

**Additional elements to support the Italian proposal to amend Regulation No. 110 (document ECE/TRANS/WP.29/GRSG/2017/29) on the basis of the results of the Italian research on type CNG4 cylinders**

The Italian proposal to **amend Regulation No. 110** (CNG/LNG vehicles) refers to **CNG4 cylinders** and is articulated in 4 different points which address **two completely different concerns**: while point 1 refers to the **visual inspection** of CNG4 cylinders for periodic requalification, points 2,3 and 4 refer to the **minimum safety level to impact damage** which should be assured to CNG4 cylinders according to the Regulation.

The research performed in Italy is related to the second subject (points 2,3,4 of the proposal). It should be noted that **points 2 and 3 are only an obvious and necessary corrigendum to UN Regulation No. 110 (R110)**: all tests for cylinder design qualification listed in Tab. 6.4 are described in detail, for each cylinder type, in paragraphs, 7.5 / 8.6 / 9.6 / 10.7. In paragraph 10.7 (CNG4 cylinders) the drop test, required in Tab. 6.4, is missing, which is an evident error and lack of information. **Then the only point under discussion should have been the need of providing a univocal interpretation to paragraph A20**, in appendix A of Annex 3A (we ask to make clear that the safety level required for impact damage should be reached by the cylinder itself, not by glued dome cover protections).

**The research started following 3 in-service failures of CNG4 cylinders, with glued dome protective covers, which have been ascribed to impact damage.** To verify the impact damage safety level of this kind of construction, **24 CNG4 cylinders with glued dome covers have been impact damage tested according to the cited paragraph A20.** The results have shown:

- that the considered cylinders (with glued dome covers) have a **weakest point in a zone of the dome where the thickness is about one half of the cylindrical part** (as in the case of the in- service failures);
- that the tested CNG4 cylinders are able to reach the **required level of safety against impact damage only for the presence of the dome covers**;
- that such a cylinder, after a change of design, could be **approved without reaching the required safety levels, not even with the dome covers on** (10 on 12 tested

CNG4 cylinders of new production failed during the hydraulic test or the fatigue test performed after impact damage);

- that the analysed CNG4 cylinders seem to have the tendency to show **dome cover failures without any impact damage** or even without being used before (see enclosed photos).

Paragraph A20 states quite clearly that the required minimum safety level to impact damage should be fulfilled by the “*finished cylinder*”. Paragraph 4.56 of R110 clarifies that finished cylinders are “*Completed cylinders which are ready for use...but free from non integral insulation or protection*”. The failures occurred in service in Italy and the results of the Italian research seem to indicate that, in some practical applications, **the meaning of “integral protection” has been extended to glued dome covers.**

On the basis of what has been above resumed, the interpretation that the safety levels required by paragraph A20 could be fulfilled not by the cylinder itself, but also with the help of dome covers, appears to be wrong and very dangerous (as the in service failures have shown). Therefore, the amendments proposed to points 2,3 and 4 of the Italian proposal are justified for the following reasons:

- **points 2 and 3 are a simple corrigendum** to the description of the “*design qualification tests*” needed for CNG4 cylinders;
- **paragraph A20** prescribes that the test should be performed on the “*finished cylinder*”;
- paragraph 4.56 clarifies that finished cylinders are “*Completed cylinders which are ready for use...but free from non integral insulation or protection*”;
- it seems **very unlikely that glued dome covers** (as the ones of the tested cylinders), for their geometry and constitution, **could be assumed to be an “integral protection”** (see enclosed photos);
- R110 gives very precise rules for the material, design and testing of all structural components, but does not consider dome covers, as it should have done if they could be used to fulfil a structural requirement. **Table 6.7 (change of design) requires the drop test** (and the related safety level) **only for changes related to the fibers or to the resin, not to the material or the design of the dome cover;**
- the possibility of reducing the thickness of the dome as much as it has been evidenced in the analysed cylinders, is theoretically justified only for the load due to the internal

pressure in cylinders made of an homogeneous material. It follows that **this reduction is not correct, in general for impact loading, but, above all, not even for internal pressure loading, in the case of CNG4 cylinders**: due to the more complex geometry of the dome, it is reasonable to assume that the chance to have some production defects is higher in the domes than in the cylindrical part. It is then reasonable also to admit that **small defects not revealed by the hydraulic test, will have a higher negative influence on the service life of the CNG4 cylinder if the thickness and the strength of the dome, on the basis of theoretical assumptions and of an unlikely interpretation of the damage safety requirements of R110, are reduced too much**;

- it is necessary **to avoid the possibility to have** on the market R110 designed and approved CNG4 cylinders **which are not able to give the required levels of safety** to impact damage which, according to R110, should be guaranteed.

Coming to the **amendment related to the visual inspection for periodic requalification (point 1 of the Italian proposal)**, it should be noted that paragraph 4.1.4 of Annex 3A states that **“Each cylinder shall be visually inspected including under the support straps”**. As far as we know, this prescription has not yet been amended and then it is still compulsory for R110 approved cylinders. In our opinion disregarding this requirement could be very dangerous, especially for composite cylinders. Indeed it seems **very unlikely that someone could dare to say that there is no danger of wear-damage on the surface under the straps for a composite cylinder**; this is particularly true after several years of vehicle operation on dusty or sandy roads. Moreover, Annex 3A, point 6.12, of R110, dealing with “exterior environmental protections”, specifies that **“The coating shall be designed to facilitate subsequent in service inspections”**. It seems very unlikely that someone could dare to say that this requirement is not to be extended to any kind of protection not explicitly considered in the Regulation. Then it seems that the **Italian request to amend point 4.1.4 (specifying that, for periodic requalification, the absence of damage shall be verified also under any kind of non integral protection, like the glued dome covers) is quite important and necessary to avoid dangerous misinterpretations** of what this Regulation requires to be accomplished at each Periodic Requalification.

## TECHNICAL DATA

IN SERVICE FAILURES OF CNG4 CYLINDERS: in Italy there have been 3 in service failures of CNG4 cylinders with glued dome covers (a 12.5 l cylinder during the first refilling after the installation of a new kit of cylinders; a 39 l cylinder during refilling after about one and a half year and 60 000 Km from the registration of the car; one 11.4 l during the hydraulic test performed for the periodic requalification). **The failure was always on the valve-dome**, in a zone where the thickness of the composite wall was very low, about one half of the one in the cylindrical zone). Although there was absolutely no evidence of a prior car collision or of any impact damage, **the failures have been always attributed to impact damage**. Only the Working Group nominated by the Italian Transportation Ministry evidenced that **the cause could also have been a non - conformity of production in the zone of the explosion**, which appeared to be the weakest link for the safety of the cylinder (not only for impact damage but also for non conformities of production).

## ITALIAN RESEARCH ABOUT CNG4 FULFILLMENT OF R110 REQUIREMENTS FOR SAFETY AGAINST IMPACT DAMAGE

24 cylinders with glued dome covers (11.4 l and 12.5 l, which is an extension of approval of the 11.4 l) have been tested against impact damage according to point A20 of R110 (Appendix A of Annex 3A) for CGFBM at RINA Consulting – Centro Sviluppo Materiali in Castel Romano – Roma. While all the 12 cylinders of 11.4 l fulfilled what required at paragraph A20, 10 over 12 cylinders of 12.5 l failed during the hydraulic test or the fatigue test performed after the drop test. The cylinders that successfully passed the test with dome covers on, were tested again without dome covers and failed, all but one. In all cases (with and without dome covers) **the failures took place in the same zone of the dome, where the thickness is about one half of that in the cylindrical zone**. The less damaging drop test resulted to be the one with the cylinder in a vertical position.

It should be pointed out that **6 of the 12.5 l cylinders evidenced cracks on one of the dome covers**, as shown in the enclosed photos, while still in the packing case, **before any kind of usage**.

## 1.1 PRELIMINARY INSPECTION

Some cylinders showed the protection dome of the capped side damaged. In particular, the damage consisted in a fracture of the dome (from Figure 1-3 to Figure 1-8).



Figure 1-3: Damaged dome – Cylinder 1



Figure 1-4: Damaged dome – Cylinder 2



Figure 1-5: Damaged dome – Cylinder 5



Figure 1-6: Damaged dome – Cylinder 6



Figure 1-7: Damaged dome – Cylinder 10



Figure 1-8: Damaged dome – Cylinder 11