This supplementary information file supplies a demonstration for the description of losses occurring during spICP-MS measurements, which includes the nebulization, ionization, ion extraction and ion transfer efficiencies. All these efficiencies are usually summarized under a generic term, the so-called "transport efficiency".

The demonstration then considers independently the case of a conventional introduction system for ICP-MS, a spray chamber, and that of a direct injection nebulizer. Conversely to a spray chamber, where more than 80% of the sample does not reach the plasma, there can be no loss during the nebulization of the sample with a direct injection nebulizer. In the following we describe how to derive equations that relate these different efficiencies to measured or known variables.

**1 –** ***Number of ions detected from a dissolved standard solution***

For ICP-MS measurements, aqueous samples are nebulized into a spray chamber. The sample droplets are transported into the plasma and are finally subject to the ionization process, as shown on Fig. S1. During nebulization in the spray chamber, part of the solution is lost as only the finest droplets are transported to the plasma (ICP) and this loss is expressed as the nebulization efficiency. In the plasma the solution droplets undergo desolvation, vaporization, atomization and finally ionization, but not all atoms that where introduced to the plasma will be ionized. This loss during the ionization process is expressed as the ionization efficiency. The very center of the ion cloud is then sampled by the cones and only a fraction of the ions initially produced in the plasma will enter the mass spectrometer (MS). This loss is expressed as the extraction efficiency. The ions are then focused and sampled again by the entrance and/or resolution slit, in the case of a Sector Field-ICP-MS or introduced in a collision/reaction cell for ICP-Quadrupole-MS. Thus, only a fraction of the ions that passed the cones will be eventually detected and this loss is globalized as the transfer efficiency.

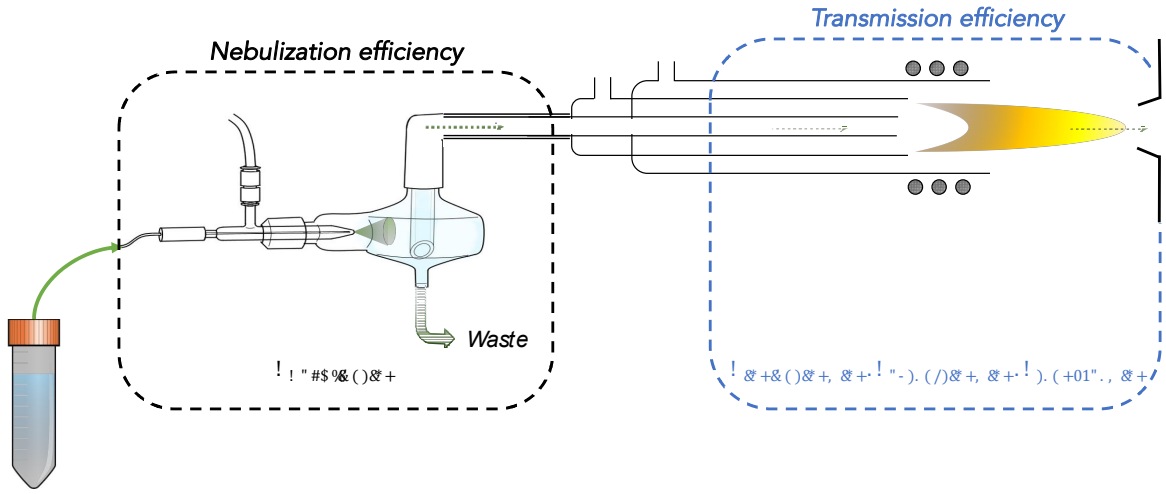


**Fig. S1** Graph of the different efficiencies using a conventional spray chamber for ionic species contained in an aqueous solution. The spray chamber is modified from ThermoScientific website

We can express the number of ions detected as a function of the number of moles of solute nebulized and of the different efficiencies:

$$N_{ion-measured} = n_{ion} . \mathcal{N}_A . \mathcal{A}_{iso} . \left(\eta_{Nebulization} . \eta_{ionization-ion} . \eta_{extraction-ion} . \eta_{transfer-ion}\right) \quad \textbf{(1)}$$

Where the number of moles nebulized is:

$$n_{ion} = \frac{C_{ion} . t_d . q_{liq}}{\mathcal{M}_{ion}} \quad \textbf{(2)}$$

With:

$\eta_{Nebulization}$ - the nebulization efficiency – the ratio of the number of moles arriving into the plasma to the number of moles nebulized,

$\eta_{ionization}$ - the ionization efficiency – the ratio of the number of ions created to the number of moles arriving into the plasma,

$\eta_{extraction\text{-}ion}$ - the extraction efficiency – the ratio of the number of ions extracted to the MS to the number of ions created,
$\eta_{transfer\text{-}ion}$ - the transfer efficiency – the ratio of the number of ions detected to the number of ions extracted to the MS,
$n_{ion}$, the number of moles nebulized (in mole),
$N_{ion\text{-}measured}$, the number of ions detected (in cps),
$N_A$, Avogadro constant (in mole$^{-1}$),
$A_{iso}$, the isotopic abundance (in %) of the mass measured,
$C_{ion}$, the concentration of the ion in the dissolved standard (in ng L$^{-1}$),
$q_{liq}$, the uptake-rate (in L min$^{-1}$),
$t_d$, the dwell-time (in min),
and $M_{ion}$, the molar mass (in ng mole$^{-1}$) of the analyte.

Combining equation (2) and equation (1), the number of ions detected is then:

$$N_{ion-measured} = \frac{C_{ion}.t_d.q_{liq}.N_A.A_{iso}}{M_{ion}} \cdot \left(\eta_{Nebulization} \cdot \eta_{ionization-ion} \cdot \eta_{extraction-ion} \cdot \eta_{transfer-ion}\right) \quad \textbf{(3)}$$

**2 – *Number of ions detected from the ionization of one nanoparticle***

In the case of a NPs sample solution, we can independently express the number of ions that are measured by the mass spectrometer according to the number of atoms per NP that were introduced to the nebulizer and to the efficiencies previously defined (Fig. S2). The difference here, compared to a dissolved analyte, is that: the measured signal is discrete (when continuous for dissolved), each NP creating a spike signal; the NP also contains eventually more than one element; and in the following equation we assume a spherical shape of the NPs. So far, there is also no reason to consider that the ionization, extraction and transfer efficiencies for the NPs be the same as for the solutes. Indeed, for instance, the high number of atoms in a NP is condensed when arriving in the plasma and then ions are extracted and transferred by clouds when for solutes, atoms and ions are incoming continuously.

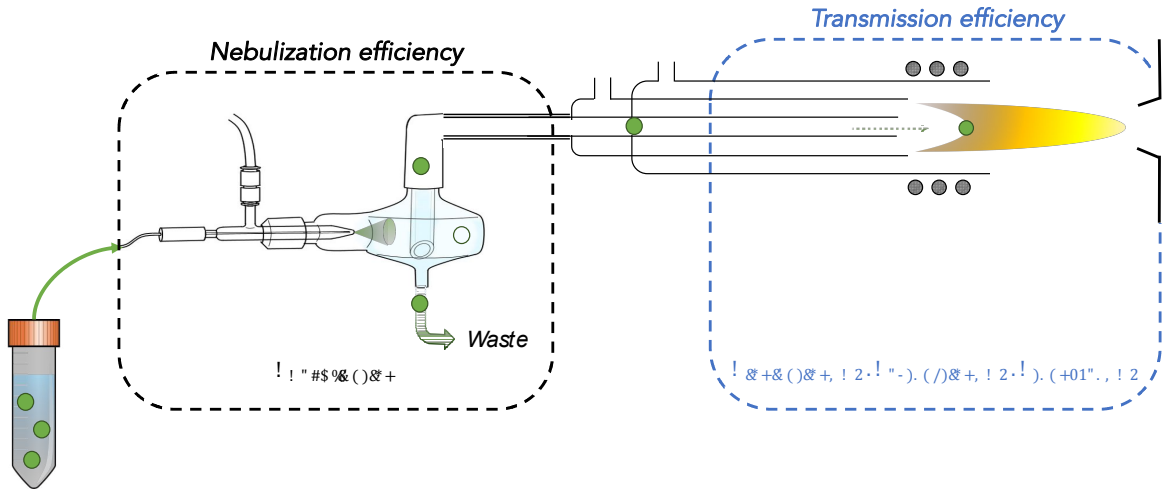


**Fig. S2** Graph of the different efficiencies using a conventional spray chamber for nanoparticles contained in an aqueous solution

Otherwise, the nebulization process for NPs is the same as for solutes and so, the number of NPs detected can be express as a function of the nebulization efficiency such as:

$$D_{NPs} = N_{NPs}.q_{liq}.D.t_d.\eta_{Nebulization} \quad (4)$$

With:
$D_{NPs}$ the total number of NPs events,
$N_{NPs}$, the total NP number concentration (in particle $mL^{-1}$) and $D$, the number of data point (*i.e.* number of dwell-time).

Here it is also important to note that contrarily to dissolved analyses, the loss of material in the introduction system has no effect on the intensity of the NP signal. In other words, the nebulization has no effect on the number of moles per NP detected. Indeed, this number of moles is only influenced by the combined efficiencies of the plasma and the mass-spectrometer and can be expressed as:

$$N_{NP-measured} = n_{NP}.\mathcal{N}_A.\mathcal{A}_{iso}.(\eta_{ionization-NP}.\eta_{extraction-NP}.\eta_{transfer-NP}) \quad \mathbf{(4)}$$

Where, considering a NP of spherical shape, the number of moles per NP nebulized is:

$$n_{NP} = \frac{{d_{NP}}^3.f_a.\pi.\rho_{ion}}{6.\mathcal{M}_{ion}} \quad \mathbf{(5)}$$

With:
$n_{NP}$, the number of mole nebulized / NP (in mole) originally expresses as $n_{NP} = \frac{m_{NP}}{\mathcal{M}_{ion}}$,
$N_{NP\text{-}measured}$, the number of ions detected per NP (in cps),
$m_{NP}$, the mass of one NP (in ng) expresses as $m_{NP} = \frac{{d_{NP}}^3.f_a.\pi.\rho_{ion}}{6}$ assuming a spherical shape,
$f_a$, the mass fraction of the element analyzed in one NP (in %, *i.e.* 100% for Au-NPs),
$d_{NP}$, the diameter of one NP (in nm),
$\rho_{ion}$, the density of the NP (in ng $nm^{-3}$) and $M_{ion}$, the molar mass of the element analyzed (in ng $mole^{-1}$).

If we combine equation (5) and equation (4), the number of ions detected per NP is then:

$$N_{NP-measured} = \frac{{d_{NP}}^3 . f_a . \pi . \rho_{ion} . \mathcal{N}_A . \mathcal{A}_{iso}}{6 . \mathcal{M}_{ion}} . \left(\eta_{ionization-NP} . \eta_{extraction-NP} . \eta_{transfer-NP}\right) \quad \textbf{(6)}$$

### 3 – Expression of the major efficiencies depending on the introduction system

In the following, we consider separately two sample introduction systems: the conventional spray chamber and the direct injection nebulizer.

- ***Efficiencies when using a conventional spray chamber***

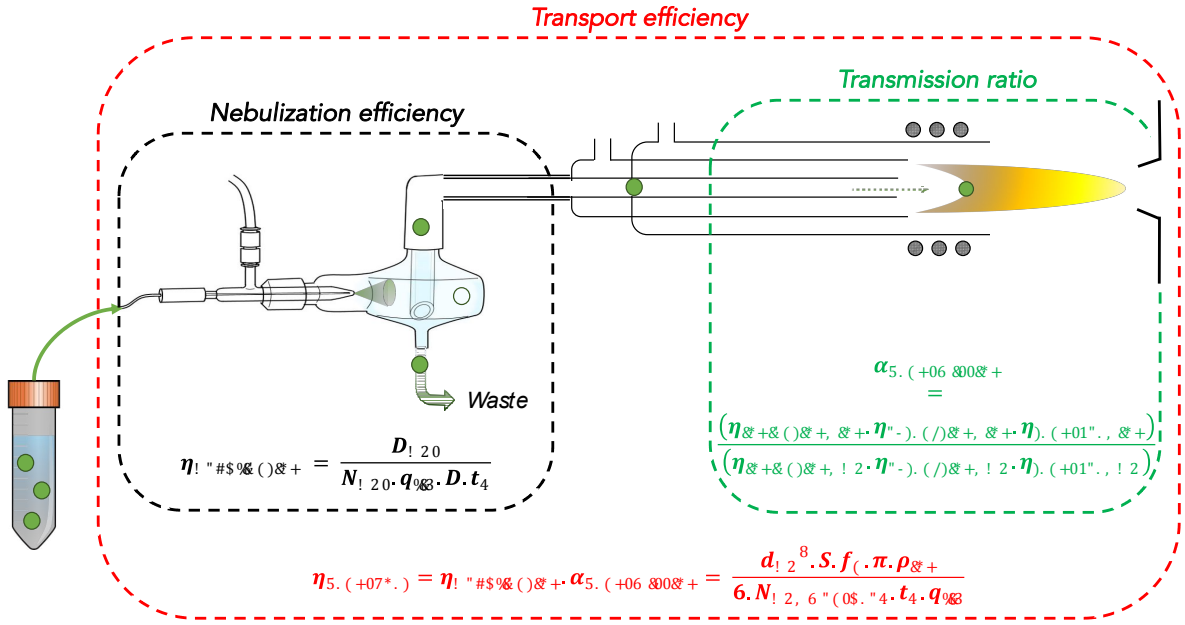


**Fig. S3** Graph of the different efficiencies using a conventional spray chamber for nanoparticles contained in an aqueous solution

In both equations (3) and (6), the only constant common parameter is the molar mass $M_{ion}$. By combining these equations expressing $M_{ion}$, we obtain:

$$C_{ion} \cdot t_d \cdot q_{liq} \cdot \eta_{Nebulization} \cdot \frac{(\eta_{ionization-ion} \cdot \eta_{extraction-ion} \cdot \eta_{transfer-ion})}{N_{ion-measured}} = \frac{{d_{NP}}^3 \cdot f_a \cdot \pi \cdot \rho_{ion}}{6} \cdot \frac{(\eta_{ionization-NP} \cdot \eta_{extraction-NP} \cdot \eta_{transfer-NP})}{N_{NP-measured}} \quad \textbf{(7)}$$

Then, we can express the nebulization efficiency as:

$$\eta_{Nebulization} = \frac{{d_{NP}}^3 \cdot f_a \cdot \pi \cdot \rho_{ion}}{6 \cdot C_{ion} \cdot t_d \cdot q_{liq}} \cdot \frac{N_{ion-measured}}{N_{NP-measured}} \cdot \frac{(\eta_{ionization-NP} \cdot \eta_{extraction-NP} \cdot \eta_{transfer-NP})}{(\eta_{ionization-ion} \cdot \eta_{extraction-ion} \cdot \eta_{transfer-ion})} \quad \textbf{(8)}$$

To simplify the equation, we know that, the sensitivity, measured from the calibration of the ICP-MS response with dissolved standards (slope of the external calibration), is $S = \frac{N_{ion-measured}}{C_{ion}}$ (in cps ng$^{-1}$ L as declared in the main text of the paper) which gives:

$$\eta_{Nebulization} \cdot \frac{(\eta_{ionization-ion} \cdot \eta_{extraction-ion} \cdot \eta_{transfer-ion})}{(\eta_{ionization-NP} \cdot \eta_{extraction-NP} \cdot \eta_{transfer-NP})} = \frac{{d_{NP}}^3 \cdot S \cdot f_a \cdot \pi \cdot \rho_{ion}}{6 \cdot N_{NP-measured} \cdot t_d \cdot q_{liq}} \quad \textbf{(9)}$$

Ionization, extraction and transfer efficiencies are not a priori known and cannot be assumed equal for ions in solution and ions in NPs. As it is not clear for the moment how we could determine these three different efficiencies independently, we can simplify equation (9) by introducing here the term "transmission ratio": $\alpha_{Transmission}$. It is defined as "the ratio of the transmission efficiency for a dissolved standard to the one for a NP" (*i.e.* a correction factor for transmission differences between the 2 species):

$$\alpha_{Transmission} = \frac{\eta_{transmission-ion}}{\eta_{transmission-NP}} = \frac{(\eta_{ionization-ion} \cdot \eta_{extraction-ion} \cdot \eta_{transfer-ion})}{(\eta_{ionization-NP} \cdot \eta_{extraction-NP} \cdot \eta_{transfer-NP})} \quad \textbf{(10)}$$

Consequently, the equation (9) becomes:

$$\eta_{Nebulization} \cdot \alpha_{Transmission} = \frac{{d_{NP}}^3 \cdot S \cdot f_a \cdot \pi \cdot \rho_{ion}}{6 \cdot N_{NP-measured} \cdot t_d \cdot q_{liq}} \quad \textbf{(11)}$$

As depicted above in Fig. S3, the term on the left side of equation (11) can then be defined as the transport efficiency – $\eta_{Transport}$ – "the ratio of the number of moles per NP to the number of ions eventually detected" giving thus:

$$\eta_{Transport} = \eta_{Nebulization} \cdot \alpha_{Transmission} = \frac{d_{NP}{}^{3} . S . f_a . \pi . \rho_{ion}}{6 . N_{NP-measured} . t_d . q_{liq}} \quad (12)$$

Also, as displayed in Fig. S3, $\eta_{Nebulization}$ defined as "the ratio of the volume effectively entering the plasma to the volume taken up by the sample introduction pump" is simply expressed as:

$$\eta_{Nebulization} = \frac{D_{NPs}}{N_{NPs} . q_{liq} . D . t_d} \quad (13)$$

Note that, alternatively, $\eta_{Nebulization}$ can be determined through spray chamber waste collection [7] (*i.e.* volume collected into the waste subtracted to the total volume of sample nebulized), but this method leads to inconsistencies since it does not take into account acknowledged partial evaporation of the sample solution in the spray chamber.

We can finally express $\alpha_{Transmission}$ for a conventional spray chamber, by combining equation (13) and equation (12):

$$\alpha_{Transmission} = \frac{d_{NP}{}^{3} . S . f_a . \pi . \rho_{ion} . N_{NPs} . D}{6 . N_{NP-measured} . D_{NPs}} \quad (14)$$

- ***Efficiencies when using a direct injection nebulizer (DIN)***

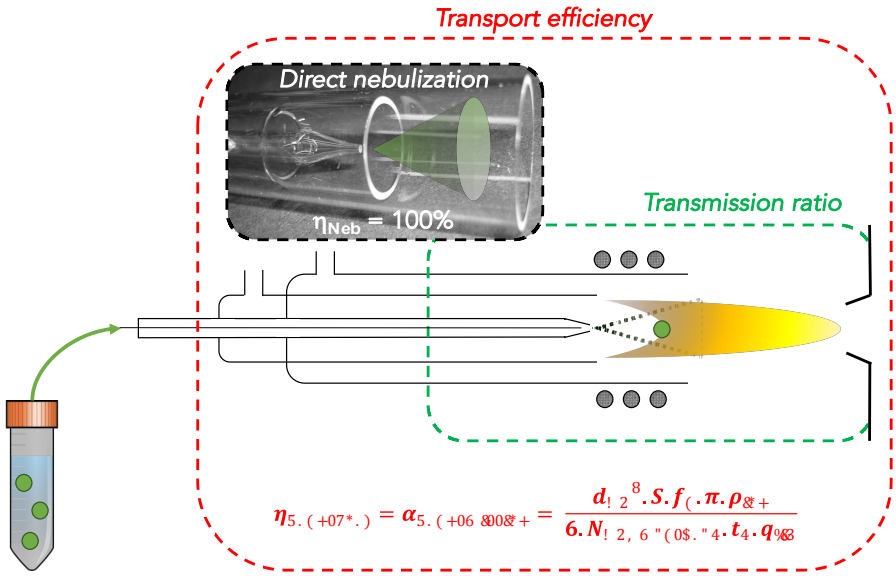


**Fig. S4** Graph of the transport efficiency using a direct injection nebulizer for nanoparticles contained in an aqueous solution

Fig. S4 illustrates that in the case of a DIN, we directly nebulize the solution into the plasma. Thus, we can assume complete $\eta_{Nebulization}$ and set $\eta_{Nebulization} = 1$ in equation (11). Consequently, the transport efficiency is equal to the transmission efficiency, giving us:

$$\eta_{Transport} = \alpha_{Transmission} = \frac{{d_{NP}}^3 . S . f_a . \pi . \rho_{ion}}{6 . N_{NP-measured} . t_d . q_{liq}} \quad (15)$$

**4 - Equations for NP characterization by spICP-MS**

Finally, the equations determined above allow us to express the diameter and the number concentration of NPs that are measured by spICP-MS. Again, we distinguish the two sample introduction systems. For both systems the calibration curve with dissolved standard solutions is mandatory. With a spray chamber, after determining the efficiencies using a certified reference material such as AuNPs of know size and particle number concentration (PND), particle size diameter (PSD) can be then calculated from the signal distribution of each NPs suspension solution. With the direct injection nebulizer µ-dDIHEN at µL $min^{-1}$ uptake rate, the calibration with a certified NP reference material is not necessary anymore, due to the complete nebulization and complete transmission of the NPs.

- ***Particle size distribution when using a conventional spray chamber***

For a known chemical composition and assuming a spherical shape, based on equation (12) using $\eta_{Transport}$, the diameter of the i$^{th}$ bin can be calculated using $I_{i-NPs}$ as the intensity of the i$^{th}$ bin:

$$d_{i-NPs} = \sqrt[3]{\frac{6.(I_{i-NPs}-I_{bckgd}).t_d.q_{liq}.\eta_{Transport}}{S.f_a.\pi.\rho}} \quad \textbf{(16)}$$

Then, the average diameter can be calculated using $\overline{I_{NPs}}$ as the average signal:

$$\overline{d_{NPs}} = \sqrt[3]{\frac{6.(\overline{I_{NPs}}-I_{bckgd}).t_d.q_{liq}.\eta_{Transport}}{S.f_a.\pi.\rho}} \quad \textbf{(17)}$$

Based on equation (13), the number concentration for each i$^{th}$ bin can be calculated with $D_{i-NPs}$ as the number of events of the i$^{th}$ bin:

$$N_{i-NPs} = \frac{D_{i-NPs}}{\eta_{nebulization}.q_{liq}.D.t_d} \quad \textbf{(18)}$$

And, finally, the total number concentration as:

$$\overline{N_{NPs}} = \frac{\overline{D_{NPs}}}{\eta_{nebulization}.q_{liq}.D.t_d} \quad \textbf{(19)}$$

- ***Particle size distribution when using the µ-dDIHEN system***

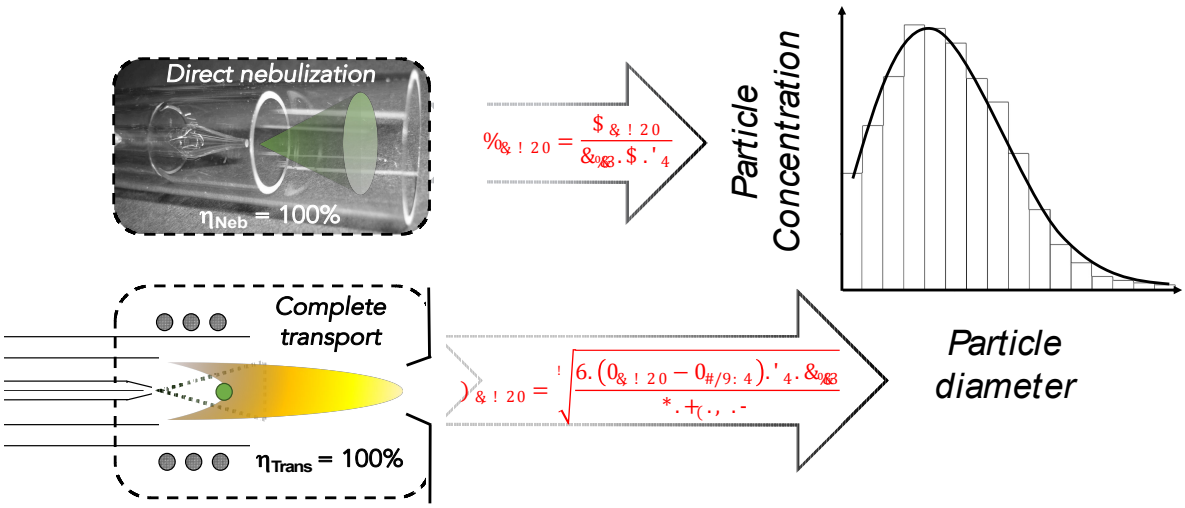


**Fig. S5** Graph of the equations for the determination of the particle size distribution when using the µ-dDIHEN system at ≤ 10 µL $min^{-1}$

Since the entire solution is nebulized into the plasma using direct injection nebulizers, we can state that $\eta_{Nebulization} = 1$. Fig. S5 shows that the determination of the number concentration for each i$^{th}$ bin and the total number concentration are simplified as followed:

$$\boldsymbol{N_{i-NPs} = \frac{D_{i-NPs}}{q_{liq}.D.t_d}} \quad \textbf{(20)}$$

And

$$\overline{N_{NPs}} = \frac{\overline{D_{NPs}}}{q_{liq}.D.t_d} \quad (21)$$

Furthermore, as stated in the manuscript, in the particular case of using the µ-dDIHEN system at an uptake-rate as low as 8 µL $min^{-1}$, $\eta_{Transport} = 1$. So, the determination of $\eta_{Transport}$ using a certified reference material is no longer required. Fig. S5 illustrates that the diameter of the $i^{th}$ bin and the average diameter are then determined using the following simplified equations:

$$d_{i-NPs} = \sqrt[3]{\frac{6.\left(I_{i-NPs} - I_{bckgd}\right).t_d.q_{liq}}{S.f_a.\pi.\rho}} \quad (22)$$

and

$$\overline{d_{NPs}} = \sqrt[3]{\frac{6.\left(\overline{I_{NPs}} - I_{bckgd}\right).t_d.q_{liq}}{S.f_a.\pi.\rho}} \quad (23)$$