Rare Earth Magnets and Their Applications

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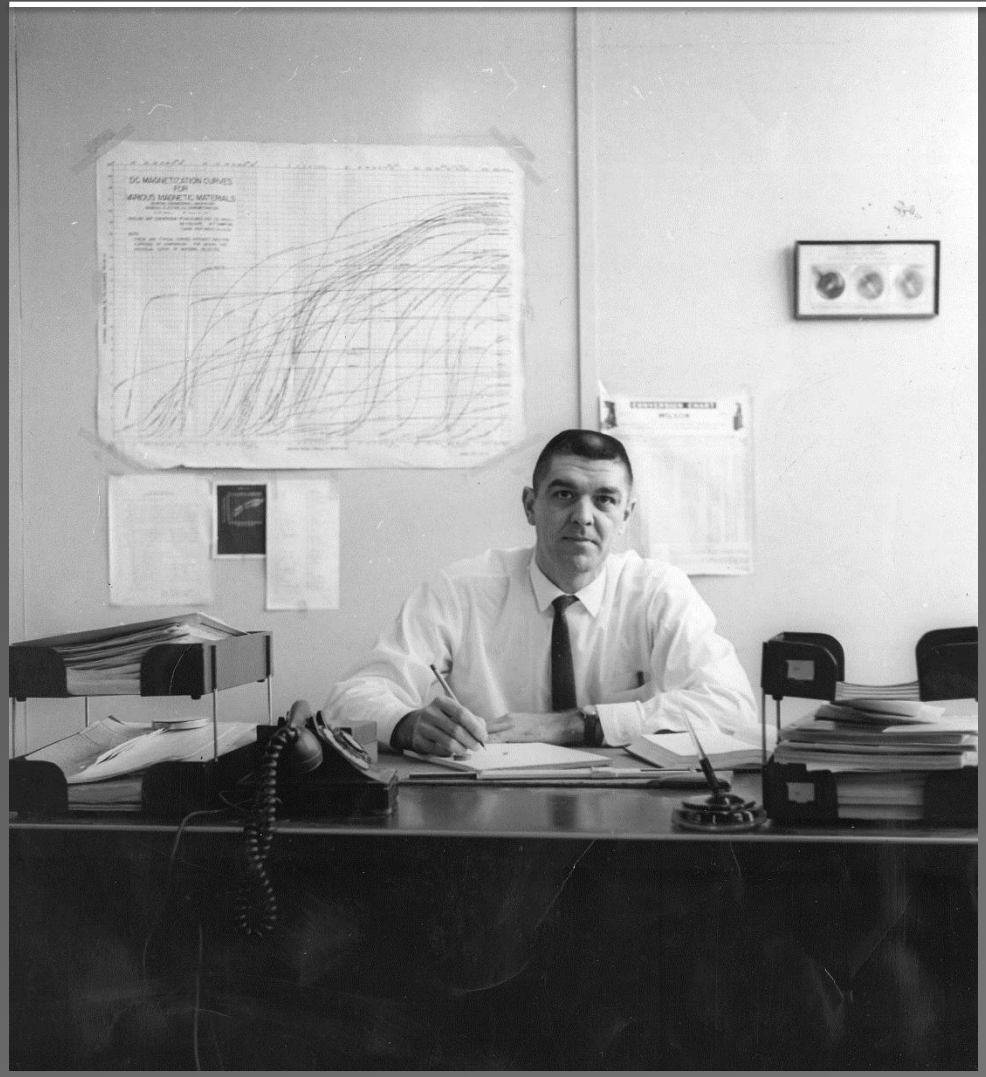
Outline

- EEC Introduction
- Overview of Rare Earth Materials
- Sintered Magnet Manufacturing Process
- Design Theory
- Magnet Applications

EEC Introduction

47 YEARS OF INNOVATION

ELECTRON ENERGY CORPORATION



Marlin Walmer

- Founder of Electron Energy Corporation
- Pioneered the processing and subsequent commercialization of an entirely new class of permanent magnets (SmCo) in 1970.

Hamilton Watch Company

World's 1st electric watch named the "Ventura"…made famous by Elvis Presley.

EEC History

EEC is founded in 1970 *(in a Milk House with **2 employees**)* as Marlin Walmer pioneered the processing and subsequent commercialization of an entirely new class of permanent magnets (SmCo)

40,000 square foot facility was built to support the steady growth of business from 1970-1985

Add a new 45,000 square foot facility now housing the magnet finishing operation

(Rapid growth of business)

1960's — **Founder Marlin Walmer is working at Hamilton Watch pioneering platinum-cobalt magnets** for the world's first electric watches

1970

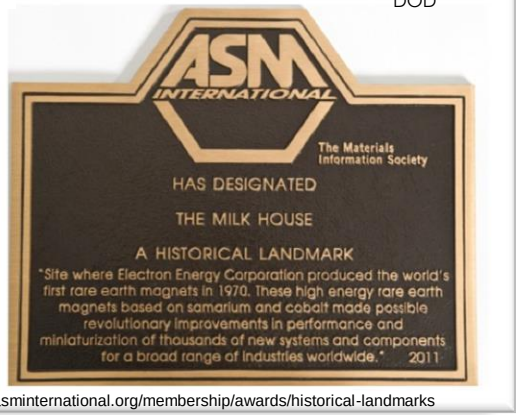
1972 — **Moved to 10,000 square foot facility** on Main St. Landisville with **67 employees**

Mid 70's — **Developed Temperature Compensated SmCo** that have near-zero change in magnetic field over temperature changes

1985

2002 — **Patented Ultra-High Temp SmCo 2:17 magnets** in 2002 which operate at temperatures up to 550°C

2012 — EEC "Milk House" is recognized as an **ASM Historical Landmark**



www.asminternational.org/membership/awards/historical-landmarks

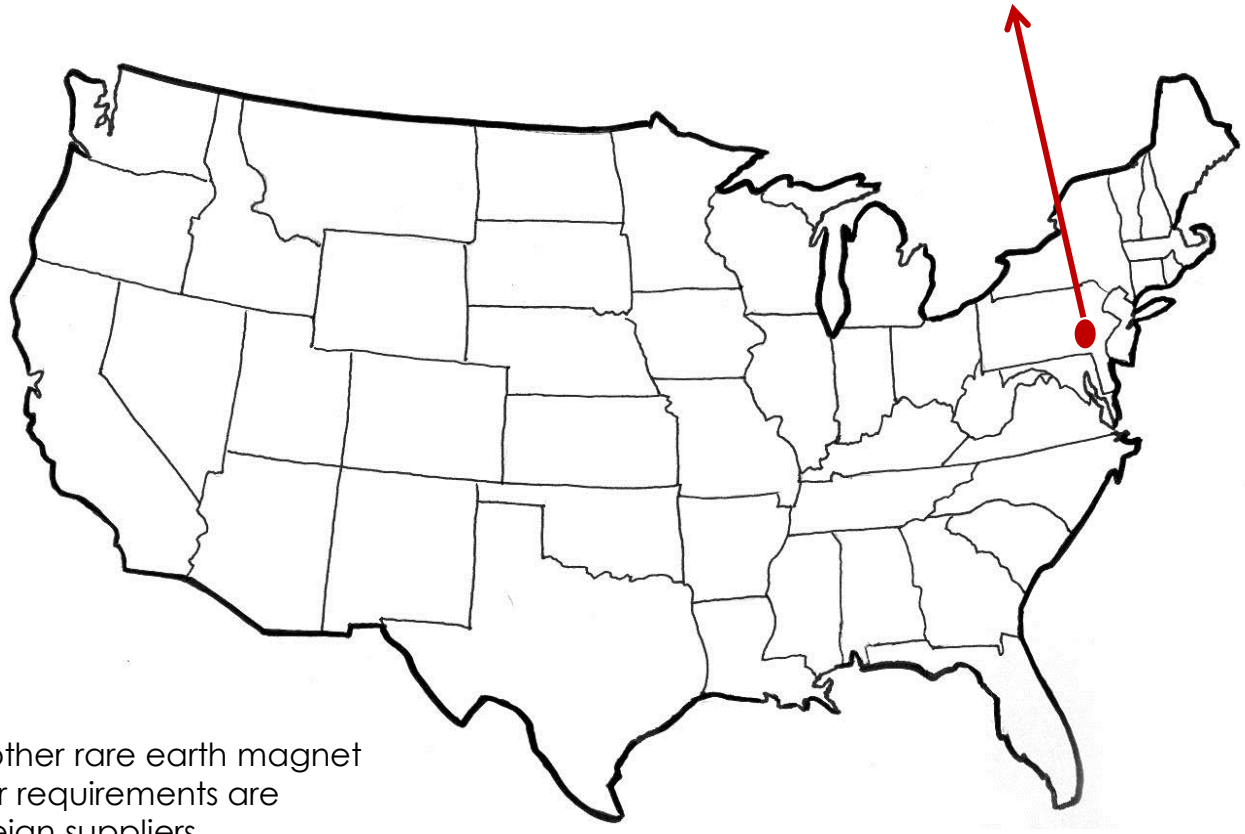
2014 — **EEC has received 25 SBIRs & STTRs awards** since 1996 from NASA, DOE, NSF, EPA, and DOD

Headquarter

Post-sintering Operations

First and Only Rare Earth Magnet Producer in USA

EEC is the only remaining vertically integrated U.S. SmCo producer remaining in the country.



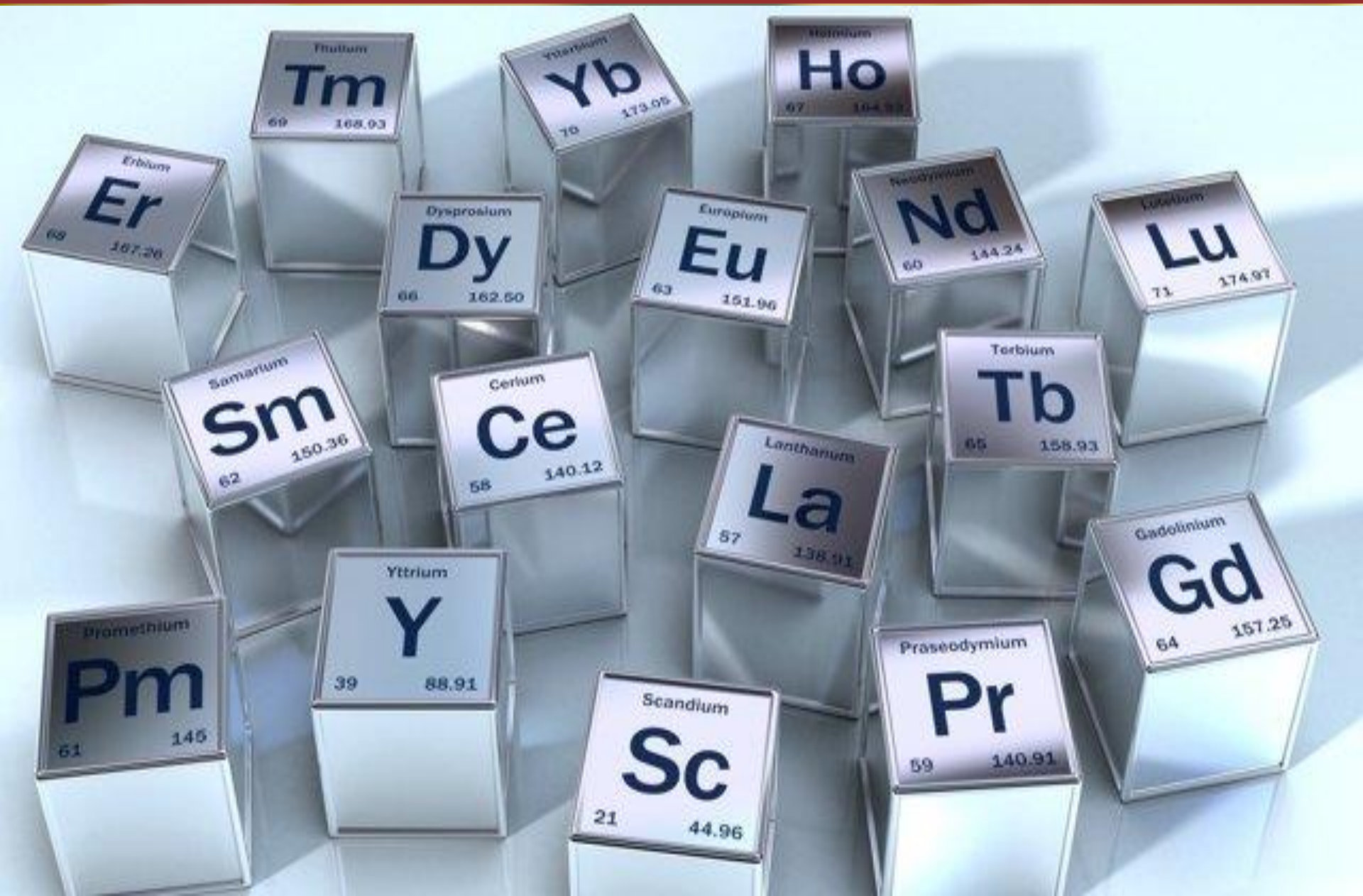
There are many other rare earth magnet suppliers, but their requirements are supported by foreign suppliers.

EEC Technology Center

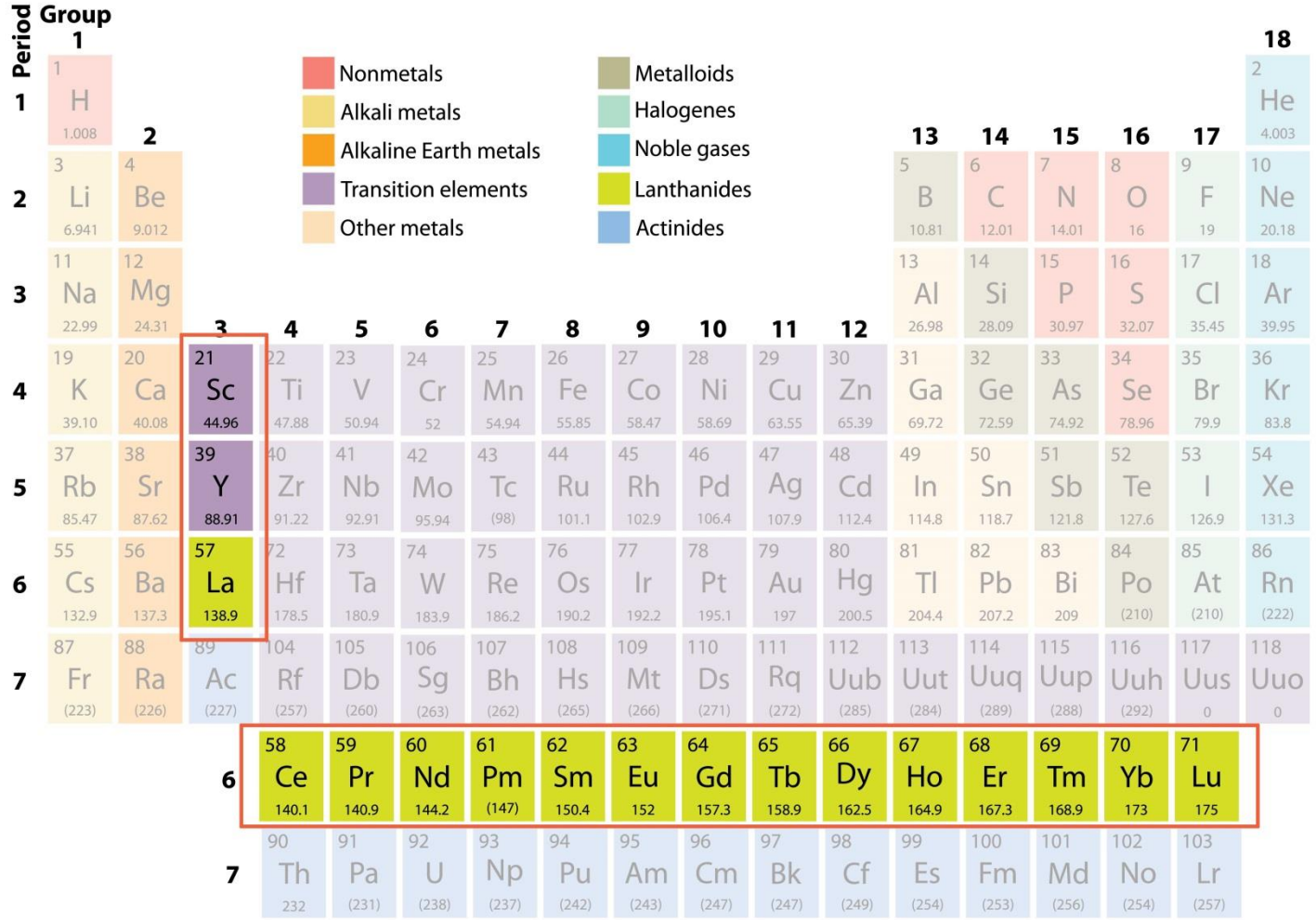
Strong and highly skilled engineering support body for efficient realization of customer solutions

- +14 Engineers with a passion for customer magnetic solutions
- Material adaptations for specific needs
  - Production requirements
  - Laboratory scale materials
- FEA Analysis (2D & 3D)
- Application Engineering development and advisory services
- Testing capabilities
- Analysis of magnetic properties
- Over 200 publications
- Diverse engineering team with scientist from China, Romania, India, South Korea, & United States

Brief Overview of Rare Earth Materials



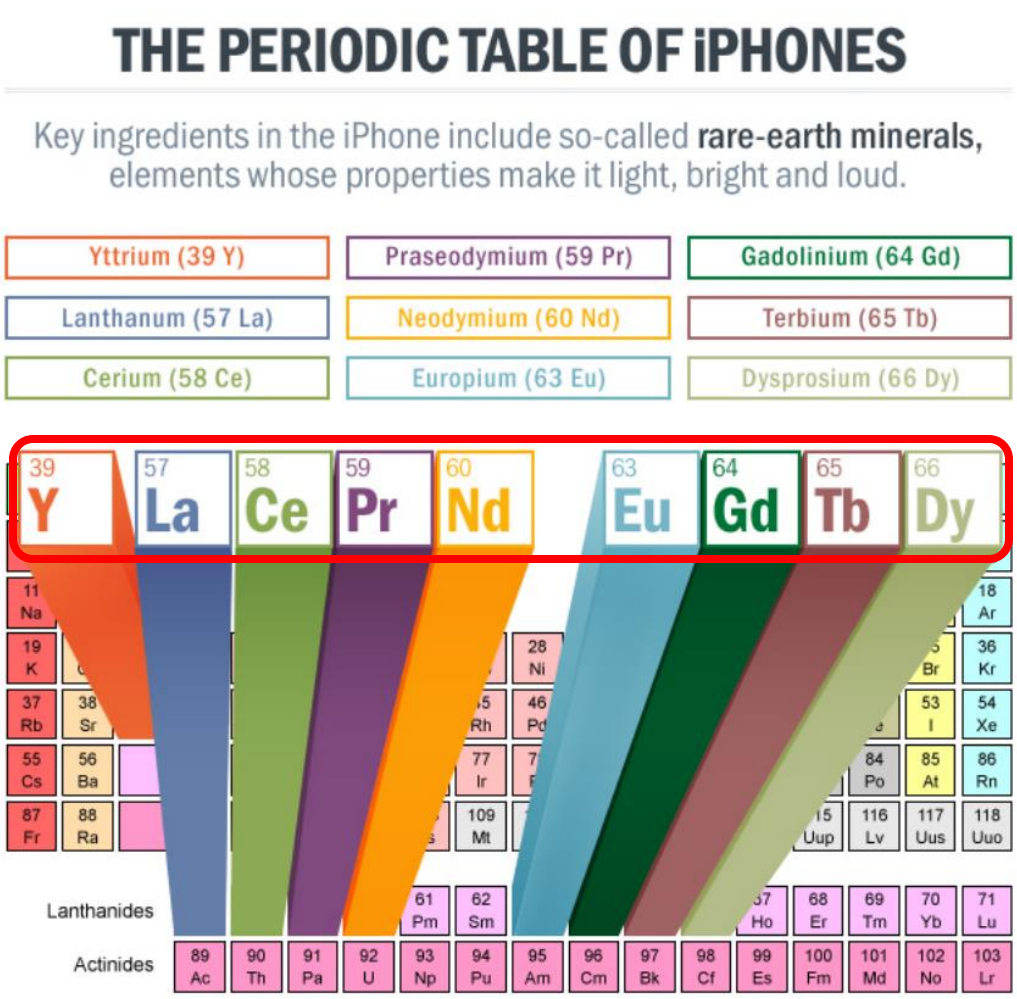
What is Rare Earth Element?



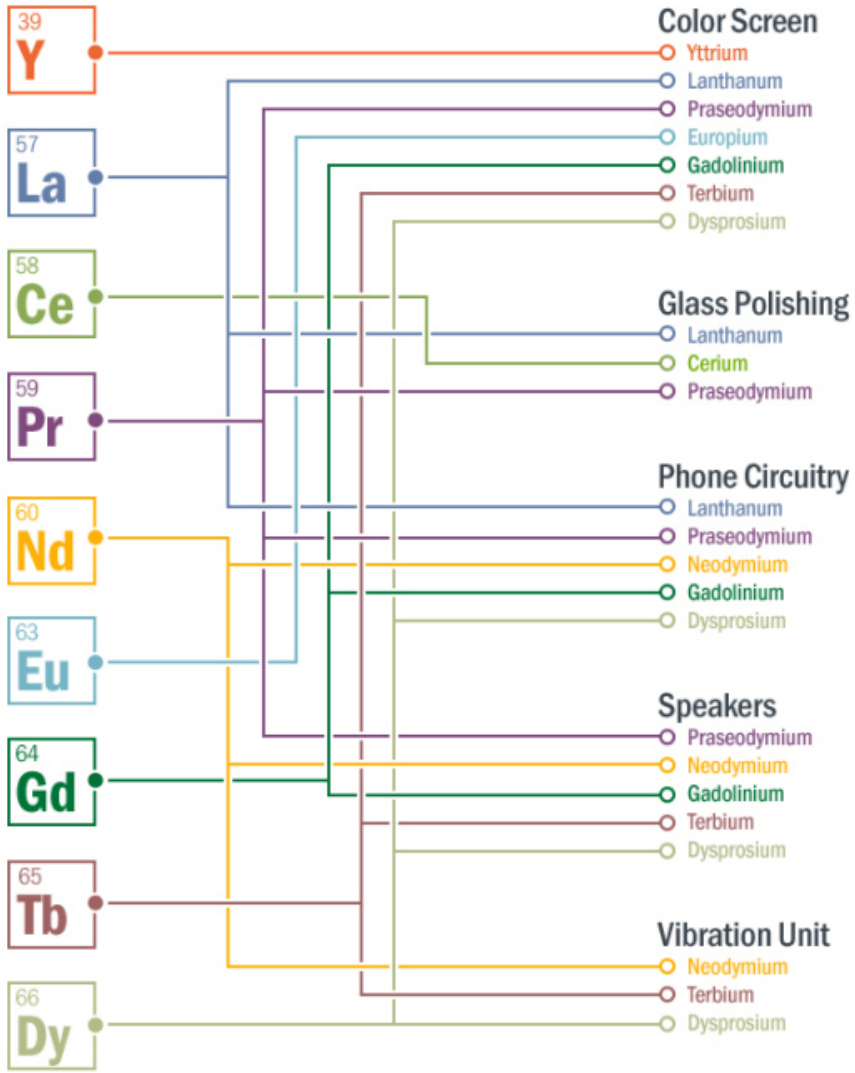
- **88 Naturally occurring elements**
- **28 created elements**
- **17 rare earth elements**

- Elements along or in combinations make up our bodies, our world, our sun, and the entire universe.
- The most abundant element in the Earth's crust is Oxygen (silicon, Al, Fe, Calcium, Sodium, Potassium, Magnesium, Ti, Hydrogen,…)
- **Are the rare earth materials really 'Rare'?** No, but very difficulty to mine because it is unusual to find them in concentrations high enough for economical extraction.

IPhone Uses 8 Rare Earth Elements

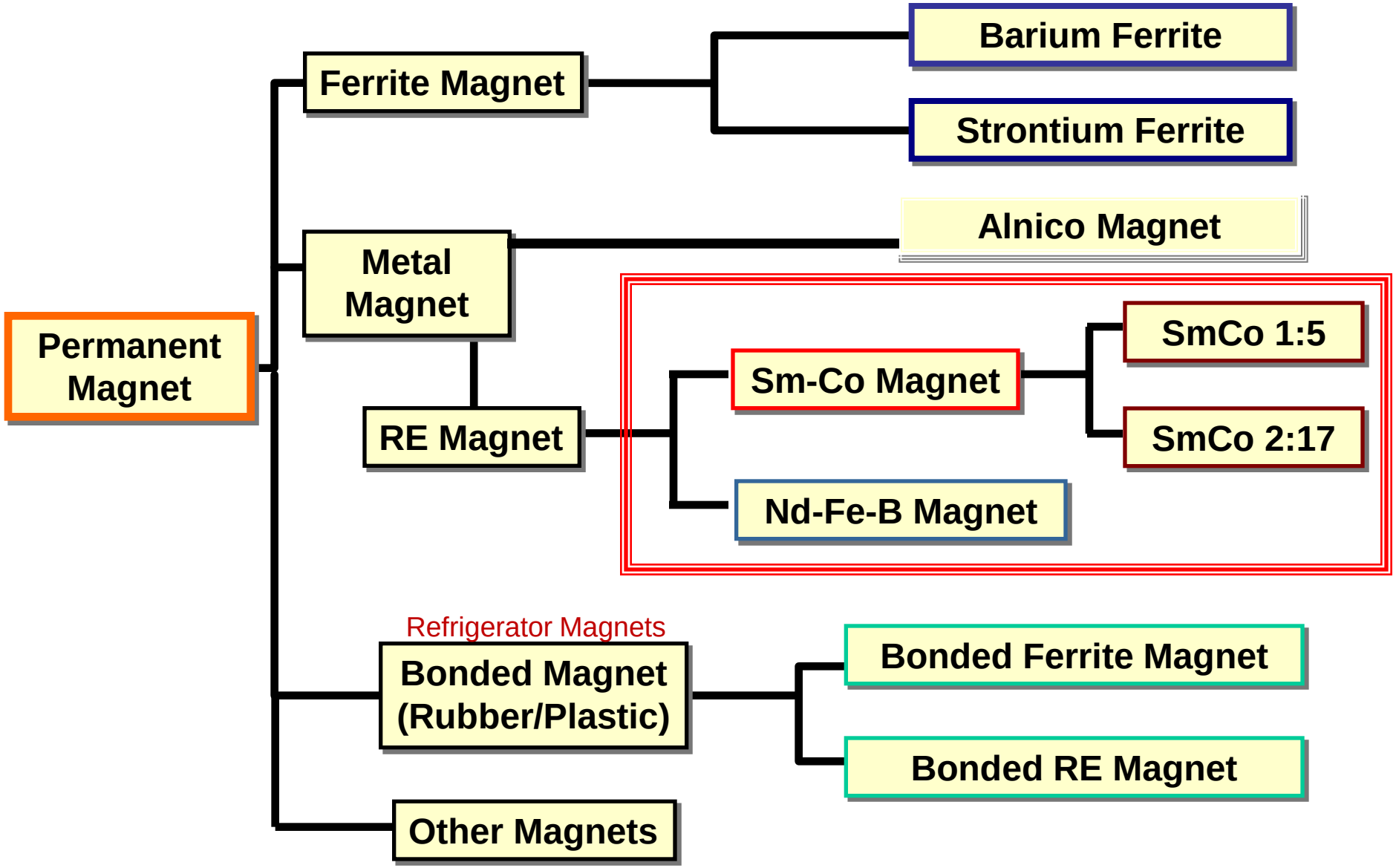


[Source: http://www.cnet.com/news/digging-for-rare-earths-the-mines-where-iphones-are-born/]

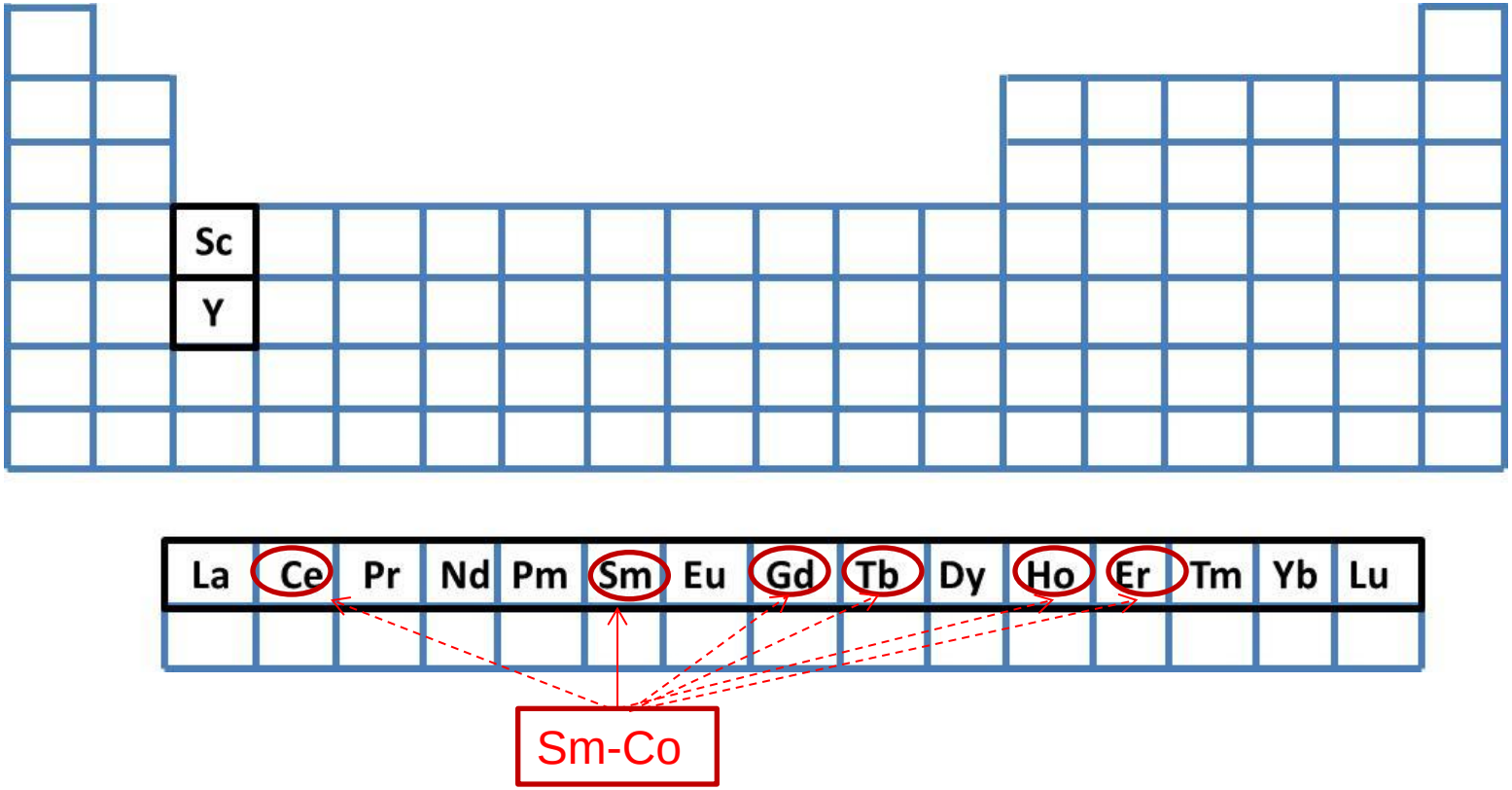


Minerals such as **Neodymium** are used in magnets that make speakers vibrate to create sound. **Europium** is a phosphor that creates a bright red on an iPhone screen. **Cerium** gets put into a solvent that workers use to polish devices as they move along the assembly line. "Your iPhone doesn't work without rare earths in there, " said Mark Smith, chief executive of Molycorp.

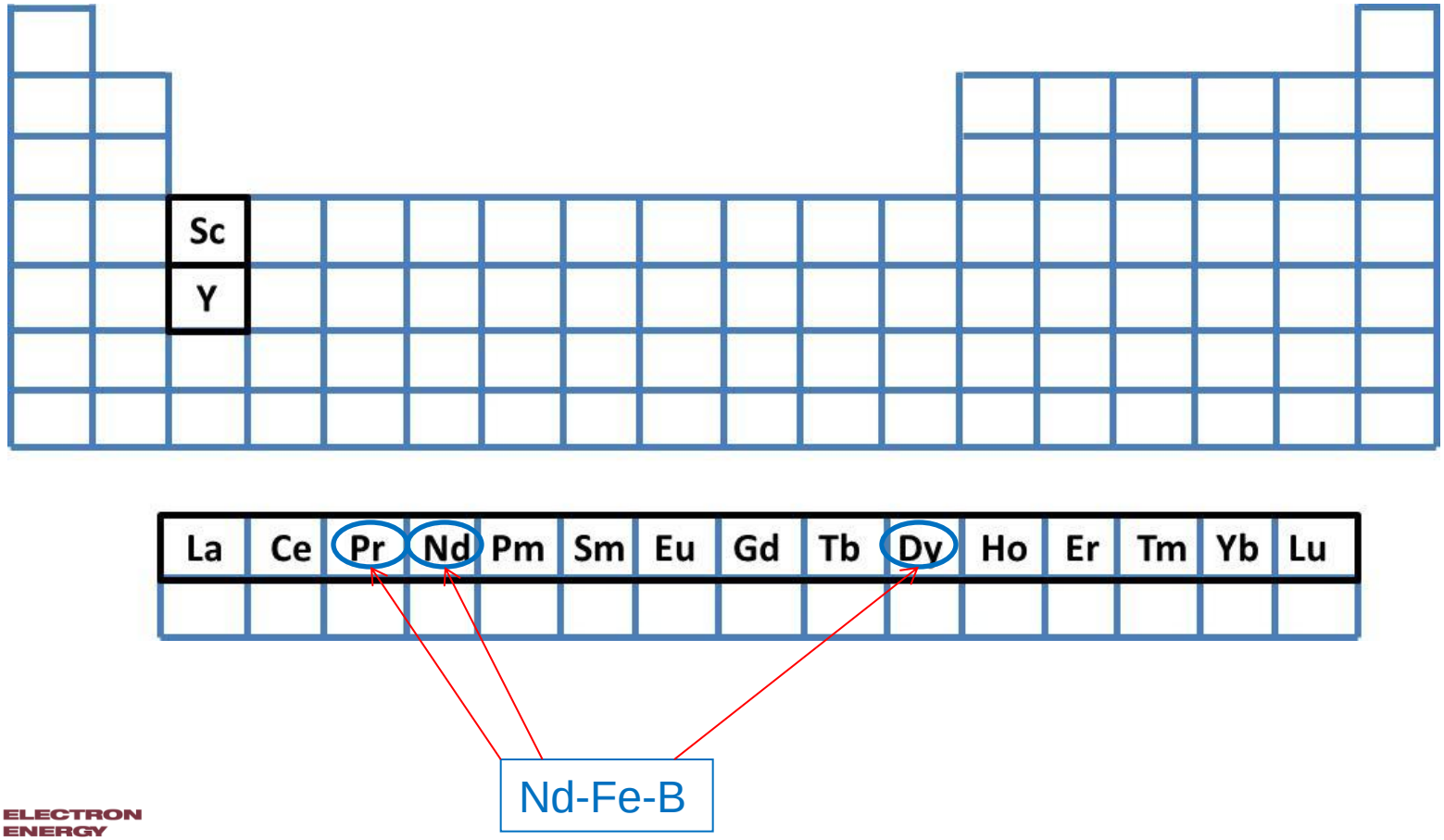
Permanent Magnet Types



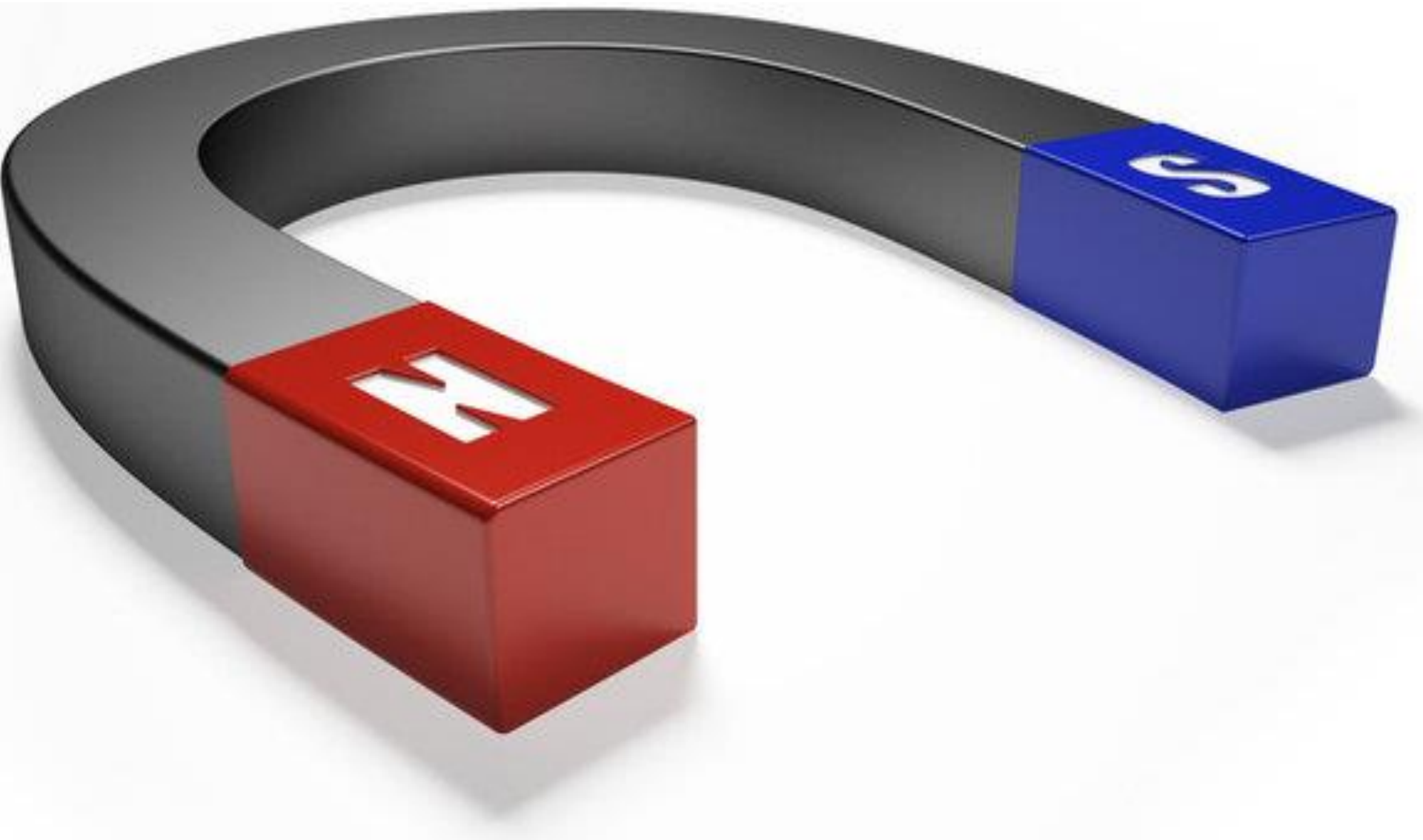
Sm-Co Magnet Elements



Nd-Fe-B Magnet Elements



How to Make Permanent Magnets



PM Manufacturing Process

Typical Manufacturing Process for Sintered Sm-Co Magnets

Raw Material

EEC purchases pure raw materials-Sm,CO,Fe,Cu,&Zr for the in-house production of SmCo 1:5 & 2:17 alloys

Induction Melting

Pure metals are alloyed in an inert gas using an induction melting furnace. Precise control of alloy chemistry allows EEC to produce a wide range of materials to meet your demanding requirements.

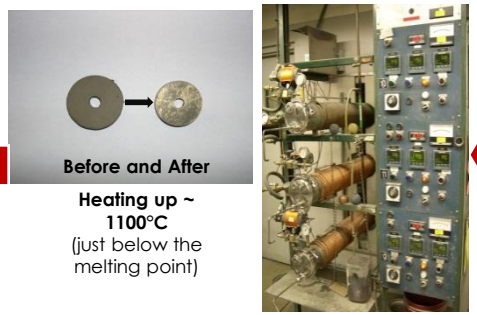
Ball or Jet Milling

We process crushed alloy by milling and reducing to a particle size. Because the resulting fine powder is chemically reactive and pyrophoric in nature, it requires protection from air (oxygen) using inert gas.

Crushed Magnet Powder

Axial, Transverse & Isostatic Pressing

Axil pressing force is parallel to alignment created by magnetic field. Transverse pressing forces is perpendicular to magnetic alignment field. Isostatic pressing provides equal pressure from all directions for pre-aligned powder.



Heating up ~ 1100°C
(just below the melting point)

Sinter

Densification and the development of magnetic properties are accomplished through sinter, solution and aging processes in the presence of a vacuum or an inert gas.

Machining

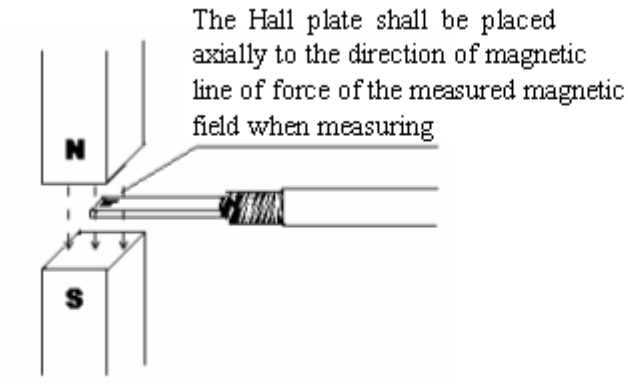
Sintered rare earth magnets, because of their brittle nature, are machined to final dimensions using grinding, slicing, or wire EDM technology.

Magnetizing, Testing, & Quality Assurance

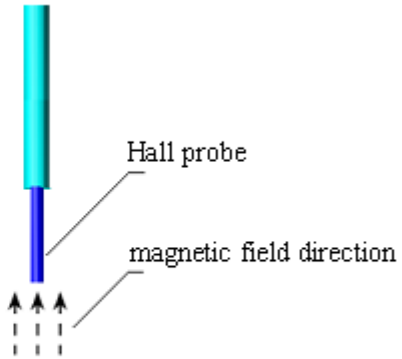
Magnetization, stabilization and testing of rare earth magnets are done to satisfy your specific requirements.

Magnet Testing Instruments

Hall Probe and Gaussmeter

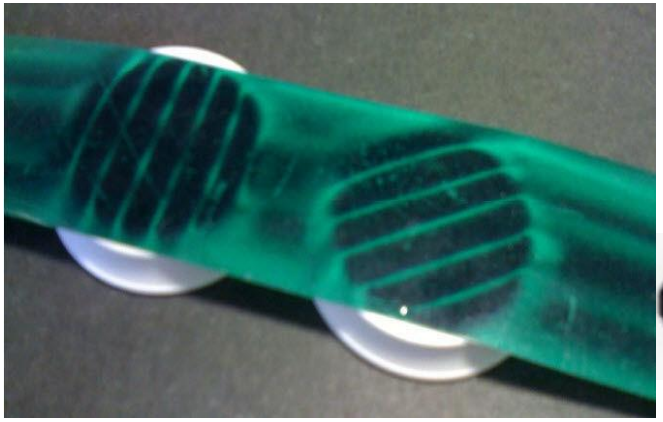


(Fig.1 Transverse probe)



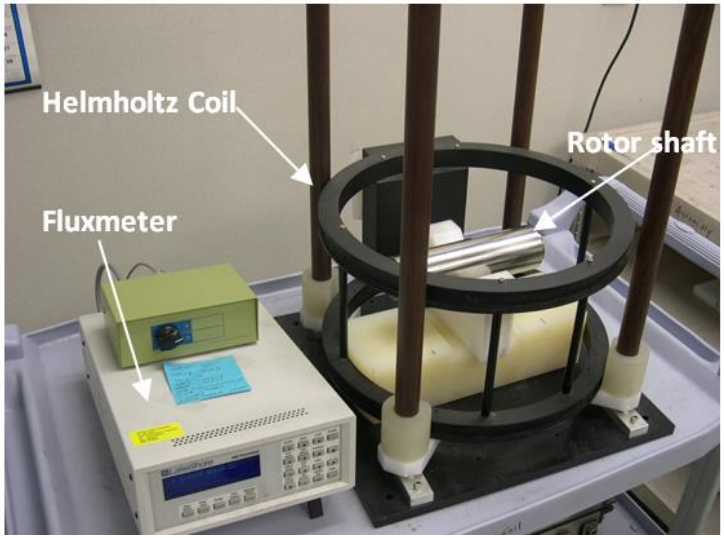
(Fig.2 Axial probe)

Magnetic film



Pole Indicator

Helmholtz Coil



EEC Applications

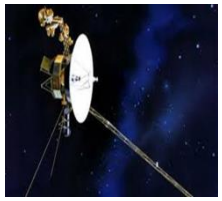
CUSTOMERS

Markets

Defense

Communications | Aerospace | Motion | Instrumentation | Medical | Sensors

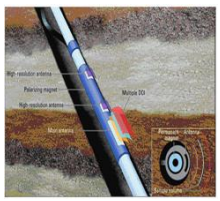
Applications



TWT, Circulators& Isolators

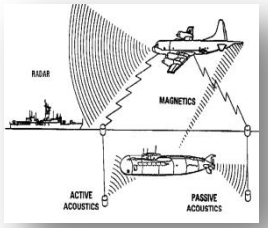
Gyroscopes
Accelerometers

Motors
Generators



NMR
Oil & Gas Exploration

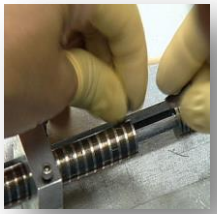
MRI for
medical

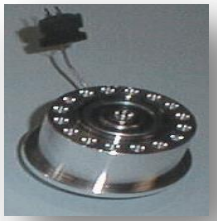


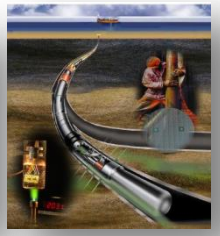
Sensors

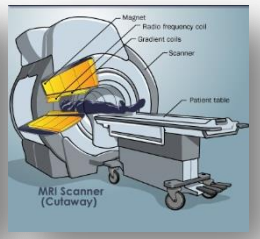
EEC

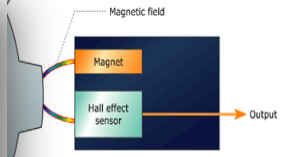
Magnet Assemblies











Magnet Components

Military Applications

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Specialists in Rare Earth Magnets and Magnet Systems

AC-130 Gunship Imaging System

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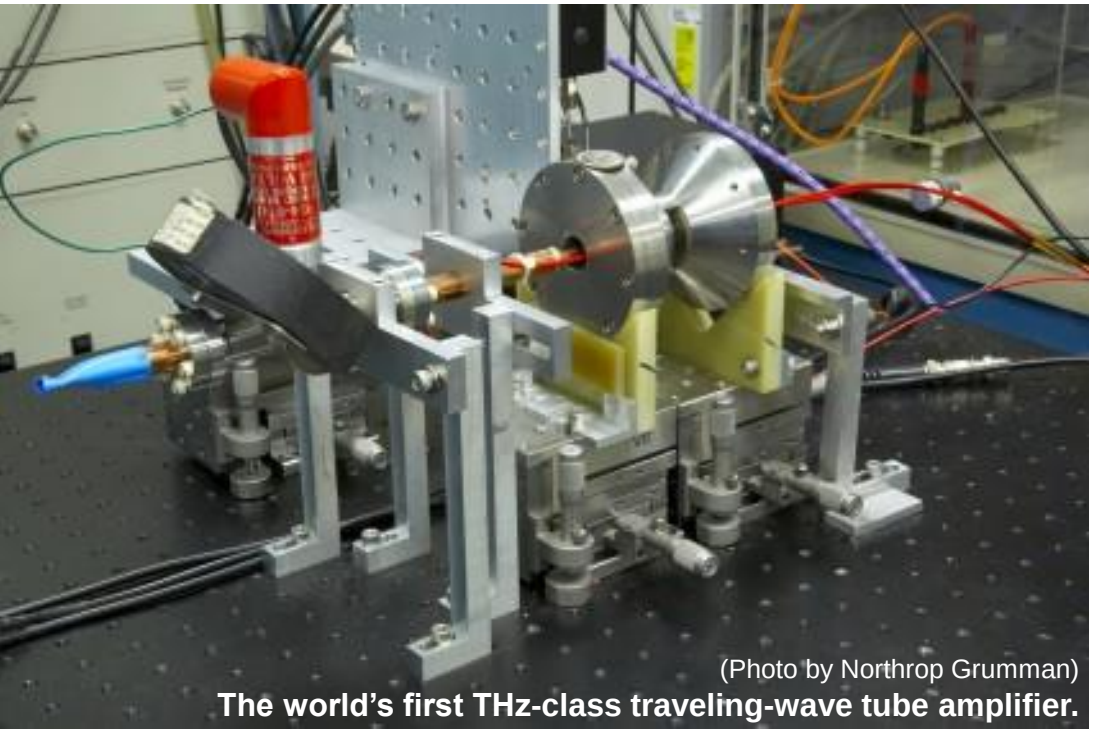
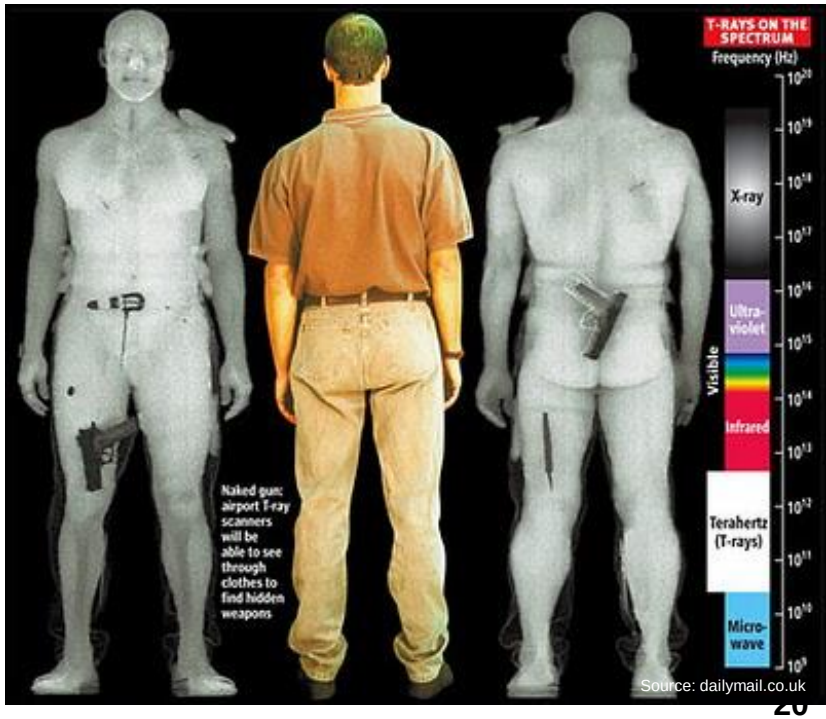
NORTHROP GRUMMAN

THz Applications

- THz waves are found between microwaves and infrared on the electromagnetic spectrum. This type of radiation was chosen for security devices because it can penetrate matter such as clothing, wood, paper and other porous material that's non-conducting..
- **Security** – Image resolution similar to that viewed with the human eye under visible light. Scanning detect explosives, plastic weapons and drugs from tens of meters away.
- **Health** - T-ray is a lot safer than an X-ray because its radiation is non-ionizing.
- **Communication** – Having a much higher frequency than microwaves, there is huge potential for them to be used to create wireless networks exceeding 100 GBs/s.



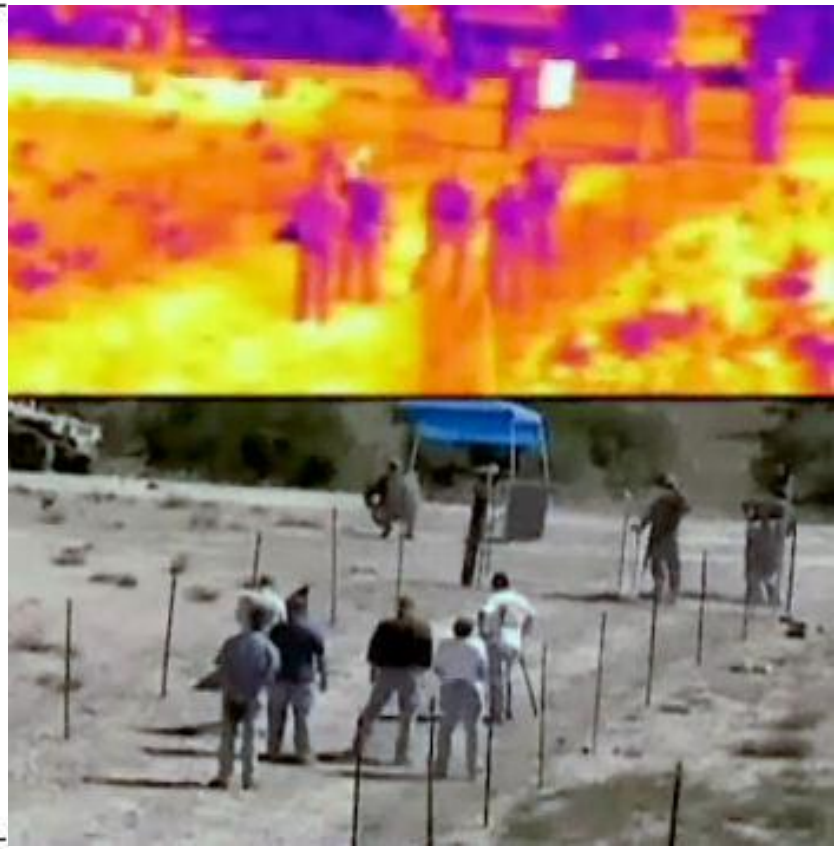
(Photo by Northrop Grumman)
The world's first THz-class traveling-wave tube amplifier.



Active Denial System

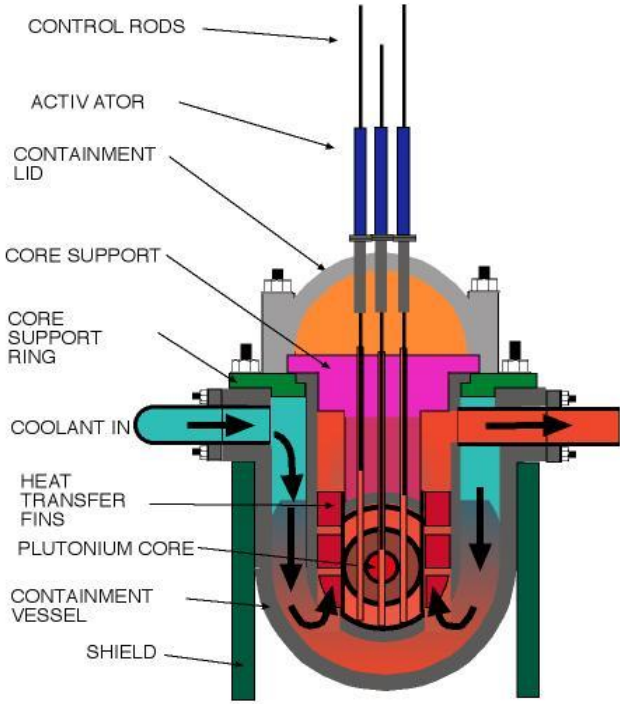
Non-lethal weapon

ADS projects a focused millimeter wave energy beam which induces intolerable heating sensation on an adversary's skin (0.4mm deep) and cause that individual to be repelled without injury. The invisible '**pain ray**' can travel up to 500m (1,640ft).



Gerald R. Ford Aircraft Carrier

EEC Sm-Co magnets are used in nuclear reactor for the Gerald Ford Aircraft Carrier.



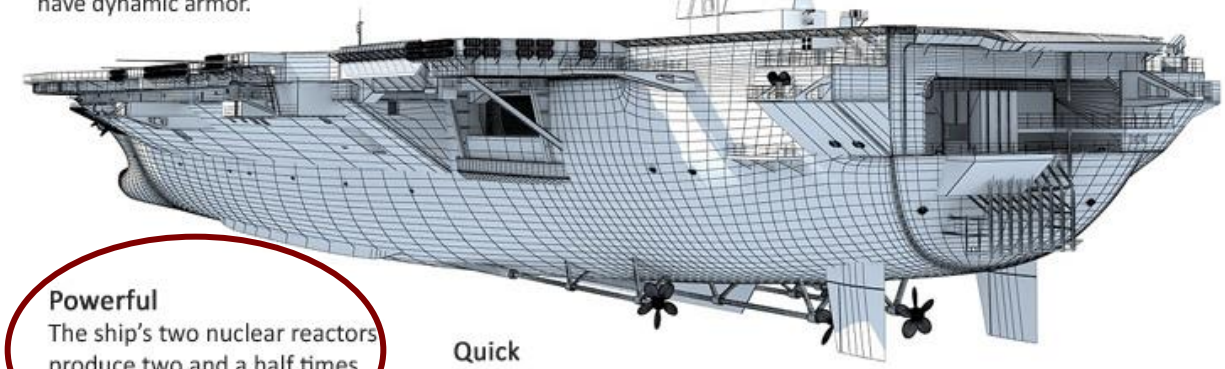
[Source: Wikimedia]

On 11/17/2013, Navy launches world's most advanced nuclear aircraft carrier.

STURDY
Critical areas of the vessel including the ammunition and fuel storage areas, have dynamic armor.

ROOMY
The more rearward position of the control tower allows more room on the flight deck for more aircraft.

STEALTHY
The Ford-Class of Aircraft Carrier features improved stealth capabilites which greatly reduces the 333 meter long vessels' radar signature.



Powerful
The ship's two nuclear reactors produce two and a half times more power than the previous Nimitz-class carrier.

Quick
Each of the four propellers measures seven metres in diameter. They allow for a top speed of 30 knots (35 mph)

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http://www.gandoza.com

F-22 Raptor vs. EA-18G Growler

Who wins?

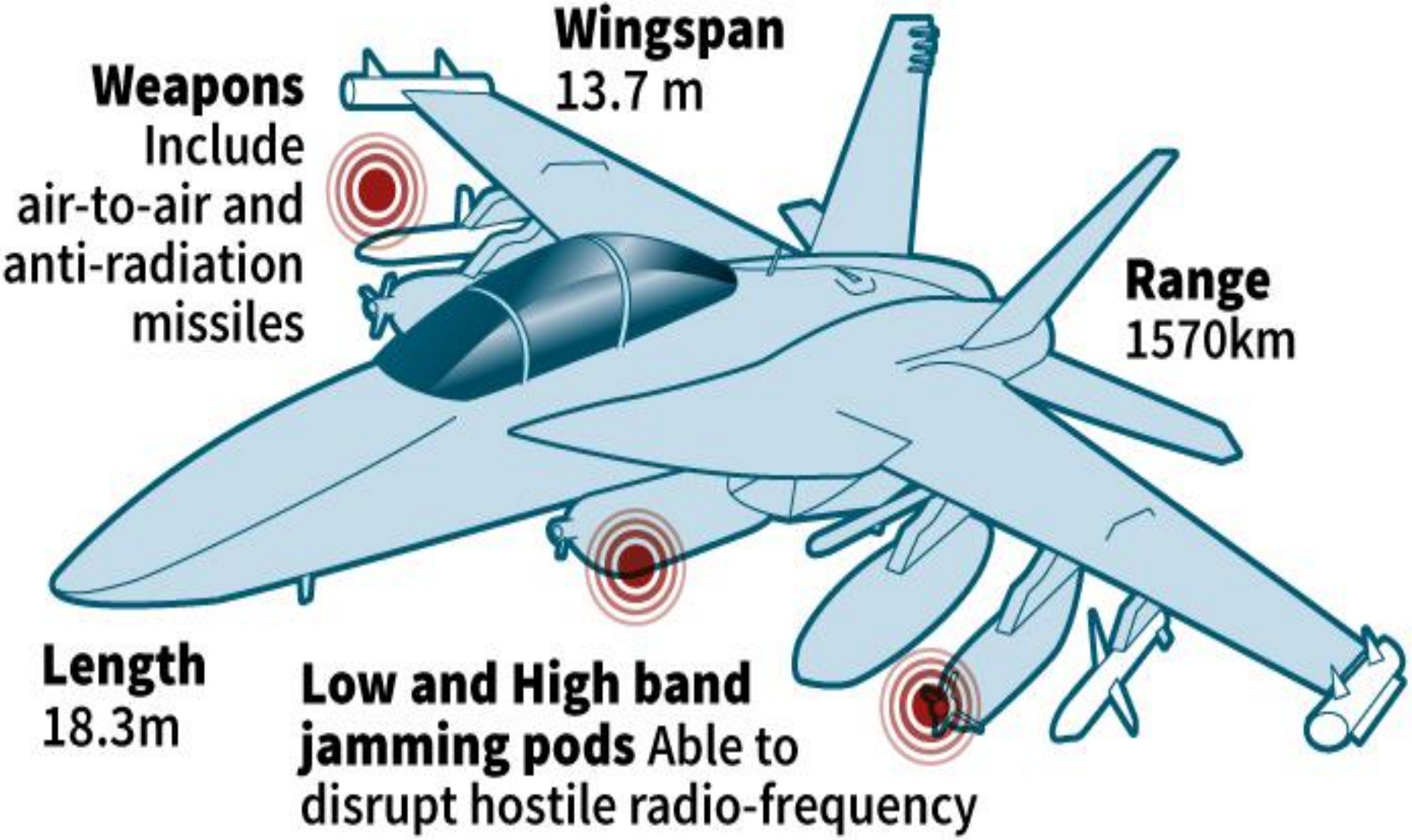
$150M vs. $68.2M

1 pilot vs. 2 pilots

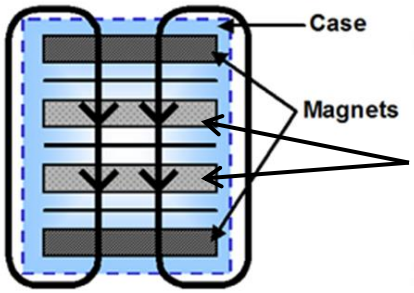
EA-18G Growler

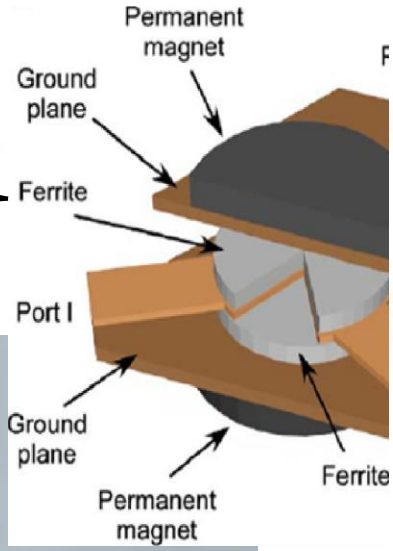
Electronic Warfare Aircraft

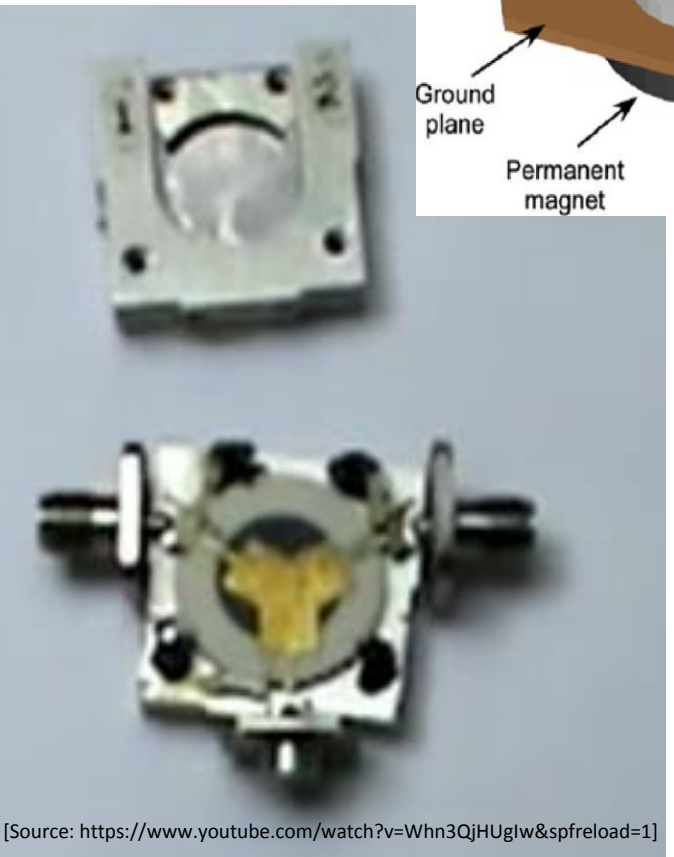
Maximum speed
1960 km/h (Mach 1.6)



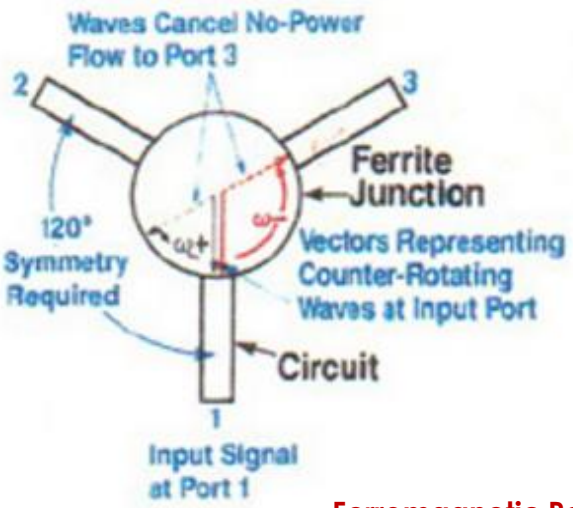
How It Works?

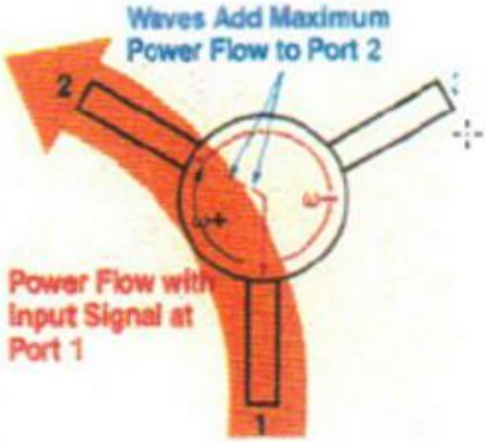




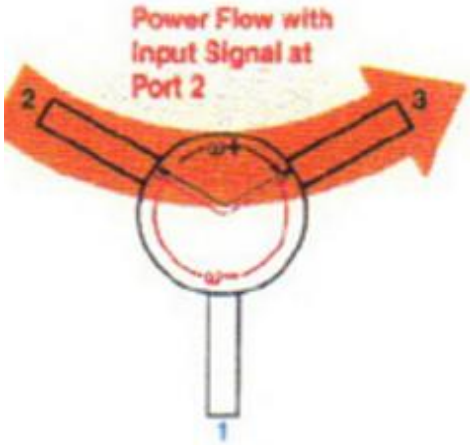


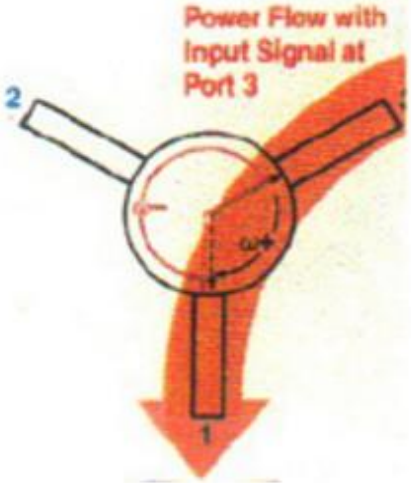
[Source: https://www.youtube.com/watch?v=Whn3QjHUgIw&spfreload=1]





Ferromagnetic Resonance Principle ('Merry-go-round')

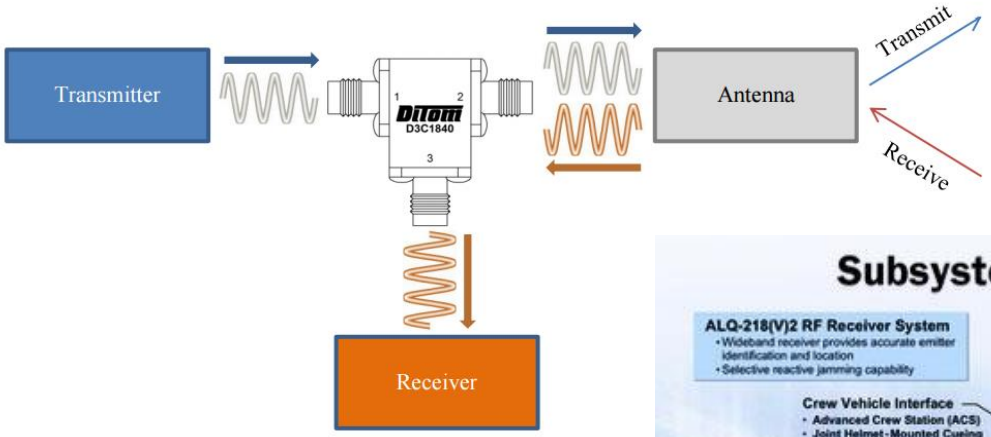




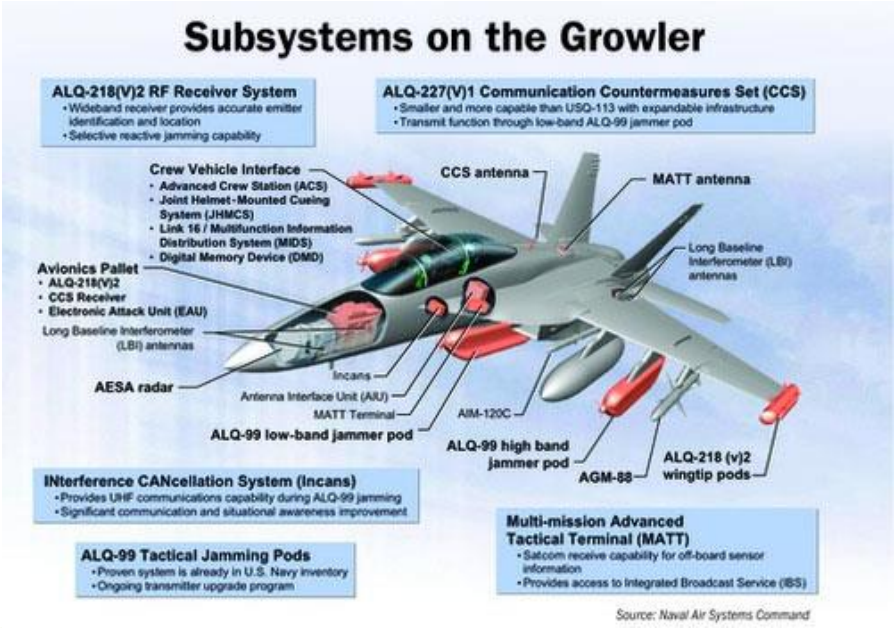
[Source: http://www.novamicrowave.com/understanding-circulator-and-isolaters.php]

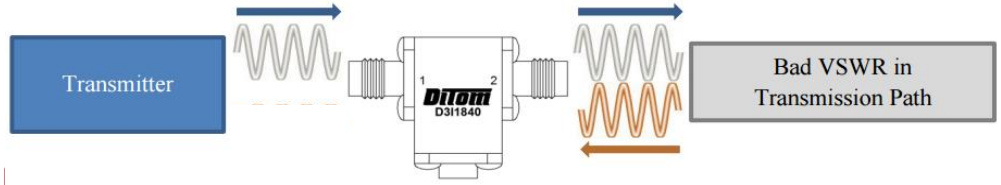
Boeing EA 18G Growler Jammer

Radar, Transmitters, Jammers, and other communication devices.



Radar – Allows two directions of communication using the same antenna, reducing the number of parts, saving space and money.





Jammer – protects the sensitive equipment from harmful reflections.

[Source: https://www.ditom.com/Application_Notes.pdf]

NIST

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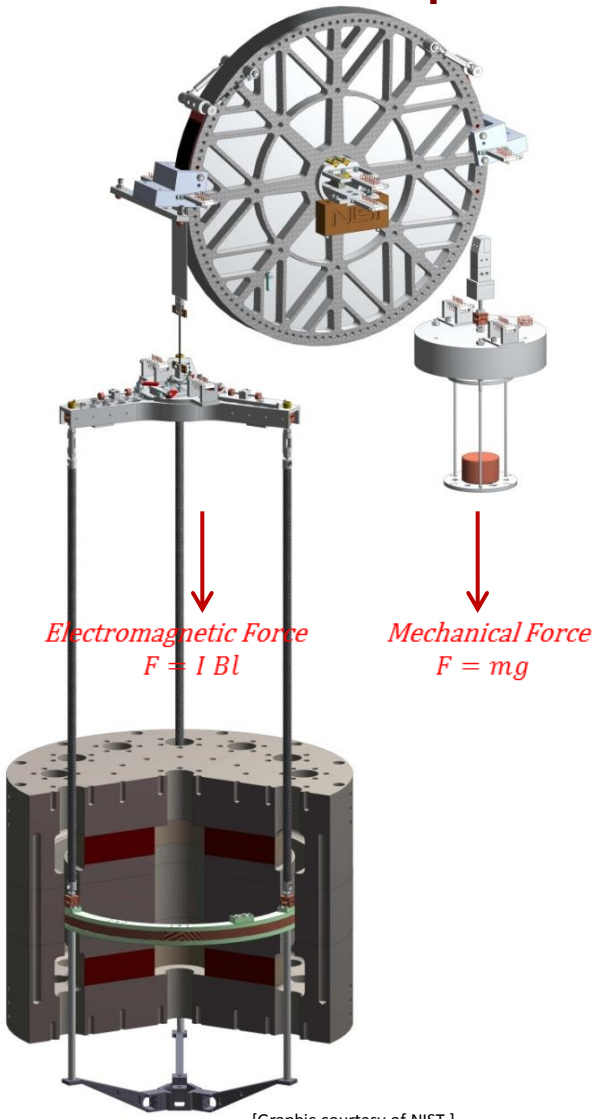
What is Watt Balance?

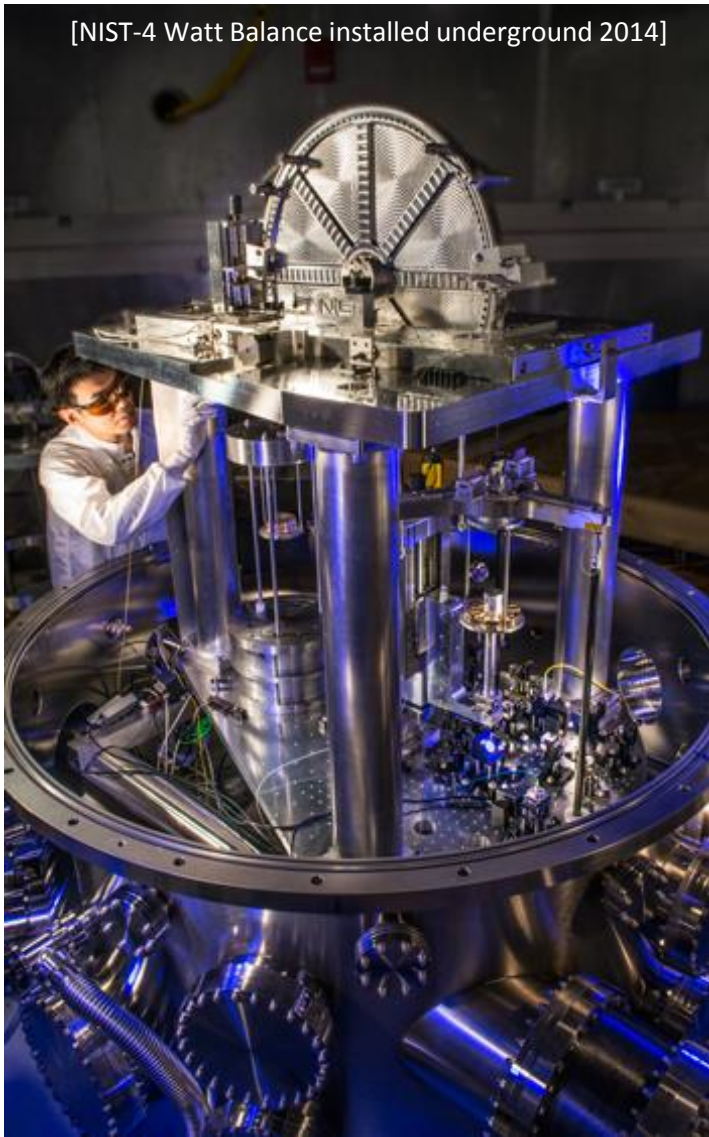
Electromechanical weight measuring instrument to define a kilogram mass by comparing electrical power to mechanical power.


[NIST-3 Superconducting Magnet]

[NIST-4 Permanent Magnet]



[Graphic courtesy of NIST]

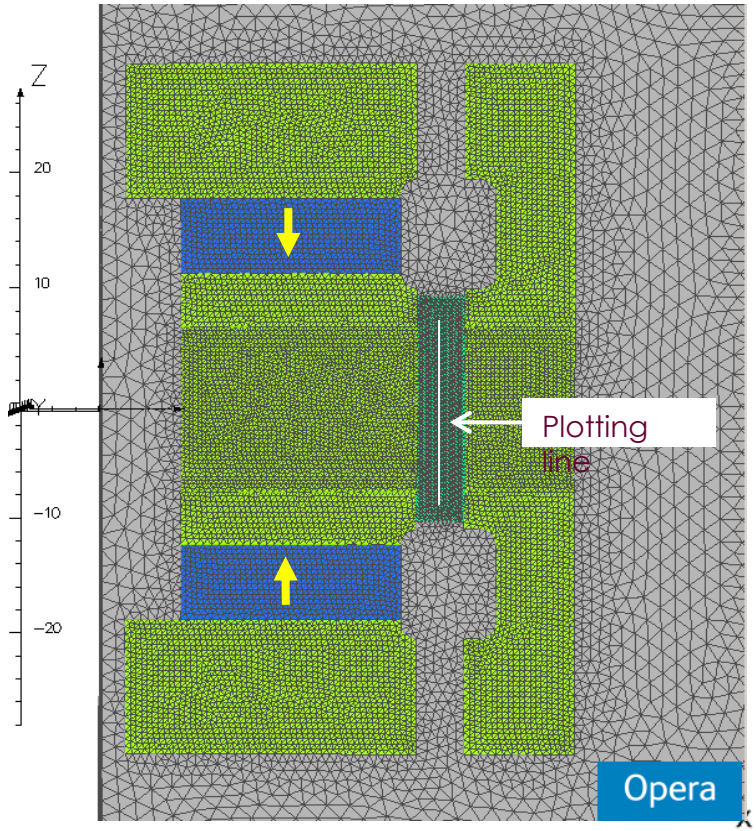

[NIST-4 Watt Balance installed underground 2014]

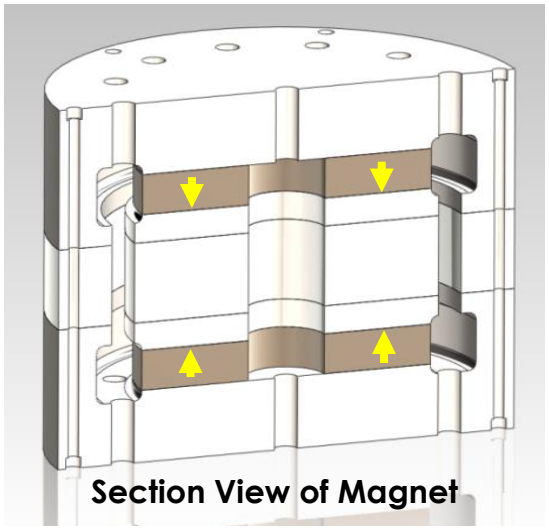
Watt Balance Design

Permanent Magnet Design

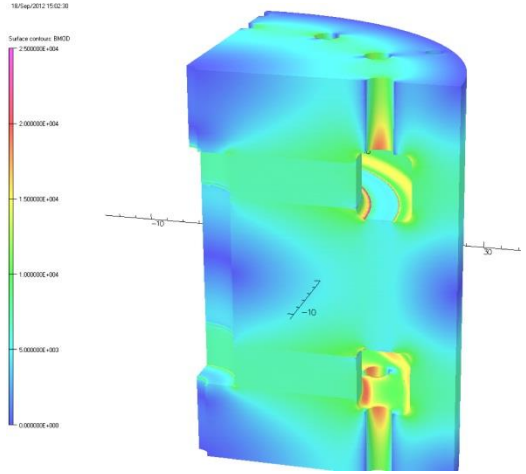
OD: 60cm
Height: 45cm
Weight: 1800 lbs (850 kg)

Vector Field Opera® Meshing View

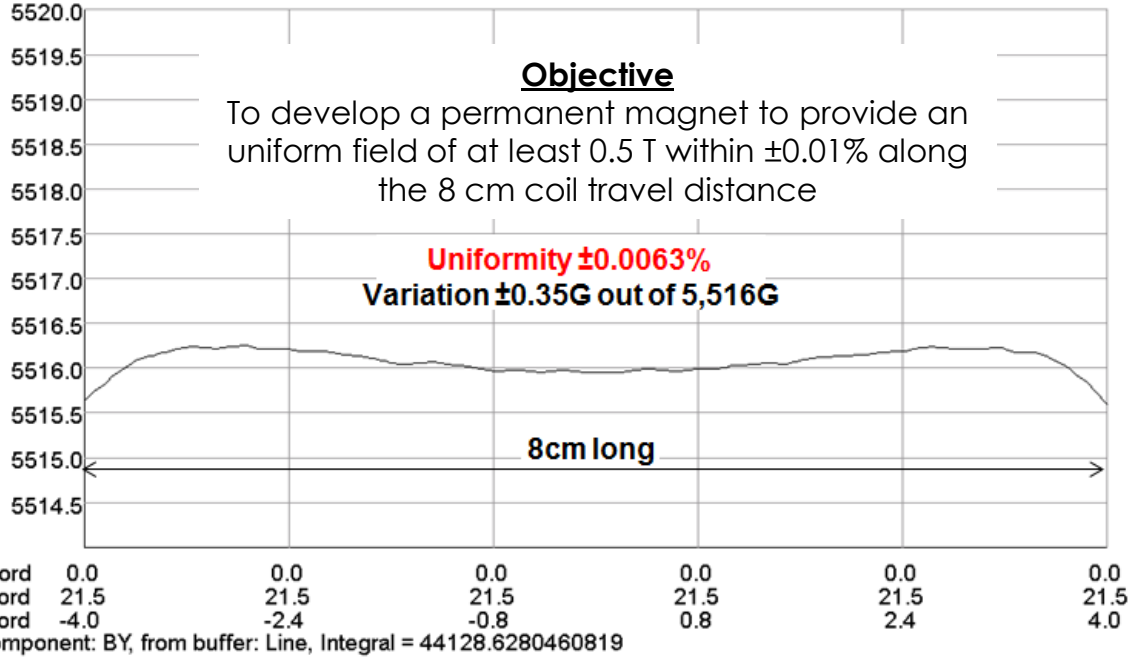




Magnetic Field Distribution



Zoomed View of Field Plot at Radius=21.5cm, Z=0cm



ELECTRON ENERGY CORPORATION


EEC
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Quality Policy Statement

Precision Guidance vs. Faraday's Law

ELECTRON ENERGY CORPORATION

Specialists in Rare Earth Magnets and Magnet Systems

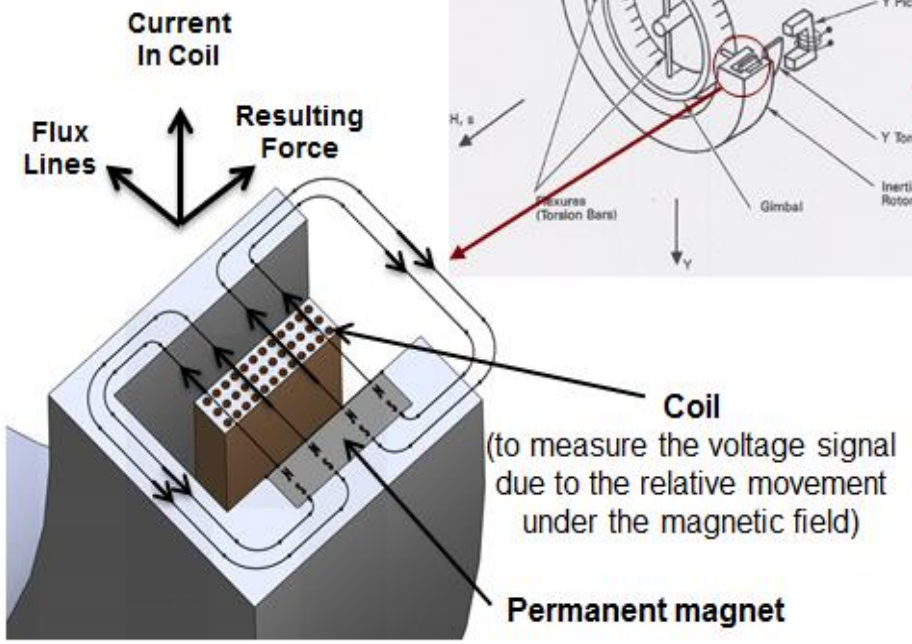
Precision Drilling Guidance

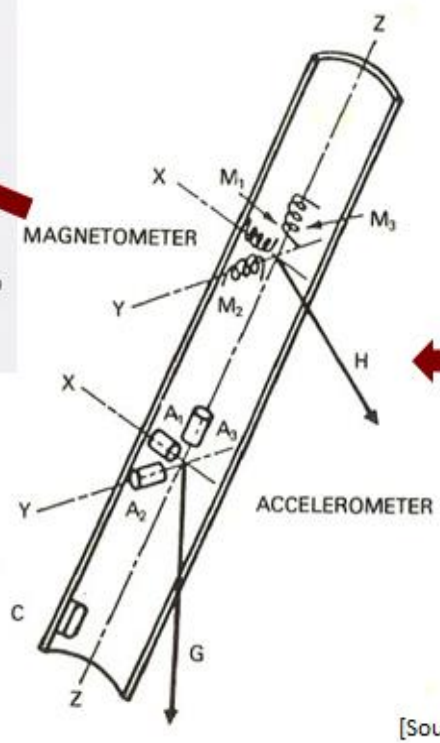
How does it work?

- The precision guidance system mounted behind the drill bit consists of three magnetometers and three accelerometers.
- Both magnetometers and accelerometers give voltage outputs, used to calculate the required directional angles.

Faraday's Law

$U = vLB$



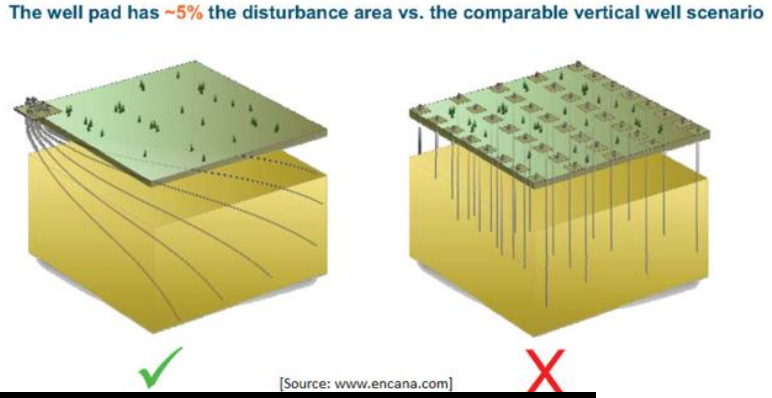


[Source: http://directionaldrilling.blogspot.com]

ELECTRON ENERGY CORPORATION

Oil Exploration

Precision Drilling guidance system measures the position, orientation and distance travelled of the drill-head. It helps the operator to determine the trajectory of the drill-head.



Why is the Precision Guidance important?

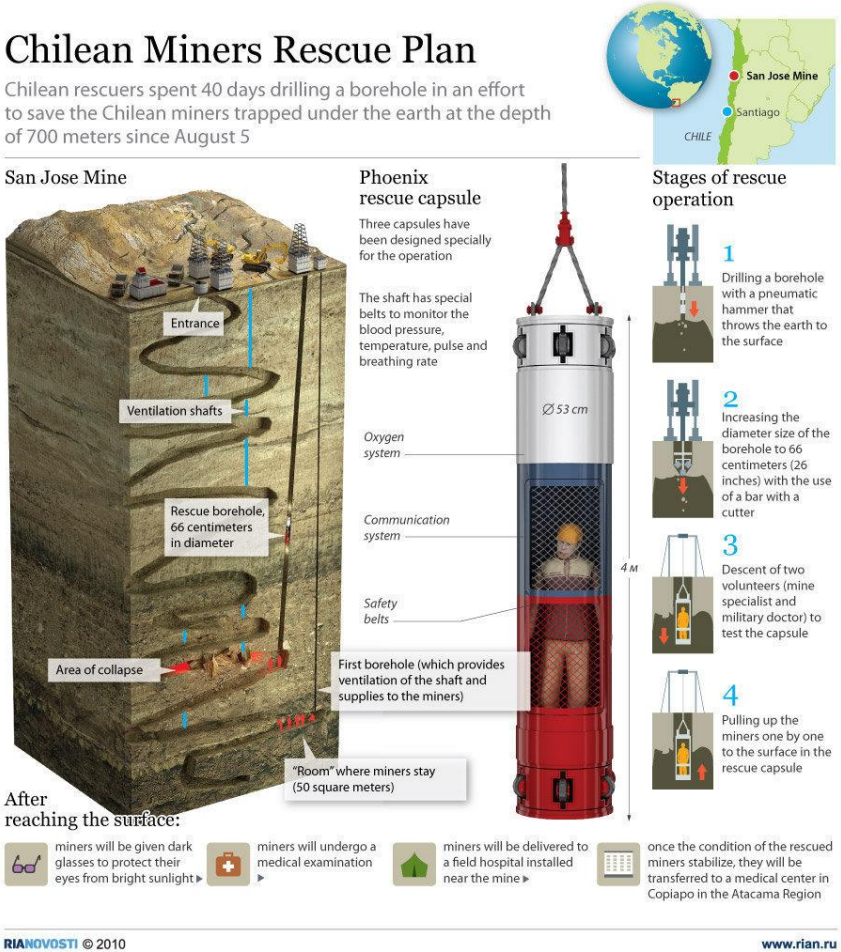
Significantly reduce the oil extraction cost.

Directional Drilling Animation

https://www.youtube.com/watch?v=uVrw3InxPyc

Saving 33 Chilean Miners

The precision guidance enables the rescue team to accurately target the starting point of the drill hole, then carefully control the orientation and direction of the drill hole to hit the target with the help of EEC magnets.



Mars Rover Curiosity

The $2.5 billion robotic explorer, landed on the Red Planet Aug. 6, 2012.

EEC Magnets are used in gyro systems for Curiosity Rover on Mars.

NASA Mars mission

The Curiosity rover is designed to travel Mars studying climate and geology. The rover is looking for signs of carbon, the building blocks of life. Some of the rover's features:

Robotic arm
Used to examine and manipulate soil and rocks; it also has two scientific instruments, one uses X-rays to determine materials' composition and the other is a magnifying camera

Laser
Burns small holes in rocks and soil up to 23 feet away and identifies chemical elements

Color cameras
Stereo mastcams on either side of the rover's mast take color pictures and movies in 3-D

UHF antenna
Primary transmission antenna

Plutonium power source
A nuclear battery that converts heat into electricity

Neutron detector
Detects water in rocks and soil

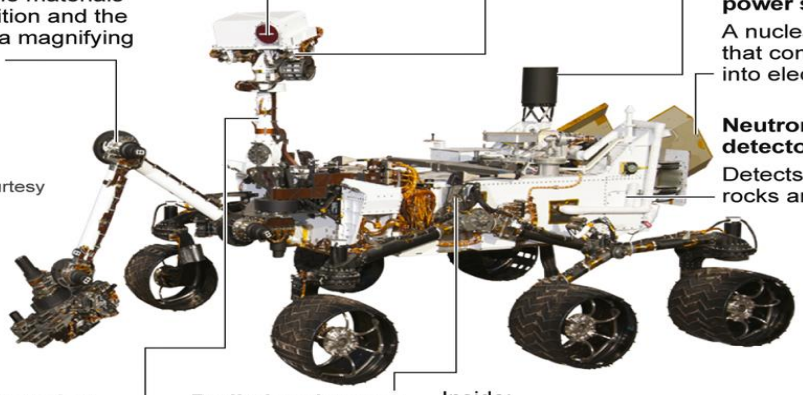


Photo courtesy of NASA

Weather station
Records wind speed/ direction, air pressure, humidity, temperature and UV radiation

Radiation detector
Measures radiation from the sun, supernovae and other sources

Inside:

Chemistry lab
Analyzes rock and soil samples for organics

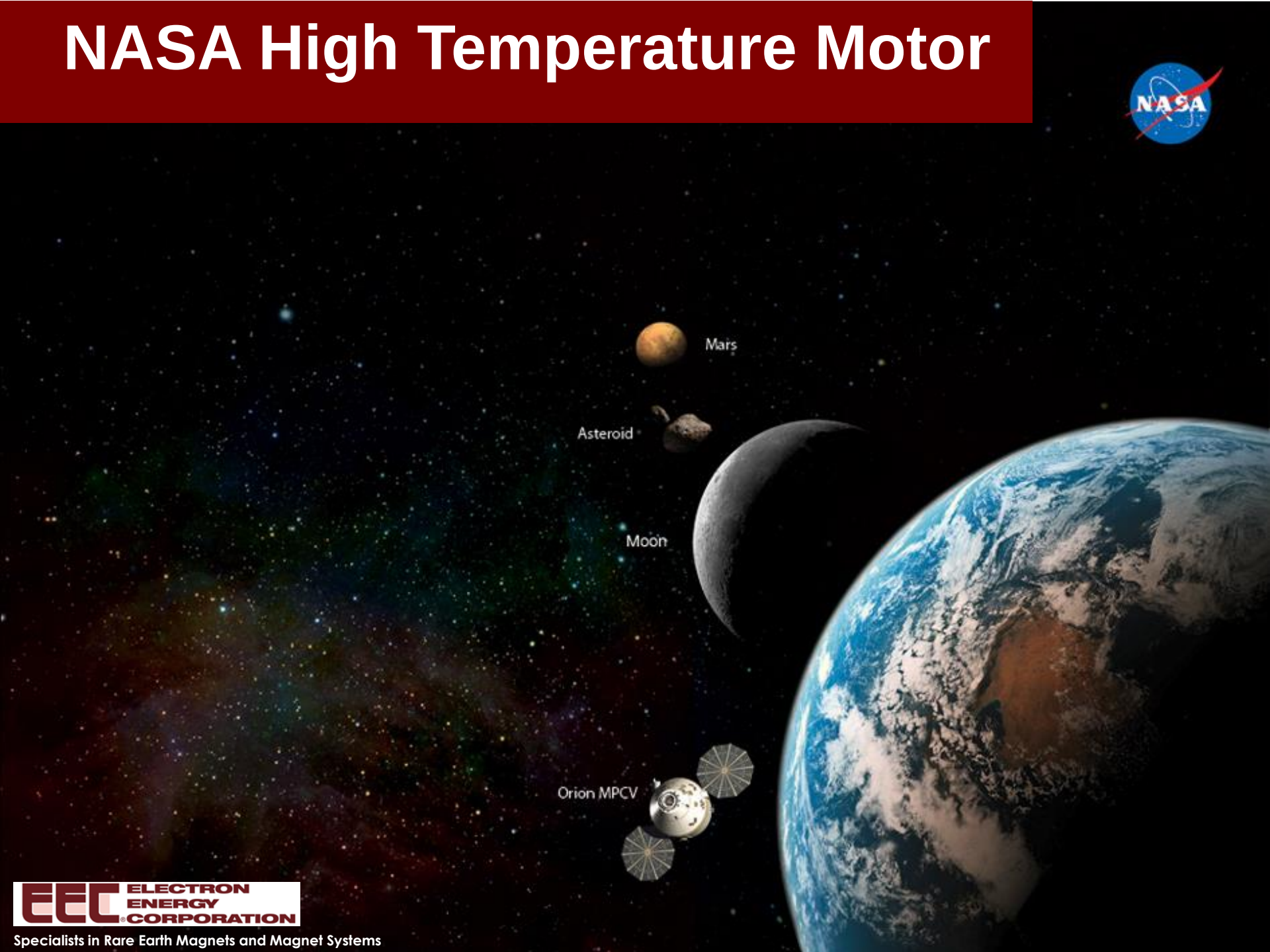
Mineral detector
Shines an X-ray beam at a rock or soil sample to identify types of minerals

SOURCE: NASA AP

Length: 10 feet (3 meters)
Width: 9 feet (2.7 meters)
Height: 7 feet (2.2 meters)
Mass: 1,982 pounds (899 kilograms)

[Photo courtesy of NASA]

NASA High Temperature Motor

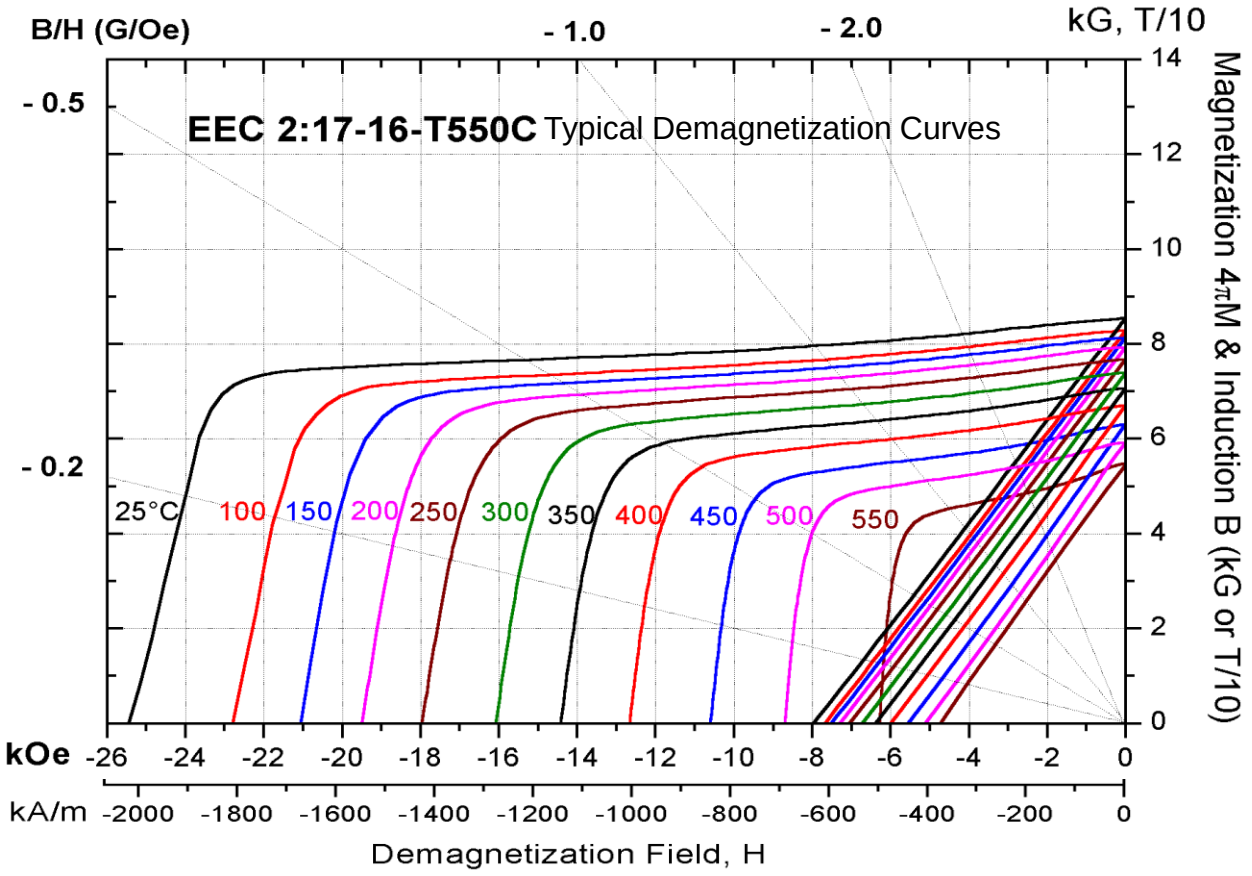


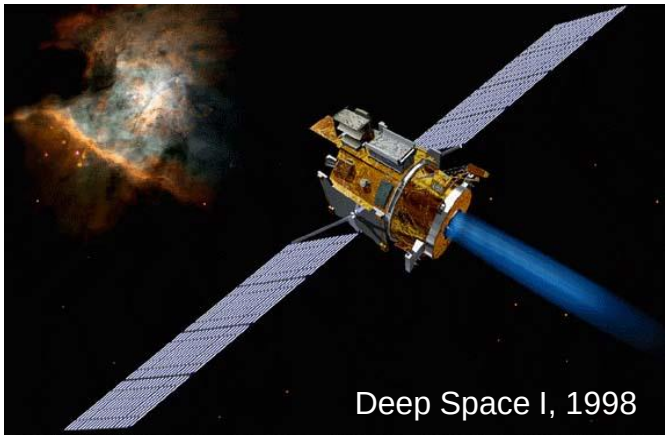
ELECTRON ENERGY CORPORATION

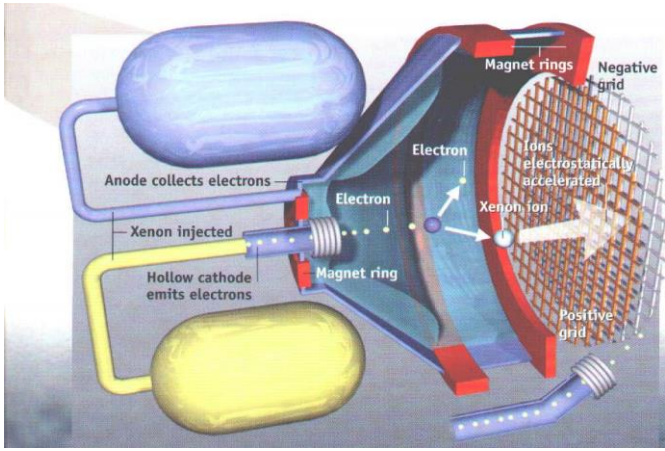
Specialists in Rare Earth Magnets and Magnet Systems

High Temperature Magnet

In the 90's EEC with DoD funding developed a series of SmCo 2:17 magnets with operating temperatures up to **550 °C** (US Patent # 6,451,132)

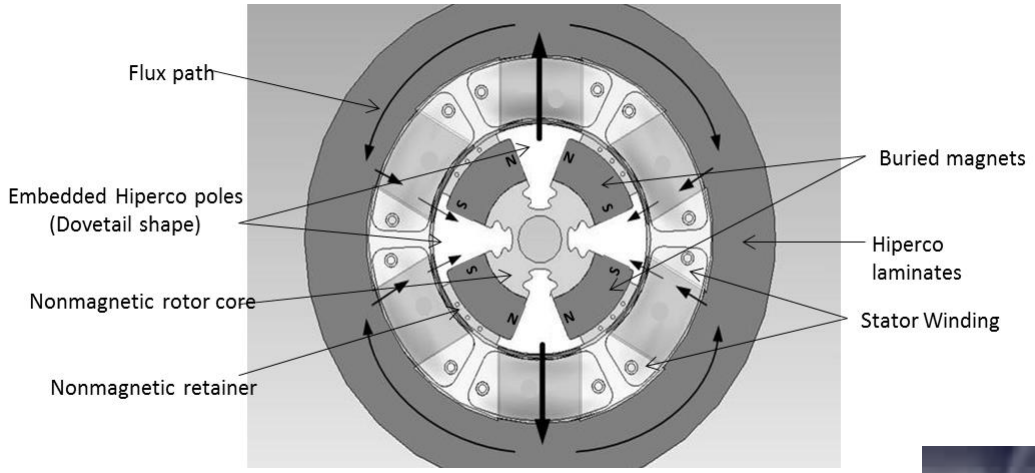


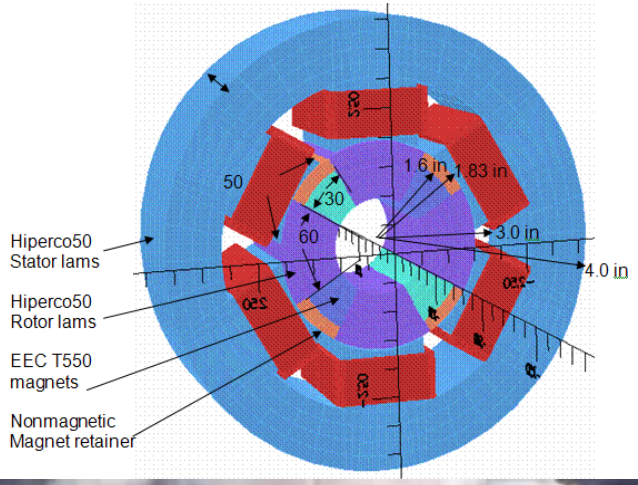




High Temperature Motor

Concept Design → FEA Validation → Prototype Development

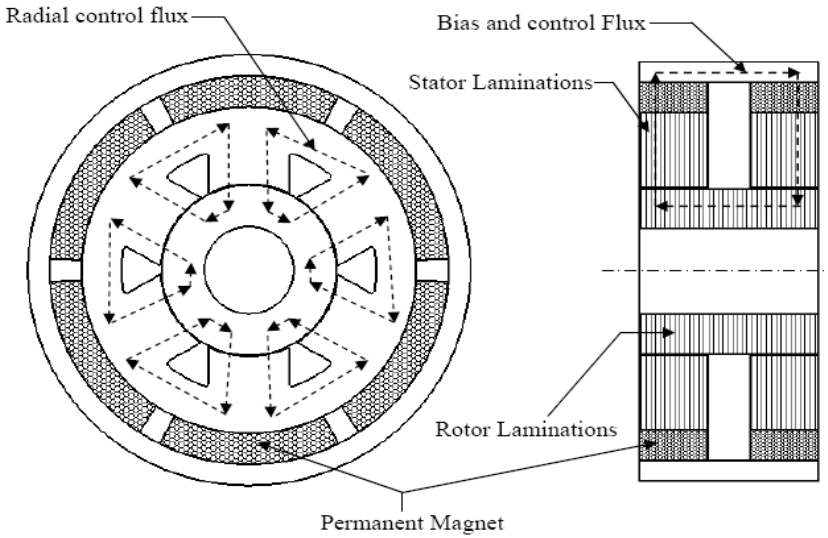


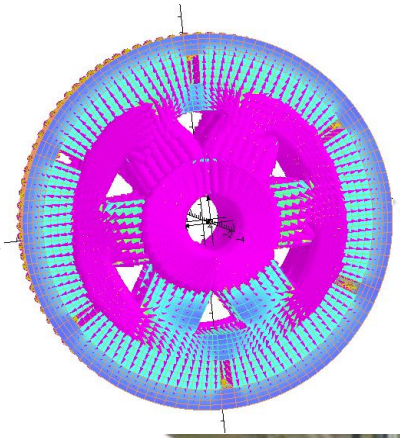


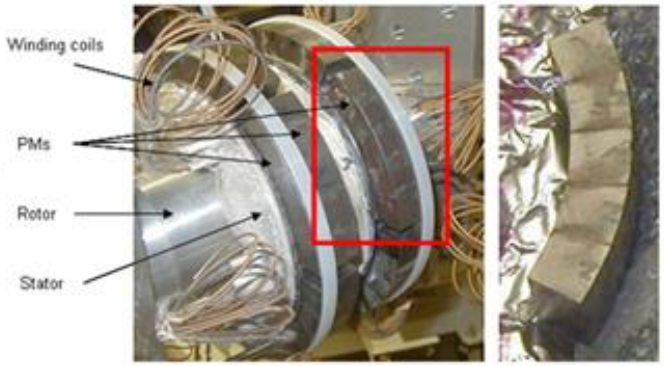
- 3 Phase 6 Pole 5.1 kW (6.8 hp) BLDC Motor with maximum operating temperature of 538°C at 20,000rpm
- The flux density in the air-gap of 0.1cm at 538°C = 0.45Tesla.
- Mechanical retention is preferred because adhesives will not survive at high temperature

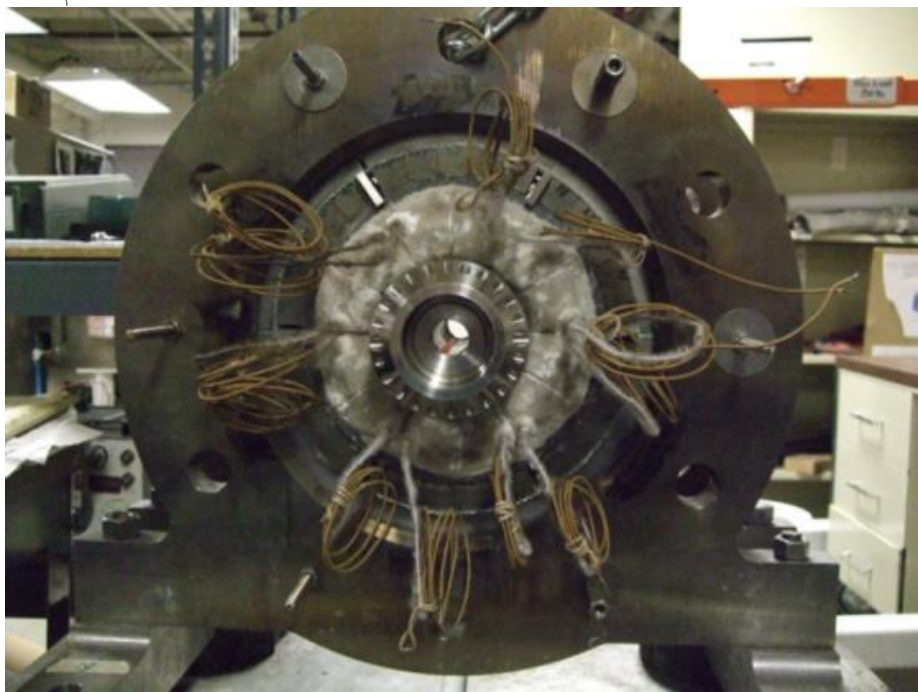
High Temperature Magnetic Bearing

Concept Design → FEA Validation → Prototype Development



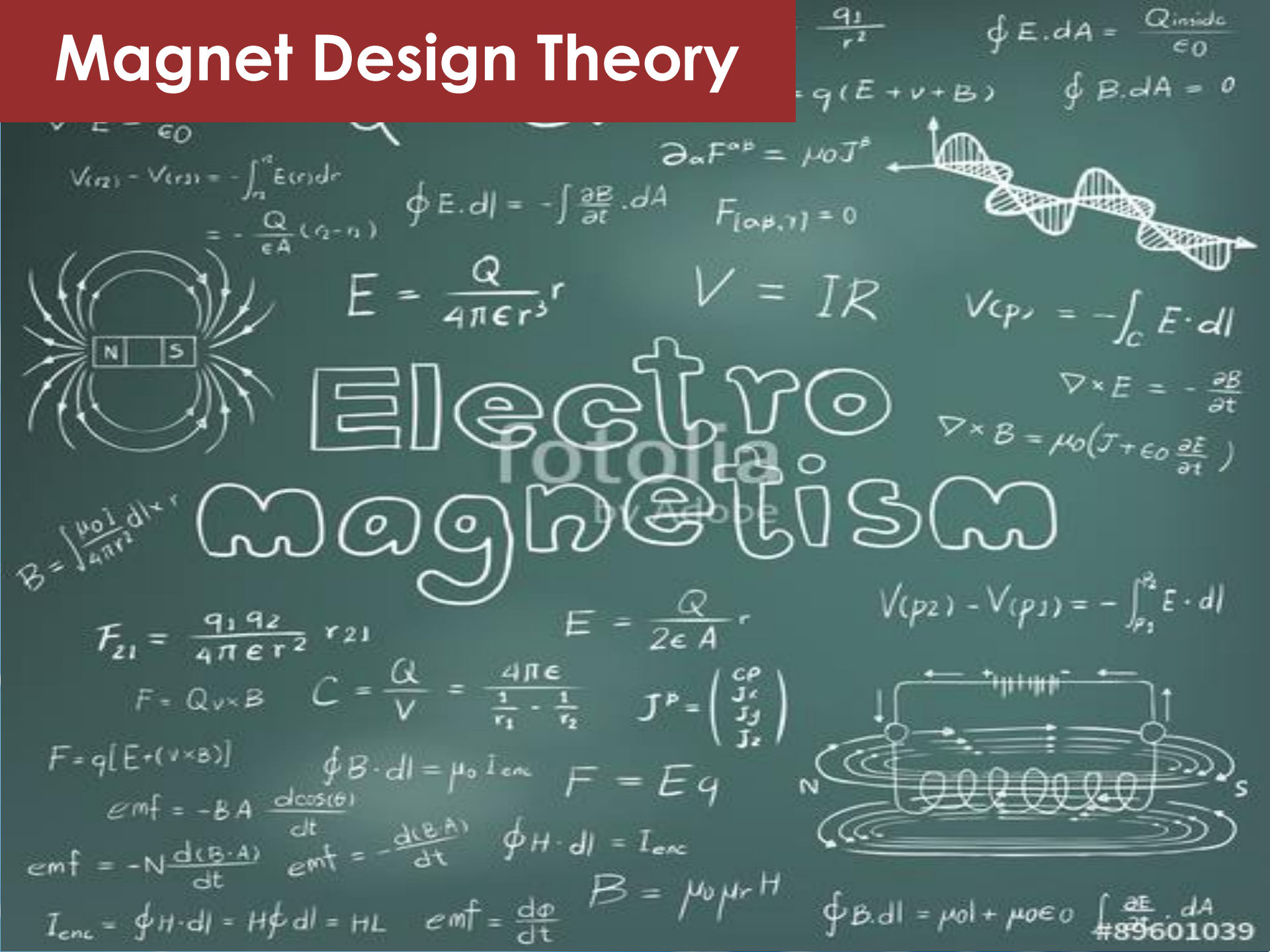




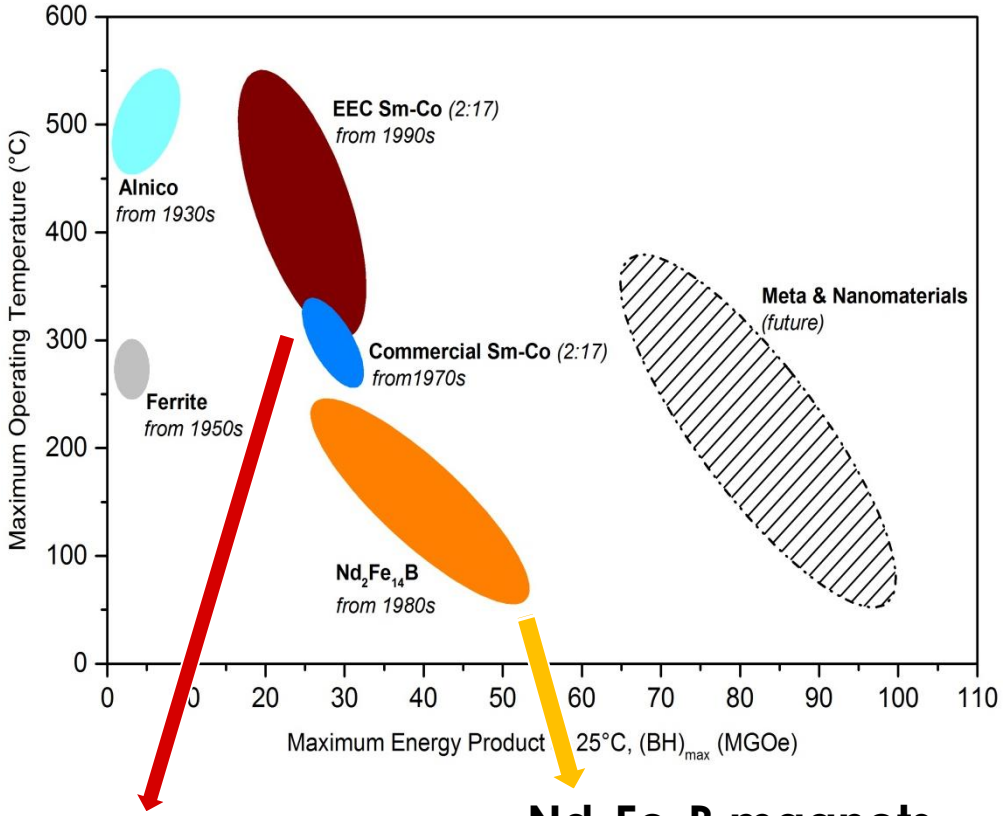


- Max. Force Output: Force at 13.3 amps with centered rotor was 2800 N (629 lbs), which is 86% of RT result.
- Max. Position-related force: 2220 N at 0.38 mm rotor offset. Yields approximate nps = 5.8 kN/mm, which is about 44% of RT result.
- Test temperatures: PM's were 493°C, Shaft was 350°C, Ceramic Layer on Poles was 366°C.
- SmCo magnets and control coils are working at elevated temperatures.

Magnet Design Theory



Magnets vs. Temperature



SmCo magnets

- Highest $(BH)_{max}$ available - up to 33 MGOe
- **Corrosion resistance is excellent;** no surface coating required
- Maximum operating temperature: 300°C
- Superior thermal stability

Nd-Fe-B magnets

- Highest $(BH)_{max}$ available up to 52 MGOe
- Corrosion resistance is low; **surface coating is needed.**
- Maximum operating temperature, ~180°C for most grades, is relatively low compared to SmCo magnets (>300°C).

FAQ

Does a rare earth magnet lose it's strength?

Permanent magnet could lose strength if:

- ✓ the working temperature exceeds the specified maximum operating temperature; (thermal demagnetization)
- ✓ the magnets are demagnetized by external magnetic field; (electrical / magnetic demagnetization)
- ✓ the magnets are heavily corroded or oxidized.

FAQ

What are the coating options?

Sm-Co Magnets

No coating is required.

Nd-Fe-B Magnets

Ni plating: very popular for sintered neo. In order to have better protection, **Ni-Cu-Ni plating** is commonly applied.

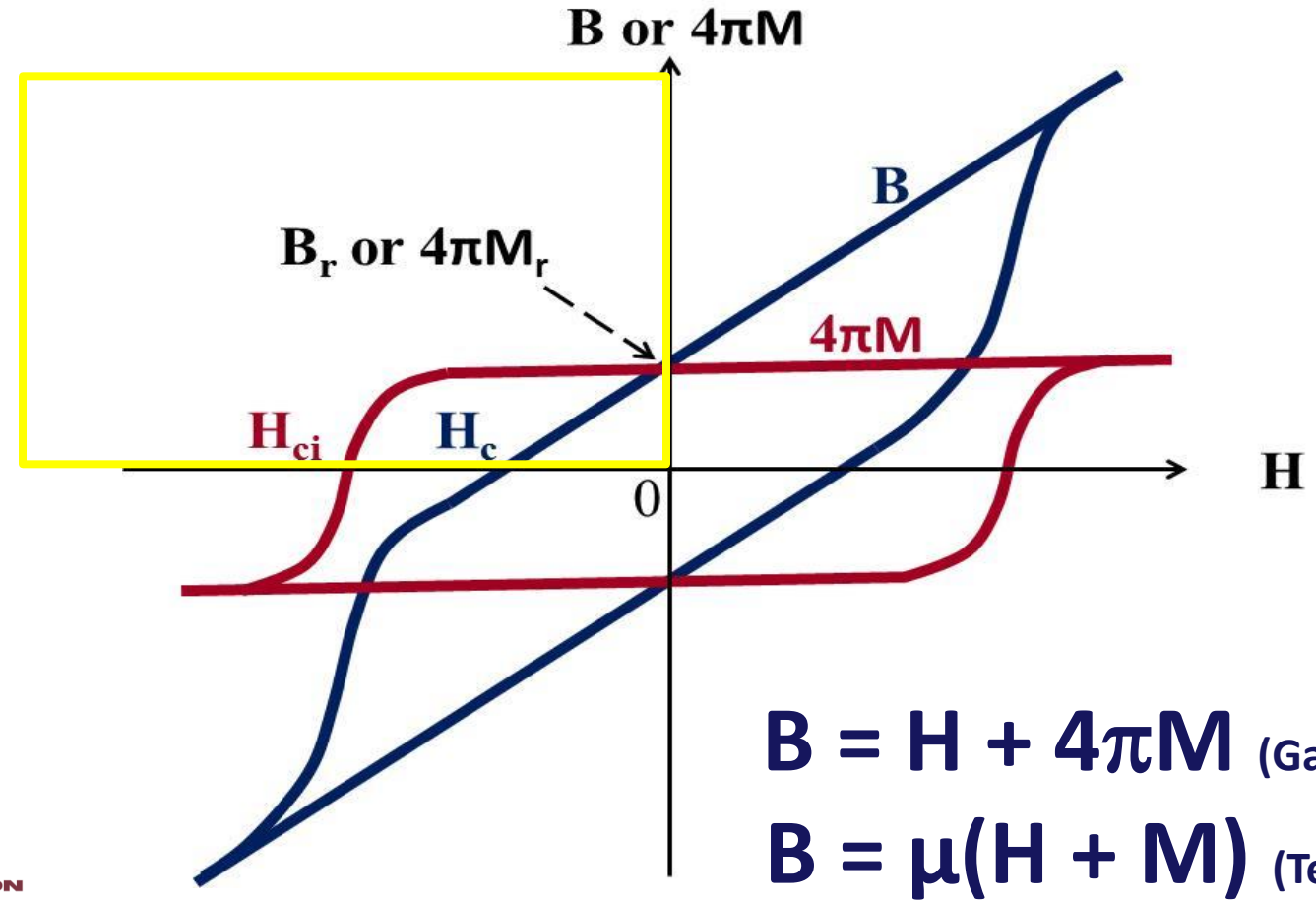
Aluminum IVD: for applications with tight tolerance

Epoxy coating: Very common for bonded neo magnets.

Best choice for outdoor applications or very humid environment.

FAQ

What is the difference between Intrinsic and Normal hysteresis loop?



$B = H + 4\pi M$ (Gauss, CGS unit)

$B = \mu(H + M)$ (Tesla, SI unit)

How Eddy Current Brake Works?

✓ **What is the Eddy Current?**

An eddy current is a swirling current set up in a conductor in response to a changing magnetic field.

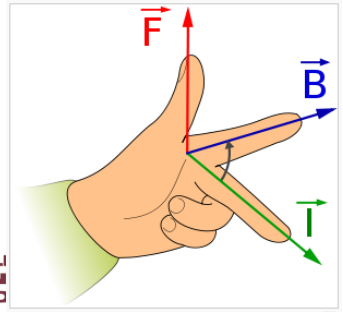
✓ **How do they work?**

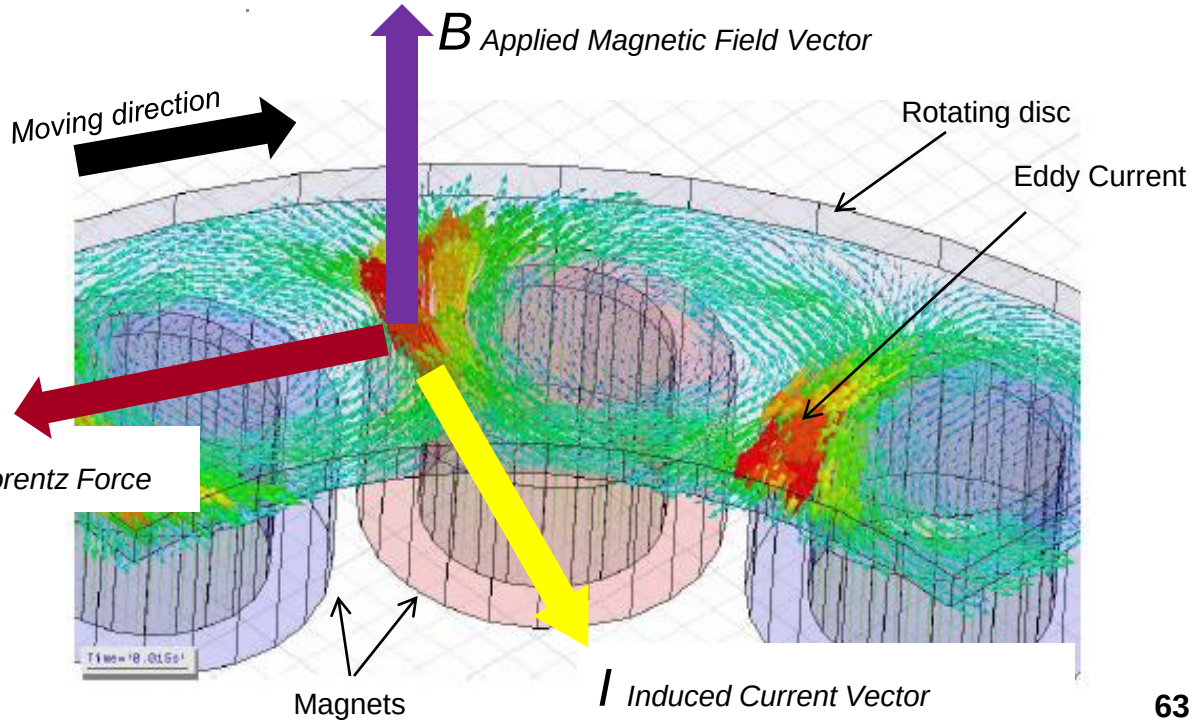
When a conductive object is moving thru the magnetic field, the eddy current is induced on the surface of the conductive material. By ***Lenz's law***, the magnetic interaction between the applied field and the eddy currents acts to slow the wheels down in such a way as to create a magnetic field opposing the change. This force is called '***Lorentz Force***'. The faster the wheels are spinning, the stronger the braking effect.

$$\mathcal{E} = -\frac{d\Phi_B}{dt}, \quad \textit{Lenz's law}$$

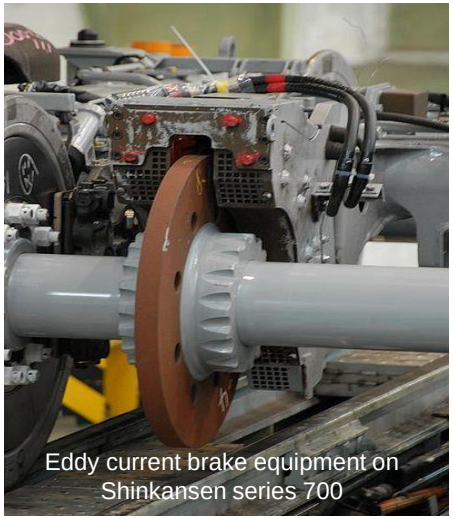
$$\mathbf{F}_{mag} = q(\mathbf{v} \times \mathbf{B}) \quad \textit{Lorentz Force}$$

F is the force
q is the electric charge of the particle
v is the velocity of the particle
B is the magnetic field

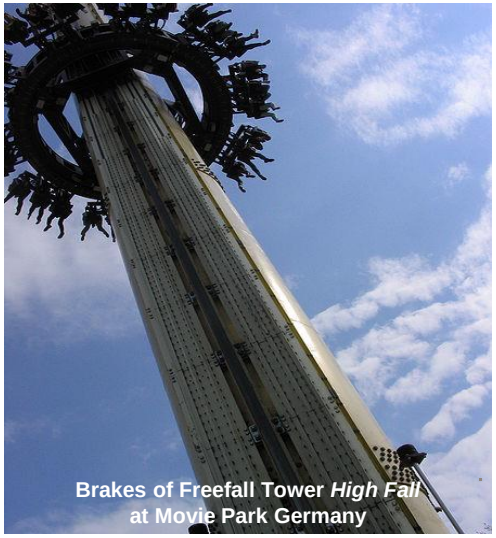




Eddy Current Brake Demo



Eddy current brake equipment on Shinkansen series 700



Brakes of Freefall Tower *High Fall* at Movie Park Germany

Brakes of Rollercoaster *Goliath* at Walibi World

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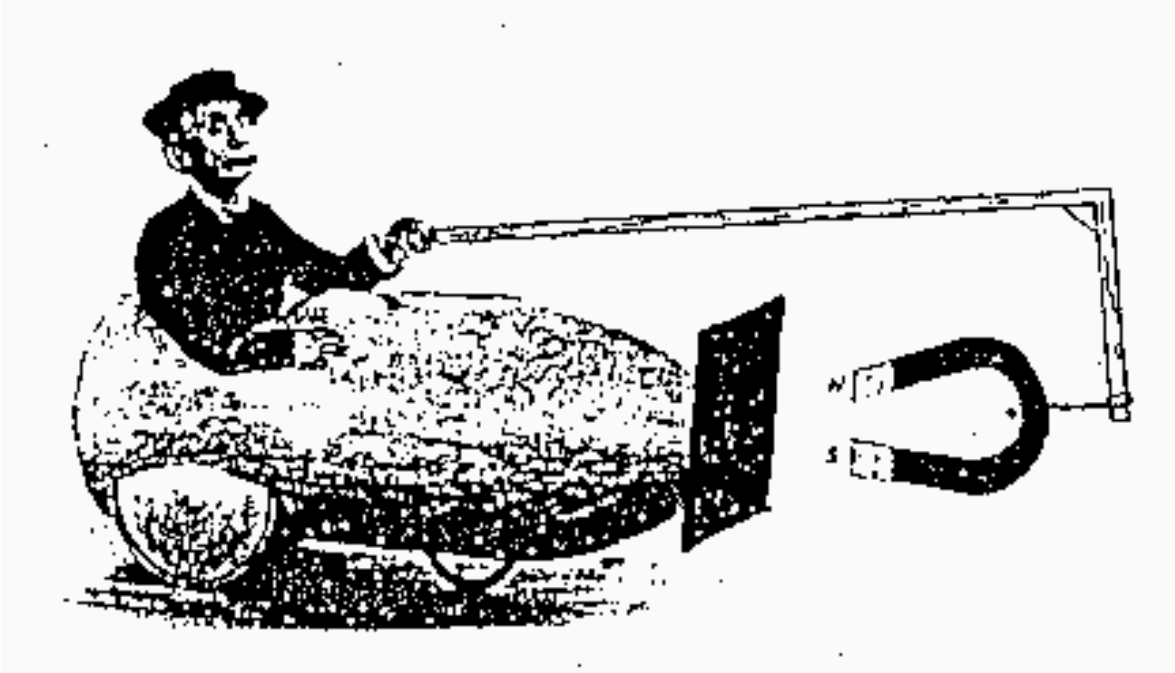
Rail Gun @ 2015 Naval Future Force S&T Expo

Thank You



Do You Want To Tour EEC

Vertically Integrated Magnet Manufacturing Facility?