Deconstructing the nuclear accident at the Fukushima-Daiichi Plant: What went wrong and what are the prospects for recovery?

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The recent large-scale industrial accident at the Fukushima-Daiichi Nuclear Power Plant was the culmination of three inter-related factors: external natural hazard assessment and site preparation, the utility's approach to risk management, and the fundamental reactor design. The reactor accident was initiated by a magnitude 9 earthquake followed by an even more damaging tsunami. However, it was othe inability to remove the decay heat in the reactor core that led to core meltdown and radioactive release. A review of the timeline of the major Fukushima accident sequences will be given. The plant first experienced a station blackout (i.e. loss of all offsite and onsite power) due to flooding of backup critical emergency cooling equipment. The lack of an ultimate heat sink led to the fuel overheating. Subsequently, the generation of hydrogen through steam oxidation of the fuel cladding led to chemical explosions causing significant structural damage.

The focus of this talk is on the engineering aspects of the reactor accident and the prospects for local environmental recovery. Radionuclide measurements in space and time provide important evidence for the exact evolution of fuel damage leading to partial core melting in multiple units. A review of the spent nuclear fuel pools is given where isotopic water composition and visual inspection images provide important evidence for the condition of the spent nuclear fuel.

While it will be several months to a year before we will be in a position to learn most of the lessons from this tragedy, several conclusions about preventative design, mitigation actions, and emergency response have been drawn by international organizations

While the public health impact appears to have been low, the economic and nearby environmental consequences are severe, There is no doubt that land restoration will take over a decade and perhaps much longer. A review is given of actions taken by the Japanese government for land recovery in areas such as decontaminating top soil and local farmland as well as highly radioactive water used during 'feed and bleed' cooling of the core.

The role of the Geochemical Society of Japan for mitigating the Fukushima accident and its aftermath

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A huge earthquake (M 9.0) and coupled tsunami on March 11, 2011 yielded enormous damage in the area from north Kanto to whole Tohoku district. Besides direct disaster caused by earthquake and tsunami, equally serious accident happened at Fukushima Daiichi nuclear power plant of Tokyo Electric Power Company. By this accident, nuclear power reactors couldn't been controlled properly, and eventually radioactive materials were released from the nuclear power reactors and dispersed over rather wide area. Consequently, agricultural materials, drinking water and food were contaminated with radioactive nuclides. It was urgent to figure out how radioactive materials were spread not only in the area close to the nuclear reactors but also over surrounding, rather wide district. Such information must release the uneasiness for public people and objectively predict the possible influence caused by radioactive material over agricultural products for people engaging in agriculture.

To grapple with this task promptly as well as effectively, scientists belonging to the Geochemical Society of Japan, the atmospheric and oceanic section of the Japan Geoscience Union and the Japan Society for Nuclear and Radiochemical Sciences were allied and presented a proposal for comprehensive and systematic survey of radioactive materials in the environment to the ministry of Education, Science, Culture and Technology (MEXT). In this proposal, aerosol, rain, soils and underground water samples are to be collected as systematically as possible and as wide as possible for the sampling area. Besides such an action, we discussed with nuclear physicists to work together in collecting soil samples in Fukushima prefecture systematically and measuring radioactivity precisely under controlled counting protocol, making contour maps of individual radionuclides. Such a collaborative project was eventually supported by the government and officially started in early June, being continued for three months. The data thus obtained are to be opened to the governmental sector as well as to the public including scientific communities in due course so that national and international academic societies can utilize these data for scientific discussion.

Geochemistry of the long term evolution of the used nuclear fuel/water interaction

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Options for stabilizing the failed reactors in Fukushima are to create a sarcophage or to remove the fuel debris for safe geological disposal. In either case interaction of the molten and re-solidified damaged fuel (corium =UO_2-ZrO_2-Zr-Fe_2O_3..) will occur with natural waters leading to certain radionuclide release. Very little is known on the interaction of this material under natural geochemical conditions. In the absence of more pertinent data, and since in corium the UO_2/ZrO_2 seems to be a tetragonal solid solution, one may use the large knowledge from used fuel/water interaction to obtain some insight in potential radionuclide release controls.

A very large experimental and theoretical database has been collected since 30 years on used nuclear fuel/water interaction in the context of deep geological disposal options in clay rock, granite and salt. Current understanding and model uncertainties were recently assessed in the just finished European MICADO project. Detailed parametric studies of dissolution and radionuclide release behavior have allowed identifying key dissolution mechanism. The comparison of spent fuel behavior to that of natural uraninite as well as to pure UO_2 and Pu doped UO_2 gave important insight into radiation effects on fuel behavior over geological time. Two radionuclide release terms can be distinguished: a rapid release of a few percent of the inventories of volatile fission products such as Cs-135, Cs-137, I-131 and I-129 from fracture surfaces and grain boundaries in the fuel and a much slower release governed by the dissolution of the fuel matrix. The latter process concerns the release characteristics of matrix bound radionuclides, mainly the actinides, Sr and the rare earth elements. Fuel surface oxidation states are of fundamental importance for fuel matrix dissolution. The gamma and alpha radiation fields may create local oxidizing conditions at the fuel surface, accelerating fuel dissolution. The radiolytical enhancement of fuel dissolution is counteracted in geological disposal by the presence of hydrogen. Estimated times needed under natural water conditions for complete fuel matrix dissolution are in the range of 10000 yr under oxic conditions and in the range of millions of years under reducing conditions.

The fraction of matrix bound radionuclides will be lower and the labile fraction will be higher in the fuel debris of Fukushima than in ordinary spent fuel since high temperatures lead to stronger volatilization. Even though reducing conditions might have prevailed in the initial stages of fuel melt-down in the accident (large oxygen potential buffer capacity of melted metal Zirconium and presence of hydrogen) the beneficial long-term effect of hydrogen is unlikely to occur in Fukushima debris since hydrogen is expected to escape and oxidizing conditions will prevail.

Atmospheric dispersion of the Fukushima effluents

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In case of an accidental situation involving radioactive material, government agencies have to provide, in support of the public authorities, a scientific estimation of the emission and of its consequences for human health and environment. The technical crisis centre of IRSN has a special focus on atmospheric dispersion since it's the first contribution to radiation exposure. IRSN operates a complete modelling platform which links a release of radioactive material to its consequences. The evolution of atmospheric and ground activity is computed by using an estimation of the source term and the state of the atmosphere. Atmospheric dispersion is modelled using a Gaussian puff model at small scale, and a Eulerian long-range transport model at large scale.

Following the earthquake and tsunami that hit Japan on March 11, 2011, IRSN has monitored in real time, the state of the Dai-ichi nuclear power plant as well as simulated the atmospheric dispersion of estimated releases. The talk will present the atmospheric dispersion of the plume simulated through the Japanese territory as well as the American and European continents. The relevance of the simulations will be assessed by comparisons with measurements. Uncertainties about the source term and the meteorological conditions will be discussed. Finally, the use of atmospheric dispersion model, inverse modelling and data assimilation techniques to narrow uncertainties on the source term will be illustrated.

Measurement of radioactivity of aerosol at a few sites in Japan after the Fukushima Daiichi Accident

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Nuclear accident at the Fukushima Daiichi Nuclear Power Plant (NPP) was occurred after the 2011 Tohoku Earthquake and Tsunami. About 370-630 PBq of radionuclides was released from the Fukushima Daiichi NPP, according to the estimation by Nuclear Safety Commission (NSC) of Japan and Nuclear and Industrial Safety Agency (NISA). To understand migration behaviour of radionuclides in atmosphere, we have to monitor radioactivities of ^{131}I, ^{134}Cs and ^{137}Cs of aerosol samples in Japan temporally and spatially.

We have been collected aerosol samples using a high volume air sampler at Wajima and Nomi in Ishikawa Prefecture, Japan before the Fukushima Daiichi NPP accident. To realize transport processes of radionuclides from the Fukushima Daiichi, the filter samples collected at above sites, about 400 km far from the Fukushima Daiichi NPP, were measured for radioactivities of ^{131}I, ^{134}Cs and ^{137}Cs using ultra-low background Ge detection system at the Ogoya Underground Laboratory of Kanazawa University.

The presentation will be reported for the radioactivities of ^{131}I, ^{134}Cs and ^{137}Cs at the Ishikawa sites from March to May in 2011, before and after the Fukushima accident. We also show temporal variations in radioactivities of these radionuclides at a few sites in Japan, reported by Japanese scientists as preliminary data, and discuss the migration of these radionuclides in atmosphere on the basis of the spatial variations.

Seismological investigations of the March 11, M9, Tohoku-oki earthquake

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On March 11, 2011, a shallow, M9 earthquake with an epicenter roughly 160 km offshore struck the Fukushima prefecture in Japan. The ensuing tsunami was responsible for 20,000 fatalities, widespread damage along the Honshu coast, and the flooding of the Fukushima Dai-ichi nuclear power station, a crisis that is still unfolding. Yet, from a seismological point of view, the response to the earthquake has been a success. Thanks to the enormous investment in seismological and geodetic infrastructure by scientists from Japan and around the world, the earthquake magnitude, faulting mechanism, depth, extent along the Japan Trench, and, hence, its tsunami-generation potential was fully understood within 30 minutes after the earthquake occurred.

The Tohoku-oki earthquake was a classic mega-thrust (i.e. reverse) earthquake. It ruptured a fault plane on the plate interface that is dipping 14 degrees to the west. The largest slip was concentrated at shallow depth near the trench which explains the exceptionally large tsunami. Every large earthquake holds surprises and Tohoku-oki was not an exception. Before March 11, the seismic record suggested that M7.5 to M8.2 earthquakes break small patches of the plate interface along the Japan Trench south of Sendai. Given this experience, the magnitude of the Tohoku-oki earthquake was unexpectedly high. Moreover, the Tohoku-oki earthquake was spatially compact. It ruptured only a 200x100 square km area of the plate interface. Just west of the trench, slip on the fault plane exceeded 60 m. This is the largest fault offset ever reported.

The Tohoku-oki earthquake has been analyzed by a large number of scientists around the world. An open-access special issue of the journal “Earth, Planets, and Space” appeared in June. Articles in this issue are already providing a detailed and remarkably consistent picture of the many complex facets of the Tohoku-oki earthquake. In this presentation, I will summarize these investigations and place the earthquake in a historical context.

Present situation of radioactive contamination in soil by the Fukushima Dai-ichi accident

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On 11 March 2011, A Great East Japan Earthquake of magnitude 9.0 happened, and generated a series of large tsunami waves in the east coast of Japan. By these events, Tokyo Electric Power Company (TEPCO) Fukushima Dai-ichi Nuclear Power Plants (units 1, 2, 3 and 4) suffered major damage, and significant amounts of radionuclides were released into the environment. Monitoring efforts performed so far have shown that dangerous contamination is mostly localized in a narrow band within 40 km of the plant, stretching to the northwest. The Japanese Government announced that the serious accident of TEPCO's Fukushima Daiichi Nuclear Power Plant was ranked up to Level 7, the most serious accident according to INES, the same level as that in the case of Chernobyl Nuclear Power Plant in the Soviet Union on April 26, 1986.

To understand the components of radionuclides released, their levels and distributions, some soil core samples up to a depth of 30 cm were taken at the zone within 20-30 km from the plant in the end of March. The samples were cutted every 5 cm in depth. Another one soil sample (0-5 cm in depth) was also collected at the ca. 1.7 km point (outside the premises) west from of the plant in April. These samples were subjected to the measurements of γ-ray emitting radionuclides and Pu isotopes

As a result, volatile radionuclides such as ^{131}I,$^{134,137}Cs$ and so on were mainly detected with various levels, showing serious contamination in the NW from the plant. The distribution reflected the role of wind pattern and rainfall in washing out radionuclides to the ground. Small amounts of Pu isotopes ($^{239,240}Pu$ and ^{238}Pu) were detected for all of the surface soil (0-5 cm) from zone within 20-30km, but their activity ratios of $^{238}Pu/^{239,240}Pu$ were around 0.03, indicating the origin of global fallout Pu. Only one sample collected from 1.7 km close the plant showed a little higher ratio of ca 0.06. Thus, currently, Pu release was negligibly small and volatile nuclides ^{131}I,$^{134,137}Cs$, etc. were responsible for a large share of released radioactivity. There are some spots of higher contamination called "Hot Spot".

A preliminary overview of studies on dispersals of radionuclides from Fukushima nuclear power plants

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The Tohoku Japan earthquake occurred on 11th March, 2011, accompanied by huge tsunami which attacked all coastal areas in northeastern Japan and caused the accdidents of Fukushima Daiichi nuclear power plant. Some nuclear reactors lost their control almost entirely or partly, and the fission products and feasible neutron activated nuclides in the reactors have been dispersing in environment.

To promote a study on disperse of the radionuclides in order to prevent further unnecessary dose for people, many scientists have gathered and started monitoring, mapping, and model simulation of disperse of radionuclides in local and large covering areas as well. This is a preliminary overview of studies on dispersals by many motivated collaborators.

Radionuclides are found to be strong tracers of atmospheric and oceanic movement with time stamps of some with their different half-lives to distinguish different emission phenomena, direct and/or rebound transport, and dry and/or wet deposition. The distribution of radionuclides in time and space is highly localized, which may be determined by their accumulation and diffusion because of distance, topography, wind direction, precipitation, surface runoff, marine gires and currents. Their occurrences, however, are sometimes difficult to be explained straightforward because of the unknown source processes and their strength, their physical and chemical forms in the atmosphere and the oceans, their transformation through chemistry, the size distribution of dusts on which they are absorbed, dry and/or wet deposition on the surface soil, and their chemistry and transport after deposition.

Some scientific programs have started and will continue before and even after the cease of the nuclear plant crisis, to obtain knowledge on the ongoing radioactive pollution, to understand and to predict their distributions, and for the unexpected similar future accidents. This is a great challenge for the scientists in this research field, geochemistry and not necessarily limited to isotope geochemists nor any scientists, but to human beings. Further international collaborations would be much appreciated in any fields of study with different time and space scales.