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Present and Future Activities on Neutron Imaging in Argentina

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Abstract

We present here a short review of the main work which has been done in the latest years in neutron imaging in Argentina, and the future plans for the development of this technique in the country, mainly focused in the design of a new neutron imaging instrument to be installed in the future research reactor RA10. We present here the results of the implementation of the technique in samples belonging to the Argentinean cultural heritage and experiments related with hydrogen storage. At the same time, the Argentinean RA10 project for the design and construction of a 30 MW multipurpose research reactor is rapidly progressing. It started to be designed by the National Atomic Energy Commission (CNEA) and the technology company INVAP SE, both from Argentina, in June 2010. The construction will start in the beginning of 2015 in the Ezeiza Atomic Center, at 36 km from Buenos Aires City, and is expected to be finished by 2020. One of the main aims of the project is to offer to the Argentinean scientific and technology system new capabilities based on neutron techniques. We present here the conceptual design of a neutron imaging facility which will use one of the cold neutron beams, and will be installed in the reactor hall. Preliminary simulation results show that at the farthest detection position, at about 17 m from the cold source, a uniform neutron beam on a detection screen with an intensity of about 10^8 n/cm^2/s is expected.

Keywords: Neutron imaging, Cultural Heritage, Hydrogen Storage, Instrument Design ;

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1. Introduction

Since 2012 it is possible in Argentina to apply the neutron radiography technique in a regular instrument environment, at the RA6 research reactor located in CNEA's Research Campus, at San Carlos de Bariloche City in the northwest of the Argentinean Patagonia. This technique is not new in the country, because some feasibility studies where done during the 70's in the RA3 research reactor, located in Ezeiza Campus, also belonging to CNEA. In those times the images were taken in the old fashioned manner by employing radiographic chemical plates, to study reactor

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fuel element integrity and metal weldings. However, the modern Scintillator-Mirror-CCD method had stimulated the design and the latter commissioning of the Bariloche's facility and, in consequence, represented a new beginning of this technique for Argentinean science.

The new horizon for the development of the discipline in Argentina is now represented by the project of the new research reactor RA10, to be constructed by CNEA and INVAP from 2015 in Ezeiza, at 36 km from Buenos Aires City, and according to the project schedule, to be finished in 2020. This reactor of 30 MW will produce radioisotopes for medicine, doped silicon wafers for electranpassungonics applications and will have several neutron beams for science, four of them looking to a liquid deuterium cold source at 20 K. One of the cold beams, directed to the reactor hall, will be the main neutron beam for the new cold neutron imaging facility under design.

The present short article describes some of the latest results achieved using the operational instrument in Bariloche, and shows the preliminary results in the design of the new neutron imaging instrument to be installed in the future RA10 research reactor.

2. Present status of the discipline

Since the year 2012 to the present, the user demand of the neutron imaging facility in Bariloche has been growing. Many of the users are physicists and engineers of the same campus where the RA6 is located, but also researchers from other disciplines like archaeology or paleontology. The instrument is also used for special practice by nuclear/mechanical engineering or physics students of the Balseiro Institute, hosted in the same campus. In fact many of the design and shielding numerical calculations that lead to the actual layout of the instrument since 2009 where done by advanced students of the Institute.

The instrument is installed near the concrete biological shielding of the 1 MW reactor, and uses a radial extraction steel tube of 248 cm lenght and 12.5 cm diameter that looks to the graphite reflector of the reactor core. In the first part of the tube, a filter of bismuth (5 cm thick) and saphire (10 cm) is used to reduce the gamma radiation and ephithermal neutrons respectively. The first design of this instrument was materialized in 2005 (Márquez (2005)), but after a re-design started in 2009, the present version is fully operational since 2012 (Pieck (2009), Sánchez (2010), Marín (2013)). The neutron flux at the sample position is typically around 2.4 10^6 $n/cm^2/s$ thermal and 6.4 10^3 $n/cm^2/s$ epithermal neutrons, when the reactor operates at 500 kW, the more usual regime. The instrument uses a scintillator screen of ZnS(Ag) with ^6LiF with 20 $cm \times 20$ cm surface, and has an L/D of 100. The camera is a Penguin 600 CLM by Pixera Corp. with a maximum resolution of 2776×2074 $pixels$ and the optics is Schneider Kreuznachque with $f = 0.95$.

2.1. Leading cases

Some of the latest results obtained at the Bariloche's neutron imaging facility are shown in this section. This is just a representative set of the work done in the last two years, but naturally most of the work is not showed here for space reasons. The selected results and images correspond to studies about Argentinean cultural heritage and hydrogen storage technologies, but other experiments glue-bonded metals, special paints and zirconium alloys were performed during 2013 and 2014.

2.1.1. Cultural heritage

Argentina has a very rich story and several archaeological sites related with the natural history, but also with the country's foundation history. In Buenos Aires, the Capital of the country, it has been commonplace in the last years to have excavations for new buildings and accidentally find an old and unknown piece of history of the city and the country. One example was the excavation in a very old and central location of the city, to construct a new hotel in the year 2010. Preliminary archaeological studies of the site, revealed the presence of old tunnels and an old jail building operative by the years 1860-70, according to the work of Orsini and Padula (2014). The archaeologist found a human waste reservoir with glass bottles, crockery fragments and very oxidized metallic crockery. In this case the neutron imaging technique was applied to try to observe the main metal structure under the oxide layer which seemes to be an old metal jar. See Figure 1.

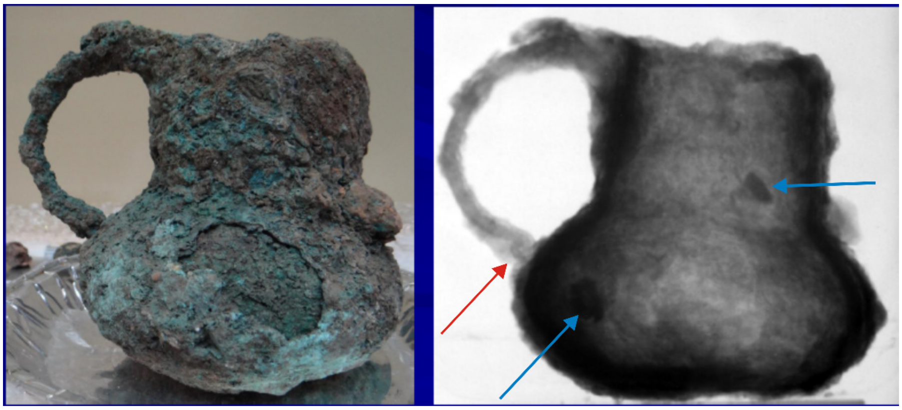

Fig. 1. The figure shows an example of Argentinean cultural heritage study using neutron imaging. The object is an old metal jar, of 125 mm maximum diameter, used to make the traditional Argentinean hot chocolate beverage. The neutron imaging revealed two apparent patches (blue arrows) and a turn in the lower part of the handle (red arrow), completely hidden by the oxide layer.

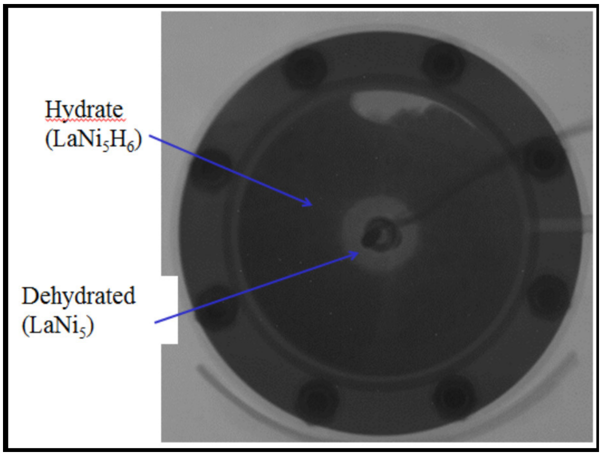

Fig. 2. A device to study dehydriding process by neutron imaging is showed. The cylinder (125 mm diameter) contains LaNi5-H6 as hydride, and with the central heater the system is warmed up during an hour, while neutron radiographies are taken regularly to compare the evolution with existing analytical models. The image corresponds to an intermediate stage of the experiment, where some desorption of hydrogen has occurred near the heater in the center.

2.1.2. *Hydrogen storage*

One of the research groups at Centro Atómico Bariloche is dedicated to study hydrogen storage related technologies. They are interested in how hydrogen sorption occurs in hydride-based storage tanks. To compare models of temperature dependence desorption with real tanks, a small tank was made to observe the process using the neutron imaging facility of Bariloche's research reactor. The container was filled with LaNi5-H6 as hydride, and a heater placed in the center of the tank was used to control the dehydriding process. The complete experiment, following the evolution of hydrogen content with the temperature, was observed in the neutron beam during an hour, and is described with more detail in the work of Baruj et al. (2014). Figure 2 shows the intermediate image of the cycle, where some dehydration is observed near the heater in the center of the cylinder.

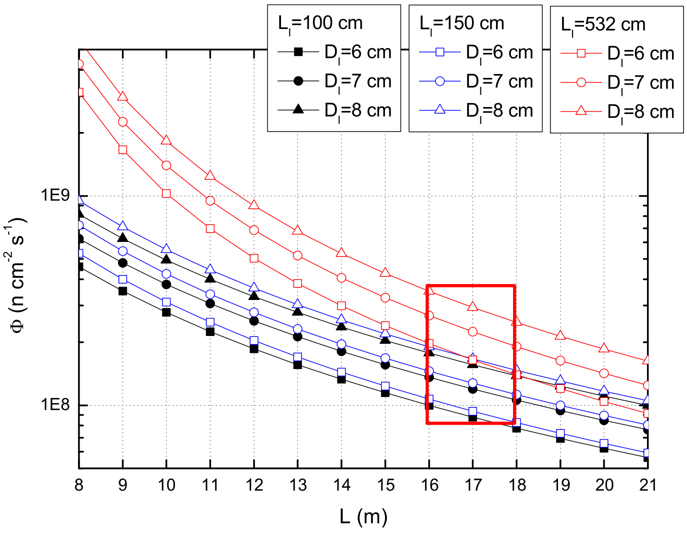

Fig. 3. The different geometric conditions for the iris and the consequences in the neutron flux as a function of distance to the could source are shown in this figure. The red square represents the estimative position of the far detector in the future instrument.

3. Neutron imaging for the future RA10 research reactor

The design of the neutron imaging facility for the future new research reactor of Argentina is at the beginning. Even when the reactor is starting to be built in the beginning of 2015, the instrument design is yet in a conceptual engineering stage.

The instrument will be located in the cold neutron beam GF3 of the reactor. This beam extracts the neutrons from the cold source to the reactor hall, being the wall of the hall located at 20 meters from the cold source. This means that the far detection position will be at approximately 17 meters from the cold source, considering the positioning of a beam catcher in the end of the setup.

The main goal until now has been to estimate analytically the neutron flux and calculate the L/D ratio, a parameter that indicates the divergence of the neutron beam, and its dependence with the distance to the neutron source by evaluating different cases of iris diameter and distance from the iris to the cold source. Different pinholes, with 6, 7 and 8 cm diameter (D_I), and a distance of 100, 150 or 532 cm from the cold source to the pinhole (L_I) were considered. The last case with a pinhole located outside the biological shielding of the reactor, at 130 cm away from reactor face, means that the neutrons should pass through a secondary shutter and an external collimator. Figure 3 and Figure 4 show the analytical results of neutron flux and L/D respectively as a function of the total distance (L) to the cold source. The rectangular area with red borders in both figures includes the estimative position of the far detector (17 m), which is the position with the highest L/D (Figure 4) and where the neutron beam would be wider. This has been at this stage of the design the main criteria: to look for the minimum divergence (maximum L/D), and the widest beam at the far detection position.

The Monte Carlo code McStas (Lefmann et al. (1999) and Willendrup et al. (2004)) was used to evaluate the different cases as well. In particular, at this preliminary stage of the design the interest was to compare the cases that maximize the L/D (more than 200) and allow to have the wider and uniform beam profile (according with the results shown in Figure 4) at the far detector position (17 m). See Figure 5.

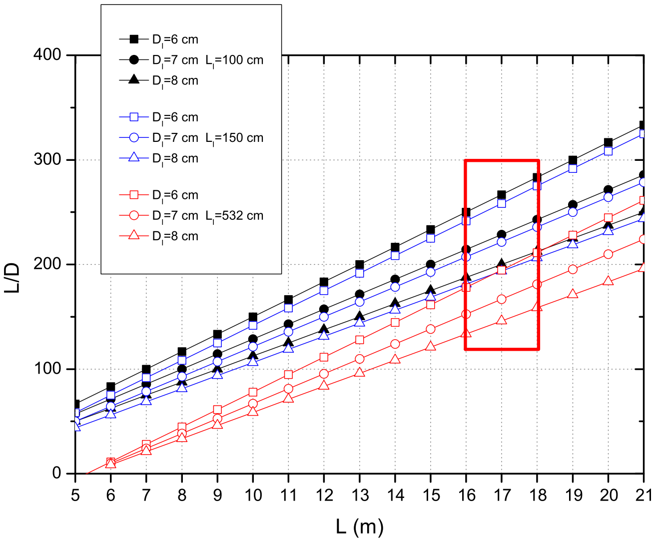

Fig. 4. The ratio L/D represents one of the central parameters in the design of a neutron imaging facility. As bigger the L/D means the lower is the divergence of the neutron beam and in consequence the instrument will have intrinsically a better resolution, at least from the geometric point of view.

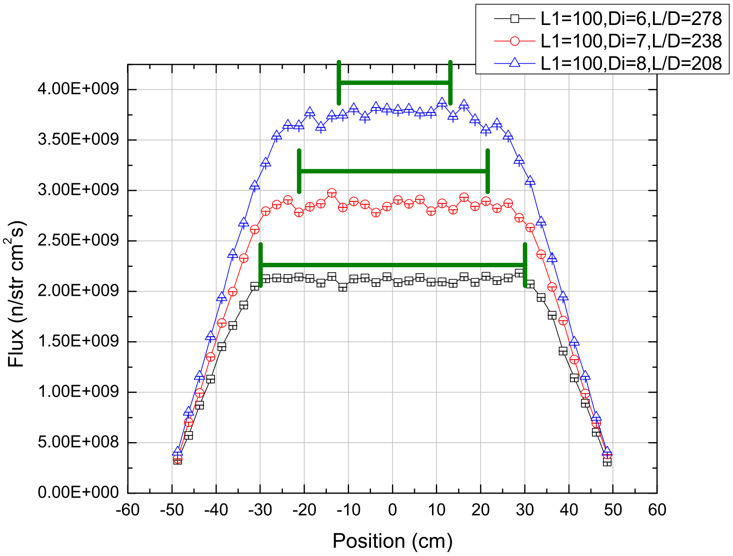

Fig. 5. All the geometries were simulated by using the McStas code. The three cases with higher L/D ratio (iris at 100 cm from the source) are shown in this figure to compare how the size of the beam and the relative flux depends on the iris diameter, for a detector located at 17 m from the cold source. For comparison purposes, the analytical beam width at the same detector position is shown (green line).

4. Conclusion

In this work we have shown that neutron imaging is an active field in Argentina, with a good perspective for the future with the construction of the research reactor RA10 and the design of a neutron imaging facility to be installed in the reactor hall.

Since 2012 the instrument at Bariloche's research reactor RA6 is being used with growing demand by users from the engineering and physics but also from cultural heritage users. Two example works for hydrogen storage and archeology have been shown, but many others are under development including tomography.

The instrument in Bariloche has another important role which is to show the possibilities of the technique to potential users in the way to have a bigger users community for which the new instrument at RA10 would result very useful. The conceptual design of the new facility has started and the first results were shown. Even when the situation with an in-pile iris of 6 cm diameter located at 100 cm from the cold source seems to be at first sight the best option, we believe that to use a fixed size iris may be a less versatile solution for the instrument. An external set of collimators would be a good option, to have higher L/D possibilities with good flux values and big enough screen size with relatively flat beam intensity shape. The next steps in the design are the evaluation of shielding considering the most conservative beam situation, and later the design of the collimation system.

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