235

A proposal of hydrogen safety technology for decommissioning of the Fukushima Daiichi Nuclear Power Plant

Hirohisa Tanaka[1], Sogo Iwata[1], Tadasuke Yamamoto[1], Tomoaki Kita[1], Atsuhiko Terada[2], Daiju Matsumura[3], Masashi Taniguchi[4], Ernst Arndt Reinecke[5]
[1]Kwansei Gakuin University, Sanda, Japan. [2]Japan Atomic Energy Agency, Naka, Japan. [3]Japan Atomic Energy Agency, Sayo, Japan. [4]Daihatsu Motor Co., Ltd., Ikeda, Japan. [5]Forschungszentrum Jülich GmbH, Jülich, Germany

Abstract

The purpose of the research

In March 2011, the Great East Japan Earthquake and subsequent tsunami caused insufficient reactor cooling at the Fukushima Daiichi Nuclear Power Plant (1F), resulting in a catastrophe of hydrogen explosions. For 13 years since then, Japan has continued to address post-disaster treatment as a national issue, such as decontaminating radioactive waste and preventing the spread of contaminated water.

The biggest challenge at present is post-treatment of high-dose fuel debris. It is estimated that approximately 880 tons of fuel debris exists at Fukushima Daiichi. The high-dose of radiation in fuel debris decomposes water and generates hydrogen and oxygen, so technology to prevent hydrogen explosions is an important issue. According to TEPCO's estimates, the maximum amount of hydrogen generated is 0.011 L/h per 1 kg of fuel debris. Thus, in decommissioning the 1F, the development of safe hydrogen technology for the retrieval, transportation, and long-term storage of radioactive fuel debris has become an urgent issue.

The International Research Institute for Nuclear Decommissioning (IRID) has been entrusted with the “Development of fuel debris retrieval, transfer, and storage technology" as part of the Ministry of Economy, Trade and Industry's decommissioning and contaminated water control project. Developing hydrogen explosion prevention technology for fuel debris storage canisters during transportation is a more difficult challenge than long-term storage in facilities due to various constraints. The fuel debris removed from the reactor will be divided into 70 to 100 kg portions, placed in storage canisters, and transported to a storage area on the Fukushima Daiichi site. Plans have been announced to store as many as 10,000 fuel debris storage canisters for a long period of 30 to 50 years on the site, and then transport them to final processing facilities. It will take seven days to transport the storage canisters, and there are concerns that the hydrogen concentration inside the canisters may exceed the lower flammability limit, making it essential to both prevent hydrogen explosions and prevent the scattering of radioactive materials. In this national project, various measures are being considered, such as drying fuel debris in advance, including the idea of opening the vents of storage canisters.

The principal results

One promising countermeasure that can both prevent hydrogen explosions and confine radioactive materials is a “Passive Autocatalytic Recombiner (PAR)”, which prevents explosions by converting hydrogen and oxygen generated in a sealed environment back into water through a catalytic reaction. Apart from the national large-scale project mentioned above, our research activities were carried out with self-research funds from JAEA, Daihatsu Motor and KGU, with the cooperation of FZJ. This independent project, an international collaboration between industry, government, and academia, aims to apply automotive monolith catalyst technology to complete a PAR that improves the safety of hydrogen (Figure 1) [1-7]. The performance of PAR has been evaluated in the laboratory and using FZJ's large capacity (5450 liters) pressure vessel REKO4. These efforts include technical applications such as (1) evaluating PAR activity in a fuel debris storage canister environment, (2) examining countermeasures in worst-case scenario tests, and (3) optimizing geometric properties. In addition, the mechanism of its high activity was analyzed by ultrastructural analysis of the catalyst using synchrotron radiation. What is particularly emphasized is that, based on the drawings of the fuel debris storage canister published by IRID, we prototyped a full-sized transparent visualization storage canister and demonstrated the catalytic effect during hydrogen generation by reproducing the actual usage environment (Figure 2). This clarified the parameters for utilizing the PAR we developed.

Major Conclusions

・The potential of the "Passive Autocatalytic Recombiner" catalyst was confirmed using a full-scale prototype fuel debris storage canister model.

・A honeycomb-shaped catalyst based on an automotive catalyst showed high durability even in a high-dose environment.

・Not only the chemical composition but also the geometrical characteristics have a great influence on the performance of the catalyst.

A "Passive Autocatalytic Recombiner" is expected to contribute to reducing hydrogen concentration in the decommissioning of the Fukushima Daiichi reactor.

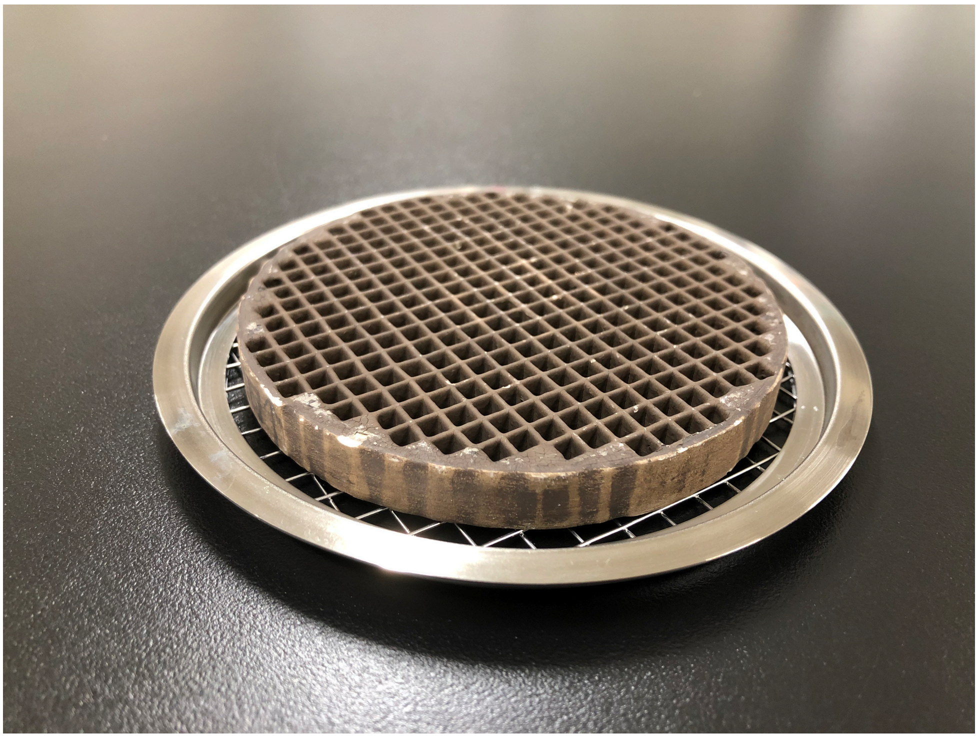

Figure 1. Passive autocatalytic recombiner developed using automotive catalyst technology

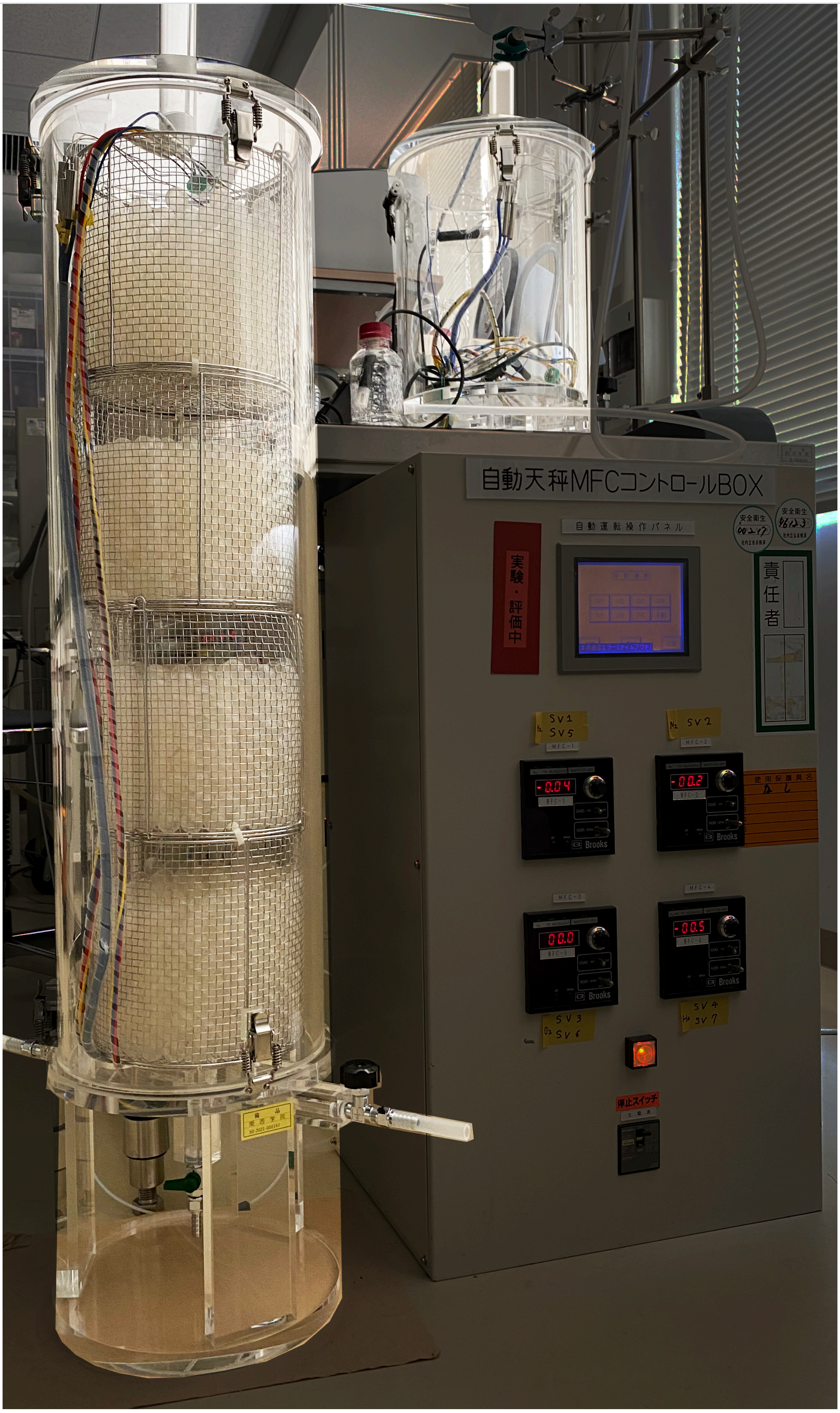

Figure 2. A prototype full-sized transparent storage canister “REKO-T” filled with simulated fuel debris

References

[1] J. Eto, M. Kawai, M. Matsumoto, H. Tanaka, R. Hino, A. Terada, M. Taniguchi, H. Sugiyama, “Experimental study of long-term catalytic effect on hydrogen generation G value of water by gamma-ray irradiation and hydrogen diffusion analysis in Compacted Hulls and End-Piece waste”, Journal of Radioanalytical and Nuclear Chemistry, (2024), doi:10.1007/s10967-023-09251-2. [2] K. Inagawa, D. Matsumura, M. Taniguchi, S. Uegaki, T. Nakayama, J. Urano, T. Aotani, H. Tanaka, “Development of hydrogen oxidation reaction catalysts to overcome CO poisoning and elucidation of reaction mechanism”, J. Phys. Chem. C, 127, (2023) 11542–11549, doi: 10.1021/acs.jpcc.3c02237. [3] A. Tearada, R. Nagaishi, “Effects of Vent

Aida, Y. Yamamoto, T. Kita, H. Ono, K. Takenaka, M. Taniguchi, D. Matsumura, E.-A. Reinecke, "An Automotive Intelligent Catalyst that Contributes to Hydrogen Safety for the Decommissioning of Fukushima Daiichi Nuclear Power Station (1FD)", SAE technical Paper, 2022-01-0534 (2022), doi:10.4271/2022-01-0534. [5] E.-A. Reinecke, K. Takenaka, H. Ono, T. Kita, M. Taniguchi, Y. Nishihata, R. Hino, H. Tanaka, "Performance tests of catalysts for the safe conversion of hydrogen inside the nuclear waste containers in Fukushima Daiichi", Inter. Jour. of Hydrogen Energy, 46 (2021) 12511-12521, doi: 0.1016/j.ijhydene.2020.08.262. [6] H. Ono, K. Takenaka, T. Kita, M. Taniguchi, D. Matsumura, Y. Nishihata, R. Hino, E-A. Reinecke, K. Takase, H. Tanaka, "Research on hydrogen safety technology utilizing the automotive catalyst", E-Journal of Advanced Maintenance, 11, 1 (2019) 40-45. [7] D. Matsumura, M. Taniguchi, H. Tanaka, Y. Nishihata, "In situ X-ray absorption spectroscopy study on water formation reaction of palladium metal nanoparticle catalysts", Inter. J. Hydrogen Energy, 42, 11 (2017) 7749.

Acknowledgements

Kwansei Gakuin University, Japan Atomic Energy Agency, Daihatsu Motor Co., Ltd., Forschungszentrum Jülich GmbH