Can reactor fuel debris be safely removed from Fukushima Daiichi?

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Using electron microscopy and secondary ion mass spectrometry (SIMS), the team has been able to report the first-ever measurements of boron and lithium chemistry from radioactive Cs-rich microparticles (CsMPs). Credit: Satoshi Utsunomiya

Decommissioning and clean-up are ongoing at the Fukushima Daiichi Nuclear Power Plant (FDNPP); however, many difficult problems remain unaddressed. Chief amongst these problems is the retrieval and management of fuel debris. Fuel debris is the name given to the solidified mixture of melted nuclear fuel and other materials that now lie at the base of each of the damaged reactors (reactor Units 1-3). This material is highly radioactive and it has potential to generate enough neutrons to trigger successive nuclear fission reactions (uranium-235 breaks into two elements after capturing neutrons, emitting enormous amounts of energy, radiation, and more neutrons). Successive fission reactions would present a serious safety and material management risk.

One of the materials in nuclear reactors that can lower the number of neutrons interacting with uranium-235 is boron carbide (B_4C). This was used as the control rod material in the FDNPP reactors, and it may now remain within the fuel debris. If so, it may limit fission events within the fuel debris.

Can the fuel debris be safely removed?

On March 11th 2011, the control rods were inserted into the FDNPP reactors to stop the fission reactions immediately after the earthquake, but the later tsunami destroyed the reactor cooling systems. Fuel temperatures soon became high enough (>2000 °C) to cause reactor meltdowns. Currently, the fuel debris material from each reactor is cooled and stable; however, careful assessment of these materials, including not only their inventories of radioactive elements but as well their boron content, a neutron absorber, is needed to ascertain if successive fission reactions and associated neutron flux could occur in the fuel debris during its removal. Many important questions remain: was boron from the control rods lost at high temperature during the meltdown? If so, does enough boron remain in the fuel debris to limit successive fission reactions within this material? These questions must be answered to support safe decommissioning.

Study shows direct evidence of volatilization of control rods during the accident.

Despite the importance of this topic, the state and stability of the FDNPP control rod material has remained unknown until now. However, work just published in the *Journal of Hazardous Materials* now provides vital evidence that indicates that most of the control rod boron remains in at least two of the damaged FDNPP reactors (Units 2 and/or 3).

The study was an international effort involving scientists from Japan, Finland, France, and the USA. Dr. Satoshi Utsunomiya and graduate student Kazuki Fueda of Kyushu University led the study. Using electron microscopy and secondary ion mass spectrometry (SIMS), the team has been able to report the first-ever measurements of boron and lithium chemistry from radioactive Cs-rich microparticles (CsMPs). CsMPs formed inside FDNPP reactor units 2 and/or 3 during the meltdowns. These microscopic particles were then emitted into the environment, and the particles hold vital clues about the extent and types of meltdown processes. The team's new results on boron-11/boron-10 isotopic ratios (~4.2) clearly indicate that most of the boron inside the CsMPs is derived from the FDNPP control rods and not from other sources (e.g., boron from the seawater that was used to cool the reactors). Dr. Utsunomiya states that the presence of boron in the CsMPs "provides direct evidence of volatilization of the control rods, indicating that they were severely damaged during the meltdowns".

Ample boron likely remains in the reactors, but more research is needed

In the study the team also combined their new data with past knowledge on CsMP emissions. From this, they have been able to estimate the total amount of boron released from the FDNPP reactors was likely very small: 0.024–62 g.

Prof. Gareth Law, a co-author from the University of Helsinki emphasized that this "is a tiny fraction of the reactor's overall boron inventory, and this may mean that essentially all of the control rod boron remains inside the reactors". The team hopes that this should prevent excessive fission reactions in the fuel debris. Utsunomiya stresses that "FDNPP decommissioning, and specifically fuel debris removal must be planned so that the extensive fission reactions do not occur. Our international team has successfully provided the first direct evidence of volatilization of B_4C during the FDNPP meltdowns, but critically, our new data indicated that large quantities of boron, which adsorbs neutrons, likely remains within the fuel debris."

Prof. Rod Ewing, a co-author from Stanford University acknowledged the importance of these new findings but highlighted that the team's measurements now need to be "extended in follow-up studies, where the occurrence and distribution of boron species should be characterized across a wide range of debris fragments".

Prof. emeritus Bernd Grambow, a study co-author from SUBATECH, Nantes, France, highlights that the work "paves the way for improving the safety assessment of debris retrieval during decommissioning at FDNPP," with the team's methods "providing a template for further studies." Utsunomiya concludes that "it is nearly 11 years since the FDNPP disaster. In addition to tireless efforts from engineers at the FDNPP, scientific contributions are becoming more and more important as tools to address the major difficulties that will be faced during decommissioning."

More information: Kazuki Fueda et al, Volatilization of B4C control rods in Fukushima Daiichi nuclear reactors during meltdown: B–Li isotopic signatures in cesium-rich microparticles, *Journal of Hazardous*

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