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In-containment source term predictability of ASTEC-Na: Major insights from data-predictions benchmarking

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HIGHLIGHTS

- In-containment Na aerosol data retrieved and gathered for code validation.
- Comparison of ASTEC-Na models for Na pool fires and aerosol ageing to data.
- Generic trends captured through a heavy models parametrization.
- Need for qualified data from representative experiments during Na pool fires.

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ABSTRACT

Modeling the containment response to a sodium pool fire is to be one of the key aspects of any comprehensive safety evaluation of the new generation of sodium cooled fast reactors. Through a peer review of earlier experimental investigations some useful data can be collected and then used for assessing the current analytical capabilities to model severe accidents or some of their specific aspects. This paper provides major insights into the in-containment aerosol behavior predictability of ASTEC-Na (CPA* module) during Na-pool fires. By comparing against tests from the ABCOVE (AB1 and AB2) and FAUNA (F2) programs, it has been shown that experimental trends can be roughly reproduced with a single-cell approach whenever natural convection is effective in making the vessel atmosphere uniform both thermally and in composition. Nonetheless, the present heavy parametrization of ASTEC-Na models should be avoided or strongly supported by further experimentation that allows setting sound default values, concerning both combustion energy distribution and aerosol formation and distribution. Anyway, the peer data review has highlighted that a meaningful comparison to predictions is not always feasible due to large data uncertainties, particularly at the beginning of Na burning. As for the particle ageing, the comparisons set seems to indicate that transformation from oxides to hydroxides is predicted to be too slow; nevertheless, a more extensive benchmarking should be conducted to confirm it.

1. Introduction

The Gen. IV International Forum has, since the early 2000s, been exploring several different advanced nuclear reactor technologies that are supposed to offer enhanced safety, sustainability, and versatility over traditional nuclear reactor designs. Relying on past experience from the 1960s, 70s and 80s, the sodium fast reactor (SFR) is at the most advanced stage of the technologies that have been explored, with prototype reactors starting to come online, like the BN-800 reactor in Russia, or at an advanced stage in their design, like the ASTRID reactor concept in France.

Nuclear safety authorities in countries considering building Gen. IV technologies still have the responsibility to independently asses the proposed reactor designs. For SFRs, evaluating the effects of a sodium fire in containment would be an essential part of any safety evaluation because of how the fire can thermally damage the plant, cause an overpressure risk in containment, and be a source of airborne fission products as radionuclides dissolved in the sodium are aerosolized. Therefore, a full-scope SFR safety analysis demands validated computation tools capable of capturing the

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Nomenclature

BC	Base case
BE	Best estimate
c_t	Thermal accommodation coefficient
F_{slip}	Particle slip coefficient
k_{gas}/k_p	Ratio of thermal conductivity of the gas over that for the particle
STICK	Particle sticking coefficient

Greek symbols

χ	Aerodynamic shape factor
γ	Agglomeration shape factor
ε	Turbulence dissipation rate
δ_{diff}	Diffusion boundary layer thickness
ρ	Aerosol density

main footprints of BDBAs in containment, so that Source Term estimates are considered reliable.

Although SFRs are being proposed as Gen. IV nuclear reactors, sodium fast reactors designs are not a new concept, and started to be investigated in parallel to light water reactors early in the nuclear era (IAEA, 2012). A vast amount of research and development was done from the 1960s to the 1980s, including the construction of different research, prototype, and demonstration reactions. With this, the development of analytical capabilities for source term analysis had to be carried out as well (Dunbar, 1985; Dunbar et al., 1984; Fermandjian, 1985). Most of the development of SFR technologies was abandoned in the 1990s with a general downturn in the nuclear industry; as a result, a lot of the expertise that was built previous decades has been lost. However, renewed interest in SFR technology is making the work done a generation ago extremely valuable, and there is a lot of rich experimental work and empirical model development that can be reapplied to evaluations of in-containment accident evolution in SFRs (Brunett et al., 2014; Herranz et al., 2013a,b; Spengler and Reinke, 2016). The EU-JASMIN project (Girault et al., 2015), for instance, has devoted a good fraction of their resources to develop and validate models in the domain of in-containment aerosols. As a consequence, a new version of the ASTEC module addressing in-containment accident evolution, hereafter denoted as CPA*, has been built by including models for sodium fires coming from SOFIRE (Beiriger et al., 1973) and models of chemical ageing of sodium-oxides particles, which were genuinely produced within the project (Mathe et al., 2015).

Beyond model development and implementation, qualification of any safety tool requires validation against a reliable and representative database. The present paper shows the results obtained in a benchmark set between ASTEC-CPA* and a number of experiments chosen from the open literature: ABCOVE-AB1, -AB2 and FAUNA-F2. These tests, conducted decades ago, investigated the anticipated pool fire scenarios during SFR severe accidents in large-scale vessels. Additionally, other codes have also been run so that modeling progress of ASTEC-CPA* can be also assessed with respect to other codes, like ASTEC-CPA, MELCOR, CONTAIN or SOPHAEROS-FEUMIX. It should be underlined that it is not the intention of this paper to discuss discrepancies among code estimates, but highlight the current predictability with the focus on CPA* behavior.

2. Selected experiments

An initial literature review of experimental information (Herranz et al., 2012) led to nearly 20 experiments related to Na fires, of which nearly half dealt with aerosol generation from pool fires. Not all of this work can be applied in this study, because they often investigate the dynamics of the pool and burning rates, rather factors important for this study, such as combustion product aerosolization and the thermal-hydraulic response of the containment volume. Likewise, working with these past experiments is often difficult, since copies of the original reports are often very difficult to obtain, and even then, data can often be incomplete or must be digitized from original plots. This is compounded by the fact that, since the work was conducted 30–40 years ago, the original investigators would have long since retired or passed away. Three of the 20 experiments identified in Herranz et al. (2012) were chosen for the benchmark purpose based on a number of criteria like their scale, completeness and accuracy of data reported and some others. As a result, attention was paid to specific tests of the ABCOVE and FAUNA programs, a succinct description of which is given below.

The ABCOVE experiments were conducted in the Containment System Test Facility (CSTF) vessel at the Hanford Engineering Development Laboratory in the United States. The containment was a cylindrical steel vessel (7.6 m diameter, 20.3 high) of about 852 m^3 (Fig. 1). The vessel was equipped with instrumentation to monitor both thermal-hydraulics and aerosol behavior. In these tests, the experimental arrangement included ten clusters of filter samples at various locations throughout the vessel atmosphere, each cluster containing 12 filters; four thief sample stations: the

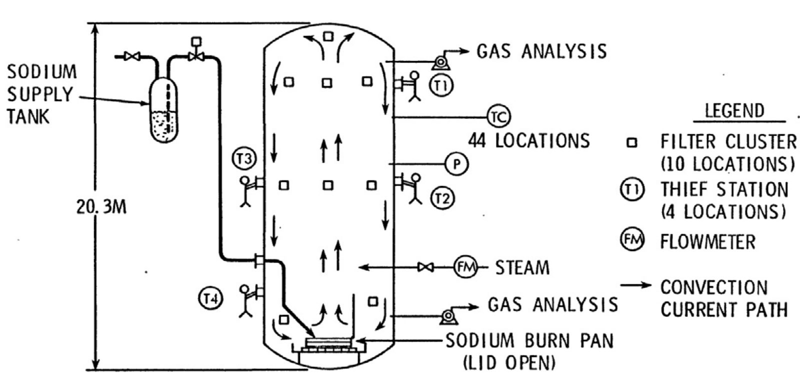

Fig. 1. CSTF vessel arrangement (Hilliard et al., 1977).