Clean Up of Lead (Pb)
contaminated Soil & Groundwater
by R N I P®
(Reactive Nanoscale Iron Particles)

December 2021

NAKAMURAKISO.CO., LTD.

What is R N I P® ?

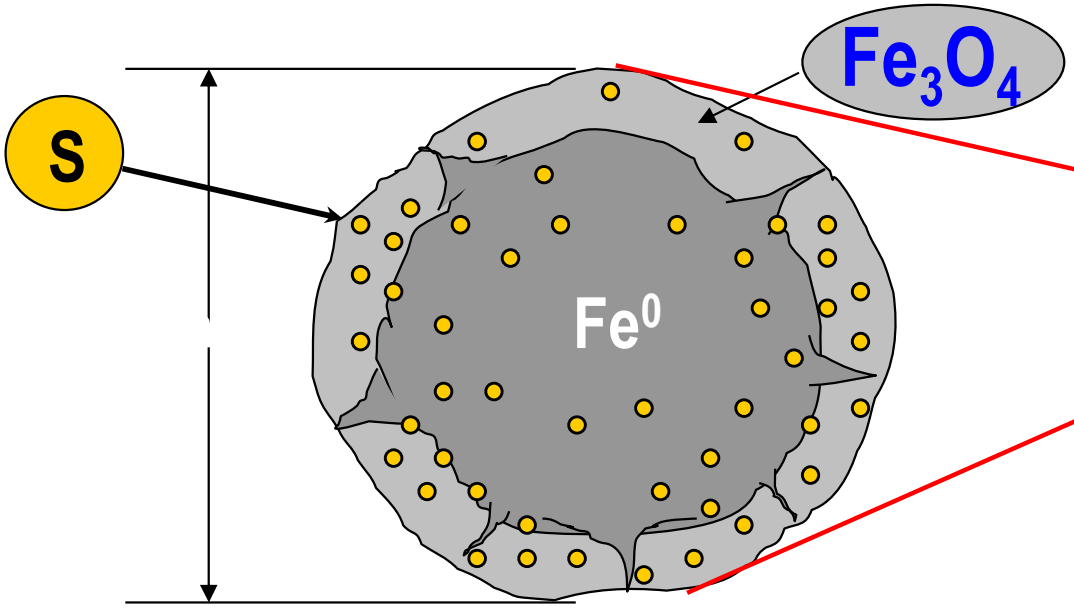


Fig. 1 Schematic RNIP® structure

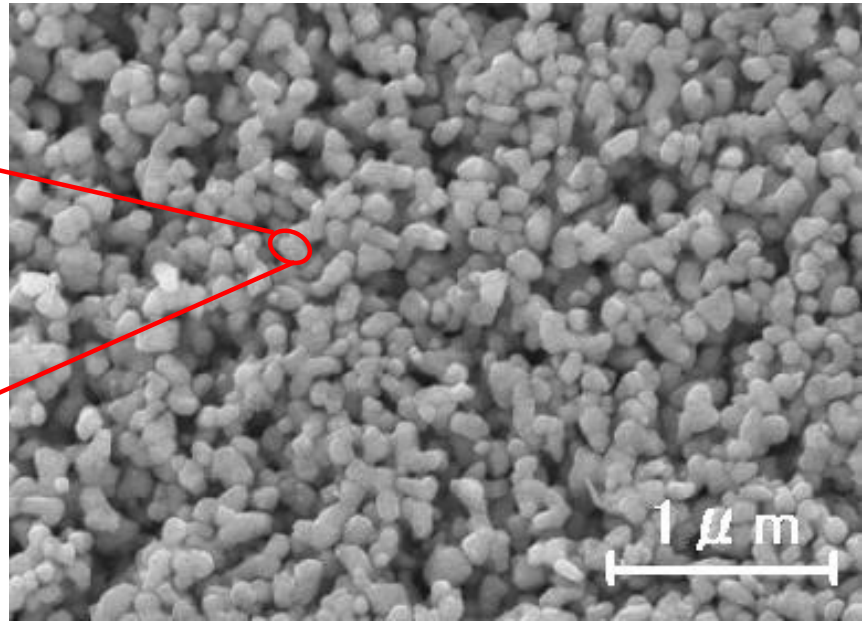


Fig. 2 SEM image of RNIP®

RNIP® consists of metallic iron core (α-Fe) and magnetite shell (Fe_3O_4).

- **Particle size; 70 nm**
- **Specific surface area; 30 m^2/g**

What is RNIP® ?

- RNIP® is processed in aqueous slurry.
  - Slurry Density; 1.25 g/ml
  - Solid concentration; 25 wt.%
  - Slurry Viscosity; 600～700 mPa･s
- Slurry of RNIP® is diluted by several to one hundred times in use.
  - Dilution viscosity; <10 mPa･s>

Fig. 3 Slurry of RNIP®

What is RNIP® ?

- **We have produced RNIP® slurry of 60 tons per month at our Higashi-hiroshima plant since 2017.**


Fig. 4 Higashi-hiroshima plant

- Site area
  ca. 4,000㎡,
  built in October 2017
- Production capacity
  60 tons/month
  (Max 90 tons/month)

- Packaging product

1m³
SUS container

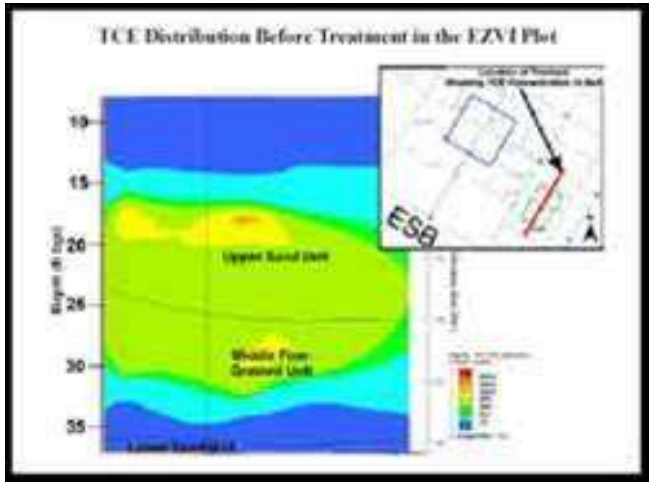
200L
Drum can

20L
Plastic container

NASA used RNIP® first in the world !

- For clean up of VOC's contaminated soil in Kennedy Space Center's Launch Complex34 November 2002.
- By Superfund Innovative Technology Evaluation program of EPA.
- NASA's Emulsified Zero-Valent Iron (EZVI) involves RNIP® into a surfactant-stabilized, biodegradable oil-in-water emulsion[1)] .
- Quantity of injected EZVI ; 0.4～0.8wt% based on solid

- **Initial VOC's 200～6000 mg/kg ⇒ After clean up : ND**



Characteristics of RNIP® summary

- **RNIP® is an environmentally friendly material that is non-toxic, safe and secure. Therefore, it does not cause a secondary environmental pollution after using it.**

- **RNIP® has a high performance for clean up of heavy metals, such as lead (Pb), chromium (Cr), arsenic (As) and selenium (Se)[2), 3), 4)].**

- **RNIP® has a high mobility performance in subsurface and is suited for in-situ rapid clean up works using a conventional chemical grouting method or a mechanical mixing method.**

- **The VOC clean up performance of RNIP® is much greater than that of commercial iron powders by 100 times[5)].**

Characteristics of RNIP® in detail

① Harmless materials

Elution test of RNIP ®

Element	Elution Value of RNIP	Japanese Regulation
Cd [mg/l]	＜ 0.001	≦ 0.01
Total-CN [mg/l]	Not detected	Not detected
Pb [mg/l]	＜ 0.005	≦ 0.01
Cr6+ [mg/l]	＜ 0.04	≦ 0.05
As [mg/l]	＜ 0.001	≦ 0.01
Total-Hg [mg/l]	＜ 0.0005	≦ 0.0005
Se [mg/l]	＜ 0.002	≦ 0.01
F [mg/l]	＜ 0.5	≦ 0.8
B [mg/l]	＜ 0.1	≦ 1
Total-Cr [mg/l]	＜ 0.1	-
Mn [mg/l]	＜ 0.1	-

On the Ministry of Environmental Notification of No. 46 from 1991 for the contaminated soil in Japan

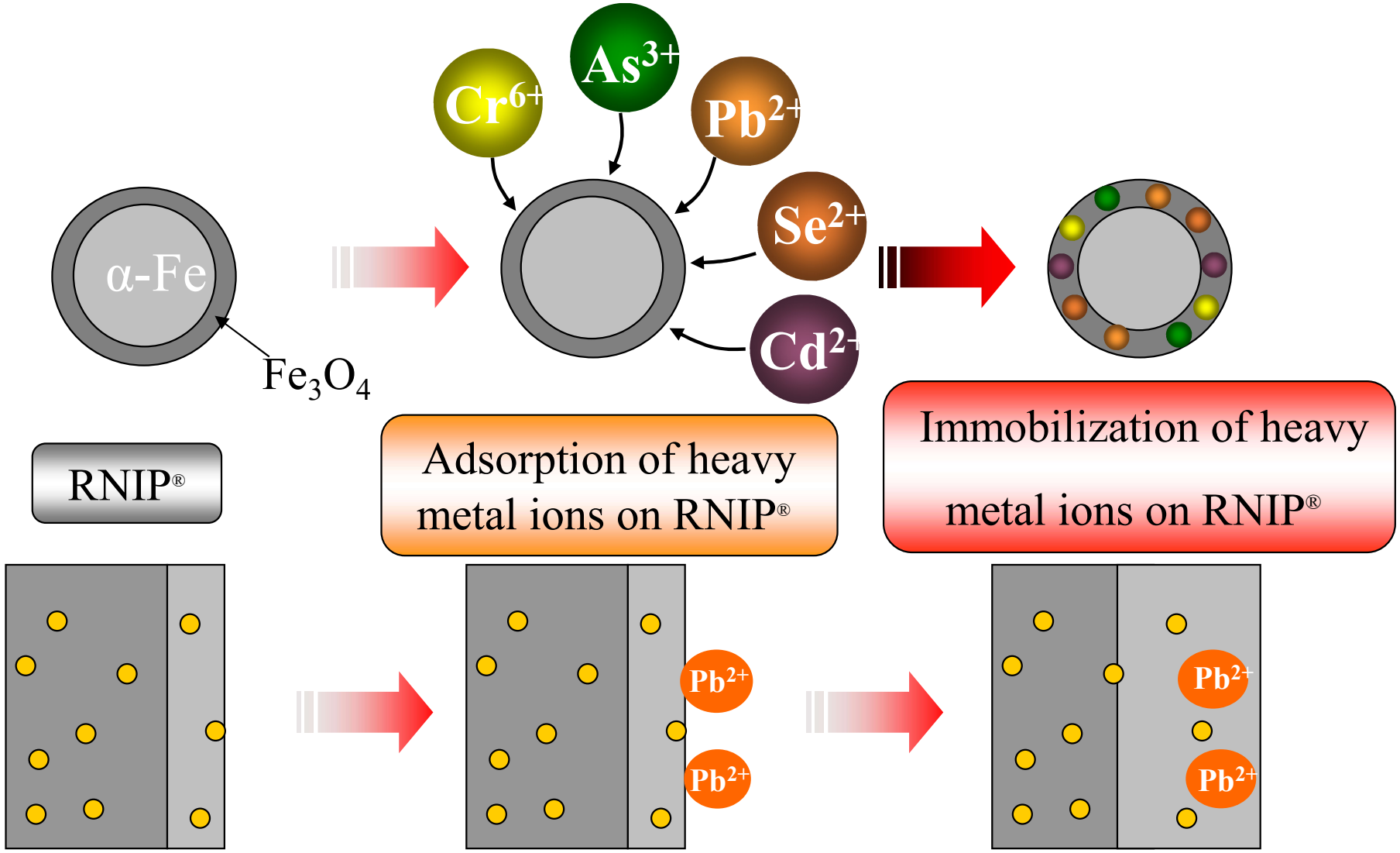
Content test of RNIP®

Element	Content Value of RNIP	Japanese Regulation
Cd [mg/kg]	＜ 2	≦ 150
Total-CN [mg/kg]	＜ 5	≦ 50
Pb [mg/kg]	＜ 5	≦ 150
Cr6+ [mg/kg]	＜ 5	≦ 250
As [mg/kg]	＜ 1	≦ 150
Total-Hg [mg/kg]	＜ 1	≦ 15
Se [mgkg]	＜ 1	≦ 150
F [mgkg]	＜ 20	≦ 4000
B [mg/kg]	＜ 20	≦ 4000

On the Ministry of Environmental Notification of No. 19 from 2003 for the contaminated soil in Japan

Characteristics of RNIP® in detail

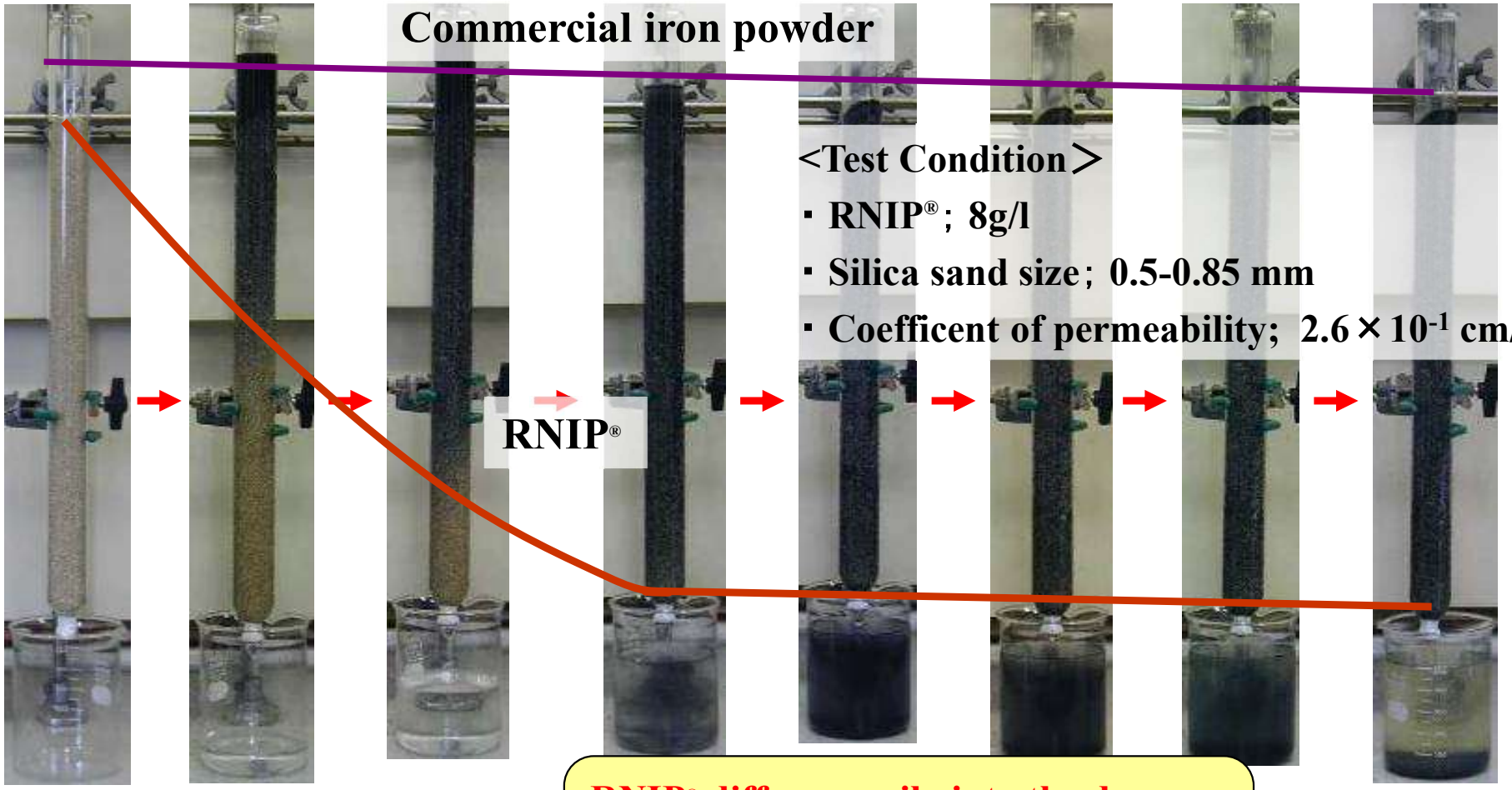
② Reaction schematic of clean up of heavy metals by RNIP®



Characteristics of RNIP® in detail

③ High mobility performance for in-situ clean up

Mobility test with saturated soil



RNIP® diffuses easily into the deep spots of contaminated soil because of very fine particles.

Characteristics of RNIP® in detail

③ High mobility performance for in-situ clean up works

Fig. 5 Injection of RNIP® with chemical grouting

Fig. 6 Mixing of RNIP® with mechanical mixing or agitating

Data of Lead cleanup by RNIP®

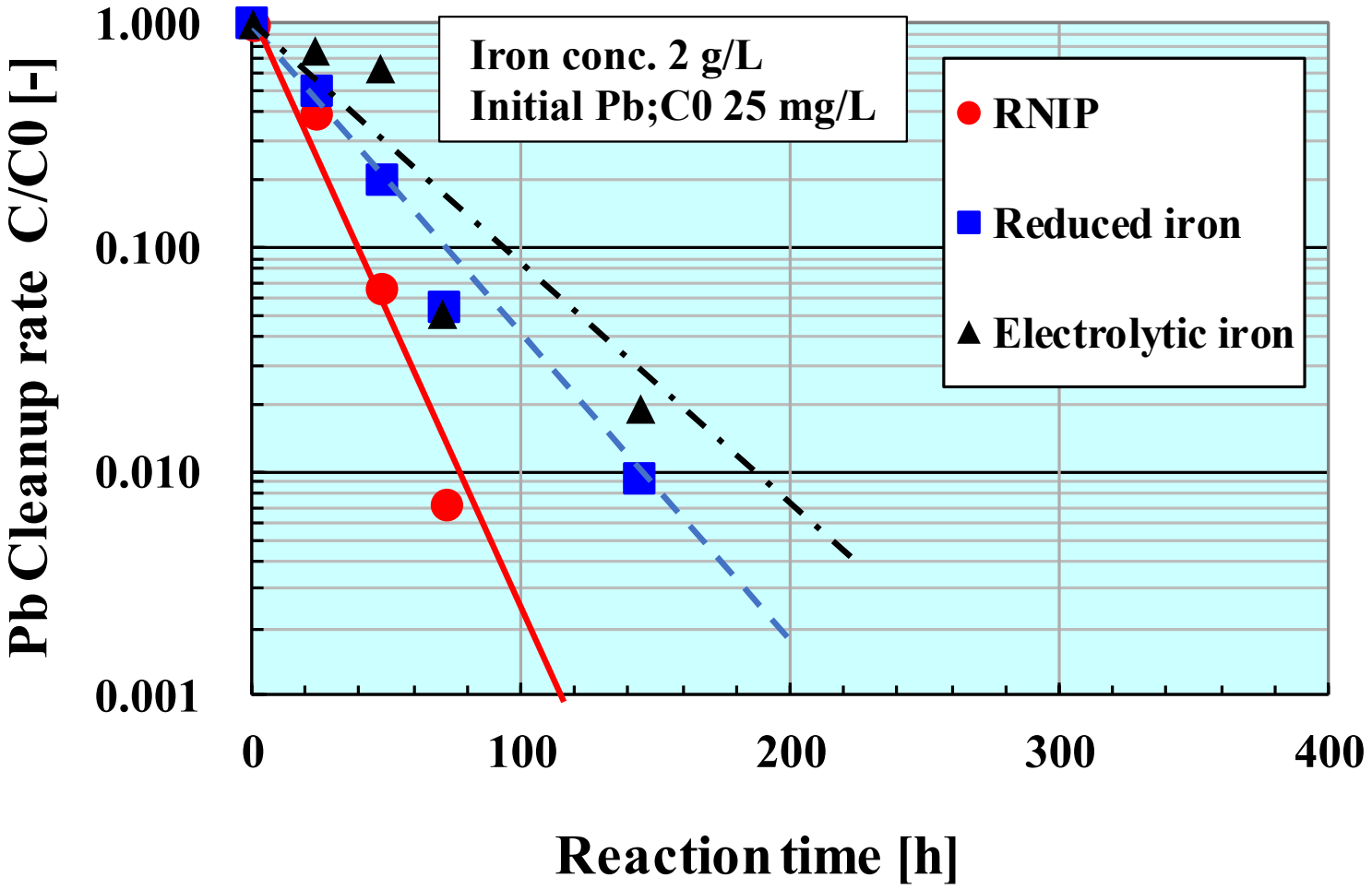


Fig. 7 Reaction time dependency of Lead cleanup rate by RNIP® compared with conventional irons[2), 3)]

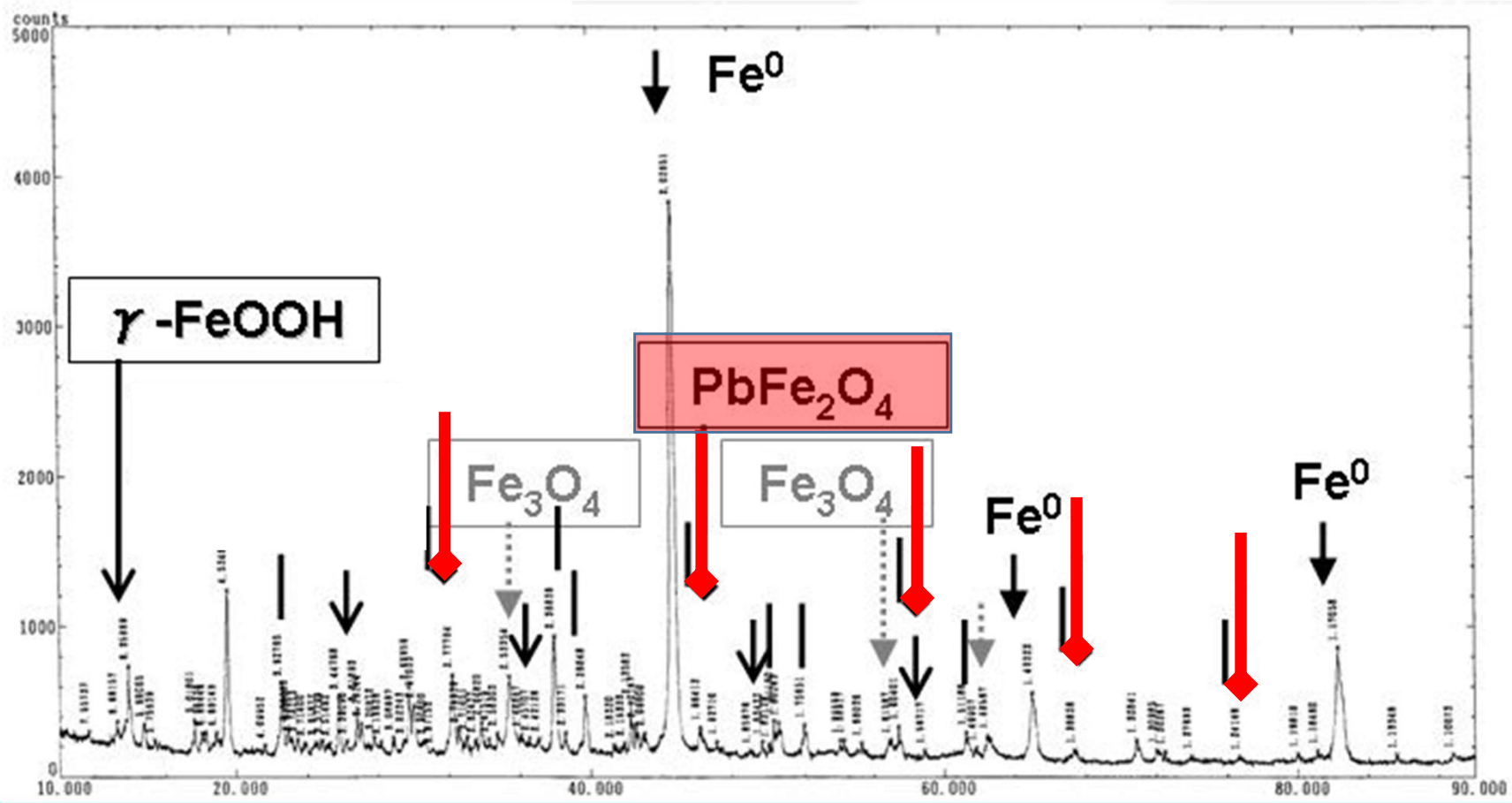
Quite rapid cleanup of lead by RNIP® can be realized

Data of Lead cleanup by RNIP®

Table 1. Required quantity of RNIP®(solid) for lead cleanup level to meet Environmental standard Japan in 2weeks

Lead concentration [mg/L]	Required quantity of RNIP® solid [g/L]
5 ～ 20	0.5 ～1.0

Data of Lead cleanup by RNIP®



X-Ray diffraction analysis of RNIP® on which lead immobilized indicates lead ferrite is formed on the surface of RNIP after cleanup of lead by RNIP®.

Lead ferrite has a very small, ultimately nearly zero, solubility product.

Data of Lead cleanup by RNIP®

Table 2. Leaching test results on Lead immobilized on RNIP® by Japanese Industrial Standards (JIS)

Assay	Lead conc. In filtered solution after leaching test [mg/L]	Environmental standard , Japan [mg/L]
Acid*	< 0.005	< 0.01
Alkali**	< 0.005	

■ **Reaction condition: Pb 10 mg/L, RNIP® solid 1g/L, after 21 days**

* **Acid addition leaching test method I JIS K 0102 61. 2**

** **Alkali addition leaching test method II JIS K 0102 61.2**

Further Overseas R&D on RNIP®

Co-operative academia-industrial R&D with Professor Dr. Volker Birke, University of Wismar, Germany, on application of RNIP® for novel cleanup technologies and an overseas market supported by the subsidy of Hiroshima prefectural government has just begun.

Professor **Dr. Volker Birke**

Prof. Dr. Volker Birke currently works at the Department of Mechanical, Process and Environmental Engineering, University of Wismar. Volker does research in Environmental Chemistry, Chemical Kinetics and Analytical Chemistry. Volker Birke has 30 years of experience in practical environmental chemistry, particularly in the destruction of hazardous wastes and toxic compounds in the environment. He has experience in remediation of contaminated sites, hazardous waste management, soil and ground water remediation, especially regarding permeable reactive barriers (PRBs), and in the application of innovative ex situ and in situ remediation to persistent organic pollutants such as PCBs using zero valent iron(ZVI) , especially nano size ZVI. He has known much about our RNIP and has long wanted to use RNIP since before.

HOCHSCHULE WISMAR UNIVERSITY OF APPLIED SCIENCES TECHNOLOGY, BUSINESS AND DESIGN

NAKAMURAKISO GROUP

TODA KOGYO CORP.

Funded by Hiroshima Prefecture

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2) K. Okinaka et al., Proceeding of the 14th Annual Conference of Japan Society of Waste Management Experts, Tsukuba, pp. 22-24 (2003).
3) K.Okinaka et al., Proceeding of the 3rd International Conference on Oxidation and Reduction Technologies for In-Situ Treatment of Soil and Groundwater, San Diego, California, pp. 144-149 (2004).
4) B. Laura et al., Environ. Sci. Technol. , 42, pp. 2600-2605 (2008).
5) K. Okinaka et al., Proceeding of the 4th International Conference on Remediation of Chlorinated and Recalcitant Compounds, Monterey, California (2003).

<Overseas Patens>

(1) US Patent No. 7482384.
(2) Spanish Patent No. 1318103.
(4) German Patent No. 1486463.
(5) British Patent No. 1486463.

Acknowledgement

Thank You for Your Warm Attention

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