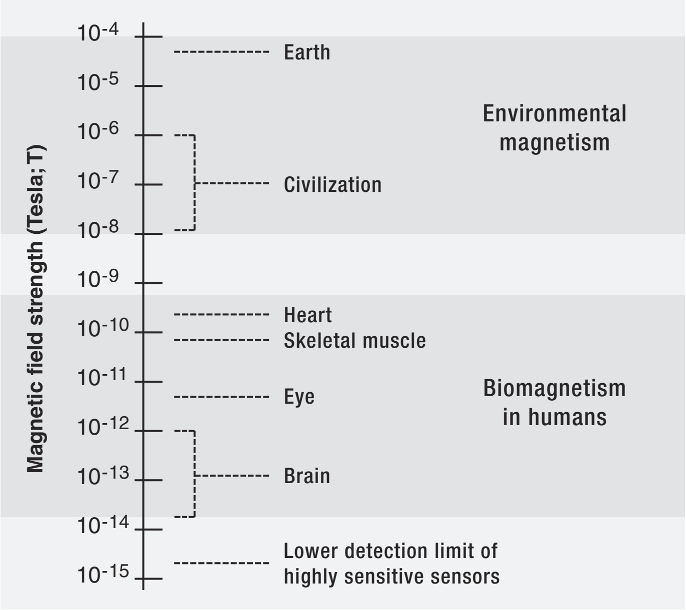
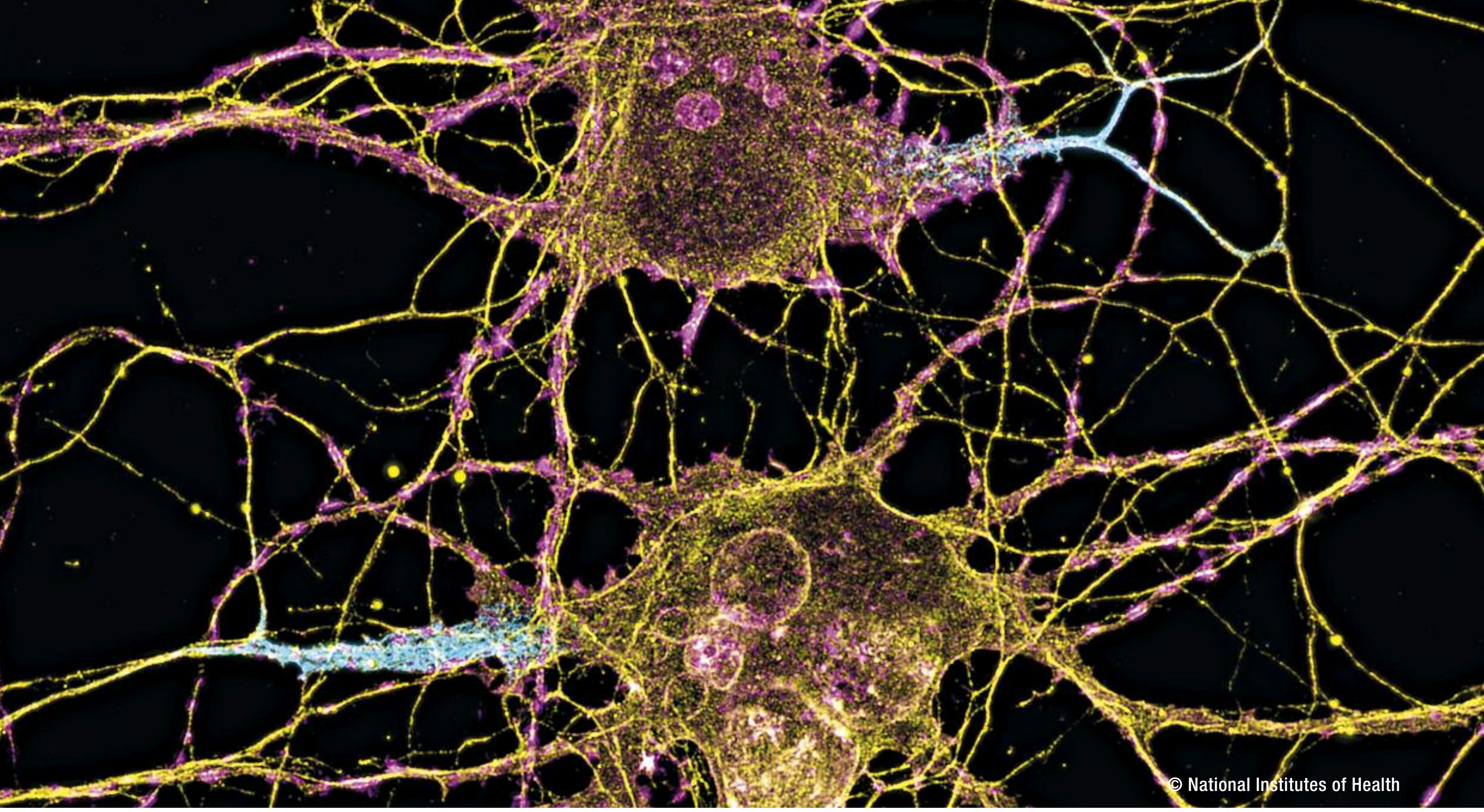
Molybdenum in magnetically shielded rooms

Detecting nature's tiniest magnetic activity for medicine and research relies on suppressing a constant barrage of external magnetic influence. For decades, a molybdenum-containing alloy called mu-metal has been used as a magnetic shielding material due to its ability to divert both the Earth's natural magnetic field and manmade sources. Today, rooms clad in layers of mu-metal and similar alloys provide unfathomable levels of magnetic shielding for procedures that save lives and extend the frontiers of science.

The typical strength of magnetic signals generated by human brain activity is around one billionth of the strength of the earth's magnetic field. To measure and analyze such weak signals without them being drowned out by the environment's much stronger magnetic field, a magnetic shielding room (MSR) is necessary to provide passive shielding. MSRs are critical for diagnostic imaging techniques of the heart and brain, such as magnetoencephalography (MEG), a non-invasive procedure used in planning for surgeries and epilepsy treatment. MEG is also very important to psychiatric and neuroscience research. For example, university researchers in Pittsburgh, US, placed subjects in an MSR and used MEG to measure their brains' magnetic activity while listening to music, revealing key insights about how humans perceive sound. Indeed, MSRs are used in a variety of research applications ranging from cognitive science to aerospace. A stable MSR with consistent performance over the years is crucial in maintaining the precision of the multi-million-dollar systems within.



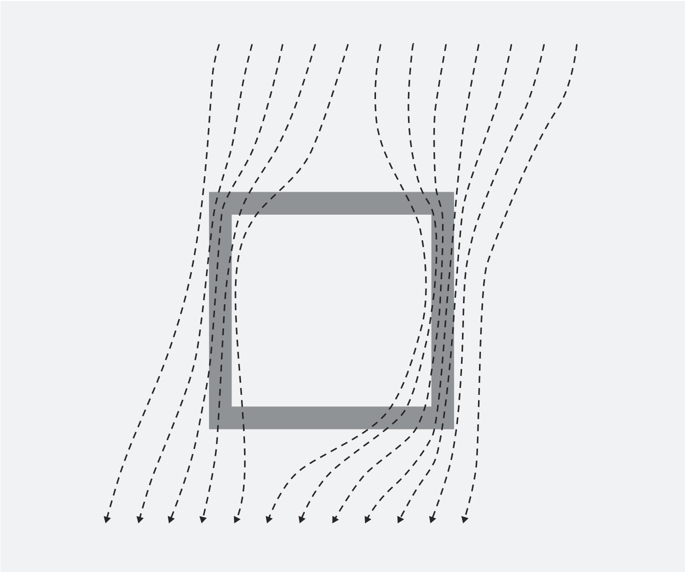
The magnetic fields of human brains and other body parts are many orders of magnitude smaller than that of the earth.



Neurons are the structures in the brain that produce magnetic fields – it is the interaction between neurons that magnetoencephalography (MEG), performed inside of magnetically shielded rooms, detects.

MSR history

Since the 1960s, scientists attempted to construct a magnetically shielded room for research in physics and biology. The first commercial MSR became available in the 1970s, with key standardization efforts in the 1980s. Today, modern MSRs are constructed by forming a room-sized enclosure using layers of both a metal with high magnetic permeability, mu-metal, and a metal with high conductivity, usually aluminum. A typical MSR consists of two or more layers of mu-metal and one layer of aluminum in the wall construction. As shown in the figure on the right, this combination of construction materials can effectively cancel out the external magnetic field inside the MSR. The MEG-system or other sensing unit is placed in the center of the room where it is essentially free of any magnetic field. The effectiveness of an MSR is quantified by the “shielding factor” – a ratio between the external field strength and the internal field strength. Today, commercial MSRs can suppress external magnetic fields by several thousands of times.



Mu-metal/aluminum walls deviate and block external magnetic fields around the magnetically shielded room. The space inside is practically free of a magnetic field.

The multi-layered MSR wall relies on two different mechanisms to block external magnetic fields, depending on the frequency of the external magnetic field. At a higher frequency, the MSR wall can react to a varying magnetic field by forming an internal electrical current (eddy current). The internal current forms a counter magnetic field that cancels out the external magnetic field. However, for static or slowly varying magnetic fields, this counter current effect becomes negligible. Therefore, the magnetic shielding solely relies on the high permeability of mu-metal, which provides an easy path for the external magnetic field, causing the field to deviate inside the wall.

❯ **The walls of magnetically shielded rooms consist of layers of mu-metal and aluminum.**

Mu-metal background

A typical mu-metal consists of nickel and iron and contains 2–6% molybdenum. When mu-metal was initially developed, it contained no molybdenum. In the 1930s, researchers added molybdenum to mu-metal intending to improve its electrical resistivity and mechanical properties. They coincidentally discovered that the addition dramatically increased magnetic permeability. Modern mu-metals and mu-metal similar alloys have various alloy compositions, depending on the application and manufacturer. However, all formulations contain molybdenum.

Due to its high permeability, mu-metal can deviate slowly-changing magnetic fields. Compared to other conventional soft magnetic materials, mu-metal's permeability is orders of magnitude higher, providing a stronger shielding effect without increasing the quantity of material used. Mu-metal is also a ductile alloy making the industrial production of thin gauges in relatively large quantities possible, and allowing flexibility in MSR design and assembly. The alloy is named after the Greek letter μ, mu (pronounced "myoo"), the symbol used to represent "magnetic permeability".

Mo makes mu-metal better

The industrial production of mu-metal for MSRs uses vacuum induction melting (VIM) technology. The alloy is processed into desired shapes before the final annealing step, where it is heated to around 1100°C in a hydrogen atmosphere. At that temperature, the metallic grains grow rapidly, leading to larger grains with increased magnetic permeability. The addition of a small amount of molybdenum increases the magnetic permeability further by optimizing the intrinsic magnetic properties of the alloy. By helping effectively shield the inside of MSRs from the external magnetic field, molybdenum enables the proper function of essential medical devices that have saved or improved the lives of thousands of patients.

The end-use applications for MSR are niche but have the potential to expand. This expansion is not only driven by a developing healthcare infrastructure globally, but also by the emergence of new research areas. Several prestigious laboratories worldwide have installed magnetic shielding chambers to study the fundamental principles of particle physics. For example, the Paul Scherrer Institute in Switzerland, in partnership with VACUUMSCHMELZE GmbH & Co. KG, developed an elite MSR that dampens external magnetic influence by a hundred thousand times. This allowed researchers to detect subatomic magnetic signals previously invisible to the latest-generation sensing technology. To achieve greater sensitivity, over 10 times more precise than its predecessor, this MSR uses more and thicker layers of mu-metal shielding than standard units. Regardless of the application, with molybdenum nickel-iron soft magnetic alloys will remain the ideal material for magnetically shielded rooms. (Pengfei Zhan)

❯ **MSRs are typically around 4 x 4 m, big enough to contain relatively large equipment. Here a projector (top right of the door) displays images. The MEG detects the activity of the subject's brain neurons as a reaction to viewing the images.**