Manufacturing a longer chain logically requires manufacturing more than one link; thus is logically manufactured a longer metrological traceability chain...

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In a previous Editorial [1], we indicated that many people, and especially analysts, still struggle with the concept ‘metrological traceability’ [2] and ‘metrological traceability chain’ [3], and have trouble trying to define it. We attempted to assist them by looking at the process of establishing metrological traceability along a metrological traceability chain consisting of one link only.

We now look at the metrological traceability chain beyond in case it has several links, and which the analyst normally does not manufacture him- or herself, but which (s)he purchases embodied in a ‘calibrator’ [4], usually termed ‘Certified Reference Material’ (CRM) [5] or ‘measurement standard’ [6].

Where does the known quantity value come from which is embodied in the calibrator the analyst is using to calibrate his/her measuring system? Obviously from another “better” measuring system which has been calibrated by means of a calibrator carrying a “better” known quantity value. “Better”, of course, means with smaller ‘measurement uncertainty’ [7]. So, where does the “better” known quantity value come from? Obviously from a “still better” measuring system calibrated by means of a “still better” calibrator. And so on. This chain becomes longer with each additional “better” calibrated measuring system, which in turn requires a “better” calibrator. The trace from the measurement result via the various measuring systems, each calibrated by an appropriate calibrator up to a reference, is called ‘metrological traceability chain’ [3].

At the time of planning the measurement, the analyst decides on the reference (s)he is going to use for his/her measurement result. Mostly, it is (the value of) the

measurement unit [8] but it could be the value embodied in any calibrator, thus making his/her final measurement result metrologically traceable to this value.

The choice of the reference—which is therefore a decision by the analyst—is done *before the measurement*. Thus is chosen the calibrator and therefore also the metrological traceability chain.

We note that various kinds of metrological traceability chains are possible along other calibrators and along other measuring systems. The analyst is free to choose any of these. That choice may be influenced by a ‘target measurement uncertainty’ [9], but that is another point not discussed here.

Whatever the reference chosen, all measurement results obtained for the same measurand on other samples by other analysts are metrologically comparable [10] if traceable to this same reference.

How can analysts *terminate* a metrological traceability chain without going further to yet another calibrator? Obviously, by *not* performing yet another calibration of an additional measuring system enabling to put a value on yet another calibrator, but by defining the value thus stopping the chain of calibrations. This is their measurement unit. It automatically terminates the chain.

There is an entirely different alternative foreseen by VIM3: a value obtained by means of a ‘reference measurement procedure’ [11] can be designated as a reference by the analysts concerned in common agreement in order to make their measurement results comparable. This approach can be used when a common measurement unit is not (yet) available.

A simple example of a longer metrological traceability chain of measurement results is a routine measurement of mass. The metrological traceability chain ends at the quantity value (in this case: mass value) of the prototype of

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the kilogram at BIPM in Paris-Sèvres which was “manufactured” and *defined* as carrying the mass value one. It has *measurement uncertainty zero because it is not measured*: its mass value has been *defined to be our measurement unit*. In other words, it is a ‘primary calibrator’ (also called a ‘primary measurement standard’ [12]). Many multiples or submultiples of that value “one” can be conceived such as g or mg or μg , creating a theoretical measurement scale. As pure conceptions of the mind, they have measurement uncertainties zero because they are *defined*, not measured: one thousandth of the kilogram exactly (a gram, g), one thousandth of a gram exactly (a milligram, mg), or one millionth of a gram exactly (a microgram, μg). Thus, on a scale of all possible mass values, we have a large number of reference points with exactly known values. If we want to use them in the laboratory, we must *realize* these theoretical values, i.e. make material objects with known mass on this scale. These will then become our ‘calibrators’, which through various intermediate links, do ensure a metrological traceability chain connecting the analyst’s measured mass to the mass of the “kg” in Paris-Sèvres, or to the mass of any intermediate calibrator, as decided by the analyst. However, as material products, they are all carrying measurement uncertainties as a consequence of their calibration.

In chemistry, we work similarly. We have a suitable measurement unit, the mole-per-litre, or the mole-per-kilogram, both ‘derived measurement units’ [13] in the SI (the mole and the kilogram are ‘base units’ [14] in the SI). By means of (sub)multiples, we build a measurement scale with a large number of reference points with exactly known values: 1 mmol/L, 5 $\mu\text{mol/g}$, 30 mmol/kg, etc. In chemistry, we can prepare or manufacture such values by making them up, see [1]. We call this building process *manufacturing* or *synthesizing a quantity value*. Their manufacturing uncertainty must be appropriately small lest they are not useful. The highest one in the chain (a primary calibrator, also called primary measurement standard) must be manufactured according to a ‘primary preparation procedure’, analogous to a ‘primary reference measurement procedure’ [15], a procedure which ensures that known quantity values embodied in materials carry small enough measurement uncertainties to be useable in an analyst’s measurement. Such primary ‘calibrators’ are the first ‘embodiments’ or ‘realizations’ of a measurement unit. We described this process in [1]. The whole process is the “realization” of metrological traceability to a measurement unit.

We note that the analyst has the potential of establishing such a *primary* calibrator him- or herself, without needing an NMI, see again [1].

We also note that measurement uncertainty [7] can now be evaluated easily by identifying the components of the ‘uncertainty budget’ [16] along the metrological traceability chain in a chronological step-by-step process enabling in the end to calculate the final measurement uncertainty of the measurement result. Note that the metrological traceability chain is necessary to identify these components. Thus is evident that the metrological traceability chain is a prerequisite for evaluation of measurement uncertainty and chronologically precedes this budget. Evaluating measurement uncertainty does not generate metrological traceability. Rather it is metrological traceability which logically precedes evaluation of measurement uncertainty. There is a chronological sequence of operations involved here. Measurement uncertainty of the analyst’s measurement is simply a *logical consequence* of the cumulative uncertainty of all the calibrations of measuring systems, made along the metrological traceability chain up to the value embodied in a calibrator chosen as reference.

A purely logical and chronological perception of the metrological traceability chain is simplifying and useful.

As the introduction of basic metrological concepts always should be ...

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References

1. De Bièvre P (2009) Manufacturing a chain logically starts by manufacturing a first link, thus is realized the start of a metrological traceability chain. *Accred Qual Assur* 14:517–519
2. BIPM, IEC, IFCC, ILAC, IUPAC, IUPAP, ISO, OIML (2008) International vocabulary of metrology—basic and general concepts and associated terms (VIM), 3rd edn. JCGM 200:2008. <http://www.bipm.org/en/publications/guides/vim.html> entry 2.41
3. Ibidem, entry 2.42
4. Ibidem, entry 5.12
5. Ibidem, entry 5.14
6. Ibidem, entry 5.1
7. Ibidem, entry 2.26
8. Ibidem, entry 1.9
9. Ibidem, entry 2.34
10. Ibidem, entry 2.46
11. Ibidem, entry 2.7
12. Ibidem, entry 5.4
13. Ibidem, entry 1.11
14. Ibidem, entry 1.10
15. Ibidem, entry 2.8
16. Ibidem, entry 2.33