(ii) Rationale for paragraph 5.1.1.2. baseline initial pressure cycle life

71~~54~~. The requirement specifies that three (3) randomly selected new containers are to be hydraulically pressure cycled to 125 per cent NWP without rupture for 22,000 cycles or until leak occurs. Leak may not occur within a specified number of pressure cycles (number of **cycles** ~~Cycles~~). The specification of number of cycles within the range 5,500 – 11,000 is the responsibility of individual Contracting Parties. That is, the number of pressure cycles in which no leakage may occur, number of cycles, cannot be greater than 11,000, and it could be set by the Contracting Party at a lower number but not lower than 5,500 cycles for 15 years' service life. **For service life of over 15 years but up to 25 years, the number of pressure cycles in which no leakage may occur is 11,000.** The rationale for the numerical values used in this specification follows:

…

[77. In Phase 2, data from various regions (Japan, Germany, United States) supported the proposal to maintain 11,000 hydraulic test pressure cycles and 22,000 "leak before burst" cycles when service life is extended to 25 years for both light-duty and heavy-duty vehicles.

(a) Japan – A database of Japanese legal inspection records as of July 2019 was analysed. This database contained 6,000 records for light-duty vehicles and 21,000 records for heavy-duty vehicles (all fuel types). For this GTR13 purpose, the focus was on the analysis of the records for commercial vehicles, as these vehicles have a higher usage (consistent with the rationale for Phase 1). The maximum lifetime miles travelled for each vehicle were determined and by applying a range per fuelling of 320 km for light-duty vehicles and 400 km for heavy-duty vehicles. Using the above, the number of pressure cycles were calculated and are shown in Table 1 below.

Table 1

Results of Japanese study

Vehicle Type	*Max svc. life*	*Max lifetime miles travelled*	*Lifetime No. of fills ("pressure test cycles")*	*Ref: GTR13 Phase 2 Proposal*
HD Commercial	**15 yrs** **20 yrs** **25 yrs**	**--** **3,500,000 km** **4,000,000 km**	**--** **8,500** **9,800**	**11,000** **11,000** **11,000**
LD Commercial	**15 yrs** **20 yrs** **25 yrs**	**--** **2,100,000 km** **2,400,000 km**	**--** **6,600** **7,400**	**5,500, 7,500 or 11,000** **11,000** **11,000**

While the details of this analysis can be found in the document "GTR13-11-12b TF1 210927 Estimation of VMT TF1-JAMA.pdf" (https://wiki.unece.org/download/attachments/140706658/GTR13-11-12b%20TF1%20%20210927%20Estimation%20of%20VMT%20TF1-JAMA.pdf?api=v2), a brief summary of the methodology is as follows:

(i) Records from periodic legal inspections were collected from about 400,000 on-road vehicles. Heavy-duty vehicles were defined according to Japanese categorization as those with greater than 10 number of seats and a loading capacity of greater than 1,250 kg (assuming the vehicle weight is greater than 3,500 kg).

(ii) The annual VMT (km/year) of each vehicle was calculated by the taking the difference between the records of the current inspection less the previous inspection. An average vehicle mile travelled (VMT) per year (VMT_{year}) was calculated for the vehicles of a certain age. A maximum VMT for each year for each vehicle age was also calculated by adding three times the standard deviation of the VMT_{year} to the average.

$maxVMT_{year}$ = $aveVMT_{year}$ + 3sigma*VMT_{year}

(iii) Finally, a maximum lifetime miles traveled (VMT_{life}) was calculated by summing $maxVMT_{year}$ over the years.

VMT_{life} (km) = $\sum \max VMT_{year}$

Data for commercial vehicles were then separated and analysed since commercial vehicles have higher mileage than personal vehicles.

(iv) The number of lifetime refuellings were calculated by dividing VMT_{life} by the fuelling interval. In Phase 1 of the GTR13, the filling range of 320 km (200 mi.) was assumed for light-duty vehicles. While production HFCVS have a much longer range now, the same value was applied to LDV as to stay consistent with the earlier methodology. For HDVs, a range of 400 km (250 mi.) was determined to be reasonable, as HDVs typically have a larger fuel capacity and therefore range. While it is difficult to get a single data-based fuelling interval value for hydrogen fuel cell HDVs, an assumption of 400 km (250 mi.) can be a sufficiently conservative value.

(v) Finally, a data filtration process was performed to ensure the data set overcame limitations of the vehicle odometer (limited to 5 or 6 digits) and those records deemed as extreme outliers. In this study, the threshold of maximum effective VMT_{year} was defined to the maximum value of the sum of averaged VMT_{year} and 6 times standard deviation within the first 5 years of the vehicle ages. The data shows that the VMT_{year} of a vehicle's early years in service are higher than later years so those that exceeded the maximum effective VMT_{year} were removed. While these maximum effective VMT_{year} can seem a near impossibility in the Japanese market (1,000 km/day and 365,000 km/year), these maximum values were maintained since only a few vehicles were close to this maximum limit and thus their effects negligible.

(b) Germany – The most recent available mileage data from heavy duty semi-trailer trucks were collected from the German Federal Motor Transport Authority (KBA). The data examined are from inspection records from 2014 to 2018 of new semi-trailer trucks after one year of service. The data shows that the average VMT over 20 or 25 years is lower than the average of the first 3 years, which is consistent with industry practice for trucks to be driven the most in the first few years of use. After examining the results from the data, the highest annual VMT from new truck data was used for this

calculation as a very conservative value, rather than the average over the actual service life. The assumptions are as follows:

- **Trucks are driven the same number of miles each year over its service life (115,017 km annually), representing an extreme usage case.**
- **The average European truck driver works 9 hours per day.**
- **The maximum speed on German highways for trucks is 80 km/h.**
- **A fully-fuelled hydrogen truck has a conservative range of 500 km.**

Using the above assumptions, a total range of 720 km per work day is calculated, resulting in approximately 1.5 fuelling cycles a day. Since GTR 13 Phase 1 did not consider partial fuelling so this number was rounded to 2. With the VMT rate expanded over 20 and 25 years, the number of fuelling cycles were estimated as follows:

Table 2

Results of German study

Vehicle Type	*Max svc. life*	*Max lifetime miles travelled*	*Lifetime No/ of fills ("pressure test cycles")*	*Ref: GTR13 Phase 2 Proposal*
HD Commercial Semi-trailer truck	**20 yrs** **25 yrs**	**2,300,340 km** **2,875,425 km**	**6,390** **7,987**	**11,000** **11,000**

(c) United States – The National Renewable Energy Laboratory (NREL) published a study in 2021 which examined the end-of-life conditions of compressed natural gas vehicle fuel tanks. The focus was to investigate the structural integrity of CNG fuel tanks under nominal operating conditions at the end of their service life to help manufacturers to "better identify, understand, and mitigate safety risks and address barriers and opportunities related to CNG storage onboard vehicles." A total of 60 Type II and Type IV CNG fuel tanks from transit buses used for 15 years were obtained from the Los Angeles County Metropolitan Transportation Authority.

These tank designs had been qualified under ANSI CSA NGV2 but the exact service history of each tank could not be obtained. Still, each tank was estimated to have been cycled from 1,000 to 4,400 pounds per square inch gauge (psig), 6 times per week for 15 years, resulting in an estimated total of 4,680 fatigue cycles over its useful life.

Non-destructive evaluation (via modal acoustic emission, MAE) and physical testing (per ANSI CSA NGV2) were performed on these tanks. Twenty of the 60 tanks were burst-tested without being subjected to any additional damage to establish a baseline understanding of the tank's structural integrity at EOL.

An additional 20 tanks were subjected to artificial notch and impact damage followed by fatigue cycling and burst pressure testing to understand structural durability. Another 20 tanks were subjected to hydraulic fatigue cycling followed by a burst test to simulate continued use of the tanks beyond their defined EOL.

The results of the structural integrity testing of the Type III and Type IV CNG fuel tanks at the end of their defined useful life of 15 years suggests the "potential opportunity of continued use of tanks", as all 60 tanks were beyond their defined useful life of 15 years but seemed to be structurally sound based on the results of the initial visual inspection and MAE examination. The tanks maintained the required strength for burst pressurization at the time of manufacture and did not experience any significant strength degradation during their use in service as determined by the burst pressurization test.

Even after additional hydraulic fatigue cycling, the tank integrity based on the burst test "suggest the potential of additional service life for CNG tanks beyond their defined end of life."

78. The current GTR13 requirement of 11,000 initial baseline cycles is already very conservative for a tank with a service life of 15 years. Data from Japanese and German trucks in service show that a 25-year VMT, and consequently the number of refuelling cycles, are much lower than what is already in the GTR 13. Furthermore, the end-of-life testing of CNG tanks designed to similar requirements at the GTR13 showed an acceptable structural integrity even after further damage and cycling. For these reasons, the Phase 2 group agreed that the current GTR13 requirements of 11,000 initial baseline cycles and 22,000 "leak without burst" cycles could be applied to an extended service life of 25 years.]