Motivation of this study
- There are a lot of valuable resources (rare earth, rare metal, precious metal) in urban mine. As one of the effective methods for physical resource recovery from urban mine, we focus on a magnetic separation using magneto-Archimedes effect.

Characteristic of this study
- In this research, valuable materials can be separated only by physical methods.
- This method depends on only two parameters, density (g/cm³) and magnetic susceptibility (m³/kg).

Theory of magneto-Archimedes effect
Magneto-Archimedes effect is a phenomenon that materials levitate at a particular position in a paramagnetic medium by applying magnetic field gradient due to the difference of magnetic susceptibility and density between the medium and the materials.

\[
\frac{dB}{dz} = \frac{\rho_i V_i g}{\mu_0} - \frac{x_f}{x_i} \frac{dB}{dz}
\]

where
- \( \rho_i \) is the density of the material
- \( V_i \) is the volume of the material
- \( g \) is the gravitational acceleration
- \( \mu_0 \) is the magnetic permeability in vacuum
- \( x_f \) is the magnetic susceptibility of the material
- \( x_i \) is the density of the material

High gradient magneto-Archimedes effect and magnetic field simulation
- We could enhance BdB/dz by setting a ferromagnetic cylinders array in magnetic field.
- We calculated BdB/dz at 10 T for various ferromagnetic cylinders array at z = 30 mm.

We confirmed that horizontal uniformity of magnetic field with ferromagnetic cylinders array lower than that.

Levitating condition
- \( BdB/ \)dz magnetic force to the liquid medium
- \( \frac{dB}{dz} \) Archimedes effect
- \( x_f \) magnetic susceptibility of liquid
- \( x_i \) magnetic susceptibility of the material
- \( \rho_i \) density of liquid
- \( \rho_f \) density of the material

Experimental results
① Levitation properties of metal grains for ferromagnetic cylinders array (BdB/dz = 2500 T²/m in 10 T)
- In order to expand the range of the high magnetic field gradient, we designed the ferromagnetic cylinders array.
- When it was used, stable levitation was obtained.
- The diameter of the metal grain is 2 mm.

Experimental method
The ferromagnetic cylinders arranged in a triangular grid in acrylic cylinder were set at the center of the room temperature bore of a 10 T superconducting solenoidal magnet.

Material properties of materials
- The density (literature data) and the magnetic susceptibility measured by a SQUID magnetometer for each metal and MnCl₂ aqueous solutions used in the experiment.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density (g/cm³)</th>
<th>Magnetic susceptibility (m³/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platinum</td>
<td>21.5</td>
<td>2.64 x 10⁴</td>
</tr>
<tr>
<td>Gold</td>
<td>19.3</td>
<td>3.45 x 10⁴</td>
</tr>
<tr>
<td>Silver</td>
<td>10.4</td>
<td>2.43 x 10⁴</td>
</tr>
<tr>
<td>Copper</td>
<td>8.93</td>
<td>2.25 x 10⁴</td>
</tr>
<tr>
<td>Copper powder</td>
<td>8.93</td>
<td>2.03 x 10⁴</td>
</tr>
<tr>
<td>MnCl₂ solution</td>
<td>1.33</td>
<td>4.13 x 10⁴</td>
</tr>
</tbody>
</table>

The copper grains and powder levitated within the range of 2 mm.