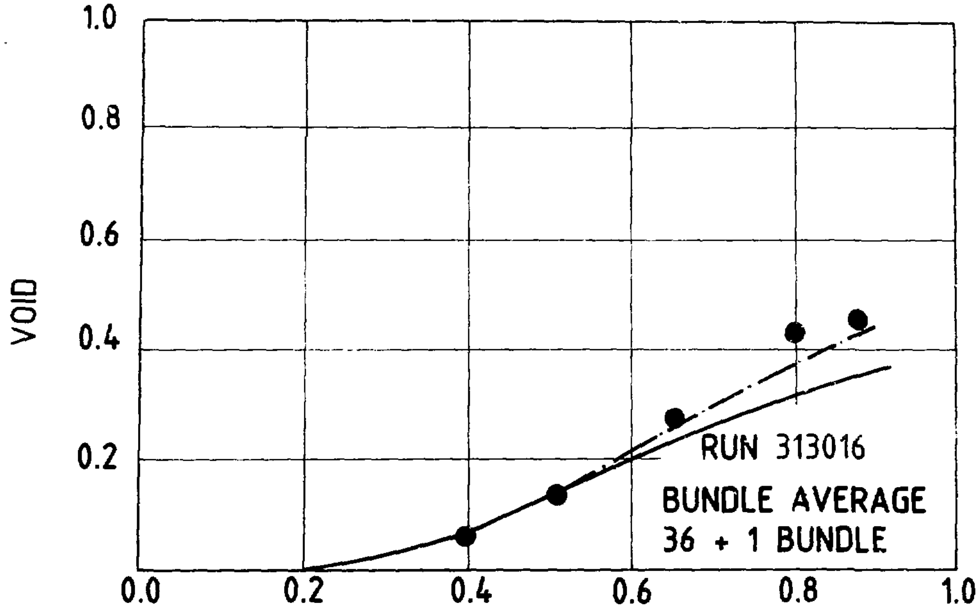
FIG. 10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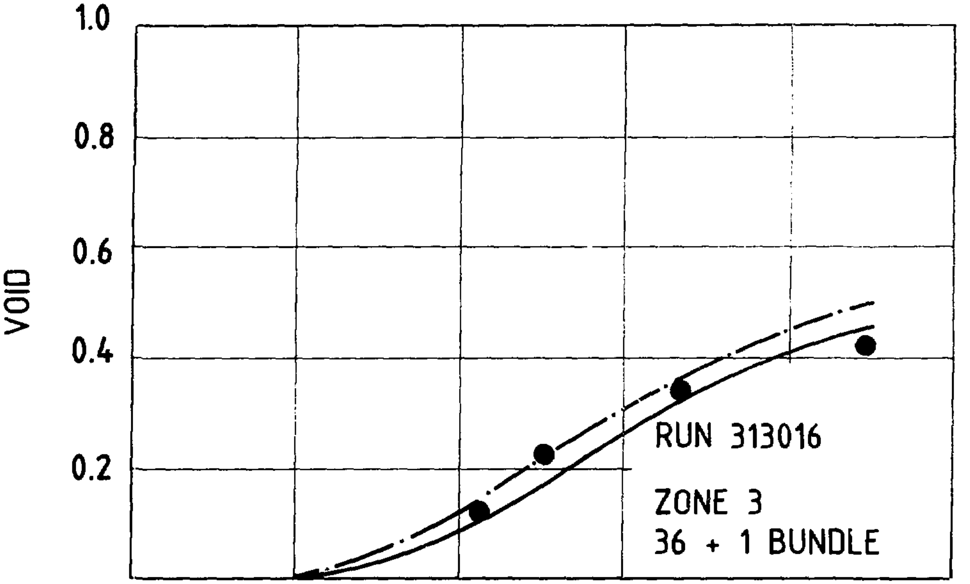
BUNDLE AVERAGE
36 + 1 BUNDLE

FIG. 11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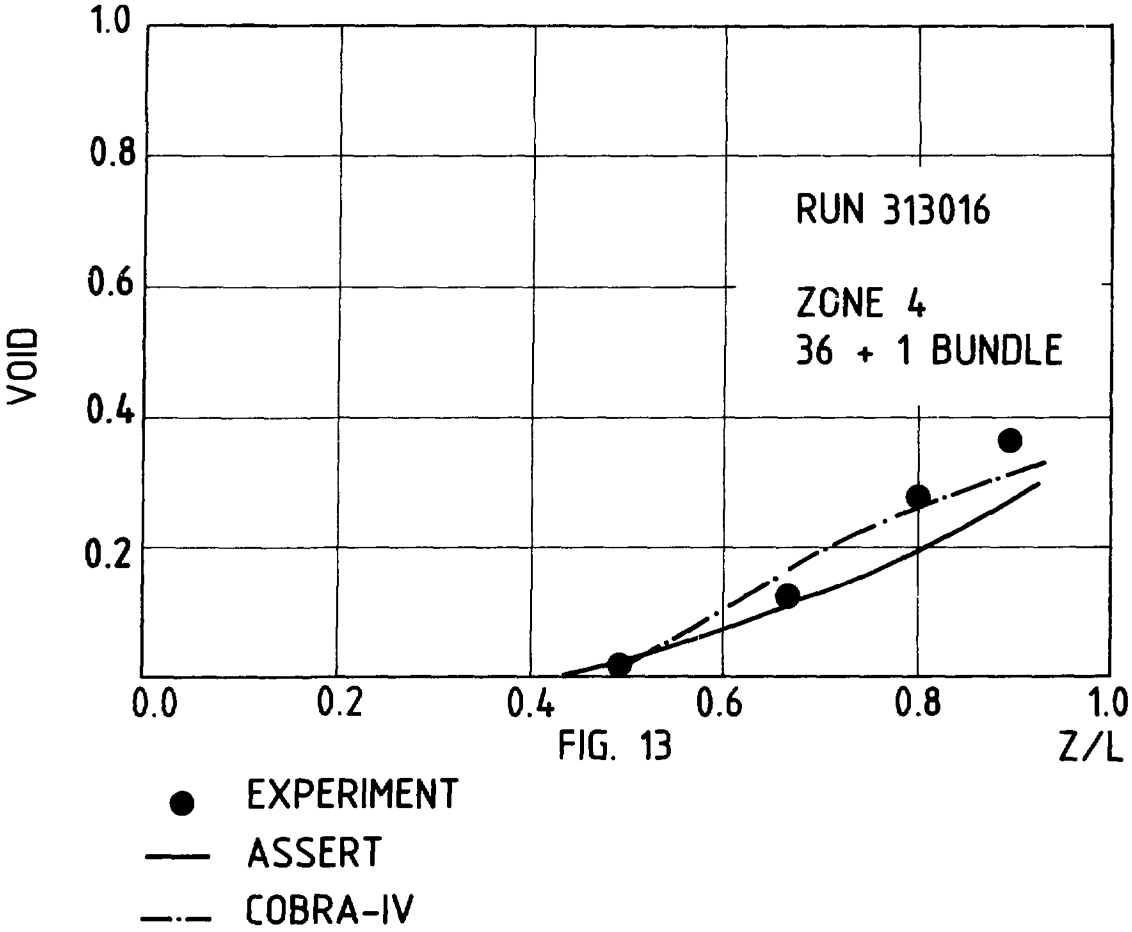
ZONE 3
36 + 1 BUNDLE

FIG. 12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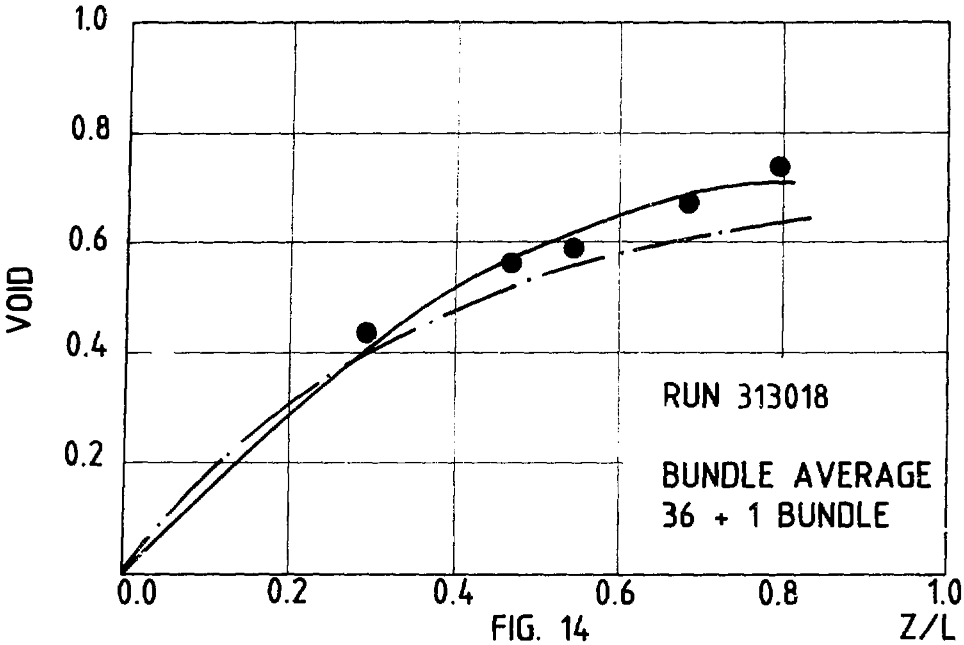
Z/L
● EXPERIMENT
ASSERT
COBRA-IV

FIG. 13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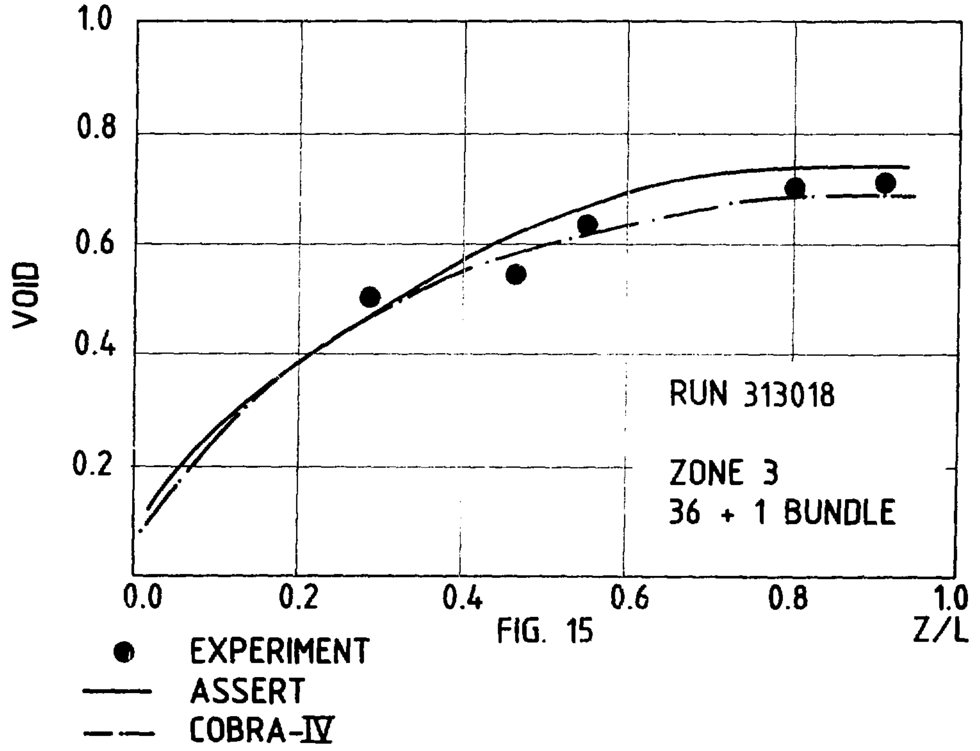
BUNDLE AVERAGE
36 + 1 BUNDLE

FIG. 14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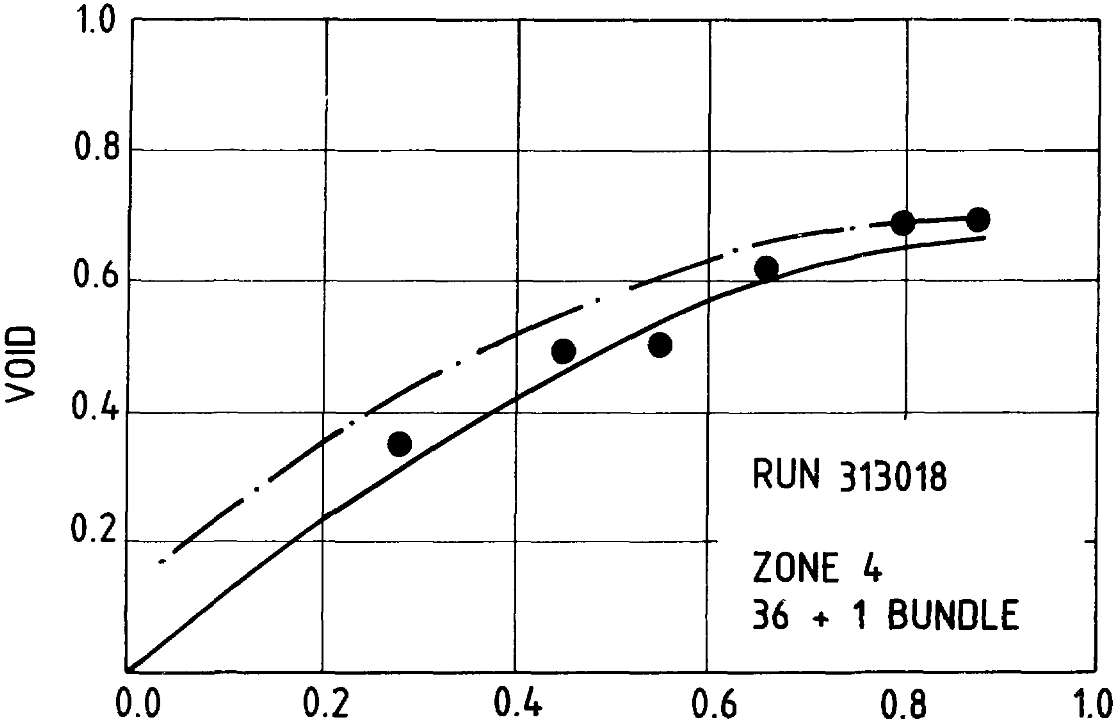
ZONE 3
36 + 1 BUNDLE
● EXPERIMENT
—— ASSERT
—·— COBRA-IV

FIG. 15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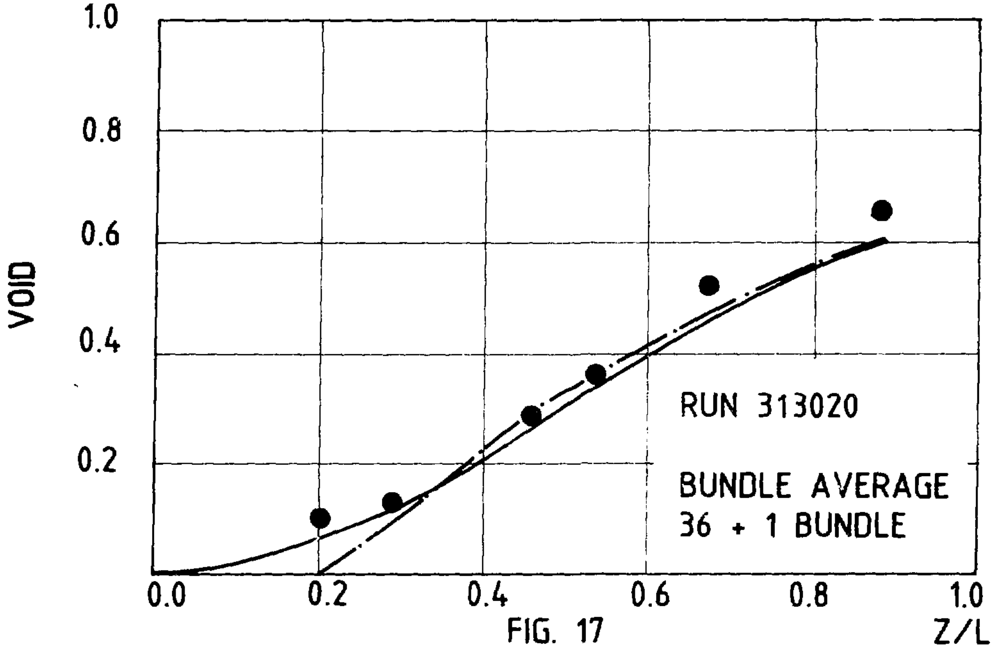
36 + 1 BUNDLE

FIG. 16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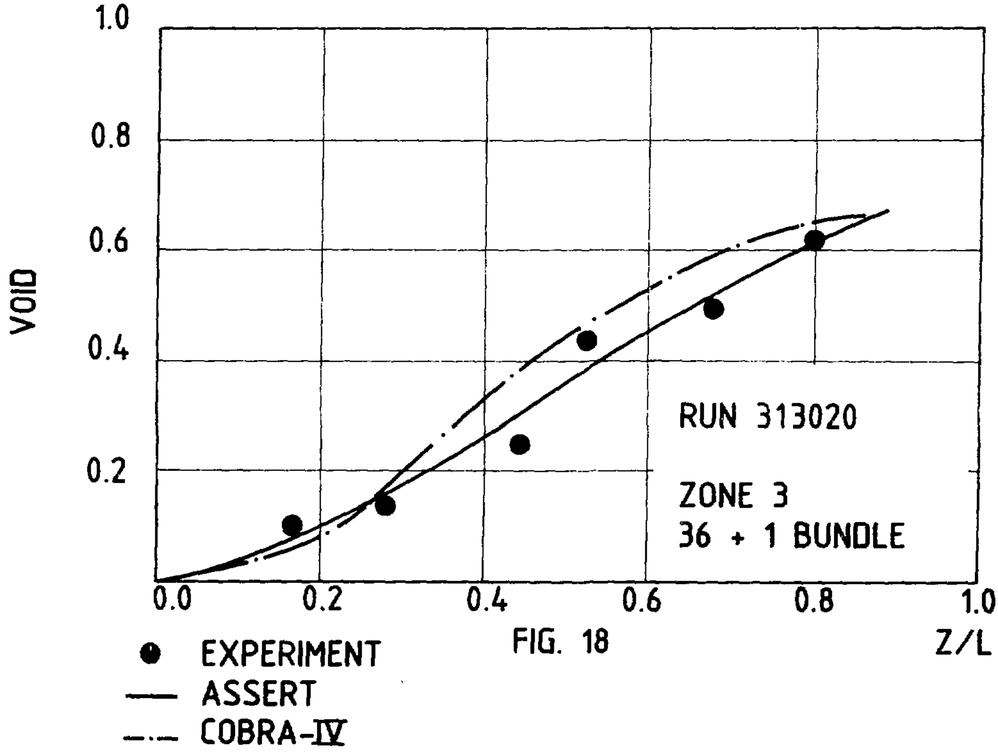
Z/L

FIG. 17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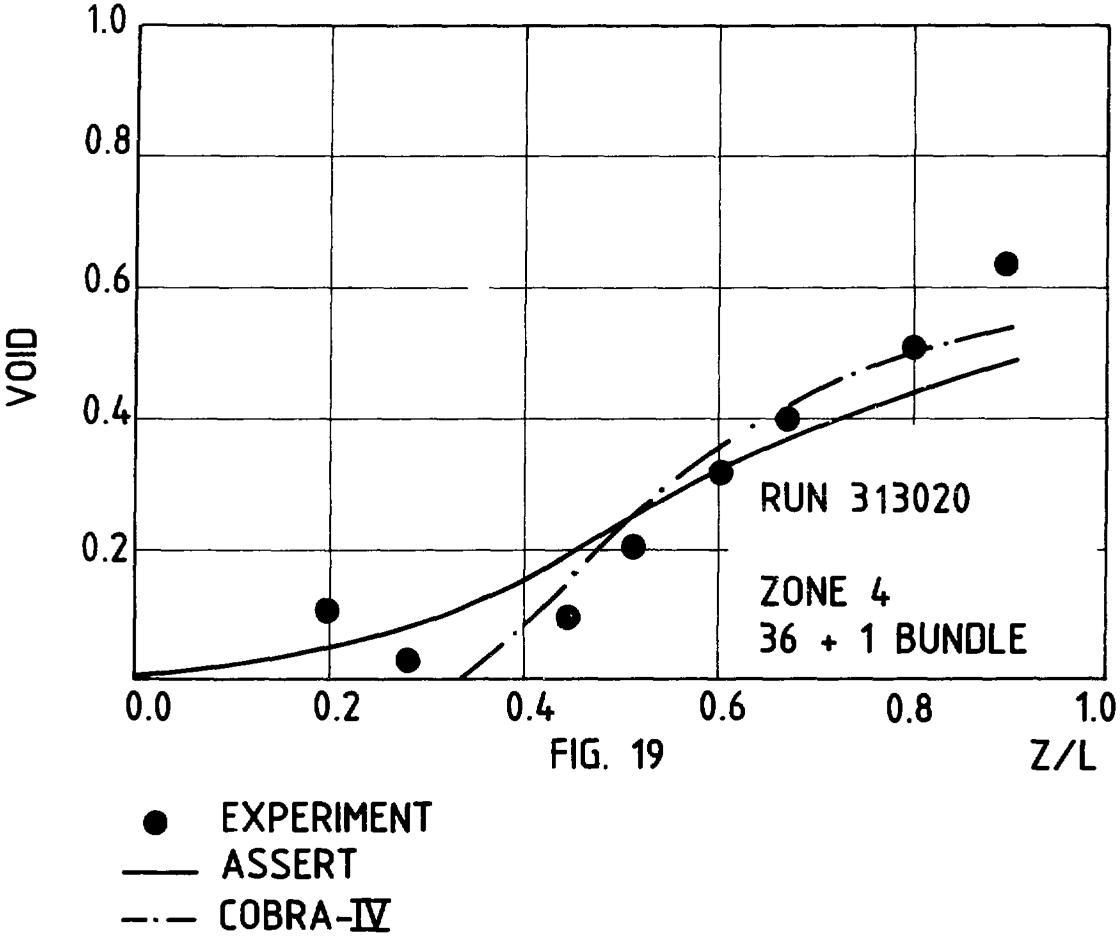
● EXPERIMENT
—— ASSERT
—·— COBRA-IV

FIG. 18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Z/L
RUN 313020
ZONE 4
36 + 1 BUNDLE
● EXPERIMENT
—— ASSERT
—·— COBRA-IV

FIG. 19

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