FROM OLD WEIGHTS AND MEASURES TO THE SI AS A NUMERICAL STANDARD FOR THE WORLD

S. DÉBARBAT, I. PASSERON, F. LAUNAY

SYRTE, Observatoire de Paris, CNRS, UPMC,
61, avenue de l'Observatoire, 75014 – Paris, France
e-mail: suzanne.debarbat@obspm.fr; irene.passeron@obspm.fr; francoise.launay@obspm.fr

ABSTRACT. After the efforts made by Charlemagne to unify weights on the one hand, and measures on the other hand, Picard was most probably the first in France to submit a proposal for a new system based on a unit linking up length and time through the second-pendulum. Despite further proposals, it was not before the end of the 18th century, one century after Picard, that the *Système métrique décimal* was adopted, with the *Mètre* as a fundamental standard. Almost one more century later, by 1960, the SI was decided at the international level and, by 1983, a new definition of the metre was decided, eventually linking up length and time.

1. AT THE BEGINNING: A DESIRE OF STANDARDIZATION

Pondere, numero et mensura "with weight, number and measure": this formulation often introduces a rational explanation of the world. But it also shows a will for political and economical power over the world through the control of possessions, human activities and exchanges. The desire to speak the same language grew with centralization and intensification of commercial exchanges.

Charlemagne was most probably among the firsts to attempt to unify weights and measures (789), due to his position in Europe: *Roi des Francs* (768) and finally *Empereur d'Occident* (800). He has put his name to the *pié de Charlemagne* for measuring lengths (human standards like the foot have been used from the beginning of metrology) and to the *pile de Charlemagne* for measuring weights.

Colbert (1619-1683) tried in vain to standardize weights and measures in all French ports. He founded the *Académie Royale des Sciences* of Paris whose main purpose was to measure the territory of France.

One of its members, Jean Picard (1620-1682), who had taken part in determining the dimensions of the Earth using astronomical observations and a one-second pendulum clock, suggested that the very length of the pendulum of this clock become the new standard for measuring lengths in France.

1669-1670: Picard designed a portable quadrant and used it for geodesic measurements along the recently fixed *Méridien of the Observatoire Royal* founded by Louis XIV in 1667. The measurements of a part of this meridian provided him the dimensions of the Earth. This meridian was measured later by the Cassinis with a better precision. It was chosen for the expedition of Delambre and Méchain, which gave eventually the length adopted in 1799 for the "*Mètre étalon*".

1720: Another French astronomer, Jacques Cassini (1677-1756), suggested linking the unit of length to the measurement of the Earth by creating the *pied géométrique*, which was equal to one hundredth of the length of an arc of 1" of the meridian, and was not affected by the gravity, as the period of the pendulum was.

Two expeditions were sent by Louis XV, one to Lapland (1736-37), close the North Pole, and the other to Ecuador (1735-1744), to determine the length of the meridian of the Earth, a universal measurement, by astronomical and geodesic observations.

The *Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers* (Diderot et D'Alembert, 1751-1765, established after the model of the English *Cyclopædia*) was the greatest editorial venture of the Age of Enlightenment; it intended to be the best compilation of the products of reason and human ingenuity. The entries for "Mesure" and "Poids" show the diversity of length and weight measures used in different places and times. On the other hand, throughout his mathematical articles, D'Alembert showed the power of geometry and analysis, especially for measuring the figure of the Earth ("Figure de la Terre" entry).

2. THE REVOLUTION

All these considerations explain why, together with domestic and foreign trade difficulties, the French Revolution succeeded in promoting the "mètre" as the fundamental unit for the "Système métrique décimal", its major quality being its decimal character. After discussion, in 1791 March 30, the ten-millionth part of a quarter of meridian was chosen by the French Academy of Sciences, as more universal than the other proposals.

The successive values of the length of the "mètre étalon" (standard meter) able to represent $1/10^7$ of a quarter of a terrestrial meridian are now given with some important dates:

1799 December 10: After the expedition led by Delambre and Méchain to obtain more accurate measurements, the *mètre* was definitely fixed as being equal to "3 pieds 11 lignes deux cent quatre-vingt-seize millièmes" of the *Toise du Pérou* (i.e. 443.296 *lignes* since there were 6 *pieds* in a *Toise*, and 144 lignes in a *pied*), a little more than half a French *Toise* (1.9484m). The yard was 0.914m.

1812: Going backwards, a Napoleonic decree set that *1 toise = 2 mètres*; *1 aune = 1.20 mètre*; there were thus 3 *pieds* in a *mètre*. What a confusion!

1837: a law enjoined to have the metric system as a unique and legal one from 1840 January 1. Victor Hugo was then able to make jokes in "*argot légal*" (legal slang).

3. THE STANDARDIZATION

1875 May 28: The *Conférence diplomatique du mètre* leading to the *Convention du mètre* and the *Bureau international des poids et mesures* (BIPM) was installed in 1876 in the Pavillon de Breteuil, at Sèvres (south-west of Paris). The "mètre international étalon" (90% platinum, 10% iridium), with an X section, was made. The original was left at the BIPM, while replicas were provided to all the participating countries for their national depots. The length of reference was the distance between the gravity centres of three lines etched on both ends of the metallic pieces at a small distance from the edges. Several institutions were successively created: Commission for the System of Units, ancestor of the *Comité consultatif des unités* (CCU), *Comité international des poids et mesures* (CIPM), *Conférence générale des poids et mesures* (CGPM), the highest authority in the field.

1960 October 14: The *Système international d'unités* (SI) was fixed; it was based on the "Système métrique décimal" created during the French Revolution. All the successive realizations of the "mètre étalon" had to be consistent with the 1799 value. In the SI system, the length of the *Mètre* is equal to 1 650 763.73 vacuum wavelengths of the orange-red emission line in the electromagnetic spectrum of the krypton-86 atom.

1983 October 20: "*Le mètre est la longueur du trajet parcouru dans le vide par la lumière pendant la durée de 1/299 792 458 seconde*" (the distance covered by light in vacuum in ...). The *Laboratoire primaire du temps et des fréquences* (nowadays the LNE/SYRTE), is one of the five laboratories which has contributed to the value chosen for the velocity of light. This decision relates time and length similarly to Picard's proposal.

2010: Fifty years later, there are still people saying that the length of the *Mètre étalon* is in error when compared to the value obtained from measurements of the distance Dunkerque-Barcelona made nowadays, with GPS. Such a false consideration has a long story, dating back to the decision taken by the end of the 18th century. Since that time, each time a new measurement is made, with more accurate instruments, methods or techniques, it is said that the "mètre" is based on some error, from calculations or measurements. It must not be forgotten than the length of the "mètre" is a convention decided in 1799, based on a will of standardization framed by a symbolic search of universality. It was then decided, and this decision was confirmed by the Bureau des longitudes (the French Board of Longitudes) by mid-19th century, that the 1799 length of the *mètre* will never change, having been fixed according to the *Toise du Pérou*, which is nowadays preserved in the collections of the Observatoire de Paris, as an historical and material proof.