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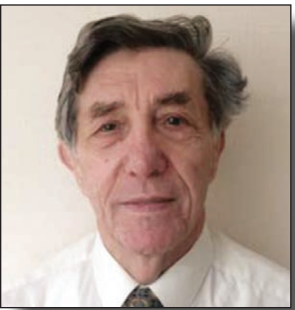
What are Metrologists Made Of?

The kind of metrologists I have in mind are not those worthy individuals who daily measure anything and everything more-or-less according to a prescription in science, industry and engineering. Instead, let's think about those in national metrology institutes throughout the world who are charged with providing proper basic units, inventing measuring techniques and writing the prescriptions. They come in both genders and all ages, shapes and sizes, and their working habits range from the pedantically neat and tidy to the downright chaotic. But the one characteristic they all have in common is a drive to arrive at the unique, correct result for their measurement, although their only comfort that the outcome might indeed be correct is eventual agreement with the measurements of their peers in other institutes. Naturally, these peers have no other guarantee that their results are right either.



How long does it take for a scientist to become a fully-fledged metrologist? It is impossible to give an exact answer because the time taken to absorb new ideas and ways of working vary so much from one individual to another, but I would suggest it is measured in many years rather than a few months, and of this their employers should be fully aware. Before starting, an apparatus has to be designed, made and assembled. Then the time-scale is composed of successive stages. In the first stage, provided the design is a good one, it usually takes only a few weeks to obtain varying results, all within the target resolution. The second stage then follows, consisting of removing the causes of variation until the same result is obtained time after time, and this might take a few months. Finally, in the last stage, systematic errors must be discovered and eliminated until the metrologist, possibly out of sheer exhaustion, concedes that there is nothing more to be done, and publishes the results of the measurement. This last stage can often last years and years. It takes the making of a great many mistakes along the way to thoroughly convince apprentice metrologists that they are not in fact infallible no matter how carefully and thoroughly they assess their measurement methods, and how many precautions they adopt to guard against error. Nature has so many ways to fool us.

It used to be the case amongst previous generations of metrologists that careful design and execution of a measurement was sufficient, but now instead of relying on one prescriptive way of carrying out a measurement with an apparatus, we make as many changes (one at a time) to the method or to the apparatus as can reasonably be devised. Following a change, one of three things may happen: 1) The change made does not affect the result for reasons which are understood; 2) The result is different, but this is expected, again for reasons which are understood, and a correction can be calculated which restores the result to the value obtained before the change; or 3) the result is unexpectedly altered, and the metrologist has no idea why. Then the problems really start. Hopefully, thought and ancillary measurements lead to the cause and suggest a remedy, but if after Herculean efforts the change in the result remains, then defeat must be admitted and the uncertainty associated with the measurement just has to be enlarged to encompass it. At the end of this long process, metrologists can claim to have served their apprenticeship.

One outcome of all of this striving should be a complete, water-tight definition of what was measured. Indeed, this is a necessary precursor of any measurement, no matter how everyday or trivial. For example, suppose that an accurate measurement of the length of a metal rod, often called an end-gauge, is required. This length could be defined as the distance between the centers of area of the nearly plane and parallel polished ends of the bar, measured with negligible force exerted on them, when the bar is at a specified temperature and supported horizontally at its Airy points. I encountered strong opposition when I once suggested that a complete set of defining conditions, the measurement result and its uncertainty are all that should be in a calibration certificate. Others claimed that it is also necessary to state the measurement method and the type of apparatus used, but I think metrologists should be free to employ any technique they please, such as interferometry or microwave resonances or mechanical callipers or whatever, providing that it fulfils the defining conditions, and the result should be the same. If not, the definition is incomplete or there is a systematic error in some or all of the techniques. All of this is true for what we might term a mature kind of measurement. For an immature kind, perhaps for example the rise-time of a fast

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photodiode, a complete definition might not yet have been arrived at because of the loading effects of the attached measuring circuitry and this must be admitted by giving details of the means by which the measurement was made, but this should be regarded as a last resort.

So what *are* metrologists made of? Certainly not "snaps and snails and puppy-dogs tails," nor even "sugar and spice and all things nice," but rather persistence to the point of obstinacy, obsession with the problem in hand, determination to spend as long as it takes to overcome it, and the need to get the best possible correct measurement in the end, which might be years away. National metrology institutes are full of these treasures to whom half-truths such as spin (in the political sense) and propaganda are anathema. Moreover, the international committees which approve changes to the SI proceed by consensus – *all* of their members have to agree before resolutions are adopted. Imagine a world where politicians acted thus!

For Dr. Kibble's contact information and bio, please follow this link, http://ieee-ims.org/publications/im-magazine.

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