SAS4ADS- 3D Space Time Dynamic Code System for ADS

R. Dagan, C.H.M. Broeders, D.Struwe, W. Pfrang
Forschungszentrum Karlsruhe GmbH
Postfach 3640, D-76021 Karlsruhe

INTRODUCTION

The dynamic phenomenon of an Accelerator Driven System (ADS) is quite unique compared with conventional critical reactor systems. The characteristic parameters are, in the steady state phase as well as in transient scenarios, strongly dependent on the sub-criticality level, the location and the number of the sources within the core. The fuel, coolant and clad neutronic, thermal-hydraulic and mechanical properties, which are dedicated to waste incineration, may also differ significantly from the ones used at customary power reactors.

For the stationary operation introducing one central source or multiple sources within a neutronic multiplying media evolves considerable high thermal peak factor [1], and substantial changes, leading to an exponential spatial flux distribution, in particular in the very near vicinity of the source(s). For a multiple source system shutting off the sources can cause a strong positive reactivity effect and one has to assure that the power will decrease below its safety margin (see fig. 1). Furthermore, in case of abnormal transients, the level of sub-criticality is one of the key safety aspects to be considered [2] . For example, shutting off the source at k_{eff} close to one, introduces decay heat power, which is up to 60% of the nominal power, compared to 7% in conventional reactors, where control rods are inserted.

The complexity and sensitivity of an ADS to all sort of perturbations and the prevailing assumption that regulating rods are replaced, at least at the designing stage, by source strength adjustment (or shut off) points out the necessity of a full space time dynamic program. The main task is to create a tool that deals with the entire spectrum of spatial dynamic effects including mechanical and material damage.

DESCRIPTION OF SAS4ADS

SAS4ADS is based on three well-validated codes: SAS4A [3], CITATION [4] and KAPROS[5]. As the concept of ADS is based on fast neutrons SAS4A was a natural choice to deal with the thermal-dynamics in addition to its mechanical and material damage simulation. The variety of details in SAS4A allows for a direct inspection of the core concerning fuel choice, fabrication, geometry etc. In parallel the impact of various component failures in the primary or secondary loop, on the entire system, are also well predicted.

The modifications applied to the original version of SAS4A code concern mainly the activation of an external source for normal and abnormal operation where the source should be shut off. The well-established Kaganove method [6] solving the amplitude point kinetic equation is kept in the modified version of SAS4A. Yet the global terms in the point kinetic equation such as reactivity, mean generation time and effective delayed neutron fraction are evaluated by means of a 3 dimensional diffusion code instead of the original reactivity feedback tables. Furthermore

the restriction of a constant power distribution in SAS4A is released and the spatial flux distortion, particularly after shutting off the sources is accurately presented. Apart from the neutronics, a new formalism for heat conductivity, and heat capacity is required so that new fuel materials or innovative fuel pin types can be analyzed. On the coolant side, SAS4A can handle diversified metal liquids, in particular, lead or sodium. Yet the gas-cooling alternative for ADS is not available.

The spatial flux calculation of SAS4ADS uses currently the CITATION [5] code, which is based on the finite difference diffusion approximation. The code solves successfully external source problems, in particular the leakage term so that the production over losses term for ADS evaluates correctly the criticality values. Burn-up simulation for ADS was supplemented to the CITATION code, and the rate of transmutation is directly obtained. Microscopic or macroscopic cross sections are possible and the number of energy groups is unlimited, yet with increasing computational endeavor. The code allows for quite complex multiple zone volumes, which in turn leads to a better optimization of the SAS4A channel structure. An automatic developed axial meshing scheme between CITATION and SAS4A grid allows for axial expansion feedbacks, to be taken into account.

The thermal-dynamic feedbacks of SAS4A are being evaluated by a special routine of KAPROS and at each user-set time-interval, the whole cross-section data are re-evaluated based on the temperature, void and densities fluctuations. The drawback of such a procedure is the large computing time needed to calculate the cross-section for the many (app. 200) diverse zones considered. The master cross–section library of KAPROS, which holds 69 energy groups is used for each material composition and than with a collapsed group scheme the required 9-10 groups structure is accomplished. In order to accelerate the calculation in SAS4ADS a new procedure COLLIB was developed within KAPROS. The underlying concept of COLLIB is to collapse the master library to the required coarse group cross-section library, before the unit cell calculation, keeping the same microscopic structure of the master library. Nevertheless, reducing the number of energy groups gives rise to the importance of the weighting spectrum and the group boundaries for the collapsing procedure. This, in return, indicates that the collapsed library is implicitly problem depended, in a sense that the material composition chosen predetermines the energy groups number (and boundaries) and the weighting spectrum. In particular, self-shielding tables and threshold reactions should be accounted for. With respect to the above-mentioned precautions, the COLLIB module introduces encouraging accurate results, compared to the ‘classical’ procedure, gaining almost a factor of 5 in computational time.

The linking subroutines between the three modified codes discussed above were developed in a modular manner so that other codes could be considered. In particular in the case of small scale ADS an appropriate transport code could replace the CITATION code or improvements in the cross section evaluations for high energies could be taken into account. Concerning the thermal dynamics, SAS4A is simulating the core by well-suited so-called ‘channels’, which represent groups of subassemblies undergoing similar procedures. Those channels are then fixed. For an ADS, one has to gain specifically knowledge about the possible power loads in each assembly in order to design the channels appropriately.

FZK MULTIPLE SOURCES BENCHMARK PROBLEM

The multiple sources benchmark configuration of FZK [1] was designed in accordance with the source strength envisaged and the fact that one central source introduces an extremely high peak factor for an ADS. The basic design uses THO_2 /UO_2 and lead coolant. In the current study sodium is being used as coolant because lead is not yet fully validated in SAS4A. Moreover, the sodium exhibits light negative void reactivity feedbacks with Thorium as a fuel. The SAS4A channels choice was aimed to emphasize the pins adjacent to the source and the center core pins. Fig 2. shows the flux distribution along a traverse line at mid core height with and without an activated source. From this figure one realizes the importance of a correct channel configuration, as the spatial location of the peak factor shifts significantly. Moreover the change of the flux distribution after source shut off indicates that a fully three dimensional space kinetic is inevitable. As a test case a pump failure incident was simulated with the SAS4ADS code system. The SAS4A detailed description of the primary loop enable in such a transient to study carefully the importance of various components on the whole inherent safety. Fig. 1 shows the power and reactivity against the time after the pumps fail, followed by source shut down. As can be seen the reactivity can rise considerably although the power decreases. This is mainly due to the specific ADS configuration analyzed, and to some extent to the temperature decrease and its reactivity feedback.

CONCLUSIONS

The SAS4ADS codes system enables a detailed analysis of most kinds of envisaged ADS concepts. It avoids the necessity of adjoint functions for reactivity calculation and describes accurately (based on proper channel choice) the spatial flux fluctuations of ADS. The modification done in CITATION and the completeness of SAS4A allows for a detailed mechanical inspection of the fuel type, geometry etc. in addition to the neutronic and thermal dynamics aspect, in particular, to analyze the unique burn-up effects of the ADS fuel. The new developed coarse group library reduces considerably the computation time with minor penalty in the criticality accuracy. The diffusion-based approximation for calculating the spatial flux distribution could be quite easily replaced, in SAS4ADS, by suitable transport codes. For the choice of gas coolant the SAS4A code should be modified. Nevertheless, it would be much more complicated and probably requires a totally new code system design.

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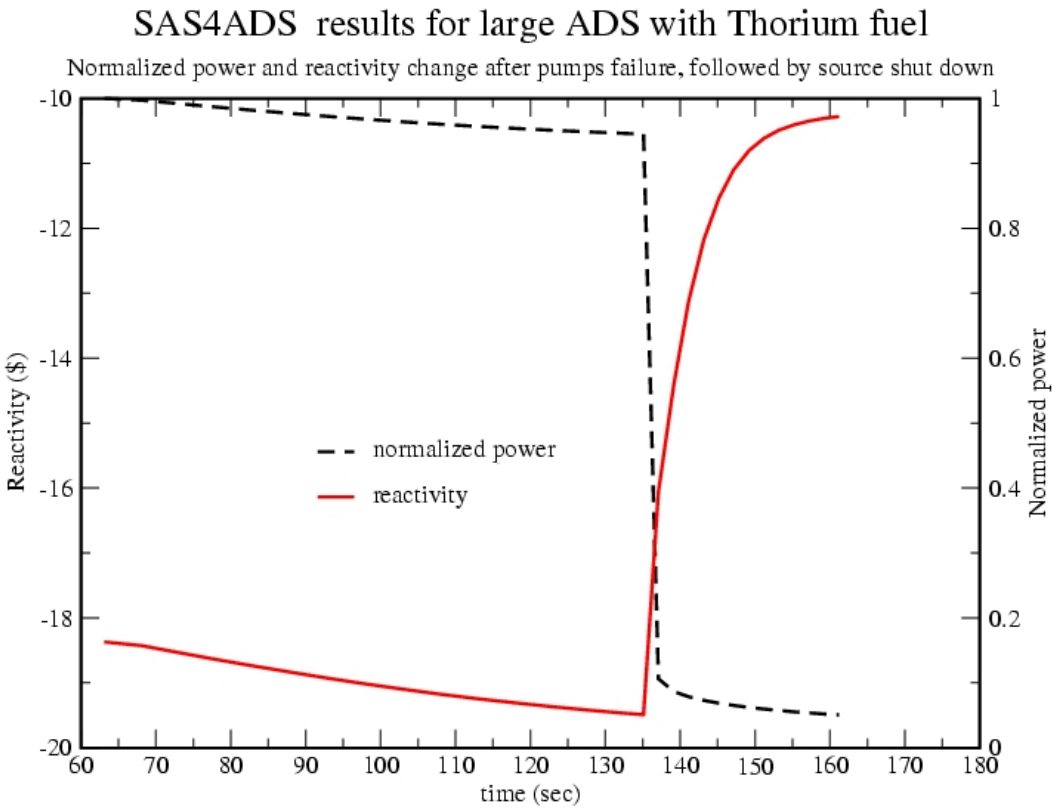

Figure 1. SAS4ADS result for large ADS with thorium fuel. Reactivity and power change after pump failure at 63 sec. At 135 sec the sources are shut off.

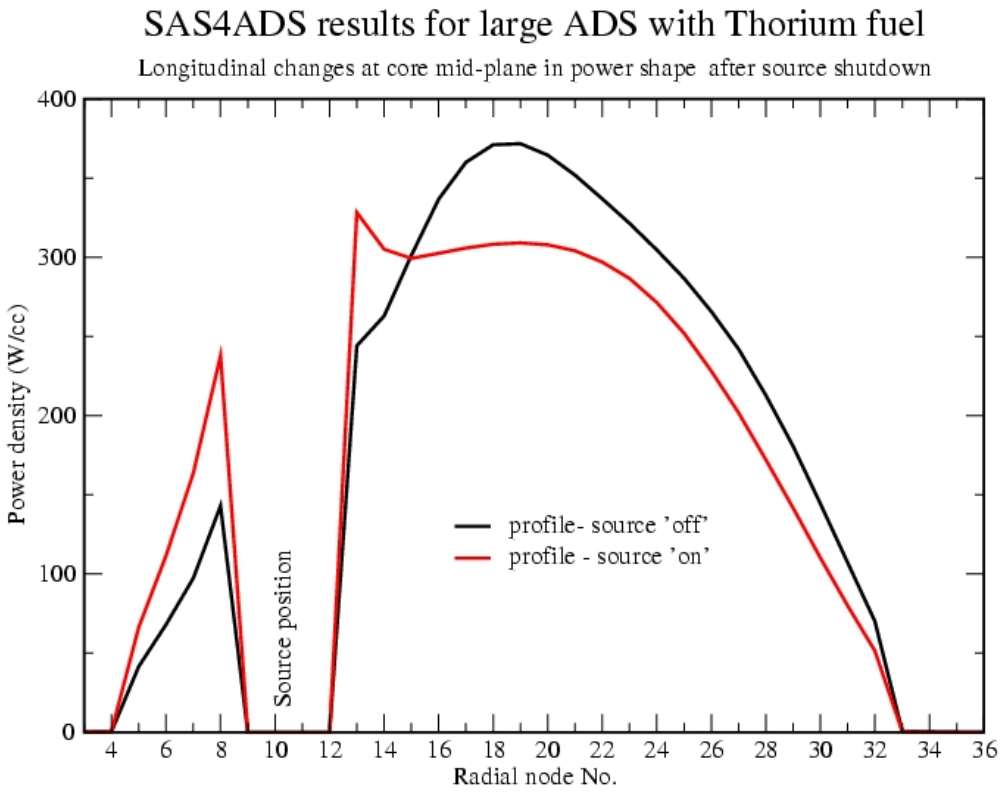

Figure 2. SAS4ADS result for large ADS with thorium fuel. Power density profiles along a traverse line before and after source shut off at core mid plane. The source is located at nodes 10-11.