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# NIST MISE EN PRATIQUE FOR THE REALIZATION AND DISSEMINATION OF THE REDEFINED KILOGRAM

*Patrick Abbott* [1], *Eric Benck* [2], *Corey Stambaugh*[2], *Edward Mulhern*[2], *and Zeina Kubarych*[2]

[1] NIST, Gaithersburg, MD, USA, patrick.abbott@nist.gov
[2] NIST, Gaithersburg, MD, USA

***Abstract*** − The kilogram will soon be realized in terms of the Planck constant within a vacuum environment. This realization must be transferred to air and then disseminated to the international measurement community. This paper describes the NIST implementation of a mise en pratique for the future realization and dissemination of the kilogram using a watt balance and a unique vacuum-to-air transfer method based on a magnetic suspension technique.

***Keywords***: mise en pratique, kilogram, magnetic suspension

## 1. INTRODUCTION

The scientific world has been working for several years in order to measure the Planck constant with sufficient accuracy [1] to redefine the kilogram. This redefinition is expected to take place in 2018 [2], when for the first time in history, the SI unit of mass will be defined in terms of something other than a physical artefact. The International Prototype Kilogram (IPK) will no longer be used for realization. This will expand the world's ability to realize the unit of mass wherever an appropriate experiment relating the Planck constant to mass exists, e.g., with a watt balance or an x-ray crystal density (Avogadro) experiment. To maintain appropriately low uncertainties, these realization methods must be done in a vacuum environment, which necessitates a means of transferring the realization to air where most mass metrology is done. Both processes of realizing and disseminating the redefined kilogram to air will be done at NIST and comprise a mise en pratique ("to put in practice") that will be used to disseminate mass to the U.S. Measurement System and the world.

## 2. COMPONENTS OF THE NIST MISE EN PRATIQUE

The realization and dissemination of the redefined kilogram at NIST is accomplished by the collaboration of several systems. Mass artefacts can be moved under vacuum (or any other pressure) between system components owing to the uniformity of design of flange and load-lock components. Each system of the mise en pratique is described below.

### *2.1. Realization – NIST Watt balance*

NIST has operated a watt balance experiment for over twenty-five years, [3] and the third prototype of this instrument, NIST-3was used to measure the Planck constant in 2013 with a relative standard uncertainty of 45 x 10-9 [4]. The next generation prototype, NIST-4, is currently under construction and is expected to measure the Planck constant with a much lower uncertainty than NIST-3. When the Planck constant is fixed (with no uncertainty) in 2018, the watt balance uncertainty in measuring the Planck constant will become the uncertainty on the realization of the kilogram. The NIST-4 watt balance will provide the NIST Mass & Force Group with kilogram artefacts that have been "calibrated" in the watt balance and are directly traceable to the SI unit of mass. These masses must then be retrieved from the watt balance under vacuum and taken to a system to transfer the kilogram value in vacuum to air.

### *2.2. Mass Transport Vehicle*

The Mass Transport Vehicle (MTV) is a mobile stainless-steel enclosure that can interface to any of the component systems for realizing and disseminating mass. A one kilogram mass artefact can be removed from one component, placed into the MTV under vacuum or in atmospheric pressure air, and then transported to another system where the reverse process is done to load the artefact. The MTV is equipped with suitable linear motion actuators and custom-designed holding jigs to capture a mass artefact from one system and secure it for transport to another. All-metal flange seals are used to ensure leak tightness, and a gate valve with pumping port is integrated to allow evacuation or venting prior to admitting an artefact.

### *2.3. Magnetic Suspension Mass Comparison System*

The magnetic suspension mass comparison system allows the comparison of a mass artefact in a vacuum environment to another artefact in atmospheric pressure air (or other gas) environment using the same high precision mass comparator. This instrument is composed of an aluminium vessel that is divided into upper and lower chambers, with the upper chamber containing the mass balance. The upper chamber is evacuated and contains a kilogram artefact that has been calibrated by the watt balance. The lower chamber contains a carriage that holds another artefact that is to be compared to the one in vacuum. The mass in the lower chamber is coupled to the mass balance using an attractive magnetic suspension technique. The suspension components are fixed to the weighing pan in the upper chamber of the balance and a magnetic field is established across the boundary between the upper and lower chambers. The suspended carriage behaves just as if it were physically connected to the weighing pan of the mass balance. By comparing masses in vacuum and air directly, it is possible to avoid empirical sorption models that are used in other transfer methods to correct for adsorption/desorption effects. This system is shown in Fig. 1 and composes the chief NIST method for dissemination of the kilogram that is realized in the watt balance. More details about this system will be given in a separate paper at this conference.

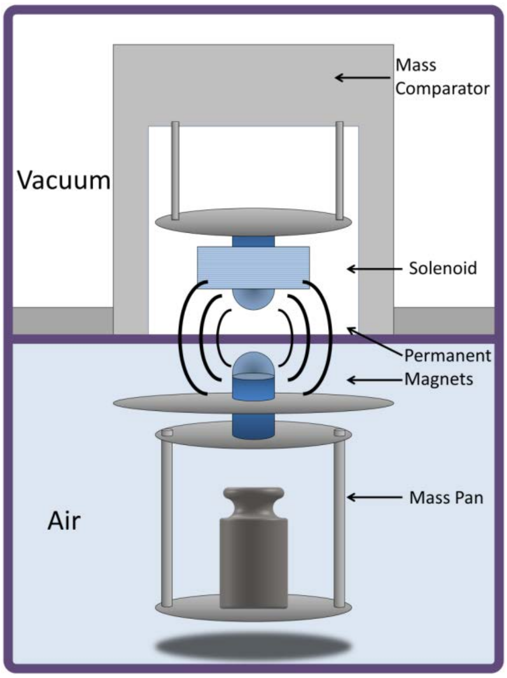


Fig. 1. Diagram of the Magnetic Suspension Mass Comparison System.

### *2.4. Mass in Vacuum System*

The magnetic suspension mass comparison system is a unique approach to transferring the realized kilogram in vacuum to air. An alternate method of doing this relies on characterizing a mass artefact for the change in mass due to sorption of atmospheric air components, primarily water vapour. Many careful studies have been done [5,6] to determine the effects of water vapour adsorption on mass standards. As mentioned above, this is an indirect method that relies on empirical corrections that are often dependent on species, surface composition, and environmental variables. Regardless, the use of sorption artefacts to determine corrections to the vacuum-realized kilogram allows verification of the magnetic suspension mass comparison system, and will be employed at NIST for this purpose. The system consists of a commercial, six place mass comparator that has been specially configured for use in a vacuum environment. The comparator is located within a stainless-steel chamber that is evacuated by a turbo molecular pump. Mass artefacts are loaded into the chamber using an integral load-lock. The NIST MTV will be used to transfer mass artefacts into and out of the integral load-lock. Using specially designed sorption artefacts and mass standards that have been calibrated in vacuum by the BIPM, the sorption properties and mass changes involved in the transfer from vacuum to air will be measured.

### *2.5. Mass Artefact Pool and Storage*

NIST will disseminate the unit of mass from the watt balance realization using a collection or “pool” of mass artefacts. This pool will be composed of several each of Pt-Ir and Stainless Steel kilogram artefacts, stored in either atmospheric pressure air or vacuum of approximately 10-3 Pa. An ensemble mass value derived from the calibrations of these artefacts will be determined and used as the NIST mass unit that is traceable to the SI kilogram. Constant monitoring of this pool will be accomplished by using the NIST MTV to carry the artefacts to and from the magnetic suspension comparison system and/or the NIST watt balance.

## 3. VERIFICATION AND TRACEABILITY

### *3.1. Traceability Paths*

There are multiple “checks” built into the NIST implementation of the mise en pratique. This is illustrated in the diagram of Fig. 2. The most important of these verifications is using the sorption artefacts method to confirm the vacuum-to-air results of the magnetic suspension mass comparison system. Stability of the watt balance results will be monitored by regularly using the vacuum balance to calibrate one or more check standard artefacts against a watt balance primary realization. The NIST pool of mass artefacts will be regularly monitored in the same fashion, using both the vacuum balance and the magnetic suspension mass comparator. Traceability of the pool of artefacts to the SI is accomplished both before and after redefinition. Before redefinition, artefacts calibrated in vacuum in the watt balance will be directly traceable to the IPK through the magnetic suspension balance, as this system will enable direct comparison to an IPK-traceable check standard in air.

The NIST pool of mass artefacts will be used to calibrate NIST working standards for the dissemination of mass from below 1 mg to over 27,000 kg. These working standards will be regularly monitored against the pool for stability, and will be used to disseminate mass to the U.S. Measurement System. Dissemination of mass will be accomplished using conventional artefact mass metrology techniques and equipment. Immediately after redefinition, uncertainties will most likely be slightly higher than those that are currently being disseminated, but will improve with time. Measurement uncertainty will depend mainly on the uncertainties achieved by the watt balance and the magnetic suspension mass comparison system, but are expected to be well within the OIML limit for Class E1 (0.083 mg at 1 kg, (k = 1)).

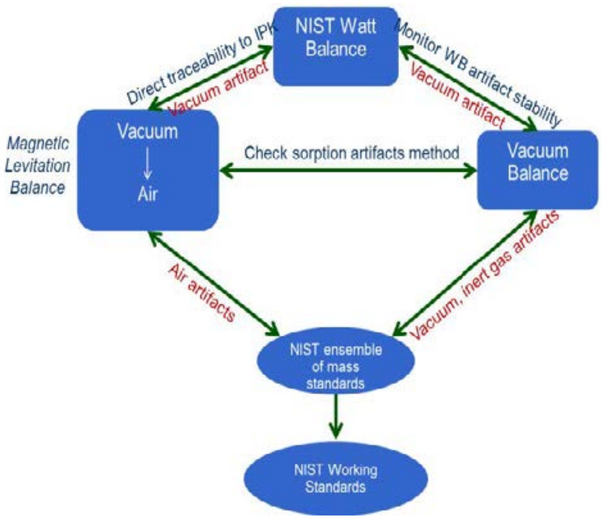


Fig. 2. Diagram showing verification and traceability paths for the NIST Mise en Pratique.

## 4. CONCLUSIONS

NIST is working on a multi-instrument implementation of the mise en pratique for the realization and dissemination of the kilogram after it is redefined in terms of the Planck constant. Realization of mass in vacuum will be accomplished with the next generation NIST-4 watt balance. A unique magnetic suspension mass comparator will be used for transferring the vacuum realization to air. Rigorous checks of system accuracy are realized through use of a commercial mass-in-vacuum balance, and stability of the disseminated unit of mass will be maintained and monitored through a pool of artefacts composed of different materials and stored in different environments. NIST expects to perform a “dry run” of the entire realization-to-dissemination process in early to mid-2016.

## ACKNOWLEDGMENTS

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