1. Aim and overview:

This protocol has been developed as an alternative to the international water boiling test (1) used to compare energetic performances of cookstoves. The adapted water boiling test has been designed by GERES to ease its implementation in developing countries, reduce errors, and take into account local methods of cooking. The WBT is regularly revised and modified, making implementation by local technicians difficult and complex. The AWBT is easier, more precise (less error sources) and accessible to local development agencies and organizations working on the evaluation and dissemination of cookstoves. In addition to the AWBT, a preliminary study should be performed in the country of testing to determine local cooking habits (cf. Protocol for determination of local cooking habits)

The main characteristics of the AWBT are:

- both cookstoves are tested at the same time (when possible);
- the same quantity of fuel is used in both cookstoves;
- there is no “hot starting” step;
- the fuel is not weighed during the test;
- approximate local cooking conditions (type of pot, quantity of water, type of fuel, geographic and climate conditions).

This protocol is used for laboratory testing, not to define an energetic yield but to provide a comparison of fuel usage between two cookstoves. It has been validated in different countries and has provided a good approximation of field testing. Of course, the final test to characterize a cookstove is the field test, the only test that provides the real fuel savings, and the test that should be used for carbon reduction calculations.

2. Conditions and limitations:

Tests are performed with an uncovered pot. Even though people may use a cover during cooking (depending on local cooking habits), this is a potential source of error, because there is no control of the pressure inside the pot.

Testing should be done in laboratory; if a laboratory is not available, the location must fulfill the following conditions:

- windless, to avoid air flow fluctuations;
- out of direct sunlight, to maintain a constant room temperature;
- quiet, to avoid external disturbances to the testers;
- well ventilated, to avoid smoke inhalation (the use of an extraction hood is recommended).

3. Equipment and materials:

- ***Measuring tools***

    - Stopwatch
    - Scale (capacity of 6kg with a precision of ±1g)

- Digital thermometer (with a precision of ±0.1°C) with 2 thermocouples (Type K or T)
- Oven, to control fuel humidity, or humidity meter

- ***Utensils and fuel***

  - Pots, preferably the ones most commonly used by the local cookstove end users
  - Metal bars or sticks of wood to fix the thermocouple in the middle of the pot, around 2cm from the bottom.
  - The type of fuel used by the cookstove's target population. The fuel must have a homogeneous size and shape. The moisture content should also be homogenous, with an ideal moisture level of 15% (general hygroscopic equilibrium) for wood and 5% for charcoal.

- ***Starter***

  - The same type and quantity of starter used by the target population.

- ***Water***

  - The quantity of water should be similar to local cooking habits, usually between 3 and 5 liters, or enough water to fill 2/3 of the cooking pot used for the test. If the temperature of the water is not constant throughout the day, a water tank can be used to limit the temperature variation.

- ***Data sheet***

  - For each test, the operator fills in a data sheet, which will be used to complete the data entry and analysis afterwards.

4. Experiment steps:

Both stoves are tested simultaneously in the same conditions. A preliminary study should be conducted to determine the following parameters:

- the types and quantities of fuel and starter (ideally, the minimal quantity required to facilitate quick and reproducible fuel ignition);
- the type of pots;
- the quantity of water.

Preliminary tests must be done to get used to cookstove operation, especially for wood-burning cookstoves (identifying the initial quantity of fuel required, how to reload the fuel, etc.) and to determine the local boiling point (depending on the altitude and local water characteristics). It is very important to always operate the stove the same way to reduce external errors. To validate the AWBT, we will

introduce a CoV (Coefficient of Variation), which should be under 10% to confirm appropriate operational conditions.

- Measure the ambient room and water temperatures.
- Weigh the empty pots and the quantities of fuel, starter and water fixed for the local context.
- Make sure the stoves are at ambient temperature and clean (no ash or soot).
- Put the fuel in the stoves and light the starters, using the same procedure with both stoves to avoid errors (arrangement of fuel, location of the starter…). Allow time (usually a few minutes) for the fuel to begin to burn easily (usually when the starter has been exhausted).
- Put the pots on the stoves and start the stopwatch. Install the thermocouples and start to record the water temperatures every 3 min until they reach a boiling point. The boiling point is reached when the temperature is constant for 10 consecutive seconds.
- Record the Time to Boil (TTB), which is the time from the start of the stopwatch until the end of the 10 seconds which indicate the boiling point has been reached.
- Keep the water boiling within a maximum range of 3°C below the boiling point. If the water temperature drops more than 5°C below the boiling point during the test, that test's results are rejected.
- When the fuel is exhausted to the point that the temperature of the water drops 3°C below the boiling point, record the Total Time of Test (TTT).
- Remove the pots from the cookstoves and immediately weigh the remaining water and eventually the remaining fuel.

The remaining fuel in the cookstoves can be weighed for comparison, but this measurement is not used for the AWBT calculation. The cookstove performances are evaluated by comparing the useful energy provided to the water, which integrates combustion efficiency and thermal transfer. An efficient cookstove should be able to consume all the loaded fuel while maintaining a sufficient simmering phase.

If in the local context, one of the purposes of the cookstove is to provide fuel after the cooking period is completed (for example, through conversion of biomass to char), the fuel remaining after the AWBT is completed can be removed from the cookstove, weighed and incorporated into the cookstove analysis.

5. Analysis of data:

A minimum of three comparative tests should be performed to compare the two stoves in the same conditions. Four parameters will be used to evaluate the stoves: the TTB (time to boil), the TTT (total time of test), the useful energy and then the potential fuel use differences.

- **Time to Boil (TTB)**

The time to boil is the time from when the pot is placed on the cookstove until the water has reached the boiling point. It is a good indicator of the thermal transfer ability of the cookstove. The TTB of an "improved cookstove" should not be too different from a traditional cookstove, to maximize the adoption of the improved cookstove by the target community.

- **Total Time of Test (TTT)**

This is the total time of the test, from when the pot is placed on the cookstove until the temperature of the water drops 3°C below the temperature recorded at TTB.

- **Useful energy (UE)**

The useful energy is the sum of the sensible heat ($Q_{SENSIBLE}$) and the latent heat (Q_{LATENT}) absorbed by the water.

$$UE\ (kJ) = Q_{SENSIBLE}\ [kJ] + Q_{LATENT}\ [kJ]$$

The sensible heat ($Q_{SENSIBLE}$) is the energy absorbed by the mass of water (M_W) to raise its initial temperature (T_I) to the boiling temperature (T_B)

$$Q_{SENSIBLE}\ [kJ] = M_W\ [kg] * C * (T_B - T_I)\ [^{\circ}C]$$

Where C is the specific heat capacity = 4.18 kJ/kg.˚C

The latent heat (Q_{LATENT}) is the energy absorbed by the mass of water evaporated (M_{WE}) to change its phase from liquid to vapor.

$$Q_{LATENT}\ [kJ] = M_{WE}\ [kg] * L_V$$

Where L_V is the specific latent heat of vaporization = 2257 kJ/kg.˚C

- **Potential fuel differences**

This is the ratio of the useful energy provided by the cookstoves. This ratio shows the potential fuel differences [PSF] between two cookstoves. It starts to be significant above 10%.

$$PFD\ [\%] = 100 * (EU_{IMPROVED} - EU_{TRADITIONAL}) / EU_{IMPROVED}$$

By multiplying this ratio with the current quantity of fuel used, an estimation of the fuel difference can be done. This difference should then be validated in real conditions.

6. Accuracy and reproducibility tests:

A minimum of three comparative tests should be performed, and results are considered statistically valid if the Coefficient of Variation (CoV) for the useful energy of each cookstove is below 10%. If this requirement is not fulfilled, one additional test should be performed and analyzed.

When possible we strongly recommend **testing two stoves simultaneously** to ensure the same external conditions. This strongly reduces the influence of external parameters on test data, improving the accuracy of the test results.

7. Bibliographical references:

1. Rob Bailis, Damon Ogle, Nordica MacCarty, Dean Stil, Kirk R. Smith and Rufus Edwards, *The Water Boiling Test Version 3*, Shell Foundation: Oregon, 2007.
2. JF Rozis, *Protocole de Test d'Ébullition de l'Eau Comparatif*, GERES Cambodge: Phnom Penh, 2008.