Numerical Analysis and Experimental Verification of a Fire Resistant Overpack for Nuclear Waste

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Abstract

Confinement systems for nuclear waste are usually designed to perform and ensure safety in view of all the assumed design basis events, including fires.
In order to reduce radiological release to workers, publics and environment, fire hazard analysis (FHA) and safety analysis identify the acceptable damage level for the containment and fire barriers.
This is the case of a non-conditioned alpha-radioactive waste lot that Sogin is going to stock in one of its temporary storage facilities.
Considering typology, activity, radiological content of the waste, according to international standards, the goal of the confinement system design is to protect the content of the steel drums against a two-hours fire event.
At this aim Sogin has chosen to use fiber-reinforced concrete (FRC) overpacks, assuring the structural integrity of the containment and limiting the temperature rise inside the drums to exclude any activity release into the environment.
Considering the strict geometrical restraints given by the storage space availability, numerical analyses were carried out to evaluate the fire performance level of the overpacks.
Two different configurations are investigated: in the former the inner gap between the concrete overpack and the drum is filled with ceramic fiber blanket (Figure 1), in the latter with air (Figure 2). Standard fire curve and thermo-mechanical properties from literature data have been used considering an axial-symmetric model.
The study has been performed with COMSOL Multiphysics® software (Heat Transfer, Transport of Diluted Species, and Solid Mechanics interfaces). The transient heat transfer simulations include conduction, convection and radiation phenomena and moist thermodynamic effects by means of Transport of Diluted Species. The fluid flow within the air gap due to buoyancy force (natural convection) is modeled with single phase flow interface.
In order to confirm the numerical results, two prototypes of the concrete shells were tested in a certified laboratory in the design configuration.
The comparison with the experimental data shows a good match of the numerical results and confirms the capability of COMSOL Multiphysics® as a multiphysics simulation tool.

Finally, a thermo-elastic analysis was performed using the thermal field computed in the previous study as input, to evaluate the stress field induced in the concrete.

The development of this work allowed us to obtain detailed information for the design of

the new fire resistant overpack.

Reference

[1] DOE Standard 1066-2012: “Fire Protection”
[2] DM 16/02/2007: “Classificazione di resistenza al fuoco di prodotti ed elementi costruttivi di opere da costruzione”.
[3] D.M. 9/03/2007: "Prestazioni di resistenza al fuoco delle costruzioni nelle attività soggette al controllo del Corpo nazionale dei vigili del fuoco. "
[4] UNI EN 1363-1:2012: “Fire resistance tests - Part 1: General Requirements”
[5] UNI EN 1992-1-2:2005: “Design of concrete structures - Part 1-2: General rules - Structural fire design”
[6] UNI EN 1993-1-2:2005: “Design of steel structures - Part 1-2: General rules - Structural fire design”
[7] UNI EN 1993-1-4:2015: “Design of steel structures - Part 1-4: General rules - Supplementary rules for stainless steels”

Figures used in the abstract

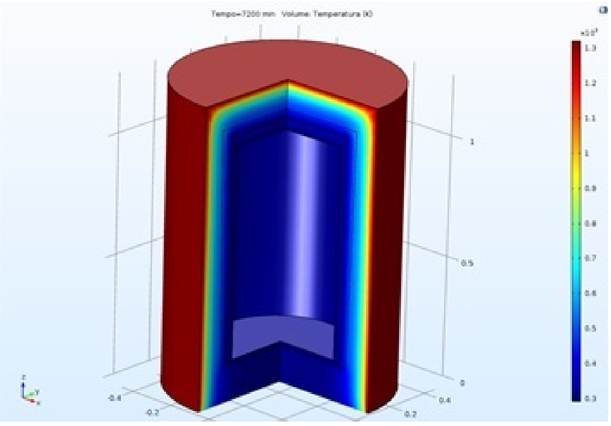

Figure 1: Temperature field for ceramic fiber blanket insulation case.

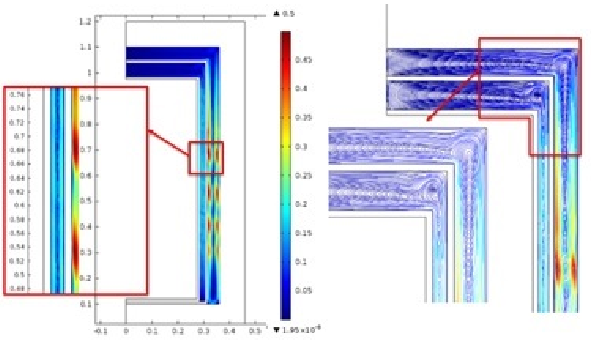

Figure 2: Velocity field and stream line for air insulation case.

Figure 3: Picture of experimental setup.