WISE Dialogue 2025
12-13 March 2025

Invention of Neodymium Magnets
- Young researchers bring about innovation -

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NDFEB Corp. President
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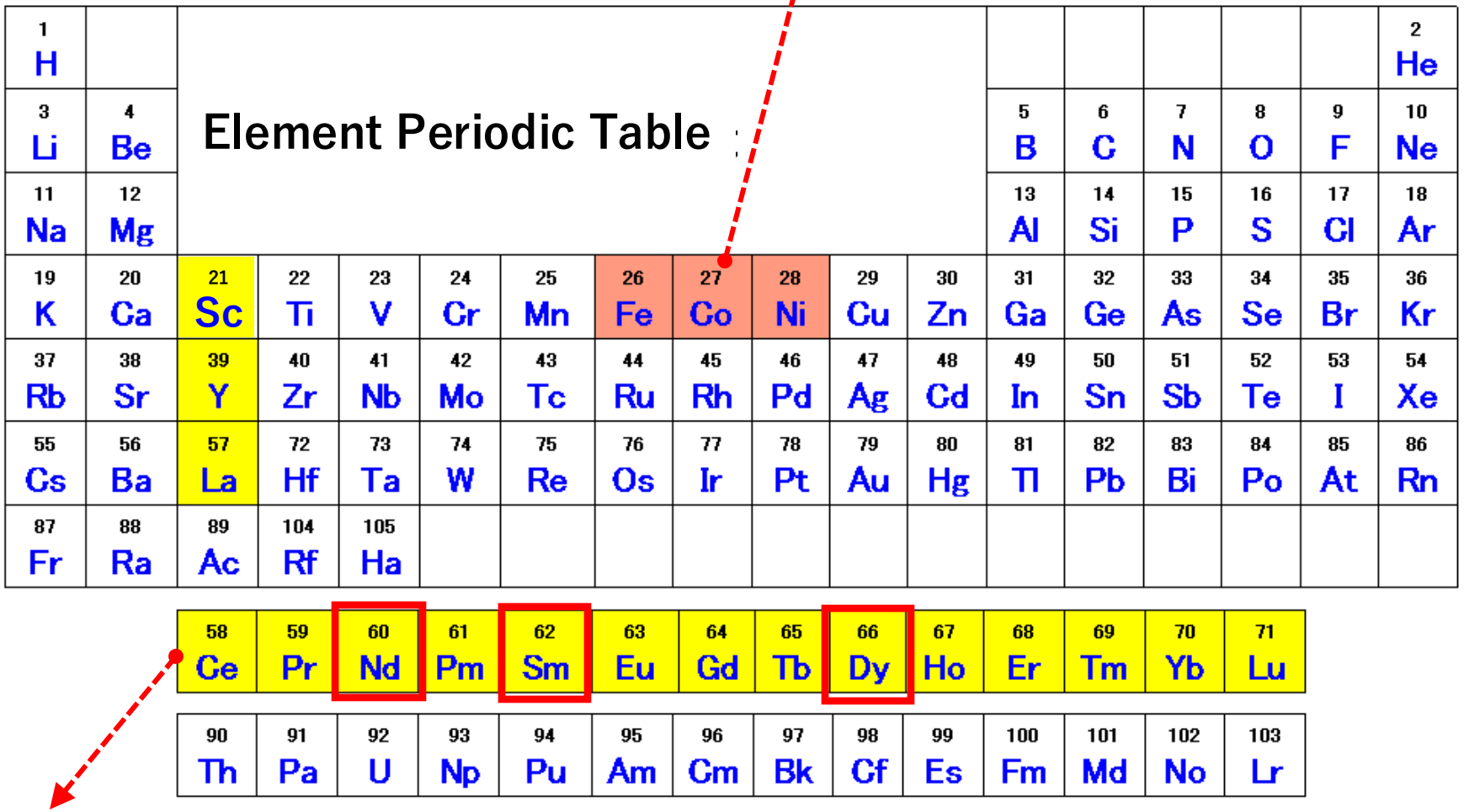
Let's Review the Periodic Table:

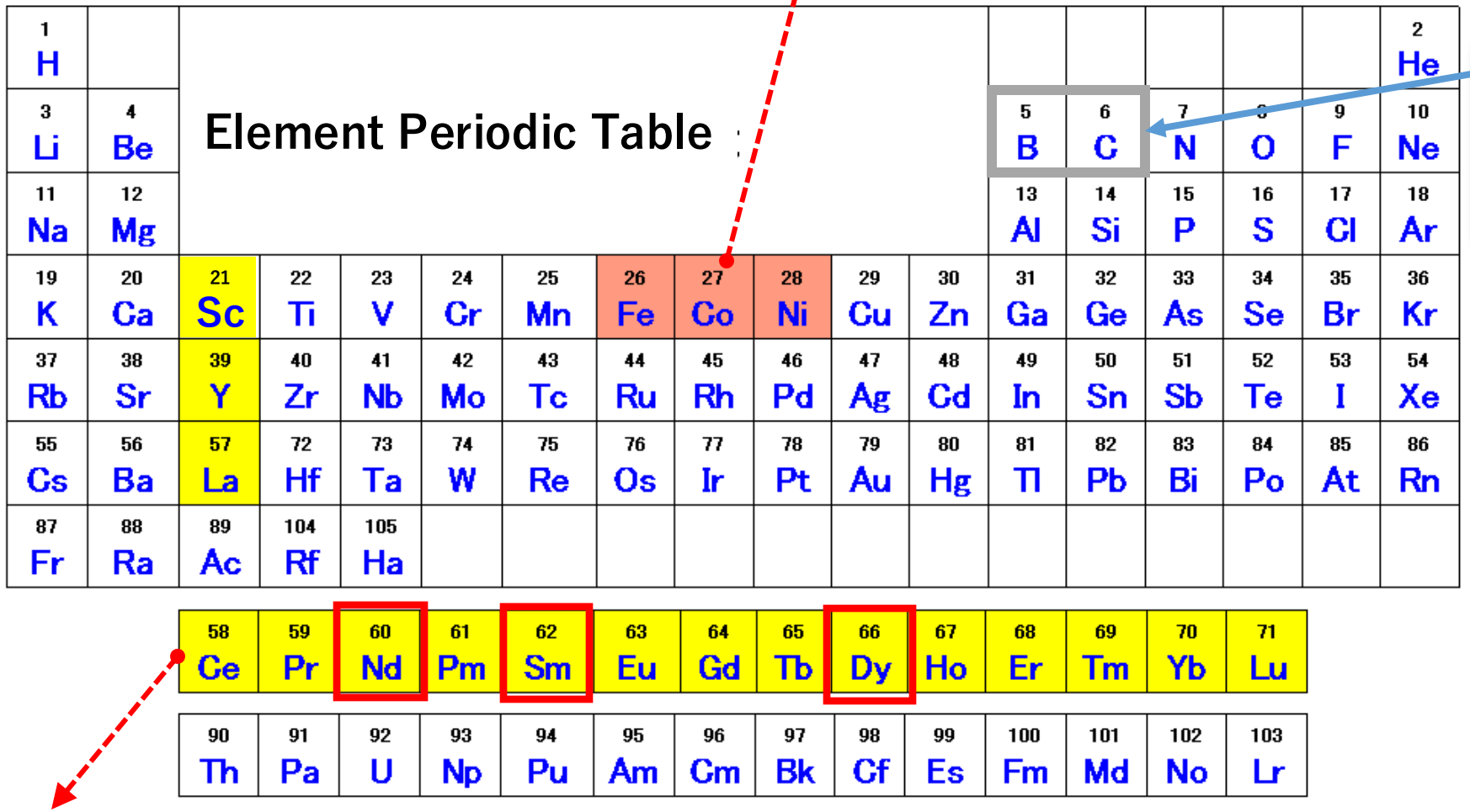
Magnetic element: T = Fe, Co, Ni



Magnetic element: R = Rare earth 17 elements

Let's Review the Periodic Table:

Magnetic element: T = Fe, Co, Ni



Light element:

B (boron), C (carbon)

Magnetic element: R = Rare earth 17 elements

Personal History

I aimed to become a materials scientist and went on to a master's course at Kobe University and a doctoral course at Tohoku University.

My research subject at those universities was:
“Crystal growth on clean surfaces of solids”

In 1972, I became a doctor of engineering.

I tried my best, but I couldn't become a good researcher.

I wanted to stay in academia, but no offers!

I have no confidence in myself.

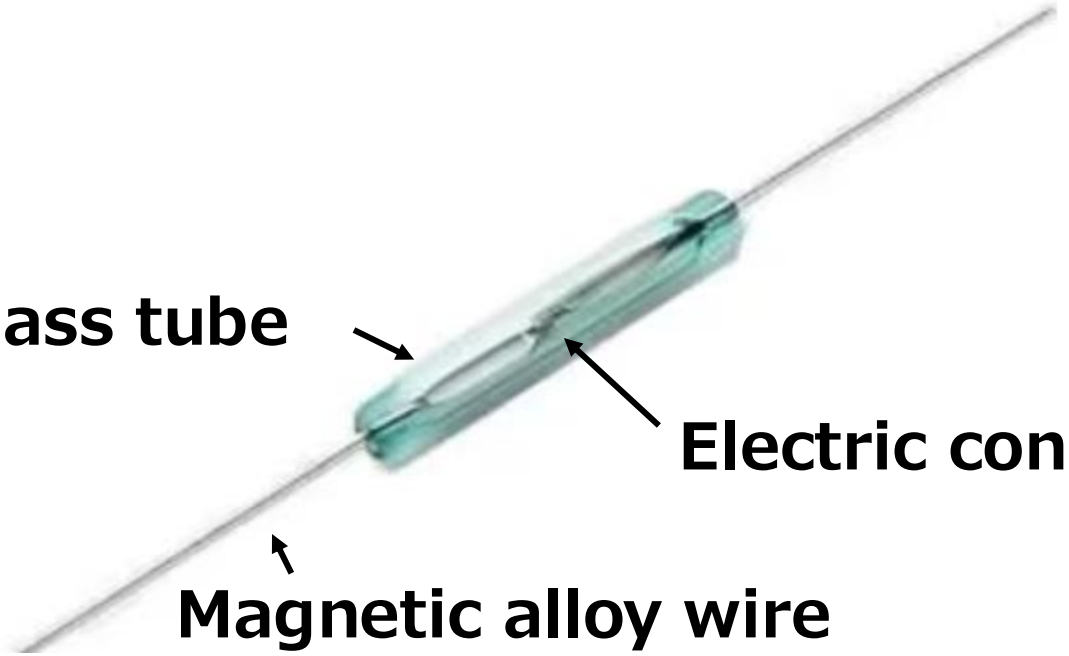
I joined Fujitsu Laboratories. (1972)

1972

Research topic given by the company

Magnetic materials for use in relays and switches

One of the main products was the reed switch.



In reed switches, magnetic alloy wires were the primary component.

1972

At first:

I’m not confident.

I worked hard and studied hard.

1973

Confident:

I'm getting the hang of it. I think I can do something by myself.

Five years since joining Company

1977

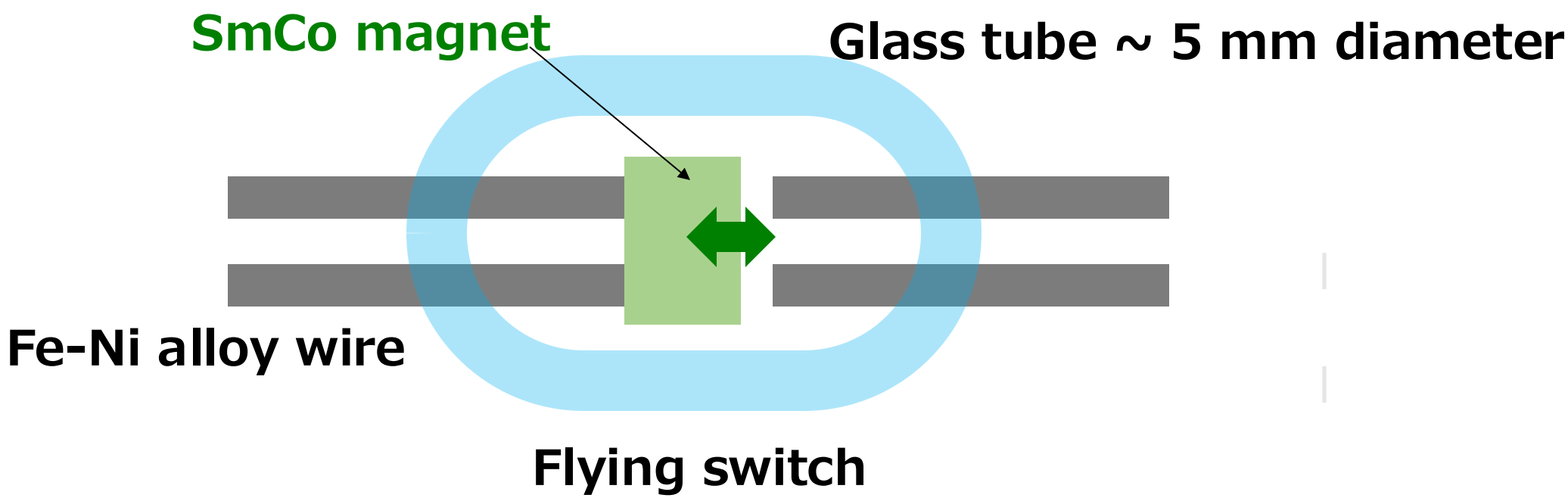
New topic

For flying switches

Unbreakable SmCo magnets

No chipping after many switching

My goal



1977 ~

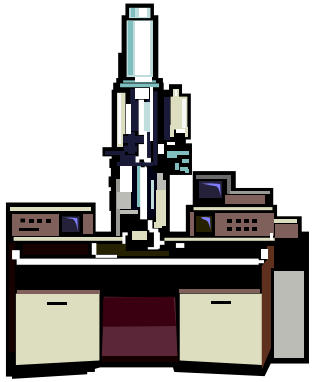
Research on SmCo magnets? ?
I've never done it before.
I have nobody to guide me.

I was a novice in the study of magnets!

1977 ~ I had to study by myself.

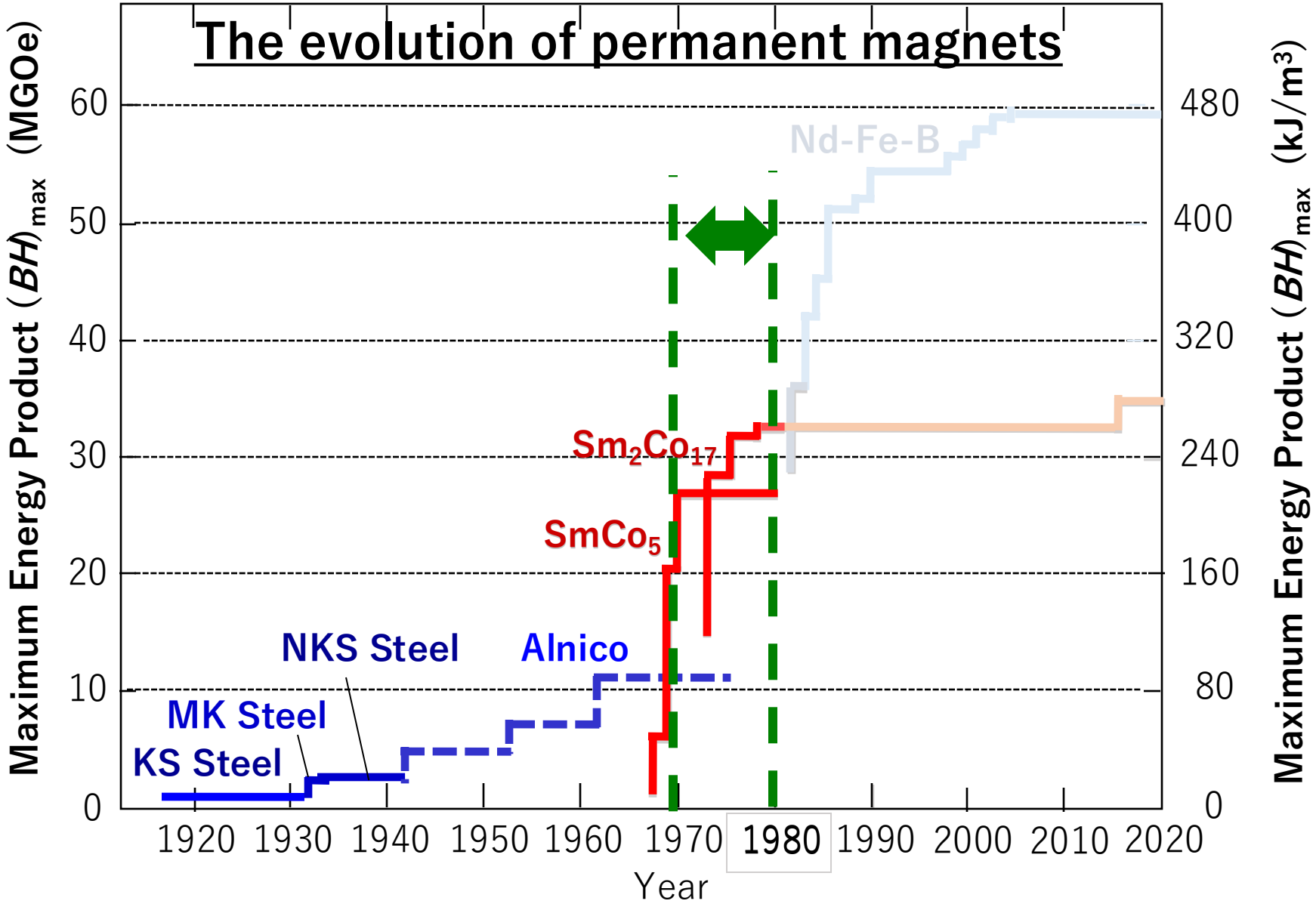
It was fun once I got started.

The basic studies I did in graduate schools, and the experience I gained from various experiments came in handy!



→ I became fascinated with the study of magnets!

Sm-Co magnets made a major breakthrough in the 1970s.



1977

My topic

For flying switches

Unbreakable SmCo magnets

Study on SmCo magnets

⬇

Ideas for improving mechanical strength

⬇

Development is progressing smoothly

Question

Why can't we make rare earth (R)-Fe magnets?

☆ Fe is an inexhaustible resource ...

☆ Fe has a larger magnetic moment than Co ...

1978

Symposium

Clue!

From fundamentals to applications of rare earth magnets

Contents

1. Phase diagrams of R-Co systems and magnetic properties of RCo_5 and R_2Co_{17}····M. Hamano

Why don't R-Fe magnets exist?

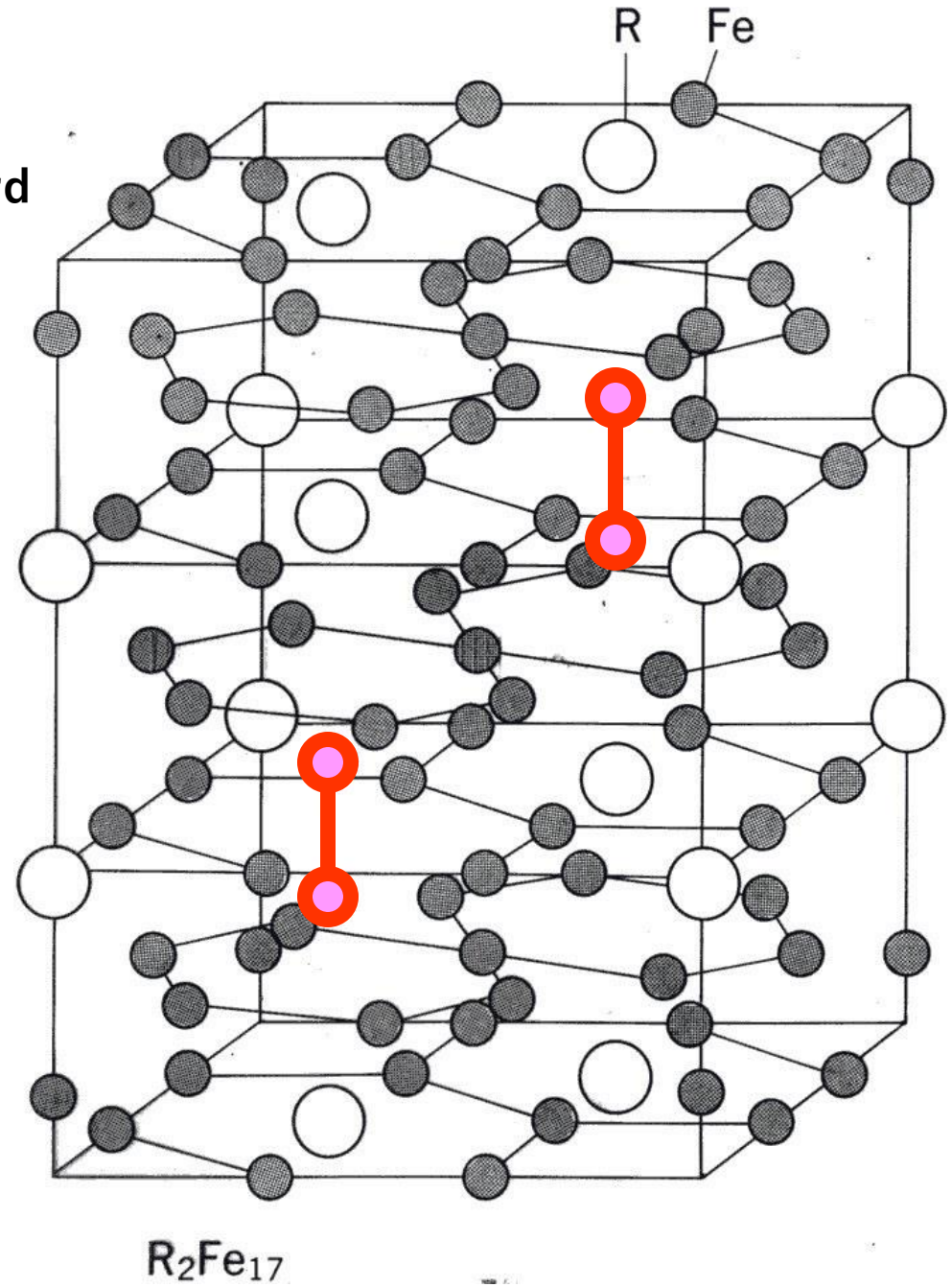
2. Coercivity of R-Co permanent magnets ·····K. Goto
3. Magnetization reversal in single crystals of $SmCo_5$ and $GdCo_5$····· R. Katayama
4. Time dependent magnetization reversal in the RCo_5 compounds····· M. Uehara
5. $SmCo_5$ permanent magnets·····K. Miyazaki
6. $MMCo_5$ permanent magnets····· S. Yamashita
7. Cu substituted R-Co permanent magnets·····Y. Tawara
8. ·····

1978

His explanation was based on a paper of D. Givord

D. Givord *

M. Hamano



Then, I got an idea:

C or B may expand the Fe-Fe distances!

"Fe-Fe distances are too short for a stable ferromagnetic compound"

* Image adopted from "In memory of Dominique Givord (1945 - 2019)" by EMMA https://magnetism.eu/news/107/38-news.htm

I did an experiment right away!

Arc melting

R-Fe-C

R-Fe-B

(R = Sm, Ce, Nd, …)

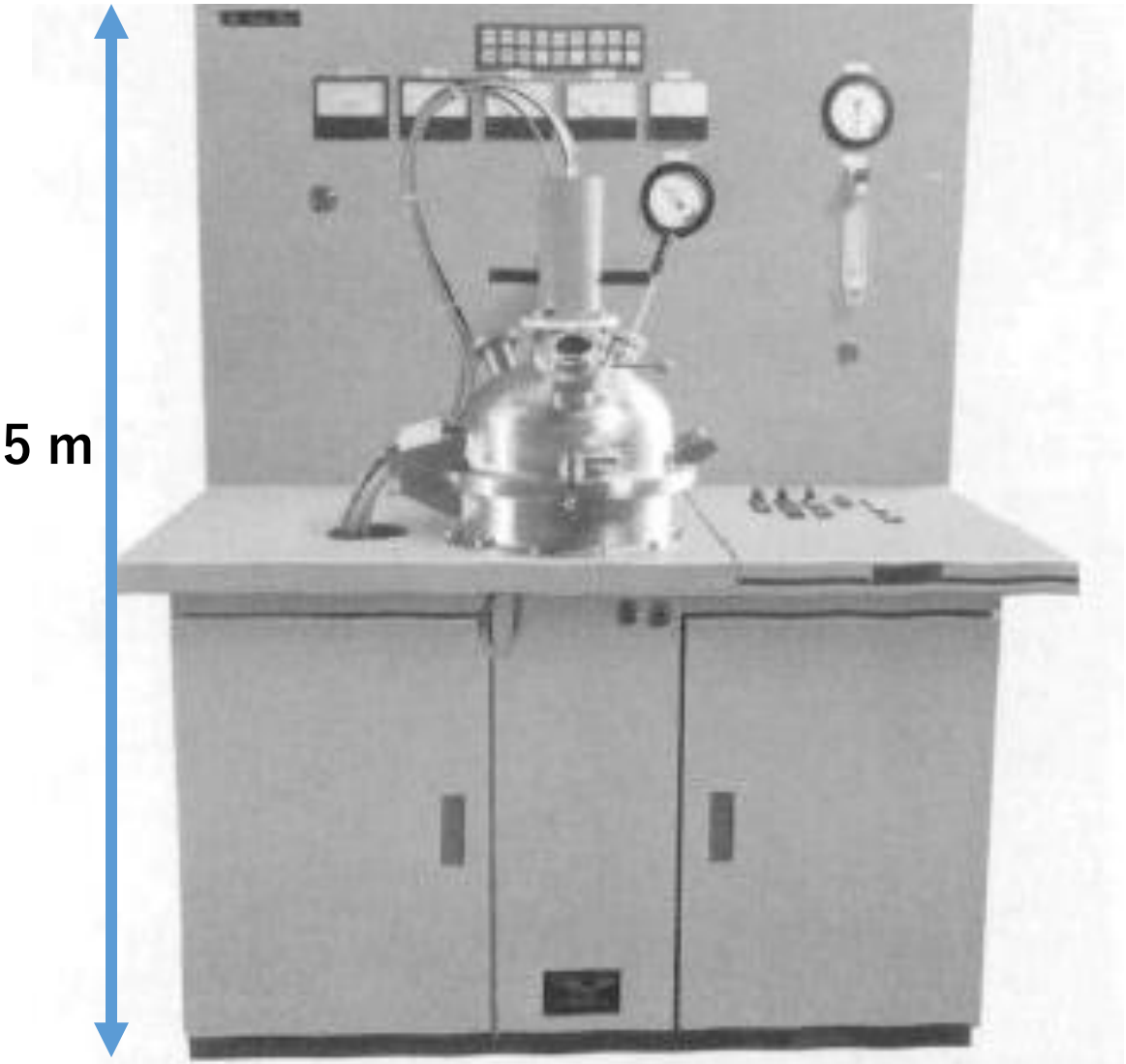
Measurements

VSM measurement

X-ray diffraction

I used an arc melting furnace - Ten different alloys can be made at once:

Very convenient and efficient.



Arc melting furnace exterior

Alloy buttons produced: 20 g each

I prepared many alloys in this order:

Sm-Fe-C ➡ Sm-Fe-B ➡ Ce-Fe-B

Sm-Fe-B

Pr-Fe-B

Nd-Fe-B

Dy-Fe-B

⋮

Then I noticed that R-Fe-B alloys are the most interesting.

To find a new magnet

Finding promising R-Fe-B compounds

Creating an **alloy microstructure suitable for magnets** consisting of R-Fe-B crystal grains and grain boundary phases

I couldn’t make this yet, so I couldn’t make magnets yet.

Birth of new magnet

1977

New topic

For flying switches

Unbreakable SmCo magnets

Study on SmCo magnets

↓

Ideas for improving mechanical strength

↓

Development is progressing well.

↓

1978

The development was successful.

1978

New topic

For flying switches

Unbreakable SmCo magnets

The development was successful.

I proposed to do research on R-Fe-B magnets

1979

No research on magnets as Company!
“Leave the research to material manufacturers!”

1979

I had to find a new topic.

How about developing applications of $NdCo_5$ spin reorientation?

That's interesting!

Spin reorientation of $Nd(Co \cdot T)_5$

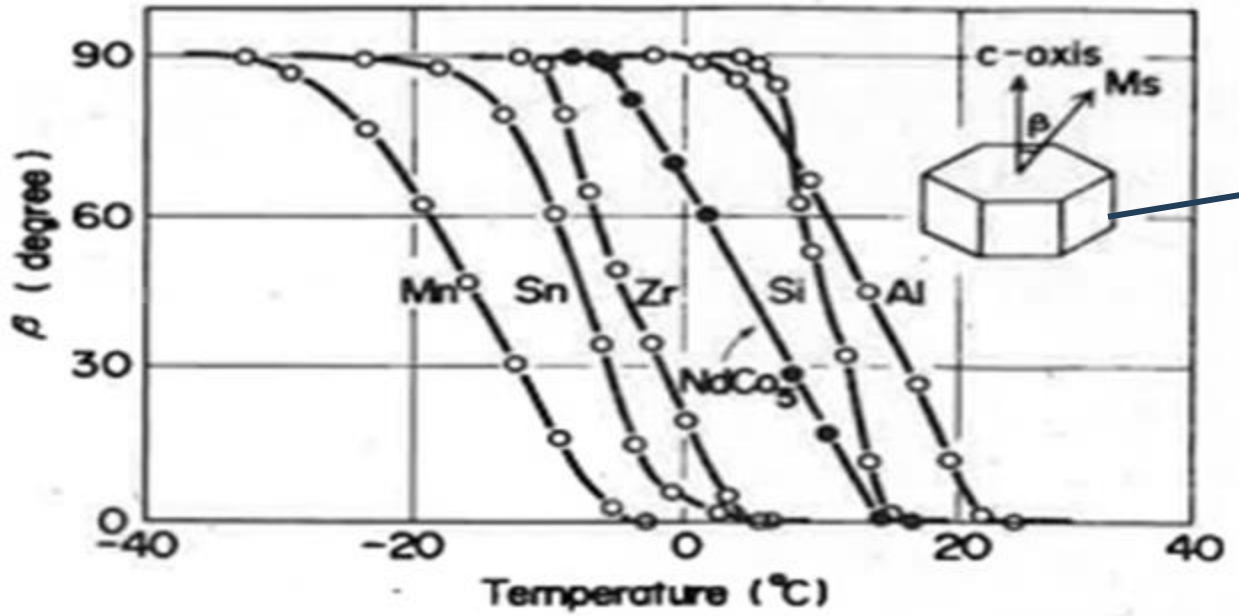


Fig. 3. Variation of the easy direction of magnetization with temperature for Nd $(Co_{0.97}T_{0.03})_5$ with T=Mn, Sn, Zr, Si, and Al.

Spin Reorientation

As the temperature increases, the direction of easy magnetization changes from the c-plane to the c-axis direction.

Applications of $Nd(Co \cdot T)_5$ → Thermal sensor, thermal valve, magnetocaloric material for magnetic refrigeration.

T = transition metal

Formal research topic

1979 Materials and applications of spin reorientation of $NdCo_5$

⬇

1980 Research success

I was promoted to a management position…

⬇

1981 Presented at an international conference

⇣ ⇣ ⇣

I became familiar with $NdCo_5$ & Nd.

Apart from formal topic : **Informal topic for R-Fe magnet**

1978 **Idea:** Inserting C or B in R_2Fe_{17} → Increasing the Fe-Fe distance → Ferromagnetism becomes stable!

1979

I pursued this informal research:

1980 How can I make R-Fe-B magnets?
I kept working in my head. Little by little, ideas for the microstructure of R-Fe-B magnets began to emerge.

1981

I began to look for a job at a magnet manufacturer.

1982　I found Sumitomo Special Metals (SSM)

Submit my resignation to the company → Start job hunting

↓

I applied to SSM but had no response.

↓

I called the president → He happened to answer directly.

↓

M. S. "I want to research rare earth magnets without Co.“

↓

The president said, "I'm very interested."

To find a new magnet

Finding promising R-Fe-B compounds

Creating an **alloy microstructure suitable for magnets** consisting of R-Fe-B crystal grains and grain boundary phases

I was close to finding an alloy structure suitable for magnets.

Birth of new magnet

1982

I joined SSM with:

A vague idea about Nd-Fe-B compound

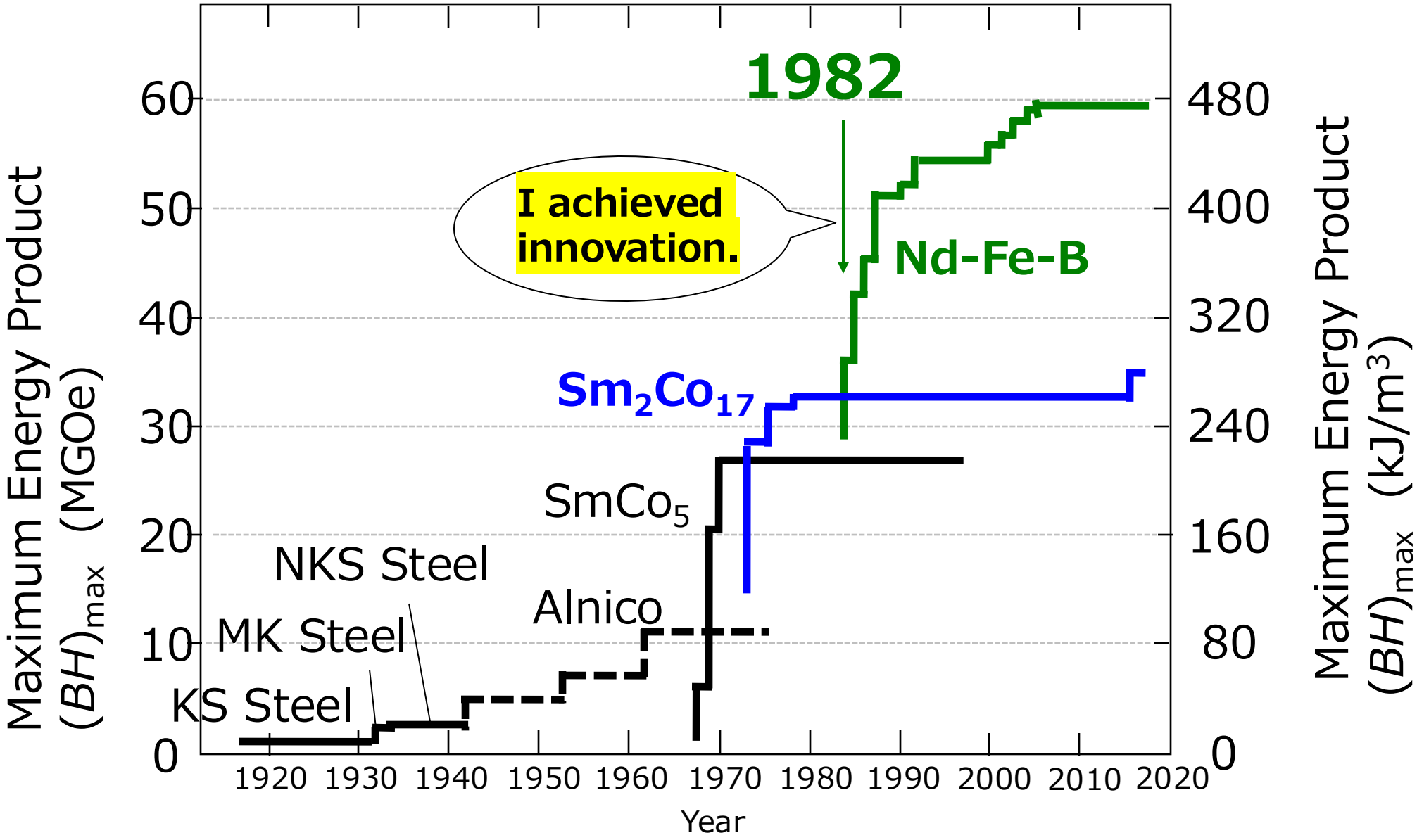
+ a vague idea about alloy micro-structure for magnets

Among 50 types of alloy compositions that I had in mind, we found the world strongest magnet.

Trial sample preparation

The world's strongest magnet was born in June 1982.
It was the sintered Nd-Fe-B magnet.

World evolution of the strongest magnets



June, 1982

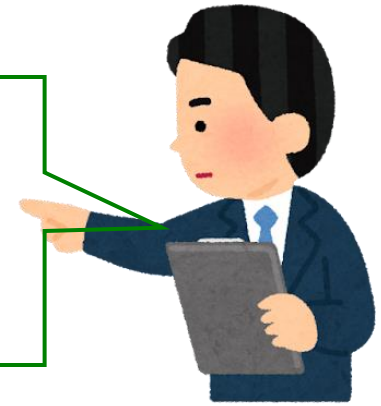
The world's strongest NdFeB magnet was born.

⇩

Two weeks later

Poor magnetic properties at high temperatures!!

This magnet can only be used for toys.



Is this the fate of Fe magnets?

But, I was not alone.

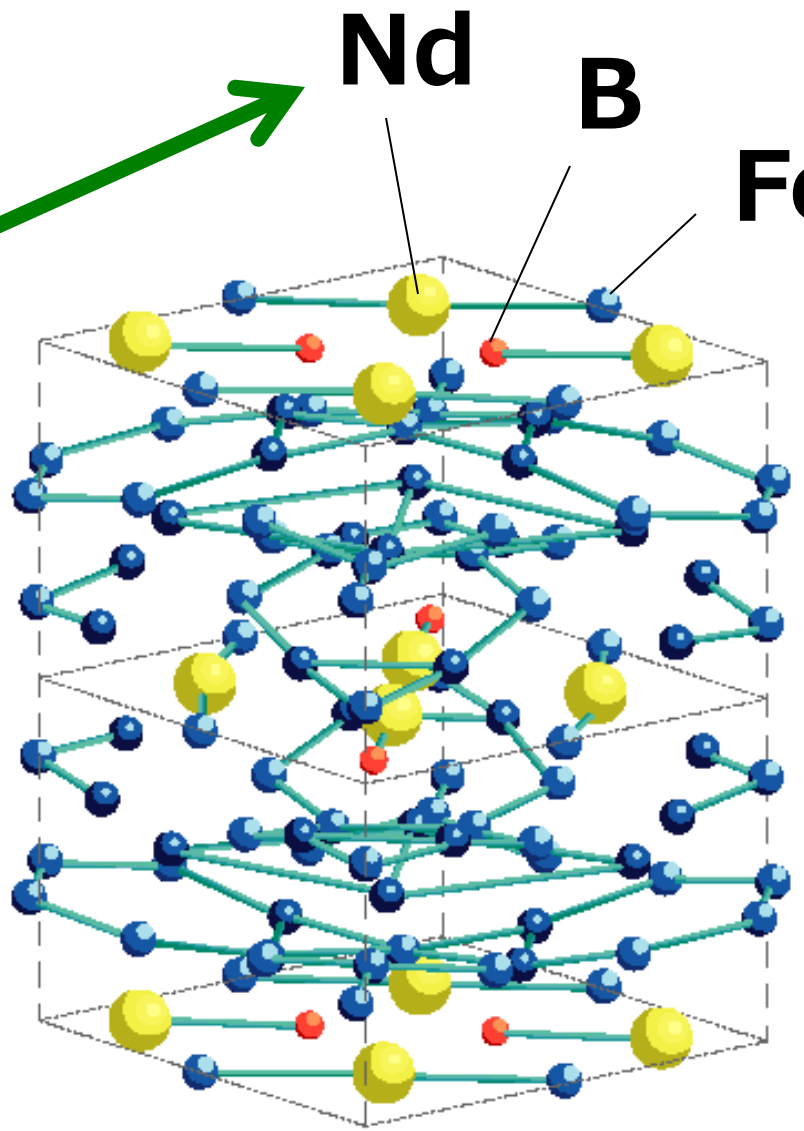
My SSM team (1982 ~ 1988) carried out the following tasks:

Development of NdFeB magnets, Patent applications, Industrialization, and Basic Research.

I am proud of this team. A very efficient team.

Replace some

Dy (dysprosium)



$Nd_2Fe_{14}B$

We discovered that Dy enhances heat resistance of the magnets!

I made the first presentation on the NdFeB sintered magnet at MMM Conference held in Pittsburgh, PA on Nov. 10, 1983

1983

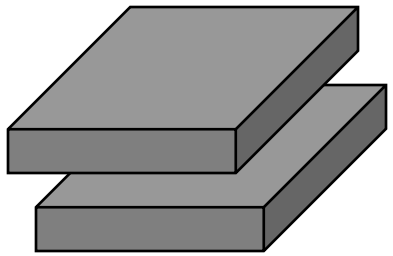
I was 40 years old at this time.

1982 Invention

↓

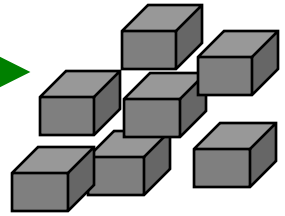
1985 SSM members established the mass production process.

Melting



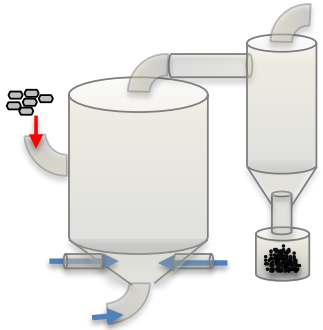
Alloy
~ 5 kg

Crushing



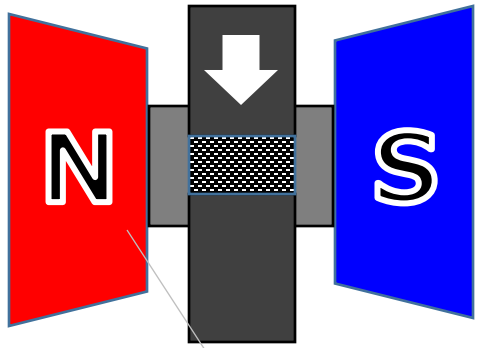
Coarse
powder

Jet milling



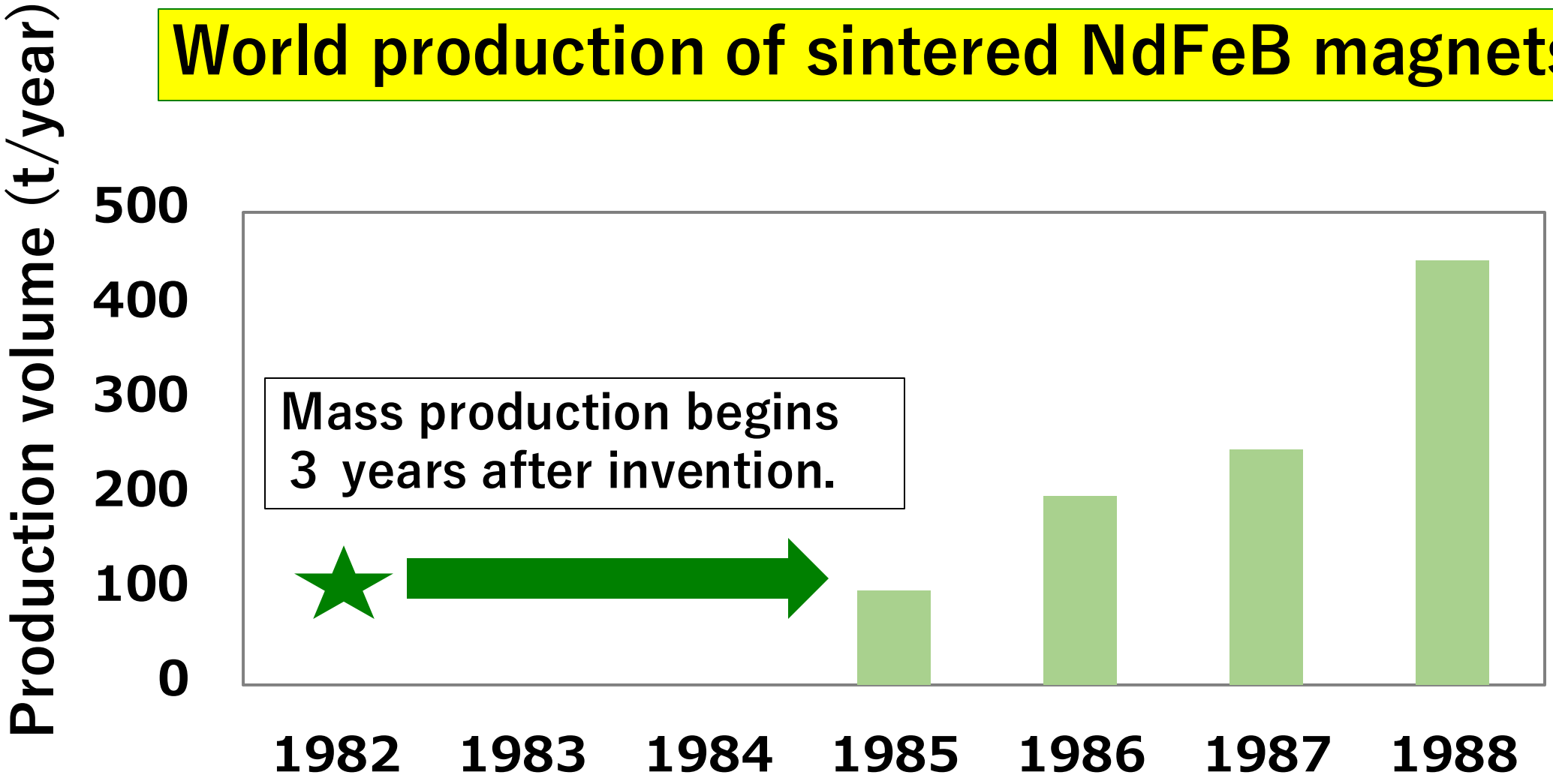
Fine powder
~ 5 μm

Pressing in a magnetic field



Sintering in vaccuum

World production of sintered NdFeB magnets



Neodymium magnets used in HDDs

Spindle motor
Neodymium resin bonded magnet
(The group of Dr. John Croat invented.)

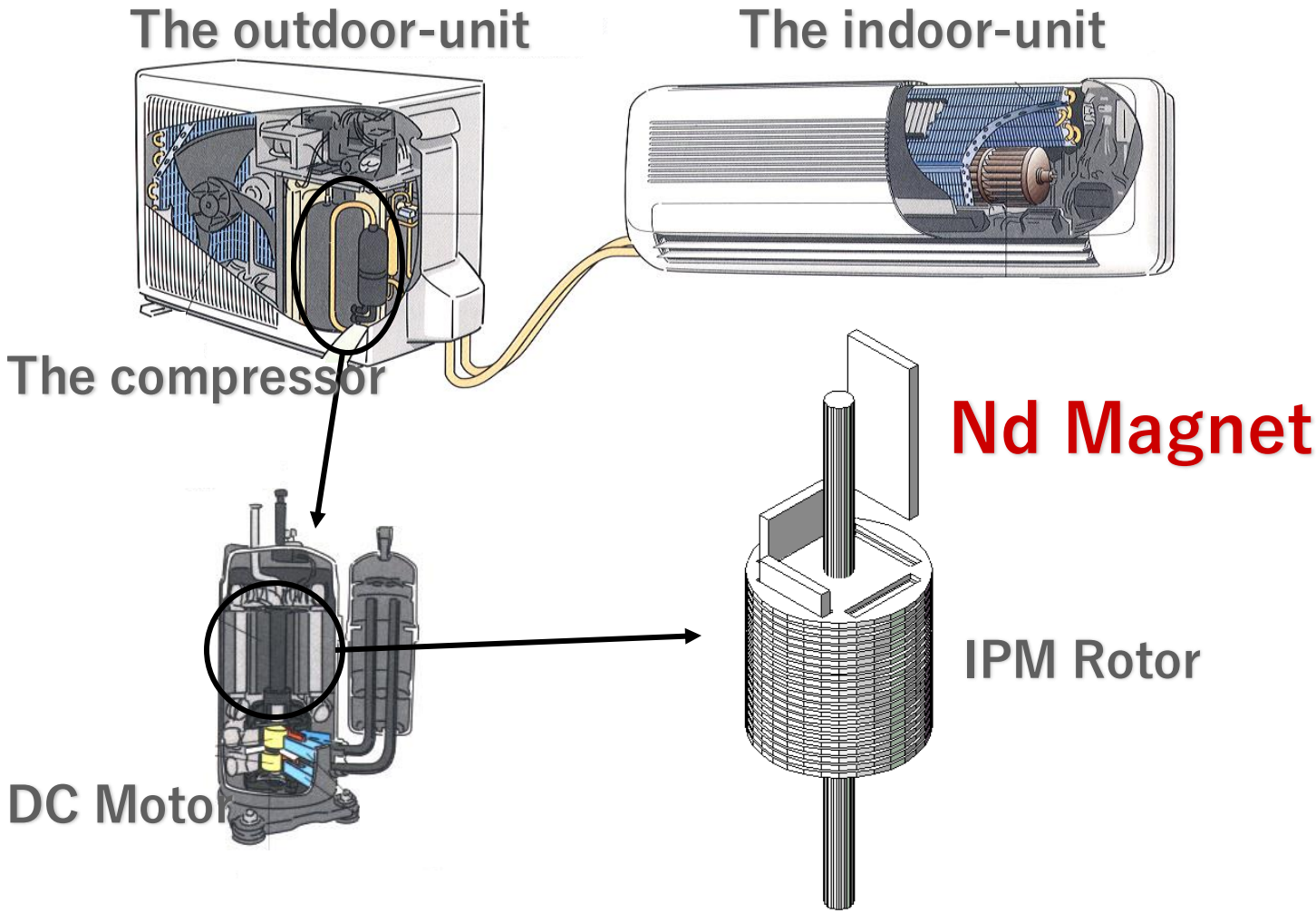
Voice coil motor

Neodymium sintered magnet
(My group invented.)

From TeraWin's website
https://www.terawin.co.jp/data-recovery/about_data/about_hdd.html

Nd resin bonded magnet is used in Spindle motor. The group of Dr. Croat invented the resin bonded magnet. In the VCM, the Nd sintered magnet is used.

Neodymium magnets used in air conditioners



Sintered NdFeB magnets are used in the IPM motor in the air conditioner. The air conditioners make people more comfortable around the world.

Neodymium magnets used in world xEVs

Toyota Prius

Lexus UX 300e

Mercedes-Benz E type

Audi S5

Nissan Leaf

BMW i8

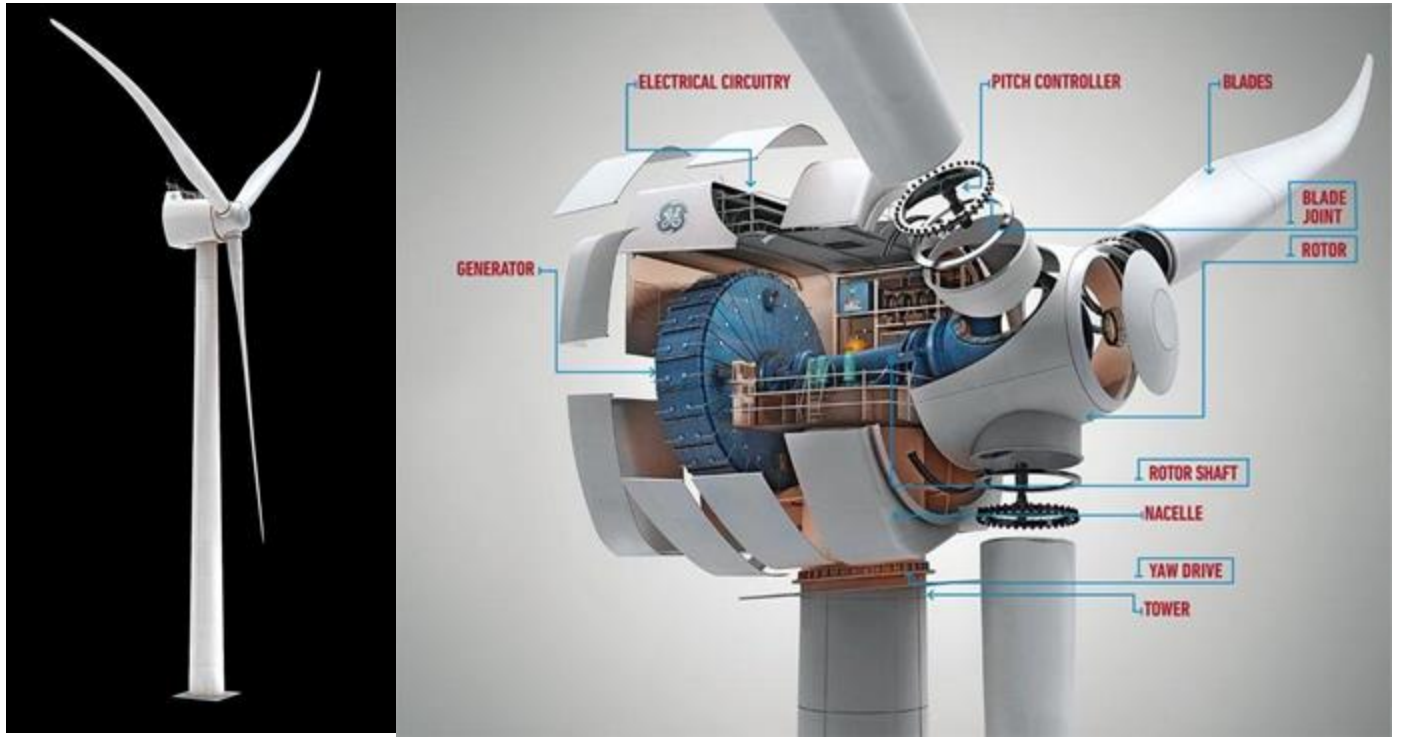
Sintered NdFeB magnets are used in EV main motors around the world, helping to prevent global warming

Neodymium magnets in action (Sintered NdFeB)

Motors for industrial robots

From the website of Yaskawa Electric Corporation
https://www.yaskawa.co.jp/product/robotics
https://www.yaskawa.co.jp/product/servomotor

Wind turbine



From the website of POPLEAR SCIENCE
https://www.popsci.com/how-it-works-next-gen-wind-turbine/

Sintered neodymium magnets are used in large quantities in robots and wind turbines.

1972

I lacked confidence

2024

I won a lot of big prizes!

Why was I able to innovate?

Because I was young.

1977

I had this question because I was young.

Question

Why can't we make rare earth (R)-Fe magnets?

Fe is an inexhaustible resource ...

Fe has a larger magnetic moment than Co ...

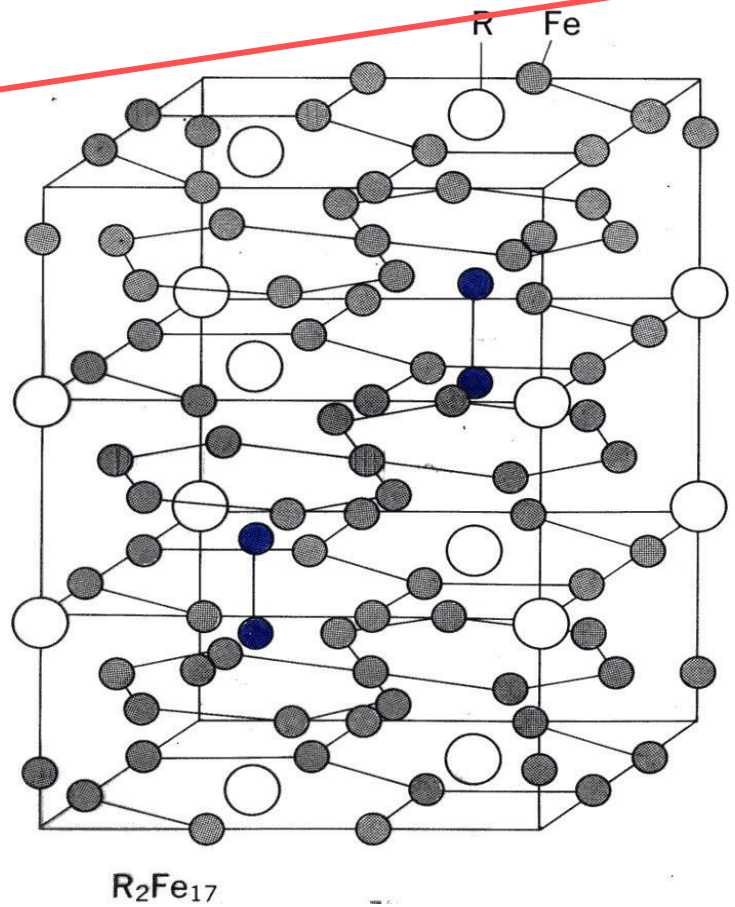
Explanation

1978

I was young so I came up with this idea.

I was inspired !

"Fe-Fe distances are too short for a stable ferromagnetic compound"



By inserting C or B in the lattice, it may be possible to increase the Fe-Fe interatomic distance!

1978

I made these alloys because I was young.

Ce-Fe-B

Pr-Fe-B

Nd-Fe-B

Dy-Fe-B

.....

.....

From the next day, I prepared many alloys:

1982

I was young so I didn't give up!

I prepared!

NdFeB Magnet

NdFeB alloys were very strong mechanically. It was common knowledge that alloys that are not easily broken do not become magnets. I went against that common knowledge and created a sintered NdFeB magnet.

I rebelled against conventional wisdom：

Invention of NdFeB sintered magnet

I was able to do it because I was young!
Veterans couldn't have done it.

Veterans tend to have difficulties in thinking "outside the box"!

The joy of successful research is indescribable!
I hope that all the young people here will become researchers and contribute to society as researchers.

Only young people can bring about innovation.

To all young researchers, please bring about innovation and further advance the human race.

Thank you for your attention.