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Ultrasonic Identification Methods of Copper Canisters for Final Geological Repository

C. Clementi[1,2], F. Littmann[2], L. Capineri[1], C. Andersson[3], U. Ronneteg[4]

[1] Dept. Information Engineering – University of Florence, Florence, Italy
[2] European Commission, Joint Research Centre, Nuclear Security Unit, Ispra, Italy
[3] Swedish Radiation Safety Authority,
[4] Swedish Nuclear Fuel and Waste Management Co

Abstract:

The Swedish system for taking care of the spent nuclear fuel includes long term geological disposal of the fuel encapsulated into copper canisters. For such Safeguards applications, it is of utmost importance to be able to trace canisters once closed in order to keep the Continuity of Knowledge from the Encapsulation Plant to the Geological Repository. One possibility is to use a tagging of the canister. This work introduces an innovative system for tagging copper canisters based on the ultrasonic reading of cavities machined on copper lids. The realization of a new identification method for copper canisters is the aim of the research. For corrosion reasons it is better to not engrave any code on the external parts of copper canisters. According to the copper lid geometry, the proposed solution envisages the machining from the inside of several inclined Flat Bottom Holes or chamfers around the circumference of the lid, while still keeping the required thickness of the copper for safety reasons. They represent a unique identification code for each canister, easily readable by an ultrasonic immersion probe on a 360° scan. A laboratory prototype for the identification system has been manufactured and successfully tested.

The copper lid is reproduced on a scaled version and a series of chamfers 50° inclined are drilled around the bottom of the lid. The reading system hosted a probe placed 14° inclined according to the Snell's law. The received ultrasonic signal represents the binary code realized by the chamfers [1].

The paper will describe the optimization studies made on the transducers, the angle and width of chamfers, the binary identification codes, preliminary design and testing of a reading system.

Keywords: ultrasound; identification; copper canister, geological repository.

1. Introduction

The spent fuel coming from operations of Swedish nuclear power plants will be inserted into copper canisters and then stored in deep geological repositories. The Swedish Nuclear Fuel and Waste Management Company's (SKB) developed the method for final disposal of fuel in copper canisters surrounded by bentonite clay about 500 metres underground in Swedish bedrock. This solution will keep the fuel isolated from human beings and the environment for many years.

The new SKB's method for final disposal of fuel comprises a number of facilities that together provide a safe chain (Figure 1). The fuel coming from Swedish reactors is stored for one year minimum in the spent fuel ponds at the reactors before it is shipped to the interim storage facility. There

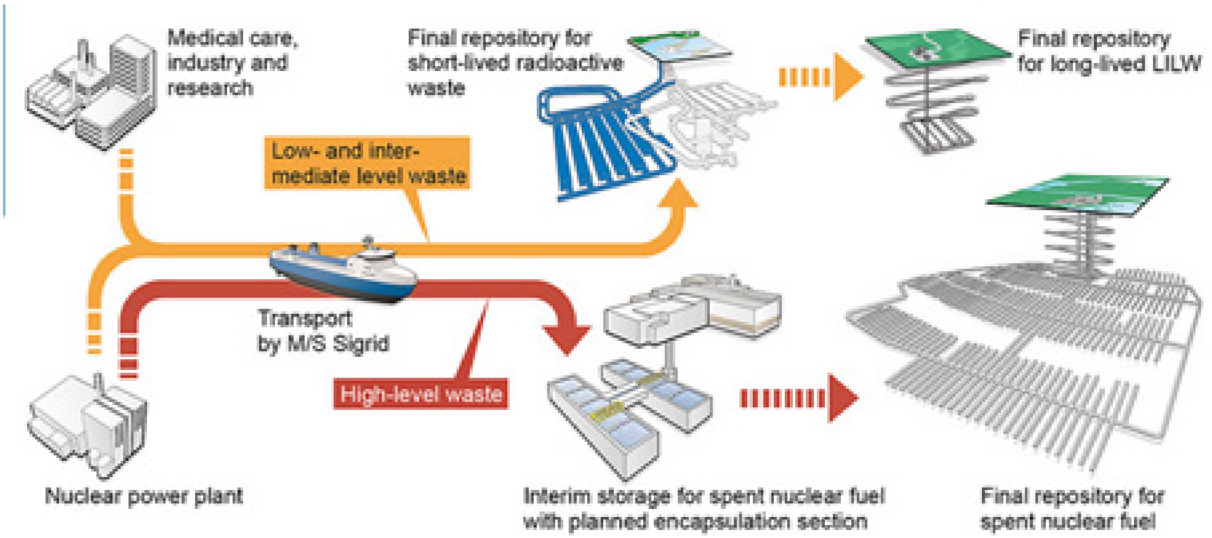

Figure 1: The SKB project for the management of spent nuclear fuel in Sweden.

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the fuel is placed in storage baskets which are stored in ponds. Later storage canisters with spent fuel will be lifted from the pools and moved to the encapsulation plant where the fuel is inserted in copper canisters with iron inserts. After encapsulation, the canisters are transported to the final repository and then located in the deposition hole. About 6000 copper canisters will be deposited, with an average of one canister per day.

Repositories present several new challenges for international Safeguards. One of them is maintaining the Continuity of Knowledge (CoK) from the encapsulation plant to the final repository.

The International Atomic Energy Agency and EURATOM safeguards approaches propose to use canisters identification during transport and deposition from the encapsulation plant to the final repository [2]. Convectional tagging techniques are various but SKB has to date not presented any method for labelling the copper canisters [3], [4], [5], [6]. An engraving or marking of the canister may impede the long term safety and integrity of the canister since it may reduce the corrosion barrier [2]. Therefore alternative solutions should be developed. Next paragraphs illustrate a possible identification method based on ultrasounds developed by the SILab, Seals and Identification Laboratory, of the Joint Research Centre of the European Commission in Ispra (VA). The first part of the research deals with studies oriented to identify the best positioning of holes or chamfers to be read by a specific transducer. Afterwards a series of simulations and experimental tests have been implemented on copper samples and slices of the copper canister (copper flanges) with the aim to demonstrate the possibility of identification of canisters by ultrasounds. In the end, the identification method is validated on a small-scaled copper lid with chamfers investigated by an ultrasonic reading system prototype.

2. The identification method

Since many years, SILab develops ultrasonic identification techniques on bolt seals with artificial cavities made on stainless steel washers, giving a fingerprint from the reflection of unique patterns. In the case of copper canisters, the geometry (Figure 2.) and dimension of the lid are much bigger than seals, therefore an adaption of the ultrasonic method is required. In particular, the solution proposed in this paper deals with the identification of copper canisters by the ultrasonic investigation of a series of Flat Bottom Holes (FBHs) or chamfers milled on the inner surface of the lid where the copper thickness is higher than 50 mm, as shown in Figure 3. Because of corrosion reasons, in fact, the minimum copper thickness must not be less than 50 mm and the machining of holes or chamfers must not affect the integrity and the stability of canisters.

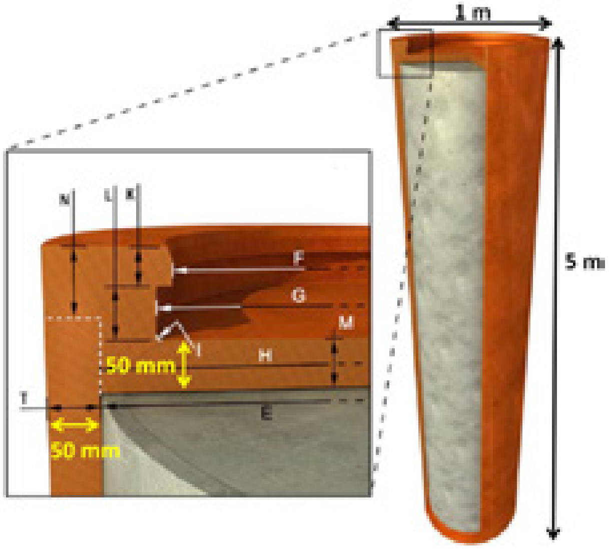

Figure 2: Copper canister geometry.

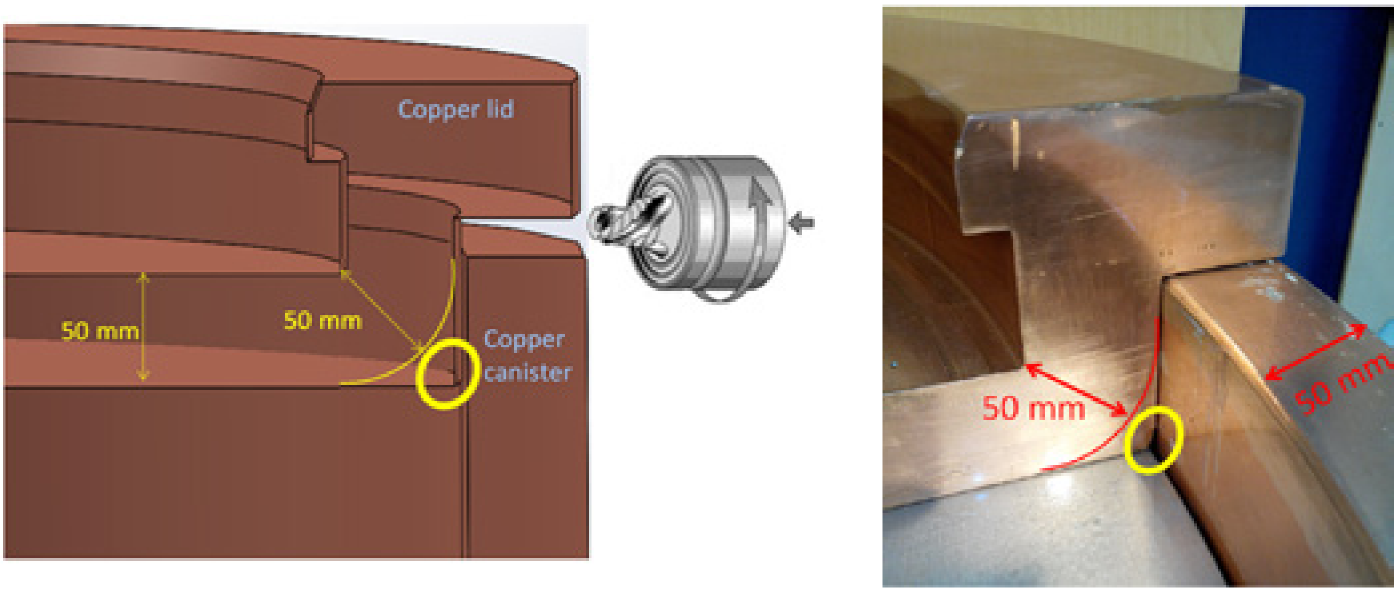

Figure 3: Area (circled in yellow) where the thickness of the lid is higher than 50 mm.

The study of the best dimension and position of holes is realized by 3D simulations and experimental measurements carried out on copper flanges that are part of a lid already been welded to the canister. The first idea was to drill configurations of FBHs with different positions and dimensions on the bottom surface of copper lids as shown in Figure 4, on the left. The ultrasonic reading of these cavities was designed to be accomplished by a single probe located on the top of the lid, rotating 360° along with the lid circumference. Before machining FBHs in copper flanges, ultrasonic tests were carried out on cylindrical copper samples with different FBHs. The analysis of results revealed the possibility to acquire echoes, however, depending on the inspection frequency, the attenuation of ultrasound in copper could affect measurements negatively and then a different configuration of holes was studied [7]. In order to decrease the distance between cavities and probe, FBHs are replaced by inclined flat holes or chamfers arranged as illustrated in Figure 4, on the right. Cavities

This new disposition of holes involves the repositioning of the transducer as shown in Figure 5. The probe must be inclined according to the Snell's Law in order to guarantee the perpendicularity between the ultrasonic beam and reflectors. Considering the velocities of sound in water (V1=1500 m/s) and in copper (V2=4651 m/s), the probe angle should be around 14° assuming that the inclination of the chamfer is 50°.

$$\sin(\alpha 1)/V1=\sin(\alpha 2)/V2 \rightarrow \alpha 1=\sin^{-1}(1500/4651)\cdot\sin(50)=14.3° \quad (1)$$

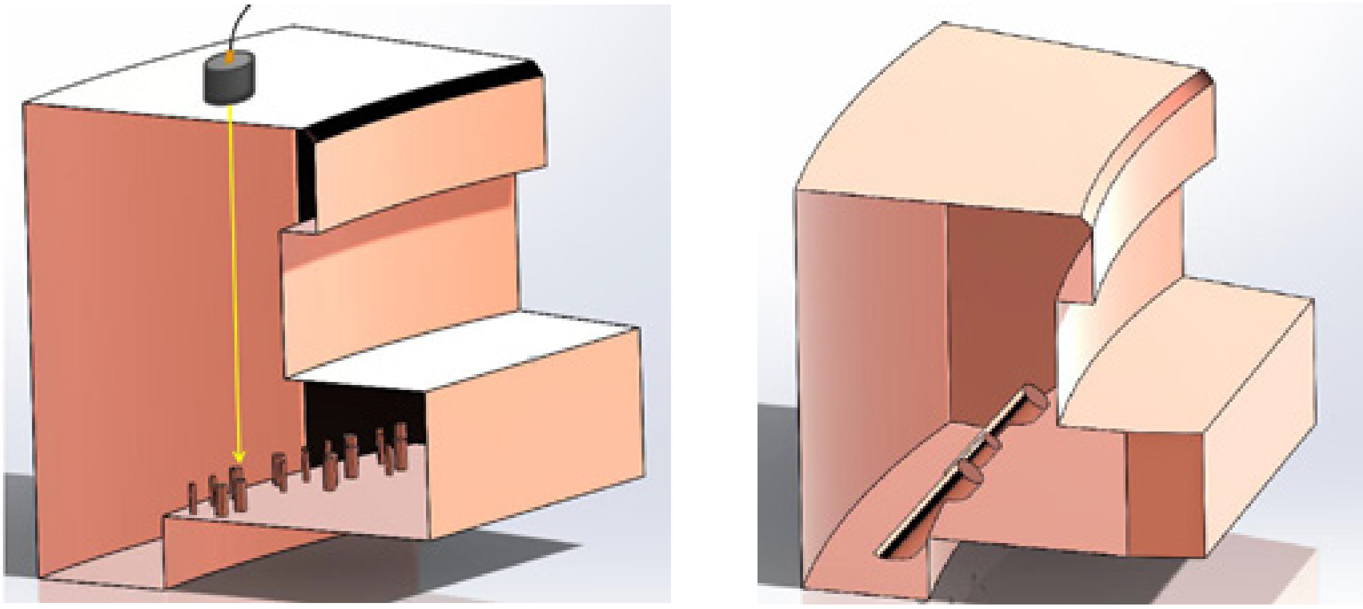

Figure 4: Two possible types of identification cavities: FBHs on the left, inclined flat holes on the right.

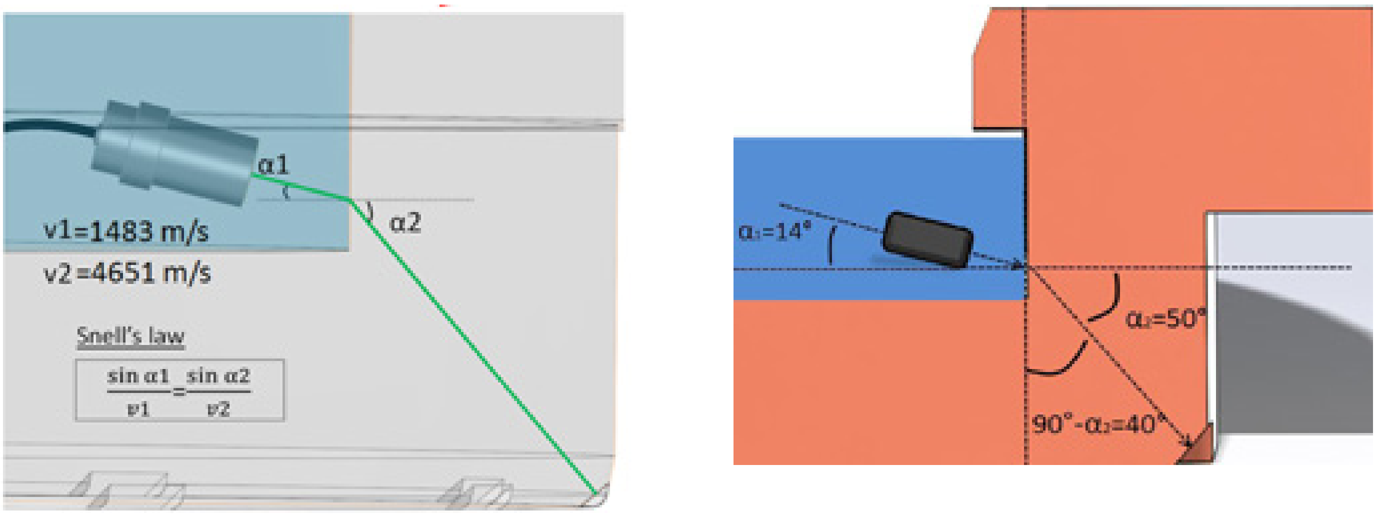

Figure 5: Position of the transducer according to the Snell's law.

Depending on the configuration of chamfers around the lid circumference, the transducer will receive different ultrasonic amplitude responses. Therefore, each canister can be identified by a unique code of chamfers readable by ultrasounds.

3. Simulations and experimental tests

Several experimental tests were carried out on copper flanges with the aim to verify the possibility of detection of flat bottom holes 50° inclined [8]. The inclination of holes has been chosen at 50° by authors for tests but it could be changed in case of necessity. The following Figure 6 shows the set-up of measurement for the investigation of an inclined hole (on the left) and the corresponding A-scan signal (on the right).

Considering that the Time of Flight (TOF) of the echo received is 31.3 µs, the corresponding measured distance is 65.88 mm, value in accordance with the geometrical distance d_h.

The analysis of measurements pointed out that ultrasonic echoes reflected by inclined holes can be detected with a good signal to noise ratio.

Before validating the method on a laboratory prototype, simulations on the CIVA software [9] were implemented to study the best dimensions and positions of chamfers to be machined on the copper lid circumference. The CIVA Ultrasonic Testing (UT) module is specific for ultrasonic NDT and offers two different types of evaluations: the beam computation and the inspection simulation, both useful for our purpose. The set-up simulated (Figure 7) is a 2D profile of the copper lid with a 50° inclined chamfer.

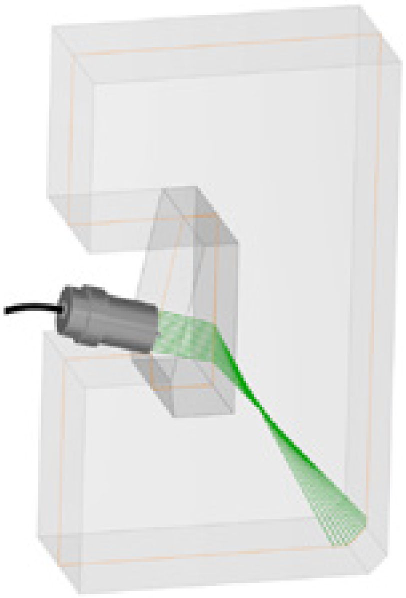

Figure 7: Simulated set-up.

The setting of transducer parameters and position is made in accordance with the testing piece geometry. Before simulating the ultrasonic response of the chamfer, the beam computation is realized to appreciate how ultrasounds propagate in the test piece. As illustrated in Figure 8 the probe is not exactly focused in correspondence of the chamfer but the focal spot is located at a depth of about 25 mm from the impact point. However the beam divergence angle is approximately 7° and the focal spot diameter at the chamfer depth is 13.2 mm. As a result, if the chamfer width is too small compared to the focal spot diameter, the echo reflected back will be not revealed by the probe.

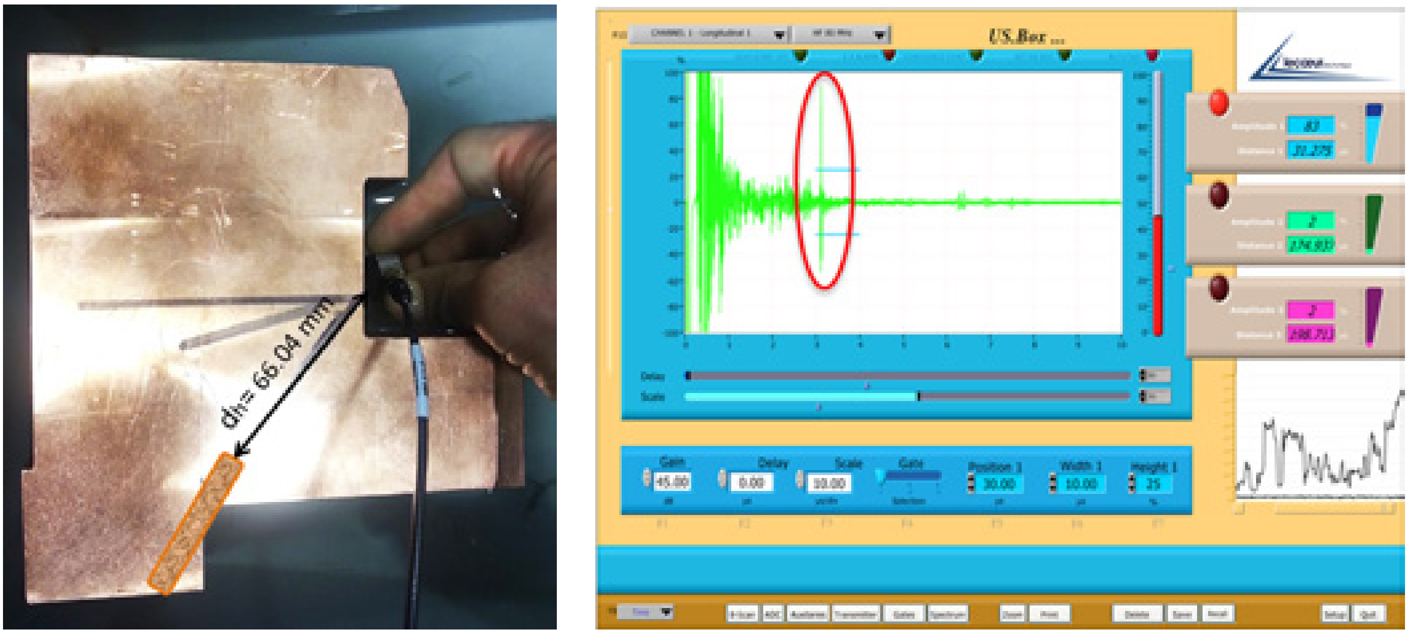

Figure 6: Set-up of the ultrasonic investigation and corresponding A-scan acquisition.

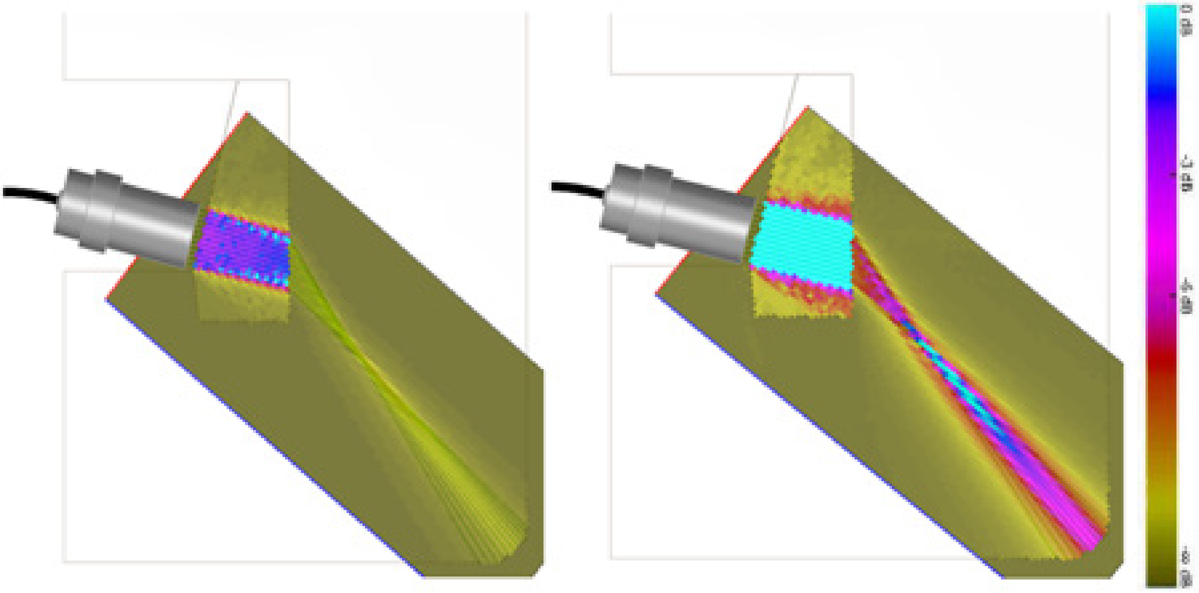

Figure 8: Beam computations for the first simulation set-up. On the left the default beam with 0dB of dynamic, on the right the post processed beam with 15dB of dynamic. Sky blue stands for the highest intensity, yellow for the lowest.

The simulation of the interactions between ultrasonic field and chamfers is implemented by the inspection simulation module. The aim of this study is identifying the best chamfers dimensions in order to do not engrave too much copper. Figure 9 illustrates four chamfers with different widths: 5, 10, 15 and 20 mm respectively. The yellow arc represents the minimum copper thickness of 50 mm to be always kept. As shown, the dimensions of all the chamfers agree with the thickness requirements but smaller they are better it is from the canister integrity point of view.

The results of simulations pointed out the chance to receive good ultrasonic echoes from each one of the chamfers. However the larger the chamfer is, the better signal quality is received. By consequence, a good compromise could be a chamfer around 10 mm wide.

4. Validation on a laboratory prototype

Following the ultrasonic tests on copper samples and CIVA simulations, an identification reading system prototype has been developed. In particular, the validation of the identification method is carried out on a scaled version (¼) of the copper lid where a barcode of cavities and chamfers is realized (Figure 10). The scale is reduced but the geometry of the ultrasonic reading zone is scale 1 compared to the real one meter diameter copper lid.

The chamfers, 50° inclined and 12 mm wide, are arranged around the small lid circumference 22.5° angle spaced (Figure 11). The binary code is created by an alternation of chamfers and cavities, which reflect the ultrasonic beam in different ways. The presence of cavities made easier the production of chamfers in the prototype. However, in the real case, only chamfers will be realized on the lid and ultrasounds will be deflected by unmodified areas. The transducer, rotating around the circumference of the lid, will receive an echo in correspondence of chamfers only.

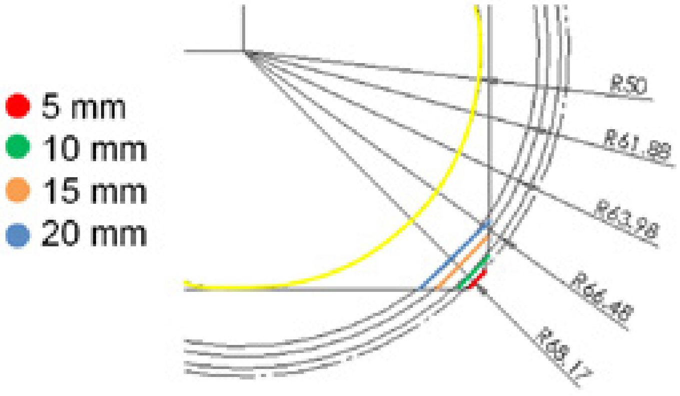

Figure 9: Study of best chamfer dimensions.

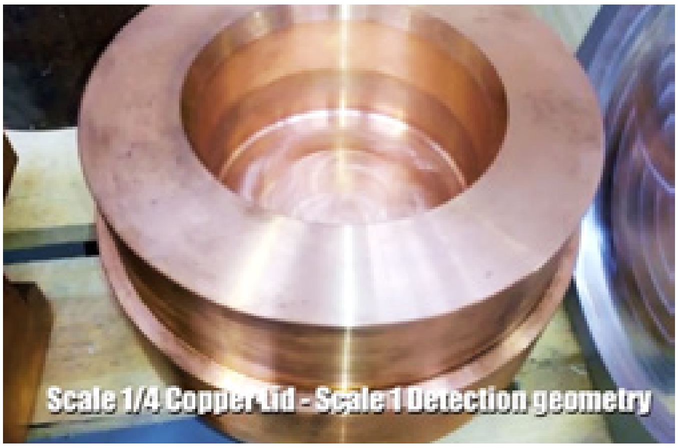

Figure 10: Picture of the small scaled copper lid (¼).

The reading system prototype that hosts the probe is realized by a modified version of reading head used for seals verification (Figure 12). The transducer is installed 14° inclined in order to receive the signal reflected by chamfers according to the Snell's law. The ultrasonic reading of chamfers is realized by an immersion testing in that a bit of water is poured inside the lid. The signal acquired by a 360° rotation of the transducer represents the code realized by chamfers and cavities.

5. Conclusions

Afterwards the result of the experimental testing is compared to a CIVA simulation, reproducing the same set-up of measurement (Figure 13). The simulated echo is evident in both A-scan and B-scan modes and the simulated amplitude ultrasonic response agrees with the experiments. As a result, we can state that the identification method is validated on this small-scaled copper lid, which means that each future copper canister could have a different binary code made of chamfers.

As a result, from simulations and measurements on scaled copper lid, we can state that the identification method proposed is validated and then each future copper canister could have a different binary code made of chamfers. This positive result paves the way for a future identification of all copper canisters, which will be easy, cheap and reliable. When manufacturing the lid, it will be enough to mill or turn a few additional chamfers to deliver on each lid a different binary code, This code will be read at the Encapsulation Plant when the canisters is welded and then on arrival in the Geological Repository.

The implementation of this identification method will contribute to support the CoK of copper canisters with nuclear spent fuel. However identification might not be sufficient to prevent attempts of falsification or duplication of canisters then another approach is necessary to ensure the originality of each container. For this purpose, an authentication method is developed by authors [10].

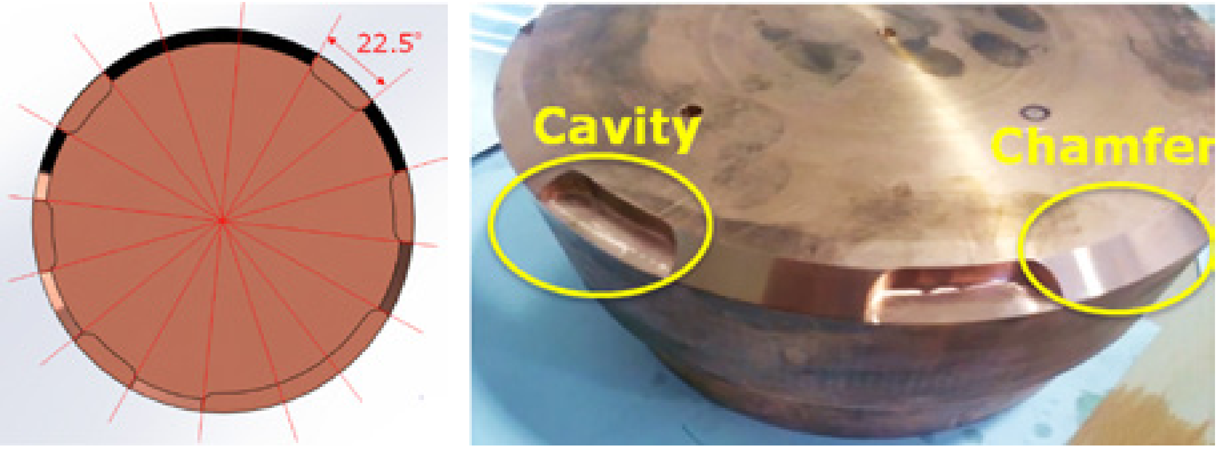

Figure 11: Chamfers arranged around the circumference of the prototype lid 22.5° angle spaced.

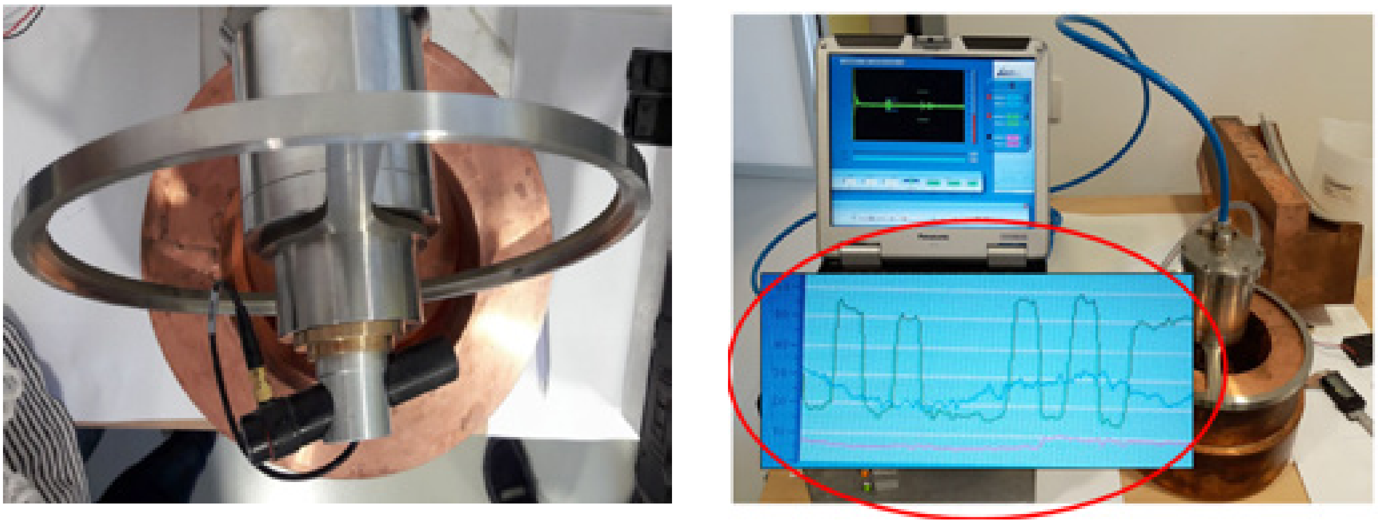

Figure 12: Reading system prototype and binary code acquired by a 360° rotation of the transducer around the small scaled copper lid.

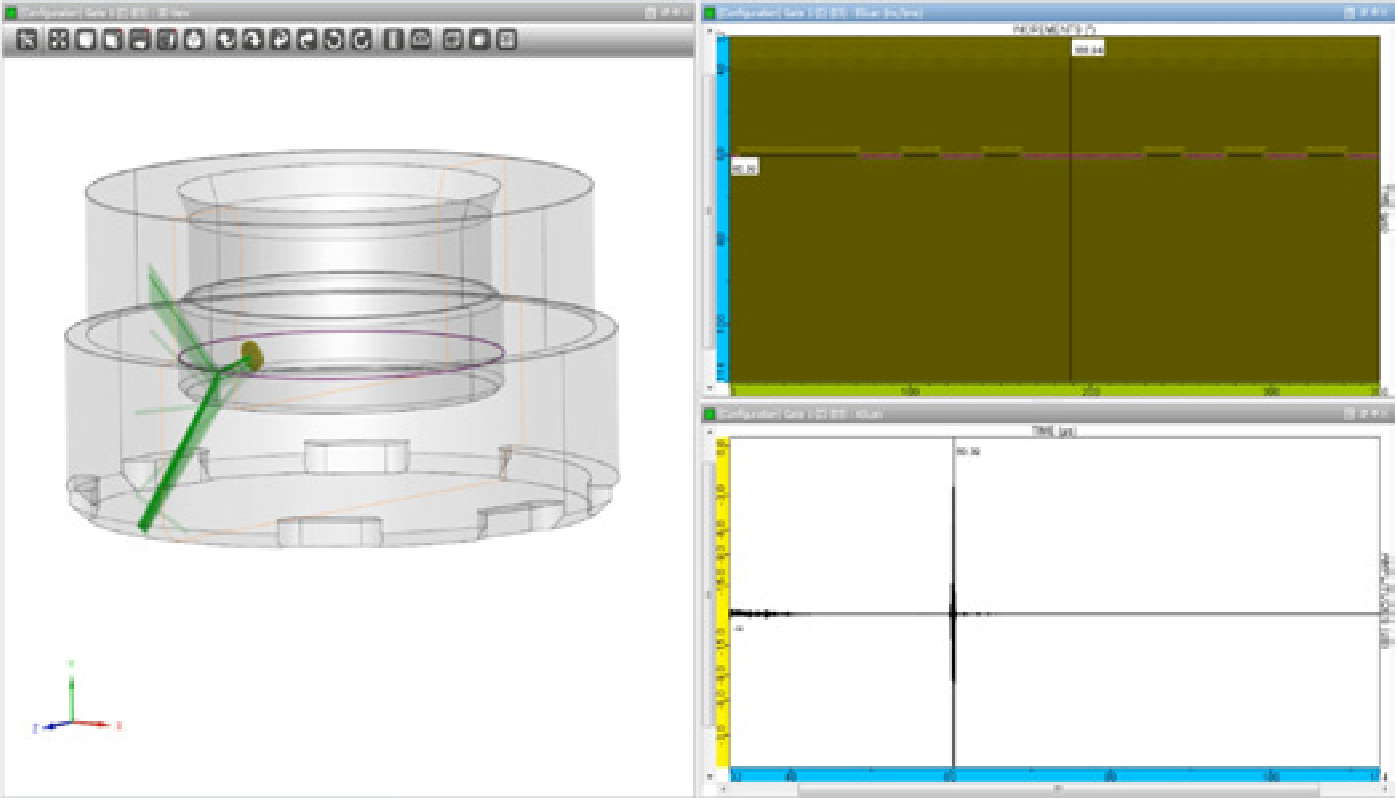

Figure 13: CIVA software simulation of the ultrasonic investigation of the copper lid prototype.

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