2LO3-07

Development of High Stable Magnetic Field HTS Magnet System for MRI

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INTRODUCTION 〜Background〜

○ Medical MRI Superconducting magnet

Features of MRI

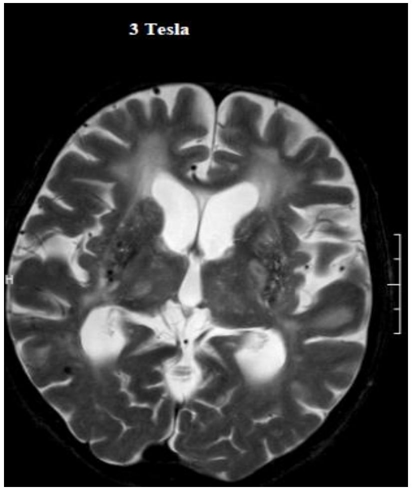
- The Magnetic Resonance Imaging does not use X-ray radiation.

- For imaging protons, can vascular imaging without contrast agent, blood flow observation possible
  ⇒It is very effective for diagnoses such as Brain disease or heart disease

- The state by the hemoglobin concentration imaging in f- MRI, it is can be observed a brain function in three dimensions

- Due to high magnetic field of by superconducting magnet , clear and detailed image is obtained, the capillary and organ condition be comes clear and contribute to early detection

- By highly uniform magnetic field, fat separating, soft tissue imaging such as high functionality



Typical MRI Images with 3T system

Required for MRI

①High magnetic field ,
High stable magnetic field ,
High uniform magnetic field

→ **Superconducting magnet**

②Credibility：non trouble, long-term maintenance

③***Low Price*** → The competition is X-rays CT

INTRODUCTION ～Background～

○ Why is a HTS MRI magnet necessary?

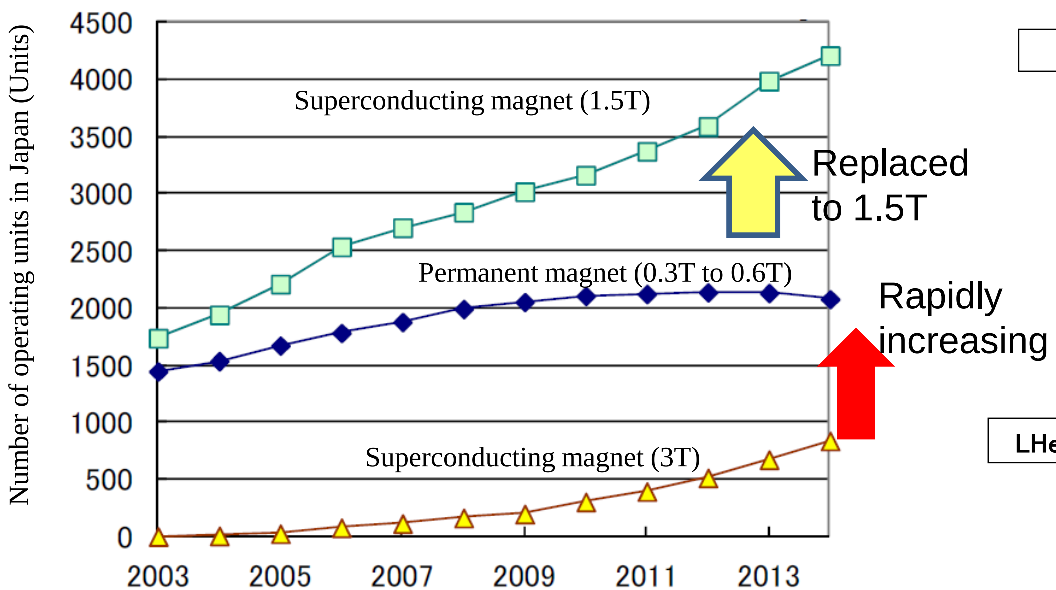
○MRI apparatus superconductivity mainstream, and high magnetic field (high resolution) is required. The growth rate of the 3T magnet is higher.

○Features of superconductivity, high magnetic field accrual (>3T), energy saving (R=0).

●In present, a NbTi superconducting magnet need liquid helium for cooling.

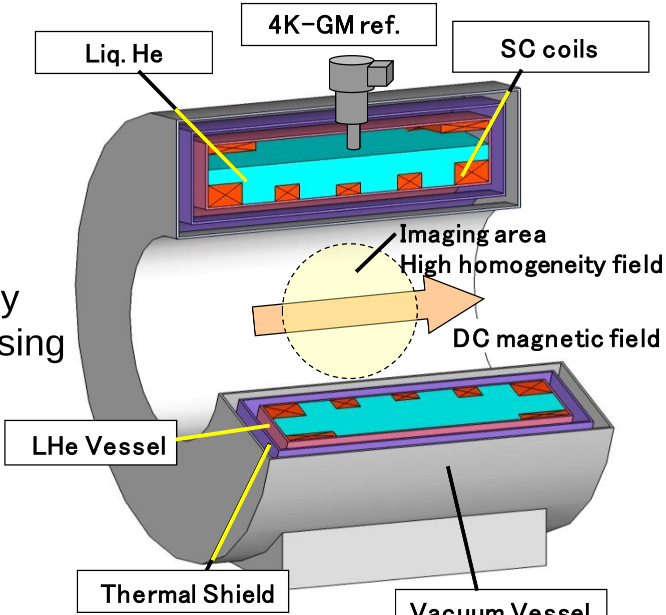
→ These several years , Supply Crisis and Price Increases of helium , and also Nb material

◎High-Temperature Superconductivity：liquid helium less, Nb less and using in high field



Number of MRI Magnets operating in Japan

(Edited from 'Gekkan Shin-Iryo' (Monthly New Medicine in Japan))



Structure of a Current model 3T-MRI Magnet

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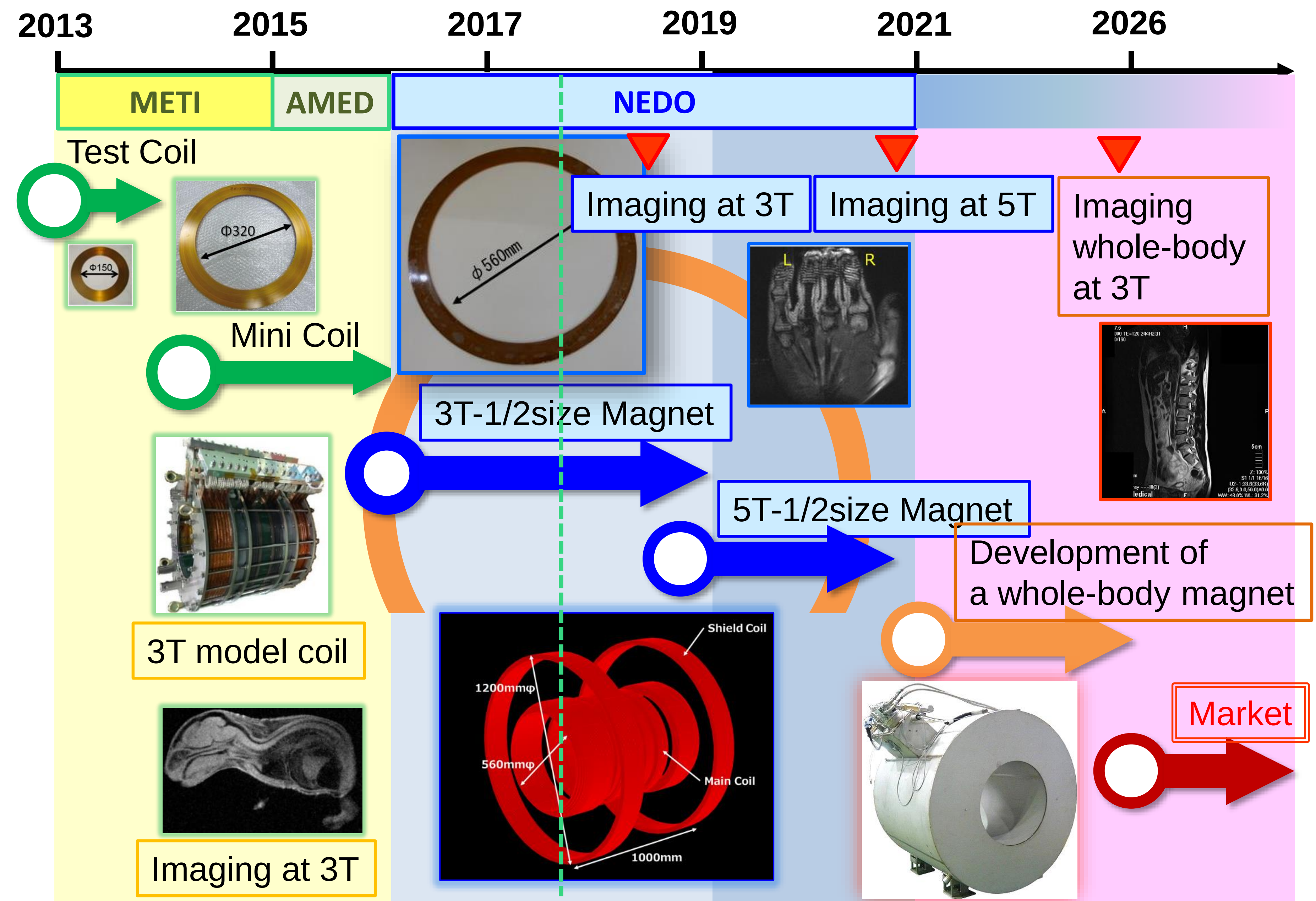
Development Plan of up to Market



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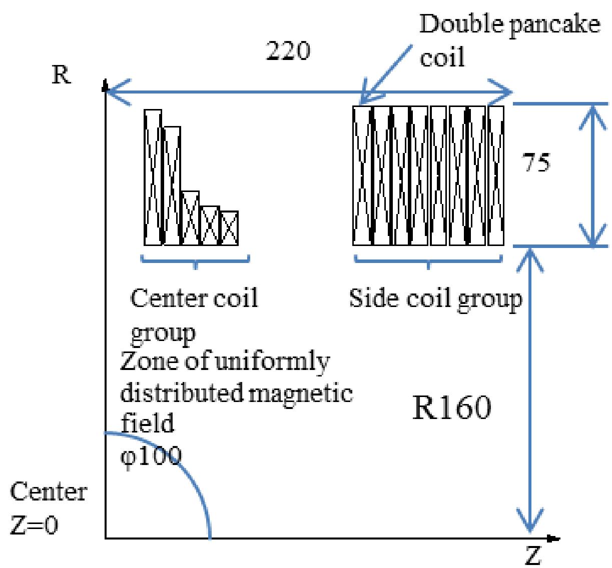
HTS 3T-Model Magnet for MRI

REBCO-3T model coil

- We designed it being conscious of a current MRI magnet.
  Central field is 2.9T
  Uniformity is 1.7ppm/100mmDSV
  Stability is less than 1ppm/hr
  ➡ for Imaging possibility

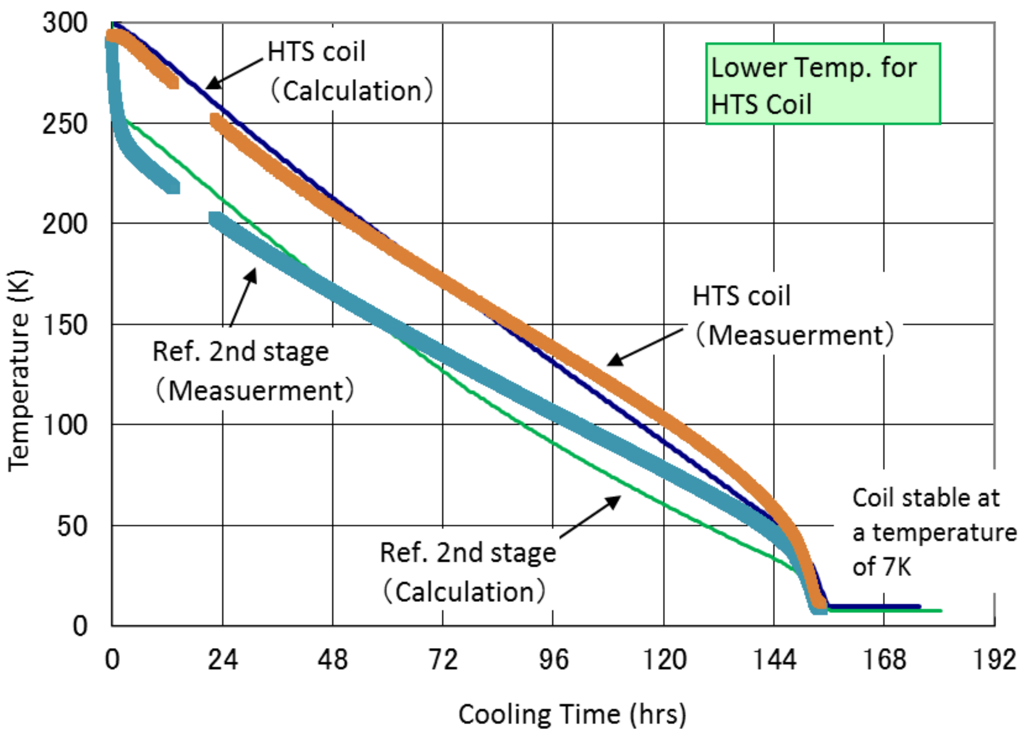


1/4 Cross Sectional View of HTS 3T Model Coil

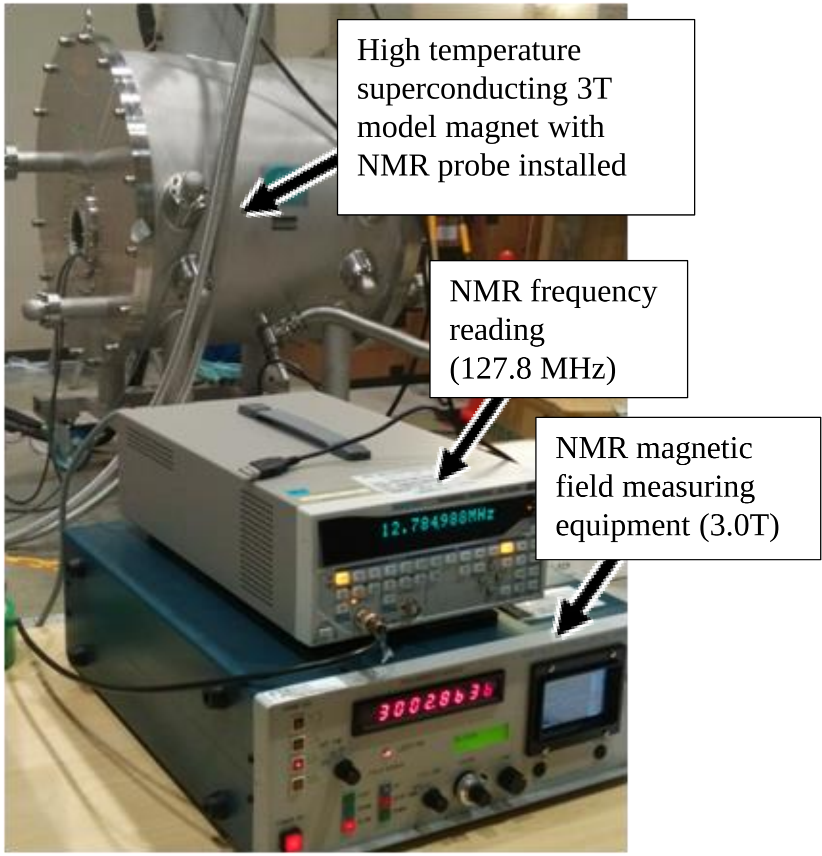
Specification of the HTS 3T Model Coil

Inner diameter	320mm
Maximum Outer diameter	471mm
Axial length	440mm
Central field	**3.0T**
Maximum field	4.5T
Critical current of wire at field	351A (20K)/4.1T(36°)
Current density of coil	113A/mm2
Inductance	32H
REBCO wire Total Length	16km
Field uniformity on design	**1.67ppm/100mmDSV**
Total Weight	180kg

Cooling and Excitation of 3T model coil



Cooling Characteristics from Room temperature of the HTS 3T Model Coil



Photographic View of Test Setup for HTS 3T Model Magnet
(At the Time of Generating Central Magnetic Field of 3T)

- ○The cooling of the coil was completed
  Stable temperature is 7K at one week.
- ○3T excitation time is 15 minutes at 0.2A/s.
  Coil temperature increased about 2K.

High-Tc Superconducting magnet for MRI

Succeed in World's first 3 Tesla MRI with High-Temperature Coils at Feb. 2016

The public information

TOKYO, May 24, 2016 – Mitsubishi Electric Corporation (TOKYO: 6503), Kyoto University and Tohoku University today announced the world's first successful 3 tesla Magnetic Resonance Imaging (MRI) using a small model MRI with high-temperature superconducting coils that do not require cooling with increasingly scarce liquid helium. Mitsubishi Electric expects that the high-quality images made possible at this magnetic field strength will contribute to earlier detection of illnesses.

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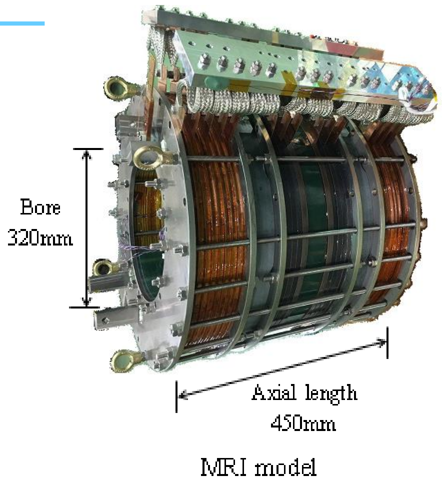
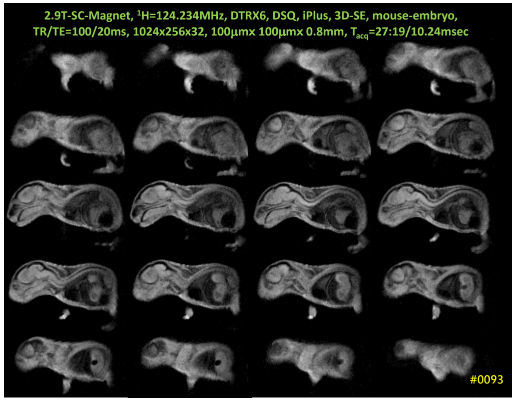
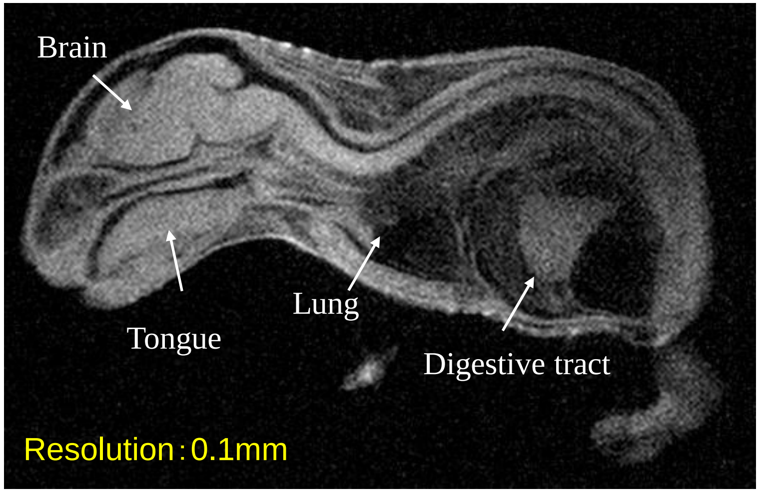


MRI model



Multi-slice image



Mouse fetus image (about 25mm long)

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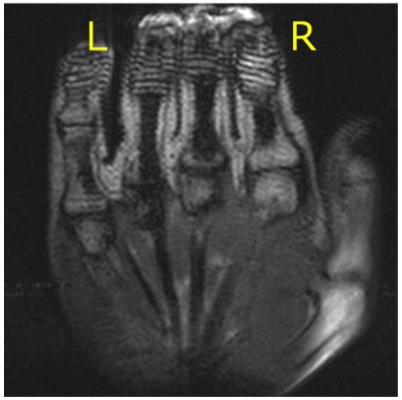


Image of Human-Left-Hand in the 150mm area by wide bore system

The Project promoting practical application is commissioned by the New Energy and Industrial Technology Development Organization (NEDO:FY2016-FY2020).

Half size HTS magnet for MRI

Fundamental Commercialization Promote Technological Development

Development of a high temperature superconducting magnet system having high stable magnetic field

Main Objective

○Test producing 3T and 5T half size HTS coils for MRI

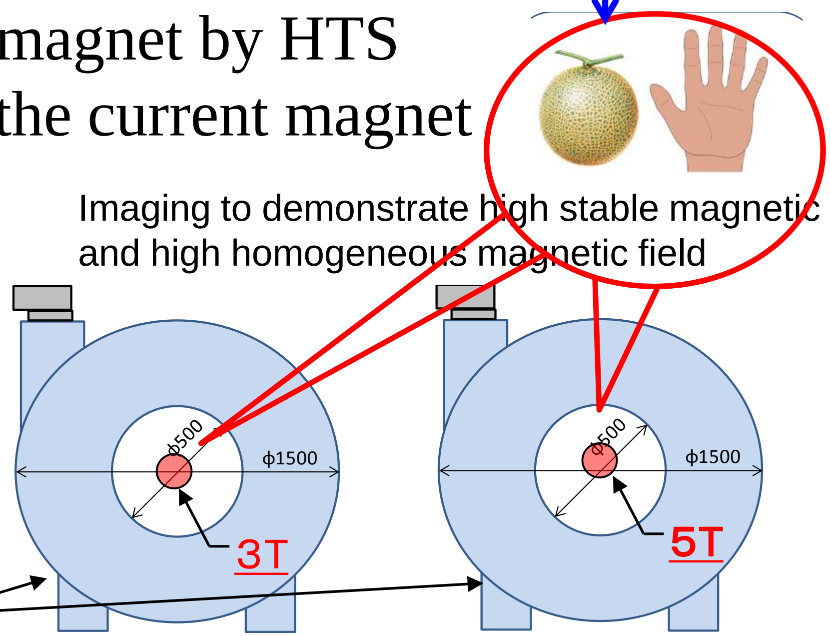
○Measurement of field uniformity and stability

○High current density coil (>200A/mm2 at 7T)

○Design of 3T whole body MRI magnet by HTS

→Compact and lightweight than the current magnet

Imaging to demonstrate high stable magnetic field and high homogeneous magnetic field



With a active shield coil

1st:FY2016~2018 2nd:FY2018~2020

R & D items and collaborators

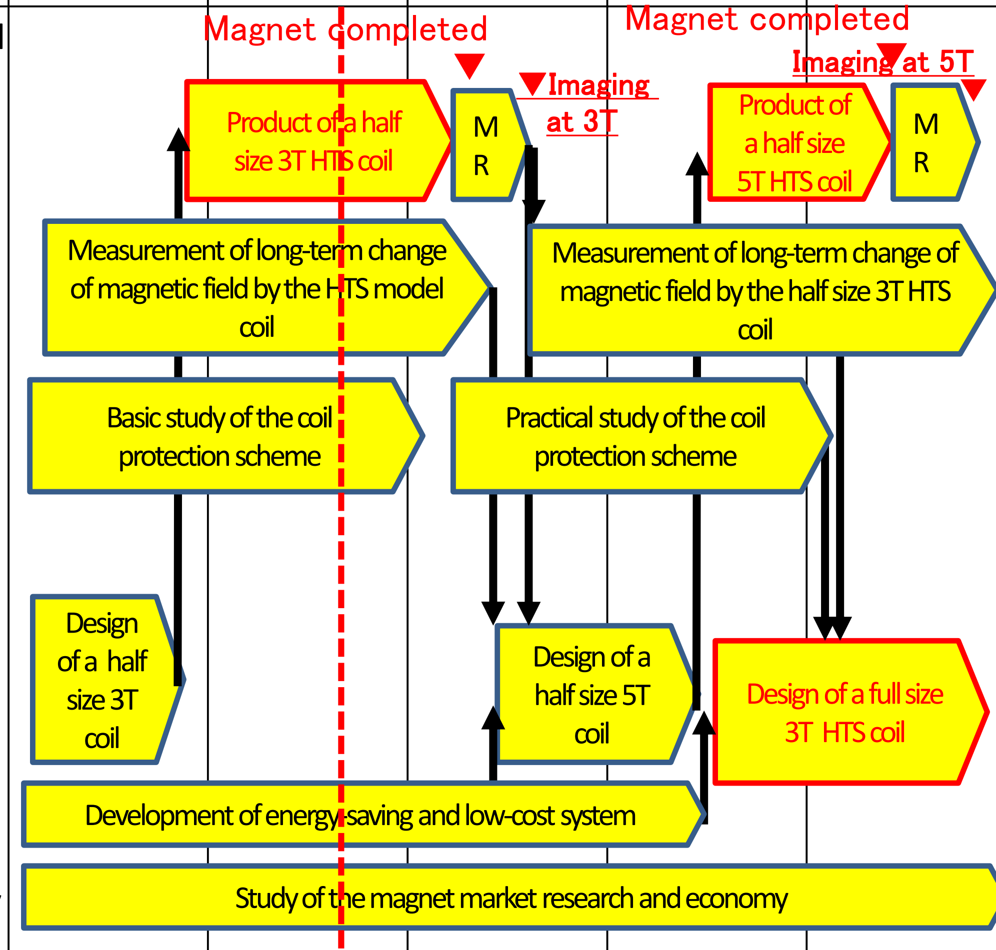
1. Development of practical technology for HTS coil
   1) **Coil Production Technology** : Mitsubishi Electric Corp.
   2) Magnetic field disturbance measures by magnetization : Kyoto univ. and Tohoku univ.
2. Development of system optimization technology for HTS magnets
   1) **High magnetic field and high current density coil design technology** : Mitsubishi Electric Crop.
   2) Development of energy-saving and low-cost system : Kyoto univ.
   3) Economic efficiency study : Kyoto univ.

3. Development of superconducting joint technology for HTS wire : National Institute of Advanced Industrial Science and Technology (AIST), others

4. Development of the coil protection and burnout measures approach
   1) Development of the coil protection for persistent mode : AIST,others
   2) Development of burnout measures approach : Mitsubishi and Tohoku univ.

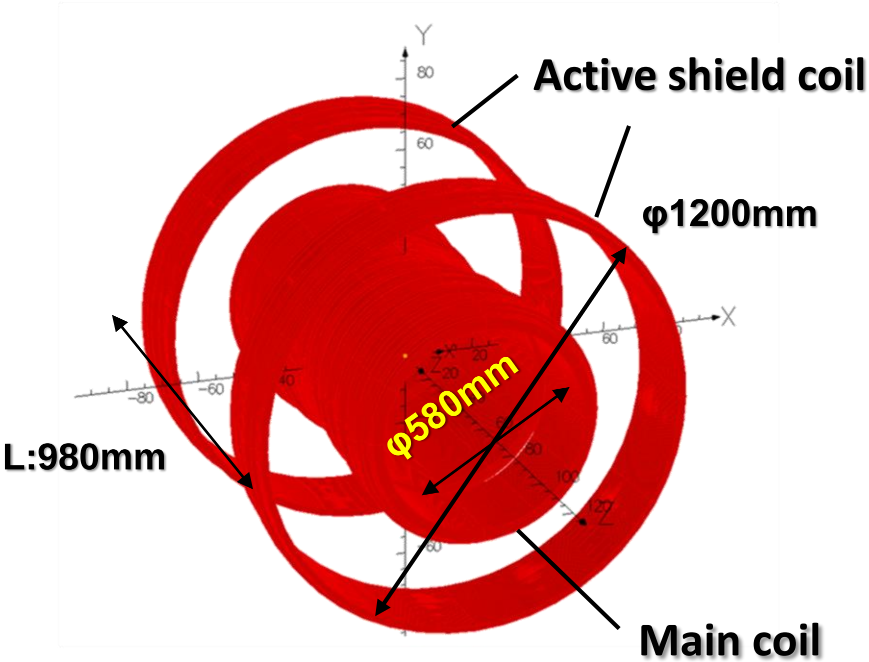
Development schedule

R & D items	1st year (2016)	2nd year (2017)	3rd year (2018)	4th year (2019)	5th year (2020)	development results
(1) Development of practical technology for HTS coil ①Coil Production Technology ②Magnetic field disturbance measures by magnetization ③Study on coil protection method						･Demonstration of outer diameter m class coil ･Imaging with 3T-1/2 size magnets →Demonstration of a AS coil ･ Imaging with 5T-1/2 size magnets →Miniaturization verification →High magnetic field verification
(2) Development of system optimization technology for HTS magnets ①High magnetic field and high current density coil design technology ②Development of energy-saving and low-cost system ③Economic efficiency study						･Optimization of cooling structure and excitation system ･Cooling temperature and current optimization, energy saving effect verification ･Economically of market input



*AS : Active Shield

Design of the half size 3T HTS coil for MRI



A design of a half size HTS 3T-coil

○Maximum axial stress is <u>**30 MPa**</u> near the center part of the main coil

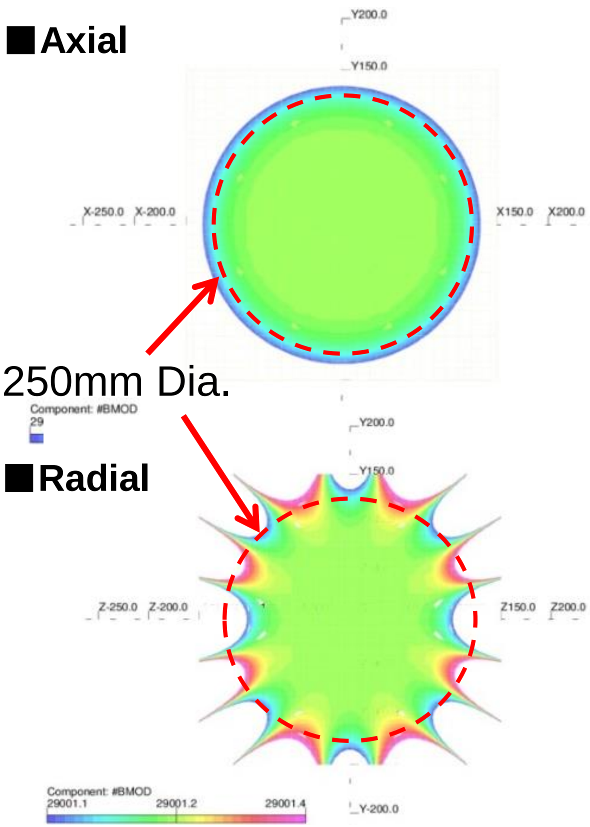
○Maximum hoop stress is <u>**55 MPa**</u> around one quarter of the main coil

Specification of the half size 3T HTS Coil

Inner diameter	580mm
Maximum outer diameter	1200mm
Axial length	980mm
Operating central field	**2.9T**
Maximum field	Bzmax=4.2T,Brmax=2.9T
Current density of coil	121A/mm2
Inductance	145H
Stored energy at operation	1.6MJ
REBCO wire Total Length	70km
Field uniformity on design	**1.7ppm/250mmDSV**
Leak magnetic field area	2.5mX3.4m (0.5mT)

Room bore is 480mm Dia.
Imaging is a region of 150 mm or more

Design of the half size 3T HTS coil for MRI

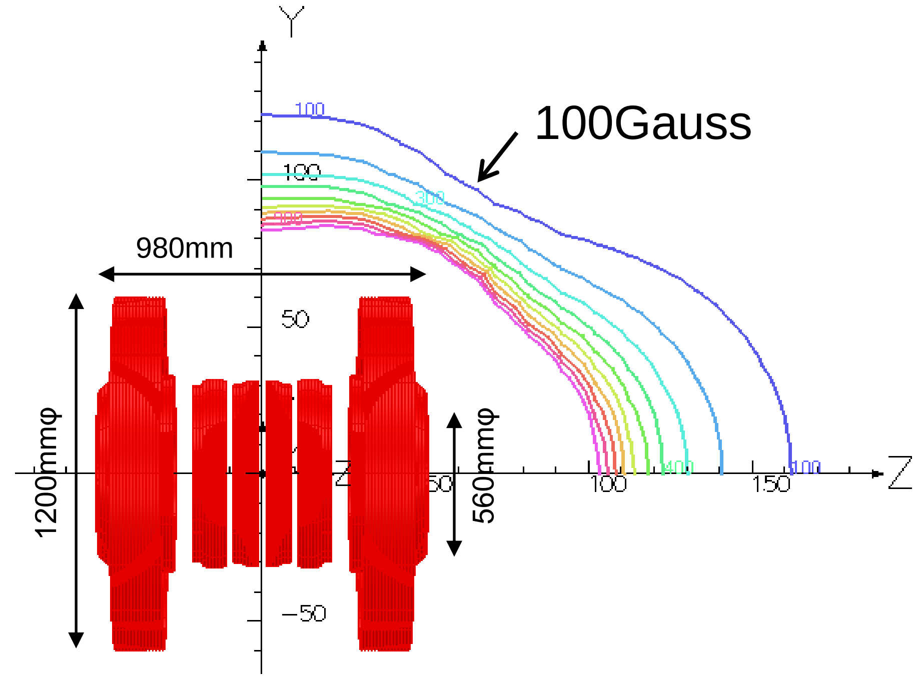


Error field coefficient

Z2	0.04
Z4	-0.26
Z6	-3.10
Z8	-16.68
Z10	-4.95
Z12	-0.15
Z14	0.77
Z16	-0.27
Z18	0.06
Z20	0.01

Unit：ppm

Magnetic field uniformity of the coil



Leak magnetic field region of the coil (analysis result)

1.6mx1.2m（100G region）

3.2mx2.5m（5G region）

〇Magnetic Field Distribution is 1.7 ppm/φ250 mmDSV on designed

〇Leakage Magnetic Field regions are 1.6mx1.2m at 100gauss and 3.2mx2.5m at 5gauss.　Ref.：3T model coil’s region is 3.8mx4.8m at 5gauss

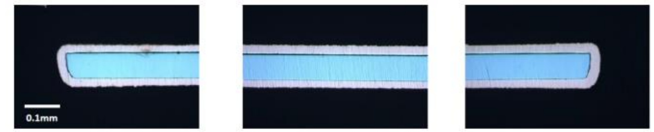
REBCO Coil Production Technology

Specifications of the REBCO superconducting conductor

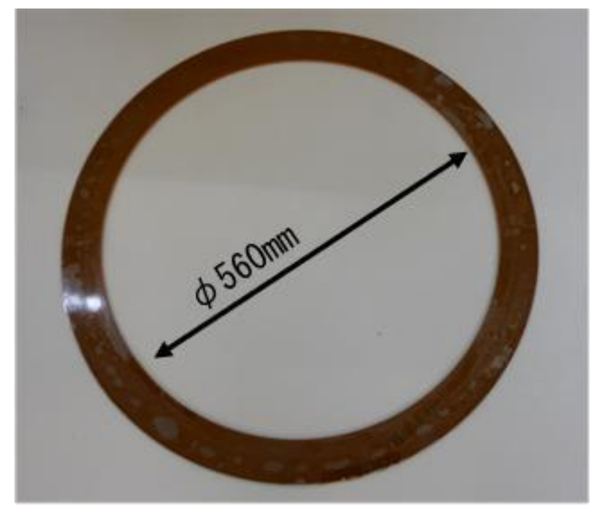
Conductor Dimensions	Width	4 mm
	Thickness	0.17 mm with Insulator
Structure	Insulation (Double insulated Tapes)	Inner: Polyimide Tape with *fluorine coating*
		Outer: Polyimide Tape
	Stabilizer	Copper plating (0.02mm thickness)
	Metal Substrate	Ni-based Alloy (Hastelloy equivalent)
Superconducting Characteristic	Critical Current	160 A or higher at 77K, self-field

Prevention of degradation by peeling

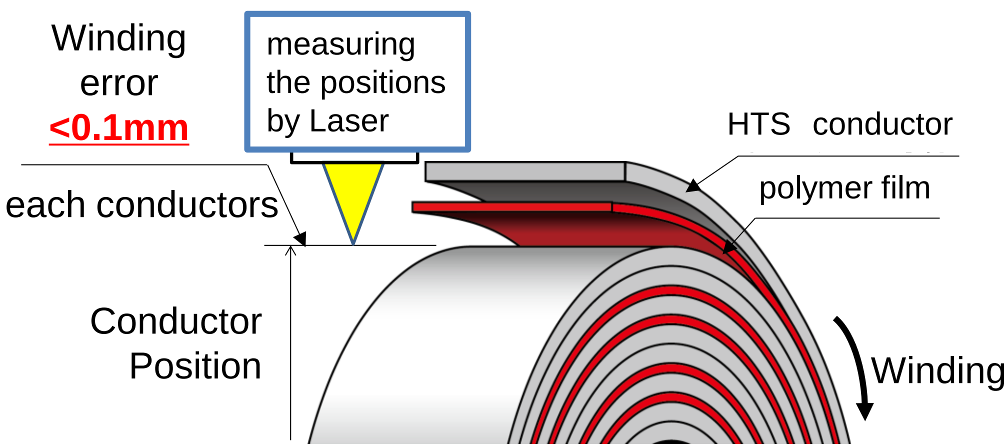
Rigidification of impregnated coil



Cross-section Image of REBCO Superconductive Wire Material



Photograph of a pancake coil with inner diameter of 560 mm for main coil. Vacuum impregnated with epoxy.



Producing high precision coils

High stability excitation system

Using a highly stable excitation power supply, it was possible to generate a magnetic field of 1 ppm or less for a long time by over-shoot method and feedback control

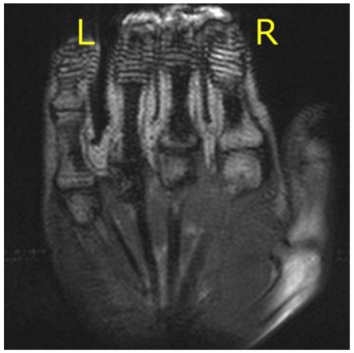
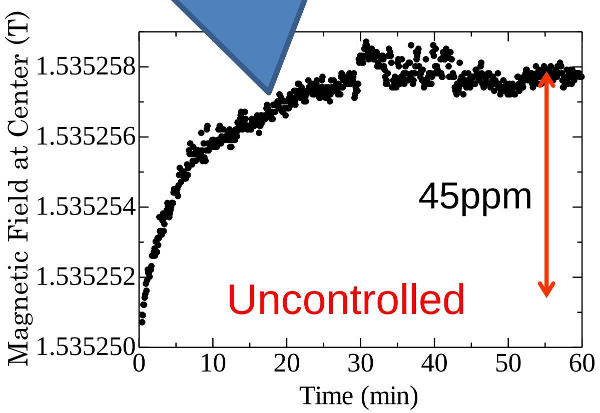
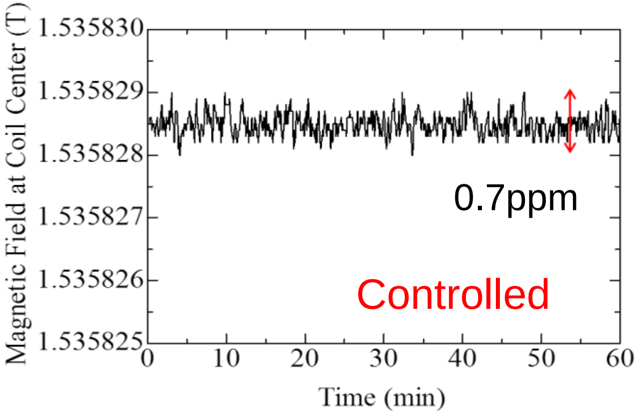
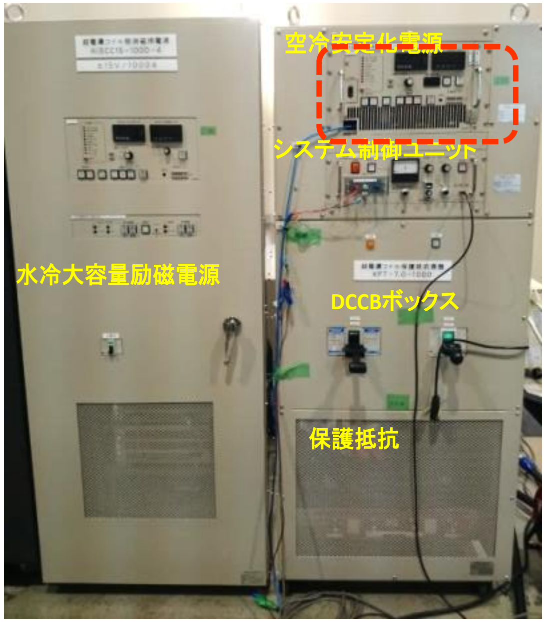


Image of Human-Left-Hand in the 150mm area by wide bore system (used LTS magnet)

Influence of magnetization of high-temperature superconducting







Highly stable excitation power supply

Highly stable magnetic field generation by overshoot method and magnetic field holding power supply and control. Measured by REBCO 3T model coil.

SUMMARY

○ As a next-generation MRI, we started the research and development of high stable magnetic field coil system fundamental technology using the REBCO superconducting coil.

○ We promote the development aimed at imaging verification magnetic field of 3 T of stability less than 1ppm / hr and uniformity of 10ppm / 20mmDSV. We successfully MRI Images of Mouse fetus using a HTS 3T Test Magnet at 2.9T were obtained.

○Advance research and development to solve problems related to the manufacture of large-diameter magnets and obtain highly stable magnetic fields as NEDO project for practical application of the high temperature superconducting coils.

○ Next year, we will complete half size active shield type 3T REBCO magnet and plan to carry out imaging of hands and feet.

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Thank you for your attention

ありがとうございました。

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