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Safety Studies for Japanese DEMO Design with AINA Code

J.C. Rivas[1,2], M. Nakamura[3], Y. Someya[3], H. Takase[1], K.Tobita[3],
A.de Blas[2] J. Dies[2], M. Fabbri[2], A. Riego[2]

1 *International Fusion Energy Research Centre (IFERC), Japan*
2 *Fusion Energy Engineering Laboratory (FEEL)-BarcelonaTech, Spain*
3 *Japan Atomic Energy Agency (JAEA), Japan*

Safety studies of plasma-wall transients have been performed with AINA code for the japanese DEMO design (Water Cooled Pebble Bed). For this purpose, a breeding blanket model has been implemented in AINA code. The configuration has been changed to implement material data, coupled neutronics and thermohydraulics results and engineering design parameters of DEMO reactor.
First analyses performed show wall thermal evolution during ex-vessel LOCA transients and during plasma overpower events. As expected, ex-vessel LOCA transients potentially lead to a severe melting scenario when no Active Plasma Shutdown (APS) is present. Thus, a preliminary conclusion is that, unlike for ITER, the APS system must be considered a Safety Important Component (SIC) for this DEMO WCPB design.

1. Introduction

AINA is a safety code that has been used for years to perform safety analyses of plasma-wall transients for ITER. Thermohydraulic accidents and overpower plasma events are suitable to be investigated with AINA code. Over the last years, it has evolved to become a reliable, robust code, with updated physics and engineering models, focused on safety studies for ITER and DEMO.

It was decided that some of the postulated initiating events found in the hazard analysis done for the Japanese DEMO design,[1] were investigated with AINA code. Specifically, loss of flow and loss of coolant in blanket, or in divertor systems, and abnormal plasma overpower events.

AINA 3.0 code was adapted to work with the Japanese DEMO design. The new version includes changes in the calculation of breeding blanket thermal equilibrium. DEMO design data was used to create the configuration for the simulation engine. Extensive benchmarking was done based in two sources:

Benchmarking of plasma equilibrium was done with results of systems code TPC.[1]

Benchmarking of wall thermal equilibrium was done with results from coupled neutronics and thermohydraulics analysis done by JAEA fusion reactor design group[2] and UPC-FEEL group.[3]

Divertor model in JAEA systems code is not consistent currently. Therefore, AINA divertor model remain unchanged, and divertor safety studies will be a future work.

Therefore, the following studies were performed with the new version, only for breeding blanket:

- Abnormal increase in fusion power
- Loss of coolant (ex-vessel)

LOFA analysis still needs of a detailed definition of the accidental scenario.

2. The AINA-DEMO code

AINA-DEMO code is based on AINA 3.0 code, an ITER safety code developed by FEEL.[4,5]

The calculation scheme remains the same used in previous safety analyses: a 0D plasma model coupled with a 1D thermal equilibrium model applied over several calculation regions in which the poloidal section is divided.

The 0D plasma model comprises two energy balance equations, for electrons and ions, and different mass balance equations for each species.

Currently, the physics basis assumed for ITER is being used, including IPB-98(y,2) scaling for confinement time.[6,7]

A heat transfer equilibrium equation formulated for a 1D model of the WCPB breeding blanket is solved for each of the calculation regions considered in a generic poloidal section.

The cooling system is modeled with the simplifying assumption of considering coolant tubes arranged at several radial positions, in the toroidal direction. For these positions, convective heat transfer is used in the area fraction of coolant tubes, and conductive heat transfer in the rest of the section. Transversal transfer effects are neglected.

The volumetric neutron heat source is an input from external neutronics analysis performed for a reference equilibrium scenario.[2,3]

The heat flux from the plasma is estimated from plasma losses calculation. The poloidal wall loading is then calculated on the basis of wall loading input data, for both neutronic and surface fluxes.[2,3]

During the plasma transient calculation, the code checks for disruption conditions and for confinement mode threshold.

The melting condition is also checked for the different wall calculation regions.

3. Numerical results

For the case of plasma overpower events, two cases of overfuelling are presented:

1.- Study of overfuelling x1.25, which produced a new steady state of 1702MW of fusion power.

2.- Study of overfuelling x1.35, which produced a new steady state of 1840MW of fusion power.

The resulting radial temperature profiles in the outer equatorial blanket can be seen in Fig. 1.

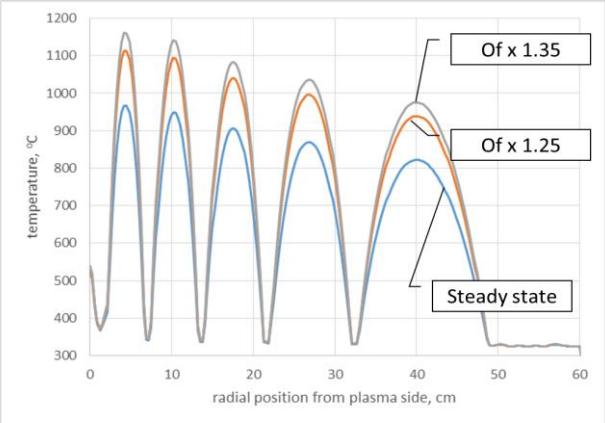

Fig.1. Radial thermal profile at outer equatorial position, 200 s after the beginning of the plasma transient

For the ex-vessel LOCA accident, the case presented considers 33% of wall surface affected. Based on MELCOR simulation, the coolant circuit is supposed to maintain the cooling function during the first two seconds. After that, during 10 seconds it is considered that a certain cooling capacity is maintained. After 10 seconds, it is considered that the cooling function is completely lost.[8] The results show in Fig. 2 that after 217 seconds, structural steel melts at the outer equatorial blanket module, after reaching 1370ºC.

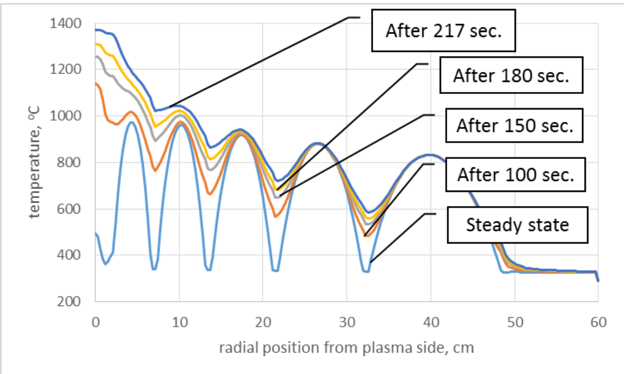

Fig.2. Radial thermal profile at outer equatorial position, during an ex-vessel LOCA accident

4. Discussion

For the case of plasma overpower events, after 200 seconds, breeder temperature reaches up to 1170ºC for the case of overfuelling x 1.35. This effect does not seem to be very severe for the blanket.

For the case of ex-vessel LOCA accident, the structural steel under the first wall melts after near four minutes, without significant effects over plasma impurity fraction.

This result follows a similar evolution pattern to that found for ITER, but in the last case, evaporation of beryllium from plasma facing components induces a passive plasma shutdown.[9]

5. Conclusions

As expected, the effect of a LOPC (Loss of Plasma Control) transient is not very severe for blanket modules, but is expected to be more important for divertor. However, divertor models in AINA code need to be upgraded in order to study divertor safety scenarios.

For the LOCA transient, the results seem to show that a passive plasma shutdown is not possible for this DEMO design, and therefore the plasma control system should be considered as a Safety Important Component (SIC). The time for the plasma control system to shutdown the plasma discharge is over 3 minutes.

Future work will include improvements in AINA divertor models, and also a detailed definition of accident scenarios, in order to study ex-vessel divertor LOCA, and LOFA for both divertor and breeding blanket.

Acknowledgement

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