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# Assessment of primary and secondary bleed and feed procedures during a Station Blackout in a German Konvoi PWR using ASTECV2.0

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ABSTRACT

In this paper, the severe accident code ASTECV2.0 is used for the verification and improvement of in-vessel Severe Accident Management (SAM) strategies in a German Konvoi PWR considering the lessons learnt from Fukushima. The scenario selected for the analysis is the total Station Blackout (SBO), which is the most risk-relevant scenario for the referred plant. Based on a systematic evaluation of a broad database of severe accident scenarios involving secondary and primary bleed and feed and active core reflooding, important recommendations regarding SAM were proposed to prevent or delay the failure of the RPV. The performed investigations elucidate ASTECV2.0 capabilities to describe the in-vessel phase of severe accident in PWRs and extend the technical basis for the further development of Severe Accident Management Guidelines (SAMGs) in Konvoi PWRs, contributing this way to increase existing safety margins.



## 1. Introduction

After shutting down a nuclear reactor, one of the Critical Safety Functions is to maintain core coolability. This can be done through dedicated safety systems of a Nuclear Power Plant (NPP). However, if those failed to attain the aforementioned goal, the core liquid level would drop below the active length of the fuel rods. In such case, the initiating event would turn into a severe accident, which is characterized by the in-vessel (core melting, corium relocation to the lower head, vessel failure) and the ex-vessel phases.

In order to prevent such sequences, NPPs foresee preventive of Accident Management (AM) measures, which are contained in the Emergency Operating Procedures (EOPs), aim at preventing core degradation and returning the plant to a safe state. On the other hand, if core melting has started, the priority is to stop the accident during the in/ex-vessel phases through mitigative measures, which are encompassed in the SAMGs (IAEA, 2004). The transition between both varies with the country and depends, among others, on the core condition and the scope of EOPs-SAMGs (Prior, 2009). Generally, this switch is based on the Core Exit Temperature (CET) and, for the particular case of a German Konvoi PWR, it occurs at CET = 650 °C (Braun et al., 2014).

Among the different preventive AM measures existing in European PWRs, the most powerful ones are the so called secondary and primary bleed and feed, which can also be relied upon after the switch to SAMGs (Hermsmeyer et al., 2014). Within the mitigative domain, one of the most important measures is the injection of water into the reactor (core reflooding). Each measure has positive and negative consequences, which should be carefully assessed by the Emergency Response Team before issuing orders to the plant crew. For example, core reflooding may terminate the accident, but may also cause a sharp hydrogen generation challenging the containment integrity (Cronenberg, 1992; Schanz et al., 1992; Steinbrück et al., 2010).

*Abbreviations:* ACCUs, Accumulators; AM, Accident Management; CET, Core Exit Temperature; CVCS, Chemical and Control Volume System; DGs, Diesel Generators; ECCS, Emergency Core Cooling System; EOPs, Emergency Operating Procedures; FOM, Figure of Merit; FW, Feedwater; HPIS, High Pressure Injection System; LP, Lower Plenum; LPIS, Low Pressure Injection System; MCP, Main Coolant Pump; NPP, Nuclear Power Plant; PCT, Peak Cladding Temperature; PORV, Pilot Operated Relief Valve; PBF, Primary Bleed and Feed; PSD, Primary Side Depressurization; RCS, Reactor Coolant System; RMFR, Reflooding Mass Flow Rate; RPV, Reactor Pressure Vessel; SAM, Severe Accident Management; SAMGs, Severe Accident Management Guidelines; SBF, Secondary Bleed and Feed; SBO, Station Blackout; SG, Steam Generator; SGTR, Steam Generator Tube Rupture; SSD, Secondary Side Depressurization; SV, Safety Valve.

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For the elaboration and optimization of SAMGs, severe accident codes are essential tools. These can be of two types: integral, if they describe the whole accidental sequence until the failure of the containment (e.g. MELCOR, ASTEC, MAAP); mechanistic, if they provide a more detailed description of a given part of the accident (e.g. ATHLET-CD, SOCRAT, COCOSYS). Furthermore, the scenarios used in the simulations should be in accordance to the overall risk of the plant, which is quantified in the Probabilistic Safety Analysis (see Fig. 1).

Significant progress has been made concerning the development of plant specific SAMGs (EPRI, 2012, 1993a, 1993b; European Commission, 2000), according to the requirements imposed by the nuclear regulatory body of each country, generally in compliance with (IAEA, 2004; WENRA, 2014, 2007). Despite this progress, the severe accidents at Fukushima in 2011 have revealed several weaknesses (NEA-OECD, 2013), leading to a renewed interest for the enhancement of SAM measures (Lutz and Prior, 2016).

Within this work, the severe accident code ASTEC V2.0 (rev3) (Chatelard et al., 2014) is used for the improvement of SAMGs of a generic Konvoi PWR (Braun et al., 2014; Loeffler et al., 2012) covering the in-vessel phase of the SA. Improvements concern the optimization of the secondary and primary bleed/feed procedures and the revision of injection possibilities under extreme conditions e.g. mobile pumps, following the post-Fukushima recommendations issued by the German Reactor Safety Commission (BMUB, 2014). The selected scenario is the Station Blackout, which is the most relevant sequence according to the Probabilistic Safety Analysis (PSA) Level 2 of a Konvoi PWR (GRS, 2002; Strohm et al., 2010).

The article starts with a general description of ASTECV2.0 code and with a generic model of the Konvoi PWR in Section 2. Section 3 studies the progression of the reference Station Blackout without any AM measure. Based on that scenario, Section 4 turns to analyse the effect of secondary bleed and feed, primary bleed and feed and core reflooding on the progression of the accident. Finally, Section 5 provides the reader with a summary of the main findings and the open issues arisen from these investigations.

## 2. Numerical tool and PWR plant model

### 2.1. The European reference code ASTEC

The integral severe accident code ASTECV2.0 (Chatelard et al., 2014) is the European reference tool for the analysis of severe accidents in LWR. The code is able to simulate complete severe accident sequences, the main application areas being the source term determination, PSA and SAM studies. The structure of ASTEC is modular, each of its modules considering a particular set of physical phenomena. For the description of the in-vessel SA-phenomena, the modules of interest are the CESAR and ICARE. In ASTECV2.0, CESAR simulates the thermal-hydraulics of the primary and secondary circuit, as well as in the Reactor Pressure Vessel (RPV) up to the beginning of core degradation. From this moment on, CESAR calculates the thermal-hydraulics throughout the primary and secondary circuit, while ICARE is responsible for the whole core degradation processes, including the corium behaviour after its slumping into the lower head. Both modules solve the thermal-hydraulics in one dimension by making use of a five-equation approach.

### 2.2. Generic PWR Konvoi plant model with ASTECV2.0

The ASTECV2.0 model of generic German Konvoi PWR used in the current analysis is identical to the one described in (Gómez-García-Toraño et al., 2017a). Therein, an extensive description of the reactor domain, the physical phenomena considered during the in-vessel phase, the automatisms of the Reactor Control Protection System and the most relevant safety systems is performed.

A simplified sketch of the primary and secondary circuits (together with the relevant safety systems for this work) is depicted in Fig. 2. The four loop PWR is represented by two loops: the loop B (containing the pressurizer) and the loop A (containing the other three loops). The RPV is radially divided in eight channels: the downcomer (connected to the cold leg collector), the bypass and the six core channels (connected to the upper plenum). The bottom of the active core height corresponds to the elevation

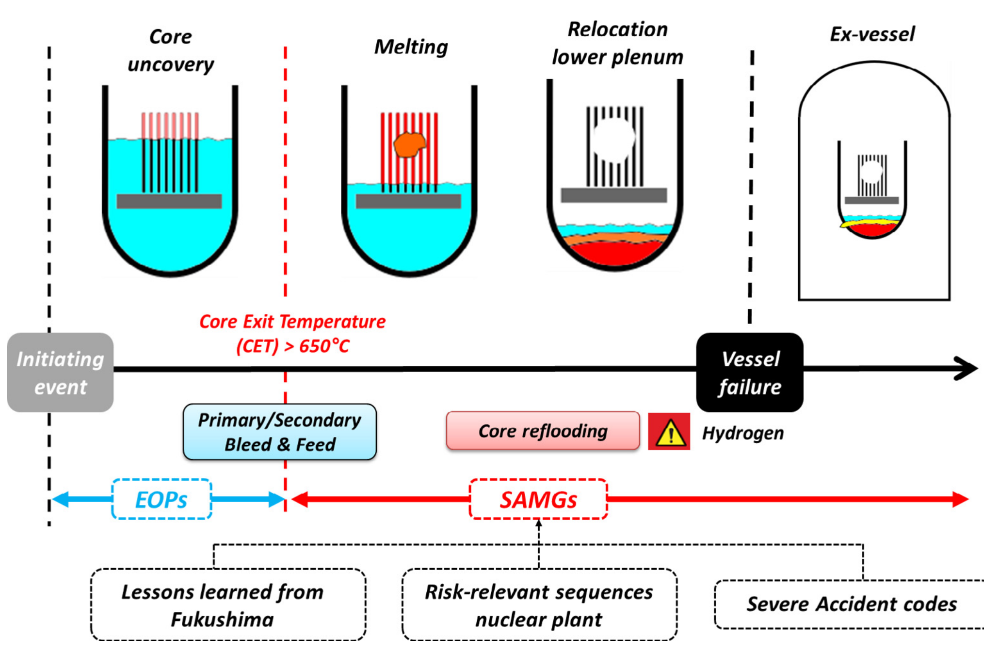


**Fig. 1.** Sketch representing the main events during the in-vessel phase of a severe accident, the domain of preventive and mitigative AM measures and the requirements to build EOPs and SAMGs.