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Analysis of an ex-vessel break in the ITER divertor cooling loop

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Abstract

In the present work the integrated ECART code, developed for severe accident analysis in LWRs, is applied on the analysis of a large ex-vessel break in the divertor cooling loop of the international thermonuclear experimental reactor (ITER). A comparison of the ECART results with those obtained by Studsvik Nuclear AB (S), utilizing the MELCOR code, was also performed in the general framework of the quality assurance program for the ITER accident analyses. This comparison gives a good agreement in the results, both for thermal-hydraulics and the environmental radioactive releases. Mainly these analyses, from the point of view of the ITER safety, confirm that the accidental overpressure inside the vacuum vessel and the Tokamak cooling water system (TWCS) Vault is always well below the design limits and that the radioactive releases are adequately confined below the ITER guidelines.

Keywords: ECART code; Fusion reactors safety; ITER; LOCA

1. Introduction

Historically, in the frame of the generic site safety report (GSSR) for the ITER plant [1], several accident analyses have been carried out to quantify in detail the radiological risk linked with the possible releases to the external environment of radioactive materials. In this context the hypothetical double-ended pipe rupture outside the vacuum vessel of the largest pipe of the divertor cooling circuit was analyzed to bind all possible leaks in the ex-vessel section of the divertor heat transport system (HTS) during the pulse operation. In the present paper, the ITER plant data and the LOCA sequence specifications are updated with respect to the

Abbreviations: AAS, accident analysis specification; ACP, activated corrosion product; AMMD, aerosol mass median diameter; DT, drain tank; DV, divertor; EDS, emergency detritiation system; GSD, geometric standard deviation; GSSR, generic site safety report; HTS, heat transport system; HVAC, heat, ventilation and air conditioning system; ITER, international thermonuclear experimental reactor; LOCA, loss of coolant accident; LWR, light water reactor; nd, not defined; PSS, pressure suppression system; RD, rupture disk; SADL, safety analysis data list; ST, suppression tank; STP, standard temperature and pressure; ST-VS, suppression tank venting system; S-VDS, stand-by vent detritiation system; TCWS, Tokamak cooling water system; VV, vacuum vessel

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previous specifications employed for the GSSR studies [1] and for previous verification analysis [2], as will be highlighted in the following paragraph. In particular, this work is related to the application of the ECART code [3] to a large ex-vessel LOCA for the ITER divertor HTS, followed by an in-vessel break, and to the comparison of the code results with the data obtained by Studsvik Nuclear AB (S) for the same sequence [4] but employing the MELCOR code in its fusion version [5]. The scope of the comparison was the quality assurance of the ITER safety studies.

A detailed description of the ECART models and of its applicability to the safety analysis of a fusion plant is reported in several papers [3,6,7] and will not be presented in this paper. All these activities have been carried out in the framework of the validation [6] of the ECART code for the studies of incidental sequences related to the ITER fusion plant, while it was originally developed by ENEL (now CESI) and EdF for integrated analysis of severe accidents in LWRs [8]. ECART gives the interesting opportunity to perform integrated accident sequence analyses, up to the environmental releases, avoiding complex interfaces between thermal-hydraulics and transport models or between circuit and containment codes. In fact, it is designed to operate with three sections (Fig. 1), linked together, but able to be activated also as stand-alone modules:

1. *thermal-hydraulic*—provides the boundary conditions for chemistry and aerosol/vapor transport models;
2. *aerosol and vapor*—calculates the amount of chemical substances that may be retained or released in the analyzed circuit components;
3. *chemical*—performs the chemical equilibrium among the compounds (only in vapor form) and reactions between gaseous phase and solid materials.

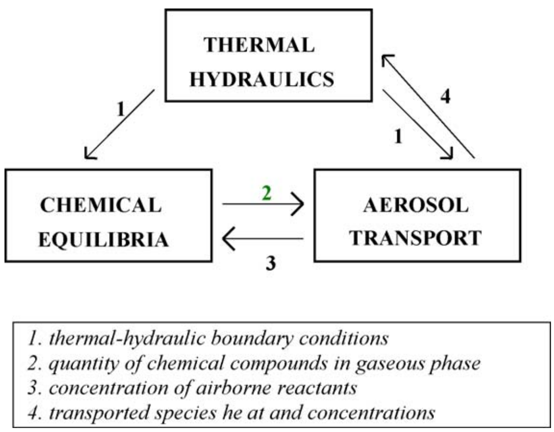

Fig. 1. Linking among the three main sections of the ECART code.

2. Characteristics of the analysis

The main objectives of the study of the divertor ex-vessel pipe break sequence, as stated inside the ITER accident analysis specification (AAS) [9] are: (1) to show that the overpressure in the TCWS Vault and inside the vacuum vessel are safely mitigated by the different emergency systems and (2) to study the transport of radioactive materials and their release to the external environment. The reference documentations for this ITER safety analysis is provided by the ITER safety analysis data list (SADL) [10] version 4.0.2, the AAS version 4.beta.1 [9] and Studsvik's analyses [4]. When discrepancies occurred among them, the Studsvik's assumptions have been adopted.

According to Ref. [9], the initiating event of the sequence is a double-ended pipe break in the divertor cooling loop, which is postulated to occur in the larger diameter pipe of the HTS cold leg at the inlet of the main circulation pump (Fig. 2). The inner diameter of this pipe is 515.0 mm and the break mass flow is initially discharged into the TCWS Vault. This external break occurs during the plasma burn and, as a consequence of the pipe break itself, the plasma disrupts 3.0 s later causing an immediate failure of the divertor cooling pipes inside the vacuum vessel (the internal break size is assumed to be 0.32 m^2 for one toroidal ring [9]). These combined failures result in a possible "by-pass" path from inside the vacuum vessel, through the divertor piping system, into the TCWS Vault.

A 1.0 h "loss of off-site power" is assumed to coincide with the initial external pipe break. As a result, the pumps in the divertor and vacuum vessel loops trip at 0.0 s and they are not restarted during the rest of the transient.

The divertor isolation valves on the divertor HTS close after 1.0 h, except one valve with a 0.06633 m^2 flow area [4], which is assumed to fail to close.