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Numerical simulation of plastic collapse of copper-cast iron canister for spent nuclear fuel

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ABSTRACT

This paper describes a finite element simulation of a spent fuel canister for geological disposal loaded in iso-static pressure until plastic collapse. The canister consists of a copper overpack and a ductile cast iron insert with steel cassettes where the spent fuel is placed. The highly non-linear finite element analysis is based on the explicit formulation and includes large deformations, non-linear material behaviour and contact between the canister components. The analysis includes comparison between two- and three-dimensional models and assessment of the different geometrical features such as corner radius of the cassette, cassette offset, different bonding/debonding conditions between insert and steel cassette. The analysis shows that the bonding cassette/insert has a large impact on the collapse load. Two large-scale mock-ups test that had been performed earlier are also simulated by the developed finite element models. There is a very good agreement between measured and computed deformations vs. applied load and collapse load.

1. Introduction

The KBS-3 copper/cast iron canisters, Fig. 1, are being developed in Scandinavia for geological disposal of spent nuclear fuel in crystalline rock [1–3]. The copper protects the canister from corrosion whereas the ductile cast iron insert provides the mechanical strength and eliminates the risk for criticality. The insert is cast around a steel cassette that provides the channels where the spent fuel is placed. The canister will be placed in shafts in a crystalline rock formation at a depth of 500–700 m. The system needs to ensure for more than 100,000 years that the level of radiotoxicity from the disposed spent nuclear fuel is negligible compared to the natural background dose. This design life is longer than any other engineered products and features such as climate change need to be taken into account; in Scandinavia this means that ice-ages need to be considered and it has been estimated that the isostatic pressure during an ice-age can be up to 45 MPa [3].

The probability for mechanical failure of the canister at this load is extremely low [4–6]. To demonstrate the safety margins, verification tests have also been performed on two KBS-3 mock-ups loaded in a cold isostatic press to 132 and 139 MPa, respectively. Thus the safety factor for the pressure load is at least a factor 3. These tests together with microstructural analysis of failure mode were presented in [7,8]. A finite element plastic collapse analysis had been performed with two-dimensional plane strain model and a quarter of the canister modelled assuming double symmetry conditions [6]. To get more confidence in predicting the failure and to understand the influence of different design parameters, more elaborate collapse models are needed. This paper describes a finite element analysis where two and three-dimensional analyses are performed. The analysis also includes sensitivity study of mesh density and relevant geometry features that had been identified as important such as cassette corner radius, bonding between cassette and insert and cassette offset.

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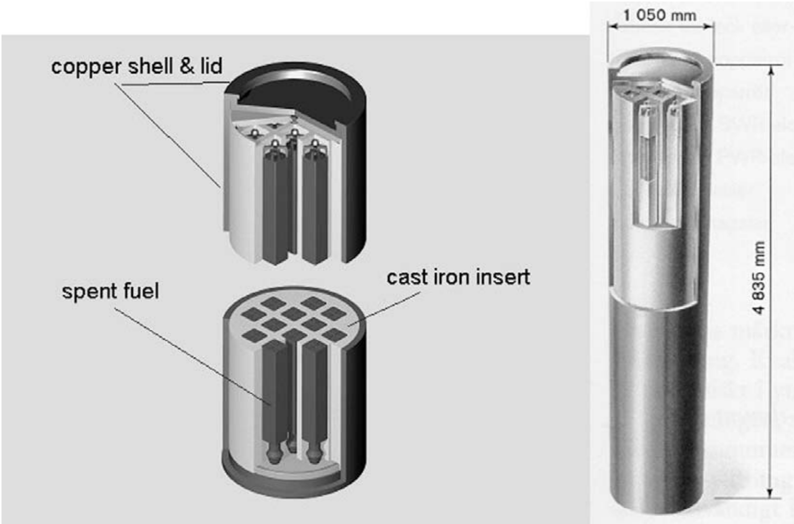

Fig. 1. The KBS-3 spent fuel canister.

2. Design of the mock-ups

Two canisters were used for the mock-up tests. The mock-ups have only a length of 1 m because of weight restrictions of the pressure test equipment. Fig. 2 illustrates the parts of the mock-up and how they are assembled. The mock-ups are made from the following parts [7,8]:

- Inserts of length 700 mm and of diameter 948 mm, cut from two different KBS-3 canister inserts (referred to as I24 and I26). The inserts have 12 almost quadratic shaped channels, each containing a square steel cassette with a thickness of 10 mm with inner dimensions of 160 × 160, respectively.
- Copper tube with inner diameter 952 mm, length 948 mm and wall thickness 50 mm.
- Two copper lids.
- Two steel plates of 48 mm thickness positioned between insert and lid at each end.

The KBS-3 canister has a length of almost 5 m and the lids are welded to the copper tube. The bottom part of the insert has no fuel channels making the ends of the canister relatively stiff. Since the mock-ups are much shorter than the KBS-3 can-

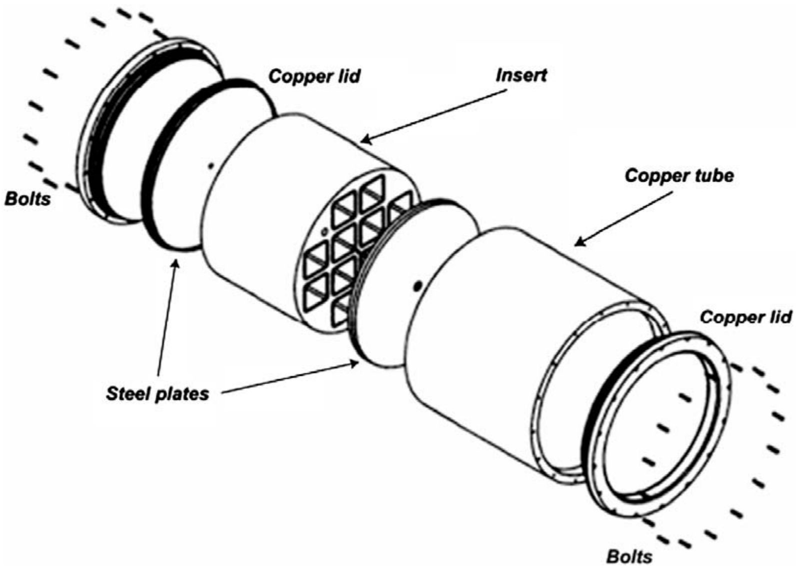

Fig. 2. The different part of the mock-ups.