Initial burst pressure requirement for the hydrogen storage containers

Transmitted by Japan

3rd Meeting of the informal working group on GTR No.13 (Phase 2)

26-28 June 2018 @ Seoul, Korea

The results of 2nd Meeting of the informal working group

<Progress>

At the 2nd meeting, JARI introduced the research results of the minimum initial burst pressure for the hydrogen storage containers.

- *See Appendix of this presentation*

<Suggestion>

It will be possible to reduce the specified initial burst pressure while keeping the requirement of end-of-life burst pressure.

- *200% NWP will be reasonable as the minimum requirement of initial burst pressure for CFRP containers.*

＜Action item for the 3rd meeting＞

The following was requested from the informal working group.

- *Japan to prepare proposed text for minimum burst pressure at next meeting.*
  (from Meeting Notes of 2nd Meeting)

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Reminder of GTR13 Phase1 (original documents)

(i) Rationale for paragraph 5.1.1.1. baseline initial burst pressure (Page 16)

52. .... Paragraph 5.1.1.1. verifies that BP_O is greater than or equal to 225 per cent NWP or 350 per cent NWP (for glass fibre composites), values tentatively selected without data-driven derivation but instead based on historical usage and applied here as placeholders with the expectation that data or analysis will be available for reconsideration of the topic in Phase 2 of the development of this gtr. For example, a 200 per cent minimum initial burst pressure requirement can be supported by the data-driven performance-linked justification that a greater-than 180 per cent NWP end-of-service burst requirement ....

I. Topics for the next phase in developing the gtr for hydrogen-fuelled vehicles

(Page 47-48)

158. Since hydrogen fuelled vehicles and fuel cell technologies are in early stages of development of commercial deployment, it is expected that revisions to these requirements may be suggested by an extended time of on-road experience and technical evaluations. It is further expected that with additional experience or additional time for fuller technical consideration, the requirements presented as optional requirements in this document (LHSS Section G of the preamble) s could be adopted as requirements with appropriate modifications.

Focus topics for Phase 2 are expected to include:

(a) Potential scope revision to address additional vehicle classes;
(b) Potential harmonization of crash test specifications;
(c) Requirements for material compatibility and hydrogen embrittlement;
(d) Requirements for the fuelling receptacle;
(e) Evaluation of performance-based test for long-term stress rupture proposed in Phase 1;
(f) Consideration of research results reported after completion of Phase 1 – specifically research related to electrical safety, hydrogen storage systems, and post-crash safety;
(g) Consideration of 200 per cent NWP or lower as the minimum burst requirement;
(h) Consider Safety guard system for the case of isolation resistance breakdown

Process from GTR13 Phase1 to Phase2

GTR13 Phase1 : The view of SGS members

■ Other than Japan：

① In principle, the initial burst pressure of 200% NWP was agreed.

② End-of-life burst pressure of 180% NWP is enough for safety including the requirement of degradation ratio between the initial and the end-of-life.

■ Japan：

Disagree with the initial burst pressure of 200% NWP, because of no technical evidences.

Technical Comments to Draft November 8, 2010-TF-Berlin (from Japan)

Requestor	Ref. Clause No./ Annex	Text	Proposed change by the Requestor	Comment (justification for change)
JASIC	B.5.1.1.1	**B.5.1.1.1 Baseline Initial Burst Pressure**. All containers tested must have a burst pressure within +10% of BP_O and greater than or equal to **180%** NWP. The midpoint BP_O must be greater than 200% NWP to accommodate + 10% manufacturing variability.	All containers tested must have a burst pressure within +10% of BP_O and greater than or equal to **225%** NWP.	/ BP0 of 200% **+ 10%** is not enough even for CFRP vessel. / The criterion should exceed 2.1NWP. / 2.25NWP, : traditional value (NGV) is appropriate as BP0. / 225% NWP is same as Japanese regulation.

■ The result of the gtr phase 1 : 225% NWP has been defined as placeholder of initial BP and subject to phase 2.

GTR13 Phase2 : Responsibility and proposal

Japan will propose the initial burst pressure requirement of 200% NWP with technical evidences under the responsibility of the GTR13 phase 1.

Contents

Proposal of the modification (Rationale : original)

E. Rationale for paragraph 5. (Performance requirements)

1. Compressed hydrogen storage system test requirements and safety needs

47. .... *(Page 14)*

Comparable stringency with current national regulations for on-road service was assured through examination of the technical basis for requirements of individual contracting parties with respect to on-road safety and subsequent recognition that the relevant expected safety objective is achieved by the gtr requirement. Two examples are noteworthy.

(a) First example: ....

(b) Second example: an overriding requirement for initial burst pressure (> 225 per cent NWP for carbon fibre composite containers and > 350 per cent NWP for glass fibre composite containers) has been used previously in some places for lower pressure CNG containers. The basis for this type of burst pressure requirement for new (unused) containers was examined. A credible quantitative, data-driven basis for historical requirements linked to demands of on-road service was not identified.

....

An additional requirement corresponding to minimum burst pressure of 200 per cent NWP for new, unused containers has been under consideration as a screen for minimum new containers capability with potential to complete the durability test sequence requiring burst pressure above 180 per cent NWP considering < ±10 per cent variability in new containers strength. The historical minimum, 225 per cent NWP has been adopted in this document as a conservative placeholder without a quantitative data-driven basis but instead using previous history in some Contracting Parties with the expectation that additional consideration and data/analyses will be available to support the 225 per cent NWP value or for reconsideration of the minimum new containers burst requirement.

Proposal of the modification (Rationale : modified)

E. Rationale for paragraph 5. (Performance requirements)

1. Compressed hydrogen storage system test requirements and safety needs

47. .... *(Page 14)*

An additional requirement corresponding to minimum burst pressure of 200 per cent NWP for new, unused containers has been under consideration as a screen for minimum new containers capability with potential to complete the durability test sequence requiring burst pressure above 180 per cent NWP considering < ±10 per cent variability in new containers strength. The historical minimum, 225 per cent NWP has been adopted in this document as a conservative placeholder without a quantitative data-driven basis but instead using previous history in some Contracting Parties with the expectation that additional consideration and data/analyses will be available to support the 225 per cent NWP value or for reconsideration of the minimum new containers burst requirement.

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The historical minimum, 225 per cent NWP has been adopted as a placeholder because of no enough quantitative data in the gtr phase 1. In the subsequent discussions of the phase 2, the capability of the container to achieve the end-of-life burst pressure of 180% NWP was verified based on the data provided from Japan, assuming that the variation of initial burst pressure is within BP_O±10%.

As the results, it has been validated that the initial burst pressure shall be specified as 200% NWP.

Proposal of the modification (Rationale : original)

(a) Rationale for paragraph 5.1.1. verification tests for baseline metrics

(i) Rationale for paragraph 5.1.1.1. baseline initial burst pressure *(Page 16)*

52. Paragraph 5.1.1.1. establishes the midpoint initial burst pressure **(**BP_O**)** and verifies that initial burst pressures of systems in the qualification batch are within the range $BP_O \pm 10$ per cent. BP_O is used as a reference point in performance verification (paras. 5.1.2.8. and 5.1.3.5.) and verification of consistency within the qualification batch. Paragraph 5.1.1.1. verifies that BP_O is greater than or equal to 225 per cent NWP or 350 per cent NWP (for glass fibre composites), values tentatively selected without data-driven derivation but instead based on historical usage and applied here as placeholders with the expectation that data or analysis will be available for reconsideration of the topic in Phase 2 of the development of this gtr. For example, a 200 per cent minimum initial burst pressure requirement can be supported by the data-driven performance-linked justification that a greater-than 180 per cent NWP end-of-service burst requirement (linked to capability to survive the maximum fuelling station over-pressurization) combined with a 20 per cent lifetime decline (maximum allowed) from median initial burst strength is equivalent to a requirement for a median initial burst strength of 225 per cent NWP, which corresponds to a minimum burst strength of 200per cent NWP for the maximum allowed 10per cent variability in initial strength. The interval between Phase I and Phase II provides opportunity for development of new data or analysis pertaining to a 225 per cent NWP (or another per cent NWP) minimum prior to resolution of the topic in Phase 2.

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Proposal of the modification (Rationale : modified)

(a) Rationale for paragraph 5.1.1. verification tests for baseline metrics

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In Paragraph 5.1.1.1, the minimum initial burst pressure has been specified as 225% NWP for the carbon fiber containers (as 350% NWP for the glass fiber containers) as a historical placeholder in the gtr phase 1.

In the subsequent discussions of the phase 2, it has been verified that the minimum initial burst pressure shall be changed from 225% NWP to 200% NWP limited to carbon fiber containers ,based on the verification data provided from Japan using the actual containers.

<Verification>

Validate the minimum initial burst pressure with the variation within $BP_O \pm 10\%$ to secure the end-of-life burst pressure 180% NWP and to be within -20% of BP_O. See the estimation of figure x.

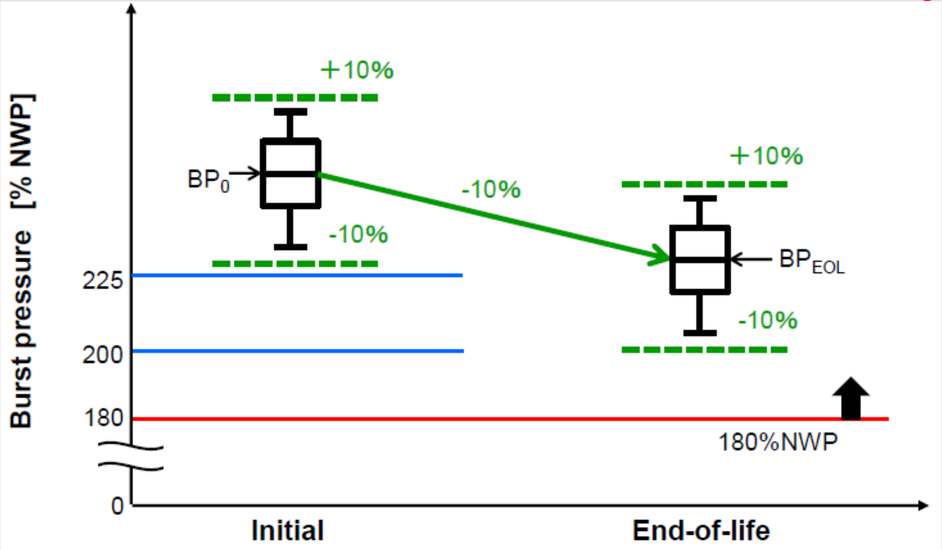


Figure x Relationship between the initial BP and end-of-life BP (Estimation)

Proposal of the modification (Rationale : modified)

(a) Rationale for paragraph 5.1.1. verification tests for baseline metrics

(Continue from previous page)

<Verification methods by the sequential hydraulic tests>
The variation of both the initial burst pressure and the end-of-life burst pressure, and the average of degradation ratio between the initial and the end-of-life have been validated from the test data of the carbon fiber containers (N≥10) selected from one batch which have the capability of the initial burst pressure of 225% NWP.

Proposal of the modification (Rationale : modified)

(a) Rationale for paragraph 5.1.1. verification tests for baseline metrics

(Continue from previous page)

<The results from verification tests>

From figure xx, found out the variation of initial burst pressure of $BP_O \leq \pm 10\%$, and the margin of end-of-life burst pressure to the requirements taking into account the variation and the degradation ratio. As the results like figure xxx, it has been validated that the minimum initial burst pressure of 200% NWP ($BP_O \geq 220\%$ NWP), the end-of-life burst pressure of 180% NWP and to be within -20% of BP_O shall be specified.

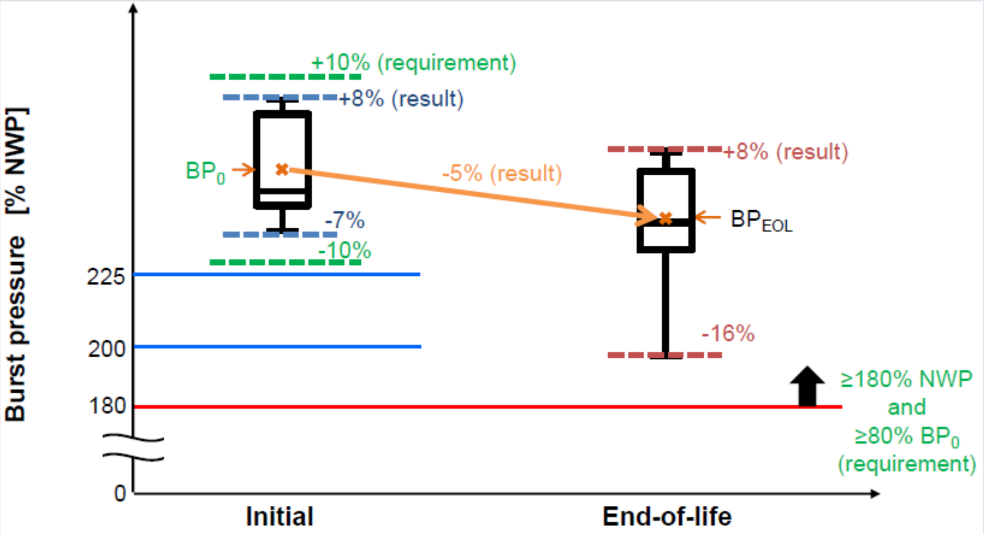


Figure xx The results from the verification test

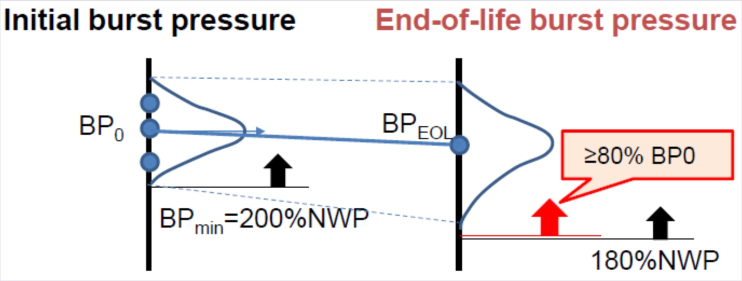


Figure xxx The requirement of design qualification

Proposal of the modification (Rationale : modified)

(a) Rationale for paragraph 5.1.1. verification tests for baseline metrics

(Continue from previous page)

<The major cause of end-of-life burst pressure degradation >
It has been observed that the degradation of end-of-life burst pressure will be occurred by the surface flaw of the containers or the delamination inside carbon fiber by the drop test, from the results of X-ray CT scanning and the numerical simulation.

In addition, the minimum initial burst pressure of 200% NWP for the carbon fiber containers must be enough as the performance based requirement for the gtr, However these verification data are based on the tests using the containers selected from one batch. The production quality related to the variation between the different production batch, etc shall be recognized as the responsibilities of container manufacturers.

Proposal of the modification (Requirements:original)

5.1.1. Verification tests for baseline metrics

5.1.1.1. Baseline initial burst pressure *(Page 57)*

Three (3) new containers randomly selected from the design qualification batch of at least 10 containers, are hydraulically pressurized until burst (para. 6.2.2.1. test procedure). The manufacturer shall supply documentation (measurements and statistical analyses) that establish the midpoint burst pressure of new storage containers, BP_O.

All containers tested shall have a burst pressure within ±10 per cent of BP_O and greater than or equal to a minimum BPmin of 225 per cent NWP.

In addition, containers having glass-fibre composite as a primary constituent to have a minimum burst pressure greater than 350 per cent NWP.

Proposal of the modification (Requirements:modified)

5.1.1. Verification tests for baseline metrics

5.1.1.1. Baseline initial burst pressure *(Page 57)*

Three (3) new containers randomly selected from the design qualification batch of at least 10 containers, are hydraulically pressurized until burst (para. 6.2.2.1. test procedure). The manufacturer shall supply documentation (measurements and statistical analyses) that establish the midpoint burst pressure of new storage containers, BP_O.

All containers tested shall have a burst pressure within ±10 per cent of BP_O and greater than or equal to a minimum BPmin of 200 per cent NWP.

In addition, containers having glass-fibre composite as a primary constituent to have a minimum burst pressure greater than 350 per cent NWP.

Contents

1. GTR13 Phase1 process and Phase2 discussion

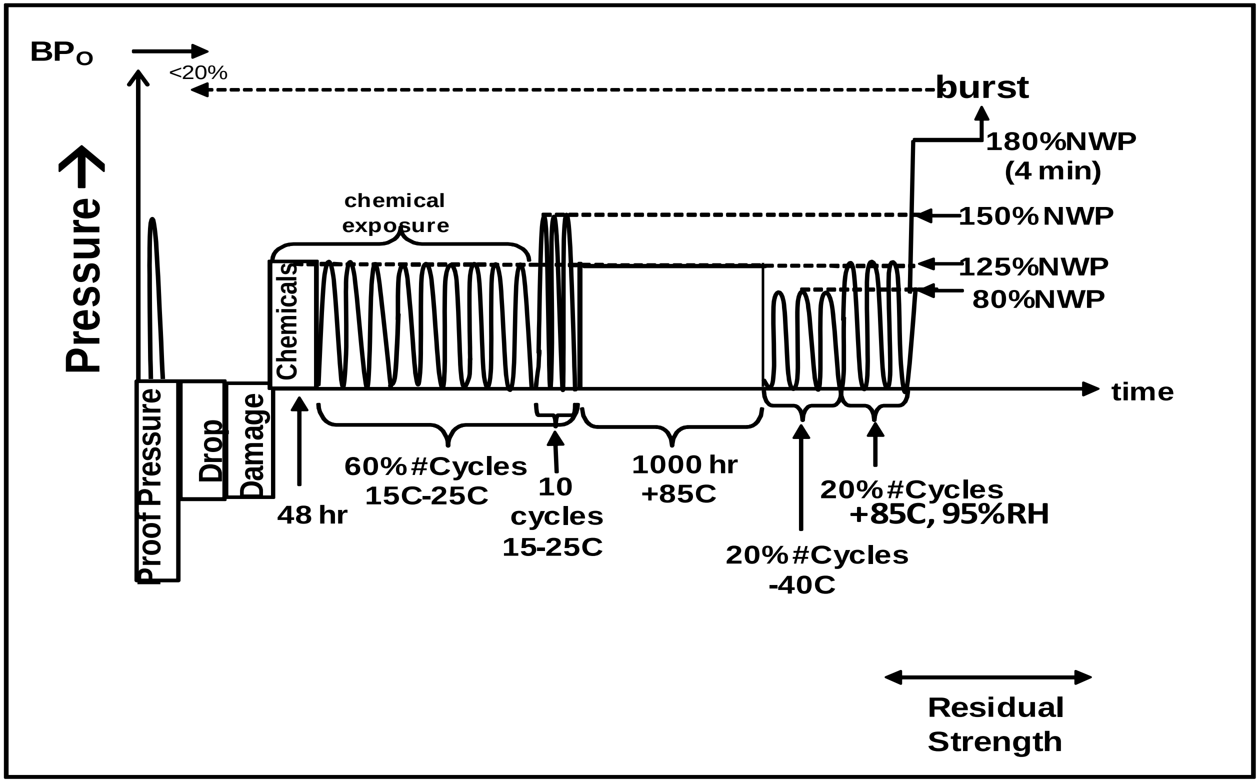
2. Proposal of the modification for the text from the current GTR13 document

APPENDIX : Background data

Consideration of appropriate initial burst pressure

- Goal : Decision of the appropriate initial burst pressure which will correlate with 180% NWP of EOL burst pressure.
- Study : Determine the appropriate initial burst pressure from verification tests which be able to find out the factors of both variation and degradation using actual cylinders.

Target tests : Sequential hydraulic tests of GTR13



Verification test planed by JARI

※ JARI : Japan Automobile Research Institute

- Methods : Data acquisition for the variation of both initial burst pressure and EOL one and for degradation value.
- Sample cylinders
  - ✓ CFRP Type 4 cylinders for 70 MPa (from one production batch) （Application criteria: EC79 (not GTR13))
  - ✓ For Initial BP : 10 cylinders each from 2 different suppliers
  - ✓ For EOL BP : 10 cylinders each from 2 different suppliers
- Additional study
  - ✓ Factor analysis by numerical simulation
  - ✓ Damage analysis by nondestructive inspection

Initial burst pressure

Evaluation for each production

- ✓ **Variation comparison**
- ✓ **Degradation ratio calculation**

End of life burst pressure

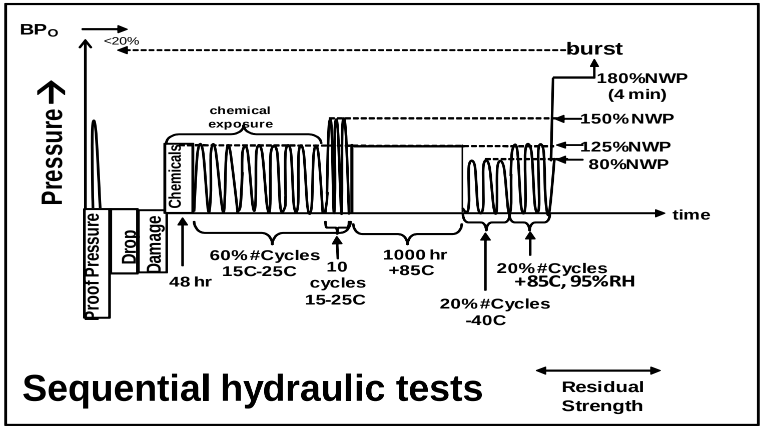
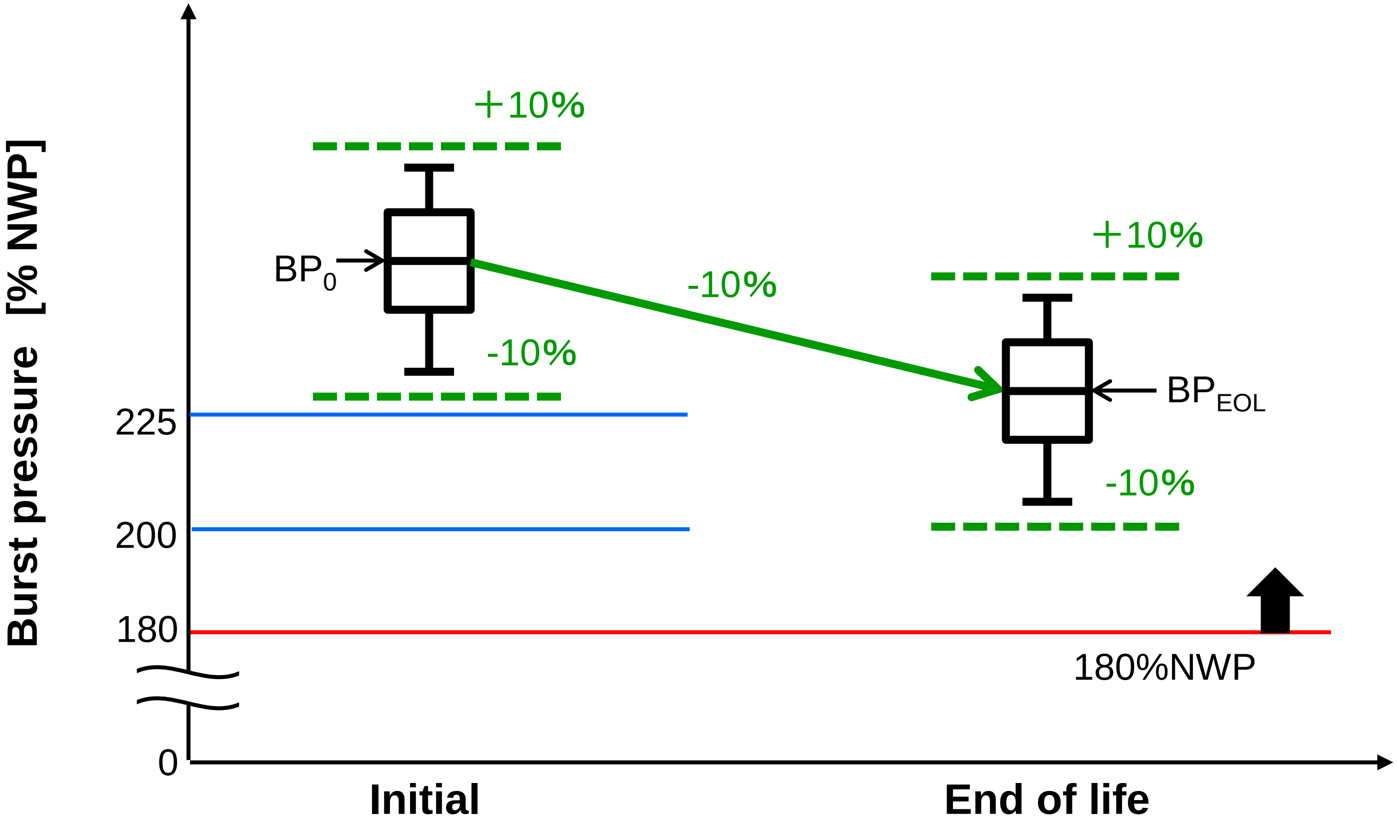


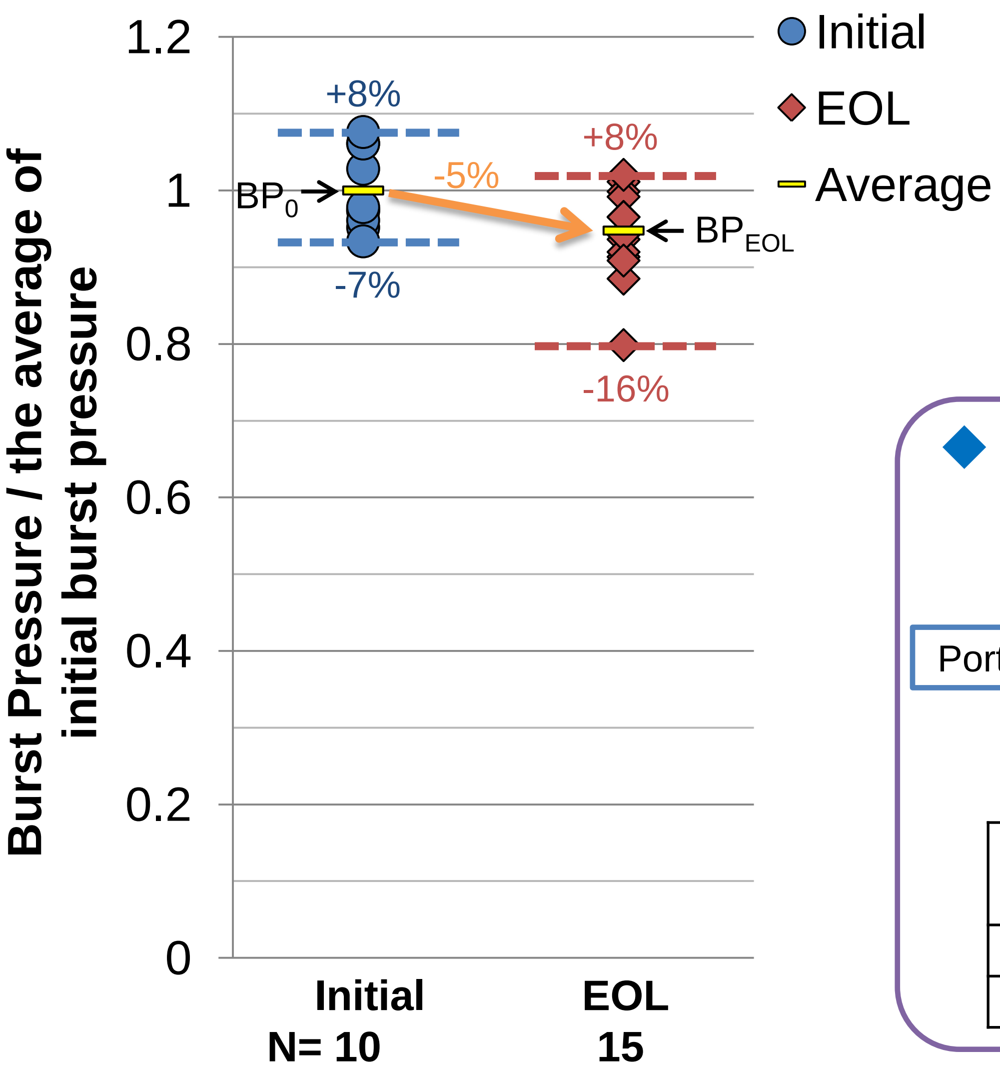
Image of the results *(Estimation)*

- Decision of the appropriate initial burst pressure which will correlate with 180% NWP of EOL burst pressure.



Relationship between the initial BP an EOL BP *(Estimation)*

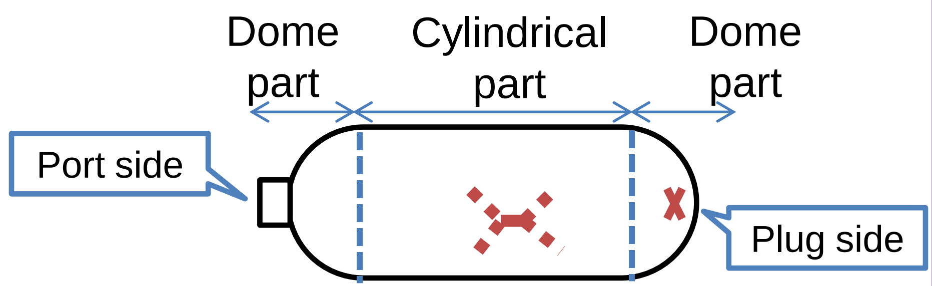
The results of the verification test (one of 2 suppliers)



◆ Test condition

Initial	Initial Burst Pressure
EOL	End of Life Burst Pressure by Sequential hydraulic tests of GTR13

◆ Starting point of rupture

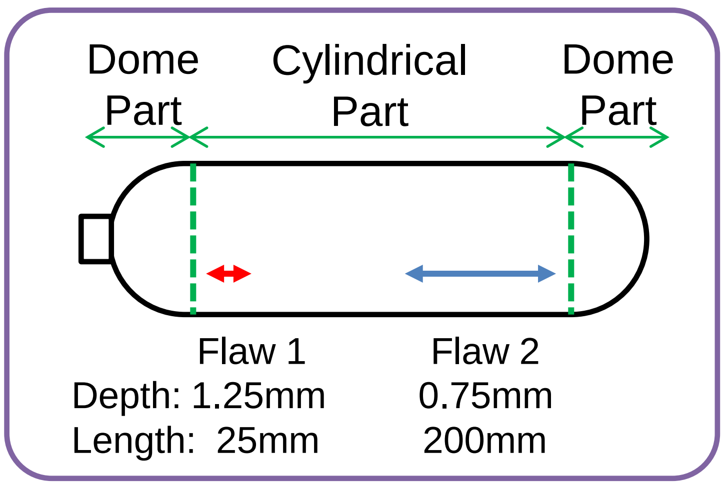


	Cylindrical part	Dome part (Plug side)
Initial	**10**	**0**
EOL	**7**	**8**

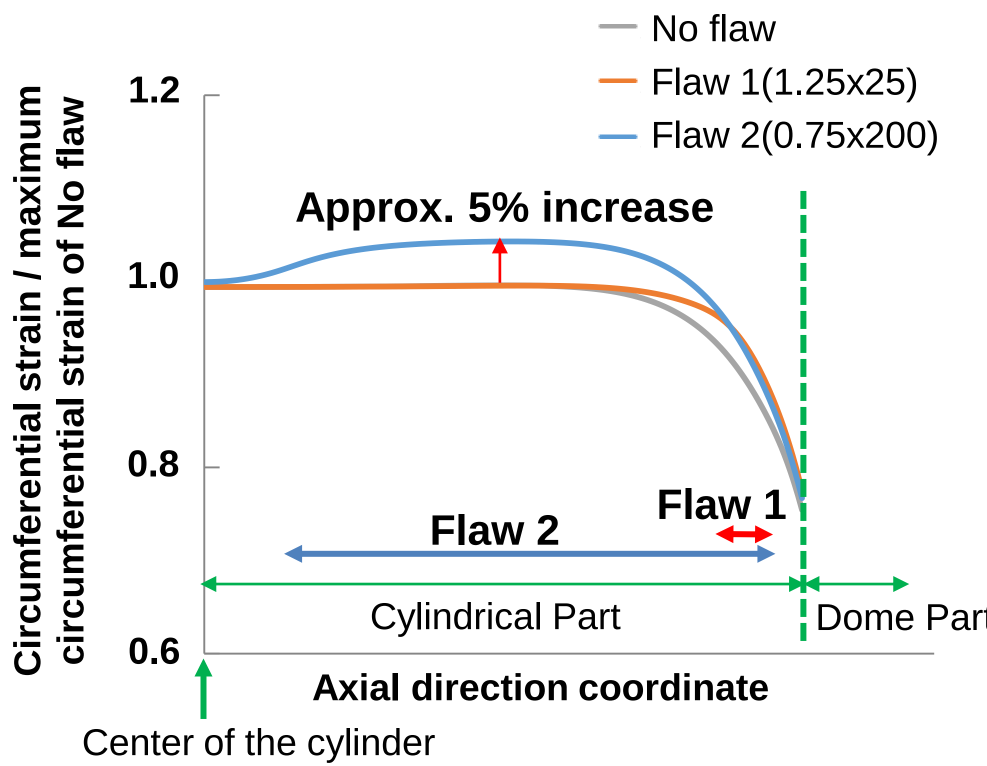
- The average of burst pressure : approx.5% decrease from initial to EOL
- The variation of burst pressure : expanded downward from approx.7% to 16%
- The starting point of rupture in EOL : half for cylindrical and half for dome

The investigation of the burst pressure degradation

- In the case of the rupture from **the cylindrical part**
  - The influence investigation of the surface flaw by finite element analysis



Surface flaw generation

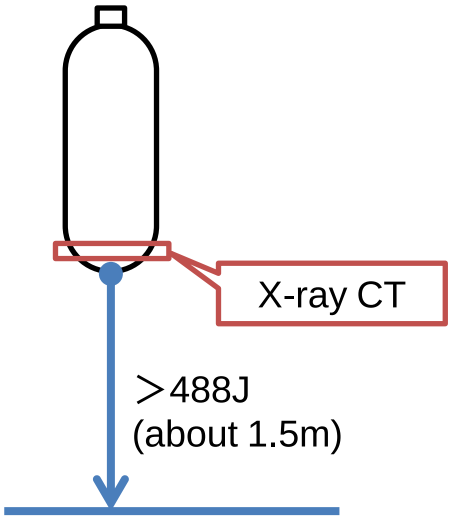


Circumferential strain distribution of CFRP with/without flaw

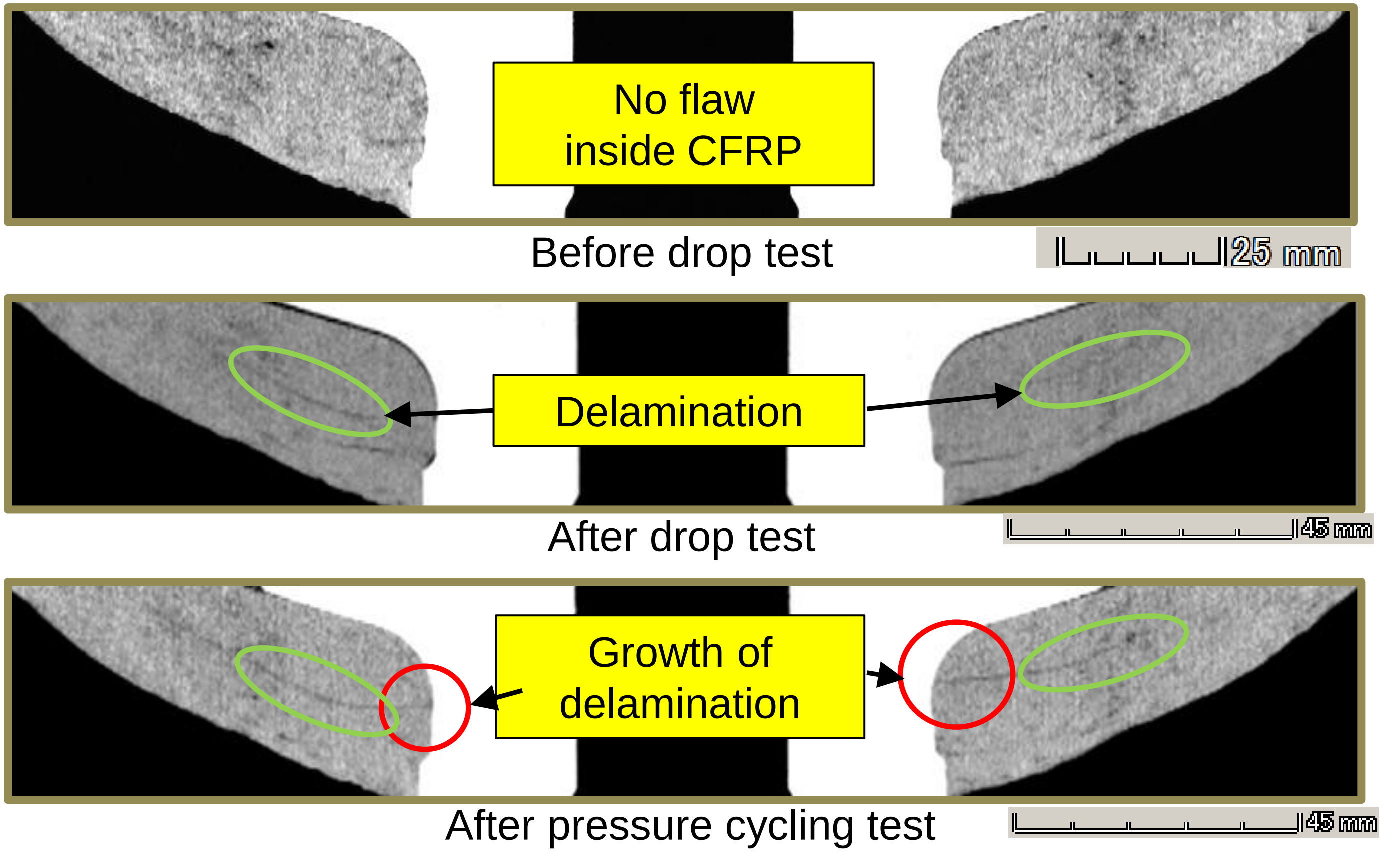
- The circumferential strain of CFRP in cylindrical part increased approx.5% due to surface flaw.
  - **The surface flaw is considered to be the factor of the decrease in burst pressure as the starting point of rupture in cylindrical part.**

The investigation of the burst pressure degradation

- In the case of the rupture from **the dome part**
  - ➢ The influence investigation of the drop flaw by X-ray CT scanning



Drop test
(Vertical Position)

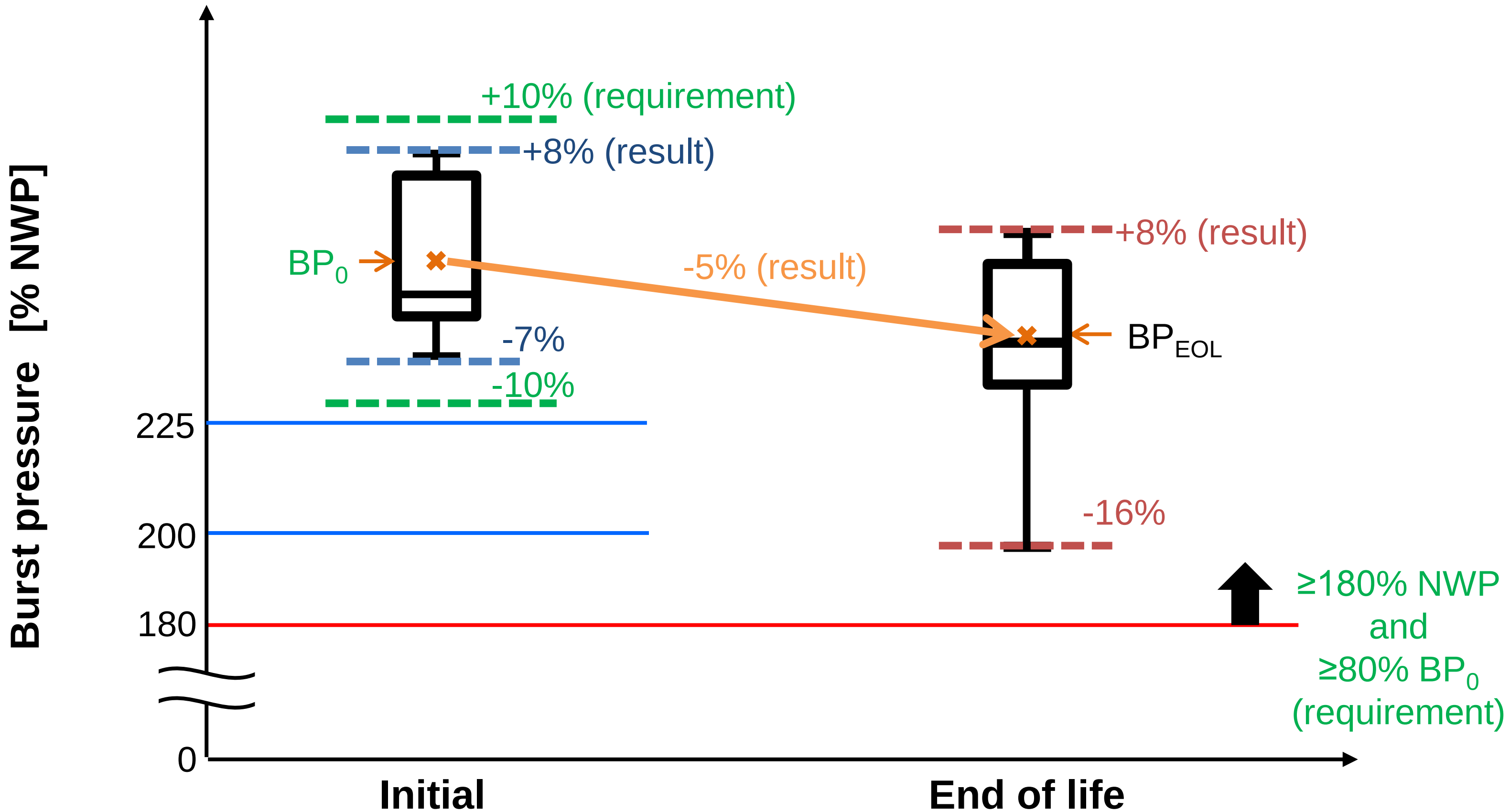


- Damage progress in CFRP by the drop test.
  No flaw (initial)➡Delamination (after drop)➡Growth of delamination (after cycling)
  - ➢ **The delamination inside CFRP by the drop test is considered to be the factor of the decrease in burst pressure as the starting point of rupture in dome part.**

The study from the results of the verification test

- Initial burst pressure : +8% / -7% of BP_0 ➡ meet the requirement (±10% of BP_0)
- EOL burst pressure : +8% / -16% of BP_{EOL} ➡ meet the requirement (≥180% NWP and ≥80% BP_0)

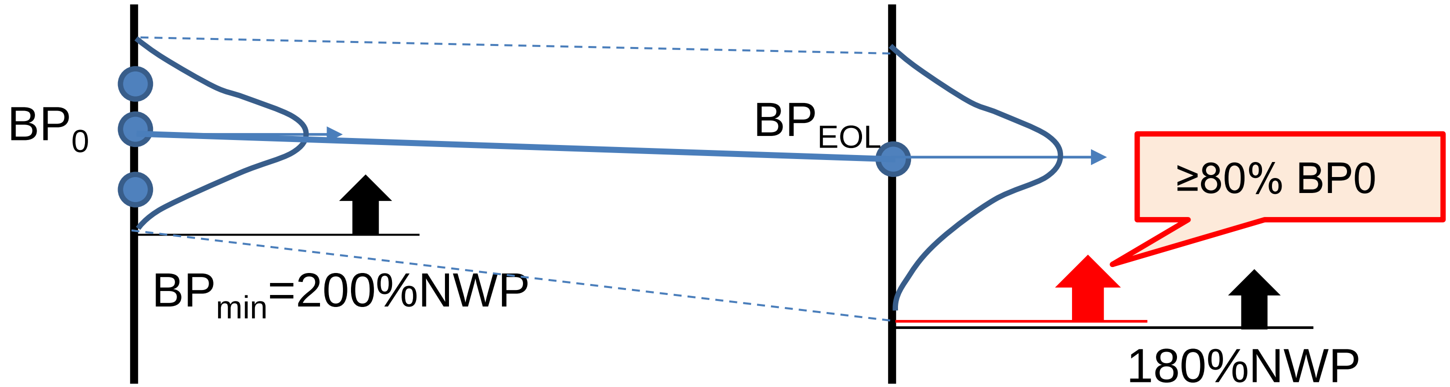
> **200% NWP as the initial burst pressure (BP_{min}) can be correlated with EOL burst pressure (for CFRP cylinders)**



The possibility of the design qualification test modification

- Change from 225% NWP to 200% NWP as the minimum initial burst pressure BP_{min}
- No change of the design qualification test without the requirement of BP_{min} (above)

Initial burst pressure **End of life burst pressure**



5.1.1.1. Baseline initial burst pressure
Three (3) new containers randomly selected from the design qualification batch of at least 10 containers, are hydraulically pressurized until burst. All containers tested shall have a burst pressure within **±10 per cent of BP_O** and greater than or equal to **a minimum BPmin of 200 ~~225~~ per cent NWP**.

5.1.2. Verification tests for performance durability (Hydraulic sequential tests)
..., then **only one (1) container** is tested...
The storage container is pressurized to **180 per cent NWP and held 4 minutes without burst**.
The burst pressure is **at least 80 per cent of the baseline initial burst pressure (BP_O)**.

Thank you for your attention.