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Safety analysis of abnormal fueling in ITER using SAFALY

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Abstract

SAFALY, a hybrid code comprising a zero dimensional plasma dynamics and a radial and poloidal thermal analysis of in-vessel components, is being progressively improved to discuss safety aspects of plasma-wall interactions in ITER. Overfueling by a factor 1.5, overfueling by a factor 3 and sudden suspension of fueling are chosen as scenarios to be simulated in current issue.

Introduction

SAFALY is a hybrid code comprising a zero dimensional plasma dynamics and a radial and poloidal thermal analysis of in-vessel components. It was initially adopted to assess abnormal events in fusion reactors from the safety point of view [1] and was progressively improved to analyse burn control, confinement mode transition or impurities transport among others in ITER EDA. Now, the *Departament de Física i Enginyeria Nuclear* of the *Universitat Politècnica de Catalunya* have made SAFALY suitable for ITER FEAT in order to simulate several accident scenarios challenging the integrity of the vacuum vessel and the other in-vessel components [2].

In the following, an outline of the code is presented and a brief remark of the updated models and parameters is shown. Fueling abnormalities, such as overfueling by a factor 1.5, overfueling by a factor 3 and sudden suspension of fueling are simulated for ITER 400MW steady state scenario in order to check the goodness of the modifications introduced in the former code. Further improvements and models are suggested as a summary after results analysis.

Outline of the code

The code is intended to give overall safety analyses ranging from plasma dynamics to thermal behaviour of the in-vessel components in accordance to event sequences. For the plasma dynamics analysis, energy and particle conservation equations are implemented and the steady state is determined on the basis of ion temperature, Q-value and fusion power. Scaling laws and confinement mode transition are implemented and points to trigger a disruption are set conservatively. Moreover several routines can be switching ON/OFF to investigate its influence on plasma transient (fueling rate control, impurities transport…).

To obtain the temperature distribution (and evolution) of the in-vessel components the structures are divided radially (i.e. in its thickness direction, see figure 1) and into 20 poloidal regions. The first wall, the blanket and the divertor have been modelled conservatively alternating layers of beryllium, cupper, SS 316L-IG and coolant channels. The code allows any material combination and configuration such us thermal gaps or radiation boundaries between cooling channel surfaces (if empty). Furthermore, erosion and melting of plasma facing components can also be simulated.

Scenario

Plasma ITER steady state parameters have been basically implemented according to reference [3]. The table 1 shows a summary of them:

Parameter	Value
R/a (m/m)	6.35/1.85
B_T(T)	5.18
I_p (MA)	9.0
κ_{95}/δ_{95}	1.85/0.4
<Ti> (keV)	12.5
P_{fus} (MW)	356
$P_{L\text{-}H}$+ P_{NB} (MW)	29 + 30
P_{rad} (MW)	37.6

Parameter	Value
Q	6.0
l_i	0.72
$q_{95}/q_0/q_{min}$	5.3/3.5/2.2
f_{He} (%)	4.1
f_{Be} (%)	2
f_{Ar} (%)	0.26
Z_{eff}	2.07
$H_{H98\ (y2)}$	1.57

Table 1. Required plasma parameters for the plasma steady state simulation

A loss of plasma control scenario without any expectation of engineering control system has been chosen to evaluate the capability of the code. Specifically, an abnormal fueling has been implemented since it was assessed as a reference event for a 500MW inductive scenario [4].

An overfueling can be consequence of a gas puffing valve sticking open. In this case, the plasma termination should produce no further consequences but there is a small likelihood that the plasma terminate with a disruption that causes damage to plasma facing components leading to an in-vessel coolant ingress [5].

4. Results

Since the aim of this work is to check that SAFALY is a ready-to-use code, producing results in agreement with previous studies and ITER documentation, only basic parameters have been analysed, i.e. fusion power, temperature profiles evolution, times to disruption and maximum heating of plasma facing components. Figures 1,2,3 and 4 shows graphically a few of them.

Stop of fueling leads to a gradual decrease of temperature and density and a shutdown occurs without further consequences after the transition from H confinement mode to L confinement mode. However, overfuelings produce increments of ~30ºC in module structures and temperature of the outboard midplane blanket (region 7 in fig. 2) reach 239.5ºC for factor 1.5 while factor 3 overfueling leads to 234,8ºC at the same module due to beta limit is reached faster.

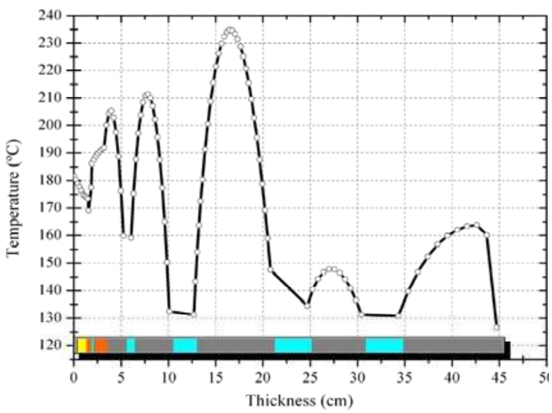

Fig. 1. Temperature profile of the outboard midplane module (region 7 in fig. 2) at 8s after overfueling by factor 3 has started. The colour bar on the X axis show the blanket configuration: yellow for beryllium, orange for copper, blue for coolant, gray for steal.

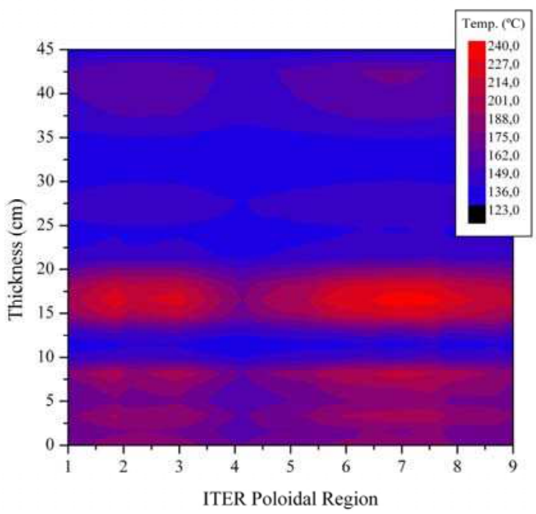

Fig. 2. Temperature distribution of first wall and blanket just before disruption (factor 3 overfueling event). Region 1 corresponds to the lowest modules of the inboard and region 9 to the lowest of the outboard

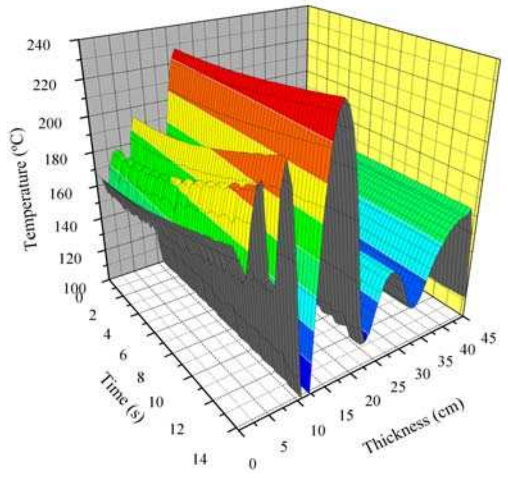

Fig. 3. Evolution of the outboard midplane temperatures when overfueling factor 1.5 occurs

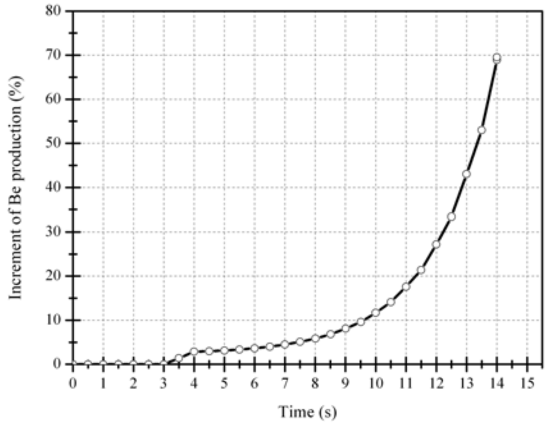

Fig. 4. Increment of Be production from plasma facing components following a overfueling event (factor 1.5)

5. Summary

A safety analysis code has been recovered to estimate anomaly sequences and their impact on ITER components. Abnormal fueling events have been simulated in order to check results agreement with previous safety studies [4]. Coherence results have been obtained but further development is required to validate fast transients during disruptions (thermal and magnetic quench) and control scenarios.

References

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