# status of design basIs Accident analyses and safety codes application for European DEMO

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The European DEMOnstration power plant (DEMO) has been developed in the Pre-Concept Design (PCD) phase (2014 – 2020) and the design is progressed in the current Concept Design Phase (CDP, 2021 – 2027). Safety studies accompany the design improvement within the EUROfusion Safety and Environmental Work Package (WPSAE) from the beginning to support the maturation of the design during normal operation, anticipated operational occurrences and accident conditions, to provide feedback on the plant design choices, and to meet the licensing requirement. To manage the safety in DEMO design the Requirement 19 Design Basis Accidents (DBA) in *Safety of Nuclear Power Plants: Design* [1] is valid for fusion:

*A set of accident conditions that are to be considered in the design shall be derived from postulated initiating events for the purpose of establishing the boundary conditions for the nuclear power plant to withstand, without acceptable limits for radiation protection being exceeded.*

DBA conditions are necessary to be controlled with the objective of returning the plant to a safe state and mitigating the consequences of any accidents. Key plant parameters shall not exceed the specified design limits. All DBAs shall be managed so that they have no, or only minor, radiological impacts, on or off the site, and do not necessitate any off-site intervention measures [1]. The design basis accidents shall be analyzed in a conservative manner with respect to postulate certain failures in safety systems, specify design criteria and use conservative assumptions, models and input parameters in the analysis. For fusion regulation there will be no need for an evacuation on technical grounds for all plant states [2].

In the PCD phase, a series of the representative events have been investigated to perform the deterministic assessment for the different in-vessel components (IVCs) such as Helium Cooled Pebble Bed breeding blanket (HCPB BB) concept, Water Cooled Lithium Lead (WCLL) BB concept and divertor:

* Loss of Coolant Accidents (LOCAs) in the vacuum vessel (in-vessel LOCA) for the IVCs (HCPB, WCLL BB & DIV)
* out-vessel LOCA
* in-BB LOCA
* Loss of Flow Accident (LOFA) due to pump / blower trip
* Loss of heat sink due to loss of condenser vacuum

Dose calculation with the release data to the environment (HTO, dust, Activation Corrosion Products (ACPs)) has been started for the events selected in the last two years of the PCD phase. The events are selected from the identified PIEs for DEMO in the Generic Site Safety Report (GSSR) Vol. 6 [3]. The accident analysis for each event has been performed and documented with the defined template [2]:

* identification of causes, accident description, and assumptions for different scenarios;
* generation of analysis model with proper computer code;
* implementation of the initial conditions, assumptions and control methods to the model;
* simulation of scenarios and evaluation of transient results;
* analysis of radiological releases;
* indication of uncertainties in the modeling;
* recommendations for model improvement and to the designers;
* summary for different scenarios.

The performed DBA analyses are summarized in the GSSR Vol.7 [4]. In the current CDP accident analyses are continued to be investigated for the IVCs with respect to the identified issues based on the performed analyses, Tokamak building arrangement including leak rate conditions and detritiation efficiencies, updated plasma, confinement and pressure suppression conditions, etc. Moreover, accident analyses for tritium process systems, blanket system connecting to the tritium extraction removal system, loss of vacuum, release of cryogenic fluid, drop loads, flooding, fire and explosion accidents, seismic safety, etc. are going to be investigated as well, and dose assessment for the radiological impact will be performed based on the resulted releases of source terms (dust, tritium, ACPs).

It is important to select proper computer code to perform the accident analysis. The GSSR Vol. 10 [5] summarizes information on all computer codes used or foreseen for DEMO safety investigation. Not only the codes used for DEMO and ITER are included, but also fission codes, which intend to be used in DEMO potentially are taken into account. Currently 32 codes have been described with a defined template:

* Overview
* Key model description for DEMO
* Key input data description
* Key validation studies
  + - * Previous Verification and Validation (V&V) studies (results of major validation studies)
      * DEMO validation studies (for the code used for DEMO)
* Improvements requested for DEMO scopes,

The codes are categorized as:

* System codes (MELCOR186 for fusion, ASTEC, RELAP5-3D, ATHLET, TRACE, CONSEN, ECART)
* Codes for plasma interaction (MEMOS, TOKES)
* Containment codes (COCOSYS)
* Source terms codes (FISPACT-II, ACAB, TMAP, ECOSIMPRO, UFOTRI, OSCAR-Fusion v1.3, PACTITER, SPUTTER\_II)
* Codes for radiological release (RODOS, MACCS, COSYMA)
* Sensitivity codes (SUSA, BEST-EST, RAVEN)
* CFD codes (ANSYS CFD, GASFLOW, SIMMER, DET3D, FDS)
* Thermal-structural codes (ANSYS Mechanical)
* Process codes (APROS)
* Neutronic codes (cR2S)
* etc.

Codes used in the DEMO accident analysis and on the key models developed for GSSR Vol. 7 and Vol. 8 with Beyond Design Basis Accidents (BDBA) [6] have detailed description for their DEMO application. MELCOR186 for fusion was selected for the DBA analyses in the PCD phase. The resulted release data are used for dose calculation with UFOTRI and COSYMA.

In the CDP the codes applied for ITER safety analyses in recent years will be taken into account as well.

Each code has its verification study with respect to the analytical and numerical solutions before the release. For code application in fusion the source code is mostly not available for further verification. Therefore, validation study needs to be performed with DEMO specific experiment or codes benchmark.

It is recommended to propose a code validation plan for DEMO to analyze the validation status in fusion, and to identify gap between the performed validation and DEMO requirement.

Regarding the code application for the DBA analyses in the PCD phase MELCOR is the first code considered in the validation plan. MELCOR182 modified for ITER has been validated with the ingress-of coolant event (ICE) facility in Japan [7] and the European Vacuum Impingement Test Apparatus (EVITA) facility in France [8]. MELCOR186 for fusion was applied for code-to-code benchmark analysis of DEMO in-vacuum vessel LOCA scenarios [9]. A MELCOR-TMAP computer code for fusion has been developed as a more comprehensive tool for analyzing accidents in future fusion reactors [10]. It is recommended during the Meeting of the European MELCOR User Group to adopt the features of MELCOR fusion version in MELCOR2.2 fission version in order to develop a common MELCOR version for fusion and fission in future [11].

In long term, the validation details for each of the computer codes used in the safety analysis for the DEMO Conceptual Design shall be provided.

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acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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