# EU-Commission
# JRC Contribution to EVE IWG:
## *In-vehicle battery durability e-HDVs breakout C-rate*

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# e-HDVs tests: C-rate discussion

## Open points to be discussed

- C-rate, constant or variable, depending on the test method
- C-rate calculation method
- Accuracy, tolerance, boundary conditions, deviation of the UBE measured across the testing methods
- End of discharge criterion, safety provision for on-road tests, requirements
- C-rate calculation based on the nominal battery energy
- C-rate charging , RTE calculation, …
- …

# e-HDVs tests: C-rate discussion table to be filled in

| Type of vehicle | Test procedure | C-rate constant | | | C-rate variable | Calculation method | | | | End of discharge criterion, safety provision, etc. | Charging C-rate | | Deviation across the testing methods | C-rate based on nominal battery energy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Single C-rate (different for categories) | Multiple C-rate (different for categories) | C-rate equal or less than C/5 and with the highest normal charging power available [≤150kW] | C-rate profile representing the WHVC | WHVC (median, weighted average) | Different mission profiles or driving cycle (median, weighted average) | Characteristic speed for vehicle category and mission profile | C-rate in the range of [C/5,C/3] (from OEMs decl.) | | Equal to discharge C-rate | Normal or ultra-fast [>150kW] | | |
| HDV without bidirectional charging | Method 1a | | | | | | | | | safety provision + on-board discharge | | | | |
| | Method 1b | | | | | | | | | | | | | |
| HDV with bidirectional charging | Method 2 | | | | | | | | | Cut-off voltage | | | | |

# e-HDVs tests: C-rate discussion

- Three testing methods: Method 1a, Method 1b, Method 2
  - **C-rate to be defined**
- Constant C-rate vs variable C-rate ⇨ constant C-rate seems favourable for simplicity of the test procedure to be applied;
- Different proposals on the C-rate calculation methods:

Method 1a

- - a C-rate representative of a range of driving power values from different mission profiles or driving cycle
- - with a constant C-rate defined as the median C-rate of the cumulative frequency of the C-rate profile equivalent to WHVC
- - a constant C-rate corresponding to the most representative operational driving speed for vehicle category and mission profile
- - a C-rate in the range of [C/5,C/3]
- - multiple C-rate calculation based on driving cycle

Method 1b

- - Variable C-rate but limits could be set

Method 2

- - reproduce C-rate profile representing the WHVC with constant C-rate phase in the middle and in the end of discharge pattern to avoid the unstable SOC at the end of measurement
- - a constant C-rate equal or less than C/5 or C/2.3 ( 0.2C or 0.43C) and with the highest normal charging power available [≤150kW] as defined in paragraph 6.1.1 of this GTR

# e-HDVs tests: C-rate discussion

- Three testing methods: Method 1a, Method 1b, Method 2
  - **Additional questions**
- Same C-rate calculation procedure  for all the test methods (1a,1b,2) ?
- Deviation of the UBE measured across methods? Accuracy? Equivalence of testing method 1a, 1b, 2 ?
- End of discharge criterion ?
  - The end of discharge criterion is reached when the cut-off voltage as defined by the manufacturer is reached.
  - Test track and on-road test: safety provision + on-board discharge? Accuracy? Deviation in respect to Method 2 needed?
- C-rate calculation based on nominal battery capacity. C-rate = power/nominal battery energy
- RTE calculation for all methods: charge C-rate equal to discharge C-rate
  - Method 1a: ? Or to long charging time so different provision?
  - Method 1b: ? Or to long charging time so different provision?
  - Method 2: a C-rate equal or less than C/5 or C/2.3 ( 0.2C or 0.43C)  and with the highest normal charging power available [≤150kW] as defined in paragraph 6.1.1 of this GTR

# e-HDVs tests: C-rate discussion

- C-rate calculation methods

# e-HDVs tests: C-rate calculation based on driving cycle

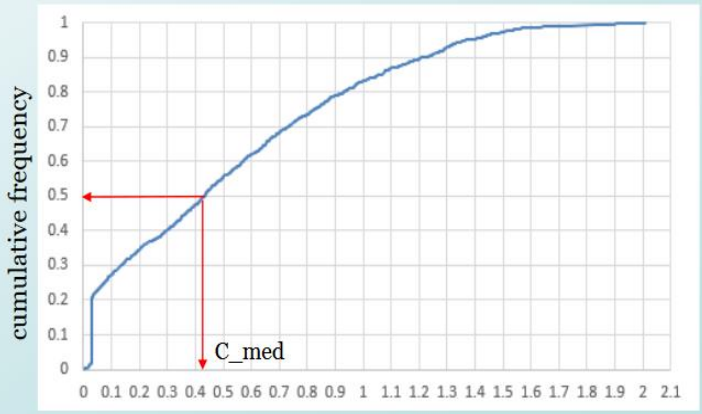
EVE-65-11e: The median C-rate of the cumulative frequency of C-rate equivalent to WHVC is defined as Constant C-rate.

METHOD FOR DETERMINATION OF C-RATE FOR BIDI (METHOD 2)

HOW TO DETERMINE CONSTANT C-RATE

FIND THE CUMULATIVE FREQUENCY OF EACH C-RATE FROM WHVC AND DEFINE THE MEDIAN C-RATE AS CONSTANT C-RATE.

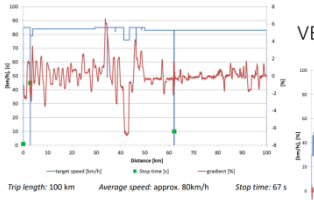
1. PREFERABLY SELECT MAXIMUM CED CONFIGURATION @ WHVC WITHIN PART A FAMILY.
2. SYSTEM POWER (P) NEEDS TO BE DEFINED FOR WHVC
3. AUTOMATICALLY OBTAIN THE CUMULATIVE FREQUENCY AGAINST C-RATE.
4. SELECT MEDIAN C-RATE (THIS IS CONSTANT C-RATE).



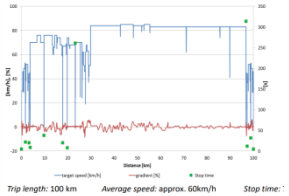

## Questions:

- WHVC cycle ?
- Different cycles ?
- Different driving cycles/mission profiles for regions but same method of calculation?
- Bin size for the sampling?

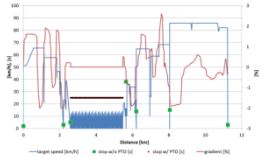
VECTO mission profiles: Long haul



VECTO mission profiles: Regional delivery



VECTO mission profiles: Municipal utility





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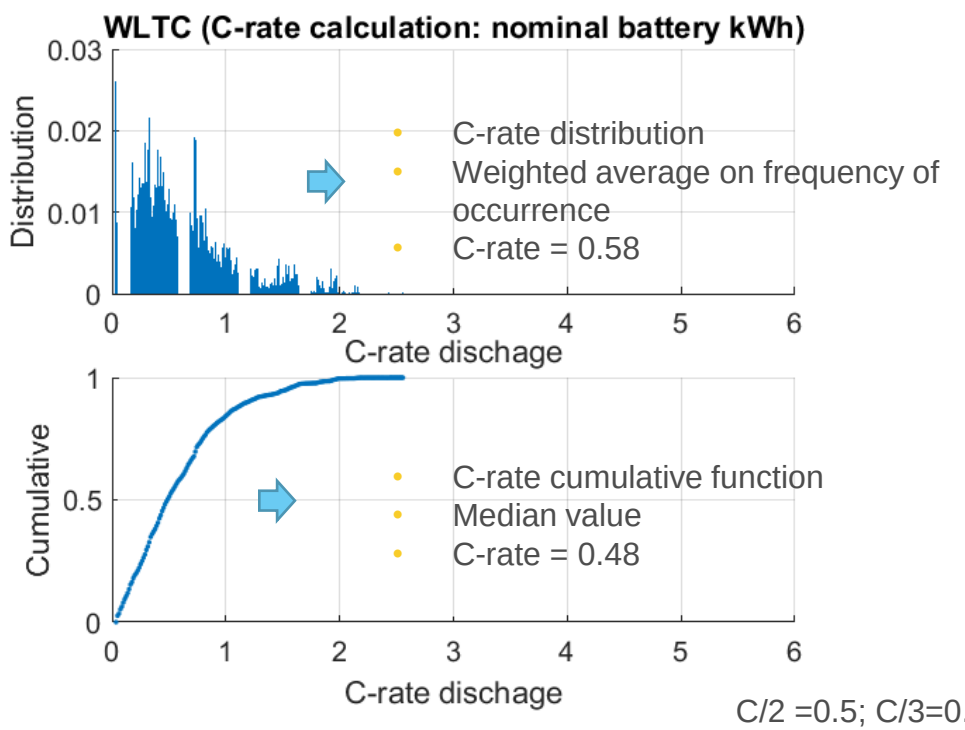
# e-HDVs tests: C-rate calculation based on driving cycle

JRC example of calculation of the C-rate based on a WLTP CCT

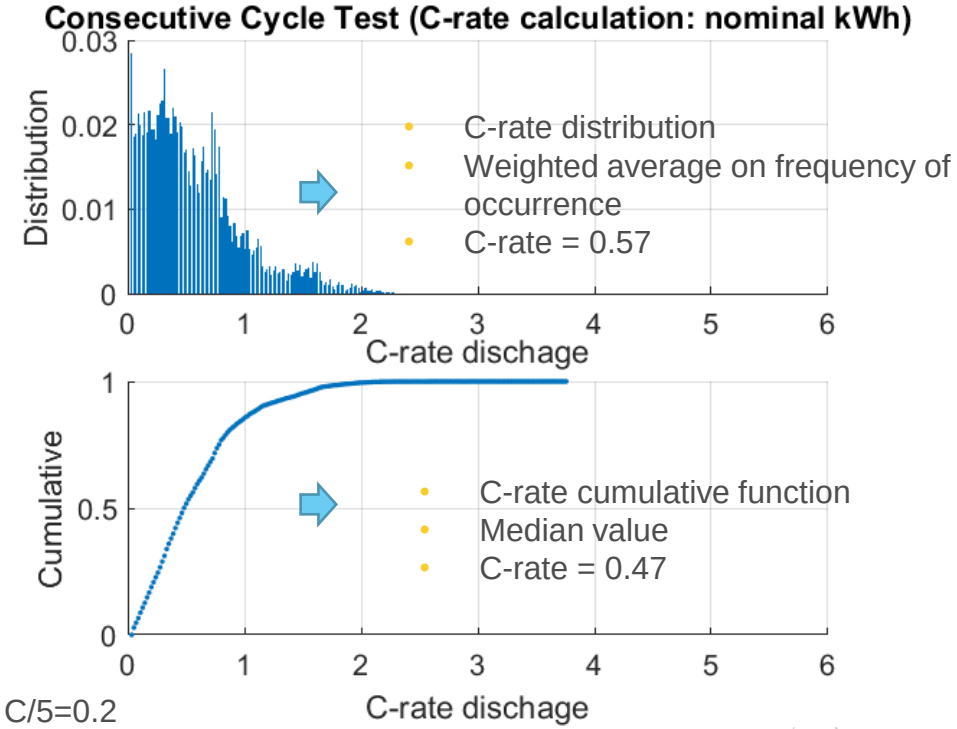
C-rate calculation based on **nominal battery energy**

C-rate distribution, **weighted average and median of the cumulative function**

1 WLTC




All WLTC




C/2 =0.5; C/3=0.33; C/4=0.25; C/5=0.2



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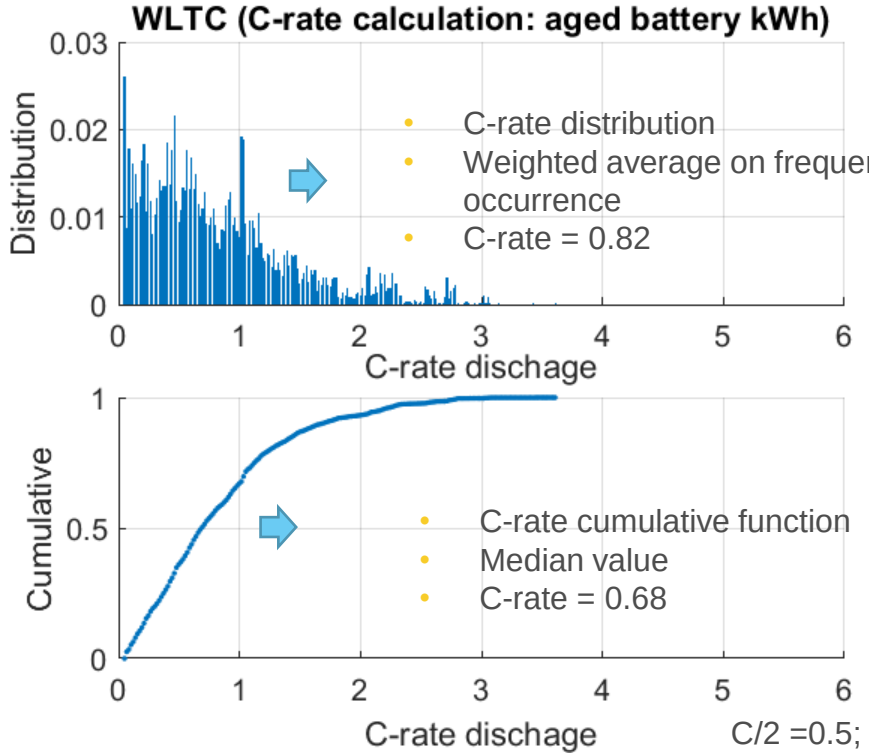
# e-HDVs tests: C-rate calculation based on driving cycle

JRC example of calculation of the C-rate based on a WLTP CCT

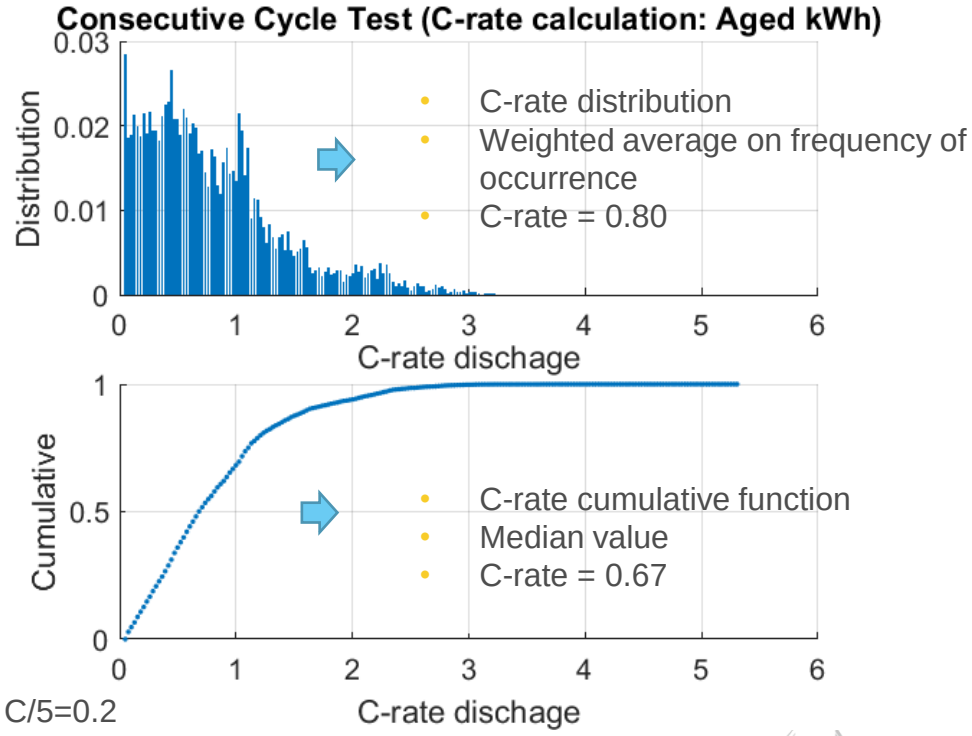
C-rate calculation based on **aged battery energy**

C-rate distribution, **weighted average and median of the cumulative function**

1 WLTC




All WLTC




C/2 =0.5; C/3=0.33; C/4=0.25; C/5=0.2



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# e-HDVs tests: C-rate calculation based on characteristic speed

| Heavy Duty Vehicles Speed Limits [km/h] | | | | |
|---|---|---|---|---|
| **Trucks** | **Urban roads** | **Secondary suburban roads** | **Main suburban roads** | **Highways** |
| Up to 3,5 t | 50 | 90 | 110 | 130 |
| 3,5 – 12 t | 50 | 80 | 80 | 100 |
| Over 12 t | 50 | 70 | 70 | 80 |
| Construction | 40 | 60 | | |
| Construction at full load | 50 | 70 | 70 | 80 |
| Transport of explosives | 30 | 50 | | |
| Trucks with a trailer Articulated lorries. | 50 | 70 | 70 | 80 |

* https://portalepatente.it/limiti-velocita-autocarri/

Questions:

- Which speed?
- Different categories, mission profiles speed?
- Different speeds for regions but same method of calculation?
- Only speed?

Vehicle speed → power calculation for given vehicles →C-rate

$$C-rate = \frac{Power\ [kW]}{Battery\ nominal\ energy\ [kWh]}$$

# e-HDVs tests: C-rate in the range of [C/5,C/3]

- with a C-rate in the range of [C/5,C/3] [according to manufacturer's recommendation  with the approval of the responsible authority and with appropriate technical justification]

# e-HDVs tests: multiple C-rate calculation based on driving cycle

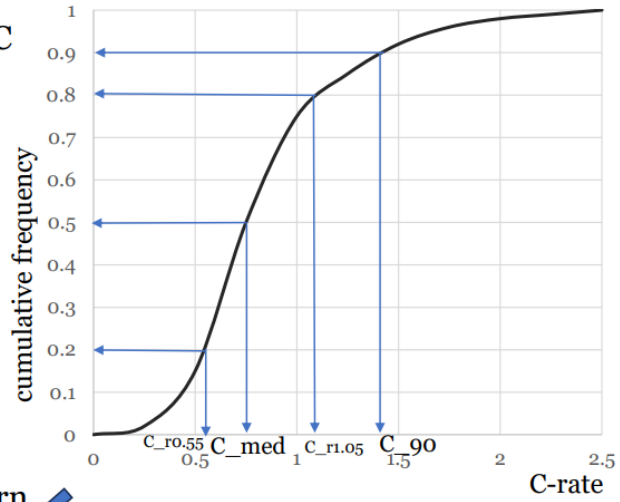
EVE-65-10

without bidi-charger

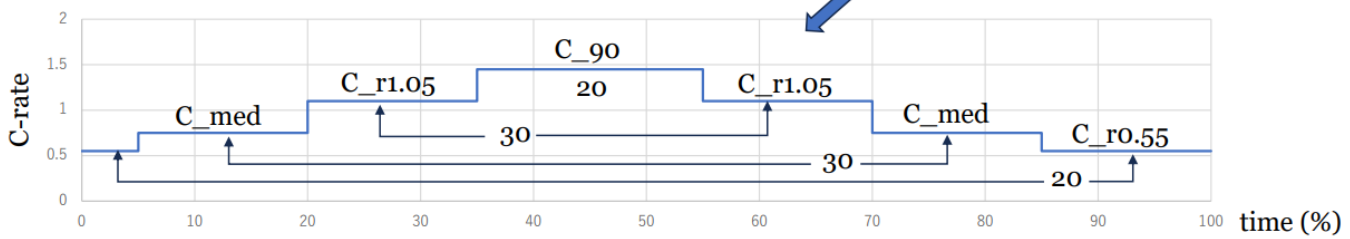
## multiple C-rates with proportional duration under WHVC condition

1. preferably select maximum CED* configuration @ WHVC within Part B family
2. system power (P) needs to be defined for WHVC
3. automatically obtain the cumulative frequency against C-rate (see right figure)
4. C_90 and C_med shall be selected
5. additional C-rates may be selected (no limitation)
6. higher C-rate covers lower C-rate duration
7. OK to split each C-rate duration

CED* : Cycle Energy Demand




sample : discharge pattern



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# e-HDVs tests: what about method 1b ?

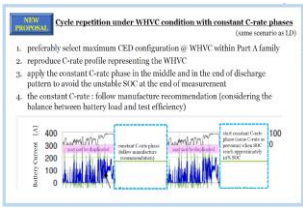
*In the discussed table*:

- Variable but limits could be set
- Tolerances of the average speed to be discussed

- Setting tolerance on the average speed of the test?
- On-road driving might help to verify/suggest C-rate and speed tolerance setting?

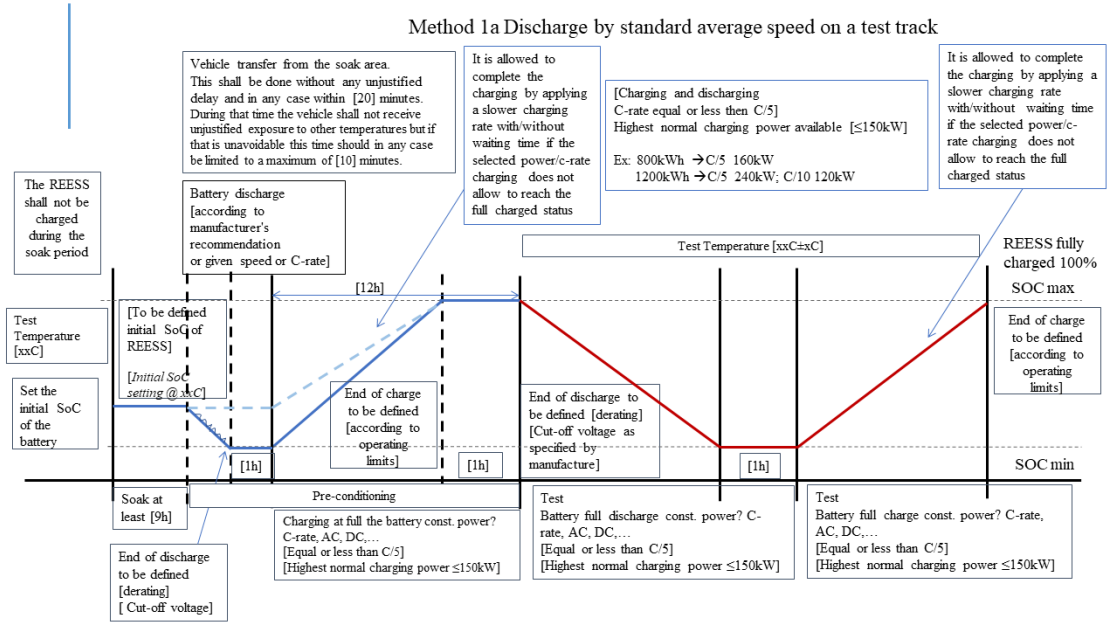
# e-HDVs tests: what about method 2 ?

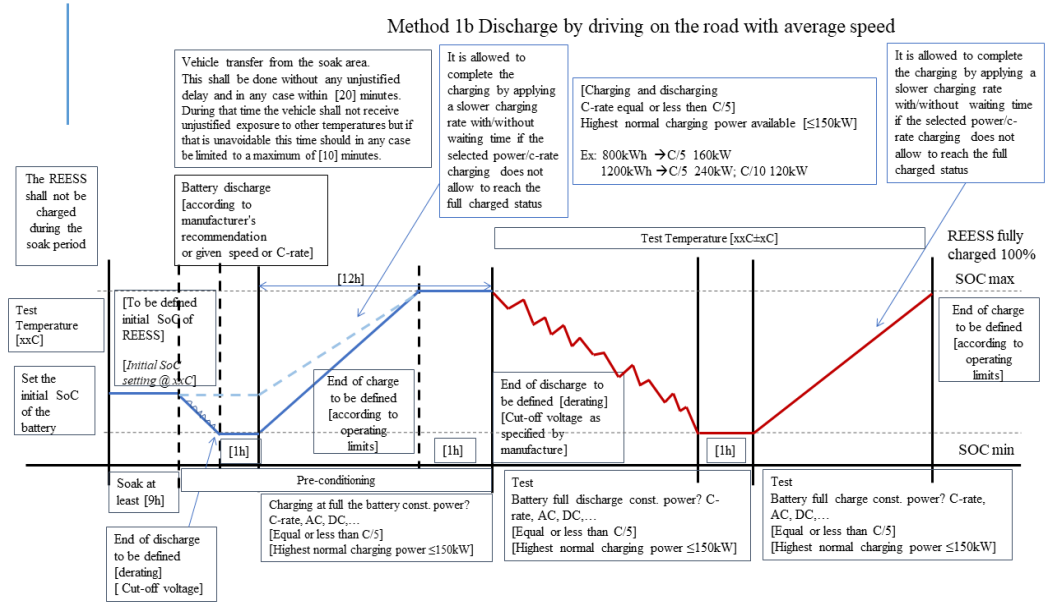
- Method 2: constant C-rate seems to be the favourable option
- a C-rate equal or less than C/5 or C/2.3 ( 0.2C or 0.43C)  and with the highest normal charging power available [≤150kW] as defined in paragraph 6.1.1 of this GTR
- Same C-rate as Method 1a?
- a C-rate profile representing the WHVC with constant C-rate phase in the middle and in the end of discharge  pattern to avoid the unstable SOC at the end of measurement




- Deviation of the UBE measured across methods? Accuracy? Equivalence of testing method 1a, 1b, 2 ?

# e-HDVs tests: additional point to be considered is the need of setting a soak, pre-conditioning steps etc.




- To be discussed as next step



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# e-HDVs tests: Test procedures table

| Methods for Checking Battery Durability Monitor for HDV | | | |
|---|---|---|---|
| | **HDV with no bidirectional charging** | | **HDV with bidirectional charging** |
| | **Method 1a** | **Method 1b** | **Method 2** |
| **Description** | Discharge by standard average speed with tolerances on test track<br><br>And charge | Discharge by driving on the road with average speed with higher tolerances<br><br>And charge | Virtual Round Trip Efficiency (VRTE) test<br><br>Charging and discharging in a column |
| **Repeatable** | Yes | Partly, if tolerances are set | Yes |
| **C-rate** | **Constant (different for categories)** | **Variable but limits could be set** | **Constant** |
| **RTE** | YES | YES | YES |
| **UBE** | Yes | Yes, but it depends on the driving | Yes |
| **UBC** | Yes | Yes | Yes |
| **comment** | **tolerances of the average speed to be discussed**<br>**Proposal from Japan on different constant speeds in the test** | **tolerances of the average speed to be discussed** | |
| **C-rate calculation method** | | | |
| **Reference section (charge/discharge)** | Comment from OICA test data:<br>flexible due to measurement results charge/discharge<br>(RTE to be discussed<br>RTE with tolerance in addition) | Comment from OICA test data:<br>due to measurement results charge event as reference<br>(RTE to be discussed<br>RTE with tolerance in addition) | Comment from OICA:<br>reference charge or discharge<br><br>and RTE with tolerance in addition |
| **Alternative Method** | HDV Dyno testing with similar driving characteristics | | |
| **Feasibility** | voltage sensor, voltage measurement, under discussion | | |
| **discharge vs charge UBE vs UBC** | UBE in discharging<br>discharge and charge RTE | | |

# Thank you

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