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STATUS AND VALIDATION OF THE SAS4A ACCIDENT-ANALYSIS CODE SYSTEM*

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H. U. Wider, G. L. Bordner, L. L. Briggs,
J. E. Cahalan, F. E. Dunn, K. J. Miles, E. E. Morris
F. G. Prohammer, A. M. Tentner, D. P. Weber

Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

ABSTRACT

The SAS4A code system is a new tool for analyzing the initial phase of Hypothetical Core Disruptive Accidents (HCDAs) up to gross melting or failures of the subassembly walls. The objective in the development of SAS4A is to provide improved analytical models which represent experimentally demonstrated modes of material response in such accident scenarios.

This paper discusses recent improvements in the phenomenological models, gives examples of verification and validation efforts that have been conducted, and illustrates the whole core-analysis implications of using this refined modeling capability.

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INTRODUCTION

The SAS4A code system is a new tool for analyzing the initial phase of Hypothetical Core Disruptive Accidents (HCDAs) up to gross melting or failures of the subassembly walls. The objective in the development of SAS4A was to provide improved analytical models which represent experimentally demonstrated modes of material response in such accident scenarios. SAS4A has considerably more detailed and realistic modeling of the primary and secondary loops, fuel pin behavior, sodium voiding due to fuel-coolant interactions (FCIs), and molten fuel and cladding dynamics than its widely used predecessor, SAS3D. The basic features of the new models have been described in an earlier paper [1].

This paper discusses recent improvements in the phenomenological models, gives examples of verification and validation efforts that have been conducted, and illustrates the whole core analysis implications of using this refined modeling capability. Highlighted are the models which play particularly important roles in the determination of fuel failure and fuel-clad relocation in the unprotected loss-of-flow (LOF) and transient overpower (TOP) scenarios. Included are the fuels characterization and fuel-clad mechanical analysis module, DEFORM III, the model of fuel motion in unvoided subassemblies, PLUTO2, and the model of fuel motion in voided assemblies, LEVITATE. Also included is a review of other major modules which are similar in capability to their SAS3D counterparts, for which continued verification/validation has been performed. Finally, an illustration of whole-core analysis capability and the safety analysis implications of these calculations is provided in the context of the European Economic Community whole-core comparative calculations (EEC-WAC) for a 1000 MWe irradiated core TOP scenario. Recent calculations of the LOF scenario are reported in another paper submitted to this meeting [2].

FUEL PIN BEHAVIOR

The new fuel pin model DEFORM III treats fuel and clad behavior during steady state irradiation and during the initial phase of an HCDA. A major recent improvement is inclusion of an axial fuel expansion model which takes into account fuel and cladding thermal expansion, irradiated fuel swelling, and the effect of fuel-cladding interaction. The calculated reduction of axial fuel expansion due to the cladding constraint is a sizable fraction of the free axial expansion in a slow TOP accident. Experimentally a reduction of axial fuel expansion due to fuel-clad interaction has been observed in the single-pin CABRI experiments [3]. Comparison calculations between the steady state part of DEFORM III and the steady state fuel behavior code COMETHE-III-J-FBR have shown fairly good agreement [4]. Comparison calculations with the transient FPIN code [5] have shown that DEFORM III predicts considerably larger nonrecoverable cladding strains than FPIN. This is mainly due to the treatment of irradiated fuel swelling in DEFORM III. The true magnitude of this transient fuel swelling will be investigated through comparisons with TREAT experiments.

VOIDED-CHANNEL FUEL MOTION

The LEVITATE model treats fuel motion inside intact fuel pin segments and fuel and steel motion in voided and disrupted coolant channels. LEVITATE can be initiated after coolant voiding or after clad motion has begun, or after the PLUTO2 calculated fuel motion and sodium voiding in intact channels have led to conditions such that clad motion or fuel pin break-up should occur. This means that the later stages of a more severe TOP accident or LOF-driven-TOP accident can now be treated with LEVITATE.

An earlier successful effort to validate LEVITATE was made by analyzing the 3-pin LOF test L7 in which a maximum power of 20 times nominal was achieved [6]. In a more recent validation effort, LEVITATE was used to simulate the milder 3-pin LOF test L6 in which a maximum power of 10 times nominal was achieved [7]. In this latter post-test analysis the same modeling parameters were used as in the L7 analysis, and it was found that the slower fuel dispersal measured in the L6 experiment can also be fairly well simulated by LEVITATE. Figure 1 shows a comparison of the histories of integral fuel worth (normalized to the initial total worth of the bundle) which were obtained from the calculation and the hodoscope measurements of the L6 experiment. Also shown in Fig. 1 is the total worth history obtained from a SAS3D/SLUMPY analysis. LEVITATE provides an improved prediction of axial fuel dispersal, because it includes some important physical models now accepted as important in the LOF fuel motion analysis, such as continuous fuel flow regimes, fuel freezing and plugging, and in-pin fuel motion [2], which are not available in SAS3D/SLUMPY.

FCI-DRIVEN VOIDING AND FUEL MOTION

The PLUTO2 model for treatment of in-pin and out-of-pin fuel motion, FCI's, and sodium voiding has been used for the analysis of several TOP in-pile tests [1]. Through analyses of TREAT experiments, such as the H6 50¢/sec simulation, the E8 $3/sec simulation [8], and the L8 LOF'd'TOP simulation [9], as well as several intercode comparisons [4], [8], the verification and validation of PLUTO2 is regarded as being at an advanced state. An example of the whole-core analysis implications of PLUTO2 is provided below.

BOILING MODEL

The current boiling model in SAS4A is a one-dimensional, multi-bubble boiling model similar to that in SAS3D. Its main novel feature is a variable flow cross section treatment which allows consistent coupling with the cladding motion model and proper treatment of experiments with variable flow cross sections. For cases with constant flow cross section, the SAS3D and SAS4A boiling models agree very well.

The SAS3D boiling model has been used for successful pre- and post-test analyses of several 7-pin R-series TREAT tests. For a more general validation, analyses of larger fuel bundles have been performed. A pre-test calculation of the 37-pin, nominal-power, in-pile test P3A is shown in Fig. 2. The difference between the predicted and measured time of flow reversal is within the experimental uncertainties. The calculated and measured inlet flows both exhibit an oscillatory behavior, with similar mean values and periods. The calculated oscillation amplitudes are initially larger than the experimental values, probably because of radial incoherence within the pin bundle. This issue will be clarified through a detailed post-test analysis.

CLADDING MOTION

Comparison calculations between the new Eulerian cladding motion model CLAP and SAS3D/CLAZAS have been performed, as have comparisons to experimental data [10]. An interesting new result of CLAP calculations is that the model predicts an incomplete upper cladding blockage. This result is due to the consistent coupling with the boiling model. A sizable flow reduction due to a near-complete clad blockage leads to enough vapor flow throttling to cause the clad below the blockage to drain. This behavior is supported by flow measurements in the 37-pin P3A test.

PRIMARY AND SECONDARY LOOP MODEL

The PRIMAR-4 thermal-hydraulic model of the primary and secondary heat transport loops treats the liquid sodium and cover gas in a generalized network of components (pipes, plena, pumps etc.). It has a multiple loop capability (up to four loops), and it can treat loop or pool systems. Initial verification efforts of PRIMAR-4 included comparisons with the simpler PRIMAR-2 module of SAS3D. These comparisons did not indicate any basic problems. Initial validation of PRIMAR-4 consists of comparisons with FFTF whole-plant natural circulation test data.

WHOLE-CORE ANALYSIS

Initial applications of the whole-core code to both TOP and LOF scenarios have been made. For example, in the recent EEC-WAC TOP study [5], which focused heavily on the fuel motion calculations such as done by PLUTO2, it was shown that early voiding and fuel reactivity effects were comparably predicted between SAS3D and SAS4A, although SAS4A's predicted net reactivity was still lower due to slower voiding progression and less fuel sweepout. Of perhaps greater significance, however, was the thermal interaction between fuel and intact clad and freezing of molten fuel in the channel. As shown in Fig. 3, the net result of failure of complete sweepout as predicted by SAS4A was a smaller reduction of power than predicted by other codes and the possibility for further failures as the ramp insertion continues. The longer time scale questions of ultimate neutronic shutdown and coolability are items of current research.

CONCLUSIONS

A reasonable level of verification and validation of the SAS4A computer code has been achieved. However, since the code should be applicable to a large number of possible initial-phase accident sequences in different reactor designs (in particular low and high void worth cores), the current degree of validation is not fully satisfactory. In particular, the fuel motion models require more validation. Analyses of additional slow-ramp rate TOP tests, relatively low power LOF tests, and high-power LOF-driven-TOP tests are deemed necessary. Of particular importance will be fuel motion tests in bundles of more than seven pins. This means that much of the further validation effort of the fuel motion models is tied to the TREAT in-pile test program which is outlined in the new TREAT Experiment Plan [11]. In contrast, radially incoherent or low power, low flow boiling experiments in large bundles, required for the further validation of the boiling model, can be performed out-of-pile.

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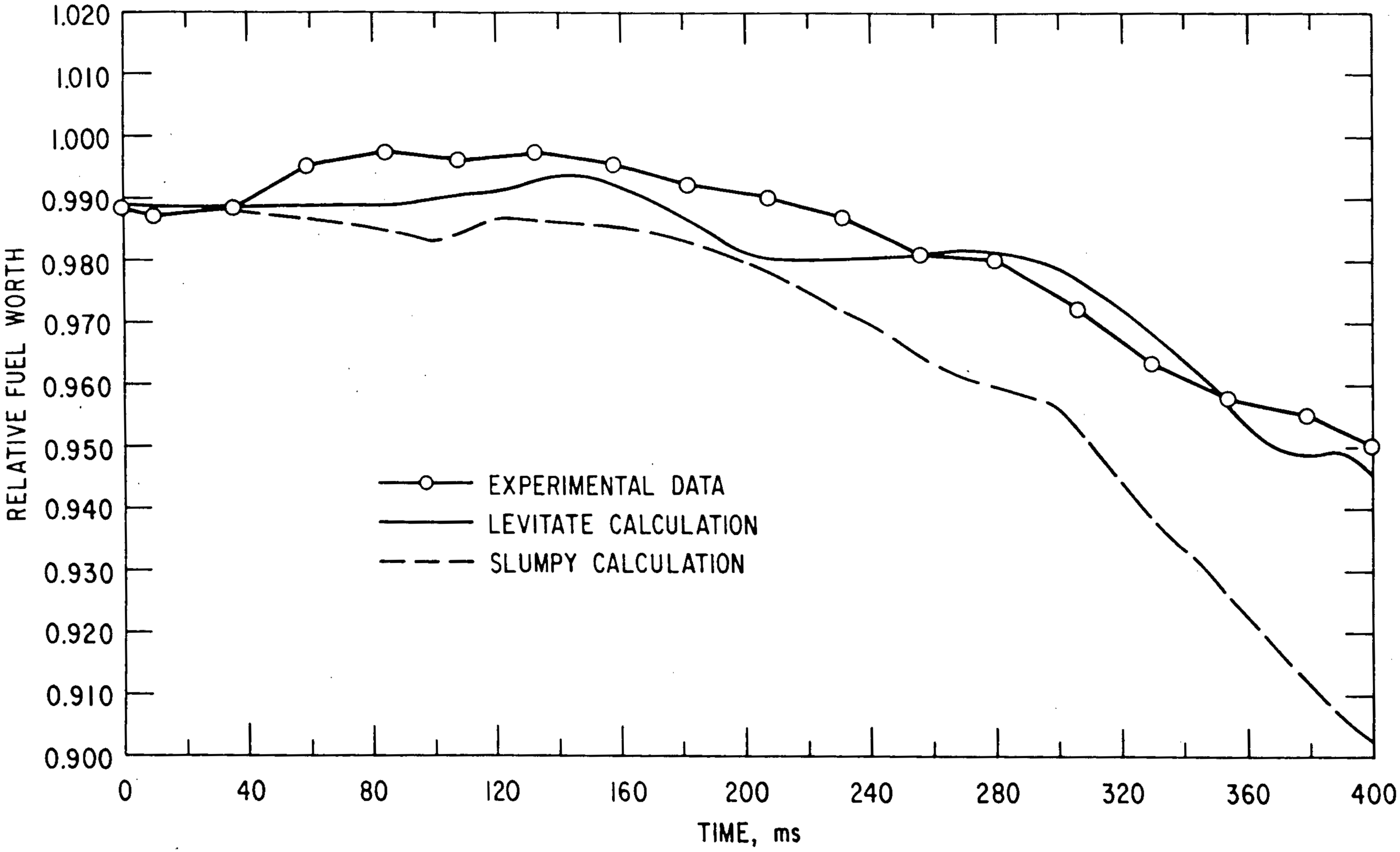

Fig. 1. Fuel Worth Histories After Pin Failure for the L6 Experiment

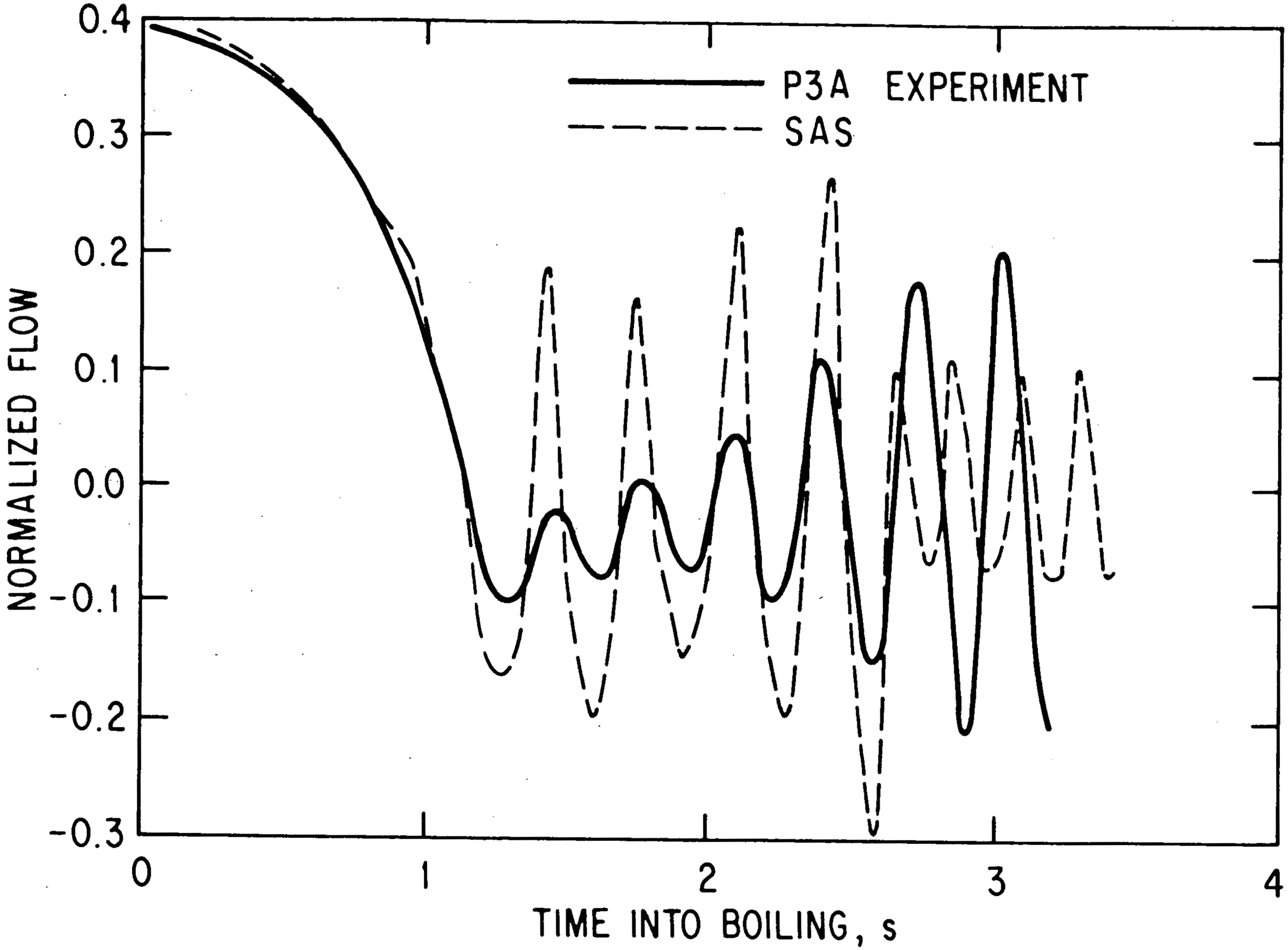

Fig. 2. Inlet Flow Comparison Between P3A Experiment and SAS3D Calculation (with 0.22 sec added to the time scale in the SAS result)

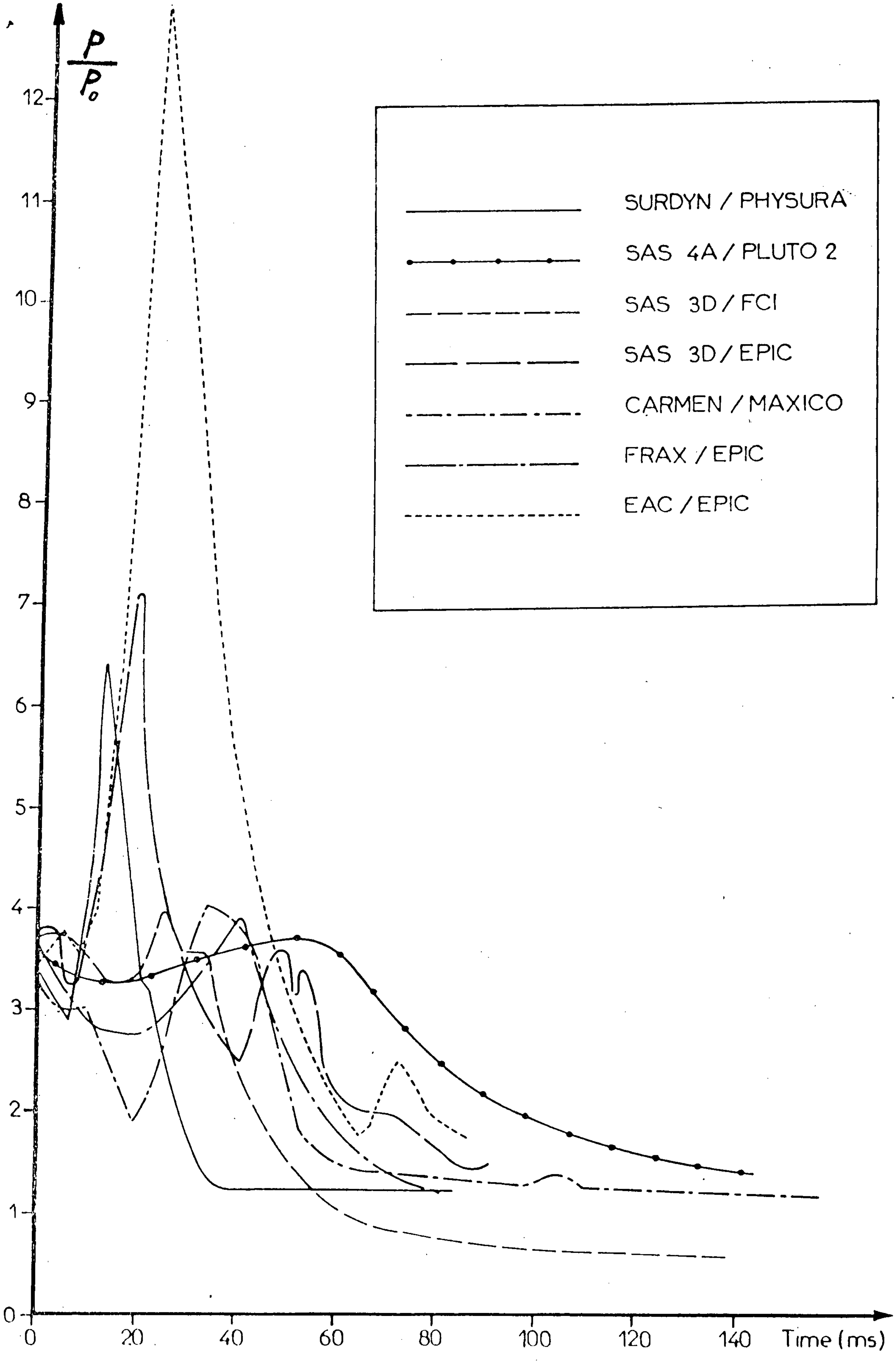

Fig. 3 - RELATIVE REACTOR POWER EVOLUTION WITH TIME