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ABSTRACT

Self-limiting transients of initial period down to ~ 12 s have been measured in the AAEC's 100 kW Moata (University Training Reactor (UTR)) and the results compared with the predictions of a point-kinetics heat transfer model (ZAPP code). Although natural convection significantly affects the burst shape of such slow excursions, calculation and experiment are sufficiently in agreement to give confidence that the ZAPP model, which has been well tested against SPERT I data, can be successfully applied in safety studies for this class of reactor to predict the consequences of reactivity additions up to the onset of core melting.

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TRANSIENTS; MOATA REACTOR; EXCURSIONS; REACTOR KINETICS; REACTIVITY INSERTIONS; REACTOR SAFETY; REACTOR CORES; SPERT 1 REACTOR

CONTENTS

1. INTRODUCTION

A recent study [Clancy *et al.* 1975, 1976] of the power transient behaviour observed with the reactors of the USAEC SPERT I program showed that the experimentally determined power burst parameters peak power (P_{max}), the energy release to the time of peak power (E_{tm}), the total burst energy (E_{tot}), the maximum cladding temperature at the time of peak power (θ_{tm}) and the maximum cladding temperature attained (θ_{max}) could be satisfactorily reproduced by a point reactor kinetics/heat transfer code ZAPP [Clancy 1977]. The reactivity feedback coefficients required as part of the code input were obtained from 2-dimensional, 4-group diffusion theory calculations of the SPERT I cores together with perturbation theory.

By the same methods, we have examined consequences of step and ramp additions of reactivity to the AAEC reactors HIFAR [Connolly & Ferguson 1977] and Moata. The latter is a variant of the ARGONAUT reactor, having two rectangular core tanks embedded in a graphite reflector and using light water as the coolant/moderator. This type of reactor is designated a University Training Reactor (UTR).

One of the conclusions reached from the Moata calculations was that the maximum step reactivity addition which the core could withstand without the fuel plate cladding exceeding the melting point of aluminium, was 0.011 $\Delta k/k$, corresponding to an initial period of 0.04 s. Because the calculated core-only reactivity feedback coefficient used in this calculation was -13.7×10^{-5} $\Delta k/k$ $°C^{-1}$ compared with a measured value of -7.4×10^{-5} $\Delta k/k$ $°C^{-1}$ for a slow heating of the whole reactor, we decided to perform some power transient experiments to assess the reliability of the calculations.

2. POWER TRANSIENT MEASUREMENTS

Calculation indicated that the shortest period that could be produced without the peak power exceeding the trip point of 120 kW was ~ 12 s. Therefore significant energy losses to the top reflector/shield of light water were expected to be produced by natural convection since the time scale of the power transients would be large. To minimise this effect the tests were performed with the water height above the top of the core reduced from 38 to 8 cm. This necessitated a redetermination of the power-current calibration of the ion chambers located above the top reflector/shield. The ratio of the chamber outputs for the above water heights was found to be 1:1.38.

The test procedure was to level the reactor power at 10 watts and turn off the primary coolant pump. The core tank water then drained slowly back into the dump tank through an ion exchange line. The closure of this line enabled the water level to be maintained at the desired height above the core. Withdrawal of the shim rod by an amount to give the desired reactor period then followed, and the reactor power was recorded by a two-pen (log and linear) chart recorder. When peak power was passed and the power level had begun an obvious decrease, the shim rod was scrammed and the primary coolant pump restarted.

In an attempt to detect the onset and rate of convective water flow, two thermocouples, separated vertically by 5 cm, were mounted in the water immediately above the core, and their output taken to two chart recorders.

The peak reactor power was read directly from the linear power trace which also allowed the energy release to the time of peak power to be obtained by numerical integration. The initial asymptotic reactor period was obtained by plotting the linear power data on semi-log graph paper and fitting a straight line to the data.

3. RESULTS

Values of P_{max} and E_{tm} obtained for ten transients characterised by initial inverse periods in the range 0.02-0.07 s^{-1} are compared with calculated values in Figure 1. Agreement is excellent for values of P_{max}, but the experimental energy releases are ~ 60 per cent higher than those calculated. This is consistent with the occurrence of significant heat losses close to the time of the power peak, resulting in wider topped power bursts than those given by the calculations which were based on a no-heat-loss model.

To investigate this heat loss further, a detailed examination was made of the power burst shapes. Figure 2 compares the ZAPP calculation of the excess reactivity of the core during a 16.5 s period excursion with that calculated by an inverse kinetics code from the power trace of the corresponding measured transient. At a power level of approximately 55 kW the slope of the experimental reactivity time curve becomes much less than that computed by ZAPP, and is taken to indicate the commencement of significant natural convective flow in the coolant.

The delay between each of the two thermocouples indicating a rise in temperature was 7 s, corresponding to a flow velocity of ~ 0.7 cm s^{-1} or an initial flowrate of ~ 0.7 ℓ s^{-1}. Although the assumption of a constant convective flowrate is a gross oversimplification, trial runs of ZAPP were made with various constant flowrates initiated from various powers, in an attempt to match the observed reactivity variation with time.

Furthermore, examination of the experimental excess reactivity data suggests that, in the early stages of the transient, better agreement with experiment can be obtained if the calculated reactivity feedback coefficient is increased by 25 per cent. With this change, a good fit to the entire transient can be obtained if a constant coolant flow of 1.2 $\ell\ s^{-1}$ is started at a power level of 55 kW (Figure 2).

The same procedure was followed for a transient of initial period 50 s. In this case a flow of 0.34 $\ell\ s^{-1}$ (commenced at a reactor power of 10 kW in the calculation) gave good agreement with the experiment. The measured and calculated power histories of both the above transients are shown in Figure 3.

4. DISCUSSION

Although the significance of the level of agreement obtained between experiment and calculation for these slow transients is limited by uncertainties in the reactor power calibration (~ ± 10 per cent) and the calculated reactivity feedback coefficients, and by the occurrence of convective heat transfer, we nevertheless consider that these measurements give confidence in the calculations made for the faster transients which may lead to core damage.

Figure 4 shows the principal power burst parameters for Moata computed by ZAPP for a range of initial inverse periods produced by step inputs of reactivity above critical. From these data, it has been concluded that for a reactivity addition of 0.011 $\Delta k/k$, the central core region cladding would just reach melting temperature if all installed shutdown mechanisms failed to operate. This is a somewhat smaller addition than that tolerated by the SPERT I reactors, largely because of Moata's long neutron lifetime (160 μs) and its low heat transfer area compared with those of the SPERT I cores.

5. CONCLUSIONS

The parameters of slow transients, self-limiting within the normal authorised operating power of Moata (100 kW), have been successfully measured.

Peak powers were in good agreement with calculations using the ZAPP point kinetics/heat transfer code with a zero heat loss model. Although energy releases to the time of peak power were found to be significantly higher than calculated, the effect is expected and has been semi-quantitatively accounted for in terms of power pulse broadening by the observed onset of natural convective flow as peak power is approached. The validity of using a calculated core-only reactivity feedback coefficient in transient response calculations rather than the smaller, pseudo-static coefficient measured by slow warm-up of the whole reactor, is amply confirmed. There is also some evidence that the true dynamic feedback coefficient for Moata may be some 25 per cent higher than that obtained from the AUS-scheme 2-dimensional, 4-group diffusion theory calculation. Such a difference is not unreasonable in view of the difficulties in modelling Moata effectively in two dimensions.

Overall, and in conjunction with the SPERT analyses, the results give confidence that ZAPP calculations for faster transients which cannot be directly verified by experiment, are valid for use in reactor safety assessment studies of the consequences of accidental reactivity additions.

Both the method of calculation and the slow transient verification technique should find useful application to a wide range of liquid moderated, low power research reactors.

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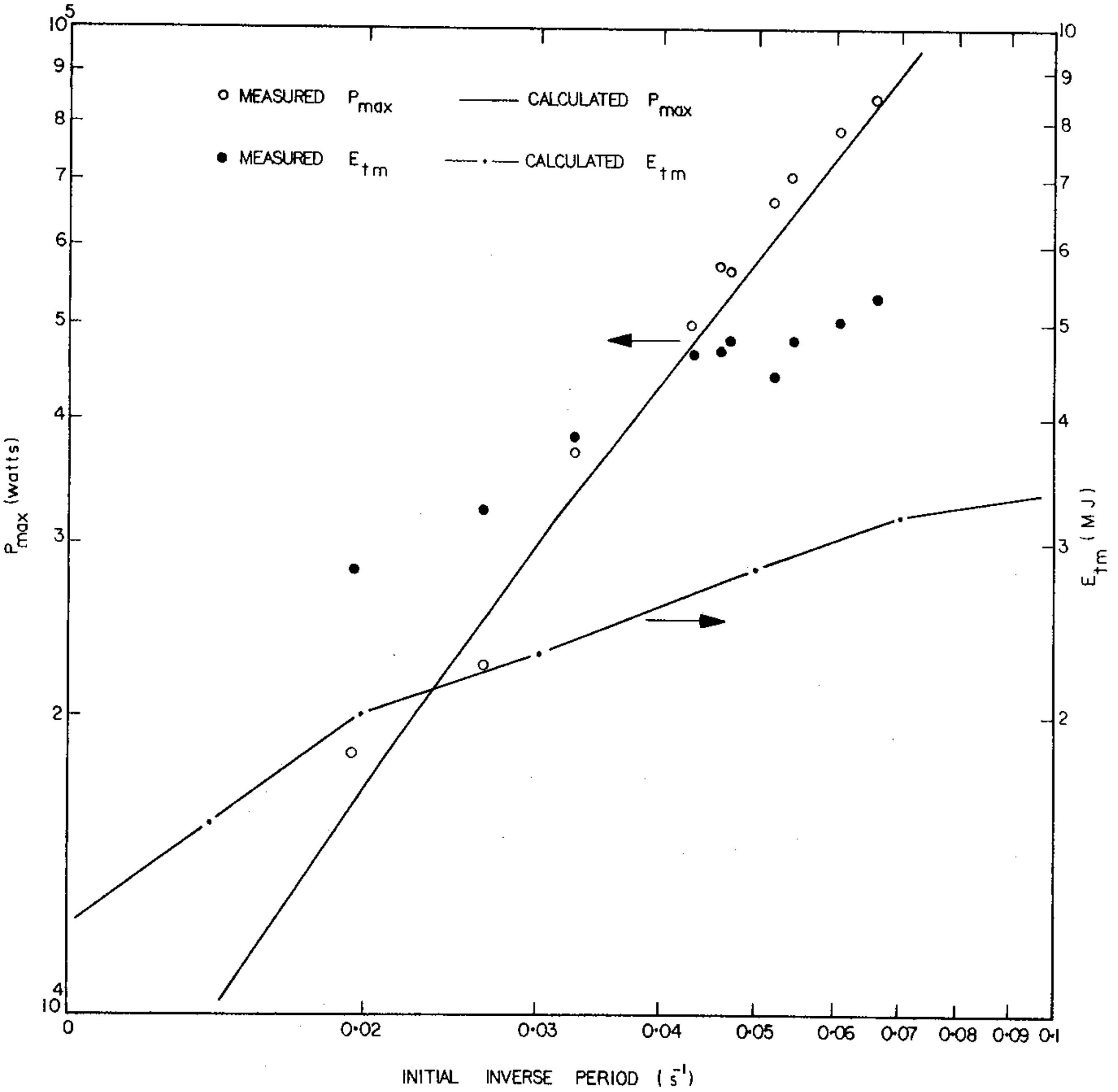

FIGURE 1. CALCULATED AND MEASURED VALUES OF P_{max} AND E_{tm}

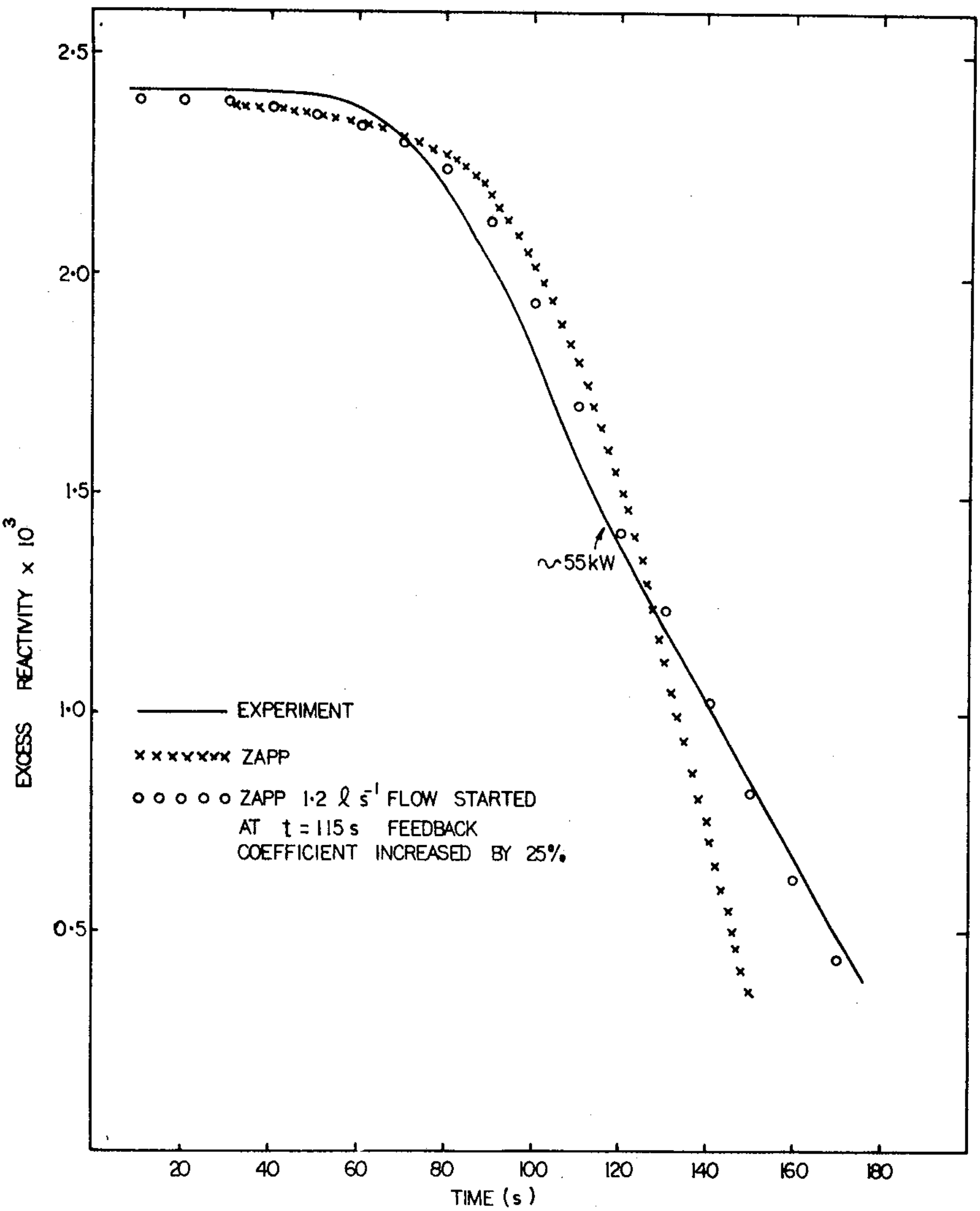

FIGURE 2. EXCESS REACTIVITY DURING A 16.5 s PERIOD TRANSIENT

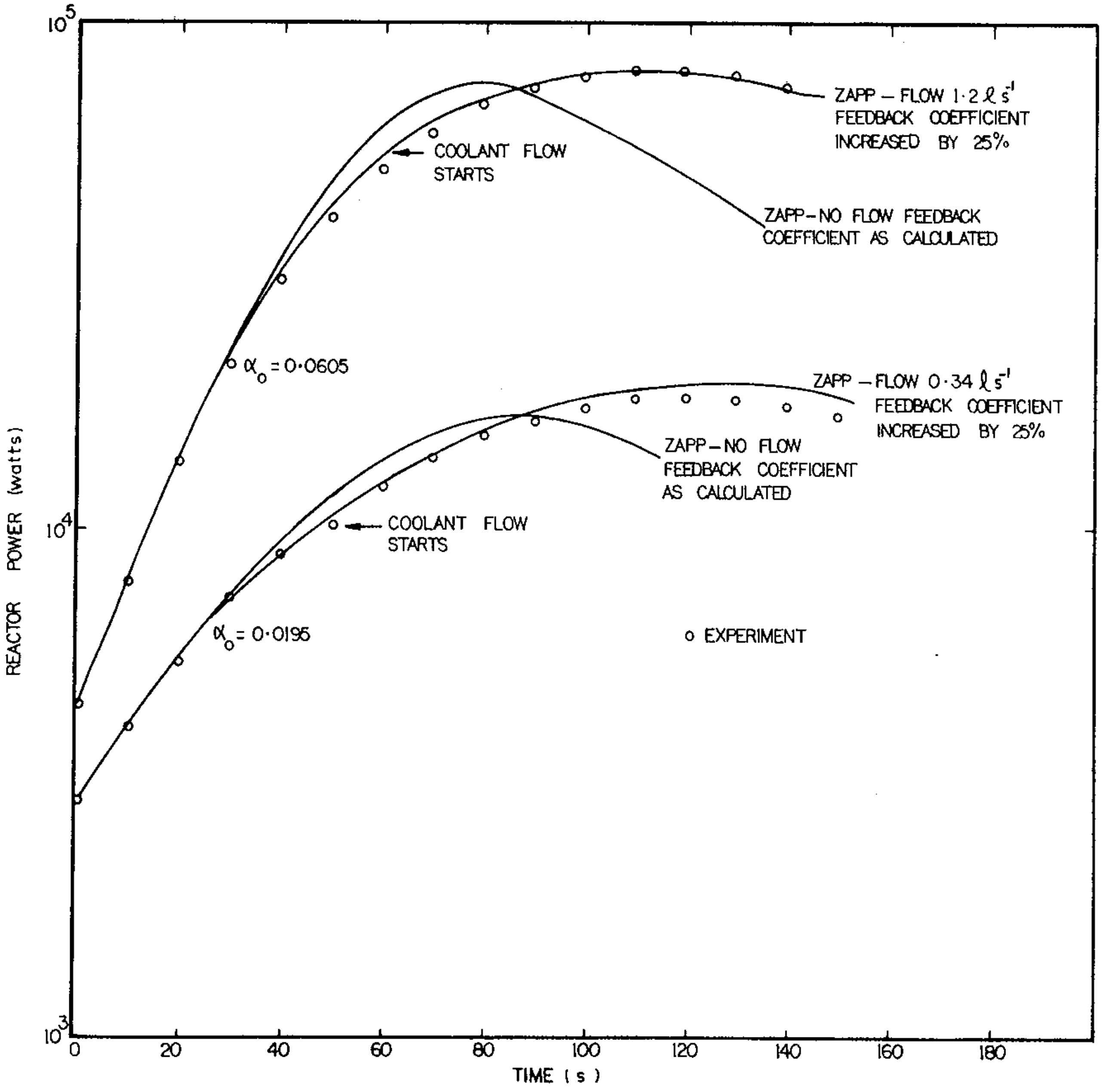

FIGURE 3. EFFECT OF COOLANT FLOW AND FEEDBACK COEFFICIENT ON BURST SHAPE

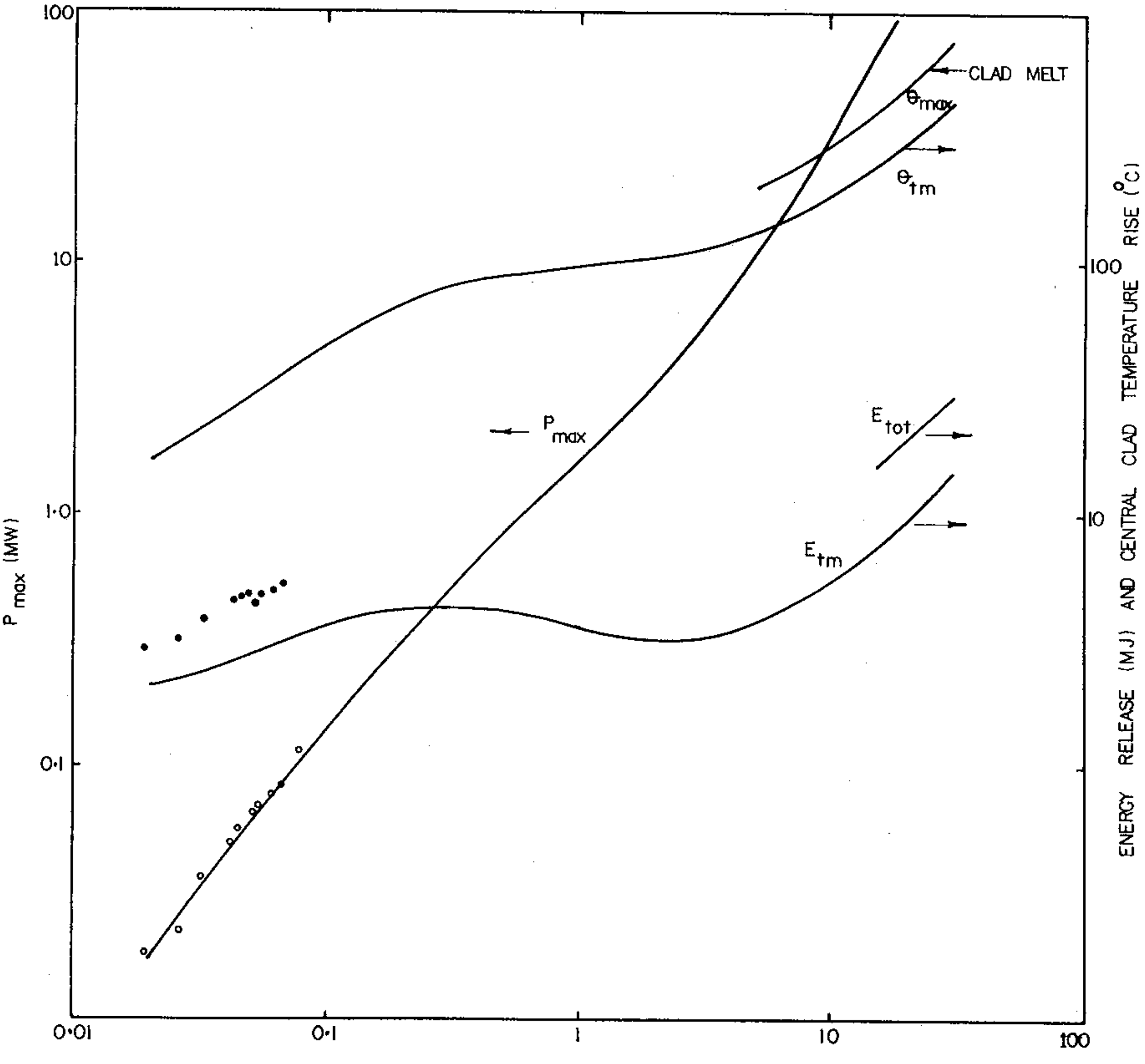

FIGURE 4. VARIATION OF CALCULATED MOATA BURST PARAMETERS WITH INITIAL INVERSE PERIOD