Source trip effects on transient ADS behaviour

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Abstract –The 80MW_{th} XADS demonstrator within the PDS-XADS program is a core design loaded with MOX fuel. The behaviour of such a core and in particular of the MOX fuel pins undergoing several types of source trips is analysed. For the proposed ADS design the resulting reactivity fluctuations seem to be rather low. A unique fuel pin mechanics model in the SAS4ADS system anticipates pronounced cracking of the fresh fuel pellet. Consequently consequences of source trips and subsequent re-establishment of the nominal power levels should be carefully analysed to assure the pins integrity during the whole operation cycle.

I. INTRODUCTION

A sub-critical core governed by a neutron source introduces new operational and safety issues, unique for Accelerator Driven System (ADS). In particular, a source trip may cause significant reactivity fluctuations, which for the given sub-criticality levels of an ADS, should be carefully examined. Some of the reactivity changes are due to the specific location of the source within the core, or in the case of various sources, due to the multiple source system configuration [1]. Shutting the source(s) off induces a shift in the core flux distribution, which leads to different sub-criticality levels. The importance of Doppler and other feedback effects is in accordance with those sub-criticality levels.

For the experimental ADS envisaged, it turns out that the MOX fuel pin mechanics under postulated source trips should be carefully analysed. The thermal shocks induced by shutting off or turning on the source distort the fuel rod shape, mainly due to crack formation within the fuel pellet. The affected different gap width between the clad and the fuel imposes a new temperature profile, which in return influences the sub-criticality level. The ADS design foresees at 80MW_{th} fuel temperatures around 1000 K. Such temperatures are too low for healing the cracks within the fuel. Therefore, a source trip series simulation is vital to understand the propagation phenomena of the cracks directly related to the fuel pin integrity and the thermal-hydraulic core behaviour.

II. THE DYNAMIC CODE SYSTEM SAS4ADS

SAS4ADS developed in FZK [2] is a full 3D dynamic code system coupling 3D transport or diffusion calculations with the SAS4A accident analysis code. The actually used SAS4A code system has been developed in co-operation between the Japanese JNC, the French IRSN and FZK based on the original ANL code version [3] and allows for examination of the phenomena mentioned in the above paragraph.

In SAS4ADS a full cross section evaluation for all core segments is performed each time step which is then followed by a 3D neutron flux calculation. Thus, all the reactivity feedbacks are mutually included. The updated flux distribution and the perturbed criticality level are then introduced in the next thermal hydraulic calculation step. SAS4ADS contains a well validated fuel pin mechanics module DEFORM-4C which simulates fuel cracking and thus allows for accurate updating of the gap width between the fuel and cladding. The thus modified gap conductance is determined using the URGAP model [4] and is connected to the thermal-hydraulic model. Therefore, consequences of source trip effects can be adequately traced. Similarly important is the ability of the module to anticipate axial expansion and shrinking of the fuel rod. Core size changes due to cooling after a source trip might introduce a non-negligible reactivity feedback, mainly due to the enlarged density of the fuel pin in the core centre zone.

III. SOURCE TRIP SIMULATION

An XADS design studied within the EU [5], proposed by FZK, is loaded with 66 SNR fresh fuel elements in hexagonal order (see figure. 1). 42 MOX lower enriched elements where introduced in the 4th and 5th ring enveloped by 24 higher enriched fuel. All the sub-assemblies are embedded in a lead bismuth reflector consisting of 20% in volume structural material. The active core length is 95cm. The thermal power amounts to 80MW_{th}. The fuel pellet is a solid fuel pellet with a high as fabricated porosity of 8.3 % and an original gap width of 0.075 mm, which is rather small. This core design has a relative low peak factor (1.46) and its reactivity jump due to source activation is about 0.2%

which is acceptably low. Other aspects of the current design are discussed in [5]. This study concentrates on reactivity fluctuations during various source trips and on the consequential reactivity margins of the system. The operational mode is also investigated as source trips result in changes of the fuel pellet geometry. Two basic types of simulations were performed. Source trip series with relatively long source shut-off time periods and several source trips each of which with different time durations for the source shut-off time periods

III.a Source trip series

Several source trips were simulated first. After each trip the source retained its original strength after 10 sec and the system stabilized at its new operational mode. In figure 2 the reactivity change during the first four source trips sequences are plotted. The last 5 seconds between 60 and 65 seconds of the steady state are followed by a first source trip at 65 sec. At this time the reactivity is falling promptly due to the shift of the flux distribution from a source governed system to a source free core. The temperature decrease, and to some extent the enhanced fuel density, reduce the core sub-criticality asymptotically. After 10 sec (at 75 sec) the source is turned on again. A prompt jump in the criticality is seen which is again (as by shutting the source off) a result of the shifted flux but this time in an opposite manner. The sub-criticality becomes larger in accordance with the core heat-up and the axial core expansion. The core sub-criticality stabilizes at several cents above its original steady state value depending on the new fuel temperature induced by a modified gap conductance. This behaviour pattern repeats itself for the next source trips. The operational sub-criticality level is rising asymptotically induced by the fuel temperature decrease after each source trip. The fuel temperature is governed mainly by the stepwise closing gap. For the criticality margins it is seen that the largest reactivity swing is about 1.3 $ which is rather small for a 10 $ reference value of the sub-critical design. Yet for other simulation where for example SPX fuel is used [5] the initially larger gap width could lead to higher values of reactivity fluctuations.

The gap conductance of the hottest channel after each source trip cycle, as explained above, is illustrated in figure 3. It can be seen that the first and second source trip cause significant increase of the gap conductance. Later on the form of the gap remains nearly constant and the gap conductance is "crawling" further upward only slightly. This means that the gap width becomes reduced after each trip and in the last source trip shown the peak value of the gap conductance indicates that the gap is almost closed at that certain fuel segment. Moreover it is evident that after each source trip the gap conductance stabilizes at another value with consequences on the operational mode regarding temperature of the fuel and hence the whole core behaviour. Here one should keep in mind that healing of the fuel cracking could occur at steady state fuel temperatures above 1800 K which are not expected at the steady states established for this $80MW_{th}$ core design..

III.b Different source shut-off time periods

Another set of simulations concerns the duration of time periods after a source trip prior to the re-establishment of the power. From simulating several cases it appears that crack formation is calculated already if the source is switched on again 0.5 sec after the source trip. Only below 0.05 sec the gap conductance appears to be indifferent to the sequence of source shut off and shut-on time periods.

The hottest channel gap conductance after one source trip is presented in figure 4. The source-off time intervals are 0.1, 0.5, 2 and 10 sec. It is seen that below 0.1 sec the source trip impact on the gap is not so significant. Only at source-off time periods below 0.05 sec the gap conductance was identical with the steady state curve shown in figure 4. From figures 3 and 4 it can be concluded that source-off time periods of more than 0.05 s will lead to a considerable reductions of the fuel to clad gap width. For the 0.5 sec source trip the first trip is noticeable as can be seen in figure 4 but a second trip of the same duration has almost no impact on the gap conductance. On basis of these results it becomes possible to derive criteria for the operational characteristics of an ADS. If one wants to maintain the original pellet geometry as long as possible during operation one should define requests of a reasonable start-up procedure for the source strength when the source-off time period exceeds a time period of 0.05 s. If one accepts deterioration of the pellet geometry from the very beginning of the operation of an ADS one needs not to define specific bounds for the "start-up" operation of the system. Then it becomes of importance to analyse carefully consequences of a fully cracked fuel pellet condition on the transients. Use of reliable fuel pin failure criteria then becomes of special importance and consequences of the pellet to clad mechanical interaction (PCMI) need to be evaluated with high precision.

Dependent on the conceptual decision discussed above more detailed investigations become necessary to determine permissible source-off time periods and possible restrictions on the subsequent "start-up" procedures. At the end such calculations should include also the anticipated solid state fuel swelling of the burned up fuel taking into account the low power density in the fuel appropriately.

It should be mentioned that the results shown in this work are specific for the considered core design and in particular for the SNR fuel type. The gap conductance values and the cracks formation pattern for other fuel types (usually with larger gap width) should be separately investigated in order to define their own criteria.

IV. CONCLUSION

Source trips are shown to have an important impact on transients in fresh MOX fuelled ADS. The analysed design is recommended as shutting off the source do not change significantly the flux distribution. Advantages are twofold. First, reactivity jumps from "source on" state to “source off” state are rather small. Second, the temperature reduction in the hottest channel is mitigated, thus improving boundary conditions for the demonstration of the fuel pin integrity. The fuel pin mechanics is sensitive to source trips. Even for the suggested core configuration, considerable high number of fuel cracks will be formed even when the source-off time period amounts only to 0.5 s , which led to the enhanced gap conductance shown in figure 4. Additional studies are needed where the behaviour of the burned up fuel is also accounted for. The burned up fuel undergoes swelling which influences the fuel pin behaviour considerably. This study is valid to SNR fuel only. Other fuel types behave differently depending on their material specification, on the core configuration they are inserted into, and in particular on the originally manufactured fuel pellet and the respective gap width.

V. REFERENCES:

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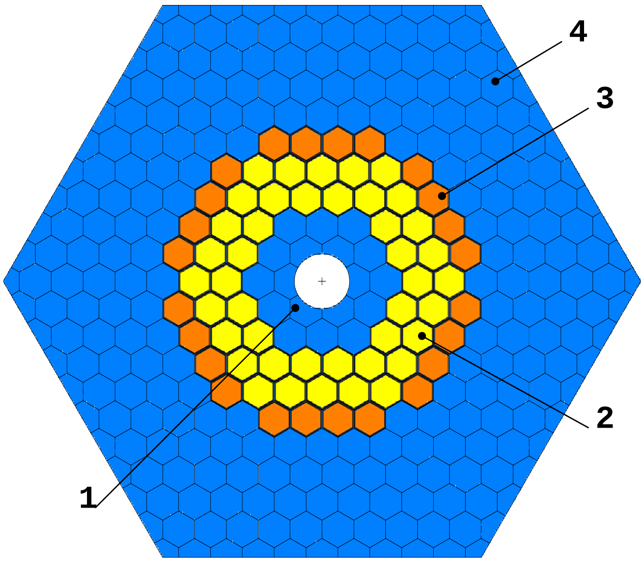

Figure 1. Reference SNR–300 core design. Low enriched C1_MAG [5] assemblies (zone 2) are surrounded by high-enriched fuel assemblies of type C2_LWR [5](zone 3). Zone 1 and 4 are the buffer zone and the lead-Bismuth reflector including structural material.

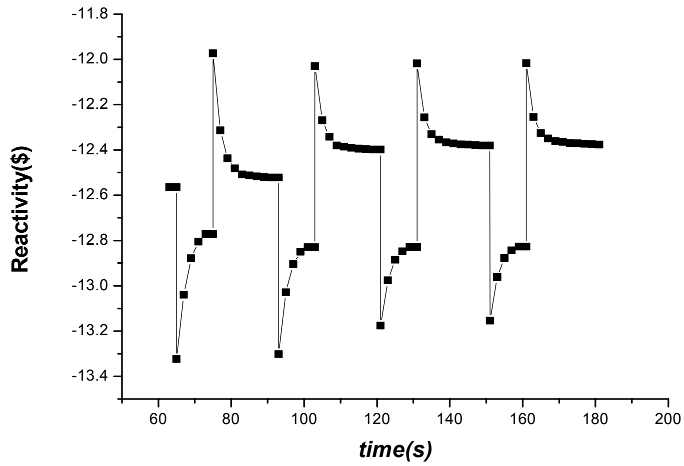

Figure 2: Reactivity change due to a 10 sec source trip series for a 66 SNR double enriched core configuration. 4 source trips are plotted

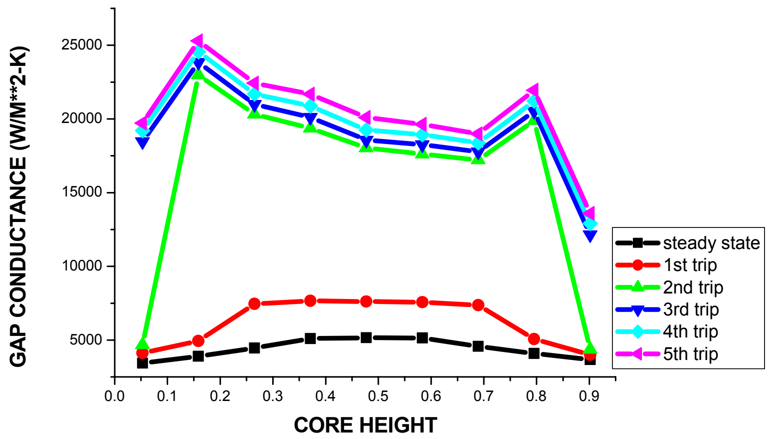

Figure 3: Hot channel gap conductance after 10 sec source trip series, for the 66 SNR subassembly configuration. Fresh fuel is considered.

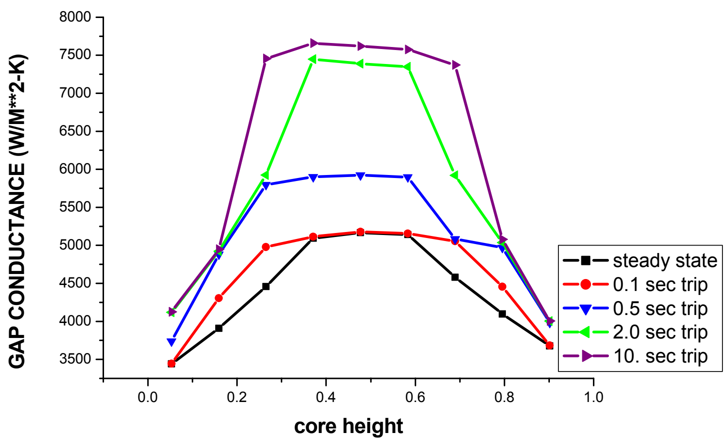

Figure 4: Hot channel gap conductance after 0.1,0.5,2 and10 sec source trips for the 66 SNR sub assembly configuration. Fresh fuel is considered.