A Hand-out

for

International Workshop on Nuclear Safety: From accident mitigation to resilient society facing extreme situations

March 22-24, 2015

University of California, Berkeley

Organized by

Joonhong Ahn
Department of Nuclear Engineering (NE) and Center for Japanese Studies (CJS),
University of California, Berkeley (UCB),
and Lawrence Berkeley National Laboratory (LBNL)

and

Franck Guarnieri
Centre for Research into Risks and Crises (CRC)
Mines Paris Tech (MPT)

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France Berkeley Fund
Centre for Research into Risks and Crises, Mines Paris Tech
Center for Japanese Studies, UC Berkeley
Resilience Engineering Research Center, The University of Tokyo

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1. Synopsis for Symposium

The consequences of the Fukushima Daiichi nuclear accident in March 2011 sparked a debate about the nuclear safety. While releases of large amounts of radioactive materials resulted in no casualties due to radiation, the impact particularly on local communities is substantial and manifold. Although local communities want to be ensured that effective actions are being taken to allow them to go back to their normal life as early as possible, the lack of understanding for the transport of radioisotopes in the environment and eventually the uptake in humans as well as in the biological effects of low dose radiation has made it difficult for various stakeholders to develop concerted efforts to accelerate recovery. These challenges are compounded by the eroded public trust for government and operators.

To address this need, currently, a new multi-disciplinary initiative is carried out by scientists at UC Berkeley and Lawrence Berkeley National Laboratory (LBNL) to provide the necessary guidance for effective assessment and remediation efforts, and to provide trusted, un-biased and nuclear-industry-independent perspective to build trust with local and global communities. UC Berkeley and LBNL have world-leading expertise and capabilities in measuring and assessing the distribution of relevant radioisotopes, in modeling and predicting their interactions and transport, and to ultimately estimate and mitigate their impact on the environment and human health.

In order to achieve a resilient society, society's exogenous and endogenous conditions and needs prior to, during, and following a disaster must be appropriately responded while monitoring changes in conditions and varied needs for resilience born by different stakeholders with a suite of appropriate performance measures. Public participation and feedback must be implemented not only for determining a right set of measures but also in planning engineering design and risk management. Mines Paris Tech has been actively developing an innovative approach, called "Resilience Engineering," as a new paradigm of safety, focusing on interactions and integrations of engineering efforts with a society.

Based on such on-going initiatives, there are two emerging questions: (1) how integration between understanding for natural scientific processes and understanding for a society at different scales and regions can be achieved for the objective of accurate monitoring, and then ultimately (2) how such accurate monitoring and public participation can and should be integrated in decision-making processes for achieving a resilient society.

To address such questions and to develop a research plan, we plan to host a two-day international workshop, as titled above. In this workshop, first, we share various observations about "damages" in a severe nuclear accident, and then address the central questions: How can we utilize knowledge of natural science and engineering in monitoring system's exogenous and endogenous conditions with a suite of performance measures that reflect different needs of resilience by different stakeholders after an accident, and in developing recipes that enable a resilient society? The discussion will focus on (1) state of the art for measurement methodologies and (2) challenges that must be overcome. Then, on the second day, three roundtable sessions are arranged to identify and discuss future research questions.

The workshop will provide a venue for natural scientists and engineers to understand social frameworks and needs for design and management of technologies, and for social scientists to understand forefront methods of monitoring and recovery.

2. Tasks and Outcome of the Workshop

- Each participant is asked to write a 5-page paper prior to the workshop by 2/28/2015.
- After the workshop, each participant is asked to complete his/her paper (10 pages) by 4/30/2015.
- Each break-up group is asked to prepare a brief summary of its research proposal for discussions at Session 5, and submit an edited version by 4/30/2015.
- Each student participant, who presents a poster, is required to prepare a 5-page paper by 2/28/2015, and complete it by 4/30/2015.
- These contributed papers and summaries of discussions developed by the rapporteurs will be made into proceedings, which will be published from an appropriate publisher.

3. Agenda

3.1. Sunday, March 22, 2015

Welcome Reception (5:00 - 7:00 pm) (*Revival Bar and Kitchen* (http://revivalbarandkitchen.com), 2102 Shattuck Avenue)

3.2. Monday March 23, 2015

Continental Breakfast (8:30 - 9:00 am) (170 Boalt Hall)

- **Introduction: Motivation, Background, and objective of the meeting (9:00 – 9:30 am)**
  - Greeting and Scope: Prof. Joonhong Ahn (UCBNE/CJS/LBNL)
  - Aim and Goal: Prof. Franck Guarnieri (MPT)
  - Self introduction by participants (20 seconds each)

- **Session 1 (9:30 am - Noon): What are damages in nuclear accidents?** (170 Boalt Hall)
  Objectives of the session: Corrective actions following a nuclear accident must be based on the definition of damage to be prevented. The difficulty lies in how we define the "damage". Therefore we propose to elaborate an original framework for the identification and characterization of severe nuclear accident damages. Speakers of this session will give various examples and thoughts, which give clues for developing definitions.

  - Session Chair's remark (9:30-9:40 am): Prof. Cathryn Carson (UCB, History)
  - Speaker 1 (9:40-9:55 am): Prof. Dominique Pécaud (MPT), Does the concept of loss orient risk prevention policy?
  - Speaker 2 (9:55-10:10 am): Prof. Kazuo Furuta (U. Tokyo), How the Fukushima Daiichi accident changed (or not) the nuclear safety fundamentals?
  - Speaker 3 (10:10-10:25 am): Dr. Rebecca Abergel (LBNL), Low-dose radiation effects on human health

Coffee Break (10:25-10:40 pm) (170 Boalt Hall)

  - Speaker 4 (10:40-10:55 am): Prof. Christophe Martin (MPT), Consequences of severe nuclear accidents on social regulations in socio-technical organizations
  - Speaker 5 (10:55-11:10 am): Prof. Jean Pierre Dupuy (Stanford U.), Philosophical problems, old and new, posed by the possibility of major nuclear disasters
  - Discussions (11:10 - 11:50 am)

Group Photo Session (11:50 am - Noon) (170 Boalt Hall)

Lunch (Noon-1:00pm) (Box lunch provided, 141 Boalt Hall)

- **Session 2 (1:00-3:00 pm): Measurement of Damages** (170 Boalt Hall)
  Objectives of the session: Now that we have developed definitions for damages after a severe accident, which are multifaceted, we need to have accurate and effective methods to measure those, as situations evolve rapidly in the aftermath. In this session, speakers introduce currently on-going efforts for applying qualitative/quantitative methods, followed by panel discussions to explore effective integration and application in decision-making process.

  - Session Chair's remark (1:00-1:10 pm): Dr. Jens Birkholzer (LBNL)
  - Speaker 6 (1:10-1:25 pm): Dr. Haruko Wainwright (LBNL), A Multiscale Bayesian Data Integration Approach for Mapping Radionuclide Contamination
  - Speaker 7 (1:25-1:40 pm): Prof. Tatsuya Itoi (U. Tokyo), Challenges for Nuclear Safety from Viewpoint of Natural Hazard Risk Management
  - Speaker 8 (1:40-1:55 pm): Prof. François Levêque (MPT), Evaluation of the expected costs of nuclear accident
  - Speaker 9 (1:55-2:10 pm): Prof. Ryoichi Komiyama (U. Tokyo), Considering nuclear accident in energy modeling analysis

- Speaker 10 (2:10-2:25 pm): Prof. Ryuma Shineha (The Graduate University for Advanced Studies), Measurements of risk perception and social acceptability
- Speaker 11 (2:25-2:40 pm): Prof. Massimiliano Fratoni (UCB, NE), Development of a knowledge management system for energy driven by public feedback
- Discussions (2:40-3:20 pm)

Coffee Break (3:20-3:50 pm) (170 Boalt Hall)

- **Session 3 (3:50-5:50 pm): Barriers against Transition into Resilience** (170 Boalt Hall)
  Objectives of the session: Recovery from nuclear accident refers to social representation of risks and cannot be limited only to technical issues or crisis management guidelines. In this view, we consider the various impediments and their interactions to the transition into resilience of the many actors of the civil society.

  - Session Chair's remark (3:50-4:00 pm): Prof. Karl van Bibber (UCB, NE)
  - Speaker 12 (4:00-4:15 pm): Dr. Aurélien Portelli (MPT), What cultural objects say about nuclear accidents and their way of depicting a controversial industry
  - Speaker 13 (4:15-4:30 pm): Prof. Kohta Juraku (Tokyo Denki U.), Why is it so difficult to learn from accidents?
  - Speaker 14 (4:30-4:45 pm): Dr. Sébastien Travadel (MPT), Decision making in extreme situations following the Fukushima Dai Ichi accident
  - Speaker 15 (4:45-5:00 pm): Dr. Kyoko Sato (Stanford U.), Japan’s Nuclear Imaginaries before and after Fukushima: Visions of Science, Technology, and Society
  - Speaker 16 (5:00-5:15 pm): Prof. Kai Vetter (UCB, NE/LBNL), Institute for Resilient Community
  - Discussions (5:15-5:50 pm)

Dinner and Student posters session in parallel (6:30-8:30pm) (Heyns Room, the Faculty Club)

Students' posters
- Hiroyasu Abe (U Tokyo), Ground motion prediction for regional seismic risk analysis including nuclear power station
- Ivana Abramovic (UCB, NE), Effects of inelastic neutron scattering in magnetic confinement fusion devices
- Aissame Afrouss (MPT), The account of the Fukushima Dai Ichi accident by the plant manager: A source to study engineering thinking in emergency situations
- Sophie Agulhon (MPT), On Safety Management Devices: Injunction and Order Use in Emergency Situation
- Sasha Asghari (UCB, NE), A Novel Neutron Counter for Nonproliferation
- Romain Bizet (MPT), Economic assessment of nuclear damage: A review of existing studies and their insights into mitigation policies
- Justin Larouzee (MPT), Human error and Defense in depth: from the "Clambake" to the "Swiss Cheese"
- Xudong Liu (UCB, NE), Criticality Safety Study for the Disposal of Damaged Fuels from Fukushima Daiichi Reactors
- Dipta Mahardhika (U Tokyo), Logical and Emotional Influence in a Time-Constrained Group Decision Making
- Hiromu Matsuzawa (U Tokyo), Evaluation of Optimal Power Generation Mix Considering Nuclear Power Plants’ Shut-down Risk
- Naoto Mitsume (U Tokyo), A Hybrid Finite Element and Mesh-free Particle Method for Disaster-resilient Design of Structures
- Delvan Neville (Oregon State U.), Lack of Cesium Bioaccumulation in Gelatinous Marine Life in the Pacific Northwest Pelagic Food-web
- Ryan Pavlovsky (UCB, NE), RadWatch Near-Realtime Air Monitoring (Natural Radioactive Backgrounds and Outreach)
- Rin Watanabe (U Tokyo), Incorporating Value Discussions into High Level Radioactive Waste Disposal Policy: Results of Developing Fieldwork

Rapporteurs:
- Dr. Charlotte Cabasse Mazel (UCB)
- Dr. Hortense Blazsin (MPT)

3.3. Tuesday, March 24, 2015

Continental Breakfast (8:30 - 9:00 am) (170 Boalt Hall)

- **Session 4 (9:00 am-10:30 am): Round table discussions: Knowledge and models for transition into resilience** (170 Boalt Hall)**,** Chaired by Prof. Joonhong Ahn (UCB, NE/CJS/LBNL)
  A short keynote to set scope and direction of discussions, including a short summary of the first day's discussion, is given by the chair, followed by a round table discussion. It is hoped that several new research questions will emerge, which will be used to organize the next break-up session.

Coffee Break (10:30-11:00 am) (170 Boalt Hall)

- **Break-up Session 5 (11:00 am – noon): to develop more detailed plans, based on new research questions that have emerged from Session 5** (141, 145, and 170 Boalt Hall)
  Each break-up group is asked to identify a moderator, and prepare a written summary. Discussions can be continued in the lunch time. (Group 1: ???; Group 2: ???; Group 3: ???)

Working Lunch (Noon-1:30 pm) (Box lunch provided, 141 Boalt Hall)

- **Session 6 (1:30-3:00 pm): Round table discussion: Wrap-up discussion** (170 Boalt Hall) Chaired by Prof. Franck Guarnieri (MPT)
  Reporting from each break-up group.
  Summary of the workshop and plans for publication and collaborations

4. Participants

4.1. Organizers

Joonhong Ahn
Professor, Vice Chair, Department of Nuclear Engineering, UC Berkeley
D.Eng., Nuclear Engineering, University of Tokyo, 1989
Ph.D., Nuclear Engineering, University of California, Berkeley, 1988

Professor Ahn's research areas include mathematical modeling and computational analyses to explore relationship between the fuel-cycle system parameters and geologic repository performance for risk minimization. In addition, he has been actively leading projects for comparative studies on nuclear power utilization in Asia and development of advanced educational materials, particularly after the Fukushima Daiichi accident. Professor Ahn served as a member of the Nuclear and Radiation Studies Board, National Research Council, US National Academies of Sciences (2008-2011). He was conferred the title of "Fellow" from the School of Engineering, the University of Tokyo in 2007. In June 2011, he was granted Minner Faculty Fellow in 'Engineering Ethics and Professional/Social Responsibility' from College of Engineering, UC Berkeley. He joined the Earth Sciences Division, Lawrence Berkeley National Laboratory as Geological Faculty Scientist in 2012, and the core faculty of the Center for Japanese Studies, Institute of East Asian Studies, UC Berkeley in 2014.

Franck Guarnieri
Professor, Chair, Centre for Research into Risks and Crises (CRC), MINES ParisTech

Professor Franck Guarnieri is the Chair of the Centre for Research into Risks and Crises (CRC) at MINES ParisTech in France and scientific advisor to the French company Preventeo. He leads research on Industrial and Nuclear Safety. He focuses on "engineering thinking" and "on-going emergency". He is also a designated expert in the French National Research Agency (ANR) and in the European Horizon 2020 program. In 2014, he received the prestigious René-Joseph Laufer Prize from the Académie des Sciences morales et politiques of the Institut de France.

4.2. Session Chairs

Jens Birkholzer
Scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory
M.Sc., Water Resources, Hydraulic Engineering, Soil and Rock Mechanics, Aachen University of Technology, Germany, 1988
Ph.D., Subsurface Hydrology, Aachen University of Technology, Germany, 1994

Dr. Birkholzer joined LBNL in 1994 as a post-doctoral fellow and has since been promoted to the second-highest scientist rank at this research facility. He currently serves as the deputy director of the Earth Sciences Division and as the program lead for the nuclear waste program, and also leads a research group working on environmental impacts related to geologic carbon sequestration and other subsurface activities. His area of expertise is subsurface hydrology with emphasis on understanding and modeling coupled fluid, gas, solute and heat transport in complex subsurface systems, such as heterogeneous sediments or fractured rock. His recent research was mostly in the context of risk/performance assessment, e.g., for geologic disposal of radioactive wastes and for geologic CO2 storage. Dr. Birkholzer has authored about 90 peer-reviewed journal articles and book chapters, and has over 230 conference publications and abstracts.

Cathryn Carson
Associate Professor, Department of History, UC Berkeley

Professor Carson is a historian of science and technology with a focus on contemporary physics and engineering sciences. The author of a monographic study of the physicist Werner Heisenberg in twentieth-century Germany (*Heisenberg in the atomic age: Science and the public sphere*), her current research areas include the interactions between science and philosophy, the role of simulations in nuclear waste management, and the ethnography of data science. She is involved in collaborations on engineering ethics and education, including the recent co-edited volume *Reflections on the Fukushima Daiichi nuclear accident: Toward social-scientific literacy and engineering resilience*. From 2010-2014 she served as Associate Dean of Social Sciences at UC Berkeley and recently received the Social Science Division's Distinguished Service Award. She is a Fellow of the American Physical Society and the American Association for Advancement of Science.

Naoto Sekimura
Professor, Department of Nuclear Engineering and Management, The University of Tokyo
Doctor of Engineering, Nuclear Engineering, The University of Tokyo, 1986

Professor Sekimura's primary research interest is safety engineering and maintenance engineering for complex system such as nuclear power plant, ageing management of light water reactors, radiation effects in nuclear materials and nuclear fuels, codes and standards for complex engineering systems. Professor Sekimura is an associate member of Science Council of Japan for these 6 years. He is a Chairperson of the Nuclear Safety Division of the Atomic Energy Society of Japan (AESJ), and has been actively involved in the AESJ's Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company. He was invited to make a lecture on Overview of the Accident in Fukushima Daiichi Nuclear Power Plant at the U.S. National Academy of Sciences in May, 2011. He has been continuously leading a national research project on Ageing Management of Systems and Components for Safe Operation of Power Plants since 2006. He served as a Chairperson in OECD/NEA SCAP project on knowledge management of ageing degradation of materials and components in nuclear systems in 2006-2010. He served as a co-chair of the IGALL (International Ageing Lessons Learned) project in IAEA.

Karl van Bibber
Professor, Chair, Department of Nuclear Engineering, UC Berkeley

Karl van Bibber received his BS and PhD from MIT in experimental nuclear physics. After postdoctoral work at LBNL, he served as an Assistant Professor of Physics at Stanford. He joined LLNL where he founded and led the High Energy Physics and Accelerator Technology Group, and was LLNL Project Leader for construction of the SLAC-LBNL-LLNL PEP-II B Factory project. His institutional service includes positions as Chief Scientist for the Physics and Space Technology directorate, and Deputy Director of the Laboratory Science and Technology Office. In 2009 he became Vice President and Dean of Research of the Naval Postgraduate School in Monterey, CA. In 2012 he joined the faculty of UC Berkeley as Professor of Nuclear Engineering, and acceded to Department Chair in July 2012. He also serves as Executive Director of the Nuclear Science and Security Consortium, a DOE Office of Non-Proliferation center-of-excellence comprised of seven universities and four national laboratories. His research focuses on basic and applied nuclear science, particle astrophysics, and accelerator science and technology. He is the recipient of an Alfred P. Sloan Research Fellowship, the DOE Deputy Secretary Award for the B Factory, and the Navy Superior Civilian Service Award for the establishment of degree and executive education programs in Energy, the first within the DoD. He is a fellow of the APS and AAAS.

4.3. Speakers

Rebecca Abergel
Staff Scientist, Chemical Sciences Division, Lawrence Berkeley National Laboratory
B.Sc., École Normale Supérieure / Université Pierre & Marie Curie, Paris, 2002
Ph.D., Chemistry, University of California, Berkeley, 2006

Dr. Abergel's research program is dedicated to investigating the coordination biochemistry of heavy and f-elements, with therapeutic and environmental applications such as chelation and bioremediation of toxic metals released in industrial processes, engineering of antimicrobial strategies targeting metal-acquisition systems, and design of advanced alpha-immuno theranostic agents. She leads a large collaborative effort on the development of new drug products for the treatment of populations contaminated with radionuclides. One of these products was granted an Investigational New Drug status from the U.S. Food and Drug Administration in 2014. In addition, she has been actively involved in the new Lawrence Berkeley National Laboratory Initiative for Resilient Communities, the radiological component of which was sparked by the aftermath of the 2011 Fukushima Daiichi accident. Dr. Abergel currently serves as the chair of the Radioactive Drug Research Committee at the Lawrence Berkeley National Laboratory. She is an associate editor for the International Journal of Radiation Biology and a corresponding member (USA) for Radioprotection. In 2014, Dr. Abergel received an Early Career Award from the U.S. Department of Energy and was selected as an Innovator under 35 – France by the MIT Technology Review. She is also the recipient of a Director's Award for

Exceptional Scientific Achievement (2013) from the Lawrence Berkeley National Laboratory, a Junior Faculty NCRP award (2013) from the Radiation Research Society, and a Young Investigator Research Fellowship (2010) from the Cooley's Anemia Foundation.

Jean Pierre Dupuy
Professor, Political Science, Stanford University

Jean Pierre Dupuy is Professor Emeritus of Social and Political Philosophy, Ecole Polytechnique, Paris and Professor of Political Science, Stanford University. He is a member of the French Academy of Technology, a spinoff of the Academy of Sciences, and of the Conseil Général des Mines, the French High Magistracy that oversees and regulates industry, energy and the environment. He chairs the Ethics Committee of the French High Authority on Nuclear Safety and Security. He is the Director of the Research Program of Imitatio, a new foundation devoted to the dissemination and discussion of René Girard's mimetic theory. His most recent work has dealt with the topic of catastrophe. Among his recent publications in English: *The Mechanization of the Mind* (Princeton University Press, 2000); *On the Origins of Cognitive Science* (The MIT Press, 2009) ; *The Mark of the Sacred* (Stanford University Press, 2013);*Economy and the Future. A Crisis of Faith* (Michigan State University Press, 2014); *A Short Treatise on the Metaphysics of Tsunamis* (Michigan State University Press, in press.)

Massimiliano Fratoni
Assistant Professor, Department of Nuclear Engineering, UC Berkeley
Laurea, Nuclear Engineering, Sapienza Università di Roma, 2004
M.S., Nuclear Engineering, University of California, Berkeley, 2007
Ph.D., Nuclear Engineering, University of California, Berkeley, 2008

Massimiliano's main research interests lie in advanced nuclear fuel cycles for maximizing natural resource utilization and minimize nuclear waste. His projects focus on the design and analysis of advanced nuclear reactor that enable the effective exploitation of neglected resources such as depleted uranium, used nuclear fuel, and thorium. Among others, he is studying molten salt reactors for used fuel incineration, improved performance light water reactors, and fast reactor technologies. In addition, Massimiliano leads research aimed to assess the impact of reactor performance on fuel cycle evaluation parameters, such as repository thermal load and long-term radiotoxicity. He also carries research on the blanket design of inertial confinement fusion reactors. Massimiliano is currently Assistant Professor in the Department of Nuclear Engineering at the University of California, Berkeley. Prior to joining the Nuclear Engineering Department at UCB, he held a Research Scientist position at the Lawrence Livermore National Laboratory and a faculty position at The Pennsylvania State University.

Kazuo Furuta
Professor, Director, Resilience Engineering Research Center, Graduate School of Engineering, The University of Tokyo
D.Eng., Nuclear Engineering, University of Tokyo, 1986

Professor Furuta's research areas include human and social factors in resilience engineering. In particular, he has been developing technologies for modeling and simulating human performance and then applying them to designing socio-technological systems. He is now leading a research project on Resilience Analysis for Social Safety Policy funded by the R&D Program of RISTEX (JST): Science of Science, Technology and Innovation Policy. Professor Furuta is a board member of the Japan Society for Simulation Technology, an editorial board member of the International Journal of Cognition, Technology, and Work; and that of Aviation Psychology and Applied Human Factors.

Tatsuya Itoi
Associate Professor, Department of Nuclear Engineering and Management, School of Engineering, The University of Tokyo
D.Eng., Architecture, The University of Tokyo, 2004

Professor Itoi's research areas include modeling and analyses relating nuclear safety engineering in the context of earthquake engineering, intensively working on probabilistic seismic risk and hazard analysis, performance-based earthquake engineering, risk-informed decision making and seismic risk management. Professor Itoi joined Department of Nuclear Engineering and Management, School of Engineering, The

University of Tokyo, as Associate Professor in 2012, until then he had been working as Research Associate at Department of Architecture, School of Engineering, The University of Tokyo (2009-2012). He is also one of Cooperative Research Fellows of Resilience Engineering Research Center, School of Engineering, The University of Tokyo since July 2013.

Kohta Juraku
Assistant Professor, Department of Humanities and Social Sciences, Tokyo Denki University
Ph.D., Information Studies, University of Tokyo, 2011

Kohta Juraku is an assistant professor at the Department of Humanities and Social Sciences, Tokyo Denki University (TDU), Japan. He has works on the sociological study on nuclear utilization and other energy technologies. He received his PhD on that topic from the University of Tokyo in 2011. His current research interests are social learning process from the nuclear accident, as well as public deliberation process on nuclear waste disposal and nuclear policy in general. Before joining TDU, he worked at the Department of Nuclear Engineering and Management, the University of Tokyo from 2008 to 2012. Also, he spent over a year at the Department of Nuclear Engineering, UC Berkeley from 2010 to 2011 as a visiting scholar. As a sociologist of science and technology, he had very particular experiences of "collaborations" with and "observations" on nuclear engineers at those departments during the period including the Fukushima nuclear accident.

Ryoichi Komiyama
Associate Professor, Resilience Engineering Research Center, University of Tokyo
Ph.D., Electrical Engineering, University of Tokyo, 2003

Dr. Komiyama's research area includes mathematical modeling and computational simulation of energy system in order to contribute an effective energy planning, employing an optimization theory and an econometrics analysis. Published papers so far deal with diverse issues associated with energy and environmental fields such as global, Japanese and Asian energy markets, distributed power system, hydrogen energy system, clean energy vehicles, variable renewable energy, nuclear energy and energy security. Dr. Komiyama has served as a visiting researcher in the Institute of Energy Economics, Japan (IEEJ) since 2010. After receiving his Ph.D. from the University of Tokyo in 2003, he was affiliated with IEEJ and worked as an economist and a senior economist until 2010. From July 2010, he joined the University of Tokyo. Until now, he studied as a visiting research scholar in Lawrence Berkeley National Laboratory (LBNL) from 2007 to 2009 and UC Berkeley from 2011 to 2012.

Francois Lévêque
Professor of Economics, MINES ParisTech
D.Eng., Biology, Agro-ParisTech, 1980
Ph.D., Economics, INA-PG, 1982

François Lévêque is professor of economics at Mines ParisTech. He is part-time professor at the Robert Schuman Center for Advanced Studies (European University Institute, Florence School of Regulation). He published a series of books on energy: Competitive Electricity Markets and Sustainability (Edward Elgar, 2006), Electricity Reform in Europe (Edward Elgar, 2009), Security of Energy Supply in Europe (Edward Elgar, 2010), The Economics and Uncertainties of Nuclear Power (Cambridge University Press, 2014). He wrote several papers in academic journals, including ***Energy Policy, World Competition, Competition and Regulation in Network Industries, Electricity Journal, Safety Science, Information Economics and Policy, Economics of Energy and Environmental Policy***. He taught economics of natural resources at Mines-ParisTech (1984-1990), environmental economics at EHESS (1997-2001) and at Pavia University (1999-2002), EU Competition Law at the Boalt Law School, University of California at Berkeley (2002-2007). He has taught industrial economics and economics of energy at Mines-ParisTech since 1996. It is fair to inform of the following potential conflicts of interest: The research program I head on nuclear energy economics at Mines-ParisTech is financed by the French power company, EDF. I am also one of the member of the EDF Scientific Committee. In addition to my main activity as professor at Mines ParisTech, I am founding partner of Microeconomix, a Paris based economic consulting firm. This company has many clients in different businesses, including EDF, ENDESA, ENEL, ERDF, GRT GAZ, TOTAL, RTE, TENNET in the energy sector. I do not held any executive position in this company where I mainly act as a scientific adviser.

Christophe Martin
Resilience Engineering & Safety Chair, MINES ParisTech

Since 2001 Christophe Martin has been involved in various R&D projects with major French companies and European and French Institutions. He has conducted research into risk management implementation methods and Occupational Health and Safety risk assessment in several industrial sectors. His specialty is Small and Medium Size enterprises, specifically subcontractor relationships. He has also worked with the gas and nuclear industries in identifying organizational failures and designing bespoke tools tailored to these organizations. From 2014, he is the head of the “Resilience and Safety” Chair hosted by MINES ParisTech and founded by four major private French companies (AFNOR Group, GDF Suez, Total and SNCF). He is also Graduate of the Political Studies Institute, France and Master of Law, France.

Dominique Pécaud
Research Associate, MINES ParisTech

Dr. Dominique Pécaud is a sociologist. He is the Director of Human Technology Institute Institute, an interdisciplinary platformfor research (Nantes University). He is also Researcher at the Centre François Viete (Epistemology and History of Science andTechnology), Nantes University (France) and Research Associate at MINES ParisTech, PSL Research University, Research Center on Risk and Crises (France). His main areas of research are the sociology and anthropology of risks, assessing the effects of the technical tools on forms ofcollective action, changing forms of construction of the territories and the analysis of human work as a social fact.

Aurélien Portelli
CRC, MINES ParisTech
ESAIP

Aurélien Portelli was trained as an historian. He passed his PhD in 2007 at the University of Nice (France). He is currently a researcher at the Center for research on Risks and Crises (CRC - MINES ParisTech) and a researcher at the ESAIP (a French engineering school). His research deals with topics in the history of nuclear industry and the social representations of the nuclear energy.

Kyoko Sato
Associate Director, Program in Science, Technology, and Society, Stanford University
Ph.D., Sociology, Princeton University, 2007

Dr. Sato’s research explores how culture and politics intersect in the development of sociotechnical systems in different national contexts. Her current research examines how postwar nuclear governance evolved in Japan and the United States, as well as the impact of the 2011 Fukushima nuclear disaster. She is currently Senior Researcher on the Harvard STS Program’s project, “The Fukushima Disaster and the Cultural Politics of Nuclear Power in the United States and Japan,” funded by a grant from the National Science Foundation. Her previous work examined the intersection of cultural meaning, policy frameworks, and politics in the development of genetically modified food in Japan, France, and the United States. Prior to the current position, Sato taught social theory as a lecturer in the Committee on Degrees in Social Studies at Harvard University (2008-2012), and was a postdoctoral associate at the Institute for the Social Sciences at Cornell University (2007-2008). She worked as a staff writer for*The Japan Times*, an English daily in Tokyo, after receiving M.A. in journalism from New York University and B.A. in English from the University of Tokyo.

Ryuma Shineha
Assistant Professor, SOKENDAI (The Graduate University for Advance Studies)
Ph.D., Science & Technology Studies, Kyoto University, 2011

Ryuma Shineha is an assistant professor at the Graduate University for Advanced Studies (SOKENDAI). His main research theme is media and policy analysis of biotechnology in Japan. After the 3.11, he has worked on the 3.11 issues with collaborators, focusing on the social structure, media discourses, and the public interests in this matter. He published works on the 3.11 as the two Japanese books, “The Disaster Vulnerable and the Information Vulnerable: What was overlooked after the 3.11? (災害弱者と情報弱者: ３・１１後、何が見過ごされたのか)” (Chikuma-Press) and “Science and Politics after the Disaster of March 11 in Japan (ポスト3.11の科学と政治)” (Nakanishiya Press) edited by Masaki Nakamura. More currently, he also participates in the risk communication survey project of the Tohoku University, and tries to conduct series of survey on the public attitudes toward nuclear power and decommission of the Fukushima Daiichi Nuclear Power Plant. Ryuma Shineha is a secretary and board member of the Japanese Society for Science and Technology Studies (JSSTS). He is a member of the ethical committee of Japan Environment and Children’s Study (Eco-Chil) of the Ministry of Environment. He is also a member of the working group for the communication with participation of the Eco-Chil.

Sébastien Travadel
Associate Professor, Centre for Research on Risks and Crises, Mines ParisTech, PSL – Research University

Sebastien Travadel’s research programm is focused on engineering thinking in extreme situation. The goal is to develop management principles, project management tools and organizational guidelines that foster transitioning into resilience in the aftermaths of a disaster. Sebastien Travadel is a chief engineer for the French Ministry of Transport and Equipment. He also holds a PhD in law and is qualified as a senior mathematics teacher. He has held several managerial positions in the French agency in charge of aircraft accident and incident investigations, notably as Head of Major Investigations. He headed the Airspace and Air Navigation Regulation Department at the French Civil Aviation Authority before co-founding the company Safety Line, which produces decision support software.

Kai Vetter
Professor, Department of Nuclear Engineering, UC Berkeley, Head of Applied Nuclear Physics, Lawrence Berkeley National Laboratory

Kai Vetter is Professor of Nuclear Engineering at the University of California, Berkeley and Head of the Applied Nuclear Physics program at the Lawrence Berkeley National Laboratory in Berkeley. Prof. Vetter leads the Berkeley Radwatch Project and the Initiative for Resilient Communities and is co-PI of the UC Berkeley-led Nuclear Science and Security Consortium. He is also founding member of the joint Medical Physics Program at UC Berkeley and UC San Francisco. Professor Vetter’s main research interests are in the development and demonstration of new concepts and technologies in radiation detection toaddress some of the outstanding challenges in fundamental sciences, nuclear security, and health. He is involved in experiments that aim toanswer fundamental questions in nuclear physics, for example those associated with the neutrino-less double beta decay in enriched Ge-76 orthe detection of the yet unobserved coherent neutrino nucleus scattering process. He oversees a wide range of developments of new concepts ingamma-ray detection and imaging and the fusion of nuclear with complementary data. These developments find applications ranging from thedetection and characterization of radiological materials for nuclear security and the mapping of contamination in Fukushima to the verificationof ion-cancer therapy and studies of the biokinetics of radioisotopes in living organisms.

Haruko Murakami Wainwright
Lawrence Berkeley National Laboratory

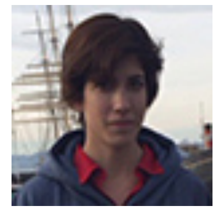
Haruko Murakami Wainwright is currently a research scientist at Lawrence Berkeley National Laboratory. After graduating with BS in engineering from Kyoto University in Japan, she earned MS in nuclear engineering (2006), MA in statistics (2010), and PhD in nuclear engineering (2010) at University of California, Berkeley. She has worked on various research topics in both nuclear engineering and environmental sciences, including nuclear waste, groundwater contamination associated with nuclear weapon productions, the Arctic ecosystem responses to climate change, biogeochemical cycling in riparian systems, and deep-subsurface CO2 storage. Her research has been focused on parameter estimation and uncertainty quantification. She has played a key role in many DOE-sponsored large multidisciplinary projects; the DOE’s Integrated Field Research Challenge (IFRC) project, Sustainable Systems Science Focus Area (SFA), National Risk Assessment Partnership (NRAP), the Advanced Simulation Capability for Environmental Management (ASCEM), and the Next Generation Ecosystem Experiment in Arctic (NGEE-Arctic).

4.4. Students

Hiroyasu Abe
Graduate Student, University of Tokyo

Hiroyasu Abe's research areas is ground motion simulation. In his paper, the ground motion simulation using fault plane is used. There are already research of ground motion simulation. More detailed model is needed to conduct probabilistic seismic risk assessment, which incorporate uncertainty in ground motion prediction. He studies a stochastic model to simulate the slip distribution of fault plane.

Ivana Abramovic
Graduate Student, Visiting Scholar, Department of Nuclear Engineering, UC Berkeley
BSc, Theoretical and Experimental Physics, University of Belgrade (Serbia), 2013
MSc, Science and Technology of Nuclear Fusion, University of Technology, Eindhoven, The Netherlands, 2015



Ivana's research areas include computational modeling of nuclear reactions and application to fusion driven systems. Nuclear structure and matter radiation interaction. She has been participating in experiments conducted by the Bay Area Neutron Group. Ivana finished her undergraduate studies in theoretical and experimental physics within top 5% of the class at The University of Belgrade Faculty of Physics. From low temperature plasma physics she has shifted her focus to nuclear fusion and enrolled into a Master of Science program Science and Technology of Nuclear Fusion at The University of Technology Eindhoven in The Netherlands. In 2014 she has spent 3 months at the Institute for Plasma Physics in Prague, in the tokamak department, working on charge exchange diagnostics. She came to UC Berkeley as a visiting scholar at the Department of Nuclear Engineering in 2014, and has been involved in fundamental nuclear research as an affiliate at the Lawrence Berkeley National Laboratory.

Aissame Afrouss
PhD Candidate, Centre de recherche sur les Risques et les Crises, MINES ParisTech
Dipl. Eng., Nuclear Safety Engineering, Ecole des Mines de Nantes, 2013
MRes., History of Science and Technology, University of Nantes, 2014

Afrouss Aissame's is a PhD student whose main research works fit within the framework of the "engineering thinking in emergency situations" concept. Currently, he studies the hearings of the former Fukushima Dai Ichi manager, held by the Investigation Committee of the Japanese Government, with regard to the "emergency situations" concept. In addition, he is also interested in the use of narratives (iconographic, textual…) to improve industrial safety.

Sophie Agulhon
PhD student, Centre for research on Risks and Crises, MINES ParisTech

Sophie Agulhon's research areas include management devices contribution to safety field in nuclear fuel-cycle industry and methodological aspects regarding social sciences. Sophie works in AREVA group General Inspectorate, Health, Safety, Quality and Environment Department (DSQE). She also assumes teaching functions and project operational responsibilities in the French National Conservatory for Arts and Crafts (CNAM) since 2012 and in MINES ParisTech since 2014.

Alexandra (Sasha) Asghari
Graduate Student, Department of Nuclear Engineering, UC Berkeley

Asghari is currently a graduate student at UC Berkeley pursuing a PhD in Nuclear Engineering with and emphasis on radiation detection and nuclear nonproliferation. She graduated with a BS in Physics from CSU, Sacramento in 2012. Currently, she is working with Adam Bernstein and Steven Dazeley at Lawrence Livermore National Lab on a Gadolinium-doped water Cherenkov neutron detector as a possible alternative to some helium-3 detectors. Sasha is particularly interested in the nexus of science (particularly radiation detection) and policy (particularly nonproliferation of nuclear weapons). Outside of academia, she loves traveling, reading, cooking, and brewing beer.

Romain Bizet
Ph.D. Candidate, MINES ParisTech

Romain Bizet is a first-year PhD student in economics at CERNA, the Centre for Industrial Economics of Mines ParisTech. His research focuses on the regulation of nuclear safety. He is supervised by Professor François Lévêque. He previously graduated from École polytechnique in nuclear engineering.

Justin Larouzee
PhD student, Centre for research on Risks and Crises, MINES ParisTech

Justin Larouzée is a geological engineer specialized in natural hazards. After joining EDF Group to work on dams' hazards studies, he started a PhD at the MINES Paristech *Centre for Research on Risk and Crises* (CRC). This thesis led him to design a dam dedicated model of human and organizational factors. He also studies knowledge co-producing processes among human and engineering sciences, research and industrial world. Also as part of his thesis, he conducted a comprehensive study of the Swiss cheese model by James Reason. He is a professional magician and private pilot.

Xudong Liu
Ph.D. Candidate, Department of Nuclear Engineering, UC Berkeley
M.S., Nuclear Engineering, University of California, Berkeley, 2012

Mr. Xudong Liu is studying the criticality safety for the disposal of spent fuels, and damaged fuels from Fukushima Daiichi reactors in Prof. Joonhong Ahn's research group. His previous works include scenario development, neutronics modeling and simulations for criticality safety assessments. His current research interest is the random geometry problems in the criticality safety assessments for radioactive waste disposal.

Dipta Mahardhika
Ph.D. Candidate, University of Tokyo

Dipta is a Ph.D. student in the Cognitive Systems Engineering Lab, in Department of Systems Innovation, School of Engineering, The University of Tokyo. He entered the laboratory as a master student in 2012. After graduated in 2014, Dipta continued his study to Ph.D course in the same laboratory. In his master study he focused on a comprehensive framework of team interaction, called Mutual Belief Model. In the current study, he is trying to implement the model in human-machine interaction process. Beside his academic activities, he studies Japanese and sometimes does yoga.

Hiromu Matsuzawa
Department of Nuclear Engineering and Management, the University of Tokyo

Mr. Matsuzawa is a master 1st grade student at the Graduate University of Tokyo. Mr. Matsuzawa's research area is energy system analysis using mathematical modeling techniques. After the Fukushima Daiichi Accident, he has got interested in energy system resilience, and he mainly studies the optimal generation mix and evaluates the installable potential of distributed generators and batteries in terms of economical perspectives, considering the generators' shut-down risk in Tokyo Bay area, where huge earthquake risk is concerned recently. His study is supported by Resilience Analysis for Social Safety Policy, JST RISTEX, which project Prof. Kazuo Furuta and Prof. Ryoichi Komiyama are also involved. Mr. Matsuzawa has been supervised by Prof. Yasumasa Fujii and Prof. Ryoichi Komiyama since 2013. In his bachelor studies, he studies the optimal generation mix including co-generation system (CGS) introduction, considering electricity supply network and urban gas supply network.

Naoto Mitsume
Doctoral Student, Department of Systems Innovation, the University of Tokyo

Mitsume's research focuses on the development and application of fluid-structure interaction simulation including free surface flow using the finite element method and the mesh-free particle methods for disaster mitigation design of structures. He develops series of hybird methods, named MPS-FE methods, and imprements large-scale parallel code of them.

Delvan Neville
Oregon State University
B.S in Radiation Health Physics, Oregon State University, 2011
PhD in Radiation Health Physics, Oregon State University, In Progress

Delvan Neville's PhD research areas have primarily focused on marine radioecology in the Pacific Northwest of the United States. Much of his work has focused on species and tissues in biota overlooked during the previous human-diet-centric paradigm of radioecology. His other research interests include forensics, robotics and bioremediation. Delvan has published two peer-reviewed publications to date, and has served as a reviewer for Springer Japan and Environmental Science &Technology. He is a senior PhD candidate in Dr. Higley's Radioecology research group at Oregon State University. He also operates a forensics company, Amaragh Associates.

Ryan Pavlosky
PhD Student/RadWatch Lead Developer, Department of Nuclear Engineering, UC Berkeley
BS, Chemical Engineering, Tennessee Technological University USA, 2011
PhD (anticipated), Nuclear Engineering, University of California Berkeley

Ryan Pavlovsky is a Nuclear Engineering graduate student at the University of California, Berkeley. For the past 3yrs Ryan has lead or taught the lab section for NE104, a class that provides students with the basics of Radiation Detection. Ryan has also been involved with the RadWatch outreach effort by communicating with the public and public offices on issues regarding naturally occurring radioactive materials in the environment. He directly mentors several undergraduate students through this program. Ryan's research interests are in the development of novel detector readout systems for silicon CCD-electron tracking detectors. He is also interested in the fundamental, but highly coupled, limits of radiation detector energy and position resolution. Ryan has expertise in Nuclear Instrumentation Physics, Nuclear Physics, GEANT4 and massively parallel computing.

Rin Watanabe
Master course student, Department of Nuclear Engineering and Management, School of Engineering, University of Tokyo

Rin's research concerns high-level radioactive waste disposal policies, and how they could be formed in relation to public opinion. Her graduate thesis compared the historical scope of arguments presented by the Japanese government and the concerned public, to show that there are several points made by the latter which could technically improve the current policy upon appropriate consideration. Her present study aims to clarify these sociotechnical points through qualitative analysis of citizen interviews. She is the chair of the Student's Network of the Atomic Energy Society of Japan, and works with a dozen students around Japan to organize academic events.

4.5. Rapporteurs

Hortense Blazsin
Research Associate, MINES ParisTech

Hortense Blazsin's research focuses on documenting and demonstrating the many ways by which individuals can be something other than "factors", of failure or even reliability, for safety. Building on the work of a contemporary French philosopher, Paul Ricoeur, Hortense Blazsin develops the concept of "practical safety". It defends the idea that safety can be preserved by relying on people's practical reason, rather than on organizational rationality, by mobilizing individual will, rather than obedience. The concept has been confronted to data gathered within a gas distribution company, showing that such an approach is both relevant and anchored in reality. Hortense Blazsin is now broadening the scope of her research to other sectors, such as construction and the nuclear industry, to further develop and strengthen the concept of practical safety.

Charlotte Cabasse
Researcher, Berkeley Institute for Data Science, UC Berkeley
Ph.D Geography, University Paris Est, January 2015.

Charlotte Cabasse-Mazel studied at the Laboratoire Techniques, Territoires et Sociétés (LATTS), Ecole Nationale des Ponts et Chaussées. Her research focuses on the creation of hybrid communities and the transformation of subjects (both resident/expert) and space, facing risk of natural disasters in the Bay Area of San Francisco. Previously researcher at EPFL, Switzerland, she worked on research projects questioning the definition of “science”, “society”, “future” and “risk”. She also participated to join research-action project with UN Agencies (ISRD, WHO) in Madagascar. Before being a PhD student, she was a civil servant in French Embassy in South Africa and an NGO project coordinator for Aide Médicale Internationale (AMI) in Afghanistan and Indonesia. She also worked a journalist, having collaborated with French local and national newspapers. She received her MA in Cultural Geography from Université de Reims and MA and BA in Information and Communications Sciences from Université de la Sorbonne, Paris, France.

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5. Draft Papers

NOTE: The papers included hereafter have been developed for the purpose of understanding each participant's research interest. These are pre-publicational, and should not be referred to or distributed beyond the participants of this workshop without prior consent from the author.

5.1. Introduction (9:00 – 9:30 am): Motivation, Background, and Objective of the Workshop

- Greeting and Scope: Prof. Joonhong Ahn (UCBNE/CJS/LBNL)
- Aim and Goal: Prof. Franck Guarnieri (MPT)

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Exploring New Paradigm of Nuclear Safety: From Accident Mitigation to Resilient Society Facing Extreme Situations

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ABSTRACT
Observing current situations in Japan after the Fukushima Daiichi accident on different scales, I discuss resilience in nuclear utilization as a new paradigm of nuclear safety. On the local-community scale, due to lack of understanding on radioactivity contamination in the environment, effective decontamination actions have not been taken. The difficulty has been compounded by the lack of effective stakeholder engagement in decision-making process in the decontamination actions. On the national and international scales, due to lack of flexibility in back-end of the fuel cycle and reactor decommissioning, resilience of a nation's reactor fleet has been significantly limited, resulting in increase in various potential risks. National-scale resilience is deeply coupled with the community-scale resilience because the trust toward nuclear technology is based on the public's trust in the 5th level defense, i.e., how resilient the society can be in aftermath of a severe accident. Thus, experts of natural and social sciences and engineering must discuss resilience as a new paradigm of nuclear safety at multiple scales and levels.

Key words: Local-community scale, National scale, Resilience of nuclear utilization

INTRODUCTION

The consequences of the Fukushima Daiichi nuclear accident in March 2011 sparked a debate about the nuclear safety. Most directly, the impact on local communities is substantial and manifold, including as of March 2015 more than 100,000 citizens who are still evacuated from their homes and nearly 2,000 deaths during the evacuation and living in temporary housing as a result of various causes triggered by the evacuation, while releases of large amounts of radioactive materials resulted in no casualties due to radiation. In addition, thousands of families, local communities, and industries were damaged or completely destroyed. On a national and international scale, Japan is experiencing complicated situations in international relations and economics, as its nuclear policy started to stray after the accident. These consequences should have been recognized, analyzed, discussed in public, and prepared for prior to the accident, but there had been serious oversight and misunderstanding about what harms must be protected against in such a severe accident.

This insufficient preparedness has been compounded by the lack of an effective decision-making process with participation from a broad range of stakeholders on local-community scale and national scale, resulting in intolerable delays in societal recovery after the accident. Numerous cases can be found on various scales in which decisions led to greater damage due to lack of timely decision-making informed by solid scientific evaluation of various risks. These challenges are compounded by the eroded public trust for government and operators.

The bitter reality is that severe nuclear accidents will occur in the future, no matter how advanced nuclear technologies become; we just do not know when, where, and how they will occur. Technologies for reactors and nuclear fuel cycles should continue to be improved to minimize the frequency and consequences of accidents in the conventional context of Level 1 to 4 in the defense-in-depth concept, as well as in the Level-5 defense. Scientific and academic communities should start efforts for establishing the scientific bases, both natural and social, for better societal resilience.

In this paper, I try to describe difficulties that Japan has been experiencing in the aftermath of the Fukushima Daiichi accident on different scales.

ON LOCAL-COMMUNITY SCALE

The Model

Fig. 1 shows the parts of Japan that were affected by fallout of Cs-134 and Cs-137 from the Fukushima Daiichi nuclear power plant. For this situation, the Japanese government enacted a law on special

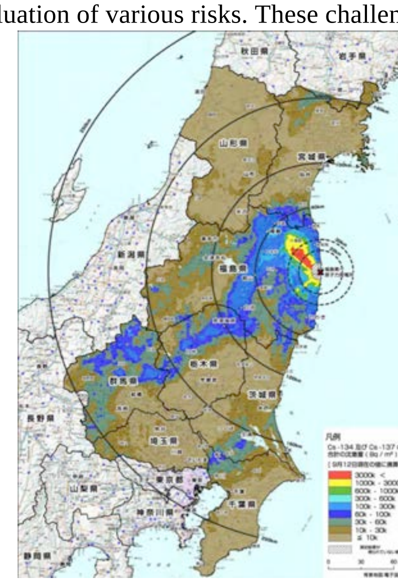

Fig. 1: The level of the surface radioactivity concentration (kBq/m^2) in September 2011.

measures on August 30, 2011 [1]. It stated that (1) the annual dose is to be made less than 20 mSv/year within 2 years, and (2) 1 mSv/year or lower at any location in the long term. In Fig. 1, the surface concentrations of cesium in the yellow and red regions exceed the 1,000 kBq/m^2 level, in which case, as the calculation in [2] illustrates, annual doses exceed the 20 mSv/year level. This fact indicates that efforts to reduce the surface concentration of cesium should be focused in these regions to achieve the first guideline. To achieve the second guideline requires decontamination of a much broader area. With the proportionality between the surface concentration and the annual dose, the target area of decontamination would be all places with a surface contamination greater than 50 kBq/m^2. With the two decontamination guidelines defined by the law, questions arise immediately as to how soon these goals can actually be achieved, how much it will cost, and what the parameters are that could significantly affect effectiveness of a decontamination job. To help answer these questions, an abstracted model was developed by taking into account three major mechanisms that would affect the surface radioactivity concentration: (1) spontaneous radioactive decay, (2) natural dispersion, and (3) decontamination by human actions. The reader is referred to [2] for further details.

Results

Table 1 shows the results for four cases as combinations of with or without decontamination and slow or fast natural dispersion. Answers to the questions addressed in relation to the two goals defined in the law can be obtained as follows:

(1) Can the annual dose be made smaller than 20 mSv/year within 2 years?

The dose rate exceeds 20 mSv/year if the initial contamination was 1,000 kBq/m^2 or higher. Table 1 indicates that for the area with 1,000 to 3,000 kBq/m^2 contamination, the dose rate would become below 20 mSv/year within at most 2.52 years. For the area with > 3,000 kBq/m^2, the time for the dose to become below 20 mSv/year is longer than that, but decontamination action can effectively shorten the time, particularly where the natural dispersion is slow. If the natural dispersion is fast, effects of decontamination on shortening the time to lower the dose rate below 20 mSv/year are limited. Thus, decontamination should be applied only in such areas where natural dispersion occurs slowly for the purpose of minimizing waste generation by decontamination.

(2) How long will it take for annual doses to become 1 mSv/year or lower at any location?

For the area with the initial contamination < 100 kBq/m^2, in any conditions of natural dispersion, within at most 1.66 years the dose rate becomes below 1 mSv/year. Actually in this area in the past four years the < 1-mSv/year radiation level has been achieved. Between 100 and 1,000 kBq/m^2, if natural dispersion is fast, then decontamination should not be applied because the time for the dose rate to become below 1 mSv/year would not shorten significantly. Thus, similar to the observation for Question (1), it is crucial to identify regions where natural dispersion occurs slowly.

Table 1 Effects of decontamination and natural dispersion (Fast: natural dispersion rate = 0.534 yr^{-1}; Slow: 0.05 yr^{-1}; -- : air dose rates always below 20mSv/yr)

Initial contamination, β (kBq/m^2)	Years to reach 20 mSv/yr				Years to reach 1 mSv/yr			
	No decontamination		With decontamination		No decontamination		With decontamination	
	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow
> 3000	>1.43	>4.32	>1.10	>2.19	>5.67	>38.4	>4.25	> 9.83
1000 – 3000	0.90	2.52	0.70	1.36	5.06	32.8	3.81	8.62
600 – 1000	--	--	--	--	3.72	20.3	2.83	6.08
300 – 600	--	--	--	--	2.91	13.0	2.23	4.64
100 – 300	--	--	--	--	1.81	5.90	1.40	2.80
60 – 100	--	--	--	--	0.61	1.66	0.48	0.92

Decontamination generates waste materials containing radioactive cesium. From the aforementioned observation, we consider that decontamination should be applied only in the region with the initial contamination of 300 kBq/m^2 or greater. In Table 2, the area for each contamination level is shown in the second column from the left. In-situ measurements for soil contamination [3] indicate cesium has migrated into the soil to a depth of about 5 cm. Assuming that the contaminated materials are removed from the area to a depth of 5 cm, we can estimate the volume of the radioactive waste to be generated by decontamination activities. The third and fourth columns of Table 2 show results of the waste volume estimate for the cases of fast and slow natural dispersion by the model shown in [2]. 16 or 24 million m^3 of waste will be generated from decontamination for regions with 1000 kBq/m^2 or greater (the yellow and red regions in Fig. 1). But if decontamination is applied to regions with lower contamination levels, the total volume of radioactive waste generated could be as large as 37 or 58 million m^3. The two rightmost columns in Table 2 show the estimated cost. Depending on the area targeted for decontamination, the cost of decontamination varies greatly. Even if decontamination is limited to highly contaminated areas where the dose rate is above 20 mSv/year, the cost is likely to be on the order of ten trillion yen.

Table 2 Evaluation of Volume and Cost of Disposal for Radioactive Waste Arising from Decontamination

Initial soil contamination, β (kBq/m^2)	Area included (km^2)	Waste volume (million m^3)		Estimated cost (trillion yen)	
		Fast dispersion	Slow dispersion	Fast dispersion	Slow dispersion
> 3,000	183	5.60	8.13	3.64	5.28
1,000 – 3,000	368	10.5	15.7	6.83	10.2
Subtotal	551	16.1	23.8	10.5	15.5
600 – 1,000	282	6.60	10.5	4.29	6.83
300 – 600	721	14.1	23.2	9.17	15.1
Subtotal	1,003	20.7	33.7	13.5	21.9
Total	1,554	36.8	57.5	23.9	37.4

Observations and Suggestions

The result indicates the importance of waste volume reduction, for which basically two approaches can be considered. The first is strategic selection of areas for decontamination. Decontamination has been found to effectively reduce the air dose rate if it is applied in areas where natural dispersion is slow. The second is development of volume reduction technologies, which include incineration, physical and chemical partitioning, and compaction. Both approaches should be applied in a concerted manner.

Unfortunately, sufficient *scientific* information and knowledge that enable strategic prioritization of areas for decontamination are *not* currently available. From the present analysis, these are primarily related to in-depth understanding about natural dispersion phenomena, including (1) the interaction of radionuclides with materials in the natural environment, (2) the transport and dispersion of radionuclides in the natural environment, and (3) the measurement of radiation and radionuclides in the environment. Furthermore, effectiveness of decontamination should have been evaluated through experiences in actual decontamination work. In the past four years, although decontamination has been carried out in more than 100 local municipalities, data, experience, and knowledge have not been made available in the public domain in forms that can be utilized for further analyses and feedback.

This lack of integrated scientific knowledge base about environmental contamination caused deterioration in trust among stakeholders in society. But, at the same time, knowledge and information about natural dispersion phenomena and decontamination effects could not be accumulated and fed back due to the lack of trust. What has actually occurred in the past three years indicates that the issue of decontamination has sensitized differences among people about what needs to be achieved by decontamination, resulting in belated decision making on various important matters, which has led to greater and prolonged hardship for the evacuees.

To halt this vicious cycle, we need to establish a fundamental scientific basis, both natural and social, for enabling in-depth analysis about what has been the most crucial damage resulting from the accident and why that occurred, and how radiological risk can or should be compared with other risks in society. Coupled with such scientific efforts, advanced concepts and technologies should be developed and implemented to facilitate decision making by a broad range of stakeholders, which would significantly enhance the resilience of society.

ON NATIONAL AND INTERNATIONAL SCALES

Status Quo

In the past fifty years of nuclear power utilization in Japan, 25,640 metric ton (MT) of spent nuclear fuel[1] has been generated. Of this amount, 7,100 MT was reprocessed in France and U.K., and the plant in Tokai-mura currently owned by Japan Atomic Energy Agency (JAEA) reprocessed 1,020 MT (Table 3). As a result, Japan possesses approximately 44 MT of plutonium (Pu) (Table 4) and about 8,000 canisters of HLW. The un-reprocessed spent fuel (25,640 – 1,020 – 7,100 =

[1] Nuclear fuel before usage in a contemporary light-water reactor (LWR) is made of uranium oxide (UOX) consisting of the fissile U-235 isotope comprising 4.5% of total U atoms. After producing 45,000 mega-watt-days of heat per metric ton (MWd/MT), the fuel is discharged from the reactor. This spent fuel still contains around 0.8 % of U-235 and 0.9 % of Pu (approximately 9 kg), of which about 0.5 % (5 kg) is fissile. If one MT of spent fuel is reprocessed, 9 kg of Pu and approximately 960 kg of U are recovered separately, and the rest becomes vitrified high-level waste (HLW), including fission-product isotopes and minor actinide isotopes, such as neptunium, americium, and curium. The HLW is solidified with borosilicate glass in a stainless steel canister.

17,520 MT) is stored either at each nuclear power plant in Japan (total 14,170 MT) or in the storage facility attached to the Rokkasho reprocessing plant (3,350 MT). 14,170 MT occupies approximately 70% of total storage capacity (20,000 MT) in all existing nuclear power plant sites. 3,350 MT is already 97% of the spent fuel storage capacity at the Rokkasho reprocessing plant.

How Has This Status Quo Been Generated?

Table 3 Japan's Spent Fuel Balance (02/2013)

Stored at JNFL in Rokkasho	3,350 MT
Stored at nuclear power plants	14,170 MT
Reprocessed in U.K. and France	7,100 MT
Reprocessed at Tokai-mura	1,020 MT
Total	25,640 MT

Table 4 Japanese Plutonium Stockpile (kg) (as of the end of 2011)[4]

in Japan (Pu fissile)	*9,295 (6,316)*
Reprocessing Plants	4,364
MOX Fuel Plant	3,363
Stored at Reactors	1,568
in Europe (Pu fissile)	*34,959(23,308)*
U.K.	17,028
France	17,931
Total (Pu fissile)	*44,254(31,837)*

In 1955, ten years after the end of World War II, Japan established the Atomic Energy Basic Law, and launched its nuclear development program. The Japanese national policy for nuclear fuel cycle was established during the 1970s and 1980s to achieve "energy independence" by decreasing dependence on oil, motivated by the experience of the oil crises in 1973 and 1979. The establishment of the nuclear fuel cycle, consisting of uranium (U) enrichment, reprocessing of spent nuclear fuel to recover Pu and U, and a fast breeder reactor (FBR), became the national policy with the highest priority. In 1988, Japan successfully reached a comprehensive Nuclear Cooperation Agreement (NCA) with the United States that enabled Japan to develop and own the nuclear fuel cycle. It was a remarkable diplomatic achievement in the international environment after the nuclear test by India in 1974, upon which the U.S. strengthened its anti-nuclear fuel cycle policy. Indeed, Japan is the only non nuclear weapons country other than EURATOM that has industrial-scale capability of U enrichment, PUREX reprocessing, and FBRs, acknowledged by the international community, particularly by the U.S. After reaching the U.S.-Japan NCA in 1988, Japan made steady progress toward construction of nuclear fuel cycle facilities in 1990s. After the 1997 Kyoto Protocol ratified at the United Nations Framework Convention on Climate Change (UNFCCC), reduction of greenhouse-gas emissions was added as the main objective of nuclear power utilization. In other words, the 1997 Kyoto Protocol solidified the raison d'etre of Japan's nuclear energy industry, and this was the mindset in place until the Fukushima Daiichi accident on March 11, 2011.

The Japanese nuclear community had never conceived of "sudden braking" scenario as the situation currently observed in Japan that all reactors halted operation after the Fukushima Daiichi accident. The sudden braking clearly revealed that there was a serious oversight, or lack of plan B, in the national policy for development of the nuclear fuel cycle and for spent fuel management.

What Are the Problems with the Current Situation?

After March 11, 2011, all forty-eight operable nuclear reactors in Japan had been put out of service one after another due to previously scheduled regular maintenance and inspection, and none could resume operations except for the Number 3 and 4 reactors at Kansai Electric's Oi Nuclear Power Station for the term between July 2012 and September 2013.

While the two units at Oi could restart for a year as an emergency measure,[2] others could not, because more stringent regulations implemented after the accident require all existing 48 reactors to be back-fitted before they obtain permission to restart. Aged reactors in general need more work to comply with new regulations, which creates higher costs, but investing in aged reactors may not pay off if the remaining license term is not long enough. This is currently urging utilities companies to consider decommissioning their aged reactors, and thus almost certainly the total number of Japanese nuclear reactors will be reduced in the future. What is not so clear at this moment is how fast the reduction process will occur, and at what capacity the Japanese nuclear fleet size will level off.

The Japanese monthly trade statistics [5][6] indicate that Japan's import of natural gas and oil increased significantly after the accident to fill the gap created by loss of the nuclear reactor fleet. Japan has to spend an extra 4 to 5 trillion yen every

[2] Prime Minister Noda expressed his support for the restarting of Oi's two reactors on June 8, 2012, driven by the projection that the Kansai area, including Osaka, Kyoto, and Kobe, would otherwise suffer from a severe electricity shortage in the coming summer.

year. In addition, burning oil and gas emits carbon dioxide into the atmosphere. In 2011, Japan emitted an extra 175 million ton of carbon dioxide compared to the average annual emission before the accident. This pattern will continue as long as Japan relies fully on fossil fuels.

When Aomori Prefecture agreed in 1989 to build in Rokkasho the reprocessing plant and attached interim storage facilities for spent fuel and HLW canisters, the central government promised that Rokkasho would never be the final disposal site for HLW. After the accident, in the course of public discussions about whether nuclear power utilization should be continued or phased out and whether reprocessing should be carried out or abandoned, Aomori Prefecture warned that all spent fuel and HLW canisters currently stored in the Rokkasho site must be returned back to their original plants *if* reprocessing is not carried out in Rokkasho. In this case, 3,350 MT of spent fuel stored currently in Rokkasho and 8,000 canisters of HLW to be returned from U.K. and France would need to be relocated from Rokkasho.

In October 2013, in Mutsu city, Aomori, the interim storage facility for spent fuel became available first with a 3,000 MT capacity with a planned expansion to 5,000 MT in the future. Considering that the fleet size is likely to be significantly reduced, and that there is a total of approximately 10,000 MT (6,000 in individual power plant sites and 3,000 to 5,000 in Mutsu) of available space for spent fuel storage, Japan can restart reactors for a decade or longer while postponing decision on reprocessing. This offers Japan an invaluable grace period to review policy, during which time a plan must be developed for the medium- and long-term range.

The United States has been demanding that Japan make clear its plans for commercial Pu utilization to avoid creating a large Pu stockpile. However, with the onset of delays in the development of FBR technologies, the Atomic Energy Commission and utilities companies decided to introduce utilization of Pu in the form of mixed oxide (MOX) fuel with existing LWRs. 44 MT of separated Pu can be made into approximately 640 MT of MOX fuel at the MOX fuel fabrication plant to be commissioned in 2017 at JNFL's Rokkasho site with production capacity of 130 MT/year. Thus, if LWRs can be restarted, the Pu stockpile can be burnt in LWRs in the form of MOX. Assurance of timely Pu consumption by MOX utilization will be helpful for the Rokkasho reprocessing plant to commence its operation. However, if an immediate nuclear phase-out is chosen, this MOX option for dealing with the Pu stockpile would no longer be viable.

Without establishing a complete fuel cycle with FBR, geological disposal becomes more complicated. Before the accident, the policy was to reprocess all spent nuclear fuel and to utilize separated Pu as MOX first for LWRs, but eventually for FBRs. If FBRs are deployed, the resultant wastes that require deep geological disposal are HLW and intermediate-level waste (so-called TRU waste) from reprocessing. Because only trace amounts of weapons-usable materials, such as Pu, are included in HLW or TRU, the International Atomic Energy Agency (IAEA) would terminate its safeguards inspection for a disposal facility for these two types of waste. But, if a repository is for disposal of spent fuel (either MOX or UOX), separated Pu and U, IAEA will not terminate its safeguards inspection in perpetuity. In addition to safeguardability issues, a geological repository for spent fuels can potentially be a greater radiological risk than that for HLW and TRU.

These issues, i.e., (1) Aomori Prefecture's refusal to store HLW and spent fuel in Rokkasho without a plan for them to be taken out to a permanent geological repository, (2) drainage of national wealth for purchasing additional oil and gas, (3) international pressure on Japan not to have an unnecessary Pu stockpile, and (4) perpetual safeguards inspection and higher potential radiological risk to be imposed on a final repository for spent fuel and separated Pu and U, are coupled to each other, creating a deadlocked situation after the accident. If reactors are back in operation and reprocessing is conducted at Rokkasho, aforementioned issues (1), (2), and (3) could be solved, but the resultant repository would require high maintenance for a long-term period. Public agreement on this scenario seems to be very difficult to reach under the current situation. If reactors restart but reprocessing is abandoned, (2) and (3) could be solved, while (1) and (4) remain unsolved. If reactors and reprocessing are decommissioned, all four issues remain unsolved, while public support for this option may be the greatest.

CONCLUSIONS

On the local-community scale, we recognize that the lack of integrated scientific knowledge base about environmental contamination caused deterioration in trust among stakeholders in society. But, at the same time, knowledge and information about natural dispersion phenomena and decontamination effects could not be accumulated and fed back due to the lack of trust. It is essentially important for various stakeholders to share common understanding on what primarily needs to be protected in a severe accident, and to have confidence that such understanding is supported by science (natural and social). From the natural science and engineering, in the level-5 defense, these are primarily in-depth understanding about natural dispersion phenomena, including (1) the interaction of radionuclides with materials in the natural environment, (2) the transport and dispersion of radionuclides in the natural environment, and (3) the measurement of radiation and radionuclides in the environment. Improvement in reactor technologies can contribute to Level 1-4 defense, and ultimately to Level 5 by minimizing the area affected by a severe accident.

On the national and international scale, resilience and flexibility need to be enhanced in a nation's fleet of nuclear reactors. Financial and technological barriers for reactor decommissioning are currently so high that reactor owners and the government cannot make timely decisions in fast-evolving environment. Spent fuel accumulation, inter alia, plutonium stockpile, is another crucial factor that reduces flexibility or variety of options that a country can take. Difficulty in getting public agreement is another factor that makes nuclear utilization less resilient and flexible. Considering that the difficulty in public agreement results from fear of severe accidents and lack of effective measures in aftermath of severe accidents, this national and international scale resilience is deeply coupled with the local-community scale resilience, which has been observed in the previous paragraph.

Thus, resilience as a new paradigm of nuclear safety must be discussed at multiple scales and levels by experts of natural and social sciences and engineering.

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From Accident Mitigation to Resilient Societies Facing Extreme Situations What I Know

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ABSTRACT
The purpose of this short paper is to revisit the language to be used at the workshop co-organized by UC Berkeley and MINES ParisTech. Its ambitions are modest: to share some (a priori uncontroversial) definitions, and take a quick look at some avenues for discussion.

KEYWORDS: Fukushima Dai Ichi – Accident – Resilience – Extreme conditions

AS THERE MUST ALWAYS BE AN INTRODUCTION

I must admit that I had not initially planned to motivate myself to participate in this workshop by writing a paper – especially given my status as a co-organizer. It could even be said that it is both impolite (given the efforts of my colleagues) and unjustified. There is no need for me to explain to my colleagues how Professor Ahn and I met or, with the support of our respective teams, the genesis of this amazing and I hope, rewarding interdisciplinary adventure.

It is clear that what unites us is the accident at the Fukushima Dai Ichi nuclear power plant. We all know what happened and for each of us, with our different scientific disciplines, it is a relevant and very singular subject of enquiry. The challenge is therefore to weave our knowledge into an original analysis, where the whole is far greater than the sum of the parts (Aristotle). With this in mind, we have borrowed a principle from the world of classical theatre: the rule of three (time, place and action: 23 and 24 March 2015, at Berkeley). Now, faced with a blank page – and despite the ongoing preparation of a substantial text on the determinants of entry into resilience – I will take up the challenge! Like a high school student facing his university entrance exams, I examine the language to be used, a highly risky exercise in the opinion of the examiners, but one that appears to me, I hope, to be useful in our forthcoming discussions and debates.

Breaking every rule about how to craft the perfect introduction, I am not going to outline what follows because it is not yet finished...

WHAT I KNOW ABOUT FUKUSHIMA DAI ICHI

I know that Fukushima Dai Ichi is a Japanese nuclear power plant, which on 11 March 2011 suffered, like the rest of eastern Japan, the effects of a terrible earthquake followed by a devastating tsunami. I learned that before becoming a nuclear power plant, during the Second World War the site was a training camp for the Japanese kamikaze [1]. I know that at the time of the accident, the Director of the plant was Masao Yoshida. I also know that Dai Ichi is not the same as Dai Ini, where Naohiro Masuda was the Director. His management of the crisis was presented as a model of good management [2]. I think that Yoshida also knew perfectly well how to handle the situation (which I will later term 'extreme') that he and his men faced, all the more so given that the damage and losses were far more extensive at Dai Ichi than at Dai Ini ... But that is another story [3].

WHAT I KNOW ABOUT FUKUSHIMA DAI ICHI AND THE CONCEPT OF THE 'ACCIDENT'

The ordinary meaning of the accident is something that happens unexpectedly or suddenly; it thwarts expectations and breaks habits. In the field of safety science, it is more pragmatically defined as 'the occurrence of an event with severe consequences'. For visionary authors such as Charles Perrow, accidents were 'normal' [4]. 'Normal' in the sense that the complex interactions and tight coupling in the system meant that they were inevitable. In the philosophical sense (according to Aristotle), the accident designates what belongs or happens to a being, but that equally, might not belong or happen to them. This is because the thing or event in question is unrelated to the essence (or substance) of the being itself; they remain themselves even if the thing or event were absent or different. This statement contradicts, as much as it enriches, other definitions.

It would fairly easy to illustrate and look deeper into each of these definitions and show how they relate in practice to what happened at Dai Ichi. However, the unprecedented situation that began on 11 March, 2011 (and that will continue to exist for decades to come) is a call to supplement the term 'accident' with the adjective 'never-ending' (although not at the expense of 'normal'). Although it is clear that Fukushima Dai Ichi was a man-made accident [5], it is unfinished. This notion of 'duration' appears to be key and much more important than the concept of 'time' (which has had little attention paid to its complexity, and is generally confined to the idea of a linear and cumulative process that does, or does not, lead to safety). Here again, the idea is not to develop the concept of 'duration', or 'time', or even 'space' (which inevitably comes to mind through its association with 'time'), but just to catch a glimpse of the range of possibilities that open up to help us rethink the concept of the accident.

WHAT I KNOW ABOUT THE CONCEPT OF 'MITIGATION'

I must admit that I was not familiar with this term, which is not much used in French. It is not in my everyday vocabulary, nor is it part of my working universe. Of course, I know the English term that is used in the domain of risk or impact studies to describe systems, resources and measures for the mitigation of effects, for example in the field of major natural hazards or negative environmental impacts [6]. I have thought a lot about it, and have come to conclusion that it is useless. Did we make a mistake when we decided on the title of the workshop? We will see if this concept can still be called science at the end of our two-day interdisciplinary exchange...

WHAT I KNOW ABOUT THE CONCEPT OF 'EXTREME SITUATIONS'

A situation is called 'extreme' when conditions are radically different from those of so-called 'normal' life and are unusually intense, becoming excessive, or even unbearable [7] (Fisher, 1990). Dealing with the extreme situation pushes people to their limits; to the edge of the abyss [1]. The individual, group, organization, company, or more simply, the system is faced with extreme violence, a radical shake-up of life as they know it.

The extreme situation leads to the destruction of identity, the loss of benchmarks and frames of reference. This can be easily explained, as everyone's identity is shaped or manufactured by external relationships (specifically, compliance) with current social norms, adherence to common and therefore shared values, responses to social expectations, and dependency or even subordination between actors in the system. From the moment the (existing) value system is shattered, a change occurs – and a new system appears.

The concept of the extreme situation therefore places the individual and the collective (organization), faced with the unthinkable, at the heart of the analysis [7]. The unthinkable takes the form of three 'entities' that become, through the forces of nature and human weakness, uncontrollable and 'unleashed'. Following a period of 'devastation' and predictions of 'certain death' [3], the actors involved in the Fukushima Dai Ichi accident began a phase of 'coping', which enabled them to mobilize multiple resources in order to survive in the short term [8]. They then began a return to an acceptable situation, despite extensive damage, widespread pollution and the hazards that endangered, and continue to endanger the site.

WHAT I KNOW AOBUT THE CONCEPT OF 'RESILIENCE' AND, LESS WELL… 'ENTRY INTO RESILIENCE'

There is no universal definition of the concept of resilience that can be applied to all domains. That said, the English term resilience, itself derived from the Latin verb *resilire* (to bounce), is made up of *re* (again) and *salire* (rise), which implies a retroactive effect [9]. While in the 1970s the term was associated with the ability to absorb and overcome the effects of significant, unexpected and brutal disruption to ecological systems [10], hybrid definitions have since emerged in many disciplines including geography [11], psychology [12], sociology [13], organizational sciences [14], ergo-psychology [15], etc. Within this smorgasbord of definitions, two fundamental ideas prevail: community[3] and the process[4].

In the absence of a consensus, resilience can be defined as the capacity of a system to absorb disturbances and reorganize itself during ongoing changes [16]. It is probably more relevant, especially in the case of an accident as serious as that at Fukushima Dai Ichi, to place less emphasis on states of equilibrium as "*frontiers as a function of the domain of attraction*" because paradoxically, highly fluctuating instability can also foster the entry into resilience [10]. In practice, a system can be very resilient, yet fluctuate significantly and therefore be fairly unstable. This approach seems more relevant in the case of Fukushima Dai Ichi where, given the enormity of the shock, it was more important to preserve relationships in the socio-technical system than to return to the previous equilibrium as quickly as possible – which in fact proved to be an unrealistic expectation [17].

Contemporary views of nuclear safety see the concept of resilience as a post-crisis process, part of a community dynamic that stresses organizational adaptability [18]. It has a predictive dimension that helps the organization to overcome adversity and get back on track [9]. However, this predictive dimension, and *a fortiori* the entry into resilience, must not neglect the role of probability, uncertainty [19] or even a "*surprise*" dimension in the success (or failure) of its implementation [20]. Here again, there is a reference to a conscious capacity to 'navigate' and 'negotiate' [21] in order to cope with an extreme situation.

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[3] In ecology, a community is a group of organisms belonging to populations of different species making up a network of relationships.

[4] A process is a system of activities that uses resources to transform inputs into outputs.

The term ‘entry’ expresses “*movement from one place to another*”[5]: therefore there is a ‘transition’ that must be taken into account. The concept is also linked to the question of “*the place through which we enter*”[6], and thus the direction of the transition. Time also plays a part, as the ‘entry into’ begins with the exercise of “*a practice*”[7]. A practice that implies a “*change of state*” [22].

The change of state is explained by unforeseen sequences of complex interactions that could not be predicted [4]. The entry into resilience must therefore be perceived as an ‘exploratory zone’ in which it is necessary to have a better understanding of the interactions in order to improve how they are managed. From this point of view, a learning phase is necessary. It is difficult to rationalize this exploration phase either upstream or during the process as it resembles “*cognitive DIY that does not belong to the scientific world (which does not mean that it cannot be effective)*” [23]. In this case, rationality could be described as procedural, with “*simple but strict rules, which certainly does not completely eliminate risk, but reduces it to a level below that resulting from substantive rationality*” [24].

The entry into resilience is therefore translated by the creation of a new system [16] when the ecological, economic or social conditions make the initial system untenable. In this case, the variables and scope that define the system must be modified. Nevertheless, the potential for the loss of a certain degree of resilience is inevitable, in the context of the dynamic interactions found in adaptive complex systems. Such multiple interactions were thrown into sharp relief during the Fukushima Dai Ichi crisis [25] and made the implementation of appropriate responses more complicated.

It is important to note that older definitions include an element of ‘privilege’, linked to the capacity to ‘enter into’. The chambers of the king of France could only be visited at specific times [26]. By extension it could be argued that this ‘entry into’ also embodies a situation where the parties involved must demonstrate in advance their capacity to access the privilege: in other words, education, training, experience, professionalism, etc. The *curriculum vitae* of Masao Yoshida [3] is illuminating in this sense as it demonstrates his competence and expertise, making him the right person in the right place.

Finally, the notion of ‘entry into’ finds support from the biological metaphor of the membrane, “*a generic organ that links the interior with the exterior, the past and the future, using the dual mode of qualification/ interpretation of the future through the past, and the integration of the future using the encoding of the past*”. [27]. This metaphor enables the introduction of the relationship between time and space.

I ALMOST FORGOT THE TERM ‘SOCIETY’

Maybe the psychoanalysts would have something to say about this oversight... I prefer the term ‘system’ to ‘society’.

According to its Greek roots, the word ‘system’ means ‘assembly’. It is derived from the verb *systeô*, which designates the action of attaching elements together. For [28] it is a set of entities in mutual interaction (between elements, actions or individuals [29]), organized according to a goal [30].

The concept of the ‘system’ suggests others, such as ‘border’, ‘flow’, ‘feedback’, etc. The description of the concept requires a description of the system itself, as it will be studied. For example, the Fukushima Dai Ichi plant is a system, as is TEPCO both as a company and in its relationships with supervisory authorities, its customers and the Japanese nuclear industry, etc. It could be said that the whole world is a system.

The concept of the system is closely linked to that of the model; its therefore is an initial element of a unitary language and synthetic methodology for describing the state of the world, and in this case, the events of Fukushima Dai Ichi and a future that is still unfolding.

WHY END HERE?

As you can see, there is no conclusion. You can also read our paper into ‘The Bulletin of the Atomic Scientists’ [31]. See you at the workshop!

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5.2. Session 1 (9:30 am - Noon): What are damages in nuclear accidents?

Objectives of the session: Corrective actions following a nuclear accident must be based on the definition of damage to be prevented. The difficulty lies in how we define the "damage". Therefore we propose to elaborate an original framework for the identification and characterization of severe nuclear accident damages. Speakers of this session will give various examples and thoughts, which give clues for developing definitions.

- Session Chair's remark (9:30-9:40 am): Prof. Cathryn Carson (UCB, History)
- Speaker 1 (9:40-9:55 am): Prof. Dominique Pécaud (MPT), Does the concept of loss orient risk prevention policy?
- Speaker 2 (9:55-10:10 am): Prof. Kazuo Furuta (U. Tokyo), How the Fukushima Daiichi accident changed (or not) the nuclear safety fundamentals?
- Speaker 3 (10:10-10:25 am): Dr. Rebecca Abergel (LBNL), Low-dose radiation effects on human health
- Speaker 4 (10:40-10:55 am): Prof. Christophe Martin (MPT), Consequences of severe nuclear accidents on social regulations in socio-technical organizations
- Speaker 5 (10:55-11:10 am): Prof. Jean Pierre Dupuy (Stanford U.), Philosophical problems, old and new, posed by the possibility of major nuclear disasters
- Discussions (11:10 - 11:50 am)

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Does the concept of loss orient risk prevention policy?

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ABSTRACT
This paper examines the concept of loss and how it is used in a political and moral context. It takes as its starting point the nuclear accident at Fukushima Daiichi and the short, medium and long-term consequences for the human and non-human environment.

Keywords: Loss – Damage – Compensation - Gift

INTRODUCTION

This paper examines the concept of loss and how it is used in a political and moral context. It takes as its starting point the nuclear accident at Fukushima Daiichi and the short, medium and long-term consequences for the human and non-human environment occupied by entities that have different “ways of life” [1].

The distinction between human and non-human belongs to the discipline of the sociology of objects. Barbier and Trépos [2] remind us that “it is an extension of the sociology of innovation and pragmatic sociology of action” and it seeks to overcome epistemological divisions such as between the individual and the collective, or methodological individualism and determinism. It “aims to repopulate the sociological universe” with the set of objects, which Latour [3] argues form part of “the construction of society”, unlike the roles found in classical sociological theory, “faithful tools, critical infrastructure or finally projection screen”.

The aim here is to clarify the concept of loss, defined in general terms as a system representing the forms of regulation governing the various relationships that exist between victims and the event that created them. We take the perspective of political philosophy, and show the overriding importance of circumstances and various forms of authority in creating and directing collective action.

Rather than take a traditional approach, this paper presents a succession of viewpoints that address both theoretical and practical aspects of the concept of loss. It seems that loss should be understood both as a moral or legal heuristic[8] and as an ‘agent’ that is able to change form depending on the circumstances [4].

SECTION 1

An (industrial) object or environment can said to be degraded even when the question of loss does not arise. In this case, there is no direct or indirect harmful impact on any person or environment. For example, nobody would claim that their health is deteriorating when they believe that they live in a healthy environment. Similarly, nobody would hold the natural environment responsible when a species abandons its long-term habitat. At the same time, these two examples show the need to define a healthy and natural environment.

Machinery can also be subject to degradation that does not necessarily create victims. While it is designed to withstand normal wear and tear, engineers may replace the entire unit, or its parts, in order to avoid a breakdown or other incident. This is termed ‘preventive maintenance’ and the aim is to maintain the unit in a satisfactory condition and anticipate any consequences due to the deterioration of the device or its parts. It is defined as “maintenance that is carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or degradation of the operation of a good” (extract from the French standard NF EN 13306 X 60-319). It can also take the form of scheduled maintenance, i.e. “preventive maintenance that is performed at predetermined time intervals or according to a specified number of units of use but without any preliminary check of the condition of the equipment” (extract from the French standard NF EN 13306 X 60-319), or conditional maintenance, which is defined as “preventive maintenance that is based on monitoring of the operation of the equipment and/ or important parameters for its operation including the actions that result from it” (extract from the French standard NF EN 13306 X 60-319). The term “important parameters” refers to key indicators of the equipment’s condition. Finally, preventive maintenance can also take the form of predictive maintenance, i.e.

[8] In law, two elements define the concept of loss: a) although there may be no damage as such, there is a causal relationship – it can be connected to something. “Loss is simply any harm caused by something. It is this cause that does harm and that gives rise to the legal concept of loss; in other words, loss does not exist naturally” (Decencière-Ferrandrière, 1925, pp. 192–193.); b) When the cause is natural, the law will only consider common-sense explanations that throw light on the causal link. Loss differs from harm, harm being defined as the result of loss.

"conditional maintenance that is carried out following extrapolated forecasts and an assessment of important parameters indicating the degradation of the equipment" (extract from the French standard NF EN 13306 X 60-319).

This leads us to the Fukushima-Daiichi disaster. The design of the plant took into account the hypothesis that earthquakes could occur offshore, leading to a tsunami. Consequently, strict construction standards were implemented to reduce the risk to the facility. Specifically, dykes, able to withstand 5.70m-high waves were constructed around the plant[9]. The height was based on data related to the region's history of tsunamis, seismological expertise and wave dynamics.

"The construction of the Fukushima Daiichi Plant that began in 1967 was based on the seismological knowledge at that time. As research continued over the years, researchers repeatedly pointed out the high possibility of tsunami levels reaching beyond the assumptions made at the time of construction, as well as the possibility of core damage in the case of such a tsunami. TEPCO[10] overlooked these warnings, and the small margins of safety that existed were far from adequate for such an emergency situation." ([5] p. 27).

It is not clear whether the tsunami was the only cause of the failure that led to the nuclear accident. The earthquake may also have had an impact, together with poor maintenance and other decisions related to the general organization of work.

"TEPCO's report says the first wave of the tsunami reached the site at 15:27 and the second at 15:35. However, these are the times when the wave gauge set 1.5km offshore detected the waves, not the times of when the tsunami hit the plant. This suggests that at least the loss of emergency power supply A at Unit 1 might not have been caused by flooding." (*ibid*, p. 31).

"Since 2006, the regulatory authorities and TEPCO have shared information on the possibility of a total outage of electricity occurring at Fukushima Daiichi should tsunami levels reach the site. They also shared an awareness of the risk of potential reactor core damage from a breakdown of seawater pumps if the magnitude of a tsunami striking the plant turned out to be greater than the assessment made by the Japan Society of Civil Engineers. There were at least three background issues concerning the lack of improvements. First, NISA [the Japanese regulatory authority] did not disclose any information to the public on their evaluations or their instructions to reconsider the assumptions used in designing the plant's tsunami defences (…). The second issue concerned the methodology used by the Japan Society of Civil Engineers to evaluate the height of the tsunami. Even though the method was decided through an unclear process, and with the improper involvement of the electric power companies, NISA accepted it as a standard without examining its validity. A third issue was the arbitrary interpretation and selection of a probability theory. TEPCO tried to justify the belief that there was a low probability of tsunami, and used the results of a biased calculation process as grounds to ignore the need for countermeasures. TEPCO also argued that basing any safety assessment against tsunami on a probabilistic approach would be using a methodology of technical uncertainties, and used that argument to postpone considering countermeasures for tsunami." (*ibid*, pp. 27–28)

SECTION 2

The term 'loss' designates the consequences of degradation. In some areas, these consequences can be anticipated, while in others they cannot. For example, in an armed conflict the intentional bombing of a military building can lead to its destruction. While this may have been the intention of those who undertook the action, it can also destroy buildings or injure people who were not the target. This is referred to as 'collateral damage'[11]. In this case 'damage' is most meaningful when injury has been caused to a person or group, their property, or an environment (if there is an interest in claiming compensation).

When it concerns a person, group, non-human living species, or an environment the term 'victim' must take on a broader meaning. Not only can it be used to designate people, but also living or non-living entities that have representatives who are able to speak on their behalf. For example, the quality of a coastline is said to be degraded following an oil spill and the media do not hesitate to describe the shoreline as a 'victim'. Bees are another example. This living species is the victim of

[9] The wave tidal wave that followed the magnitude 9.0 earthquake occurred on 11 March, 2011 at 2:46 p.m. local time reached its maximum height of 23.6 meters at Ofunato, in the Iwate Prefecture, north of Fukushima-Daiichi (Executive Summary of Urgent Field Survey of Earthquake and Tsunami Disasters, 25 March, 2011, Port and Import and Research Institute). The height of a tsunami varies according to many criteria. It was estimated to be about 14 meters at Fukushima-Daiichi.

[10] Tokyo Electric Power Company

[11] "*Collateral damage* and *proportionality* are two inseparable concepts. The concept of proportionality in *jus ad bellum* reflects the balance that must be maintained between, on the one hand, military requirements and, on the other hand humanitarian interests, such as the cost in human lives. It aims to limit damage to civilians during attacks against legitimate military objectives, by weighing the military advantage that would result from the attack against the losses that it would cause to the civilian population (i.e. collateral damage). It was not until 1977 that this proportionality rule would be included in a Treaty. It is found in Articles 51, 5.b and 57, 2.b of the First Additional Protocol of 1977 to the Geneva Conventions of 1949." (emphasis added). The International Law Centre of the Free University of Brussels, https://dommagescollateraux.wordpress.com/pratique/ accessed 15 February 2015.

agricultural chemicals, or, as described in a French newspaper, the "victim of the lack of biodiversity"[12]. Finally, before work-related accident legislation was implemented, there were no official victims of occupational accidents or illnesses. They could not be acknowledged until dangerous working conditions or hazardous machinery was recognised. Similarly, an analysis of breakdowns due to human factors can be seen as the clumsy (or even malicious) use of machines by operators.

In general terms, there are no non-human victims. Instead, they are represented by individuals or groups who speak on their behalf and defend their interests before an authority that is responsible for estimating the loss they have suffered.

SECTION 3

Once is has been established that there has been a loss, it can be estimated. This estimate is not an end in itself. Its purpose is to provide compensation to the victim. Objective losses must be recognized by the party responsible and the victim, while its assessment is usually carried out by scientific experts and judicial authorities. Once this is done, the victim can receive compensation. Here, the purpose is to re-establish a situation that the party responsible for the damage, the victim and any third parties (scientific and/ or judicial) assess as having been compromised. The new situation should be as similar as possible to the previous situation, although full recovery may be impossible. For example, the judicial process may end with the victim receiving financial and/ or non-material compensation, such as a symbolic award, which takes into account any 'damages and interest' and corresponds to the non-material harm suffered by the victim. Here, the intention is to compensate for the victim's suffering.

The issue of loss should be seen in an anthropological context, that of the links that create and sustain a society. Two paradigms can be used to characterize these links: the market and the gift.

The market paradigm

The first is the market. From a political liberalism perspective, the market represents a utility. It regulates trade, guarantees individual freedom and collective effectiveness. For example, debt repayments end an unequal relationship, in which the borrower is beholden to the lender. Once the debt is repaid, both parties are fee to act and a new exchange can begin. Another example is the prison sentence, which settles a debt that the convict has to society.

In 1839 the lawyer F. G. J. Thimus [6] used the example of the duel to illustrate the dynamic of compensation. Here, we look at it from the perspective of natural law. In a duel, the injured party seeks redress and other party risks damage to their reputation if they refuse the challenge. Doing so would not only break the symbolic link between them, it would also negate their shared values. When community membership depends on shared values, the refusal to honour a claim for compensation ends the relationship. From the point of view of the injured party, should the other party refuse to offer compensation, they are excluded from the community.

We can transpose this relational dynamic to the Fukushima disaster. In this case, who may seek redress, and from whom?

A disaster always expresses a conflict that manifests as an imbalance between human and/ or non-human entities. In the case of Fukushima-Daiichi, it concerns two 'energy' entities: the plant and its environment. These are social and cultural constructions and embody antagonistic forces. The nuclear power plant can be described in very simple or very complex terms. It can be seen as: a simple technical device that generates electricity; as a socio-technical system that regulates functional relationships between humans and machines, and between it and its environment; or in terms of a combination of human and non-human elements linked by a struggle for power. At the same time, it is the result of human activity, which is called into question from the moment it is unable to recover from the catastrophe. Its energy takes multiple forms[13].

The plant's environment is overwhelmed and transformed by natural forces: a magnitude 9.0 earthquake, followed by a tsunami.

Each of the three protagonists – the earthquake, the tsunami, and the nuclear power plant – has destructive potential, leading to an examination of the relationship between nature and the nuclear plant. In this context, the disaster represents an increase in entropy. Can it be seen as the last stage in a conflict? Using Marc Bloch's war metaphor, does the disaster put an end to the conflict? "A last resort for the resolution of political disputes, war must be used to end a conflict and allow a return to equilibrium, even if fragile. However, modernity sterilises this organized violence, the capacity for destruction, the sacrifices are so great that they make it impossible to go back"[14].

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[12] *Le Figaro*, 25 November 2014.

[13] This observation is not based on technical arguments; it simply refers to the ability of the nuclear reactor to destroy its own cooling mechanisms.

[14] Quoted by Emilio in *L'apocalypse de la modernité, la grande guerre et l'homme nouveau* [The Apocalypse of Modernity, the Great War and the New Man], Flammarion, 2011, p.171.

The gift paradigm

The second paradigm is that of the gift [7]. Unlike the market, reciprocal gift-giving corresponds to an exchange that has no beginning or end. Although the giving of a gift should not correspond to a state of indebtedness, it is nevertheless the position the receiver finds themselves in. In turn, reciprocating the gift makes the new receiver indebted. The Fukushima disaster can be considered as part of this relational system.

Three consequences arise. First, the system creates a long-term context, assuming that gifts continue to be exchanged. Should the receiver not reciprocate, the donor has a hold over them. Second, the gift that is given in return is never the formal equivalent of the initial gift, and the new giver must demonstrate the superiority of their gift to the initial giver. Third, the power that is expressed by the gift giver and the recipient who reciprocates makes a lasting impact on their shared world view. The exchange system that unites giver and recipient requires everyone to benefit. The relational system of gift and counter-gift is ternary. Each of the elements of the exchange results in three obligations: giving, receiving and reciprocating. The exchange is based on the capacity of each party to receive, therefore to assess what is received and what should be given at a later date. Their shared understanding of what has been received defines the gift and the counter-gift and maintains the momentum.

The market and gift paradigms highlight different views of exchanges. In the case of the market, the relationship is unsustainable as it is ended by a payment. The relationship and conflict must be renewed, beginning again from zero. In the case of gift giving there is no end-point, although an inability to reciprocate unbalances the exchange and changes its modalities. The unbalanced relationship becomes fixed, and the party that cannot reciprocate becomes beholden to the gift giver. They are left at the mercy of the donor and the subject of their political decisions.

The reconciliation of these paradigms with the concept of loss appears to be a very useful heuristic. The question is: does loss correspond better to the market paradigm or the gift giving dynamic? This leads to another question: what, in both cases, drives the dynamic?

Before considering some answers to these questions, it is first necessary to consider two important elements related to the concept of loss.

The concept of loss

First, does the concept of loss exist in the context of a temporally closed exchange system (e.g. a breakdown, disaster or recovery) or, an open exchange system (e.g. between a disaster and the ensuing ecological resilience)[15]? In both cases, we need to clearly define environmental, political or industrial compensation on the one hand, and resilience, on the other [8].

Second, we must not forget that loss can only be defined or assessed if victims can be identified. This usually requires a third party, a mediator who can identify both the loss and its victims. It assumes that the victims and the party responsible for the loss share an understanding of the situation that led to the loss and that there is no need for mediation. Identifying losses and victims becomes difficult or impossible when the victims are silent, either because they are incapable of speech or because they are not asked to speak. However, acknowledging the views of the parties involved is essential in understanding not only the material consequences of the disaster, but also its symbolic construction, considered to be one of the phases of resilience.

SECTION 4

The relationship between people, whether they be settlements in the neighbourhood of the Fukushima-Daiichi plant or humanity in its entirety (defined either as anything that belongs to the human species on the one hand, or other material and natural elements on the other hand) must be taken into account if the definition of the nuclear disaster is to go beyond technical aspects. As time passes, it is seen as a ‘total social fact’ [7] and the dynamic is that of gift giving. On the one hand, the elements that make up this relational system can be considered as an endless sequence of actions and reactions (sometimes referred to as a chain reaction), which describe an inevitable succession of events (rather than a causal chain). On the other hand, it must be possible to clearly identify the victims of the disaster. This requires an understanding of how victims emerge, the balance between them and the losses they have suffered, and how to assess the extent of their losses in the context of an exchange defined by the social (and potentially natural) limits of the ‘resilient’ world. Ecological resilience corresponds to changes in an environment that is affected by a disaster, which lead to a more stable situation where the consequences of the disaster are mitigated either physically or symbolically.

SECTION 5

[15] Here, ecological resilience refers to the ability of the overall system to rebalance itself in the long term; it does not necessarily mean that it returns to the state that it was in prior to the disaster, which may be impossible to achieve [8].

The market or the exchange of gifts? The market is governed by rules applied by statutory law, while the dynamics of gift giving are rooted in the philosophical presuppositions of natural law.

Statutory law reflects the actual legal position of a society at a given time. It is made up of regulations governing, for example, trade. On the other hand, natural law allows and protects the expression of human nature; it addresses universal principles. For example, Rousseau [9] considered that it was based on two principles that preceded reason. Nowadays this would be what is not covered by instrumental or logical rationality: self-love and altruistic pity are two practices that form the foundations for human relationships. These two principles suggest a universal human nature that falls short of the rational rules that govern collective action. However, despite the universality that philosophers and law-makers of the Enlightenment sought to give it (notably through the Declaration of the Rights of Man and the Citizen) natural law has been discussed in terms of its potential relativity in space-time. The inclusion of local and traditional cultures changes the idea that men are the product of their relationships with each other or their environment. Ways of living together become defined for both humans and non-humans, which show that the idea of human nature is historically and culturally relative. This is manifested, for example, through the definition that each individual has of human health or an acceptable level of pollution. The ensuing discussion focuses on a universal definition of health (e.g. the World Health Organisation) and negotiations to establish indicators, then standards for environmental pollution. Other debates focus on securing financial compensation for victims, the social acceptability of a hazardous technology, or the pristine condition of a shoreline prior to environmental clean-up or decontamination, etc.

The search for the foundations of natural law corresponds to the desire to define, then respect ‘the’ or ‘a’ human nature. The latter cannot be distinguished from nature itself, which is here defined as what surrounds human beings. Both the history of ideas about human nature and growing awareness of environmental degradation show the need to reduce the philosophical, political, moral and economic divide between Man and Nature.

This is not without consequences. It means that in the context of the Fukushima-Daiichi catastrophe, Nature (i.e. human and non-human elements), should be considered as an integral victim of the nuclear accident, and should be able to claim compensation.

Distinguishing the three elements that made up the disaster suggests that only the nuclear accident was the source of the damage to Nature. It cannot be likened to a simple natural disaster, just because there was an earthquake and a tsunami. Nature cannot be considered as a victim of itself, nor can a natural disaster be distinguished from a manifestation of Nature. The argument simply lends weight to an anthropocentric perspective that maintains the divide between Nature and human nature. Nature is constantly evolving, and the distinction between how this happens (e.g. low-level changes or sudden and dramatic events) may reinforce the anthropocentric tendency.

The distinction between natural and nuclear disaster makes it possible to think about two types of resilience: the first relates to the self-regulation of Nature, which is constantly changing and can never be considered as the return to a previous state; while the second relates to human resilience and focuses on life after the disaster. An illustration of this comes from Fukushima-Daiichi (or Chernobyl) where a decision was taken to establish no-go zones around the facility. This type of decision implicitly reaffirmed the divide between human and non-human beings. It designates humans as the most important victims of the disaster. However, the decision to ban fishing or hunting in areas adjacent to the no-go zone shows than there were other victims.

Although the earthquake and tsunami led to the destruction of nature, humans did not see it as a victim. However, this depends on the anthropological status that is assigned to it. Moving a random stone may not lead to a claim for damages, while moving another that is part of a dyke or historic monument (e.g. a Shinto temple) can lead to funds being allocated for its reconstruction. In the first case, the stone does not have victim status, it the second, it does. The same argument can be made about living species. Whether they are designated as victims will depend on the degree of domestication or their value in terms of heritage (e.g. protected and other endangered species). In all cases, the designation as a victim of a natural disaster depends on the degree of humanization attributed to living or inanimate natural elements. This attribution can be implied or voluntary, traditional or political.

It must be noted that the Fukushima-Daiichi accident could only have been caused by humans, even if other elements contributed to material, imaginary and symbolic construction of the disaster[16] [10]. First and foremost, the plant was created

[16] See Le Poulichet (1991, p. 9). The construction of the disaster can be viewed in terms of its material, imaginary dimensions (fantasies, individual and collective representations) and symbolic (collective meaning attributed to material phenomena and individual and collective representations) dimensions.

by humans. In simple terms, if the plant had not existed, there would have been no nuclear accident[17]. The nuclear accident is therefore unlike the earthquake or tsunami. The identification of those responsible and victims is indicative of instrumental thinking and statutory law. The accident finds its origin in the fact that humans have used nuclear fission to generate electricity, and they designed the necessary technology; while external natural forces (the earthquake followed by the tsunami) damaged the plant, they did not create an imminent danger to the environment. Radioactivity is a natural (re)action that has been exploited by humans and become an organised, industrial activity[18] designed to produce electricity. The nuclear accident and its consequences were an assault on the technology's environment and made it dangerous or unliveable for its inhabitants. Not only humans, but also their pets were evacuated from around the Fukushima-Daiichi plant[19].

The investigations that are being carried out into the accident and the ensuing devastation seek to determine the responsibilities of human beings. They focus on why the plant was built, why it was located in an area subject to earthquakes and tsunamis, construction techniques, the use of data to assess the risk of earthquakes and tsunamis[20], etc. Their findings will determine who is responsible and the human and non-human victims. In time, their understanding of the disaster will become part of local and international statutory law.

Investigations that seek to establish who is responsible will address questions such as: were emergency services sufficiently responsive and appropriate to the situation? Were anti-seismic building codes met? Did land-use plans take account of the risk of a tsunami? Was a full risk assessment carried out? Was the plant in a satisfactory condition? What controls and maintenance procedures were in place? Were they sufficiently rigorous and respected? Was the data related to the plant's design and technical operations satisfactory? In the event that these investigations and the courts identify particular weaknesses or shortcomings, the victims will receive financial and/ or symbolic compensation. These 'gifts' will contribute to resilience that will act as a reciprocal gift, thereby creating new human requirements, such as gifts to the environment.

CONCLUSIONS

Our work looks the question of the losses resulting from the nuclear accident at Fukushima Daiichi from multiple perspectives: natural and statutory law; compensation based on the market paradigm and that of gift-giving; and the designation of victims, losses and compensation.

On the latter point, it seems interesting to think in terms of a kind of non-radical environmentalism[21] [11]. The situation is already a reality. The disaster began on 11 March, 2011 and it does not yet appear to have reached its end[22]. Many observers believe that it is just beginning. Current discussions focus on two areas: an objective explanation of the disaster; and the designation of victims and the assessment of losses. But who will be invited to the discussions and for how long? It must not be forgotten that in French the word 'loss' is equivalent to the concept of "harm or damage caused to someone or something" (*Dictionnaire Littré*). This presupposes a spectacular event that takes place over some time (with the idea that the timeframe widens – or not – its scope). It also presupposes that it is possible to identify the persons or things that have or will suffer harmful effects, either immediately or at a later stage. The definition of losses requires the identification of all persons and things marked by the event and an attempt to establish causal relationships between them. Epistemological caution should inform these discussions, their development and the decisions to be taken.

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[17] This observation forms the basis for radical anti-nuclear protests. See Topçu (2013) *La France nucléaire, l'art de gouverner une technologie contestée* [Nuclear France, the art of governing a disputed technology], Seuil, Paris, p. 359.
[18] Sometimes called the domestication of nature.
[19] http://www.actu-environnement.com/ae/news/japon-evacuation-animaux-centrales-fukushima-ifaw-12578.php4
[20] See *Les ancêtres savaient* [The ancestors knew], article in the French newspaper *Le monde*, 7 May, 2011
[21] Afeissa ([11], pp. 10–11) defines environmental ethics as an ethic "which produces a new *object*, the non-human natural world, judged worthy of moral consideration on its own merits, in other words regardless of any coefficient of utility for the existence of man and considered as a place of intrinsic value or as a holder of rights whose existence as such, command a number of moral and legal obligations." It raises several questions that this article seeks to clarify: To whom should natural rights (of Man or Nature) be given? Can it be done, and can we assign rights to non-humans without strengthening an anthropocentric perspective leading to radical monism? Who can claim these rights (humans, non-humans) and, in the case of non-humans, how does this manifest? Who attributes such rights? In particular, who speaks on behalf of whom?
[22] Tawada ([12], p. 91) points out that there is no Japanese word "that is an exact translation for the German work 'catastrophe'. In German, the word is used in relation to nature and politics. In the event of a natural catastrophe, politics comes readily to the mind of people." While Le Poulichet (1991, pp. 15–16) considers that it has "become impossible to clearly separate the movements of political change from those that lead to an environmental threat." It is seen in the symbolic dimension of the catastrophe, "the overturning of the world of meanings leading to the revelation of a gap where legislation was supposed to take over" (*ibid*, p. 16). From this flows the importance of understanding how compensation can be used to fill the gap.

This article is part of broader thinking on resilience engineering applied to the Fukushima Daiichi disaster. But is it the time to talk about resilience, when we still do not really know if the disaster is over. What is resilience? In the case of Fukushima-Daiichi, resilience refers to the capacity of a technical system to continue operating, or to resist further damage in an unfavourable environment. It also refers to the ability of an ecosystem to recover its operations or development as they were before the system was disturbed.

Losses require the evaluation and implementation of compensatory measures that are designed to cancel out any injury to humans or non-humans who are designated as victims of the disaster. The aim of these practices is to restore harmony to the relationship between a victim (human or non-human) and the party responsible (human or non-human). In all cases, the assessment of losses and the implementation of measures designed to compensate for the harm suffered (reciprocal gift-giving) help to create shared meaning. We argue that this construction triggers disaster resilience. Any meaning must be a preamble to such practices. A shared understanding appears to be necessary for the design of this resilience. A shared vision and sensitivity to, *a minima*, what needs to be considered, foreseen, done, and said is necessary for the construction of new meanings and practices linked to resilience. The definition of loss presupposes other shared intentions: to carry out repairs, and manage resilience in the best way possible. Practical and technical issues must be addressed, which must not overlap, merge or lead to the same answers. The redefinition of loss is perhaps an indicator of a consensus, if it can be accepted by the various stakeholders.

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How the Fukushima Daiichi accident changed (or not) the nuclear safety fundamentals?

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ABSTRACT
In this presentation, the fundamentals of nuclear safety that the Fukushima Daiichi accident did and did not change will be discussed. While the most basic strategy of defense-in-depth principle is still valid, some problems have emerged after Fukushima, preparedness for all-hazards and multiple disasters, and importance of the administration of emergency response. From this observation, enhancing the resilience of nuclear systems is a critical issue after Fukushima. The safety enhancement measures considered in nuclear facilities will be reviewed referring to the elementary characteristics of systems resilience, and a new framework will be proposed for dealing with unsafe events, where unsafe events are classified into three categories.

Key words: Defense-in-depth, residual risk, beyond design-basis, resilience, Category 2 events.

INTRODUCTION

After the Great East Japan Earthquake (*Tohoku Earthquake*) and the Fukushima Daiichi accident (*Fukushima*), people used a word "unanticipated" for describing the disaster. It is true that the up-to-date seismology at the time of disaster could not foresee that such a huge earthquake and tsunami can ever occur in the area, and the main cause of the accident was insufficient preparedness of the plants against tsunamis. It seems an improper remedial action, however, just reevaluating the risk of tsunamis more precisely and increasing the height of seawalls. It seems wrong also to think that the fundamentals of nuclear safety has broken down and it should be replaced with another one. Having reviewed the experiences of the disaster, what we have to do is rather renovating the basic strategy of nuclear safety, defense-in-depth principle, from a viewpoint of systems resilience.

WHAT DID NOT CHANGE AFTER FUKUSHIMA

After *Fukushima*, many people including the press condemned that the myth of nuclear safety was over and the thoughts of experts were totally wrong. The accident, however, has shown clearly that the most basic strategy of defense-in-depth principle is still valid, because the accident was caused exactly from the lack of defense-in-depth. The single safety barrier that had protected the Fukushima Daiichi plants against tsunamis was the seawalls. Since the maximum scale of tsunamis that may possibly occur in the area is uncertain, multiple barriers should have been installed for protecting the plants against tsunamis. In this situation, the tsunami caused by *Tohoku Earthquake* that exceeded the design basis was fatal.

In addition to the seawalls of an insufficient height, the areas of safety-relevant equipment in the plants were not watertight. The emergency power supply such as metal clad switchboards as well as diesel generators were located under the ground level. All these equipment were therefore submerged and lost functions. The backup systems against station blackout were insufficient, either, both in the emergency power supply and the means of water injection.

Safety barriers were not well prepared for mitigation of the consequence of an accident. Before the JCO criticality accident (*JCO*), which occurred in 1999, emergency response that requires evacuation of nearby residents had been a taboo in Japanese nuclear development. As an aftermath of *JCO*, Act on Special Measures Concerning Nuclear Emergency Preparedness was enacted, and emergency response drills were enforced in each prefecture of major facility sites. It was revealed, however, in *Fukushima* that these efforts were ineffective, because the scale of accident was far beyond the prescribed scenarios of emergency response plans.

As described above, the disaster of *Fukushima* occurred, not because the very basis of nuclear safety was wrong, but because it was not maintained properly. Defense-in-depth is the most basic strategy of nuclear safety that had been established at an early stage of nuclear development, before sophisticated methods of risk-informed safety management were introduced. After *Fukushima*, some people claim that we should rely more on risk-informed methods for safety management and we should evaluate more precisely the risks of external hazards. It is necessary to do so, but only introducing more sophisticated risk-informed methods is not the final answer.

Fig. 1 shows an overview of the safety management based on a probabilistic concept of risk, which is a combination of the scale and probability of damage. A certain risk limit can be chosen as the curve shown on the scale-probability plane in the figure. If the system status is located above this curve, one must make all efforts to reduce the risk. Even if the system status is located below the curve, however, it does not mean that the risk has vanished. The risk that still remains after having satisfied the risk limit is called the residual risk. We also have to deal with the residual risk after having satisfied the risk limit. Occurrence of an unanticipated event often leads to reduction of the risk limit and then to elevation of safety regulation, but this process is an endless loop. Management of the residual risk is performed by risk retention and risk transfer, which are often out of the scope of ordinary safety regulation, and the strategy of their application is to be established.

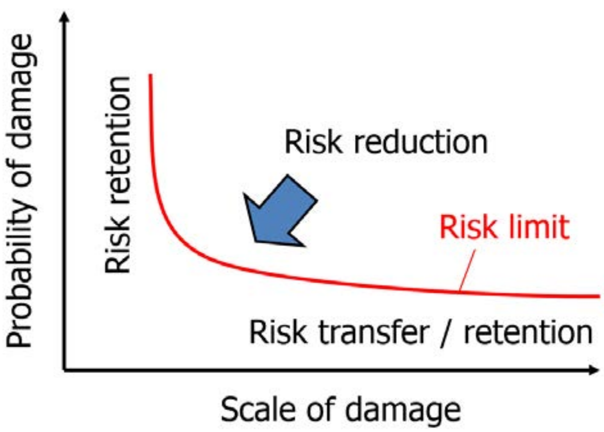

Fig. 1. Safety management based on a probabilistic concept of risk.

Renovating deterministic approaches following the defense-in-depth principle will be a key. After *Fukushima*, the Nuclear Regulation Authority (NRA) of Japan enforced new regulatory standards for commercial power reactors in July 2013. The new standards request enhancement of design basis, protection against earthquakes and tsunamis, and new requirements for severe accidents. In order to fulfil the standards, Japanese utility companies are now taking remedial actions to their plants and installing various safety measures such as follows, and these measures are in line with enhancement of defense-in-depth rather than introducing new principles.

- Reevaluation of the maximum scale of earthquakes and tsunamis;
- Installation of watertight structures and countermeasures against submerging;
- Reinforcement of emergency power supply;
- Reinforcement of emergency water supply including that for spent fuel pits;
- Prevention of reactor containment vessel damage, e.g., installation of filtered containment venting;
- Preventing dispersion of radioactivity.

WHAT CHANGED AFTER FUKUSHIMA

All-Hazards and Multiple Disasters

Though the basis of nuclear safety did not change even after *Fukushima*, some problems have emerged that caused the lack of defense-in-depth. We should learn lessons on these points and reflect them in taking concrete measures for safety enhancement.

Firstly, we must be concerned more about preparedness for all-hazards and multiple disasters than had been. The safety barriers against tsunamis were very fragile, because people in the nuclear industry were so concerned about seismic motion that less attention was paid to the risk of tsunamis. Almost all of the equipment for emergency power supply and emergency water injection are located below the ground level, because the location is the best for protecting them from seismic motion. Such consideration, however, did harm for protecting them from tsunamis. We should have been more concerned about natural disasters other than seismic motion.

The backup systems against station blackout were insufficient, because the reliability of power grid is extremely high in Japan and station blackout for a long period of time was unthinkable before *Fukushima*. The multiple disasters over a very wide area after *Tohoku Earthquake* easily denied such expectation and the external power supply from the grid became completely unavailable. Relying just on the quality of power grid is vulnerable in front of such multiple disasters.

Preparedness for all-hazards, unrestricted to natural disasters, is now a critical issue of nuclear safety in Japan after *Fukushima*. Aircraft crashes and terrorists' attacks should be considered also. Progress of these events may easily exceed the conventional event scenarios, and it is difficult to take preventive countermeasures to achieve prescribed design bases, in particular by installing some hardware equipment. It is therefore unsuitable to cover all these hazards by safety regulation. Meteorite strikes are out of the scope of design bases at present, but some response scenario should be imagined as an unforced activity. What can we do if most of the plant staff are down due to pandemic?

Administration of Emergency Response

Secondly, we should attend more to the administration of emergency response rather than preventive measures with hardware equipment. While no casualties from radiation exposure have been reported, many people died during or just after evacuation due to improper evacuation planning and operation in *Fukushima*.

An offsite center, which is expected to be the local headquarter of nuclear emergency response, was constructed in each area of major nuclear facility sites after *JCO*. But the offsite center in the Fukushima area did not function at all due to the blackout and a high radiation dose. The administrator failed to collect monitoring data of radiation dose and could not use SPEEDI (System for Prediction of Environmental Emergency Dose Information) for decision-making in evacuation planning, in particular for deciding which areas to be evacuated. In addition, information sharing was so poor between different organizations such as TEPCO, the central government, Self-Defense Force, police, and the local governments, that evacuation planning and operation were carried out on an ad hoc basis. The most symbolic and miserable case of the consequence from the poor administration was 50 deaths in the evacuee patients from the Futaba Hospital.

The disaster described above could have been avoided if we had elaborated the administration of emergency response considering accident scenarios that really match the crisis. Different from engineering design of hardware equipment, however, no systematic or technical design methods have been established for the administration of emergency response. Techniques for optimal planning or normative decision-making have been developed in Operations Research and applied to emergency response problems such as evacuation planning. Most of them do not work in ill-structured situations of emergency, because they rely on complete and accurate information to set up mathematical models and obtain solutions. In addition, the conventional mathematical methods cannot deal with organizational interactions, which play a very important role in emergency response as described so far. Some new approaches of administration design therefore are expected such as agent-based organizational simulation or application of bio-inspired design of complex social systems.

ENHANCING RESILIENCE

Resilience, which is the ability of a system to absorb changes and to maintain its functionality, has attracted interests of experts in many areas after *Tohoku Earthquake* and *Fukushima*. While the conventional safety design of artifacts focuses just on the within design-basis region, resilience sheds light also on the beyond design-basis regions. Resilience of a system is often represented by the speed of recovery from a degraded state of system functionality after a crisis. It is, however, multifaceted features of a system, and Woods enumerated the following four essential characteristics of resilience:

- Buffering capacity: the size or kinds of disruptions the system can absorb or adapt to without a fundamental breakdown in performance or in the system's structure;
- Flexibility: the system's ability to restructure itself in response to external changes or pressures;
- Margin: how closely or how precarious the system is currently operating relative to one or another kind of performance boundary;
- Tolerance: how a system behaves near a boundary, whether the system gracefully degrades as stress/pressure increase, or collapses quickly when pressure exceeds adaptive capacity.

Following his proposal, Fig. 2 shows a summary of how the safety enhancement measures adopted in Nuclear Power Plants (NPPs) before and after *Fukushima* contribute to enhancing resilience. The conventional within design-basis approaches of safety design are for enhancing margin. Accident management is a typical enhancement measure of tolerance for beyond design-basis events. Nuclear disaster prevention appears at two places in this figure, tolerance and buffering capacity. The scale of disaster differs between the two and they correspond respectively to the 4th and 5th level of defense-in-depth. Buffering capacity is related to the recovery process from damaged conditions after a disaster, while flexibility contributes to the improvement above the previous performance level by organizational learning and reengineering. The remedial actions undertaken by the utility companies for satisfying the new regulatory standards can be classified in the same manner.

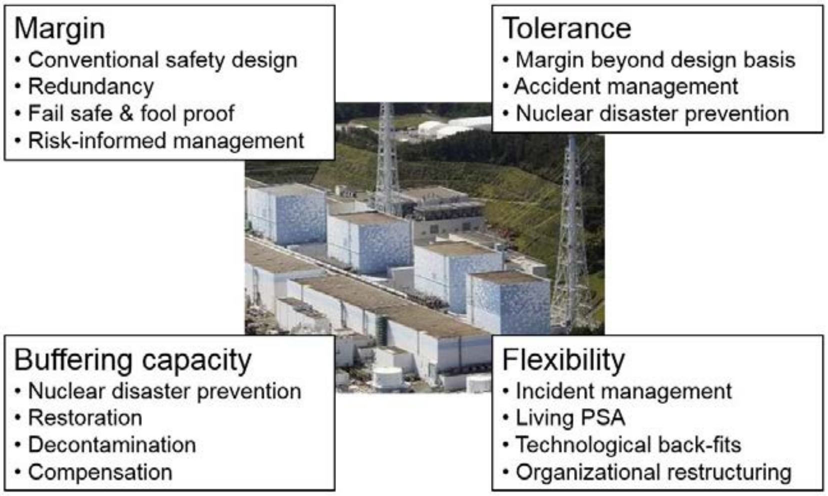

Fig. 1. Resilience enhancement measures in Nuclear Power Plants.

THREE CATEGORIES OF UNSAFE EVENTS

Though the basic strategy of nuclear safety has not changed even after *Fukushima*, now we are requested to deal with a wider scope of events including beyond design-basis. This situation is described in Table I, where unsafe events that occur in NPPs are classified into three categories.

The author made the original version shortly after *JCO*. Category 1 corresponds to unsafe events of relatively a high frequency and low consequence and they do not differ from work accidents in the ordinary industries. The risk of these events can be evaluated statistically and remedial actions are taken in ergonomics and work management. In contrast, Category 3 includes design basis events of a low frequency and high consequence and they are unique to the nuclear industry. The countermeasures for this category are evaluating their risks theoretically and installing some engineering safety features. Category 2 is a new type of unsafe events that emerged in the past decades. This category includes complex events of systemic or organizational accidents, and they sometimes exceed the design bases.

Table I. Three categories of unsafe events.

	Category 1	**Category 2**	**Category 3**
Manifestation	Work accidents or single failures	Systemic or organizational accidents	Design basis events or anticipated incidents
Frequency	Relatively high	Extremely low	Very low
Scale of damage	Local and limited	Medium ~ devastating	Devastating
Primary victims	Interested people	Interested people and/or third party	Interested people and/or third party
Complexity of scenarios	Simple	Complicated and non-linear	Complicated but linear
Variety of scenarios	Diverse but classifiable	Extremely diverse	Limited and finite
Quantitative risk assessment	Statistically possible	Impossible	Theoretically possible
Safety goal	ALARP*	ALARP*	Absolute risk limit
Countermeasures	Quality assurance and work management	Systems approach	Engineered safety features
Trade-off with economy	Compatible	Partly compatible	Conflicting
Status in nuclear industry	Already resolved	Unresolved	Already resolved

* ALARA: As Low As Reasonably Practicable

A locus of interest will be the trade-off with economy. Since NPPs are protected from Category 3 events with engineered safety features, most of which are out of service during the normal operation, their enhancement conflicts with the plant economy. In contrast, safety enhancement measures for Category 1 events often contribute also to the improvement of efficiency and productivity of works, and they can be compatible with the plant economy. It differs from the natural image that safety and economy are in a trade-off relationship. Those for Category 2 are located between the both, i.e., if safety enhancement measures using engineered safety features are necessary, the investments are costs. Otherwise, they are sometimes compatible with the plant economy.

When this table was created a term of resilience was unknown among the community of nuclear safety, but now it has become clear that enhancement of resilience contributes to solving a problem how to prevent and mitigate Category 2 events. General principles as well as practical methods, however, to do so are not yet enough established, and resilience engineering should challenge to solve this issue.

CONCLUSIONS

The Fukushima Daiichi accident was caused mainly by the breach of defense-in-depth against tsunamis, which is the very basis of nuclear safety, and it is unnecessary to substitute it with a new concept. The accident rather showed that defense-in-depth is effective even in unanticipated emergency conditions of beyond design-basis, and the remedial actions now undertaken by the utility companies in Japan are in line with the principle. It must be taken into consideration, however, that the breach occurred due to insufficient preparedness for all-hazards and multiple disasters. The administration of emergency response rather than preventive measures by hardware equipment should be more concerned about than before. Enhancing the resilience and renovating the defense-in-depth of NPPs are crucial and Category 2 unsafe events will be the targets of these efforts.

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Abergel

Consequences of severe nuclear accidents on social regulations in socio-technical organizations

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Abstract
Major nuclear accidents have generated an abundant literature in the social sciences. They are the source of many key concepts that have led to studies of the organization and its links to system safety. Social psychology and sociology have shown that such bodies have their own modes of organization, while resilience engineering has hypothesized that they have the capacity to learn from the past and anticipate potential causes of serious damage. This paper revisits some major contemporary accidents, notably the accident at the Fukushima Daiichi nuclear power plant, through an analysis of the resilience capacity of systems in terms of the sociology of organizations and especially, social regulation.

Keywords: industrial disaster, social regulation, resilience engineering, negotiation, independence

INTRODUCTION

The major industrial accidents of the 20th and 21st centuries have been the source of a variety of interpretations. Technological causes initially held the top spot. However, it was subsequently agreed that human factors were a major cause of disaster in these complex technological systems leading, ultimately, to the idea that the causes of accidents could be found at the organizational level. Here, we do not offer an exhaustive overview of work that has modernised performance factors at the organizational level in at-risk industries; instead we present arguments from the sociology of organizations in order to better understand how the day-to-day work of organizations complements or substitutes what is prescribed, either to adapt to operational necessities, or in an emergency. In other words, is post-accident management possible based on “safety in action”, which finds its foundations the negotiation of prescribed regulations, what de Terssac (1) describes as a consequence of social regulation (2).

The arguments used in this article are based on a reinterpretation of major industrial accidents in terms of the sociology of organizations; in particular we aim to establish bridges between knowledge of the organization’s operations, and the restructuring of organizational ecosystems during the management of a crisis. We argue that modes of social regulation that enable prescriptive orders to be adapted to the daily work of organizations can play a positive role in the capacity of systems to anticipate and adapt, which in turn creates resilience.

This paper begins with a brief review of some major industrial accidents in order to highlight the main phases of research in the social sciences. It discusses the contribution of the sociology of organizations, particularly the French school of strategic analysis and social regulation, which examines *in fine* the role of social regulation in understanding both operational systems and the post-accident period.

MAJOR INDUSTRIAL ACCIDENTS AND CHANGING PARADIGMS

The major accidents that have occurred over the past four decades have changed the research paradigms used in risk management. They have influenced industry practice both in terms of analytical tools and management culture. The engineering culture that dominated safety decisions opened a door to the humanities and led to the development of cross-cutting approaches that could address system complexity. This section presents a brief history of this evolution.

The industrial accident at Three Mile Island (TMI) was the origin for a profound examination of the organizational dimension of accidents (although it did not lead to work on prescriptive organizational design). Perrow (3) describes complex systems with a high potential for disaster and highlights the systemic dimension of accidents in tightly coupled systems where trivial errors can interact and lead to an unwanted event. However, according to Perrow (3) these systems only concern the ‘normal’ accident. This unacceptable sociological approach, in a society where risk management is a corollary to technology, was nevertheless, the starting point for the growing interest of sociologists in at-risk organizations.

This appeal to the sociologists of organizations would be reiterated by Reason (4). Having observed the limits of engineering and cognitive science in understanding the Chernobyl accident, he used theories from sociology in order to understand and track the latent errors that hide at all levels of the system and (using the cancer model), interact with one last operator, resulting in disaster. Reason’s well-known ‘Swiss Cheese’ model would lead to the development of many audit methods that aimed to detect weaknesses in the system. The Tripod method (5) is one example.

Moreover, the Chernobyl accident was the origin of the concept of safety culture (6) and would lead to further work on its definition in both high-risk organizations and industry in general. The importance of the safety culture concept would be widely discussed and the source of many industrial initiatives. This was the case in France, where the creation of the *Institut pour une Culture de Sécurité Industrielle* [Institute for an Industrial Safety Culture] followed the AZF accident on 21 September 2001.

These wide-ranging conceptual developments, which attempted to limit major disasters, are marked by the creation of methodologies for the observation of high operational reliability in organizations, in order to understand their characteristics and eventually design prescriptive operational principles. The emergence of High Reliability Organizations (HRO) (7) in the 1990s was a major advance on Perrow's work and the fatalistic vision of the 'normal' accident. However, despite an unprecedented observation methodology, researchers themselves were forced to admit that it was not possible to develop a theory of HROs, although they constitute an important set of case studies on high-risk, high reliability organizations. Nevertheless, this work has served as the basis for many industrial studies by organizations that want to change and improve their level of safety culture, for example in the oil sector.

In the 2000s, resilience engineering would once again change perceptions of safety systems. Hollnagel (8) argued for the understanding of the day-to-day operation of systems, through the study of system successes rather than failures. This understanding of the capacity of a system to anticipate an accident and to react to adverse events constituted an important development in the management of at-risk systems and major accidents.

The aim of these various currents of research was to provide a better understanding of at-risk systems during both routine operations and in times of crisis. The work of sociologists would lead to the emergence of established concepts from the sociology of organizations. The next section presents a summary of French research, in particular the school of social regulation, which emphasises the negotiated dimension of safety systems.

THE SOCIOLOGY OF ORGANIZATIONS AND AT-RISK INDUSTRIES

In the late 1990s, Bourrier (9) carried out a study of American and French nuclear plants. This study would conclude that, far from being HROs, nuclear power plants were normal organizations, given what was known about the sociology of organizations. Specifically, normal organizations are the result of the negotiations and strategies undertaken by their actors. Such organizations may be the source of virtuous ecosystems, although their managers may not be aware of it.

We also found, in our study of the decommissioning of a nuclear plant, that the plant's informal organization may be relevant driver of safety (10).

In the French school of the sociology of organizations, this dimension of an organization that does not fully meet the prescribed, formal requirements of managers is well-known. Crozier and Friedberg developed and demonstrated a theory concerning the strategies of actors and power relations in organizations (11). The work of de Terssac (1), particularly following the explosion of the AZF factory in France, refers to the negotiated dimension of safety in relation to social regulation theory. This theory argues that rules can be revisited and that they are the result of negotiations between actors. They structure collective action, while independent initiatives can create conflict with external controls. How the system is regulated become the result of compromise and negotiations between these two forms of regulation.

The analysis of de Terssac (1) highlights the development of everyday safety in a factory, beginning with negotiations between workers and supervisors. It clarifies what he calls "safety manufacture", which does not depend on prescriptive procedures that explain what safe behaviour is, but is the result of rules that are supplemented and negotiated by users. For the author, "safety in action" is the ability to decide whether (or not) to apply a safety rule and adapt it to the context. Different actors in the organization will have different ideas of safety that are linked to their role in the company. Safety culture results from the comparison of these different ideas.

An at-risk organization is not therefore fundamentally different to a normal organization, although it has its own characteristics. The study of such organizations simply considers that during normal operations, what is prescribed has been negotiated and adapted to the situation on the ground, and that these adjustments are part of the daily life of the organization.

It therefore seems appropriate to ask whether maintaining this shared safety culture after a major accident is an element of system resilience. Specifically, do negotiated rules make the organisation better able to anticipate and adapt or, on the contrary, must the organization resort to extremely strict procedures to manage a major disaster?

The Fukushima Daiichi accident required rules to be adapted to the realities of the situation regardless of the procedures to be followed in an emergency. The next section highlights the decisions taken by the plant's Director in the application of the venting procedure and cooling the reactors with seawater. We show that in a post-accident situation, assessments of procedures are a function of the context, notably with respect to the positions occupied by actors.

FOLLOWING THE RULES, POST-ACCIDENT

In a crisis, where nothing corresponds to any previous situation, it seems foolish to guide behaviour with reference to known procedures. The management of the Fukushima Daiichi crisis showed that certain actions taken by the plant's crisis unit and its Director were taken in the light of their knowledge of the status of the system – and that their understanding was different to that of governmental authorities and TEPCO (12). During the hearings that followed the accident, the plant's Director stated that technical problems were encountered during the venting procedure that even he was not able to grasp because the crisis unit was too far away from where the action was happening. Therefore, he initially tried to follow instructions from headquarters, given the difficulty of the situation and delays in executing procedures.

"*Yes, but at that moment, it was the first time for me as well that I found myself confronted with such a situation, and, to be very honest, I didn't even understand it myself. We didn't yet know the details of the situation on the ground. And in that, we were in the same position as the people at headquarters. Of course, on the ground, they couldn't see the indicators in the control room any more – they were in the dark, all the main instruments were off, but we were under the impression that if they were set to vent, this could happen. Of course, there was no electrical power supply, or air supply, but bizarrely, we were completely convinced that in order to vent all we had to do was open a valve, that if we could open this valve, it would work. We only understood afterwards. The AOV had no air. Naturally, the, MOV did not work either. We wondered if we could do it manually. But there was too much radioactivity for us to go in. And that's where we finally realized how difficult it was. But we could not get the message across to the head office or Tokyo, get them to see how difficult this venting was*" (12).

Although the order to vent would be repeated by the government, it would be repeatedly delayed because the levels of radioactivity made it impossible to access the valves. The Director then realised the differences between the people at head office and the situation on the ground, and that the order could not be executed. He therefore adapted the procedure, taking into account the state of the system at the time. Later in the hearing, he spoke of the distance that was created between headquarters and plant staff. The same problem also existed at the plant itself – between the crisis unit, the control centre and shift teams who had to manually carry out the venting and who would be exposed to the high levels of radioactivity. It was this distance that led the Director and his team to take important decisions without the approval or authorization of headquarters. These actions included the decision to cool reactors with seawater.

The hearing indicates that preparations were carried out much further upstream than the strict chronology of events would suggest. Knowledge of the system status necessitated the use of a cooling source that was available in large quantities. The only option was the on-site seawater. Independent of any discussions with headquarters, the plant's staff prepared to execute the order.

"*Here, it's not really a case of 'continue'. To be really precise, we began preparations for this seawater injection well before 2:54 p.m. This means that the order to prepare the injection was given well before then. But it was at that time that the preparations were completed and the injection became possible. This is why I gave this order, which was more like an order to implement that an order to prepare, if I remember correctly. Except, this is when the explosion occurred. We could not move to implementation and we ended up back at the beginning. What is clear is that the order to look at how to inject seawater was given at an earlier stage.*" (12, p. 169).

While TEPCO's management were aware of the intentions of the plant's Director and the crisis unit, they did not take part in any discussions or decisions about pumping procedures or water transport. Only on-the-ground personnel knew what resources were available and how to adapt them to the situation. Furthermore, after an initial attempt, the order was given to suspend the manoeuvre; the Director decided to continue, but did not reveal his decision to headquarters.

"*So we had ended the test and we were going to stop. It had been decided to stop. It was only me, arriving at this point, I had no intention of stopping the injection of water. Furthermore, they were talking about stopping, but we didn't even know how long it would go on for. They could have said thirty minutes, or more. But stopping with no guarantee of recovery. For me, there was no question of following such an order. I decided to do it my way. So I announced to the people at the crisis table that we would stop, but I quietly took the 'safety' group leader to one side, XXXXX, which was in charge of the injection and I told him that I was going to announce to anyone who would listen that we would stop the injection, but that he, at all costs, must not stop sending water. Then I prepared a report for headquarters to say that we'd stopped*" (12, p.188)

This manoeuvre was also hidden from certain members of the crisis unit. This suggests that amongst the network of actors in the field, there were some who would execute orders from the Director, which were not in line with the instructions issued by headquarters. This indicates that the internal authority of the Director was such that members of the safety group would follow his orders rather than instructions from headquarters.

The procedure implemented at this time was therefore based on the capacity to find technical solutions in an emergency situation and networks of actors who shared the Director's beliefs. These networks of actors were responsible for the production of the rules that were applied at the time.

In a crisis, social regulation takes places in compressed time; it is the result of negotiations between headquarters, supervisory and government authorities and independent regulators. The decisions of the Director could only be translated into action with the consent of his team, through a process of negotiation. This is reflected in both the venting procedure (that would be delayed several times for technical and human reasons) and the decision to inject seawater, which was the subject of an internal search for technical solutions and led to the decision to carry on with the action against the orders from headquarters.

DISCUSSION

From the perspective of the sociology of organizations, the reinterpretation of major accidents and particularly the accident at the Fukushima Daiichi nuclear power plant leads to questions about respect for rules and procedure in crisis management. We argue that a crisis should not cause the strict application of control regulations that are the result of procedures that were established in advance. Decision-making and the rules that apply should be the result of negotiations between decisions taken by headquarters and independent, on-the-ground regulation that takes into account the context.

An analysis of the in-depth feedback from the Fukushima Daiichi accident suggests that the capacity of the plant's teams to find new solutions to deal with the various problems is wholly characteristic of the HRO as described by Weick and Sutcliffe (13). In other words, an organization that is able to identify and anticipate failure, overcome *a priori* assumptions, and comply with (or defer to) authority and expertise based on experience and intuition. While all of this may be true, it also seems necessary to understand the negotiation processes and power relations internal and external to the group in order to understand its actions. We argue that the social regulation dimension in a constrained timeframe exists, and is the result of negotiations that enable collective action.

Moreover, it appears that there was a significant bias in the analysis of a decision that was temporarily successful. de Terssac's (1) safety paradox states that it is possible to act safely and still not avoid disaster. This leads us to believe, given the limited rationality of actors, that rules that are negotiated in periods of normal operation or crisis may also lead to disaster (which was the case for the AZF accident in particular).

CONCLUSIONS

The aftermath of accidents does not prevent social regulation processes, which appear to be constrained by time and the emergency. Negotiations between actors occur despite conflicting interests and value systems – in this case, protecting the population, making decisions in line with international expectations, and protecting equipment and the workforce.

All of these interests are the subject of negotiations that create cooperation (or in some cases conflict) between actors in the system. We are therefore far from the situation where safety in a crisis is governed by universal basic procedures, or the intervention of a providential hero. The resilience capacity of a system is based on its capacity to adapt, and therefore knowledge of the dynamics governing the relationships between its actors.

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Philosophical problems, old and new, posed by the possibility of major nuclear disasters

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1. Powerlessness of the Calculus of Chances (= Probability Theory)

- Infinitesimal probabilities, momentous consequences;
- "Fractal" distributions;
- "Planning the Unthinkable".

2. Sorites (Heap) Paradox

- The nagging issue of the consequences of "small doses" (see Appendix 1.)

3. The Real, the Imaginary, and the Symbolic

- The symbolic and imaginary dimensions of the Fukushima triple disaster (see Appendix 2;)
- Fukushima as Hiroshima 2.

4. Counterfactual Consequences

- The consequences that *might have* occurred: 3-Mile Island or Fukushima as Chernobyl;
- Concept of "Near Miss".

5. The Invisibility of Evil and Blindness to the Apocalypse

- An Illichian analysis of a nuclear disaster;
- Günther Anders on the discrepancy between what we can do/make [*herstellen*] and what we can "think" or represent to ourselves [*vorstellen*].
- Hannah Arendt on thoughtlessness.
- Hans Jonas' two principles: Principle of Responsibility and Principle of Precaution.

6. The limits of Consequentialism

7. Phenomenology of Contaminated Life

- The inversion of the concept of ruins;
- Contaminated nature as virgin nature;
- Obsession with the past or freedom through oblivion;
- Inhuman temporal scales;
- Etc.

Appendix 1
Variations on the Sorites Paradox

I) Basic structure:

(1) $A + \mathbf{v} = A$
(2) $N \textit{ times } \mathbf{v} = X > \mathbf{v}$
(3) $N \textit{ times } 0 = 0$

v is the symbol for a "*vanishingly small*" quantity. Added to a finite quantity A, we still get A. This is what (1) is saying.

Illustration (John Allen Paulos, an important American mathematician, in November 2000, in the context of the Gore-Bush recounting of votes).

This the story of a museum guard who would inform visitors that the dinosaur on display was 70,000,006 years old.

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> One day, a little girl challenged his number. Seventy million and six? How did he know for sure?
>
> The guard looked down and explained, "When I took the job, they told me it was 70 million years old. And that was six years ago.
>
> ***A 70-million-year-old T-Rex is still 70 million years old 6 years later***. That's what the equation (1) is saying.
>
> Paulos used that tale to illustrate the absurdity of arithmetic precision in the face of margins of error. Al Gore's mistake in the Fall of 2000 was to have ignored this logic.

N is an integer sufficiently large – potentially infinite – for the product of N and **v** to be a non-vanishingly small quantity, X.

(3) is true since any number multiplied by zero gives zero.
At first sight (1), (2), and (3) seem to make up an inconsistent set of axioms. (1) seems to be saying that **v** is indistinguishable from zero while (2) and (3) cannot be true at the same time if **v** is equal to zero. Those 3 axioms are made *compossible* in the framework of what Skolem, Paulos and others called *non-standard arithmetics*.

II) The *Sorites* Paradox

Suppose that A hairs make a man bald but [A+X] hairs make him non-bald.

However, A + X = A +N *times* v = A + **v** + **v** …. + **v**, with N "+" symbols.

Now perform each of the N additions *one by one*. You never take off from A, because of (1). That's the Sorites paradox.

III) The Chernobyl Paradox

v is an incremental probability – increase of the a priori probability of dying of leukemia, say, because of the Chernobyl disaster. N is the population affected. My estimate of N times **v** is of the order of magnitude of tens of thousands.

For the ten million minus 800,000 people living in the contaminated zone and submitted to small doses of Strontium-90, Caesium-137 and Plutonium-239, the official count of casualties arrived at by the Chernobyl Forum was Zero, in spite of its declared adherence to the proportional (= "linear without threshold") model.

It is as if the Chernobyl Forum had decided that **v** was indistinguishable from zero – and this, in the final instance, because of (1); as though, in other terms, they had thought that, since one is either dead or alive, to be one thousandth of one percent dead was equivalent to being alive.

It is true that one is either dead or alive – except poor Schrödinger's cat. This reference is not innocent. It turns out that non-standard arithmetics and non-standard probability theory – the one that conforms with quantum information theory – are related.

At any rate, it is thus shown that the Sorites paradox and the Chernobyl paradox derive from the same paradoxical structure.

Appendix 2

The symbolic and imaginary dimensions of the Fukushima disaster

In 1958, the German philosopher Günther Anders traveled to Hiroshima and Nagasaki to take part in the Fourth World Conference against Atomic and Hydrogen Bombs. After many conversations with survivors of the catastrophe, he noted in his diary: "Their steadfast resolve not to speak of those who were to blame, not to say that the event had been caused by human beings; not to harbor the least resentment, even though they were the victims of the greatest of crimes—this really is too much for me, it passes all understanding." And he added: "They constantly speak of the catastrophe as if it were an earthquake or a tidal wave. They use the Japanese word, *tsunami."*

At about the same time as Hannah Arendt, a fellow student at Marburg whom he later married and divorced, Anders sought to identify a new regime of evil. Arendt spoke of Auschwitz, Anders of Hiroshima. Arendt had diagnosed Eichmann's psychological infirmity as a "lack of imagination." Anders showed that this was not the failing of one human being in particular, but a weakness common to all human beings when their capacity for acting, which includes their ability to destroy, becomes disproportionate to the human condition. In that case evil acquires a power that is independent of the intentions of those who commit it. Both Anders and Arendt probed the scandalous reality that immense harm may be caused by a complete absence of malignity; that a monstrous responsibility may go hand in hand with an utter absence of malice. Our moral categories, they discovered, are powerless to describe and judge evil when it exceeds the inconceivable. "A great crime offends nature," Arendt observed, quoting the legal scholar Yosal Rogat, "so that the very earth cries out for vengeance; that evil violates a natural harmony that only retribution can restore." The fact that European Jews have substituted for "holocaust" the Hebrew word *shoah*, which signifies a natural catastrophe—specifically, a tidal wave, or tsunami—attests to the urge to naturalize evil when human beings become incapable of imagining the very thing of which they are the victims and the cause.

The tragedy that struck Japan on March 11, 2011 seemed suddenly to have stood this image on its head: an actual tidal wave, the most tangible and unmetaphorical wave imaginable, now awakened the nuclear tiger. In this case, of course, the tiger was caged. An electronuclear reactor is not an atomic bomb; indeed, it is in a sense the opposite of one, since it is meant to control a chain reaction that it itself has triggered. In the realm of the imagination, however, a negation affirms what it denies. In reality, the other realm that we inhabit, the tiger escapes from its cage from time to time. And in Japan, more than elsewhere, the military and peaceful uses of nuclear energy cannot help but be linked in the public mind. "The earthquake, tsunami, and the nuclear incident have been the biggest crisis Japan has encountered in the sixty-five years since the end of World War II," the prime minister, Naoto Kan, told the nation. Sixty-five years ago, there were no nuclear reactors. But two atomic bombs had already been used against civilian populations. In uttering the word "nuclear," this, no doubt, is what the prime minister meant his listeners to recall.

It is as though nature rose up before mankind and said to it, from the terrible height of its forty-five-foot surge, "You sought to conceal the evil that lives inside you by likening it to my violence. But my violence is pure, impervious to your conceptions of good and evil. How should I punish you? By taking you at your word when you dare to compare your instruments of death with my immaculate force. By tsunami, then, you shall perish!"

The human and physical destruction in Japan has not come to an end. To a large extent the tragedy is being played out on the stage of symbols and images. Among the places first to be evacuated in the Pacific were the Mariana Islands. The name of one of these, Tinian, should remind us that it was from there, in the early hours of 6 August 1945, that the B-29s took off on their mission to reduce Hiroshima to radioactive ashes, followed three days later by another wave of bombers that was to visit the same devastation on Nagasaki—as if the gigantic tide unleashed by the earthquake last month was sent to wreak vengeance on this speck of land for having given sanctuary to the sacred fire.

The special fascination of the tragedy that still continues to unfold in Japan today derives from the fact that it joins together three types of catastrophe that we have long been accustomed to keep separate: natural disaster, industrial and technological disaster, and moral disaster—Tsunami, Chernobyl, and Hiroshima, as one might say. This blurring of traditional distinctions, which can now be seen as the outstanding characteristic of our age, is a consequence of two countervailing tendencies that have collided in the Japanese archipelago. One of them, the naturalization of extreme evil that I mentioned in connection with Arendt and Anders, grew up with the horrors of the previous century. The other arose in the wake of the first great tsunami to leave its mark on the history of Western philosophy, the deluge following the earthquake that struck Lisbon on All Saints Day in 1755. Of the various attempts to make sense of an event that astounded the world, Rousseau's reply to Voltaire ultimately prevailed. No, Rousseau said, it is not God who punishes men for their sins; and yes, he insisted, a human, quasi-scientific explanation can be given in the form of a connected series of causes and effects. In *Émile* (1762), Rousseau stated the lesson of the disaster: "Man, look no further for the author of evil: you are he. There is no evil but the evil that you do and that you suffer, and both come from you."

Proof of Rousseau's triumph is to be found in the world's reaction to two of the greatest natural disasters in recent memory: the Asian tsunami of Christmas 2004 and Hurricane Katrina in August of the following year. For it is precisely their status as *natural* catastrophes that was immediately challenged. The *New York Times* reported news of the hurricane under the headline "A Man-Made Disaster." The same thing had already been said about the tsunami, and with good reason: had Thailand's coral reefs and coastal mangroves not been ruthlessly destroyed by urbanization, tourism, acquaculture, and climate change, they would have slowed the advance of the deadly tidal wave and significantly reduced the scope of the disaster. In the case of New Orleans it turned out that the levees constructed to protect the city had not been properly maintained for many years and that troops of the Louisiana National Guard who might have helped after the storm were unavailable because they had been called up for duty in Iraq. The same people who later questioned the wisdom of building a city on marshland next to the sea now wonder why the Japanese should have thought they could safely develop civilian nuclear power, since geography condemned them to do this in seismic zones vulnerable to massive flooding. The lesson is plain: humanity, and only humanity, is responsible, if not also to blame, for the misfortunes that beset it.

In addition to moral catastrophes and natural catastrophes, there are industrial and technological catastrophes. Here human beings are quite obviously responsible, unlike in the case of natural disaster; but, unlike in the case of moral calamity, it is because they wish to do good that they bring about evil. Ivan Illich gave the name “counterproductivity” to this ironic reversal. Illich foresaw that the greatest threats are now likely to come, not from the wicked, but from those who make it their business to protect the general welfare. Evil intentions are less to be dreaded than the good works of organizations like the International Atomic Energy Agency, whose mission is to promote “peace, health, and prosperity throughout the world.” Antinuclear activists who believe they must accuse their adversaries of malevolence and perfidy fail to grasp the true situation facing the world. It is a matter of far graver concern that the managers of the immensely powerful systems and machines that threaten mankind are able and honest people. They cannot understand why anyone would think of attacking them, or blame them for doing anything wrong.

I have reserved for last the most grotesque of these catastrophes, which is economic and financial. The vast global market that dominates nations today is a dumb and craven beast that takes fright at the slightest noise and in this way brings about the very thing that it shrinks from in terror. The monster has already seized Japan in its grip. It knows Japan well. In the late 1980s, Japan’s market capitalization accounted for half of the market capitalization of the world’s economies. Some feared at the time that the land of the rising sun would soon rule over the entire planet. Yet the monster would not allow it, and two decades passed before its victim could lift its head again. Today it senses that the nuclear industry, perhaps the only industry on earth incapable of recovering from a major catastrophe, has been thrown back on its heels. The monster will not let go.

5.3. Session 2 (1:00-3:00 pm): Measurement of Damages

Objectives of the session: Now that we have developed definitions for damages after a severe accident, which are multifaceted, we need to have accurate and effective methods to measure those, as situations evolve rapidly in the aftermath. In this session, speakers introduce currently on-going efforts for applying qualitative/quantitative methods, followed by panel discussions to explore effective integration and application in decision-making process.

- Session Chair's remark (1:00-1:10 pm): Dr. Jens Birkholzer (LBNL)
- Speaker 6 (1:10-1:25 pm): Dr. Haruko Wainwright (LBNL), A Multiscale Bayesian Data Integration Approach for Mapping Radionuclide Contamination
- Speaker 7 (1:25-1:40 pm): Prof. Tatsuya Itoi (U. Tokyo), Challenges for Nuclear Safety from Viewpoint of Natural Hazard Risk Management
- Speaker 8 (1:40-1:55 pm): Prof. François Levêque (MPT), Evaluation of the expected costs of nuclear accident
- Speaker 9 (1:55-2:10 pm): Prof. Ryoichi Komiyama (U. Tokyo), Considering nuclear accident in energy modeling analysis
- Speaker 10 (2:10-2:25 pm): Prof. Ryuma Shineha (The Graduate University for Advanced Studies), Measurements of risk perception and social acceptability
- Speaker 11 (2:25-2:40 pm): Prof. Massimiliano Fratoni (UCB, NE), Development of a knowledge management system for energy driven by public feedback
- Discussions (2:40-3:20 pm)

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A Multiscale Bayesian Data Integration Approach for Mapping Radionuclide Contamination

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ABSTRACT
This paper presents a multiscale data fusion method to estimate the spatial distribution of radiation dose rates at regional scale around the Fukushima Daiichi nuclear power plant. We integrate various types of radiation measurements, such as ground-based hand-held monitors, car-borne surveys, and airborne surveys, all of which have different resolutions, spatial coverage, and accuracy. This method is based on geostatistics to represent spatial heterogeneous structures, and also on Bayesian hierarchical models to integrate multiscale, multitype datasets in a consistent manner. Although this approach is primarily data-driven, it has great flexibility, enabling it to include mechanistic models for representing radiation transport or other complex processes and correlations. As a first demonstration, we show a simple case study in which we integrate two datasets over Fukushima City, Japan: (1) coarse-resolution airborne survey data covering the entire city and (2) high-resolution ground-based car-borne data along major roads. Results show that the method can successfully integrate two datasets in a consistent manner and generate an integrated map of air dose rates over the domain in high resolution. A further advantage of this method is that it can quantify estimation errors and estimate confidence intervals, which are necessary for modeling and for robust policy planning. In addition, evaluating correlations among different datasets provides us with various insights into the characteristics of each dataset, as well as radionuclide transport and distribution.

Key words: radiation dose rate mapping, Bayesian hierarchical models, geostatistics

INTRODUCTION

Radiation measurements and monitoring in the region around the Fukushima Daiichi nuclear power plant (NPP) have been performed continuously since the accident [1,2]. Such mapping is essential for protecting the public, guiding decontamination efforts, estimating the amount of decontamination waste, and also in planning the return of evacuated residents. Radiation measurements have been conducted using various techniques such as portable hand-held monitors, car-borne surveys, and airborne surveys. Soil samples have been collected to assess the extent of contamination in the terrestrial environment [3].

Despite such large-scale and continuous efforts, there are still significant challenges in mapping the radiation dose rates and radionuclide contamination. Detailed ground-based measurements have revealed that the radiation dose rates and contamination are both quite heterogeneous, often with many hotspots [4]. Although many datasets are becoming available, it has been difficult to integrate those datasets, since each type of data has a different level of accuracy and represents a different support scale (i.e., spatial coverage and resolution). For example, although ground-based car-borne data provide high-resolution air dose rates, car-borne data are limited to the locations along roads [5]. Airborne surveys have been extensively used to map dose rates in the regional spatial coverage (e.g., 100 km radius) [6]; such data are, however, known to exhibit some discrepancies with co-located ground-based measurements. These discrepancies result mainly from the differences in support volume, since airborne measurements represent the average dose rate over a much larger area (typically a several-hundred-meter radius) than ground-based measurements (~several tens of meters).

In environmental science, monitoring and spatial-temporal mapping of various properties—such as CO_2 concentration, wind velocity or reactive transport properties in subsurface—have been the focus of extensive research. Although many traditional datasets have been sparse in time and space, more recently available datasets can cover large areas, such as remote sensing data in atmospheric/terrestrial sciences and data from geophysical techniques in subsurface science. Such datasets, however, are known to have some discrepancy with traditional point measurements, because they tend to have a larger support volume (or lower resolution), such that each pixel represents the average of heterogeneous properties in the vicinity. Various approaches have been proposed to integrate remote-sensing or geophysical datasets with traditional point measurements [7,8,9]. Many of them are based on geostatistics, a powerful tool for characterizing spatial heterogeneity (or correlation) structure based on available datasets [8,9,10]. In addition, a Bayesian framework is often used to integrate different datasets consistently and also to quantify the uncertainty associated with the estimated maps [7, 9].

In this study, we develop a Bayesian data-integration approach to estimate the spatial distribution of air dose rates and radionuclide contamination in high resolution across the regional scale (several kilometers to several tens of kilometers). We integrate various radiation measurements, with particular focus on airborne and ground-based measurements. Geostatistical approaches are used to identify spatial correlations and represent small-scale heterogeneity that is not resolved in the coarse-resolution airborne data. We employ a Bayesian hierarchical model for integrating the low-resolution airborne data and sparse ground-based data. We demonstrate our approach using the airborne and car-borne datasets collected in Fukushima City, Japan, in 2012. This integration aims to provide a more resolved and integrated dose-rate map, and also quantify the uncertainty associated with the map for modeling and for policy planning.

METHODOLOGY

Our approach is based on a Bayesian hierarchical model [7, 8], which typically consists of three types of statistical submodels: (1) data models, (2) process models, and (3) prior models. The process models describe the spatial pattern (or map) of dose rates within the domain, given the parameters defined by the prior models. Geostatistical models are often used as process models based on the spatial heterogeneity structure identified by available datasets. The data models connect this pattern and the actual data, given measurement errors. These data models can represent, for example, a direct ground-based measurement or a function of the pattern—for example, spatial averaging over a certain area for a low-resolution airborne dataset. The prior models determine the distributions or ranges of the parameters based on pre-existing information. The overall model— a series of statistical submodels—is flexible and expandable, able to include complex correlations (such as correlations with land use, soil texture, or topography) or various observations. Once all the submodels are developed, we can estimate the parameters, as well as the radiation map and its confidence interval, using sampling methods or optimization methods. To fully quantify the uncertainty, here we will use the Markov-chain Monte-Carlo method. When the domain size and the number of pixels are large, optimization-based methods will be used to obtain the mean estimate and its asymptotic confidence intervals.

In this paper, we show one simple example; the integration of airborne and car-borne radiation measurements. We assume that each point of the airborne measurements is the weighted average of radiations from radionuclides distributed over the ground. To develop an integrated map, we denote the radiation dose rate at *i*-th pixel by y_i, where $i = 1, \ldots, n$. We also denote two vectors, representing the airborne data $\boldsymbol{z}_\mathrm{A}$ (each data point is represented by $\boldsymbol{z}_{\mathrm{A},j}$, where $j = 1,\ldots,m_\mathrm{A}$) and car-borne data $\boldsymbol{z}_\mathrm{V}$ (each data point is represented by $\boldsymbol{z}_{\mathrm{V},j}$, where $j = 1,\ldots,m_\mathrm{V}$). The goal is to estimate the posterior distribution of the radiation dose-rate map $\boldsymbol{y}$ (i.e., the vector representing the radiation dose rate at all the pixels) conditioned on two datasets ($\boldsymbol{z}_\mathrm{A}$ and $\boldsymbol{z}_\mathrm{V}$), written as $p(\boldsymbol{y} \mid \boldsymbol{z}_\mathrm{A}, \boldsymbol{z}_\mathrm{V})$. By applying Bayes' rule, we can rewrite this posterior distribution as:

$$p(\boldsymbol{y} \mid \boldsymbol{z}_\mathrm{A}, \boldsymbol{z}_\mathrm{V}) \quad p(\boldsymbol{z}_\mathrm{A} \mid \boldsymbol{y})\, p(\boldsymbol{y} \mid \boldsymbol{z}_\mathrm{V}). \qquad (1)$$

The first conditional distribution $p(\boldsymbol{z}_\mathrm{A} \mid \boldsymbol{y})$ is a data model representing the airborne data as a function of the dose-rate distribution $\boldsymbol{y}$. We assume a spatial weighted averaging function of the dose rate map:

$$z_{A,j} = \sum_{i \in C_j} w_{i,j} y_i + \varepsilon_j. \qquad (1)$$

where C_j represents the pixels within the spatial averaging range, $w_{i,j}$ is the weight determined by the distance between *i*-th pixel and *j*-th airborne data point, and ε_j is an error associated with each data point. We assume an inverse square distance function for the weights, $w_{i,j}$. The range is typically considered to be equal to the flight height, following Torii et al. [6]. We assume that the error ε_j includes not only measurement errors associated with hardware (such as instrument noises) but also the uncertainty associated with other factors (such as the variable height of buildings, small-scale spatial variability). In this example, we assume that ε_j follows an independent normal distribution with zero-mean and the error variance σ_A can be determined from the correlation analysis between two datasets.

As a process model, we assume that $\boldsymbol{y}$ is a multivariate Gaussian field described by geostatistical parameters. For simplicity, we assume that the ground-based measurements have insignificant errors compared to the airborne measurements, and hence we use the ground measurements as conditional points to constrain the distribution of $\boldsymbol{y}$ as $p(\boldsymbol{y} \mid \boldsymbol{z}_\mathrm{V})$. Since two conditional distributions are both multivariate Gaussian, we can derive an analytical form of this posterior distribution as a multivariate normal distribution with mean $\mathrm{Q}^{-1}\boldsymbol{g}$ and covariance Q^{-1}, where $\mathrm{Q} = \Sigma_\mathrm{c}^{-1} + \mathrm{A}^\mathrm{T}\mathrm{D}^{-1}\mathrm{A}$ and $\boldsymbol{\mu} = \boldsymbol{\mu}_\mathrm{c} + \mathrm{A}^T\mathrm{D}^{-1}\mathrm{z}_\mathrm{A}$ [7]. In Q and $\boldsymbol{g}$, $\boldsymbol{\mu}_c$ and Σ_c are the conditional mean and covariance given the ground-based data ($\boldsymbol{z}_\mathrm{V}$) and geostatistical parameters. D is the data-error covariance matrix; each of the diagonal components is σ_A. The matrix A is n-by-m_A sparse matrices, where $\mathrm{A}_{ij} = w_{ij}$ if *i*-th pixel is within the range C_j; otherwise A_{ij} is 0. We may directly sample $\boldsymbol{y}$ or estimate the mean (or expected) dose map by $\mathrm{Q}^{-1}\boldsymbol{g}$. Although the example shown here is quite simple, we may add more complexity, such as, for example, physics-based radiation transport models (instead of weighted averaging) to represent the airborne data or data-derived correlations between dose rates and land use or topography [2].

DEMONSTRATION

In this example, we applied the developed method to the air-dose-rate data collected in Fukushima, Japan. We used the ground-based car-borne data from the second car-borne survey (December 5–28, 2011; http://radioactivity.nsr.go.jp /en/contents/5000/4688/24/255_0321_ek.pdf), as well as the airborne data from the fourth airborne monitoring survey (October 22–November 5, 2011; http://radioactivity.nsr.go.jp/en/contents/4000/3179/24/1270_1216.pdf). We assume that the effect of radiocesium decay is negligible between the two surveys. The airborne data were processed and converted to the values equivalent to the dose rate one meter above the ground surface.

We first compare the co-located data values of the car-borne datasets to the airborne datasets. Direct comparison (Figure 1a) shows significant scatters in the higher dose region, although the datasets are clearly correlated (the correlation coefficient is 0.78). The car-borne data have larger variability (larger variance), suggesting that small-scale variability is averaged out in the airborne data. When we take into account the weighted spatial average for the airborne data (Figure 1b), the correlation improves significantly (the correlation coefficient is 0.84). We would note that the airborne data values are systematically higher than the car-borne ones, with and without spatial averaging. There are several possible reasons for such a shift: (1) there could be calibration issues in the airborne data, and (2) the center of roads (where the car-borne data are collected) is known to have lower contamination than the side of the roads or undisturbed land. For demonstration purposes, we assume that the car-borne data are still accurate representation of the radiation map in this example.

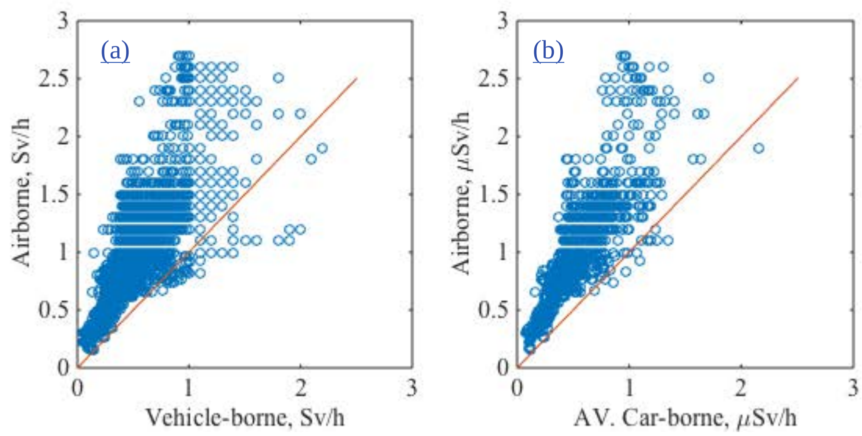

Fig. 1. Comparison between the car-borne data and airborne data: (a) direct comparison of data values and (b) including spatial averaging for the airborne data.

Using the correlation between the airborne and car-borne datasets that we found in Figure 1, we determined the error variance σ_A a well as the shift factor. In addition, geostatistical parameters were estimated based on the variogram analysis of the car-borne datasets, representing the spatial correlation structure of small-scale heterogeneity. Figure 2a shows the airborne survey data in the part of Fukushima; the eastern portion of the domain has higher dose rates, possibly because the area lies along the initial plume direction and is also a forested area. By overlaying the car-borne and airborne data (Figure 2b), we see that the car-borne data show smaller-scale variability than the airborne data, and that the airborne data overestimates the air dose rate. The estimated map (mean field) from the data integration in Figure 2c shows more detailed and finer-resolution heterogeneity than the original airborne data (Figure 2a). The systematic shift in airborne data was also corrected. As shown in Figure 2d, the estimation variance is smaller near the car-borne data points, since the model includes spatial correlation.

Figure 3 shows the validation result to evaluate the performance of the data integration and the dose-rate estimation. One hundred of the car-borne data are excluded from the estimation, and used for validation purposes. Without the data integration, the airborne data (blue dots) have large scatters and a systematic shift compared to the car-borne measured data. After the data integration, the predicted values (based on the both airborne and car-borne data at other locations) are tightly distributed around the one-to-one line and are mostly included in the 95% confidence interval. Figure 3 shows that this method successfully estimates the fine-resolution dose-rate map based on the spatially sparse car-borne data and coarse-resolution airborne data. Having such a confidence interval would be useful for practical applications, such as estimating the range of the potential health effects or estimating the decontamination waste volume.

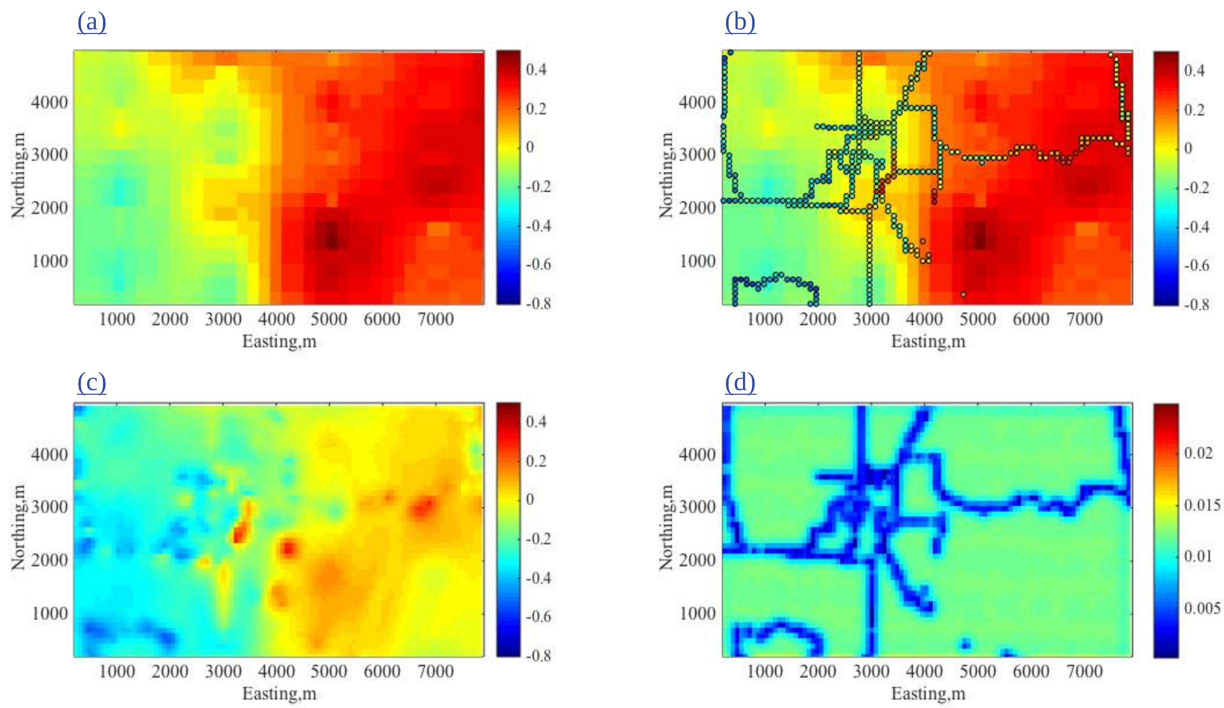

Fig. 2. (a) Airborne dose-rate data over Fukushima City (December 2011), (b) car-borne data (colored circles) over the airborne data (colored map), (c) the estimated integrated dose-rate map (mean field) based on the developed data integration, and (d) the estimation variance. In all the plots, the data values are log-transformed.

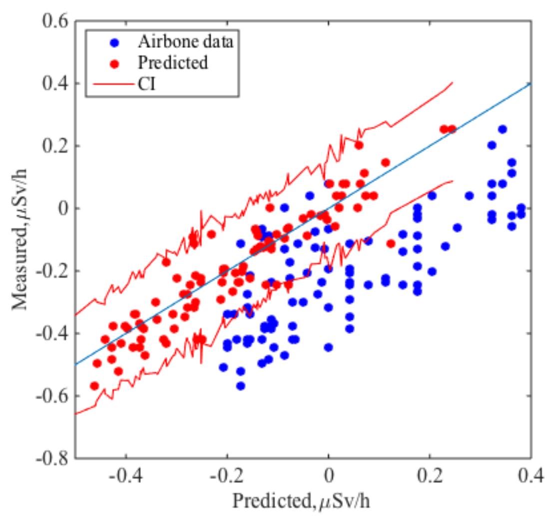

Fig. 3. Comparison between the predicted and measured air dose rates (log-transformed) at the car-borne data locations not used for the estimation. The red dots represent the predicted values based on the data integration method; the blue dots are the airborne data before the integration. The blue line is the one-to-one line; the red lines are the 95% confidence intervals.

SUMMARY AND FUTURE WORK

In this paper, we described a multiscale hierarchical Bayesian method for integrating multiscale, multitype dose-rate measurements. As an example, we illustrated how this method could be used to integrate coarse-resolution airborne data and fine-resolution (but sparse) car-borne data in a consistent manner, with the estimation uncertainty quantified. Although the current example model is still simple, results have suggested that the effective combination of ground-based data and airborne data could provide detailed and integrated maps of radiation air dose rates at regional scale around the Fukushima Daiichi NPP. In addition, this method could quantify estimation errors or confidence intervals, representing the uncertainty associated with the integrated maps. We also showed that statistical analyses could provide vaious insights into both the characteristics of each dataset and the spatial trend of contamination, which would be useful for predicting future radiation levels at the regional scale.

In future work, we are planning to improve the estimation approach by including other information, such as the correlations between dose rates and land use and/or topography. Physics-based radiation transport models will be used to replace the spatial averaging function to accurately represent airborne data as a function of soil contamination. In addition, spatiotemporal integration—by integrating spatially sparse but continuous-time monitoring data and temporally sparse but spatially extensive data, such as airborne data—will be carried out to provide a detailed map of the air dose rate and radionuclide contamination at regional scale, at any given location and time, including their confidence interval.

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Challenges for Nuclear Safety from Viewpoint of Natural Hazard Risk Management

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ABSTRACT

In this paper, lessons learned from the Fukushima Daiichi NPP Accident and challenges for enhancement of the concept of nuclear safety is summarized from the viewpoint of earthquake- and tsunami-resistant design and regional natural hazard disaster prevention and mitigation.

Key words: Fukushima Daiichi NPP Accident, Earthquake, Tsunami, Nuclear safety

INTRODUCTION

It is well understood among public as well as engineers that use of nuclear energy involves potential risk associated with accidents, which was clearly recognized by the experiences that the potential risk became obvious during the Fukushima Daiichi NPP Accident. Analysis of the experiences before, during and after the accident is considered essential to discuss the public acceptance of nuclear power in the future. In this paper, future challenges addressed by several reports on Fukushima Daiichi NPP Accident are summarized from the viewpoint of natural hazard risk management.

CHALLENGES INDENTIFIED IN LIGHT OF THE FUKUSHIMA DAIICHI NPP ACCIDENT

Risk management is a process, which consists of the identification, assessment, evaluation, treatment and monitoring. If risk is evaluated high, risk is reduced by introducing a countermeasure, then retained. Contingency plan is also needed for preparation for retained risk. In our society, however, risk assessment of nuclear power plants, i.e., probability of occurrence of accident, is often used only to judge whether risk is acceptable or not. Then, simply speaking, nuclear operators together with regulator may fail preparing the contingency plan in case the risk becomes obvious.

Risk-informed framework for Nuclear Safety

Conventionally, risk R is defined as the mean value for possible adverse consequences, i.e., consequence times its frequency, as follows:

$$R = \sum_i C_i P_i \tag{1}$$

where, C_i is the consequence and P_i is the probability of occurrence of C_i for the i-th scenario. It is effective, however, from the viewpoint of risk management, that risk is defined more generally as the information as (Kaplan & Garrick, 1981):

- What can go wrong? (Scenario)
- How likely is it? (Likelihood)
- What its consequences might be? (Consequence)

The importance of the scenario is more emphasized in this definition to be used for risk management and decision making. It is also required the risk information includes what is within/out of scope and how much uncertain the result of risk assessment is.

For nuclear power plants in Japan, accident management was planned and introduced as countermeasures for severe accidents around 2000 by operators as voluntary basis without regulatory requirements. Reports on probabilistic risk assessment were published in 2002 for internal events to confirm the effectiveness of introduction of severe accident countermeasures. However, it has been recognized among experts that the main source of risk is not from internal events but from external events like earthquake. Therefore, a standardized method was prepared and published as AESJ (Atomic Energy Society of Japan) standard for seismic risk assessment by 2007. Natural hazard risk assessment was not published for each specific plant in Japan before the Fukushima Daiichi NPP Accident in 2011. Accident management was not yet reinforced by continuous efforts. It is one of the most important points of open debates after the Fukushima Daiichi NPP Accident, how we can utilize risk information including site-specific probabilistic risk assessment for decision making not only by the operator but also by other stakeholders including regulator.

Defense in depth

"Defense in depth" is considered to be the fundamental concept for nuclear safety. It is sometimes said that the Fukushima Daiichi NPP Accident, which occurred due to the severe natural event, is a challenge to defense-in-depth. It was conventionally considered that natural hazard risks can be avoided through appropriate siting criteria and conservative design, without any consideration of higher levels of defense in depth. The accident management introduced at NPPs in Japan mainly for accidents from internal event was based on an implicit assumption of such an ideal condition. There was no effective mechanism to evaluate and reduce the risk from both internal and external events continuously in Japan.

It is natural and reasonable, even if there was not Fukushima Daiichi NPP Accident, that occurrence of natural disaster is considered when accident management and emergency management is considered. Fig. 1 explains the levels of "defense in depth" for nuclear safety in case of severe natural disaster. Levels 4 and 5 defense-in-depth are on-site and off-site activity respectively in order to prevent and mitigate the consequence of accident. Though these activities are not hardware-oriented but management-based, it is possible that levels 4 and 5 of defense in depth suffer damage prior to levels 2 and 3, because usually on-site and off-site facilities other than reactor building are designed to resist a smaller natural event than a reactor building, which is discussed in the following section.

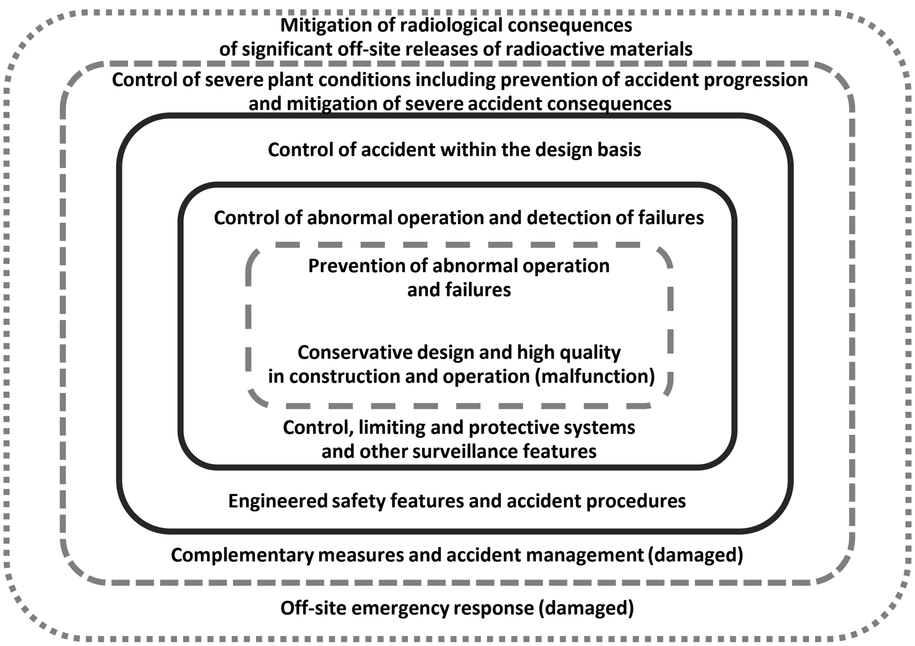

Fig. 1. An example of the levels of defense-in-depth in case of occurrence of natural disaster.

Earthquake- and Tsunami-Resistant Design

Hardware design of nuclear power plants takes a central role for their systems' safety. Major direct causes of the Fukushima Daiichi NPP Accident are considered to be underestimation of design tsunami height and lack of preparation for beyond-design event, which includes both lack of contingency planning and deficiency in design. The latter is discussed as the importance of identification and resolution of "cliff edge".

There are two background factors as to the underestimation of design tsunami height. One is the insufficient understanding of importance to follow the updated scientific knowledge where the paradigm occasionally dramatically shifts, as our knowledge on natural hazards changes; the other is over-insistence on need for historical evidence to take preventive action. Design earthquake ground motion and tsunami are evaluated for supposed active faults and subduction zone earthquake. For subduction zone earthquakes, supposed earthquake is determined based on the historical records only for several hundred years, while geological data with longer period of time can be available for active faults.

Table I shows a reference probability level for different categories of structure, such as NPP and ordinal civil structure. For the design of NPP, earthquake which is not experienced in history is assumed in some cases, because the reference probability level for NPP design is considerably small, which is 1/10 of that for ordinal civil structure and is smaller than that for disaster preparation for a nation.

Table I. Reference Probability Level for Earthquake-Resistant Design

		Annual probability of exceedance	Cf. Exceedance probability in 50 years
Design ground motion of NPP	Level 1	10^{-2} (mean) (IAEA)	40% (mean) (IAEA)
	Level 2	10^{-4}-10^{-3} (mean) (IAEA) 10^{-5}-10^{-4} (median) (IAEA)	0.5%-5% (mean) (IAEA) 0.05%-0.5% (median) (IAEA)
Design ground motion for civil structure	Serviceability limit state	1/500-1/25 (AS/NZ) 1/50-1/20 (Japan)	5%-86%(AS/NZ) 63%-92% (Japan)
	Ultimate limit state	1/2500 (US) 1/2500-1/250 (AS/NZ) 1/500-1/1000 (Japan)	2% (US) 2%-20% (AS/NZ) 5%-10% (Japan)
Cf. Regional disaster prevention & mitigation		$<10^{-3}$ (Japan)	<5% (Japan)

Regional Disaster Prevention/Mitigation

It is of significant public concern that people can successfully evacuate from the nuclear accident. For this purpose, we need to provide the information on the likelihood and possible amount of radioactive material release. Because all the units may suffer from identical external events, multi-unit risk assessment is necessary considering the disturbance of on-site and off-site activities related to mitigate the consequence of the accident, as was observed in hydrogen explosion in the Fukushima Daiichi Accident.

For the off-site emergency response, it is critically important that we recognize that off-site facilities suffer nuclear accident after damage due to natural events. There are many kinds of possible interactions. The first point is the difficulty for the local residents in evacuation and also the difficulty for the nuclear site to receive supports from external organization, due to spatial distribution of damage of infrastructure (see the examples of surface transportation in the Fukushima Daiichi Accident shown in Figs. 2 & 3) and so on. The second point is that the rescue activity for people suffered by severe natural event is disturbed, because of the forced evacuation due to nuclear accident, i.e., a rescue team is forced to leave the site. The third point is that people is discouraged repeatedly by natural event as well as by nuclear disaster.

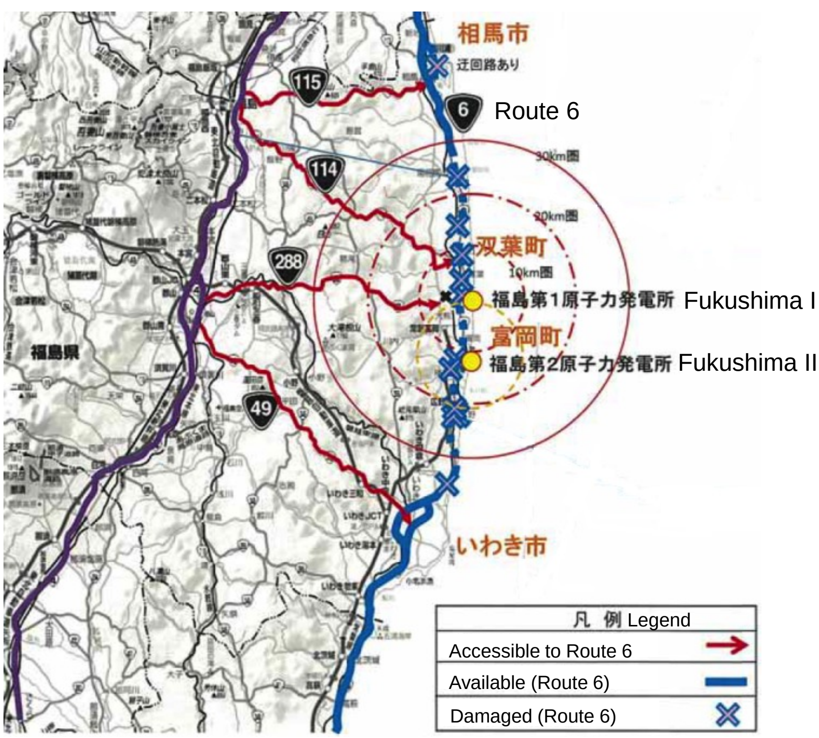

Fig. 2. Location of damage along Route 6.
http://www.thr.mlit.go.jp/road/jisinkannrenjouhou_110311/dourohisaijyoukyou.pdf

Fig. 3. Collapse of road surface due to ground motion (Route 6).
http://www.thr.mlit.go.jp/road/jisinkannrenjouhou_110311/dourohisaijyoukyou.pdf

SUMMARY

In this paper, challenges for nuclear safety with respect to natural hazard risk management are summarized from the viewpoint of risk-informed framework, defense in depth, design and regional disaster prevention/mitigation.

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Evaluation of the expected costs of nuclear accident

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ABSTRACT
From an economic perspective, cost estimations are useful to make better ex ante decision (e.g., technological choice between nuclear and gas powered station). Economists therefore calculate both frequencies and damages to estimate the expected costs (e.g., the costs of car accidents per mile). In the case of nuclear accident such a mean cannot be calculated because observed events are (fortunately) too sparse. Economists also take into account that people are risk-averse. Nuclear accident are dreadful, a feature that makes risk aversion a more complex phenomenon. This paper discusses these two specific challenges in estimating probabilities of nuclear accidents. A companion paper by Romain Bizet deals with the evaluation of damages.

Key words: Probabilistic analysis, dreadful event, nuclear accident, costs assessment.

INTRODUCTION
Why have costs of accidents to be estimated? The first reason is victims' compensation. The assessment takes place after the accident. It focuses on the evaluation of different damages to individuals, to society and to nature. Such ex post assessments are usually legally driven (see BP Deepwater Horizon or TEPCO Fukushima-Daiichi payouts). The second reason is ex ante decision-making. The costs of accidents is one component of private and social costs that has to be included in cost-benefit analyses before deciding the location of hazardous activities, their extension, their phase-outs, their relative advantages vis-à-vis other technologies, etc. Ex ante costs assessment are economically driven. Another major difference between the ex ante and ex post approaches is that the former is confronted with much more uncertainties. The future is less known that the past and the accident is only one possible outcome. The cost to consider is the expected cost, that is, the damage by the probability of the accident. Generally speaking, the probability is derived from observed frequencies of accident. More rarely, the product of multiplication is also increased by a coefficient to take risk aversion into account. This canonical method in the economics of accident is not easy to apply to nuclear catastrophes. Probabilities cannot be derived from observed frequencies and psychological biases regarding dreadful events are not simply risk-aversion.

The paper discusses these two challenges the economics analysis of nuclear accident is confronted to. It is divided into two parts. Part 1 deals with the limitations of observed frequencies and of so-called Probabilistic Safety Assessments (hereafter, PSAs) as methods to estimate the overall probability of nuclear accidents. It argues that knowledge from observed occurrence of accidents and knowledge from safety engineers and experts have to be combined. Part 2 focuses on the gap between the probabilities of nuclear accidents as calculated by experts and the probabilities of nuclear accident as perceived by individuals. It shows how psychological biases in estimating probabilities are all amplifying the perceived risk of nuclear accidents. The paper preliminary concludes on further directions of research.

LIMITATIONS IN ESTIMATING PROBABILITIES OF NUCLEAR ACCIDENTS

The expected costs of nuclear accidents as viewed as car crashes
How to compare different technologies to produce electricity? What is the optimal mix of power generation? To answer these questions economists use the levelized cost of electricity methodology (hereafter, LCOE). It determines the price of electricity required to balance discounting costs and benefits throughout a power plant's service life. From a general interest perspective, the costs and benefits must include both the private costs the operators will incur (e.g., fuel costs) and the external costs society will have to pay for (e.g., polluting emissions). For instance, the UK department of energy and climate change estimates the LCOE of a Combined Cycle Gas Turbine and of a nuclear power plant (hereafter, NPP) to respectively 80£/MWh and 90£/MWh for a project starting in 2013 with a 10% discount rate[24].

As far as nuclear generation is concerned, accidents have to be included in the LCOE. However, this inclusion has a negligible impact because the huge amount of damage is multiplied by an infinitesimal probability. Let's consider a simple back-of-the-envelope calculation: 1 billion euros of damage and a large early release frequency of 10^{-5} per reactor-year. This

[24] DECC, *Electricity Generation Costs 2013*, Table 2 p. 18, July 2013.

leads to 1 €/MWh, that is about one hundredth of the total cost to produce one MWh from a nuclear plant. According to a recent study on nuclear costs based on a comprehensive literature survey (d'Haeseleer, 2013), the order of magnitude of external costs due to nuclear accident is between 0.3 and 3 €/MWh.

Such an approach to compute the social external cost of nuclear power generation is far from satisfactory. It views nuclear accidents as transport crashes. It is reasonable to make cost comparison of different means of transportation because their probabilities can be derived from observed frequencies. For instance, there have been worldwide 90 to 118 annual airplane accidents between 2009 and 2013 (including 9 to 13 annual fatal accidents with 173 to 655 fatalities per year)[25]. Based on the observed frequencies during this period, the probability for a passenger to have an airplane accident when embarking at the airport is about $3x10^{-6}$. Road traffic accounts for more than 1 million deaths per year worldwide, mainly pedestrians and motorcyclists[26]. In a small country like New Zealand, the number of fatalities due to car crashes has been 254 in 2013. It corresponds to a frequency of 0.8 deaths per 10.000 vehicles[27]. On the basis of 2011-2013 statistics the probability for a driver to be killed is about $3x10^{-9}$ per km. In 2013, the social cost of fatal car accident is estimated to NZ$ 4.5 million. The expected cost of fatal accident per km can be estimated to 0.03 NZ$, that is about one tenth of gas price. Given the observed frequencies of transport accidents (and assuming the value of loss life is the same and neglecting other damages), one can easily compare the social accident costs of rail, air, maritime and road transportation per km or per travel. Moreover, data on car accidents can generally be broken down by local area, models of car, types of roads, age categories of the driver, etc. As a result precise probability can be estimated according to different situations.

Nuclear accident is not a car crash

Estimating probabilities of nuclear accident from frequencies is a non-sense. Since the first grid-connection of nuclear power plant in 1956 there have been 12 core-meltdowns of reactors, including very limited ones[28]. According to the INES classification there have been 2 major, or level 7, accidents (Chernobyl and Fukushima-Daiichi) and 21 accidents with a level equal or higher to 4. Knowing that since the end 1950s 14.500 reactor-years have passed worldwide the observed frequencies are $1.6\ 10^{-3}$ per reactor-year for INES>3; $8.3\ 10^{-4}$ per reactor-year for core-meltdown; and $2.7\ 10^{-4}$ per reactor-year for INES=7. Is it sound to infer probabilities from these values? For instance, using a Poisson distribution and knowing that the worldwide nuclear fleet amounts to 435, is it relevant to say that the probability of an INES 7 accident in 2015 on the planet is 0,11 (i.e., $[1-(1-2.7x10^{-4})^{435}]$?

No! The reasons are twofold. The obvious one is that the number of observations is too small. The observed events cannot be assumed as representative. Reactors are neither identical, nor exposed to the same locational risk (e.g., seism, flooding). The events are not independent – the current nuclear fleet is close to the 1980s fleet for more than three quarters of reactor is over 25 years old –. Moreover, the evolution of safety performances and standards makes heroic to assume that safety is time-invariant.

The second reason is that assessing the risk of nuclear accidents exclusively on data from past observations implicitly assumes that no other knowledge is available on nuclear safety. It ignores all the works carried out over the past 50 years by thousands of nuclear scientists and engineers on safety. This knowledge has partly crystallized in PSAs. The first large-scale probabilistic assessment was carried out in the US in the 1970s. It was led by Norman Rasmussen, then head of the nuclear engineering department at MIT. PSAs have now been carried out on all nuclear power plants (hereafter, NPP) in the US and many others worldwide. Similarly reactor vendors carry out such studies for each reactor model while it is still in the design stage. For instance, the calculated core meltdown frequency for the UK EPR is 10^{-6} per year and the core damage with early containment failure is estimated to $3.9x10^{-8}$ per year.

As for observed frequencies, assessing the risk of nuclear accident based exclusively on PSAs would be unsound. The use of PSAs has strong limitations, too. Firstly, they are not mainly designed to provide a final single number. They are designed to detect exactly what may go wrong, to identify the weakest links in the process and to understand the failures which most contribute to the risk of an accident. Secondly, PSAs have a limited scope. They study known initiating events such as seism or loss of coolant but not all the possible states of the world because the list of all causes and failures is unknown. Thirdly, PSAs assumes perfect compliance with safety standards and regulatory requirements. An implicit assumption is that safety

[25] International Civil Aviation Organization, *2014 Safety Report*.
[26] World Health Organization, *Global Safety Support on Road Safety*, 2013.
[27] Ministry of Transport, *Motor Vehicle Crashed in New Zealand,* 2013.
[28] T. B. Cochran and M. G. McKinzie , *Global Implication of the Fukushima Disaster for Nuclear Power*, World Federation of Scientists' International Seminars on Planetary Emergencies, Etore Majorama Centre Erice, August 19-25, 2011.

standards are enforced thanks to an independent, competent and powerful safety regulatory authority. All these limitations can explain in part why PSAs figures are much lower than observed frequencies[29].

If we want to make progress in estimating probabilities of nuclear accident, we have to use all the current available quantitative knowledge and therefore to combine information from PSAs and observed accidents. Escobar-Rangel and Lévêque[30] have made such an attempt. The issue addressed in their paper is to compute the post Fukushima-Daiichi global probability of a core-meltdown. Different models are used including a Poisson Exponentially Weighted Average model to capture the idea that recent accidents are more informative than past ones and to introduce some inertia in the safety performances of the fleet. This model shows that the Fukushima Daiichi accident results in a huge increase in the probability of an accident. The arrival rate in 2011 is similar to the arrival rate computed in 1980s. To put it another way, this catastrophe has increased the probability of an accident for the near future in the same extent it has decreased over the past 30 years owing to safety improvements. This huge effect of Fukushima Daiichi in revising the global estimation of a core meltdown can be interpreted as evidence that besides the design, the location and the operating of reactors the probability of an accident also depends on institutional factors like the strength and ability of nuclear safety authorities, a factor which is not taken into account in probabilistic assessments. In fact, like in Japan there are a lot of countries wherein nuclear safety authorities are captured by operators and fail to enforce safety standards.

As a conclusion, uncertainties prevail. There is no overarching probability of nuclear accident to use to make a rational decision for society to invest in or to phase out nuclear power generation, to determine the right level of nuclear safety expenditures, not to say to identify the economically optimal level of nuclear safety. Unlike transport crashes no means can be inferred from observed frequencies. Moreover, the probability of a nuclear accident differs according to the design and the location of reactors but also according to institutional characteristics (independent regulator, liability rules, experience of operators, etc.). We do not know the probability distribution of nuclear accident, even for a given reactor design and location. Last but not least, one has always to keep in mind that probabilistic analysis requires knowing all the state of the world. A probability cannot be assigned to an unknown event, or to put it another ways to black swan and unknown unknowns.

PERCEPTION OF PROBABILITIES

Utility function and human behavior

It is well known that many people are risk-averse: they would rather, for instance, a certain gain of 100 to an expected gain of 110. Since Bernoulli (1738)[31], this psychological trait is represented by a concave utility function. The Swiss mathematician opened the way for progress towards decision theory[32] through a back-and-forth between economic modeling and psychological experimentation. The latter would, for instance, pick up an anomaly – in a particular instance people's behavior did not conform to what theory predicted – and the former would repair it, altering the mathematical properties of the utility function or the weighting of probabilities. The works by Allais and Ellsberg were two key moments in this achievement. Following an experiment showing that people with good knowledge of the theory of probability were violating an axiom of expected utility theory, Allais (1953)[33] proposed to weight probabilities depending on their value, with high coefficient for low probabilities, and vice versa. Putting it another way, preferences assigned to probabilities are not linear. This is more than just a technical response. It makes allowances for a psychological trait, which has been confirmed by a large body of experimental study: people overestimate low probabilities and underestimate high probabilities.

Another anomaly well known to economists is ambiguity aversion. This characteristic was suggested by Keynes and latter demonstrated by Ellsberg (1961)[34] in the form of a paradox. In his treatise on probabilities Keynes (1921)[35] posited that greater weight is given to a probability that is certain to one that is imprecise. Ellsberg has shown that just as there is a premium for taking risks, some compensation must be awarded to individual for them to be indifferent to gain (or loss) with a one-in-two probability or an unknown probability with an expected value of one-in-two. Technically speaking there are several solutions for this problem, in particular by using the utility function, yet again. What is important to keep in mind

[29] For a detailed discussion on the discrepancy between observed frequencies and calculated frequencies in PSA models see F. Lévêque, *The Economics and Uncertainties of Nuclear Power*, Cambridge University Press, 2014, chapter 4.
[30] L. Escobar-Rangel and F. Lévêque, How Fukushima Daiichi core meltdown changed the probability of nuclear accidents, *Safety Science*, 64, (204), pp. 90-98.
[31] D. Bernoulli, Exposition of a new theory on the measurement of risk, *Econometrica* **22** 23–36 (Translation of D. Bernoulli 1738 Specimen theoriae novae de mensura sortis, *Papers Imp. Acad. Sci. St. Petersburg* **5** 175–192)
[32] For a comprehensive panorama on decision theory under uncertainties see I. Gilboa, *Theory of Decision under Uncertainties*, Cambridge University Press, 2009.
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here is that with a choice between a hazard associated with a clearly defined probability – because experts are in agreement – and a hazard of the same expected value – because experts disagree – people are more inclined to agree to exposure to the first rather than the second hazard. Putting it another way, in the second instance people side with the expert predicting the worst-case scenario.

More recently, Kahneman's work followed on that of Bernouilli, Allais and Ellsberg. He and his fellow author, Tversky, introduced loss-aversion (1979)[36]: individual are more affected by loss than gain. Kahneman also diverged from his predecessors in adopting a more positive approach. Observing the distortion of probabilities is a way to understand how our brain works rather than to build a theory where the decision-maker optimizes or maximizes the outcome. Kahneman's line of research is comparable to subjecting participants to optical illusions to gain a better understanding how our brain functions. For example, a 0.0001 probability of loss will be perceived as lower than a 1/10,000 probability. Our brain seems to be misled by the presentation of figures, much as our eyes are confused by an optical effect which distorts an object's size or perspective. This bias seems to suggest than our brain takes a short cut and disregards the denominator, focusing only on the numerator.

The effects of perception biases on nuclear accidents

The overall biases in our perception of probabilities, briefly discussed above, amplify the risk of a nuclear accident in our minds. A nuclear accident is a rare event, so its probability is overestimated. The risk of a nuclear accident is ambiguous. As expert appraisals diverge, people are therefore inclined to opt for the worst-case scenario. The highest probability of accident prevails. Along with plane crashes or terrorist attacks targeting markets, hotels or buses, a nuclear accident is a dreadful event. Rather than acknowledging the probability of the accident, attention focuses exclusively on the accident itself, disregarding the denominator. Moreover, several other common routines or heuristics which have been identified by experimental psychologists distort the probability of a nuclear accident[37] and increase our aversion vis-à-vis such a disaster.

As a consequence, public decision exclusively based on perceived risk entails a series of drawbacks. Firstly, it tends to an over-investment in nuclear safety. The perceived risk of a nuclear accident being amplified, the benefits to decrease it seems higher and therefore efforts to reduce it seems more worth to be undertaken. Secondly, the choice of technology is distorted in favor of ways generating electricity which are not less hazardous. Coal is perceived as less dangerous whereas according to data on fatalities it is more (OECD, 2010)[38]. Thirdly, public decisions exclusively based on perceive probabilities could lead to costly premature phase-outs. After Fukushima-Daiichi, the German government decided to accelerate the decommissioning of NPPs. It entails an economic loss estimated to a 100 billions of euros in comparison to the previous more progressive nuclear exit as enacted in the Atomic law passed a few months before the accident[39].

However, public decision ignoring perception biases can also result in wasting a lot of money. It could be costly to treat the attitude of the general public as the expression of fleeting fears which can quickly be allayed, through call to reason or the reassuring communication of the 'true' facts and figures. The reality test, in the form of hostile demonstration or electoral reversals, may substantially add to the cost for society of going back on past decisions ignoring public perception. Nuclear power history is full of cases of abandoned projects after several years of construction. In France, for instance, about 10 billions of euros have been spent to build the fast breeder commercial reactor Superphénix for nearly nothing. It has only produced a modest quantity of electricity when it was shutdown.

In short, public decision-making must avoid two pitfalls: ignoring how probabilities of nuclear accident are perceived and exclusively taking them into account.

PRELIMINARY CONCLUSIONS

Uncertainties on probabilities of nuclear accidents are as large as uncertainties on damages. Both uncertainties make the scientific estimation of the nuclear risk a considerable challenge. More research is needed but uncertainties on probabilities and on damages are of different types and posit different methodological, empirical and theoretical problems.

Regarding probabilities two lines of research could be worthwhile. The first would try to better measure and estimate the possible occurrence of nuclear accidents. It mainly involves applied mathematics. It includes works on uncertainties propagation in PSAs event trees, on models combining observed frequencies and calculated probabilities, and on using new probability axiomatic such as imprecise probability theory. The second line of research would attempt to find methodologies to balance and integrate probabilities as calculated by experts and probabilities as perceived by individuals. It includes

[36] D. Kahmann and A. Tverski, Prospect Theory: an analysis of Decision under Risk, *Econometrica*, 47 (1979), pp. 263-91.
[37] See F. Lévêque, supra note 6, pp. 115-117.
[38] OECD-NEA, *Comparing Nuclear Accident Risks with those from other sources*, (2010).
[39] J. H. Keppler, The economic cost of the nuclear phase-out in Germany, *NEA News*, 30 (2012), pp. 8-14.

experiment to estimate and measure probability distortions and biases as well as the design and assessment of different institutional arrangements involving nuclear safety authority, government and NGOs.

The theory of decision under uncertainties and its modern developments remain an interesting tool to get a better knowledge on the nuclear risk and the means to manage it.

Considering Nuclear Accident in Energy Modeling Analysis

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ABSTRACT
After the Fukushima nuclear accident, alternative energy sources show a dramatic growth such as natural gas, petroleum, solar PV and coal to compensate the loss of nuclear energy in Japan, and in new national energy policy, the government promises to introduce renewable energy at a level even higher than the one pursued in the previous policy. Hence, the Fukushima accident can be viewed as the tipping point for the country to elaborate alternative energy and environmental policy adjusting into the situation after the Fukushima. So far, energy model has been developed to discuss long-term energy scenario in a consistent way and to analyze the effectiveness of energy policy. However, the model developed until now does not explicitly consider the impact of a nuclear accident on the long-term pathway of energy portfolio, in spite of the fact that the Fukushima accident is actually observed to dramatically change the situation of energy demand and supply in Japan. This manuscript aims to overview the transition of energy supply and demand in Japan after the Fukushima and to discuss the possibility of considering a nuclear accident in energy modeling analysis by applying stochastic dynamic programming.

Key words: Nuclear energy, Nuclear accident, Energy mix, Energy modeling, Stochastic dynamic programming

1. INTRODUCTION

Energy supply plays an essential role to maintain socio-economic activity together with national governance. For Japan which highly relies on the import of energy resource, ensuring energy supply security is regarded as an important challenge to be tackled with. In the context of global energy market, Japan is one of the big energy consumers and importers, becoming fifth in primary energy consumption, third in both petroleum imports and consumption, and first in LNG imports. In addition, petroleum holds the largest fraction in the primary energy supply mix (44%), followed by coal (27%) and natural gas (22%), and the fraction of fossil fuels amounts to 93% in 2013[1]. Since Japan depends on imports of almost all fossil fuels, the energy self-sufficiency ratio shows a considerably lower level; Japan's energy self-sufficiency ratio is only 7% in 2013[1], which exhibit a level below that in other developed countries. Moreover, Japan is heavily dependent on the Middle East for about 80% of its crude oil supply. Thus, nuclear energy supply has traditionally served as an important pillar to reinforce domestic energy supply in Japan where energy supply situation is considerably vulnerable as explained.

However, the impact of Fukushima nuclear accident, caused by Great East Japan Earthquake in Japan, is quite influential on its energy mix and economy, and has caused deep discussion for restructuring energy policy thereafter which strongly promoted nuclear energy. Fukushima nuclear accident has influenced the Japanese society concerning energy issues since the first and second oil crisis of the 1970s. The accident has accelerated the government to rethink the country's energy and environmental policy as well. Obviously, enormous political and technical effort is required to replace the loss of nuclear power, a major base-load technology contributing to energy security and environmental sustainability before the Fukushima. Actually, after the Fukushima accident, alternative energy sources replacing nuclear have shown a dramatic increase such as natural gas, petroleum, solar PV, coal as well as electricity saving. Therefore, the severe nuclear accident is considered to be one of driving force which might change the pathway of the country's energy mix, and the Fukushima can be understood as the tipping point for the country to elaborate energy, environmental and nuclear policy adjusting into the situation after the Fukushima.

So far, a lot of academic effort has been dedicated to the development of energy system model which allows us to yield long-term energy scenario in a consistent way and to analyze the effectiveness of energy or environmental political instrument such as carbon tax or regulation. However, the majority of existing analysis does not explicitly consider the impact of nuclear accident and its successive shutdown on the long-term pathway of energy portfolio, although the accident is actually observed to dramatically change the situation of energy demand and supply in Japan.

The objective of this manuscript is to overview the transition of energy supply and demand in Japan after the Fukushima, and, based on that, to discuss the possibility of considering nuclear accident as contingency risk in energy modeling analysis by applying the methodology of risk analysis such as stochastic dynamic programming. The paper is organized as follows: section 2 describes the energy market situation in Japan before and after the Fukushima; section 3 discusses the possible appropriate methodology to consider a nuclear accident in energy model and section 4 depicts the concluding remark.

2. IMPACT OF FUKUSHIMA NUCLEAR ACCIDENT ON JAPANESE ENERGY MARKET

The Great East Japan Earthquake and subsequent tsunami caused heavy damage to nuclear power plants together with other critical infrastructure such as thermal power plants, oil refineries, and LNG (liquefied natural gas) import terminals. Particularly the damage in power sector was extremely serious. Due to the sudden loss of 27 GW of electric power generation capacity where Japan's total power generation capacity is 231 GW, power shortage became a serious problem shortly after the earthquake. For resolving the power shortage, enormous efforts were concentrated on increasing the power generation capacity by restarting idle and aging thermal power plants such as petroleum-fired power plant, while compulsory power saving was adopted to cope with insufficient supply. In order to compensate the electricity supply loss of power plants that had shut down due to the serious damage caused by the earthquake, urgent measures were conducted to maximize the use of natural gas (LNG) - and petroleum- fired power plants, including aging idled plants. In the demand side, rolling blackouts were implemented from March to April in Tokyo/Kanto area in 2011, and then the government announced mandatory cuts in power use from July 1, 2011 to treat the peak power load in summer for the first time since the oil crisis. Through a combined implementation of those measures, the period shortly after the Fukushima in 2011 experienced no serious unplanned blackouts. However, thereafter, Japan faced the unprecedented situation that all of 50 nuclear power reactors shut down. There has remained strong concerns over the safety of nuclear power plant after the Fukushima, and profound difficulty and complexity consist in obtaining an official permissions for restart of nuclear power from the local authorities which installs nuclear power plants in their sites. Those nuclear shutdown has influenced the power supply mix and energy supply in Japan so far.

Trend of energy mix after Fukushima

After the Fukushima, national concerted efforts to expand the use of thermal power generation as well as electricity saving have contributed to prevent the occurrence of any serious power shortage. LNG-fired power plants and oil-fired power plants, which serves regularly as middle-peak power generator, operate so as to replace nuclear power which is responsible for base load in power load profile. It should be also noted that power utility companies attempt to newly build thermal power capacity as well as to bring retired or very old power plants back on line.

The Fukushima nuclear accident triggered the shutdown of the country's entire nuclear power plants, which accounted for 30 percent of the country's electricity supply before the Fukushima (Fig.1)[2,3]. Since the utilization of nuclear power generation significantly declined due to the accident, the fraction of fossil fuel over total power generation reached at the highest level (94.4% in January 2014) in the last three decades (Fig.2)[3].

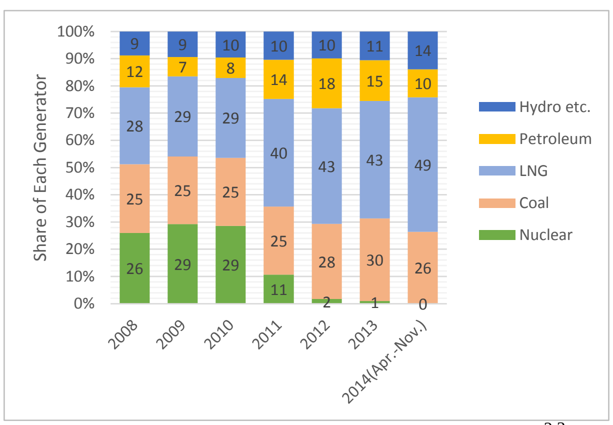

Fig. 1. Annual power generation mix in Japan[2,3]

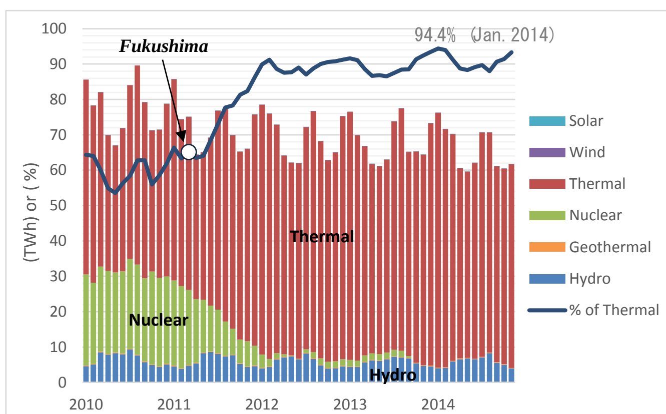

Fig. 2. Monthly power generation mix in Japan[3]

Substantial increase in natural gas (LNG) and oil is attributed to power generation to offset the decline in nuclear power generation after the accident. In particular, a radical shift to LNG occurred to make up for the loss of nuclear. Currently, LNG-fired power accounts for almost half of power generation mix in Japan (Fig.1) and LNG becomes indispensable fuel in Japanese energy supply portfolio. In reality, Japan's LNG imports increased from 70.5 million tons (MT) in FY 2010 to 83.2 MT in FY 2011, 86.9 MT in FY 2012 and 87.7 MT in FY 2013[1]. The increase in LNG use in particular in power generation caused an increase in import payments for LNG (Fig.3)[4,5], electricity supply cost, dependence on Middle East for LNG supply (Fig.4) and CO2 emissions, and produced a decline in the country's energy self-sufficiency. Since 96 % of natural gas supply in Japan depends on overseas, Japan's highly increased LNG imports put pressure on Asian LNG market pushing up already higher prices even higher. LNG is traded at the highest price in Asia at $15/MMBtu compared to $10/MMBtu in

Europe, while US natural gas is priced at around $5/MMBtu backed by the growing domestic gas supply through shale gas revolution. Figure 3 shows Japan's monthly imports of LNG. Japan's import payments for LNG in 2013 were a record high at 7.1 trillion yen, 205% up from FY 2010, causing the balance of payment turned to negative in fiscal year 2011 for the first time since 1980[4].

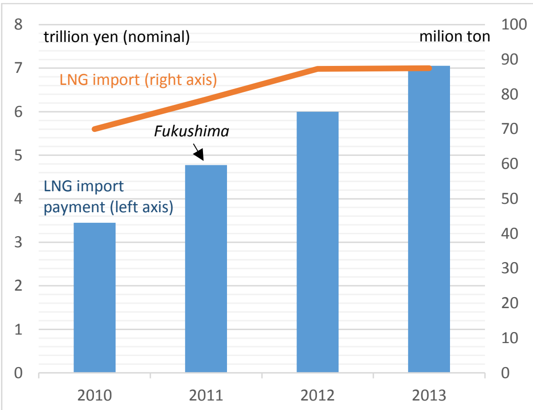

Fig. 3. Monthly payment for LNG import in Japan[4,5]

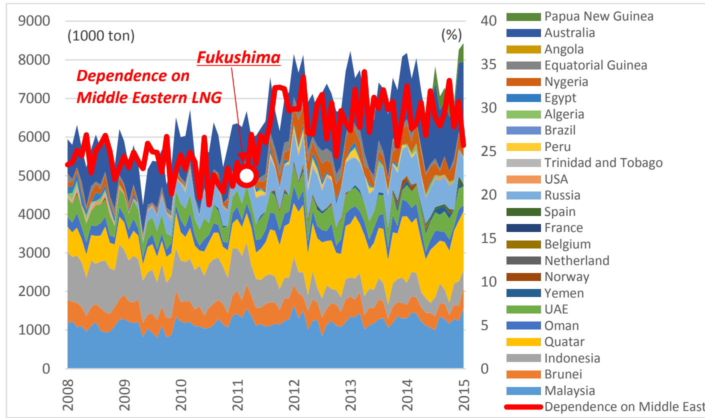

Fig. 4. Monthly LNG import by country in Japan[5]

Meanwhile, coal has an important advantage of being economically affordable cost, although it has an environmental disadvantage due to its higher intensity of CO_2 emissions. Thus, coal-fired plant is important for providing an economical power supply as base load power generator in Japan. As nuclear power plants in Japan remain shut down since the Fukushima nuclear accident, Japanese utility companies actually began planning the new operation of coal-fired power plants in order to reinforce the economical power supply capability, pressured by the soaring import payment for LNG. For example, Tokyo, Kansai, Chubu, Kyushu and Tohoku electric power companies plan to add 1.0 GW[6], 1.2 GW[7], 1.0 GW[8], 1.2 GW[9] and 0.6 GW[10] of coal-fired power plant in their power generation mix respectively. Including that plans, total 13 GW of newly building plan of coal-fired is under consideration in Japan. Japan needs to do a special consideration for coal in order to secure the economic competitiveness of power supply and to effectively negotiate for purchasing other forms of fuel through the best employment of coal as a bargaining power. Additionally, to suppress its external environmental impact, Japan is expected to develop clean coal technologies such as IGCC (integrated coal gasification combined cycle) and CCS (carbon capture and storage).

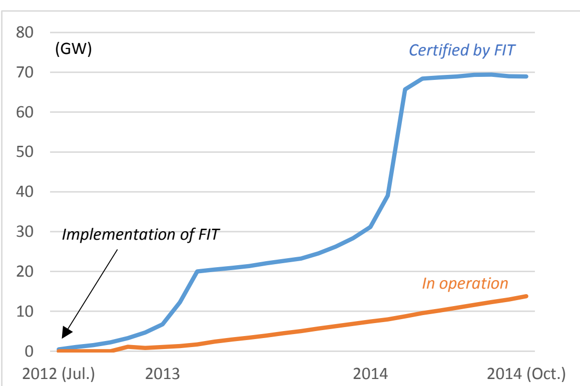

Fig. 5. Installed Solar PV capacity (certified by FIT & in operation) in Japan[11]

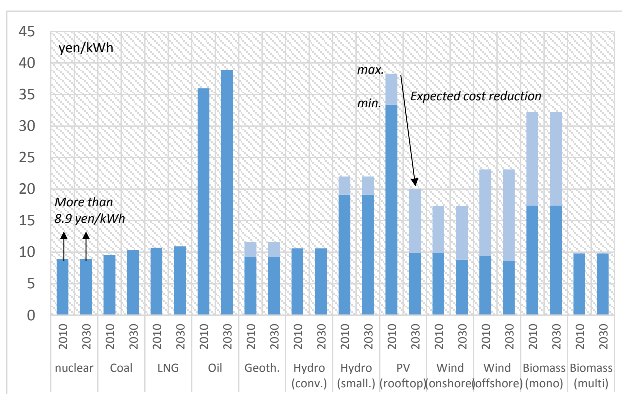

Fig. 6. Assessment of power generation cost in Japan[12]

As explained so far, fossil fuel serves as main alternative energy substituting nuclear energy after the Fukushima. However, expectations has been currently concentrated on renewable energy sources such as solar photovoltaic (PV) and wind power systems, since those are domestic and carbon-free energy sources that will contribute to create new industries. In addition, renewables are socially preferable options due to its reliance on natural sources of energy as distributed power sources. Since July 1, 2012, the Japanese government started to implement a Feed-in Tariff (FIT) system for renewable electricity in Japan, aiming at the promotion of renewable energy in the country's energy mix. Particularly after the implementation of FIT in 2012 by the government, the cumulative installed PV capacity rapidly increased from 7.3 GW in FY 2012 to 14.3 GW in FY 2013 (Fig.5)[11]. Moreover, PV capacity, which is certified to be built for the future and eligible for FIT, amounts to 68.9 GW as of October 2014 against 231 GW of total utility capacity in Japan (Fig.5)[11], suggesting that the effects of FIT have been so powerful, although the power generation cost of PV is still more expensive (Fig.6)[12]. However, a set of FIT tariff is difficult in terms of integrating renewables in an optimal way as implied by the experiences of other countries such as Germany and Spain. If the tariff is set to be profitable for PV owners, PV investment rapidly expands well beyond the managerial capability of power grid and increasing electricity price through a surcharge by FIT puts a financial burden on end-users. It should be carefully considered that massive integration of PV and wind poses a lot of challenges in technical and financial aspects, derived from their output intermittency and higher generation costs. Technical efforts are required to stabilize the power supply system through flexible resources such as rechargeable battery, back-up generators and demand response, and massive investments to enhance power grid capability will be indispensable. Meanwhile, if the tariff is set at a lower level, the installation of renewable power will not be successfully promoted. Paying cautious attention on the situation of electricity marketplace such as electricity price, it is important to promote renewable energy and improve the grid capability in a long-term energy development plan.

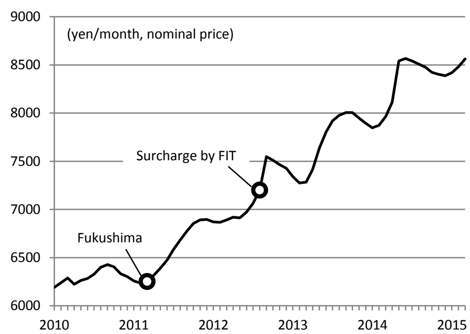

Fig. 7. Monthly electricity bill of average household in Tokyo[14]

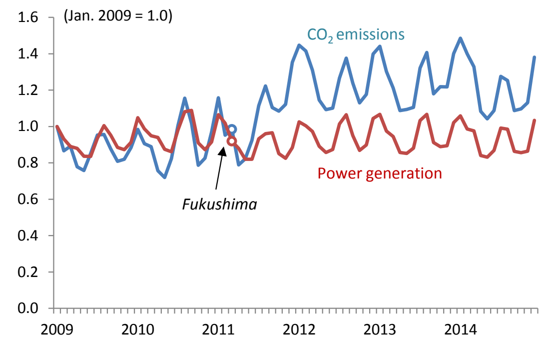

Fig. 8. Monthly CO_2 emissions and power generation in Japan (estimated from reference[3])

Increased dependence on fossil fuel supply and the associated growing import payments for the fossil fuels have eventually resulted in higher power generation cost and soaring electricity retail price. The increase in import payments for fossil fuel for power generation is projected to still cause an increase in average unit costs by 3.0 yen/ kWh in FY 2015 from their FY 2010 levels[13]. Higher power generation cost has serious economic impact, causing more than 35% escalation in electricity bill for the average household in Tokyo after the Fukushima (Fig.7)[14]. Actually, Kansai Electric Power Company, around half of which power generation mix is derived from nuclear energy, submitted applications for approval to the government about a 10.23% increase in power rates for the customers from FY2015. In those surroundings, rising electricity bills will pose a serious challenge for Japanese economy. Particularly for Japanese manufacturing sectors which come up against challenges in its international competitiveness, a further energy cost escalation is considered to be economically harmful. Since electricity price in Japan is relatively expensive in the context of an international comparison, the further increase in energy prices can be understood as an additional financial burden. Trade deficit in Japan is forecast to show a higher level of 9.8 trillion yen in FY 2014 and 7.4 trillion yen in FY 2015 even if considering the restart of 9 nuclear reactors, resulted in enormous outflow of Japan's national wealth.

CO_2 emissions will also increase because of increased usage of fossil fuel to replace the loss of nuclear power after the Fukushima. The utility power companies accounted for 439 million tons of CO_2 for the year 2011 (after the Fukushima), up 17 percent from 374 million tons in the year 2010 (before the Fukushima)(Fig.8). Kansai Electric Power Company, which relies most on nuclear power, produced 65.7 million tons, a 40 percent increase in CO_2 emissions. Japan's total CO_2 emissions increased from 1.124 billion tons (6.1 % higher than that in FY 1990) in FY 2010 to 1.173 billion tons (10.8% higher) in FY 2011, 1.208 billion tons (14% higher) in FY 2012 and 1.224 billion tons (15.6% higher) in FY 2013[1]. Growing CO_2 emissions due to higher fossil fuel use to offset nuclear reduction has imposed new challenges for Japan to strategically consider post-Kyoto climate change policy. As discussed so far, it is important to note that Japan currently faces multiple difficulties and challenges concerning energy security, sustainable economic growth and environmental conservation.

Energy policy overview in Japan before/after Fukushima

Before the Fukushima, the Japanese government, in its Strategic Energy Plan officially approved in June 2010[15], established a target of increasing the energy self-sufficiency ratio from the present level of 38% to 70% by 2030 and of mitigating CO_2 emissions by 30% compared with the 1990 level. An important technical measure was to expand the contribution of nuclear power supply in future energy mix for achieving those targets. The Energy Plan assumes that carbon-free energy sources, that is, nuclear and renewable, account for 70% in power generation mix in 2030. The fraction of nuclear power itself amounts to more than 50% in the mix as semi-indigenous and carbon-free sources. The Japanese government planned to build additional 14 reactors, thereby boosting the installed nuclear capacity from 49 GW in 2010 to 68 GW by 2030 while maintaining all the existing plants. In addition, the government aimed to raise the capacity factor of nuclear power plants to average 90%. However, the Fukushima nuclear accident required a rethink of this Plan in terms of nuclear energy development.

The new circumstances after the Fukushima necessitate the fundamental review of energy policy described in the Strategic Energy Plan before the Fukushima. The new Strategic Energy Plan of Japan[16], the first national energy policy of Japan after the Fukushima accident, was officially approved in April 10, 2014. The plan focuses on the optimal power generation portfolio in 2030 and beyond in Japan and displays future directions of energy policy toward a future optimal energy mix by reviewing problems and features concerning nuclear power and other alternative energy sources. The plan proposes the optimization of the power portfolio to satisfy energy requirement in terms of 3Es: economic efficiency, environmental protection and energy security, and places nuclear power as an important base load power generator which satisfies all of the agenda in 3Es. The plan states that nuclear has advantage in economic efficiency based on its higher density of power output and in environmental compatibility as carbon free sources during operation. However, the new Strategic Energy Plan describes that the enhancement of safety has higher priority than the assurance of 3Es and the adequate fraction of nuclear energy in the energy supply portfolio should be discussed while decreasing the dependence on nuclear energy in a long-term perspective. The plan also suggests to maximize the ratio of renewables at a level even higher than the one pursued in the previous plan. Specific ratio of the country's future power generation mix was not yet shown in the plan because of the incapability of projecting the nuclear reactors which come online in the future.

3. ATTEMPT FOR ENERGY MODELING CONSIDERING NUCLEAR ACCIDENT

Due to the unprecedented increase in fossil fuels imports to substitute the loss of nuclear energy after Fukushima nuclear accident as explained so far, Japan again recognizes itself as the country where the energy planning based on the nuclear disruption is required to reinforce the country's energy security. This manuscript regards a nuclear accident as a phenomena to cause a shutdown of nuclear power supply and attempts to discuss a potential methodology of considering the contingency risk, such as nuclear accident and fuel supply disruption, in energy modeling analysis formulated as mathematical programming. This section specifies fuel stockpiles, corresponding to SPR (strategic petroleum reserve) in U.S., as control variables to compensate for the loss of nuclear power supply in the accident based on a series of anecdotal evidence after the Fukushima, and attempts to formulate the mathematical optimization method which minimizes the country's total energy system cost, using stochastic dynamic programming[17] considering nuclear power shutdown. However, this manuscript focuses on describing the overall framework to consider nuclear energy shutdown and does not fully describe the details of energy system.

Firstly, fuel price volatility can be modeled as stochastic process. The daily time profile of the fuel import price in the study is assumed to have a certain cyclic pattern in average. In this model, the fluctuating change of the fuel import price P_t is expressed with Winner process dZ_t. As the specific stochastic process, the mean reverting process was assumed where price recurs to the average price for the long term. The stochastic process of fuel price is shown as follows.

$$d\log P_t = \frac{dP_t}{P_t} = \alpha(\log\theta_t - \log P_t)dt + \sigma dZ_t \qquad (1)$$

$$log\theta_t = \frac{1}{\alpha}\frac{\partial logF(0,t)}{\partial t} + logF(0,t) + \frac{\sigma^2}{4\alpha}(1 - e^{-2\alpha t}) - \frac{1}{2\alpha}\sigma^2 \qquad (2)$$

where P_t : fuel price at t [yen/specific unit], θ_t: equilibrium fuel price at t[yen/specific unit], α : reversion rate, σ : volatility, dZ_t : winner process, F: future price.

As an estimation period, this manuscript assumes a short-term such as one or several years, and energy supply capacity is assumed to be fixed variable, while optimal charge and discharge strategy of fuel stockpile is endogenously determined under the risk of the nuclear power supply disruption. The expected total energy system cost (the total cost that is necessary from t to the expiration of an analytical period) in the state of s and $\boldsymbol{i}$ at t is defined as $V_i(P_t,s,t)$. By stochastic dynamic programming, $V_j(P_t,s,t)$ becomes the sum of the minimum expected values of the total energy system cost after the time of $t+dt$ and the total energy system cost in each unit of time corresponds to $TC_j(PtAv(u,Imi),Ft)dt$.

$$V_i(\boldsymbol{P_t}, \boldsymbol{s}, t) = \min_{\boldsymbol{u}} \left\{ TC(\boldsymbol{P_t}, Av(\boldsymbol{u}, \boldsymbol{Im}_i), \boldsymbol{F})dt + Stk(\boldsymbol{P_t}, \boldsymbol{u}, \boldsymbol{s})dt + e^{-rdt} \sum_j \Pr(i \to j) \cdot E\left[V_j(\boldsymbol{P_t} + d\boldsymbol{P_t}, \boldsymbol{s} + d\boldsymbol{s}, t + dt)\right] \right\} \qquad (3)$$

where i, j: State of fuel supply and nuclear, t: time step, $V_i(\boldsymbol{P_t}, \boldsymbol{s}, t)$: discounted total energy system cost, $\boldsymbol{u}$: daily change of fuel stockpiles, $\boldsymbol{s}$: Stockpiles of crude oil and LNG, $\boldsymbol{Im}_i$: Import of crude oil and LNG, $Av(\boldsymbol{u}, \boldsymbol{Im_i})$: oil and LNG available in a day, $\boldsymbol{F}$: Power generation capacity, dt: Differential of time （=1 day）, $Stk(\boldsymbol{P_t}, \boldsymbol{u}, \boldsymbol{s})$: Daily O&M cost of fuel stockpile, r: discount rate, Pr (·): State transition probability, $TC(\boldsymbol{P}_t, \boldsymbol{Av}(\boldsymbol{u}, \boldsymbol{Im}_i), \boldsymbol{F})$: Daily total system cost

The relational expression of $V_i(P_t,s,t)$ and $V_i(P_{t+}dP_t,s+ds,t+dt)$ is derived by transforming those expressions into the partial differential equation. The total energy system cost is derived based on the boundary condition at the expiration. The following expression (4) and (5) are led by Ito's lemma (6) and (7), where variable X corresponds to fuel price P.

$$\begin{aligned} &dV_j(X, \boldsymbol{s}, t) = V_j(X + dX, \boldsymbol{s} + d\boldsymbol{s}, t + dt) - V_j(X, \boldsymbol{s}, t) \\ &= \left[\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial t} + a\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial t} + \frac{1}{2}b^2\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial X^2}\right]dt + b\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial X}dZ + V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t) - V_j(X, \boldsymbol{s}, t) \end{aligned} \qquad (4)$$

$$a = \alpha(log\theta_t - X_t), b = \sigma \qquad (5)$$

$$dX_t = \alpha(\mu - X_t)dt + \sigma dZ_t \qquad (6)$$

$$df_{X_t,t} = \left[\frac{\partial f}{\partial t} + \mu_{X,t}\frac{\partial f}{\partial X} + \frac{1}{2}\sigma_{X,t}^2\frac{\partial^2 f}{\partial X^2}\right]dt + \sigma_{X,t}\frac{\partial f}{\partial X}dZ_t \qquad (7)$$

Following equations (8) and (9) are obtained considering $E[dZ]$=0.

$$\begin{aligned} &E\left[V_j(X + dX, \boldsymbol{s} + d\boldsymbol{s}, t + dt)\right] = E\left[V_j(X, \boldsymbol{s}, t) + dV_j(X, \boldsymbol{s}, t)\right] \\ &= E\left[V_j(X, s + ds, t) + \left\{\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial t} + a\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial t} + \frac{1}{2}b^2\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial X^2}\right\}dt + b\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial X}dZ\right] \\ &= V_i(X, \boldsymbol{s} + d\boldsymbol{s}, t) + \left(\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial t} + a\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial X} + \frac{1}{2}b^2\frac{\partial^2 V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial X^2}\right)dt \end{aligned} \qquad (8)$$

$$\begin{aligned} V_i(X, \boldsymbol{s}, t) = \min_{\boldsymbol{u}} \Bigg[& TC(X, \boldsymbol{Av}(\boldsymbol{u}, \boldsymbol{Im}_i), \boldsymbol{F})dt + Stk(X, \boldsymbol{u}, \boldsymbol{s})dt + e^{-rdt}\sum_j Pr(i \to j)\, V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t) \\ & + e^{-rdt}\sum_j Pr\ (i \to j)\left\{dt\left(\frac{V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial t} + a\frac{\partial V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial X} + \frac{1}{2}b^2\frac{\partial^2 V_j(X, \boldsymbol{s} + d\boldsymbol{s}, t)}{\partial X^2}\right)\right\}\Bigg] \end{aligned} \qquad (9)$$

Through the computational simulation of the above equation (9), the optimal operation of crude oil or LNG stockpile can be theoretically identified under the risk of nuclear supply disruption assumed appropriately in Pr (·) (State transition probability). As a future challenge to be considered, the author attempts to conduct the evaluation of the optimal installed capacity of fuel stockpiles in a long-term perspective.

4. CONCLUSIONS

The Fukushima nuclear accident has necessitated the fundamental review of Japan's energy supply portfolio and is a turning point for the country to rethink energy, environmental and nuclear policy acclimating to the socio-economic situation after the Fukushima. For developing effective long-term energy policies, it is important to optimize the country's energy mix, considering contingency risk such as nuclear severe accident which has actually and dramatically changed the country's energy balances. This manuscript reviews the transition of energy supply/demand in Japan after the Fukushima and discusses the energy modeling approach to consider nuclear accident as contingency risk by applying stochastic dynamic programming.

In a bid to appropriately revise its long-term energy policy, various uncertainties need to be considered, and the discussion over long-term energy planning should be closely rooted in consistent and quantitative analysis based on certain mathematical tool. In this context, the proposed approach such as stochastic dynamic programming in this manuscript is expected to provide insight for developing effective energy policies. In realities, however, discussing the best energy mix is not just an argument of identifying the optimal combination of energy source. Comprehensive discussion must be more done in multiple viewpoints for achieving the best mix such as the relationship between political measure and market mechanisms and the resource diplomacy toward energy consuming and producing countries.

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Measurements of risk perception and social acceptability

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ABSTRACT
The aim of this paper is to share basic descriptions of social aspects of the 3.11 disasters for the future discussions. Through questionnaire and media analysis, this paper tries to examine the diversity of "reality" of the 3.11 according to areas. As the result, I found that there were two implications. First, there was a diversity of damages and social conditions among devastated areas. This means that this disaster that struck so broad an area brought many kinds of "realities" to different areas. Therefore, we cannot treat them uniformly. The second point is related to this first point: there are clear differences of people's interests according to areas and gaps of attention between national, social, and local media. In addition, the rapid decrease of interest concerning 3.11 occurred in national and social media, while local media continued to face their "realities" at each site. Moreover, the damage of the 3.11 disasters continues.

INTRODUCTION
On March 11th in 2011, a huge earthquake and tsunami struck Japan and resulted in many victims. The earthquake and tsunami caused severe accidents at the Fukushima first nuclear power plants (NPPs). The impact and damages of these triple disasters, called "Higashi-Nihon-Daishinsai" or "3.11," continue to this day.

To consider various issues resulting from the 3.11 disasters, we must understand the continuing damages and social structural issues behind the devastated areas. Understanding this situation comes from more description and focus on "realities." In response to this need for understanding, we conducted a variety of investigations: collecting narratives, analysis of resident's attitudes toward the 3.11-related issues, analysis of social conditions of devastated areas, and quantitative media analysis.

The aim of this paper is to share basic descriptions of the 3.11 disasters. For this purpose, this paper takes description-oriented. Through a discussion of varieties of analyses, we try to look at social situations of 3.11 multilaterally.

RESULT

Basic description of the 3.11 disasters
For this horrible disaster, there were over 20,000 deaths and 290,000 people evacuated from their homes in Japan. Three prefectures in particular—Miyagi, Iwate, and Fukushima—were the most affected (for example, deaths in the Miyagi prefecture reached over 10,000). We summarize the number of victims, focusing on these three prefectures, in Table 1[40]. The tsunami wiped out several hundred kilometers of coastline in towns. Concerning causes of death, over 90 percent were caused by drowning, and about 65 percent of the victims were over the age of 60 (Cabinet Office, 2011). In addition, evacuation zones were set up after the NPP accident and many people were forced to leave their towns, particularly in the Futaba-are. Fig. 1 shows the current situation of the Namie-town, which was established as a mandatory evacuation zone after the NPP accidents. The town became available for short-time stays. The level of damage varied among the affected regions.

Although damaged areas of 3.11 are often regarded with the phrase "Tohoku" like a monolith, residents actually faced different realities from these disasters. Local towns which were seriously injured by the 3.11 disasters were aging populations, farming and fisheries workers, and generally economic disadvantaged areas than metropolitan areas such as Sendai, which is the biggest city in the Tohoku area. Although it does not suggest a direct relationship between social conditions and damages, it does show that local areas with those populations became victimized areas of 3.11.

Diversity of damages, social conditions of areas, and resident's attitudes concerning 3.11
In addition to the diversity of damages and social conditions of each area, we also have to focus on the diversity of interests among damaged areas. To draw this diversity of interests, we conducted an internet-based questionnaire and

[40] Table1 was represented first in R. Shineha (2013). And Figure 4 was represented first in M. Tanaka, R. Shineha, and K. Maruyama (2012).

collected 712 valid responses. In this survey, we compared the average of relative strength of interests of each area.[41] Fig. 2 show examples of the responses. As the result, we found that there are different interests according to area. In Miyagi and Iwate areas, interest in "earthquake" and "tsunami" were relatively higher with significant difference than other topics. The high score of "Kansai Area" in topics related to earthquake and tsunami can be interpreted as the effect of the "Hanshin-Awaji Great Earthquake" in 1995. On the other hand, "Fukushima" marked higher score in topics related to the NPP accidents and radiation.

Gap of attentions among variety of media

In this section, we present issues concerning media attentions. Through our comparison, it will be shown that there is a gap of interest among a variety of media such as national newspapers, local newspapers, and social media.

Fig. 3 shows the comparison of topic trends between newspapers and Web news. Compared to newspapers, Web news showed a rapid decrease in topics on the 3.11 disasters, but there were simultaneous increases in topics regarding "entertainment," "sports," "economics," and so on. Although this shift of center in topics is common for media, the difference of degree between media is illustrated. This result can be interpreted as newspapers continuing to take up 3.11 issues more actively than Web news and underpin public interests on the 3.11 disasters. However, we should not dismiss that topics of 3.11 in newspapers have also been dominated by topics regarding "NPP," and the topics of "earthquake and tsunami" were covered with them.[42] In summary, our analysis indicates that the "NPP" accident played a strong role in setting topics and engulfed interests on "earthquake and tsunami." At the same time, the return to daily life occurred. On Twitter, the rapid decrease of interest in NPP was found (data not shown). In the analysis of Twitter, we categorized a variety of topics like "NPP," such as "NPP accident," "Nuclear power policy," etc. In the aftermath of the NPP accidents, tweets regarding "NPP" occupied over 10 percent of all tweets, however, by the third month after the disasters, the coverage decreased to less than 2 percent.

Fig. 4 shows the timeline change of appearance ratio of three keywords of *Asahi newspaper*, *Yomiuri newspaper*, *Kahoku-Shinpo*, and *Fukushima-Minpo*. *Asahi* and *Yomiuri* are the most famous newspapers with a large circulation in Japan. *Asahi* has a liberal-pole, on the other hand, *Yomiuri* has conservative-pole. *Kahoku-Shinpoi* is the most famous and important block newspaper in the Miyagi Prefecture. *Fukushima-Minpo* is a key local newspaper in the Fukushima Prefecture. It is clear that different trends exist among those newspapers. In national newspapers (*Asahi* and *Yomiuri*), the appearance ratio of "earthquake" gradually decreased and on the other hand, the ratio of "NPP" increased. At the same time, "tsunami" marked a lower score than "NPP." The papers *Kahoku-Shinpo* and *Fukushima-Minpo* had a rather different trend. In *Kahoku-Shinpo*, the appearance ratio of "tsunami" was equal to "NPP." And in *Fukushima-Minpo*, the appearance ration of "NPP" was much higher than the other three newspapers.

CONCLUSION AND DISCUSSION

As summary of our analysis shows, there were two implications. First, there was a diversity of damages and social conditions among devastated areas. This means that this disaster that struck so broad an area brought many kinds of "realities" to different areas. Therefore, we cannot treat them uniformly. The second point is related to this first point: there are clear differences of people's interests according to areas and gaps of attention between national, social, and local media. In addition, the rapid decrease of interest concerning 3.11 occurred in national and social media, while local media continued to face their "realities" at each site. Moreover, the damage of the 3.11 disasters continues.

Disaster struck local sites but the discussion of reconstruction process related to national level regulations. Considering previous discussions of media studies, it can be say that gaps of attentions between national/social media and local media will influence the distribution of capitals and social interests during reconstruction process through their agenda and frame building process. Through our group-interview like dialogue (Lesson-learning), local journalists often said that they felt weak to set the agenda process at the national level. Briefly, the locals were made "periferized" and agenda-setting was developed in the "center" without enough care for local contexts and diversity of "realities". While the situation continues, the gap of

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[41] We defined nine areas. In this paper, I show results of Miyagi and Fukushima. In addition, we calculated the relative strength of interests, defined as the subtraction of interested score of individual topics from the average score of the respondent for all topics.

[42] In addition to Figure 3 and 4, we also conducted other analyses. As the result of our co-word network analysis, we found that there were strong and dense connections between keywords clusters "earthquake and tsunami" and "NPP." In addition, results from a timeline analysis of the change of contents uploaded in blog entries showed that the contents "earthquake" and "tsunami" rapidly decreased. After the decrease of "earthquake" and "tsunami," "radiation exposure," and "NPP accident" rapidly increased but interests in them was not sustained. The remaining and stable interest was about "low radiation exposure" and "internal exposure." (Tanaka, Shineha, and Maruyama 2012).

reconstructions has been spread gradually according to gaps of damages and social conditions of areas. However, attentions continue to decrease.

ACKNOWLEDGEMENT

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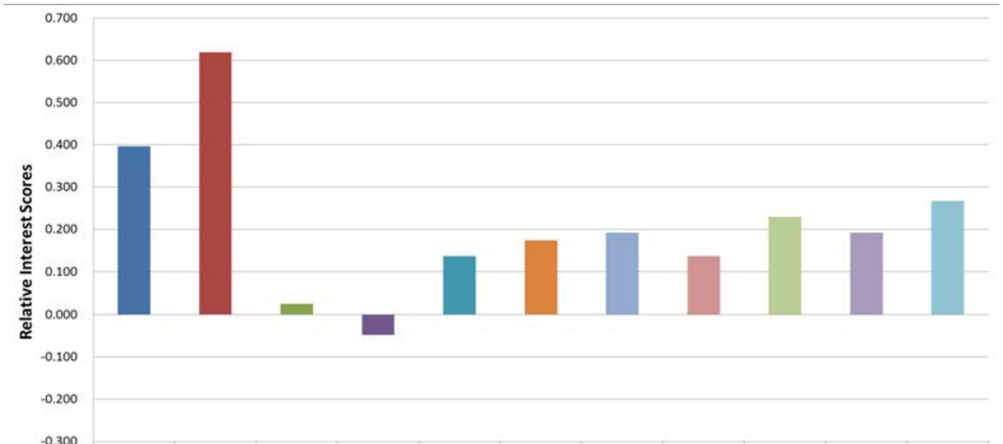
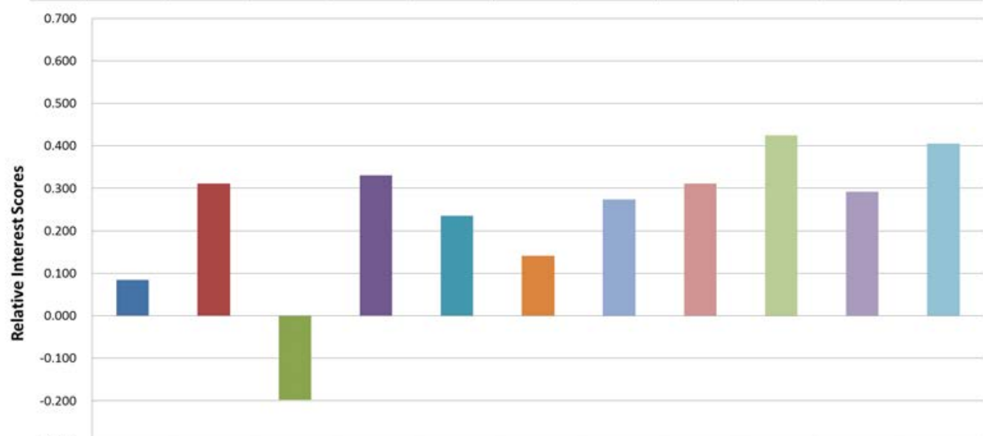
Table.1 Breakdown of damage

		Iwate	Miyagi	Fukushima
Human damage	Death	5113	10487	3558
	Disappeared	1132	1274	3
	Evacuee (to other Prefecture)	34662 (1441)	88736 (6813)	126889 (45279)
Collapse of buildings/ houses	(Complete or half destroyed)	25706	238110	94825

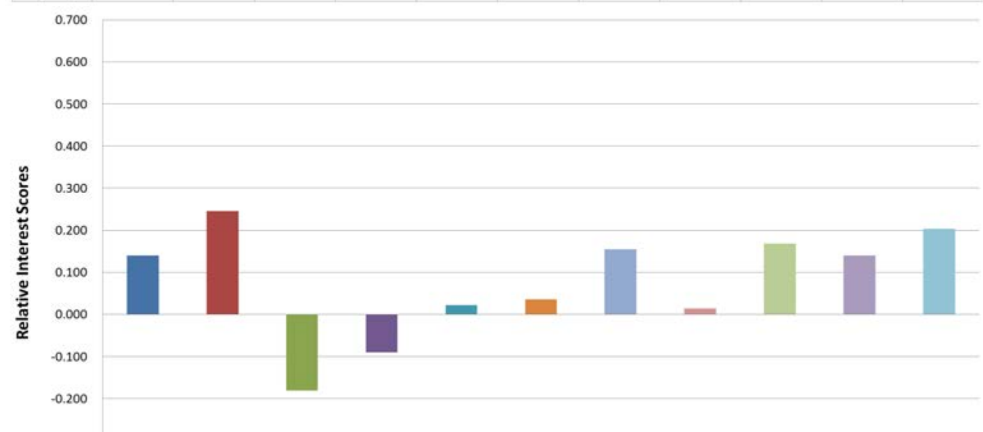
Fig. 1: Namie-town collapsed by earthquake and isolated for the NPP accident（April 11, 2013）



	Damages by earthquake & tsunami	Recovery from earthquake & tsunami	Disaster prevention countermeasures of local towns	Compensation of the NPP accident	Effects on human health of low/internal dose	Food Contamination of radiogen	Resume operations of NPPs	Disposal of High Level Waste	Future of Nuclear energy	Future of thermal and natural power system	Decommissioning of reactor
Miyagi (n=54)	0.396	0.619	0.026	-0.048	0.137	0.174	0.193	0.137	0.230	0.193	0.267



	Damages by earthquake & tsunami	Recovery from earthquake & tsunami	Disaster prevention countermeasures of local towns	Compensation of the NPP accident	Effects on human health of low/internal dose	Food Contamination of radiogen	Resume operations of NPPs	Disposal of High Level Waste	Future of Nuclear energy	Future of thermal and natural power system	Decommissioning of reactor
Fukushima (n=53)	0.085	0.311	-0.198	0.330	0.236	0.142	0.274	0.311	0.425	0.292	0.406



	Damages by earthquake & tsunami	Recovery from earthquake & tsunami	Disaster prevention countermeasures of local towns	Compensation of the NPP accident	Effects on human health of low/internal dose	Food Contamination of radiogen	Resume operations of NPPs	Disposal of High Level Waste	Future of Nuclear energy	Future of thermal and natural power system	Decommissioning of reactor
Tokyo areas (n=143)	0.141	0.245	-0.181	-0.090	0.022	0.036	0.155	0.015	0.169	0.141	0.203

Fig. 2: Public attitude toward the 3.11 related topics.

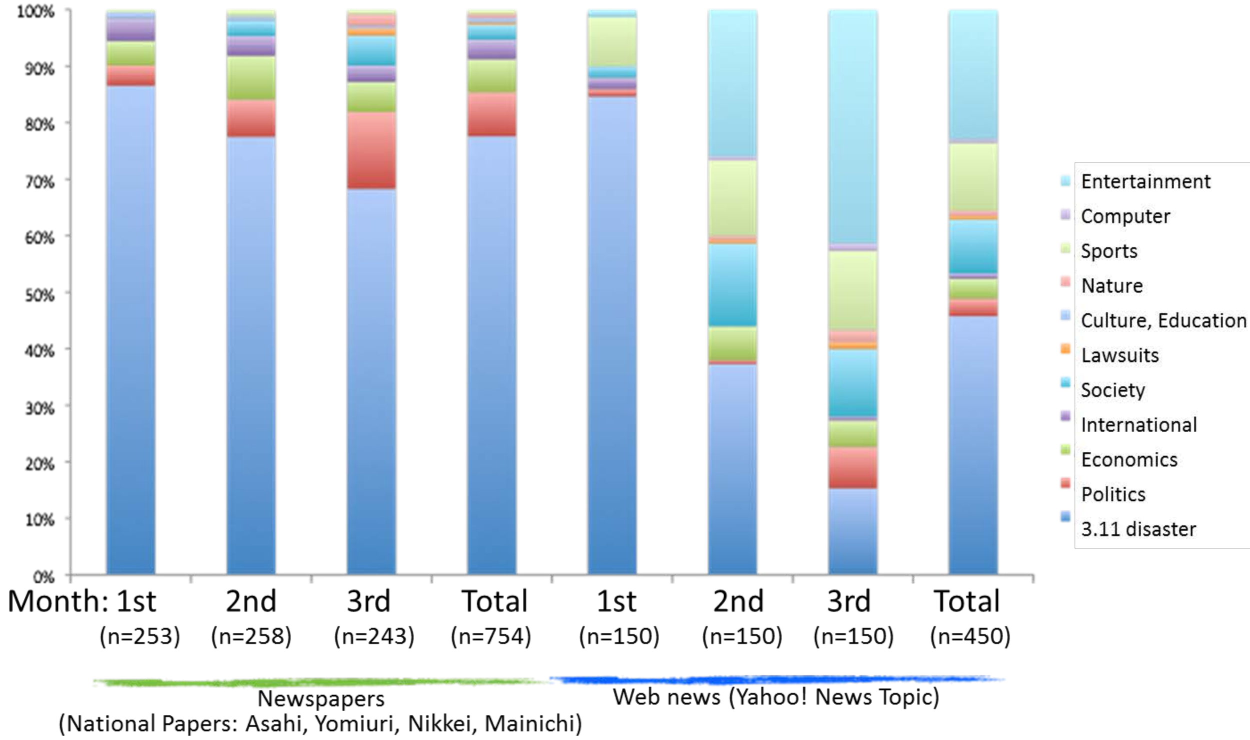


Fig. 3: Time-lined change of appearance ratio of topics during first 3 months in newspaper and web news

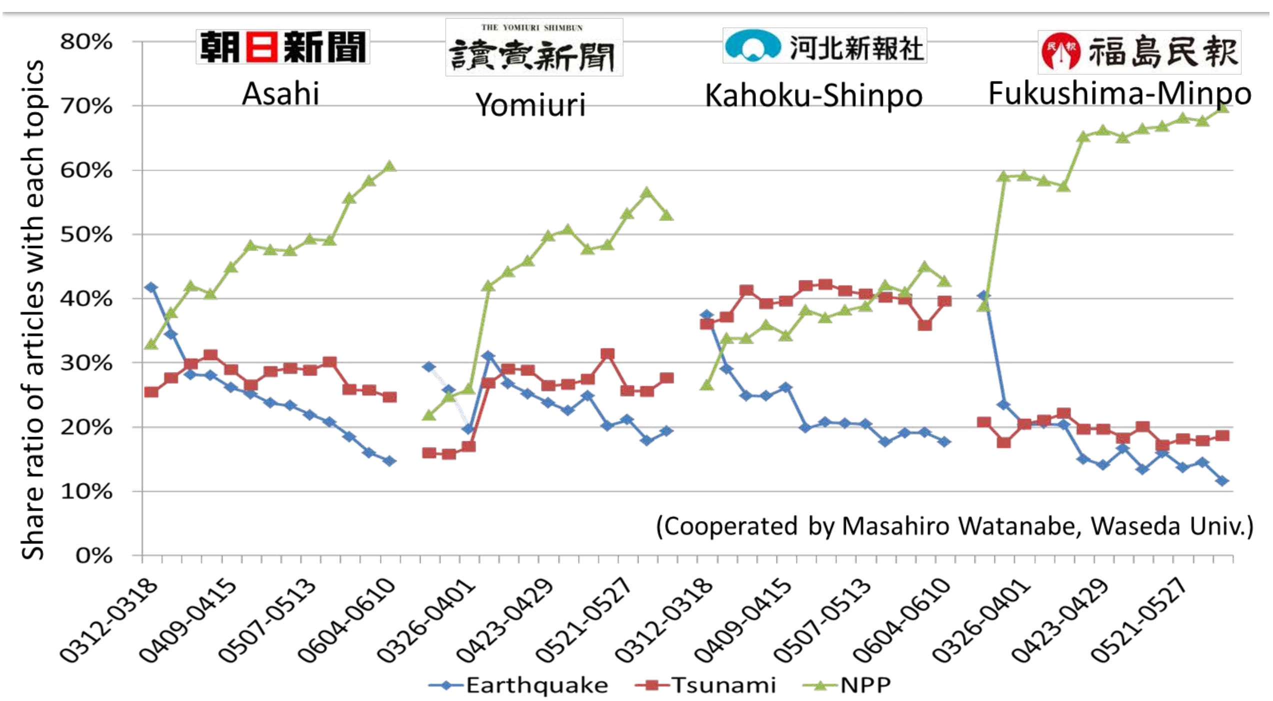


Fig. 4: Time-lined change of keywords appearance of national and local newspaper during first 3 months

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Development of a knowledge management system for energy driven by public feedback

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INTRODUCTION

In the era of information technology a large amount of data is readily available at everyone's fingertips. Energy and its implications, scarcity or abundance of resources, impact on climate change, emissions of pollutants, and more are topics of global interest that receive strong attention across all media. Opinions, official statements, and scientific data create a continuous flow of information. Nuclear energy among all sources is the subject of strong debates with cohorts of supporters and detractors ready to pinpoint its benefits or its drawbacks, respectively. In this large pool of information, it is of paramount difficulty even for field experts to isolate scientific data on energy, and to select reliable and coherent sources. Furthermore, higher quality data are often packaged in scientific jargon and are presented in forms and ways to which the general public does not relate (e.g. investment NPV, Sox produced, GDP impact, etc.). The Nuclear Engineering Department at the University of California, Berkeley, in collaboration with the Industrial Engineering and Operations Research Department and the University of Lincoln in the United Kingdom, is proposing to create an open web platform that (1) makes high-quality scientific data on energy sources readily available, (2) assembles those data into metrics more suitable to the general public's knowledge and interest (e.g. impact on the family's budget or green house gas emission), and (3) visually renders such information in a straightforward manner. Through this platform users will be able to create "energy portfolios" by mixing energy sources and evaluating how different choices impact the metrics they are interested in. Rather than a top-down approach, the platform will solicit feedback from the end-user on the prioritized topics as well as contribute additional topics with help of a knowledge management system.

FUNCTIONALITIES OF THE ENVISIONED PLATFORM

The proposed web platform will include two major components: a user opinion component with working name "Energy Report Card" and an information component with working name "The Energy Challenge".

The "Energy Report Card" integrates elements from the Opinion Space project (http://opinion.berkeley.edu/) and the California Report Card project (http://californiareportcard.org) developed at the CITRIS Data and Democracy Initiative and informed by work done by the World Bank on the use of report cards as assessment tools of government performance. The Energy Report Card gathers feedback on users' perceptions toward environmental, social, and economic impacts of energy sources. Upon entering the system users will be asked to assign a value from 0 "Strongly Disagree" to 9 "Strongly Agree" on six quantitative assessment questions that will be used to gauge each user's preference for environmental, social, and/or economic impacts as high priority issues (Figure **1**). For example, participants will be asked whether they believe global warming (environmental impact) is a high priority issue, whether job creation (social impact) from energy production is a high priority issue, and whether energy cost stability (economic impact) is a high priority issue, among others.

Participants will then enter "The Energy Challenge" where they will be presented with an energy portfolio that matches their personal environmental, social, and economic interests. Participants will be able to adjust the different energy sources composing their energy portfolio. As they add and remove components to the portfolio they can observe how the selected metrics respond to each change. Additional text, graphics, videos, and links will also be provided through the page to explain the correlations between sources and metrics (similarly to what is done in the "California Budget Challenge"). Unrealistic scenarios, i.e. 100% nuclear energy or 100% solar energy, will prompt a warning message with an accurate and straightforward explanation of why such scenarios are unrealistic. A visual rendering system will be developed to visualize the outcome of the users' choices in intuitive ways. For example, users could choose to visualize a comparison of the volume of waste created by each source, or visualize the fraction of US territory that needs to be used for each source on a US map. Users will finally have the option to share their personalized energy portfolio and metrics of choice through email and social media.

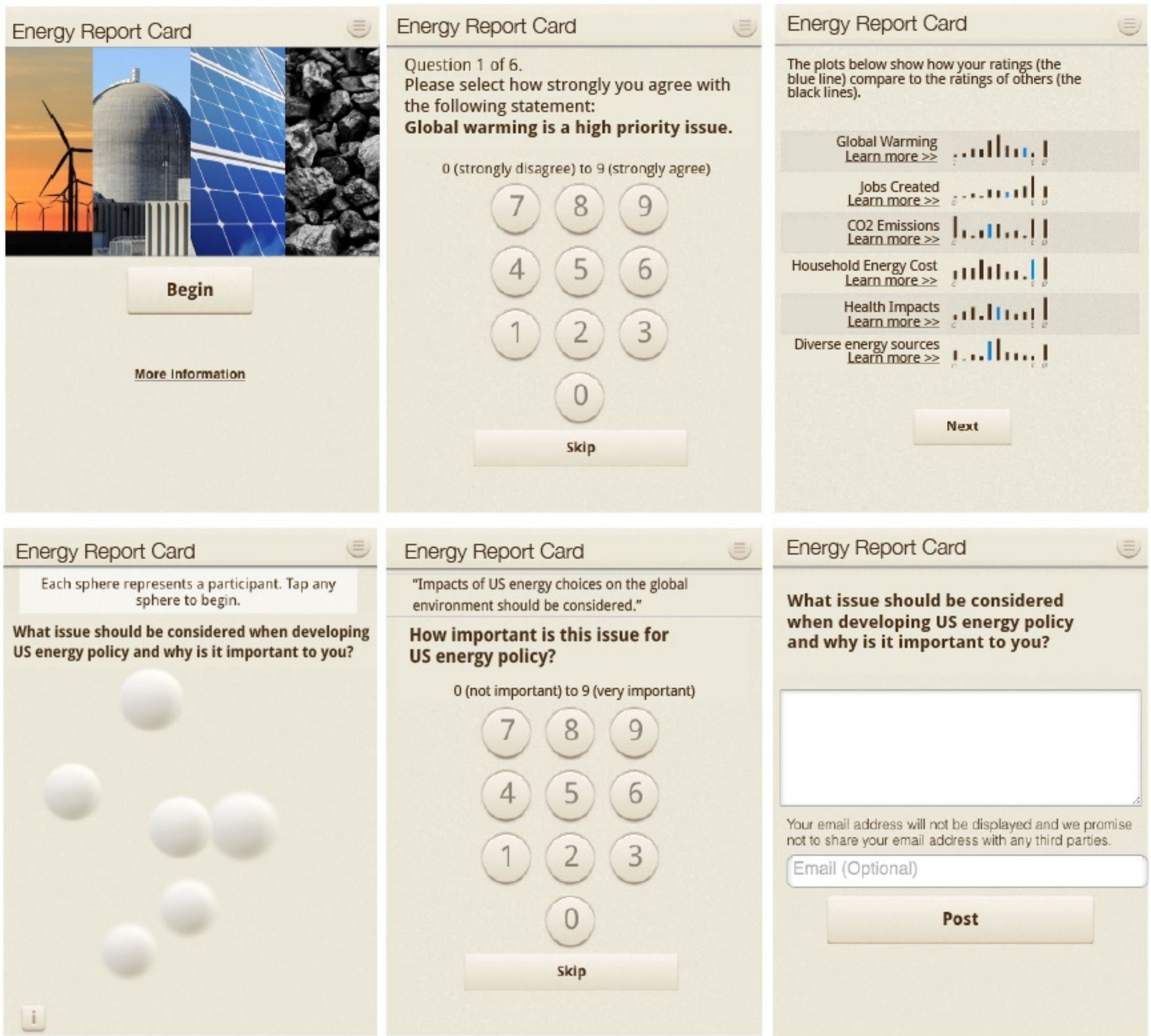

Figure 1. Example of the structure and functionalities of the "Energy Report Card". The panels from left to right, top to bottom show: introductory panel; example of quantitative assessment; individual vs. average assessment distribution; 2-D Principal Component Analysis display; assessment of opinions of other users; user input panel. This example was adapted from the "California Report Card" and actual name, content, metrics, functions, and graphics will be developed as part of the proposed project.

After completing "The Energy Challenge", participants will then enter the final portion of the "Energy Report Card" where they will be able to suggest additional issues they believe are important to consider when designing an energy portfolio. Participants will also rate the importance of others' suggestions, enabling crowd-sourced insights. We apply Principal Component Analysis (PCA) to display each participant's suggestion on a two-dimensional plane. Each user is represented in the system by a sphere (see bottom left panel in Figure **1**). To avoid overcrowding, we load only a few spheres onto the plane at a time. In a first step, we associate each user with a k-dimensional vector: one entry corresponding to each response to the assessment questions. We then apply PCA to the set of vectors and the algorithm returns a two dimensional (x,y) location for each participant. This point corresponds to the top 2 eigenvectors of the covariance matrix. We then center the visualization on the user's (xp,yp) position, and then arrange the spheres in the new coordinate space. Spheres in closer proximity represent users who responded to the assessment questions similarly. This allows users to immediately see how people similar to them feel about what issues should be considered when developing an energy portfolio. Spheres that are larger in size represent users whose suggestion has been rated as highly important by others.

EVALUATION METRICS

The metrics that we will use to gauge public perception of energy and its sources must be familiar to the general public rather than technical. At the same time the significance and relevance of such metrics will be guaranteed following a well-established framework. The United Nations World Commission on Environment and Development (WCED) in the 1987 defined sustainable development as the *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* [1] A typical framework, empowering this definition is the "Triple Bottom Line" [2]. The Triple Bottom Line (3BL) is a framework, well established in the scientific literature as well as public-oriented publications, with three key elements: social, environmental (or ecological) and economics. It provides a holistic perspective to assess the sustainability of several engineering solutions. A state-of-the-art framework to assess the sustainability of power plants and their life cycle (nuclear in particular) is provided in Reference 3. Regarding environmental indicators in particular, the US EPA has focused on determining and developing the best impact assessment tool for Life Cycle Impact Assessment (LCIA), Pollution Prevention (P2), and Sustainability Metrics for the US. This research led to the creation of TRACI—the Tool for the Reduction and Assessment of Chemical and other environmental Impacts. The methodology has been developed specifically for the US using input parameters consistent with US locations. Site specificity is available for many of the impact categories, but in all cases a US average value exists when the location is undetermined. The average values were implemented in the ecoinvent data. Further information is available at http://www.epa.gov/nrmrl/std/traci/traci.html. TRACI is therefore useful to compare different power plants and their life cycle. Unfortunately, these frameworks are hardly compressive for non-experts. In particular regarding the power sectors, people often have misconceptions that the tool envisaged by this research program will contribute to overcome. Some of the most relevant examples that we will address are:

(1) Thinking at technology level is inappropriate
- The same technology has different performances in different scenarios: e.g. technology X can have great performance in scenario A (desert with plenty of sun), poor performance in scenario B (north country with several rainy days).
- An electrical system to work in an efficient way (from technical and economical perspectives) needs the right mix of power plants: base load, peak load, ancillary services, etc.

(2) Energy cost is just one aspect of economics
- People need to distinguish between Production Cost (technology driven), Electricity Price (market driven) and Value (usage driven). Gas turbines working as spinning reserve are costly, get a high price, but are extremely valuable. A private company working in a market has, usually, the goal to maximize profits minimizing risk, not minimize production costs.
- Let us assume that technology A has an overall production cost (LUEC) of $100 per MWe and B $70 per MWe. Is B better than A? We need to include environmental issues, but also social. Let's think about social. Maybe B is not creating local national jobs, while B is more expensive, but the cost is boosting local/national economics.

(3) Global warming
- The majority of scientific publications say it is an issue. However, we still lack understanding of how citizens feel about global warming and their preferences for dealing with it. In a world (or nation) with limited resources it is important to prioritize budget allocations for important social, economic, and environmental issues. Identifying how citizens would allocate limited resources could provide insights into citizens' feelings toward global warming. For example, having $100 to invest—how much should be allocated to "cutting greenhouse gas emission", "funding cancer research", "paying for vaccinations in poor countries", "creating grants for student education", and "developing more sustainable food production techniques"?

This research leverages the state-of-the-art knowledge to create an innovative social engagement platform that will allow for key insights to emerge on public perception toward different energy sources, including perceptions toward different environmental, social, and economic impacts. The 3BL elements can be broken down into categories (and eventual sub-categories) and the categories in quantitative indicators. This framework, common for all the energy sources, differs for the specific values of each indicator, specific for the source considered. The key idea is to use indicators that are intuitive for the "average citizen". This indicator requires a "life cycle perspectives" and needs to be tuned from existing research and database (e.g. http://www.externe.info/). In this way the user can focus his/her attention on specific aspects.

We will give the option to the user to assign "weight" to different categories to obtain the "ideal ranking". For example, an "Environmentally sensitive user" can assign a high importance to the environmental indicators and/or categories and the system will return an energy portfolio that reflects these interests. There is precise set of mathematical methods to address in an exact way this issue, and they are built around the Multi Attribute Decision Making theories. The Analytic hierarchy process (AHP) is rather simple and straightforward [4], but if there are interactions between categories it is better to use the Analytic Network Process (ANP) [5]. The system, receiving the input from the user, will apply these methods for the ranking of different energy-mix alternatives. Figure 2 shows an example of three possible choices from three different users. This system will record the choice of each user and will display. The overall ranking calculated from all users. This information, “the voice of the average citizen”, will be of paramount importance paving the way for research and policy decision-making in the energy sector. At the present time there is very limited understanding about how the public addresses trade-offs between the different 3BL elements and which indicators are more relevant. Moreover, users will be asked to provide demographic information (e.g. zip code, gender, age, education), allowing for more in-depth analyses. This “feedback data” will be released in a public user-friendly way for the benefit of the public, policymakers and the scientific community.

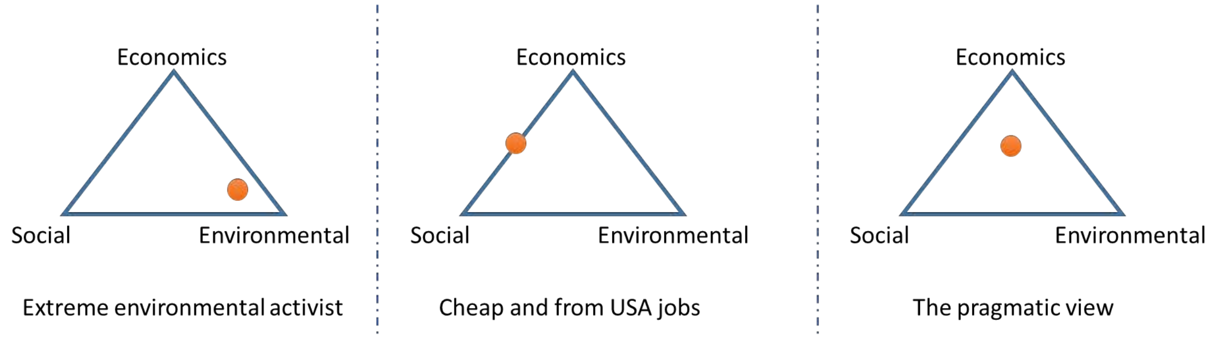

Figure 2. Example of the choices respect to three key elements by three hypothetical user’s profiles.

DISCUSSION

We expect that the development of a web platform for comparing energy sources through easy-to-relate-to metrics will promote dialogues between experts and the general public, and will enable exploration and visualization of the public’s points of interests, so that the policymakers can correctly understand the needs and priorities of their constituents. Unlike typical top-down approaches with predefined recipes and query items, the proposed system lets the end-user prioritize metrics of interest, provide additional metrics not originally included, provide suggestions and evaluate other users’ ideas. While such sense of trust is sought providing technically reliable data sources and models, interpretation into a straightforward rather than technical language is essential.

This platform will implement best practices derived from similar existing efforts like “my2050”, but it will largely depart from the underlying philosophy of such tools. We strongly believe that a visually attractive platform is necessary to attract users to engage with critical energy issues. Nevertheless, the success of the platform will be determined by the rate at which users return to the platform and make constant use of it. The unique features that we propose allow users to express their opinions and concerns, and to understand the impact of their choices on easy-to-relate-to metrics. We expect that the personalization aspect and the focus on the user’s interest, rather than providing a pre-packaged solution, will make the user want to come back and bring other users to the platform. Furthermore, energy policymakers in general will want also to come back to the site and continuously monitor it as data and metadata evolves with time and events. A transparent interface with social media will further facilitate users’ participation.

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5.4. Session 3 (3:50-5:50 pm): Barriers against Transition into Resilience

Objectives of the session: Recovery from nuclear accident refers to social representation of risks and cannot be limited only to technical issues or crisis management guidelines. In this view, we consider the various impediments and their interactions to the transition into resilience of the many actors of the civil society.

- Session Chair's remark (3:50-4:00 pm): Prof. Karl van Bibber (UCB, NE)
- Speaker 12 (4:00-4:15 pm): Dr. Aurélien Portelli (MPT), What cultural objects say about nuclear accidents and their way of depicting a controversial industry
- Speaker 13 (4:15-4:30 pm): Prof. Kohta Juraku (Tokyo Denki U.), Why is it so difficult to learn from accidents?
- Speaker 14 (4:30-4:45 pm): Dr. Sébastien Travadel (MPT), Decision making in extreme situations following the Fukushima Dai Ichi accident
- Speaker 15 (4:45-5:00 pm): Dr. Kyoko Sato (Stanford U.), Japan's Nuclear Imaginaries before and after Fukushima: Visions of Science, Technology, and Society
- Speaker 16 (5:00-5:15 pm): Prof. Kai Vetter (UCB, NE/LBNL), Institute for Resilient Community
- Discussions (5:15-5:50 pm)

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What cultural objects say about nuclear accidents and their way of depicting a controversial industry

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ABSTRACT
Nuclear accidents have provoked the creation of numerous cultural objects, such as novels, films, comics and posters. The objective of this contribution is to show what cultural objects can teach us about the social representation of the nuclear industry. Cultural objects are both representational products and agents. They can influence mentality and partly configure the cognitive framework of the controversy with the nuclear industry. Thus, they impose a diversity of practices defined by the interests and objectives of the communities which appropriate them. The documentaries on the Fukushima Dai Ichi accident present a coherent body of work to identify the elements of rupture or continuity in the history of social representation. Film makers have used the symbols, myths and analogies produced by Chernobyl to evoke Fukushima. They equally show that the Japanese accident has marked the end of the myth of soviet negligence, reactivated discursive elements of the antinuclear movement in French public debate and provoked a social rebirth in Japan.

Key words: Cultural objects, representation, controversy, catastrophe, mobilization of citizens.

INTRODUCTION

The Tower of Babel, in the eponymous painting by Bruegel (1563), represents *"the spiral of knowledge, the implacable hive of activity, and the image of pride"* (Robert-Jones, 1997). In 1975, the graphic artist Pierre Brauchli reproduced this painting in poster form, finishing the top of the edifice with the cooling tower of a nuclear reactor. The poster was displayed in 1979 at an anti-nuclear campaign in Switzerland. It symbolizes the technological outrageousness of man, and the catastrophe that it could generate.

This illustration reflects the social fear which came true with the Chernobyl nuclear accident and happened again 25 years later with the Fukushima Dai Ichi nuclear accident. The commentaries related to the event give a tragic dimension to it, as indicated in the article in the French newspaper *Le Monde Diplomatique* entitled "Nuclear Japan or the hubris punished" (avril 2011). The media comments incessantly on the Japanese catastrophe which has become a major element in the controversy of the nuclear industry. Certain representations which fell dormant after the dust settled from "the battle of Chernobyl" were reactivated in collective thinking and taken up again in novels, films and graphic works. These productions called "cultural objects" have interacted with pre-existing images resulting in the production of new ones.

The aim of this contribution is to show what cultural objects can teach us about representing nuclear accidents and the industry. The first part defines the terms: "representation", "sociotechnical controversy" and "cultural objects". The second part describes the specificities of cultural objects, both as representational products and agents. And finally, the third part deals with the consequences of the Fukushima nuclear accident on social representation using the case study from French documentaries on the subject.

DEFINITION OF THE CONCEPTS

Generally speaking, social representation manifests itself, on the one hand, as the sum of content, and on the other, as a process that can modify thinking and behavior. Moscovici defines two major processes in their creation: objectification and integration (1961, 1976). Objectification corresponds to the origin and formalization of knowledge concerning objects. It allows for the materialization of the meaning of things and facilitates exchange (Valence, 2010). Integration enables assimilation into the mentality of society (Seca, 2010). It corresponds to the manipulation of objects, which allows the players to use it in real terms and can lead to a change in mentality.

Different analytical models then appear as structural analyses (Jodelet, 2006). These design social representation as systems composed of central cores and peripheral systems (Abric, 1976). The central core is the key element of the representation. It is characterized by its stability and its capacity to resist change in context. Peripheral systems are more permeable to change. They are subordinate to the core and ensure the link between the elements at the center and the social realty of the object. They allow representation to adapt to context while protecting the central core.

The study of social representation is based on the analysis of several types of data: interviews, questionnaires, related texts and images (archives, novels, press articles, caricatures, paintings, comics, photographs, films). This content creates the symbols and images from which social representation is formed and can cause major social controversy, such as with nuclear technology.

A socio-technical controversy refers to a public debate where opposing opinions are used to interpret a particular object or technical system. The development of nuclear energy caused no controversy in France until the end of the sixties (Topçu, 2013). Following the announcement of the Mesmer Plan[43], the anti-nuclear movement started to get organized and intensify its activities. Activists rejected its large scale development with sabotage, bomb attacks and confrontation with the police. In response industry stakeholders organized a successful information campaign to reassure the public, who had generally always been in favor of atomic energy. As for the resistance movement, it declined at the end of the seventies.

Chernobyl marked a rupture in the history of nuclear energy. Anti-nuclear protests declined and the form of action changed (creation of independent laboratories, increase in the number of emergency notification calls). New groups appeared in the nineties, however they had less impact than those in the seventies.

The debate was revived with the Fukushima catastrophe. The media started investigating the safety of sites, the management of waste, the feasibility of the industry, working conditions of subcontractors as well as the viability of decommissioning. France however has refused to abandon its nuclear program. The controversy will continue long term based on strong, clear collective identities and practices that are appearing in the production and the reception of cultural objects.

These refer to textual, iconic, cinematic and other productions that convey a reconstructed vision of the world and participate in the creation of social representation. Their form is determined by more or less rigid codes depending on the type of object. They are diffused in reception communities of varying cohesion and size. Their influence on social reality is therefore difficult to evaluate, so researchers must gather information separately from these works. They can do this by confronting cultural objects with other sources to determine their function in public areas and their contextual importance, or by examining how they are perceived by critics. However, the comparing of them must not be to the detriment of the internal analysis of the object, which is the starting point of research.

Cultural objects on nuclear accidents show great diversity in form and content. Nevertheless, they all deal with their subject from a dramatic angle, showing the consequences of disaster both on man and the environment. The distinction between nuclear power plant and nuclear weapon representation is not always clear in cultural objects. This comes from the referent symbols of an imaginary radioactive world, influenced by the A bomb fear generated during the Cold War and the risk of nuclear weapon proliferation. An example is found in the *Treehouse of Horror XV*[44], when Homer Simpson blows up the Springfield nuclear power plant, provoking the destruction of the city in the same way as Little Boy razed Hiroshima.

Cultural objects are more or less close to reality. The classification of fiction films, based on the criteria of realism, defines a typology applicable to the entire corpus. Films can evoke a narrowly avoided fictitious accident (*China Syndrome*[45]), a fictitious accident which happened (*The Mount Fuji in Red*[46]), a real accident (*Land of Oblivion*[47]), and a real accident followed by a fictitious accident (*The Land of Hope*[48]). The connection of imaginary can therefore produce an infinite number of possible interactions. This creative dynamic shows the discursive potential of cultural objects, which have a double link with social representation.

THE INTERACTION BETWEEN CULTURAL OBJECTS AND SOCIAL REPRESENTATION

Firstly, we can consider cultural objects as products. Their analyses imply that this point of view clarifies the elements of continuity or rupture that nuclear accidents cause in the perception of risk and in their relationship with the system of representation of social reality.

The infinite consequences of Chernobyl constituted a radical change that manifested itself with the evacuation of vast territories as well as the invisible threat of radiation (Le Breton, 2012). For Ulrich Beck, man has always separated his own

[43] The Prime minister Pierre Messmer announced a reinforcement of the nuclear program in march 1974.
[44] M. GROENING, *The Simpsons - Treehouse of Horror XV*, Season 16, Episode 1, 20th Century Fox TV & Gracie Films, 30 min. (2004).
[45] J. BRIDGES, *China Syndrome*, Columbia Pictures, 122 min. (1979). The film came out in the American cinemas twelve days before the Three Mile Island accident. It popularizes the scenario of the “China Syndrome”, which shows the risk caused by the corium to drill through the reactor tank, then the concrete of the protective casing and to drive through the earth, to reach symbolically China.
[46] A. KUROSAWA, *Dreams – The Mount Fuji in Red*, Warner Bros, 119 min. (1990).
[47] M. BOGANIM, *Land of Oblivion*, Les Films du Poisson & Arte France Cinéma, 108 min. (2011).
[48] S. SION, *The Land of Hope*, Rapid Eye Movies & Third Window Films, 133 min. (2012).

sufferance, misery and violence from others (1986), but Chernobyl put an end to that detachment, making it impossible to exclude the dangers of the nuclear era for all mankind.

In this manner, from an apocalyptic back-drop, cultural objects translate the violence of this technology and interpret it as a form of transcendence. This can be illustrated for example when facing the protective concrete casing covering the Chernobyl nuclear power plant, where the observer is overcome by *"sacred terror"* (Dupuy, 2006) . Or in the film *The Mount Fuji in Red*, the eruption of the volcano provoked the explosion of all the Japanese nuclear power-plants. The sequence connects cataclysm to spirituality, creating a representation of divine punishment, which is on the one hand specific (the mountain is venerated by the Japanese) and on the other hand universal (the myth of the end of the world present in all cultures). The representation therefore reveals technological pretentions of modern society and the helplessness of man facing unchained forces.

The Chernobyl accident modified contemporary thought. At times it has been compared to the Holocaust or Hiroshima, unveiling a new world (Dupont, 2003), leading cultural actors to reflect on the possibility of representing the "invisible evil" and its impact on the perception of reality. The manipulation of colour plays a key role in getting round the problem of "impossible representation". In *The Mount Fuji in red*, the explosions of the nuclear power plants produce long vapour trails of red and purple loaded with radio-active particles. One of the survivors explains this strangeness: *"The stupidity of man is limitless. Radio-activity is not visible so we have invented a technology which colours it as it spreads through the air"*[49]. The idea here associates the nuclear industry with a sector as dangerous as counterproductive. The chromatic process is used again in *The Land of Hope.* An accident occurs in the Nagashima nuclear power plant – the contraction of Nagasaki, Hiroshima and Fukushima. An inhabitant goes to a clinic and finds out she is pregnant. As she is leaving the clinic she notices that outside a red cloud is obscuring the road - reverse angle and close up of the woman. Red, the symbol of the radio-active hell, is reflected in her eyes. The illusion disappears in the blink of her eyes but the character remains possessed by the fear of contamination.

The sensory impact of the accident is evoked differently in the comic book "*Un printemps à Tchernobyl*"[50] in which Le Page describes his stay in the forbidden zone in 2008. A double page shows a landscape at dusk, in the foreground electric pylons, the symbol of the "electricity fairy" and modern society. In the background, a threatening, rising shadow is represented in the form of a haunted house. The chiaroscuro and violence of contrast reinforce the lugubrious heaviness of the scene. Images of the zone follow. A tropical forest suddenly appears, breaking away from the previous dark images. Changing from this iconic style, Lepage shows a world without men, where nature transformed, reasserts itself. The author describes his malaise: *"What I see before me, what I am drawing, is not the truth! I don't see disaster, but an explosion of dazzling colors. (…) How do you draw the invisible?"*[51]. The shameless beauty of form and colour seems to end in a betrayal of reality. This is the specific characteristic of the representation of radioactive space, the construction of which depends on the contradictory phenomenological elements of its composition.

Cultural objects correspond to a reorganization of social reality. They obtain their substance from symbols and myths which fuel the collective imaginary world. The creation of objects then produces new images, which in turn play a role in the representational process and the creation of social interaction. Cultural objects are therefore not only products but also agents, which can influence mentality and partly configure the cognitive framework of the controversy with the nuclear industry. They generate a diversity of practices defined by the interests and objectives of the communities which appropriate them and can play an instrumental role especially when the groups are led by strong ideological concerns. Consequently their use can turn out to be strategic, allowing the members of groups to mobilize and act, rallying people who would normally be less concerned by their cause.

The antinuclear movement provides a multitude of examples to illustrate this function of cultural objects. A good example is the online shop of "Réseau Sortir du Nucléaire" (a French antinuclear network). It offers its visitors a range of derivative products including a poster called *"La Gaule sous occupation nucléaire"*[52]. The poster parodies the map found at the beginning of all the *Astérix* comic books. It shows the occupation of Gaule by the Romans after the conquest of Caesar, however in this case France is occupied by nuclear power plants and prophesizes a nuclear disaster in the country. Located on the Atlantic coast, is a place named "Tsunamus", while the Chinon power plant is called "Fukushinum". The image thus refers to a very representative cultural object of popular French culture to condemn the massive presence of the nuclear industry in the country. It allows for the diffusion of ideas from the anti-nuclear network and the reinforcement of activist identity by creating cultural content which can be easily used by individuals.

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[49] A. KUROSAWA, *op. cit.*
[50] E. LEPAGE, "*Un printemps à Tchernobyl*", Paris, Futuropolis, 163 p. (2012).
[51] *Ibid.*
[52] B. AFLALLO, "*La Gaule sous occupation nucléaire*", affiche sur papier recyclé, 29,7 x 42 cm.

This section focuses on the characteristics of the cultural objects on nuclear accidents. These objects provoke the interaction of cultural references, whose analyses allow access to social representation by means other than interviews or surveys. Cultural objects are both products and agents in the circle of representation. This double function is particularly visible when considering every day type conversations which generate social representation. Such work fuels a discursive dynamic and stimulates the production of new images.

Concerning the nuclear industry, the production and circulation of content define the areas of battle that groups involved in the controversy must conquer. Indeed, no one can influence decisions and behavior without before modifying the representations that are linked to them. The way of representing the industry can therefore, depending on the context, become an important concern in determining energy policy.

The analysis of content must not however be carried out to the detriment of a more esthetic approach to representation. The iconic and narrative dimension of cultural objects, by their capacity to formalize the data of a piece of work, plays a significant role in the building of knowledge and understanding of the world. The study of form (film, comics, etc.) is indeed of key importance when identifying the elements of rupture or continuity provoked by an event. The cultural objects produced by Fukushima constitute, on this point, a field of investigation that is pertinent for defining the meaning that societies have attributed to the accident.

THE REPRESENTATION OF FUKUSHIMA IN DOCUMENTARIES

Among these objects are found the French documentaries on Fukushima. Their intent is to present a coherent body of work, which upon analysis allows one to determine the impact of the accident on social representation. "*Le monde après Fukushima*"[53] gives an ambiguous representation of the disaster by superposing its natural and technical aspects.

A dolly shot reveals a devastated landscape resulting from the earthquake and tsunami. According to the commentary, the accident was provoked by these two factors. However, the causes are found in the flaws in the Japanese system. The words distort the images by assimilating the destruction caused by the earthquake, the tsunami and the accident. This presents an open ending and illustrates the theory of society at risk with "the invisible evil" diffusing on a planetary scale. "*Fukushima, vers une contamination planétaire*"[54] reveals that tuna caught off the coast of San Diego have been contaminated by radioactive waste, making consumers worldwide potential victims of the contaminated waste from the accident.

This is equally represented as a repetition of history as in dolly shot in *Le Monde après Fukushima* which ends in a fade effect of merged, archive footage of Hiroshima, filmed on august 6 1945. The Hiroshima-Fukushima combination becomes the contraction of the one and only atomic catastrophe. Fukushima has been placed in the linage of huge nuclear crises. The account of the accident in "*Catastrophes nucléaires*"[55] suggests that other accidents will happen as long as the warnings of TMI and Chernobyl are not taken seriously. And as many, if not more will happen, as with the Japanese accident, which was predicted and became a reality.

The documentaries emphasize the lack of reactivity and the incompetence of the actors in the crisis. "*Catastrophes nucléaires*" criticizes the non-professionalism of TEPCO and discredits the Naoto Kan Government. Nuclear crises are long term affairs. The text on the black screen, at the end of *Welcome to Fukushima*[56], describes a terrifying scenario: the evacuation of more than 50 million Japanese if an earthquake of enormous amplitude occurs before TEPCO can empty the nuclear fuel pools of the power plant. Apocalyptic scenarios are only prolonging the ongoing catastrophe. The men in charge of the rehabilitation and the decontamination of the site are thus subjected to extreme work conditions. The exploitation of their bodies represents the dark side of the post-accident operations and is a reminder of the soviet liquidators.

The social dimension of the crisis is also very present. A wide shot of a gymnasium transformed into a reception center, appears in "*Japon: nucléaire, la filière du silence*"[57]. A horizontal pan shot shows the living conditions of the nuclear refugees. They are grouped together in conditions with a total lack of privacy, waiting to find housing. The authorities seem to have underestimated the extent of contamination. In "*Fukushima, une population sacrifiée*"[58], a technician from the CRIIRAD[59] is measuring radioactivity in a Fukushima City primary school. Filmed but out of view, he reads the figures indicated on his electronic gage, while the pupils are getting ready for sport in the background. The depth of field shows the resignation of the authorities, who let the radioactive pollution root itself in the daily lives of the children. The radioactivity is

[53] K. WATANABE, "*Le monde après Fukushima*", ARTE France & Kami Productions, 117 min. (2013).
[54] L. CONINCK, "*Fukushima, vers une contamination planétaire*", Code 5, 52 min. (2014).
[55] C. LE POMELLEC, "*Catastrophes nucléaires: histoires secrètes*", Tac Presse & Canal+, 93 min. (2012).
[56] A. DE HALLEUX, "*Welcome to Fukushima*, Simple Production, Crescendo films, L'Indien Productions, 59 min. (2013).
[57] S. LEBRUN & C. BARREYRE, "*Japon: Nucléaire, la filière du silence*", Envoyé Spécial, 30 min. (2011).
[58] D. ZAVAGLIA, "*Fukushima, une population sacrifiée*", LCPAn & Scientifilms, 52 min. (2012).
[59] The CRIIRAD is an independent association from the State, whose aim is to check radioactivity levels and inform the population about risk.

isolating and fragmenting communities, announces the narrator in "*Fukushima, des particules et des hommes*"[60], preventing any return to normality in the contaminated territories.

The operations carried out by the workers and the fate of the population reflect a sacrificial system, the Japanese replica of the "nuclear Goulag" of Chernobyl (Ackerman, 2006 ; Tchertkoff, 2006). Faced with this extreme situation, criticism is rising in the archipelago. In "*Le monde après Fukushima*", the Japanese nuclear industry is associated with an autocratic form of governance. In "*Nucléaire: exception française*", the French nuclear industry is compared to an anti-democratic lobby and a dangerous industry, which necessarily generates a centralized police and military system. These discursive convergences seem to correspond to the anti-nuclear paradigm. This model of interpretation, based on the rejection of the authoritarian dimension of the nuclear industry, and the promotion of a more autonomist society, seem to be driving the film interpretations of the social consequences of the Fukushima accident.

This is bringing about a modification in mentality and behavior. The disciplinary culture of the Japanese is cracking up and the antinuclear movement is making significant progress. French opinion is also changing, according to the activists who were interviewed in "*Nucléaire la grande explication*"[61]. According to the antinuclear network, Fukushima has made the French population aware of the fact that safe nuclear energy is a fallacy. According to Greenpeace, local government representatives have realized that their towns, even if situated 30 km from a power plant, aren't protected from an accident: *"we believe it's the change in the field which will lead to the death of nuclear energy in France"* [62].

While waiting for the end of the nuclear industry, the narrator in "*Nucléaire, exception française*", reminds us of the Fukushima context. Germany and Switzerland have programmed their break from nuclear power. The Italians have stated by referendum that they are against the revival of the nuclear industry. Japan has stopped using of its nuclear power plants. But France refuses to give up on the atom: *"Our governments have made nuclear energy the religion of the state, defended by a powerful technocracy"*[63]. French dogmatism concerning nuclear power comes across as a hindrance to common sense: in spite of the accident, the state wants to preserve the nuclear industry, a symbol of France's independence and power.

In reaction to the nuclear crisis, documentaries have shown a mobilization of the Japanese population that has never been seen before. Volunteers have flooded in from all over Japan to help clean up the contaminated zones. Groups have been created to measure radioactivity and carry out other necessary tasks and the images we are seeing depict a range of positive interaction and incentives including the sharing of knowledge and skills, the setting up of support systems, the strengthening of links between man and nature and reflection on the sense of collective action. This neo-activism is confronting the hierarchical management system dealing with the disaster and we are witnessing the appearance of an alternative society driven by a profound desire for autonomy, capable of regenerating the foundations of democracy. The society that dreamed up the antinuclear movement of the seventies seems to be coming to life on the screen.

CONCLUSION

The development of nuclear energy has provoked a rebound controversy paced by the episodes which have affected the industry. The consequences of major accidents that have marred its history go way beyond the industrial framework and have become significant global issues. Cultural objects deal with this immeasurable dimension of nuclear disaster and provide researchers with the opportunity to question the formalization of representation. The analysis of esthetic process thus allows us to better understand the way that representational elements materialize in a particular cultural system. This materialization in reality provides a horizon for the study on cultural objects.

Research on documentaries offers several paths for reflection concerning the evolution of representation. Fukushima does not seem to have disrupted the figurative system of nuclear accidents. Movies on the subject depict a world which would be the duplication of Chernobyl. The soviet accident produced new sensitivity, new ways to show the invisible and to say the unsayable. It created a whole range of signs, almost a language that the films on Fukushima have used.

But the representation of Fukushima is not only the transposition of a Japanese Chernobyl – reiteration always produces it part of singularity. Fukushima thus marks the end of the myth of soviet negligence (Géal, 2011). Faced with a nuclear accident, even a great technological power like Japan is like a house of cards. Consequently it is not surprising that documentaries have provided a platform for anti-nuclear groups, as well as for them to appropriate some of their views, as they had envisaged a Fukushima type disaster a long time before.

[60] G. RABIER & C.-J. PARISOT, "*Fukushima, des particules et des hommes*", Kami productions & France Télévisions, 52 min. (2014).
[61] F. BIAMONTI, "*Nucléaire: exception française*", Morgane & Kami Productions, 70 min. (2013).
[62] J.-C. DENIAU, "*Nucléaire: la grande explication*", JEM productions, 75 min. (2012).
[63] *Ibid.*

The accident has reactivated discursive elements in public debate, such as the myth of safety, the nightmare of toxic waste, the exploitation of workers, “nucleocracy” and the desire for social independence.

However, Fukushima hasn’t managed to bury the nuclear industry in France, neither federate a national movement against nuclear power. Conversely, Japan was struck directly in the heart and experienced a social rebirth. The accident destabilized technological certitudes, condemned the industry actors in the crisis and gave meaning to collective action.

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Why Is It So Difficult to Learn from Accidents?

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ABSTRACT
After the Fukushima Nuclear Accident, the whole Japanese society had swiftly achieved a consensus to have comprehensive accident investigation to identify the root causes of the disaster. The Government and other major actors established several accident investigation commissions responding to that public will. However, the author has to say the lessons have not been learned and absorbed well, with regret. The issues centering on responsibility and social justice have not been dealt with so that the outputs of the investigations transformed into alternative sanction on nuclear industry – not well articulated regulatory reformation. This trajectory have been considered the result of particular culture of East Asian society, but the author argue that it should become global problem in contemporary world with high-reliability technologies. The integration of the concept of risk governance to build prescribed consensus of responsibility distribution is suggested as an idea of remedy to this problem.

Key words: Accident Investigation, Responsibility, Social Justice, Risk Governance

INTRODUCTION

Why is it so difficult to learn from accidents? This is the given question of this paper. In fact, it seems that the learning process from the Fukushima nuclear accident has not been satisfying so far. For example, the deficits in risk governance of Japanese nuclear program has not been getting better, but has even become worse in some aspects [1]. Difficulty in post accident (or disaster) learning process often shows similar symptom to it, although many people point out the importance of comprehensive accident investigation and reflection from its result, and actually try to carry out those processes. People notice that we are taking wrong trajectory again, but it is always difficult to breakthrough it. Why do we have to have such frustrating, regrettable and disappointing experiences again and again in many fields of modern technical enterprise? The author would try to explore the background of this aporia from the point of view of sociological perspective. This is not based on strict empirical analysis. It would rather be something discursive illustration. But the author believes that it should be still suggestive to stimulate the discussions centering on the concept of "resilience." The discussion will also touch upon ethical issues in post-accident consequences.

POST-FUKUSHIMA ACCIDENT INVESTIGATION AND AFTER

It is common understanding that deliberate, comprehensive and careful investigation for terrible accident is essentially important and must be done officially. For example, the major two accident investigations in the USA; the President's Commission on the Accident at Three Miles Island (so-called Kemeny Commission) and the Presidential Commission on the Space Shuttle Challenger Accident (Rodgers Commission) are often acknowledged as the milestones of the accident investigation activity and its report. Now many people believe that we can learn from disaster through accident investigation process.

This belief seems to be well-shared in Japan, too. Soon after the Fukushima accident happened, the discussion about formal and comprehensive accident investigation was begun. This belief was realized by the Japanese Government, the Japanese Diet, TEPCO (Tokyo Electric Power Co.) themselves and an NPO established for an independent investigation. These four major committees (or commissions) carried out their investigation about a year. All of them published their final report by the mid of 2012. We can now have them on the web and/or as printed matter, and some of them have already translated into English, for non-Japanese readers. Post-Fukushima formal accident investigation was finished.

This fact creates an expectation that many lessons have already learned well, next Fukushima will be prevented by the measures responding to those lessons and the society as a whole should have become more resilient to similar (and even other) type of disaster. Also, some people have believed and even still believe that such changes should have positive effects on public opinion/sentiment about Japanese nuclear program.

However, the reality in Japan now is pretty far from those expectations. It has taken different trajectory than people's belief of "learning from disaster through investigation" theory.

As mentioned above, some deficits in Japanese nuclear governance is remained, or even become worse than before the Fukushima accident. Majority of public opinion is still negative on nuclear program as a whole, relevant organizations and restart of safety upgraded nuclear power plants while the Abe Administration officially decided to maintain Japan's nuclear power utilization (and abolish the gradual nuclear phase-out policy that was approved by their predecessor) [2][3]. Nuclear advocates continue the discussion to restore public trust, to build the consensus and to promote their program again. Critics persist in their counterarguments on the efficiency, risk, transparency and feasibility of "nuclear village's" theory. Sandwiched in between those polarized discourses, the rate of pro- and con-nuclear poll has been stabilized – at the point of a little bit negative against nuclear – for a couple of years. General public lost their interest on nuclear dispute as well as positive feelings to the people relevant to it. On the other hand, nuclear power station restart program get stuck and experts in nuclear field is demoralized. It is hard to say the learning process through accident investigation was successfully finished and we overcome the accident. It is really far from the oracle of "learning from disaster through investigation" theory.

UNTAKEN RESPONSIBILITY: UNSUCCESSFUL PROSECUTION AND SANCTION THROUGH REGULATION

Then, a question comes up: what has Japanese society been doing after the accident investigation? The author's answer is "unsettled discussion about the locus of responsibility." Not only the stakeholders, but also the whole society have experienced the difficulty in coping with the separation of the issues centering on social justice and practical improvement based on the lessons learned from the accident since it happened.

Severe nuclear accident is one of the most extreme and typical cases of organizational accident with serious consequences [4]. Needless to say, the Fukushima case was the first experience of it for Japanese society.

It is well known that Japanese society (and perhaps other East Asian societies) have pretty strong retributivism and martinetism (severe punishment policy) for individuals involved in the cause of disaster even when the nature of accident is organizational [5][6]. There is a long history of controversy about separation of criminal prosecution process and accident investigation activities in Japan. People in those societies feel pretty strong feeling of unjust without strict punishment for individual's fault that cause and/or worsen the damage caused by accident.

In fact, no one has been officially punished through criminal prosecution process on the Fukushima accident. This fact should be very uncomfortable for accident victims as well as the whole society. Damage compensation and life recovery assistance for suffered people has been carried out by incrementally improved official schemes, of course. But it does not work instead of the punishment of responsible person.

To fulfill this unfocused anger, accident investigations and their reports played another role in society than practical learning of lessons from the accident.

It was the most authoritative one that the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC) among four major accident investigation committees (or commissions) established after the Fukushima accident. NAIIC was established on December 8, 2011, with the legal basis by an ad hoc act.

Their report was published on July 5, 2012 and some statements attracted the strongest public attention and even encouraged public anger. The author would take two examples from their provocative theories here: 1) "manmade" and "Made in Japan" disaster theories on the root cause of the accident and 2) "regulatory capture" criticism against the corruption of the past nuclear regulation [3].

The first case, "manmade" and "Made in Japan" disaster theory was suggested in the "Message from the Chairman" page of the Executive Summery written by Chairman Kurokawa, not in the full report [7]. That page was original in English version and no counterpart in Japanese version of the report. The word "manmade" attracted rapid and positive attention mainly in Japanese domestic public opinion because this interpretation was consistent with the tradition described above. In fact, the criminal prosecution process was virtually started on August 2, 2012, after the NAIIC's report published, although no one was finally indicted after prosecutor's investigation.

Kurokawa also suggested another message at the same time – the theory of "Made in Japan" disaster with "Japanese Culture" explanation. It was spread all over the world very quickly, as wells as in Japan. This could obscure our analytical understanding on the root cause of the accident and there were negative responses on this point from foreign major journalism [8][9]. It also seemed odd because this was something contradictive to individual prosecution approach supported by his own "manmade" theory (because everyone could be dismissed their responsibility if the root cause was the "culture"). But, these keywords are often cited simultaneously without any inconvenience, and considered those as the most important messages of the NAIIC report.

The second eye-catching narrative suggested by the NAIIC report was "regulatory capture" criticism against the corruption of the past nuclear regulation. It strictly pointed out the deficits of past nuclear regulatory system, then proposed the fascinating keyword – "regulatory capture." Shuya Nomura, a member of the NAIIC, a jurist and the proponent of this concept described its outline precisely: "Regulatory capture is a theory posited by George Stigler in The Theory of Economic

Regulation. It refers to a condition in which regulators are "taken over" by the operators due to their lack of expertise and information, which results in the regulations becoming ineffective" [10].

However, this Nobel Prize awarded concept was never used as an analytical framework in the report. It just exemplified the historical process of collusive regulatory practices as a case of "regulatory capture." This was interpreted as just a strict criticism against the corruption and became very popular. But, causal relationship between any particular factors and the result (=corruption) has not been demonstrated by using this concept in the NAIIC report.

These NAIIC's narratives inspire us an approach to punish victimizers: sanction through regulation.

People's unsettled anger has seemed to result in unlimited efforts to reduce the risk from hazard created by any nuclear activities. New regulatory authority (NRA: Nuclear Regulatory Authority) adopted decisively strict approach that calls for further measures to increase and to demonstrate plant safety in bit-by-bit manner (i.e. additional safety measures against similar scenario to the Fukushima case, safety review with "new regulatory standards," earthquake resistance retrofit, on-site active fault survey, and so on). This sequential regulatory actions has made operators and manufacturers impoverished by never-ending review process while public trust has not been effectively recovered in proportion to their efforts. It could be interpreted that regulation fulfills the public will to punish "evil" nuclear industry instead of legal prosecution process.

Additionally, in should be noted that the final conclusion of the investigation reports and the actual design of nuclear regulatory reform did not have causal relationships as a matter of fact. The discussion about the reform of regulatory system was carried out at the Government and the National Diet before NAIIC and other major final reports were published. Japanese Government established the NRA in September 19, 2012, three month after the Act was approved on June 20, 2012. The sessions about the change in law was held during spring of the year. At that moment, only the report of so-called "Independent Commission" (established by an NPO) and the interim report of the Governmental Commission (ICANPS: Investigation Committee on the Accident at the Fukushima Nuclear Power Stations) were released. It was chronologically impossible to reflect the final recommendation of NAIIC report on this institutional reformation formally.

Actually, NRA themselves don't include the NAIIC report as a part of the background of their establishment, according to their website [11]. It seems to be quite unreasonable that the National Diet didn't wait for their own commission's conclusion and recommendation, as well as other major committees', though their final reports had almost been finished.

IMPLICATIONS OF THE CASE ON "RESILIENCE" DISCUSSION: BEYOND CULTURAL EXPLANATION

This situation should cause a serious contradiction – random walk rigorous regulation without securely upgraded safety.

Past discussions on this issue have focused on the cultural background of Japanese society that was descried above, and tend to suggest ways to "redress" it to comply with "global standard" of separation of prosecution and investigation [6][12]. This tendency shows interesting consistency with Kurokawa's "Made in Japan" theory.

However, the author should like to discuss further implication of this responsibility issue to deepen and broaden the discussion centering on the concept of "Resilience."

Indeed, retributivism and martinetism is particularly prominent characteristics of East Asian societies. It should be admitted that these "cultural" differences are observed and need to be considered. Separation of prosecution and investigation is still essentially important to make accident investigation effective, reliable and just, in principle. We should call for careful arrangement when we think about institutional and legal harmonization with international standards such as multilateral treaties on utilization of nuclear and other advanced technologies.

But, the author would argue that this issue should become more and more global, and more and more difficult to cope with. It cannot be trivialized as a local issue caused by particular "cultural" context. It should become more and more unsolvable even in other societies that have not been so "retributivistic" or "martinetistic" so far.

As a series of studies including the ones on the cases of nuclear accident have shown, the contribution of so-called human factors has increased both in causes of accidents and amplification of damages by them, inversely proportional to the improvement of reliability of advanced technological system. This trend is perhaps irreversible, historically inevitable one. It becomes one of the central questions in many fields of contemporary society to cope with the problems that are relevant to human factors to prevent or to improve the "resilience" to possible disasters. Every leading nuclear engineer knows that the most dominant and variant factor in the PRA (probabilistic risk assessment) is human factor. For this very reason, it is still under discussion how to appropriately include it to make the PRA method reliable and suggestive. After the long history of engineering efforts to improve technologies in "technical" sense, human factors are coming back to the core of the discussion about the success and failure of our artifacts.

On the other hand, accident always creates its victims in some sense, regardless of the nature of the cause of accident. This proposition has been unchanged since ancient times. We always have to face the issue of social justice: to remedy damaged and violated rights of them.

These two contexts would make more and more difficult to separate the issue of responsibility from the other parts of discussion to learn lessons from accident. Separation of prosecution and investigation might become much more difficult even in the societies that adopt this principle and have long experience of practice of it.

In our conventional idea, especially in engineering field, we believe to look at accident analytically. We break down an accident as a whole into "factors" and find causal relationships among them. Finally, we identify the root causes of each accident. In this approach, "factors" caused by or relevant to individual or organization also need to be dealt as "human factors" or "organizational factors." Experts consider those "factors" as manipulable (operational) elements. Thus, many researches have invented various ways to prevent undesirable human behaviors or to encourage desirable ones (so-called human engineering).

But, this conventional approach of engineering effort has little impact on the post-accident human-related issues – responsibility issue and its ethical consequences. As described, it is inevitable that increase of weight of human factors in causes and amplification of damages of future accident. It should lead people's attention and even anger to responsibility issue. Without to invent and implement the way to deal with this aspect appropriately, every society would experience the similar social deadlock that has been observed in post-Fukushima Japan centering on nuclear issue. This is no longer a local requirement but the universal condition to realize more resilient governance on advanced technologies, including nuclear technology, of course.

CONCLUDING REMARKS: A SUGGESTION TO BREAKTHROUGH THIS APORIA

Some of (engineering) experts may still argue that this problem is solvable by "education" of public (that encourage them to accept experts' notion). If this is a discussion about just "failure," not "accident," that strategy might be possible to be maintained. However, it is an indisputable principle that we deal with the issue of damage and responsibility by ethical considerations with the sense of social justice. So, it is inevitable to cope with those aspects integrated with technical and practical activities to understand and overcome accident.

As the concluding remarks of this paper, the author would suggest an idea to help to breakthrough the aporia described in the sections above: to build a consensus about framing, characterization and evaluation of risks and distribution of mandates, roles and responsibilities among stakeholders. This is the most substantial goal of risk governance, and its core activity is risk communication.

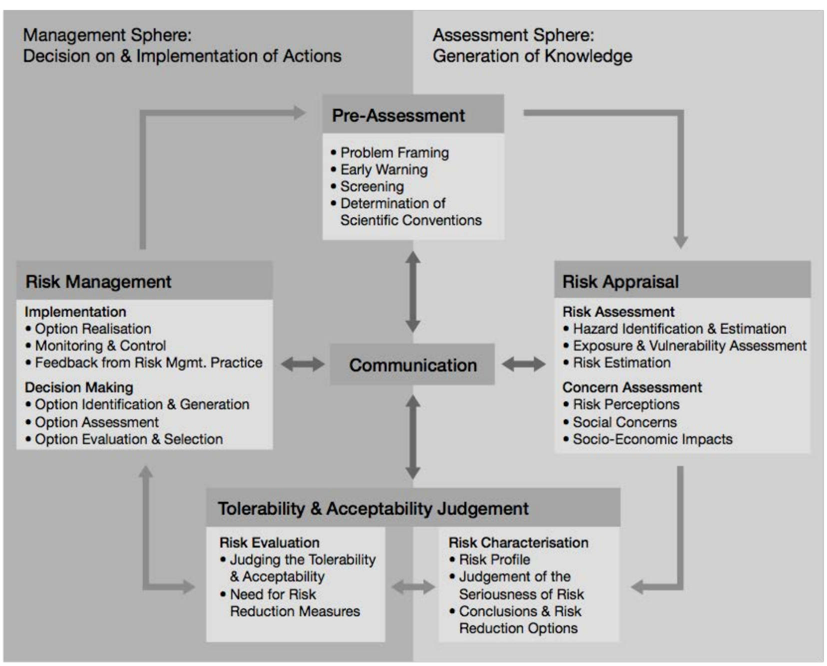

Fig. 1 IRGC Risk Governance Framework

It is one of the contributing things to prevent settlement of public anger that the locus and distribution of responsibility become vague, intentionally changed or trivialized afterward. These injustices trigger public outrage. It heavily destroys public trusts towards major actors. Once it is damaged, trust would never restored in the short term, as classical social psychology work demonstrated [13]. Loss of public trust should cause deadlocked situation that spoils public interests in the same way to Japanese case described in the earlier sections of this paper.

To avoid such fault and to realize effective risk governance, the figure illustrated by IRGC (International Risk Governance Council) would be suggestive even for “resilience” discussion in engineering field (Fig. 1)[14]. It consists four phases of activities to cope with activities and the “communication” element connects those four factors. The important implication of this figure is that the concept of “risk” is not so clear-cut, quantitative and easily operational thing. It should be discussed that the framing of risk issue in the “pre-assessment” phase. It should be included the “concern assessment” process in “risk appraisal” phase in parallel with so-called “risk assessment.” To make any judgment on risk issue, we need to “characterize” the profile of risk. It is not an automatic output from the result of assessment. Finally, “managing” risk but it is not the end of once-through cycle but the beginnings of next cycle. Communication is the key element for all of these four phases and not on-directional flow of the result of evaluation or decision made by limited number of experts.

In this multi-dimensional process of risk governance, all of stakeholders should participate in the discussion about the distribution of mandate, role and responsibility to keep risks smaller than tolerable level. This discussion should be done on a daily basis and build consensus about locus of responsibility before something wrong happen. Prescribed (formal and informal) agreements would help remedy process if accident happens unfortunately and help to proceed to proactive discussion to learn from and overcome the disaster.

Considerations on ethical implications of accident and integration of the concept of risk governance with risk communication will encourage constructive discussion towards more “resilient” engineering practices.

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Decision making in extreme situations following the Fukushima Dai Ichi accident

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Abstract
The Fukushima Dai Ichi accident raises questions about current decision-making models. Faced with an overwhelming situation, which threatened both their own lives and that of the entire population, the plant's operators were obliged to take action, despite the lack of resources. In these conditions, decision making cannot be reduced to an optimization exercise based on a range of possibilities, or the application of heuristics and other operational responses to an emergency situation. The inevitable catastrophe, the social pressure it generates, the moral dilemmas it creates and the psychological drivers for action are characteristic of an extreme situation. The action plan must therefore be reinvented and individuals mobilised to these ends. It is therefore in a broader context of 'action' that decision making takes shape, and finds its logical foundations, meaning and temporality. Understanding decision making in extreme situations first requires a grasp of the development of a specific value system (that is mediated by the physical experience of the situation) in which the individual and social representations play a central role.

Keywords: Decision-making, extreme situations, uncertainty, ambiguity, rationality, temporality.

INTRODUCTION

When Circe warned Odysseus about the dilemma he would face when passing through the Strait of Messina, she reminded him that it would be a decision of the heart. However, the priestess suggested that he choose the peril of Scylla: better to lose a few companions than to see them all engulfed by Charybdis. Odysseus followed this advice. Therefore, how can we say he 'decided'?

The word 'decision' typically refers to the "*end of the deliberation in a voluntary act that results in the choice of an action*"[64]. The meaning given to each of these terms varies according to different schools of thought. For Aristotle, the decision related to the available resources needed to reach a given, desirable, conclusion[65], while Cartesians[66] would argue that without Circe's advice, Odysseus was taking a decision that was beyond his ability to understand and he therefore did not choose. At a minimum, Leibnitz[67] argues that understanding is not a necessity – it only provides a guide – and that the decision exists only through the effort of action. In terms of expected utility theory ([14]), Odysseus rationally opted for the path that minimized the maximum damage.

Beyond these considerations, if the sacrifice of companions can be made acceptable, it must be integrated into a social and symbolic universe that gives it meaning. It is the will of the gods that allows Odysseus to return to his kingdom, which places him above other men. Of course, nowadays Man is emancipated from the gods and can think for himself. He decides, after careful reflection on causes, which "*must always be mixed with chance in order to form a basis for reasoning*"[68]. However, despite this distancing that is at the heart of Technology, the human being must still find meaning in their actions.

In his testimony ([19]), the Director of the Fukushima Dai Ichi power plant shows how operators, who were obliged to decide between the survival of some and the sacrifice of others, gave meaning to such decisions. Some of their critical decisions are set out below (section 1). The inability of current theories to account for the magnitude of such decisions (section 2) leads us to introduce the concept of 'project time' (section 3), and to explore mechanisms for the development of meaning in extreme situations (section 4).

1. FUKUSHIMA DAI ICHI: FAULTY DECISION-MAKING?

[64] Source: *Cultural Dictionary*, A. Rey, Ed. Robert (2005).
[65] Aristotle, *Nicomachean Ethics*, Trad. R. Bodéüs, Paris, Flammarion (2004).
[66] R. Descartes, *Metaphysical Meditations*, 1641, electronic version edited by PhiloSophie, 68 (2010) available at http://www.ac-grenoble.fr/PhiloSophie/file/descartes_meditations.pdf .
[67] G. Leibniz, *Essais de Théodicée*, 1710, repr. Flammarion (2008).
[68] D. Hume, *L'entendement. Traité de la nature humaine.* Book I, 1739, p. 195, translated by. P. Baranger and P. Saltel, Flammarion (1995).

It has become normal to describe the Fukushima accident as the result of poor decisions or a failure to act[69]. In particular, the nuclear community has recognised that the accident could have been avoided through appropriate prevention measures. This would have entailed raising the height of the dykes that surrounded the site and protected it against waves following the results of numerical simulations, conducted in 2008, which indicated the potential for flooding. Moreover, a consensus needs to be reached on the usefulness of such information: TEPCO indicated that it found the scenario unlikely given additional geological studies that invalidated the predictions[70].

Furthermore, how the accident was managed in the first days following the earthquake illustrates how decisions were taken in a context of crisis. The Japanese government's Investigation Committee was particularly interested in the circumstances in which Reactor 1 exploded on the afternoon of 12 March, 2011, when on-site teams thought they had vented it and cooling via the injection of seawater was about to begin ([36]). Investigators asked the Director of the plant about his decision-making process given the information available to him ([19]). To understand their approach, it is useful to recall certain facts.

On 11 March, the Director, Masao Yoshida, ordered preparations to begin for the injection of water into Reactor 1 using fire conduits and fire engines, to ensure cooling when the isolation condenser (IC)[71] stopped working because of electrical failure. The water level in the tank was checked by reading an indicator. The level was normal, which supported the belief of operators that the reactor was correctly cooled. The level, however, could not be constantly monitored. At around 02:00 on 12 March, the indicator showed a stable or slightly rising water level, while at the same time the pressure inside the tank fell. Communication between the control room and the crisis room was difficult and the Director had not been informed of problems in the IC conduit. Perplexed by the rise in radioactivity, he concluded that the water level indicator was malfunctioning, that the IC had potentially been non-operational for several hours and that the core was probably exposed ([19]). This was confirmed by measuring the increase in pressure in the containment vessel, which had exceeded its structural limits.

The plant's Director said that he regretted having placed too much confidence in the water level indicator and not having asked the control room about the IC conduit. For their part, investigators expressed their surprise at the apparent passivity of operators, given that an IC valve had been closed for no apparent reason and that the injection of water was impossible, with the result that the reactor was not cooled between 18:25 and 21:30. It appeared that none of the shift leaders had alerted the crisis cell.

Yoshida also stated that, "*anyway, in terms of solutions, we did not have anything much better than the diesel pump, injecting with the fire pump and using the fire engine, which we finally did. Could we have reacted more quickly if we had known? I think that physically, we could not have gone faster*" ([19]).

Faced with pressure that exceeded the structural limits of the containment vessel, the Director asked for Reactor 1 to be vented. This operation required the activation of a valve, which proved particularly difficult and dangerous because of the high levels of radioactivity, the lack of electricity or pneumatic equipment, and the lack of indicators or light in the control room. As none of the operators had taken the initiative and studied the plans and diagrams of the network in anticipation of venting, investigators asked Yoshida about when he had proposed this solution. He said that he had only considered venting when he had sufficient data to confirm that there was excess pressure in the chamber. The priority was therefore to obtain information on the key parameters indicating the state of the reactor ([19]).

The Commission was also surprised that operators had not considered the possibility of a hydrogen leak from the tank to the containment vessel into damaged pipes, although it was known that core fusion can produce large amounts of hydrogen. The Director said he had been aware that, if the core was damaged, hydrogen was produced; notwithstanding, he felt that it would remain confined within the vessel and he had focused on the threat of a container explosion, given the high pressure that had been observed. He stated, "*the top of the reactor building is covered and ventilation panels are arranged on the side. We had not even imagined that these panels were closed and that hydrogen and oxygen had accumulated. We focused on the containment vessel. [...] We were prisoners of our a priori assumptions*" ([19]). Moreover, the entire international nuclear

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[69] The Japanese Parliamentary Commission investigating the accident concluded that it was a 'man-made disaster'. See The National Diet of Japan, *The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission. Executive Summary* (2012), available at www.nirs.org/fukushima/naiic_report.pdf.

[70] H. Drumhiller, "How did Individual and Organizational Use of Probability and Risk Assessment at TEPCO Contribute to the Fukushima Accident?" , *International Experts' Meeting on Human and Organizational Factors in Nuclear Safety in the Light of the Accident at the Fukushima Dai Ichi Nuclear Power Plant*, Vienna, May 2013, IAEA (2013) available at www-pub.iaea .org/iaeameetings / IEM5Presentations.aspx.

[71] A backup system in some boiling water reactors. It cools the core when power cannot be evacuated by the main condenser. The system condenses the steam produced in a heat exchanger, and then re-injects it into the tank using gravity.

community was unaware of this scenario ([19]). It was only several hours after the explosion, following an investigation of the destroyed buildings, that operators concluded that the accumulation of hydrogen was probably the cause. They then studied the measures that needed to be taken in order to prevent a similar scenario at the plant's other reactors.

At dawn on 15 March, although Reactors 1 and 3 had already exploded, operators felt a strong jolt and heard a loud noise, which they could not immediately identify the source of; at the same time they noted damage to the building of Reactor 4 and that the pressure in the containment vessel of Reactor 2 had fallen to zero ([36]). Although they gave little credibility to the reading from the pressure indicator and, on a scientific level, the hypothesis that Reactor 2 had exploded was not consistent with the available information, Yoshida considered the noise to be the most important factor and ordered an evacuation.

These examples suggest that the criteria for decision making, the relevance of the decision and the resources available to the decision maker were deficient, to the extent that they hindered the management of the accident. According to Yoshida himself, "*it was total confusion. And that was in this atmosphere that it was necessary to give orders. So I recognize that it was not done in a logical and considered order*" ([19]). However, identifying potential derivations from logical reasoning and understanding the circumstances presupposes that the processes at work can be formalized.

2. TESTING DECISION MODELS USING THE FUKUSHIMA DAI ICHI ACCIDENT

A classical approach in management science is to model decision making in four phases. After collecting the information necessary to diagnose the problem, the decision maker formulates potential ways to resolve it, based on a necessarily limited rationality; they then select a particular mode of action, and evaluate a provisional satisfactory solution before iterating the process if necessary ([31]). The comparison of potential scenarios results in mathematical formulations, developed from an economic perspective. The choice is equivalent to the optimization of a function (the utility). A set of axioms expresses postulates about the properties of preferences (for a discussion of the various theories see [11]). If an objective assessment of the probabilities of the consequences of an act is not possible, the decision maker can use 'subjective' probabilities. The probability distribution is therefore measured according to their knowledge of the possible states of the object they are interested in and upon which they wish to act. Nevertheless, the assessment of subjective probabilities can be arbitrary and, in many practical situations, the behaviour of agents does not reflect preferences that are consistent with these axioms, without being necessarily called an 'error' ([14]). To account for the assumed ignorance of the decision maker of certain states and their aversion to uncertainty, Gilboa and Schmeidler ([16]) showed that decisions can sometimes be seen as the maximization of a form of expected utility that takes into account the worst case scenario, which is consistent with the 'maxmin' model. It is also possible to broaden the spectrum of reactions in uncertain situations ([12]), in order to model less paranoid attitudes ([14]).

From this perspective, the behaviour of the decision maker is interpreted according to a concept of ambiguity relative to their knowledge of the world, which is how the questions of the Japanese investigators should be understood (see section 1). Faced with ambiguity about the state of Reactor 1, it could be argued that Yoshida violated expected utility theory by not deciding to immediately cool the core; or, alternatively, he demonstrated an aversion to uncertainty, by deciding to rely on information about the water level, while simultaneously preparing cooling mechanisms[72]. The fact that he did not foresee hydrogen leaks can be interpreted in two ways using the 'maxmin' model: either he failed (cognitively) in his assessment based on all of the objective information available; or his attitude or imperfect knowledge led him to limit his choices to a subset of possible states. As for his decision to send staff to gather information on the state of the reactors before considering operations such as venting, this can be interpreted as an example of incomplete preference, where the status quo is maintained until such time as a conclusively better, new alternative appears.

Can we conclude that Yoshida acted irrationally, or do the models provide an incomplete description of such decisions? Gilboa ([13]) argues that we qualify behaviour as 'irrational' if whoever violates its precepts regrets their actions. The regret expressed by Yoshida about the confidence he placed in Reactor 1's water level indicators (see section 1) would suggest that the decision was irrational. However, the Director immediately qualifies his comments by stating the impossibility of conceiving an alternative solution. Through this remark, Yoshida integrates his decision into a wider context of action.

This is to be compared with observations from current research in Natural Decision Making (NDM) that aims to account for decision making in the presence of changing conditions, ill-defined tasks, time pressure and significant personal risks in the case of error ([24]). In these conditions, the decision maker's accounts of their decision making "*do not fit into a decision-tree framework*"; they are not "*making choices*", "*considering alternatives*", or "*assessing probabilities*", but they see themselves as acting and reacting on the basis of prior experience, generating and modifying plans to meet the needs of the situation ([23]). The decision maker acts on the basis of heuristics, then develops a mental simulation to assess the

[72] The Director had to manage limited resources and set priorities. Therefore, in this case it is not possible to apply a principle of dominance and conclude that the "ignore the water level" option was better.

feasibility of the proposed response[73]. Coordination and leadership modalities also change when tasks are unpredictable and interdependent, as is the case in an emergency context ([25]).

However, if the context for the intervention of firefighters or emergency room surgeons is sometimes called an 'extreme situation' ([27]), in practice these 'dynamic' situations constitute the predictable working environment of the decision maker. The problem relates more to the definition of the case in question, than the solution once the diagnosis has been made. Ultimately, the 'extreme' nature of a situation is assessed differently by different researchers and does not necessarily imply that the decision maker is completely overwhelmed or out of their depth ([17]). Such individuals have substantial resources at their disposal, a well-established set of procedures and the impact of their actions is limited at the scale of society.

In addition, whether they focus on decision making processes based on scenarios or on more empirical approaches, investigations of the influence of stress ([38]), a hostile physical or social environment ([39]), or the formal organization ([1]) on the performance of the decision maker are simplistic. They lead the analysis to be focused on the physical or emotional factors that could have led Yoshida to make errors (for example his decision to evacuate the site). This cognitive approach is indicative of the common sense meaning of 'emotion', i.e. a complex state of consciousness, usually sudden and momentary, accompanied by physiological disorders[74]. However, this perspective largely ignores the role played by emotions in decision making ([30]). Ellis ([10]) considers that emotions and values are necessary components of a decision, which does not mean that the decision becomes 'irrational'. This assertion is illustrated by the way in which the plant's staff decided to return to the field following the explosion at Reactor 3 on 15 March. According to Yoshida, "*everyone was in shock, frozen, unable to think. So I got them all together to talk to them. [...] I also told them [...] that if we did not respond, the situation would become even more catastrophic [...] It was at that point that I experienced one of the most emotional moments of my life. They all wanted to go back, they even pushed each other out of the way to get there*" ([19]).

The Fukushima accident demonstrates how difficult it can be to make decisions when the realities of the situation are not conducive and the unfolding scenario cannot be stopped (due to a serious lack of resources); at the same time, the physical integrity of individuals cannot be guaranteed and the consequences of taking action – or not – have societal significance. The inevitable catastrophe, the social pressure it generates, the moral dilemmas it creates and the psychological drivers for action are characteristic of an extreme situation, as described by ([40]). In extreme situations, the action plan must be reinvented and individuals mobilised to this end. Yoshida therefore stated that he initially had no solutions, no idea how to react, and fell back on 'administrative' procedures in an attempt to regain self-confidence ([19]). Similarly, organizational theory tends to regard a crisis as a situation where, "*not only are there insufficient resources, but it is a situation where the rules were not thought of yet*" ([6]). The new order must be acceptable, when life itself – that of workers or of an entire population – is threatened.

Current models do not make it possible to deepen our understanding of the practical management of such situations. To progress, the analysis must be based on suitable metaphysics and integrate the world of the decision maker, in which their decisions make sense. The following sections consider these two dimensions.

3. DECISION MAKING AND CATASTROPHE: BACK FROM THE FUTURE AND RETURN

The concept of decision making inevitably refers to concepts of causation and rationality. Through the introduction of probabilistic links between states of the world and actions, expected utility theories opened up the debate on the causal link. Savage's axioms (for a discussion, see [11]) apply to actions that do not have a causal influence on the state of the world in which their consequences are experienced[75], which rules out many decision-making scenarios. To overcome this problem, (unconditional) utility was replaced by a concept of utility which conditions the probabilities of states of the world (those leading to the expected consequences) to the execution of the act. These probabilities are interpreted either in terms of classical conditional probabilities, or causal probability ([21]). In the first case, evidential decision theory computes an act's expected utility using the probability of a state given the act $P(S|A)$[76]; in the second case, causal decision theory replaces $P(S|A)$ with $P(A \rightarrow S)$ or a similar causal probability ([43]). This choice defines the decision making perspective. Thus, according to Jeffrey, "*in decision-making it is deliberation, not observation, that changes your probabilities. To think you*

[73] These studies are consistent with those of Gilboa and Schmeidler ([15]), who axiomatized a *Case-Based Decision Theory*, which postulates that the decision maker acts by comparing the current situation to one already experienced. However, this theory is not specific to an emergency situation.
[74] Source: *The Cultural Dictionary*, supra.
[75] The problem can be reformulated to make it the case ([21]). Consequently, the final state of the system is often associated with a fixed point. This is the case in economic models such as the 'perfect competition' model in which the actions of one agent do not change the overall balance.
[76] This theoretical orientation has led to debate about the ability of an agent to assess the likelihood of their actions – a problem that is resolved by invoking the predisposition of the agent to act ([21]).

face a decision problem rather than a question of fact about the rest of nature is to expect whatever changes arise in your probabilities for those states of nature during your deliberation to stem from changes in your probabilities of choosing options" ([20]).

Rationality is therefore at least dual, and Lewis's counterfactual decision theory can account for both aspects ([8]). The fundamental idea of this analysis is that the counterfactual "*If A were the case, C would be the case*" is true just in case it takes less of a departure from actuality to make the antecedent true along with the consequent than to make the antecedent true without the consequent ([33]). The causal dependence is then stated as follows: Where c and e are two distinct actual events, e causally depends on c if and only if, if c were not to occur, e would not occur.

A dual rationality goes hand-in-hand with the concept of temporality. Either the decision maker operates by projecting a set of possible futures and seeks to maximize the consequences of their actions, or they try to make their actions as consistent as possible with a desirable state of the world. Dupuy ([9]) thus states that: either, at every moment in 'occurring time', regardless of the predictions of an infallible Predictor, "*agents have the power to act in such a way that, if they were so to act, they would render inaccurate the predictions of the supposed Predictor*", which means that causal links are probable ones; or, at all times in 'projected time', causal links are fixed and the agent has the power to do something such that, if he were to do it, the 'script' of his life would have been different. Dupuy suggested merging these two concepts of temporality form a loop, in which the past and the future determine each other. In particular, a future state, when represented by a favourable probability and another that is disastrous (with a very low probability) can serve as an anchor point for ongoing action in an approach that is constantly under review ([8]).

We argue that Yoshida was guided by these two representations of temporality. He applied a causal type of reasoning – specifically a search for causal dependence consistent with the definition found in counterfactual decision theory – in order to deduce from the information at his disposal that the core of Reactor 1 was undergoing fusion. He expected to find proof of an 'event e', for which it was then necessary to find the cause. Using the same reasoning, (this time in anticipation) he decided to start the venting manoeuvre and avoid an explosion, based on the objective data available to him. At the same time, he organized actions to be taken based on information that he did not yet have in a measurable form, but which he had nevertheless convinced himself was true. Although it had not yet happened, the future catastrophe seemed real enough to him to guide his actions. The destruction of an entire region – not simply an official accident – constituted, at least a partial anchor point for the decisions that he took. He repeated this point many times during the hearing, "*it was clear that we were heading for a major accident and we had to prepare for it*" ([19]). He stated that he had always had such a situation at the back of his mind, beginning with his initial instructions to prepare alternative cooling methods. Yoshida's decisions therefore took place in a sort of 'project time' temporality. It would therefore be wrong to say that he 'expected' the loss of the cooling systems, as this would place his actions in a causal type of rationality and an 'occurring time' temporality. This idea is similar to that of Dupuy ([9]), who argues that temporality should not be seen as a container in which human activities take place, but as a result of human activities.

This observation may seem trivial. Naturally, where the cooling systems of a nuclear reactor are damaged, the operator must consider the potential for disaster. However, limiting the investigation to the critical bifurcations of the decisions as the situation unfolded, and trying to understand the rationality of choices based on available information or resources – an exercise that is at the heart of traditional investigation processes – means that the disaster is only looked at in terms of its potential, which is likely to significantly weaken its power of determination. A contrario, when rationality is viewed in terms of 'project time' it "*is a fundamental existential problem that rears its head every time we are confronted with absolute uncertainty concerning a variable on which our 'salvation' depends*" ([9]). By comparison, an approach in terms of scenarios sees the future as a distant objective reality for the individual. In this context, the paradox highlighted by Dupuy ([8]) is as follows: prospective methods make it possible to socially create an image of the future; at the same time, they empty it of its physical dimension, they do not acknowledge reality of any kind.

Difficulties arise when the decision is counterfactually examined using a probabilistic-causal approach, with a view to arriving at a moral judgment. The expression of a causal link is inherently relative. Core fusion, overpressure or leaks in the containment vessel of Reactor 1, like the accumulation of hydrogen and the failure of ventilation equipment, may be considered as the 'causes' of the explosion of Reactor 1. Emphasising one over the other is relevant depending on the class of situation in question, the context or the contrast to be established between a situation and an event. For this reason some authors have suggested the reformulation of the counterfactual causal dependence as follows: If c* had occurred instead of c, then e* would have occurred instead of e ([33]). Whichever is the case, this observation shows that causality has no transcendent reality, except in the narrow field of science (i.e. excluding human affairs). An assertion of causality requires adopting a point of view; the mark of subjectivity. The *a posteriori* allocation of probabilities in causal reasoning leads to short-circuiting the infinity of potential future bifurcations, and the retention of only a few of them. Reasoning is thereby biased because, unlike moral judgments, "*the foundation for probabilistic judgment cannot include any information that is only available after action has been taken*" ([8]). This may explain the discrepancies between the questions of the investigators and the action taken by Yoshida (see section 1). The Commission's investigators mixed two interpretations: their causal analysis in an 'occurring time' frame (reconstructed *a posteriori*) support a value judgments of the actions taken by the plant's Director. This approach does not take full account of the decisions made at Fukushima Dai Ichi. To make sense, Yoshida's actions must be understood in their entirety; it is impossible to separate decisions from the close connection that the individual has with the realities they confront.

4. FROM DECISION MAKING TO TAKING ACTION IN EXTREME SITUATIONS

The plant's Director was unambiguous in his description of the relationship between his staff and the production facility, which he characterised as a fight, dominated by fear and suffering. His lexicon and register provide further evidence: he speaks of "three monsters", "*three nuclear units that were unleashed*", and tries to "*achieve the impossible with very few staff*" to "*tame this thing*" ([19]). In this context of sensory stimulation, impressions and perceptions had a strong influence on his decisions. His order to evacuate the site is an example of this (see section 1).

However, emotions do not always disrupt the ambient order and well-regulated planning. Damasio ([3]) showed that they are a key component in the development of rational thinking. Several experiments have since confirmed the need to reintroduce emotion into the process of conceptualization. Similarly, it has been demonstrated that individuals produce concepts according to their perceptual experience ([35]). Such studies show that the embodiment of emotion can ground concepts. An illustration of this is found in Yoshida's testimony. He stated that following the explosion of Reactor 1 (when the pressure was about 500 kPa), the number '500' left him "ill at ease". He went on to add, "*I know this is totally irrational, it was just a feeling*" ([19]); this feeling would influence his decisions concerning the other reactors.

Leontyev ([29]) put forward similar arguments. He claimed that human activity forms the foundation for consciousness – a back-and-forth process that operates between an individual and an object, guided by a pattern and determined by sensual contact with the outside world. Leontyev goes on to say that beyond this circular process, which influences interactions between the organism and the environment, mental representations of the objective world are governed by processes in which the individual is in physical contact with it and thereby obeys its intrinsic properties and its own relationships. It is the object that initially determines how actions unfold and, secondly, it is how it appears as a subjective product of the action that records and stabilizes the objective content of the activity. The resistance of the object breaks the cycle of internal mental processes and provides an opening to the outside world. Moreover, Vygotsky ([42]) showed that actions are social by nature; they always take place in the presence of others. Recent studies characterize the moderating role of social relations in the relationship between the individual and their body as a conceptualization tool: the "*current (social or other) context influences the way in which a concept is represented in a conceptual task and the extent people recruit embodied information to solve it*" ([35]).

In line with these theoretical results, embodied embedded cognition (EEC) considers that meaning is grounded in bodily processes of perception and action. The organism's bodily interaction with the environment is of crucial importance to its cognitive processes ([22]). What is meant here by the 'body' is not the body as a functional system with input and output, "*but rather the body as an adaptive autonomous and therefore sense-making system*" ([7]). As the "primary technical object" ([32]), the body appears as a support and provides meaning, "*It is impossible for a man not to be permanently changed and transformed by the sensory flow that runs through him. The world is the product of a body which translates it into perceptions and meaning, one cannot exist without the other. The body is a semantic filter*" ([28]).

From this perspective, phenomenology, which is specific to the experiential aspect of emotion, can be linked to values. Here, 'values' represents what gives meaning to action, although not exclusively as an abstract object to consciously work towards. At a more primitive level, 'values' are more properties of a particular type that are exemplified by contexts, objects or behaviours: we argue that emotions – such as fear –link us with exemplifications of these evaluative properties – for example danger ([5]). In an emotional state, the body becomes prepared to potentially take action and "*the specific way it is prepared is interpreted, very naturally, as an apprehension of some of the evaluative aspects of the environment. Here, then, bodily sensations are not understood as simply the effect of thinking about the environment, they play a direct role, by virtue of their phenomenology, as an explicit presentation of their own objects, i.e. values. Emotions are what is felt by a body that is prepared for action: it is therefore in this narrow sense that one can say that emotion is an experience of value*" (ibid.).

Plunged into an unprecedented sensory universe, the operators at Fukushima Dai Ichi had to redefine the meanings and values in their world. The scene was apocalyptic: high levels of radioactivity, extreme temperatures, piles of debris, aftershocks, floods, darkness and exploding reactors formed the context in which they were required to take action. Decision making was shaped by their contact with this material and social reality, physical challenges, and the way they behaved and saw others behaving.

Individual commitment was influenced by the need to take action and the resources required, the rules and shared representations of the action to be performed. Group behaviour is indeed partially determined by the image it has of its task ([34]). In extreme situations, the construction of this image integrates current social representations from the public sphere. In this case, public opinion of the Fukushima Dai Ichi accident hinged on interference from the Prime Minister in the management of the crisis and the incompetence of TEPCO ([2]). The validity of the actions taken by on-site operators was not acknowledged until long after the events of 11 March, 2011. Three months after the accident, workers suffered from an unusually high level of psychological problems, linked to the social discrimination they were subject to ([37]).

The decisions of the plant's Director were therefore influenced by the need to protect the physical and mental wellbeing of his colleagues ([19]). Nevertheless, when it became clear that the only way to vent Reactor 1 and prevent its explosion was to manually open a valve located in a highly radioactive zone, technicians reported for work. The Director stated, "*We decided to do the operation by hand, as a last resort. We decided to do this because we thought that it could be done, if all it took was to accept being irradiated*" (ibid.). It could have been the case that economic considerations dictated this decision: the loss of a few employees could have brought a solution to the crisis as long as it would not have jeopardized the remaining resources. However, such a decision can only be seen as acceptable as a result of a personal and interpersonal journeys of the decision maker and his colleagues, through an action process leading to a singular system of values. In order to understand decision making in extreme situations, one must first understand the development (mediated by physical experience of the situation) of this value system in which individual and social representations play a key role.

5. CONCLUSION

Investigations into the accident at Fukushima Dai Ichi highlighted failures in communication, and a lack of foresight and anticipation on the part of operators in some of the decisions that were taken. These analyses implicitly suggest that there was a range of options based on a known state, and they reduce decision making to an optimization exercise. Consequently, the feedback from experience becomes focused on the lack of coordination between the operator's headquarters, the Japanese government and the plant, obsolete instrumentation, or the effects of stress on behaviour[77]. Of course it is clear that our understanding of the impact of stress or emotions on behaviour or decision making is still preliminary ([26]), and merits further examination. However, paradoxically, this type of 'safety science' approach seeks to place behaviour in a theoretical context made up of bloodless social mechanisms that take no account of the humanity of those who must act. Moreover, in the nuclear context, executives are sometimes tempted to resort to formalisms to demonstrate a high degree of control, even if it means negating the difficulties faced by operators ([4]). In extreme conditions, the risk is that the factors that determine the 'entry into resilience' are ignored [18]).

In their current state, the lessons that have been learned from the accident may hide some key drivers for the planning and development of actions taken in the face of devastation. The concept of the extreme situation invites us to supplement these lessons and reintroduce factors related to the human body, emotions, and kinaesthetic, which create our initial relationship with the world, and constitute a socio-sensual structure for behaviour. In order to understand behaviour in extreme situations we must first understand the experience, which is marked by radical changes that cannot be easily aggregated into logical arguments. Moreover, the integration of a more sensitive approach to the behaviour of others into an otherwise rational approach to decision making would appear to be a promising avenue for better management ([41]).

On-site management problems were compounded by the injunctions of remote decision makers. The conflict between the plant's staff and the Japanese government cannot simply be reduced to a failure to share information or a lack of awareness of each other's problems. It is the result of different relationships with danger, through social pressure, to moral issues. It is therefore necessary to establish an ethical framework that is appropriate to extreme situations, which articulates different temporal and rational registers. The intervention by the residents of Olympus offers a universal interpretation of Odysseus's decision. A contrario, due to the fact that all parties sought to make their own sense of the situation, the Japanese population, its government and authorities did not understand the magnitude of Yoshida's actions or those of his colleagues.

[77] See for example the conclusions of the Japanese Parliamentary Investigation Commission (available at http://www.nirs.org/fukushima/naiic_report.pdf) and the work carried out under the auspices of the Nuclear Energy Agency, *The Fukushima Dai Ichi Nuclear Power Plant Accident - OECD / NEA Nuclear Safety, Response and Lessons Learned*, NEA No. 7161 (2013).

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Japan's Nuclear Imaginaries before and after Fukushima: Visions of Science, Technology, and Society

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ABSTRACT

Two recent insights regarding social imaginaries are of particular relevance in thinking about the Fukushima disaster and its aftermath. First, social imaginaries are consequential for social resilience. Second, imaginaries play a significant role in the way a society addresses science and technology. In light of these insights, the paper explores nuclear imaginaries in Japan before and after Fukushima, and presents several key historical factors that shaped such imaginaries in the lasting manner. It presents how Japan's nuclear imaginaries have persistently embraced certain ideals of science and technology, and excluded people subject to radiation risks. The paper concludes by calling for explicit engagement with our nuclear imaginaries, in terms of social resilience, and also as an arena where we can explore more democratic approaches to science and technology. Such engagement is also consequential to larger visions of society.

Key words: Social imaginaries, sociotechnical imaginaries, resilience, public engagement with science and technology, Fukushima nuclear disaster

INTRODUCTION

For decades, scholars in humanities and social sciences have explored the role of imagination in social life. After influential works by Anderson (1983),[78] Castoriadis (1975/1998), Appadurai (1990) and Taylor (2003), the concept of social imaginaries – imagined collectivities, together with shared assumptions about social relations and practices, as well as collective representations and narratives about a society's past, present, and future – has become a common analytical tool in such fields as anthropology and sociology.

Two recent insights regarding collective imaginaries are of particular relevance in thinking about the Fukushima disaster and its aftermath. First, social imaginaries are consequential for social resilience. Hall and Lamont (2013a, 2013b) argue that social imaginaries are constitutive of the collective capabilities of a community or society, as they not only bind its members with narratives of its past accomplishments and a vision of what it means to belong to it, but also indicate how its members understand what they are capable of doing together. Defining social resilience as "the capacity of groups of people bound together in organizations, classes, racial groups, communities, or nations to sustain and advance their well-being in the face of challenges," (Lamont and Hall 2013), they argue that imaginaries can provide significant resources for such a capacity. For instance, a strong group identity has been found to alleviate the impact of adverse experiences (e.g., Feliciano 2005, Oyserman et al. 2006), and members of stigmatized groups rely on their collective imaginaries to cope with discrimination (Lamont et al. 2013).

Second, imaginaries play a significant role in the way a society addresses science and technology. Jasanoff (forthcoming; also see Jasanoff and Kim 2009) argues that visions of future developments in science and technology are inevitably and intricately connected to collective visions of good and attainable futures, and posits a concept of sociotechnical imaginaries. Defined as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff forthcoming), this concept allows us to explore and understand the complex interplay between developments in science, technology, and society. Importantly, such imaginaries are variable across groups; they are durable yet changeable; and they are not only descriptive, but also prescriptive – engaging with what kinds of future should be pursued and how they should be achieved through science and technology. They also encompass shared fears of harms that might result from invention and innovation.

These recent insights call for an explicit examination of Japan's nuclear imaginaries, both before and after the 2011 disaster. What visions of society were pursued through nuclear technology? What visions do current politics and policy approaches embody? Do they facilitate resilience of communities affected by the disaster? In the following, I present a few

[78] In his seminal account of the emergence of nation-states, Anderson defined the nation as "an imagined political community" – the product of the shared imaginations of those who perceive themselves as members.

findings from a larger ongoing project that traces such imaginaries.[79] To clarify, different groups in society might harbor and advocate different, competing imaginaries, but some can be more dominant than others. Policy is a particularly important site that presents and institutionalizes certain imaginaries as authoritative and representative.

NUCLEAR IMAGINARIES IN JAPAN: AT THE TIME OF THE 2011 DISASTER IN FUKUSHIMA

Among the most striking aspects of the way nuclear technology was imagined by the general public in Japan right before the 2011cdisaster are: (1) how decoupled and dissociated nuclear energy production was from nuclear weapons; and (2) how rarely the former was imagined at all. The public was overwhelmingly indifferent, and took it for granted that there were 17 nuclear power plants (NPPs), supplying 30 percent of the country's electricity. As former-nuclear-engineer-turned-opponent Tanaka (2008) argued, nuclear energy solicited little public attention: "what supports the national policy to promote nuclear power more than anything is the unrecognized indifference of people in big cities" (my translation). Pointing out that none of TEPCO's 17 reactors existed within the areas (including Tokyo) to which the company supplied electricity – all were located in Fukushima and Niigata Prefectures. "We have 55 reactors, but most of us live our daily life as if they don't exist" (my translation). This was the climate in which any critiques or even reservations about nuclear power would have one labeled as "unrealistic dreamer," as Murakami (2011) later described. Nuclear phase-out was unthinkable to many Japanese.

This paradigm was to continue: A month before the March 11 disaster, the Japanese government decided to extend the operation of existing nuclear power plants, partly as a measure to reduce greenhouse gas emission. At the time of the disaster, TEPCO had plans to start constructing two additional reactors at the Daiichi (1F, from now on) site the following year. In general, the predominant policy discourse about nuclear energy centered on the following ideas: (a) it is a source of stable supply; (b) it is economically efficient; (c) it produces zero carbon emission; and (d) by ensuring safety and gaining public understanding, we need to expand it. For instance, in the 2010 Basic Energy Plan, long-term energy plans announced every several years, nuclear energy was categorized as "non-fossil" and "zero-emission sources" together with "renewable energy," and it was proposed that the ratio of these two types of energy be raised from the then 34% to more than 50% by 2020, and about 70% by 2030.[80] The Plan stipulated that more nuclear power stations ("at least 14 reactors") be built and the operating rate of the facilities be increased (to "about 90%") by 2030, while gaining public understanding and trust, especially of local residents, and on the condition of ensuring safety.

At the time, for the government and other proponents of nuclear power production, it was linked to the nationhood both as an indispensable technology that allowed the country with scarce natural resources to prosper and as a technological domain in which Japan excelled. This is evident in the 2006 "Nuclear Power Nation-Building Plan," a report submitted by the Nuclear Energy Subcommittee in the Advisory Committee for Natural Resources and Energy.[81] The plan urges Japan to increase the share of nuclear power, spread its nuclear technology globally, and contribute to nuclear non-proliferation. Similarly, in his ill-timed book, writer-critic Toyota (2010) argued that Japan's nuclear technology was the safest in the world and that the country should promote it both for the economic gains and for the good of humanity, such as a solution to climate challenges.

Organized opponents existed throughout Japan, though marginalized as Luddites, hippies, or "unrealistic dreamers." They had called attention to various issues of concern, such as unfounded "safety myth," the insularity of the nuclear community as "village," and the industry "capture" of policy processes (e.g., Study Group on the Problems of Aging Nuclear Power Stations 2008; Kamata 2001) — many of these have become accepted and shared understandings after the 2011 accident, even presented by major investigative reports put out in 2012 by the Diet, the Cabinet, and a private foundation.

Notably, not only the general public, but also many activists against nuclear power and weapons did not necessarily consider the two applications tightly connected. Even a number of *hibakusha* and anti-nuclear weapons activists were uncritical of nuclear energy production.[82] In July 2011, Terumi Tanaka, Secretary General of *Nihon Hidankyo* (Japan Confederation of A- and H-Bomb Sufferers Organizations) organization, said: "I have been thinking since the nuclear accident, perhaps we *hibakusha* may not have thought very much about nuclear power. These days I think that we need to

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[79] I currently work with Lamont and Jasanoff on a multi-year project, funded with an STS grant from the National Science Foundation (Award No. SES 1257117), that traces the development of dominant nuclear imaginaries in Japan and the United States. Our data include media coverage, policy documents, organizational documents, interviews, and ethnographic data.

[80] http://www.enecho.meti.go.jp/topics/kihonkeikaku/100618honbun.pdf

[81] http://www.enecho.meti.go.jp/topics/images/060901-keikaku.pdf Based on the Framework for Nuclear Energy Policy, approved by the Cabinet in October 2005.

[82] One of them, *Gensuikin* (Japan Congress against A- and H-Bombs), has long been calling for nuclear phase-out in energy production,; it held its annual meeting in Fukushima in July 2013, clearly signaling its opposition to the two related applications of nuclear technology. Another group, The other group, *Gensuikyo* (Japan Council against Atomic and Hydrogen Bombs), has been cautiously against certain aspects of nuclear power production, but has not opposed to the idea itself completely.

revisit and more thoroughly study the background of the technology, the system of management, how the industry and government addressed it, etc., and continue to debate about what we can say and do as *hibakusha*."

In the pre-Fukushima dominant imaginaries, future Japan is ecological, efficient, and equipped with clean energy and strong science and technology, and these objectives are facilitated by nuclear technology. In this vision, technological prowess is an important part of the country's national identity (see Hecht 1998 for the French case), and major social problems are solved by advances in science and technology.

Also implied in these imaginaries is so-called the "deficit model," in which the public's skepticism toward and/or rejection of a specific scientific or technological development is attributed to its ignorance and incomprehension. In this model, knowledge is monopolized by experts, and solutions to the public objection consist of educating them with more and better information about science and engineering and raising their "literacy." STS scholars have presented various critiques to this model, showing how sophisticated and productive "lay" knowledge can be (Wynne 1982, 1996; Epstein 1996), how "local" and parochial – as opposed to "universal" – expert knowledge can be (Wynne 1996), and how increased scientific "literacy" does not always lead to acceptance and appreciation of science and technology (Bucchi and F. Neresini 2008). Critics of the deficit model have called for public engagement in various aspects of science and engineering: not only final assessment of a given for policymaking objectives (e.g., public hearings, consensus conferences, deliberative polls), but also early stages of scientific research and technological development (Rowe et al., 2005; Wilsdon, 2005; Jasanoff 2003; Stirling 2008; see Delgado et al. 2011 for a review of current issues regarding public engagement).

Furthermore, lacking conspicuously in these imaginaries surrounding nuclear technology are certain actors, practices, and phenomena: workers at nuclear power plants (NPPs), local residents, day-to-day operations at NPPs, and risks of radiation for workers and residents. After the 2011 accident, it was a significant surprise for many Japanese to learn about the precarious conditions of labor at the plants (Higuchi 1981; Asakawa 2011; Jobin 2011), as well as how "manual" and low-tech some of the workings and physical realities of NPPs are, as opposed to the images of a clean control room, which was a typical representation of an NPP, and how much uncertainty surrounded a control and effects of radiation. Urban Japanese were also largely oblivious to the risks that local residents bore as NPPs supplied energy to their cities. Moreover, decoupling from bombs prevented *hibakusha*'s postwar social, political, and physical struggles from being relevant to discussion of life with NPPs.

Historical Factors behind the pre-Fukushima Nuclear Imaginaries

While nuclear imaginaries described above are obviously a product of long-term, complex historical processes involving numerous actors, events, and cultural, political, and economic resources, below I highlight several key factors that have significantly shaped them in early postwar years in the way that have persisted since then.

First, in postwar Japan, the public discussion of nuclear technology – and the war experience in general – was significantly shaped by the systematic censorship, carried out by the Allied Occupation from September 1945 to October 1949. Under this censorship, discussion or expression of the experience of the bombings was prohibited. For instance, a 1946 documentary film made by the Japanese government, experts and filmmakers, which depicted the aftermath of the bombs in black and white, was confiscated by the Occupation, and kept in the United States, only to be returned to Japan in 1967 and shown in 1996. Not only did the Occupation censorship forbid criticism of the United States or other Allied nations, and references to experience of the atomic bombs, but also no indication of censorship itself was allowed. The insidious nature of this censorship had a profound impact on the way the Japanese talked about and thought about the atomic bombings. Kawamura (2011) argues that this kind of manipulation contributed to the way the issue of atomic bombings became meaningless, hidden, and invisible to most Japanese in plain sight.

After the end of the Allied Occupation in 1952, many Japanese saw visual representation of victims of atomic bombs for the first time when *Asahi Graph* – a *Life*-like general interest photo magazine – published a series of photos in its August 6th 1952 issue. While the photos certainly were shocking by most standards, with charred bodies and badly injured children, what was strikingly missing was any critiques of the act of bombings themselves. The brutality and inhumanity of the bombs were emphasized without an agent, and also portrayed as a deterrent of another war, or a purveyor of peace. Notably, an organized movement against nuclear bombs did not emerge until after the Bikini Atoll incident in 1954, when the crew of a Japanese fishing boat was exposed to nuclear fallout from the American testing of thermonuclear bomb.

Second, in the Cold War context, Japan came to thoroughly embrace the concept of "peaceful" use of nuclear technology, which was aggressively promoted by the United States. With the 1953 "Atoms for Peace" speech, Eisenhower sought to recast nuclear technology for world redemption and incorporate it into the emerging Cold War order by promising to share it with non-communists countries. Japan's nuclear energy industry came about in this context, coinciding with the rise of anti-nuclear weapons movement. Here, the rejection of weapons not only did not contradict the excitement about "peaceful" use, but also served as a driving force of the latter (Yamamoto 2012). In the name of turning a tragedy into inspiration, the US government even launched a campaign to build an NPP in Hiroshima in 1955 (Tanaka and Kuznick 2011). The US found Japanese allies including young politician Yasuhiro Nakasone (later Prime Minister) and Matsutaro Shoriki, who ran the *Yomiuri Shimbun* and was known as the father of Japanese baseball (and later member of the parliament and the father of nuclear power). For instance, Shoriki worked with the US government to organize the traveling exhibition on "the peaceful use of atomic power." The exhibition started in Tokyo and visited nine other cities including Hiroshima, where it was co-sponsored by the Hiroshima City Council, Hiroshima Prefectural Government, Hiroshima University, and the *Chugoku Shimbun*, and received enthusiastically in spring 1956. While many *hibakusha* were initially cautious about this "peaceful" application of the technology, arguing that no solution had been found to the problem of managing radioactive materials, by summer 1956, even Moritaki Ichiro, an intellectual leader of survivors and nuclear weapons abolitionist, came to embrace the idea of "peaceful" use (Tanaka and Kuznick 2011). Importantly, this dichotomous view in which the tragedy of military use is contrasted to the prosperity of "peaceful" use, as well as decoupling of the two, resulted from concerted efforts by the US government and Japanese supporters of nuclear energy. In the late 1950s, very little opposition existed to the ideas of nuclear power production or plans of building NPPs. Narratives of nation-building through nuclear energy were not hindered by the memories of the bombs or the growing anti-nuclear weapons movement; rather, they were supported by the idea that, as the "sole victim" of the bombs, Japan should lead the world in this technology.

Third, as some scholars argue, behind the de-politicized nature of nuclear energy production was the long-standing history of internal colonization in Japan, whereby Tokyo and the power that be there have exploited and colonized the periphery such as the Tohoku region, of which Fukushima Pref. is part of. As Hopson (2013) points out, Tohoku-born intellectuals have long described the region a domestic colony of the center, whose subjugated and "backward" status resulted from official policy decisions during the Meiji period (1868-1912) of rapid modernization. These intellectuals were aware – some as early as in the 1890s – that the region's often essentialized "backwardness" was a product of the exploitation of its resources and domination (Hopson 2013). As the region turned into a significant provider of rice and labor for the growing Tokyo Metropolitan area, the narrative that the backward region needed to be developed also became common, and local support for projects such as NPPs became strong. In this context, Tohoku became the primary provider of electric power for Tokyo, and the constructions of NPPs in Fukushima was an extension of this historical trend.[83] (For more studies of exploitation of the periphery by the center, see Kainuma 2011, Takahashi 2012, Kawanishi 2011). With this unequal relationship as a backdrop, a sociotechnical system that isolates NPPs, their workers, and local residents from urban areas came about, corroborated by narratives of nation-building as a noble goal.

Fourth, Japan's science and technology nationalism preceded World War II (Mizuno 2010), but after the defeat by the atomic bombs, narratives of nation-building through science and technology became a constitutive element of government policy in various areas. Despite a number of debates about the relationships between science, technology and society in the 1950s and 1960s, often carried out by prominent scientists and engineers such as Hideki Yukawa and Mitsuo Taketani (e.g., Doi 2012), the ideas that science and technology belong to the elite and experts prevailed and survived various challenges, including pollution diseases, anti-NPP movements, and various NPP accidents, both at home and abroad. While this deficit model has been prevalent globally, in Japan it had an elective affinity with the country's technocratic tradition and scientific nationalism, leading to the rise of safety myth and nuclear village and the systematic exclusion of lay voices.

NUCLEAR IMAGINARIES IN JAPAN: AFTER FUKUSHIMA

The 2011 nuclear disaster was a colossal event in Japanese history that has prompted unprecedented efforts to review and discuss what happened, how and why, as well as where we should go as society. Issues of nuclear power, long marginalized and depoliticized, have come into the spotlight in the Japanese public discourse. Numerous TV programs, magazine and newspaper articles, blogs, films, and books have explored a variety of issues, from historical backgrounds of Japan's NPPs to causes of the disaster to the effects of radiation on human health to the energy future of Japan. Furthermore, there have been multiple large-scale efforts to investigate the accident, and new regulatory framework was introduced.

However, despite these efforts at reflection and momentary openness to change that followed, much of the older imaginaries remain today, dictating policy and political debates, as well as the way the pubic can engage with decision processes. In particular, the deficit model, the way the polity is imagined as centralized, and the way radiation risk bearers are hidden all persist.

For instance, despite the consistent majority opposition to restarting of reactors (all the 48 of them are currently offline) in opinion polls, the 2014 Strategic Energy Plan has paved ways to restarting of NPPs whose safety has been confirmed by the

[83] As an effort to unearth the region's rich culture and history and understand what its reality says about Japan's past and present, noted folklorist Norio Akasaka has been advocating "Tohoku-gaku," or Tohoku Studies.

Nuclear Regulation Authority (NRA) under "the new regulatory requirements, which are of the most stringent level in the world."[84] The Plan presented nuclear power still as a primary, "base-load" source for the country's energy supply, emphasizing the same rationales as earlier (e.g., efficiency, stability, Japan's scarce natural resources, less greenhouse gas emission than fossil fuel-based energy), and in case of restarting a reactor, the government will "make best efforts to obtain the understanding and cooperation of the host municipalities and other relevant parties."

On one hand, the Plan shows some new approaches, emphasizing the significance of opening up the regulatory processes, increasing transparency over the energy policy planning process, and obtaining public trust. It even calls for an end to the national government's monopoly over many decision-making processes, as well as more open engagement with various stakeholders. On the other hand, the idea that the issue is communication with the public, rather than the public's democratic participation, still prevails. In this line of thinking, safety is presented as a domain exclusively for elite efforts, whether scientific or managerial, and the public's concerns and anxiety as something to be resolved with explanation and communication. Such ideas of unproblematized expertise and the deficit model still predominate, despite much soul-searching that took place.

In this context, young mothers who show concerns about the effects of low-dose radiation exposure are portrayed as irrational and pressured to be silent; uninformed workers are mobilized to participate in decontamination efforts in a precarious, exploitative manner; evacuees from some areas with decreased radiation are nudged to return, with financial support about to be reduced or cut; and municipalities within 30kim of a NPP, although now part of emergency evacuation plans, do not have a say in its restarting (Jobin 2013; Williamson 2014).[85] These are consistent with the earlier visions of nuclear technology, even though Japan's nuclear imaginaries have forever been changed by the accident.

CONCLUSIONS: TOWARD DEMOCRATIC IMAGINARIES

If new nuclear imaginaries are to serve as resources for social resilience, they need to allow those affected by its negative consequences to feel that their experience matters, that they are part of this social enterprise that explores new relationship to nuclear technology, that they have a say. Japan's dominant nuclear imaginaries have consistently excluded their voice, before and after Fukushima, and we need to reexamine whether that is the direction we want. It is also an opportunity to reflect further on our relationship to science and technology. While many countries in the West have incorporated public engagement in their policy processes, Japan lagged behind, although some provisionary attempts have been made since the disaster (Tanaka 2013). Nonetheless, the deficit model still prevails, and what kinds of public engagement would be productive in Japan need to be explored. And if, in addressing nuclear technology, we are signaling and performing where we are going as society, we should reexamine our approaches carefully and explicitly. After all, the key issue is not simply whether we want nuclear energy or not and how; it is also about whether we want a society that exploits and abuses the vulnerable (Takeda 2011).

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Institute of Resilient Communities

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ABSTRACT
The recent events at the Dai-ichi nuclear power plant in Fukushima, Japan, have highlighted the need to enhance the resilience to radiological and nuclear events. The incidence and the associated large releases of radioactive materials had and still have an enormous societal and economical impact in Japan and globally. Although no casualties and health effects have been and likely will be attributable directly to radiation, these events have manifold and substantial impact on local communities and have provoked ongoing anxiety and concerns globally. We are establishing a new Institute for Resilient Communities in Berkeley in collaboration with Japanese partners to address the needs for better scientific and technological capabilities to assess, predict, and minimize the impact of disruptive events in the future and to enhance the understanding of associated risks in the public. While the initial focus resides in radiological resilience and is closely related to the events in Fukushima 4 years ago, the goal is to establish a broader framework for researchers, educators, and communities to enhance resilience locally and globally.

Keywords: Radiological and nuclear accidents, real and perceived risks of nuclear radiation; radiological resilience.

1. THE CHALLENGE

The events at the Dai-ichi nuclear power plant in Fukushima, Japan, have highlighted the need to enhance the resilience to radiological and nuclear events. The incidence and the associated large releases of radioactive materials had and still have an enormous societal and economical impact in Japan and globally. Although no casualties and health effects have been and likely will be attributable directly to radiation, these events have manifold and substantial impact on local communities and have provoked ongoing anxiety and concerns globally.

In order to minimize the impact of these and possible future radiological incidents, technologies and scientific understanding have to be enhanced and equally important, the understanding of nuclear and radiological matters in the public. An important reason for concerns and anxiety in local and global communities can be found in the lack of knowledge and accessible information about radiation and the lack of clear and transparent communications resulting in an evolving distrust of the authorities and potentially of the scientific community. In addition, more effective technologies are required in combination with better scientific models to assess and predict the distribution and transport of radioisotopes in the environment and ultimately, to understand the transport into and minimize the impact onto the biosphere.

The events in Fukushima underscore the necessity and provide the opportunity to address both aspects, the need for better science and technologies and for better understanding in and communication with the public. Currently, local communities and global societies are vulnerable to such events and exposed to the actual and physical as much as to the perceived risks associated with nuclear and radiological incidents. Major releases of radioactivity will have a global impact for two reasons: 1.) The radioactive materials can be transported globally quite effectively as has been observed after Chernobyl or Fukushima or previously with the nuclear weapons program; 2.) Any event related to the releases of radioactivity will end up as headlines in the global and social media as it is seen news-worthy and will be – in most cases wrongly - associated with a significant health impact. Both aspects will cause increased concerns and fear world-wide, which can only be addressed by an enhanced understanding of radiation and the associated risk for environmental or biological and health effects. Furthermore, the perceived risk and perceived danger of radiation is and will hamper public acceptance of nuclear power which can contribute to a mix of carbon free energy sources necessary to meet the increasing future energy demands while reducing the global CO_2 footprint.

The concept of resilience, i.e. the ability to recover quickly from a disruption, appears provocative to the public, as it implies the possibility for more disruptions or accidents to happen. However, this is exactly what has to be realized, the fact that there is a finite probability for more accidents to happen. We need to enhance our resilience in order to be better prepared so we can minimize the physical and ”measurable” impact as well as the psychological and emotional health impact. Only an informed public and educated decision-makers are able to provide an effective response to a disruption. The necessity for a better-informed public on radiological matter or more broadly for a “technologically literate citizen” is not new. As we can see from the events associated with Fukushima or more recently associated with the Ebola outbreak in West Africa, the U.S.

and global society are susceptible to a perceived risk rather that a factual risk. The Ebola outbreak had an enormous impact in the media and received significant attention by decision makers in the U.S. While the impact of Ebola in the originating countries was and still is enormous, in the U.S. less than 5 five person got infected and the only person who died was infected in Africa. Similar to Fukushima, both events resulted in a significant physical and socio-economical impact locally and mainly a – not-to-be underestimated – psychological effect elsewhere. Not to diminish the local effects, however, just to put the impact in the U.S. in context: About 150 people died of influenza and pneumonia every day in 2012 and about 15 per day in California alone.

2. THE APPROACH

In order to enhance the resilience for current and future radiological incidents, we have established a new activity that consists of a science and technology component and an outreach and education component.

Outreach – The Berkeley Radwatch project

With the releases of radioactive materials on and shortly after March 15, 2011 from the Dai-ichi nuclear power plant we set up initially rudimental, later more sophisticated means to collect rain water and air samples on the top Etcheverry Hall on UC Berkeley campus. The goal of this activity was two-fold: 1.) To study the characteristics such as type and quantity as well as the appearance and the disappearance of radioactive materials that we could associate with the releases in Fukushima; 2.) To publish our results and to engage the public in a dialogue about radiation and to put our findings in the context of the radiation we are exposed to naturally or electively on a daily basis.

Our ongoing measurements at UC Berkeley are part of the Radwatch project. We have established a website where we publish and discuss our results as well as claims and results from elsewhere. Our measurements include a large range of environmental and food samples. Early in 2014, we installed an automatic and near-realtime air monitor that provides activities of radioactive particulates captured in a filter mounted in front of a high-energy resolution high-purity gamma-ray spectrometer on an hourly basis. Associated with our Radwatch activity, we have established the Kelpwatch project in collaboration with Steve Manley from California State University in Long Beach, CA. The goal of this activity is the measurement of radioisotopes in marine Kelp that is collected along the Pacific Coast of North America. Similar to the arrival of radioisotopes from Japan that arrived in California by means of the jet stream within about 70 hours after the releases into the atmosphere in Japan, the main goal of Kelpwatch is to observe the arrival of radioactive materials that were released into the Ocean in March 2011 by means of the Pacific Ocean currents. While we expect the arrival of radioisotopes such as Cs-134 and Cs-137 that can be associated with the releases in Japan over the next year or so, the concentrations will be extremely small, close to the detection limit of our monitoring system of about 10 mBq/liter and will not pose any health risk. The Woods Whole Oceanographic Institution recently published the first observation of Cs-134 off the Northern California Coast. The observed concentration of 2 mBq/liter is significantly less than the about 10 Bq/liter of the naturally occurring K-40 observed in the Pacific Ocean. The ongoing releases of contaminated water in the Ocean in Japan result only in fairly small concentrations even close to the harbor of the power plant. For example, the water concentration of Cs-134 in close proximity to the harbor of the Dai-ichi nuclear power plant is about 20 mBq/liter, if detectable at all.

Science and Technology – Assess, predict, and minimize the impact of radiological contamination

Our research within the context of radiological resilience at LBNL is currently engaged in 4 different scientific and technology domains, which address current needs in the evacuated areas to ensure the safety of the population when they return and in the future. As of October 2014, about 85,000 people are still evacuated and many, particularly older people want to move back to their homes and communities. The research areas we are currently pursuing in collaboration with scientists from JAEA aim at more effective means to map the contamination, at a better understanding and improved predictive power of environmental transport models, enhanced understanding and measurements of internal human radiation dose, and at the removal of contamination from soil. While the focus initially is on the most abundant contaminant left, cesium, and the environment of Fukushima, the knowledge gained and technologies developed will provide significantly improved means in the aftermath of any radiological event in the future that is associated with the release of radioactive materials. The Fukushima Prefecture represents a very different environment than for example the region of Chernobyl as it consists of large portions of forests and mountains with significant precipitation over the whole year causing continuous changes in the contamination patterns. Fig. 1 summarizes the four areas of research and their relationships. These activities are coordinated with the substantial efforts by the JAEA in Japan.

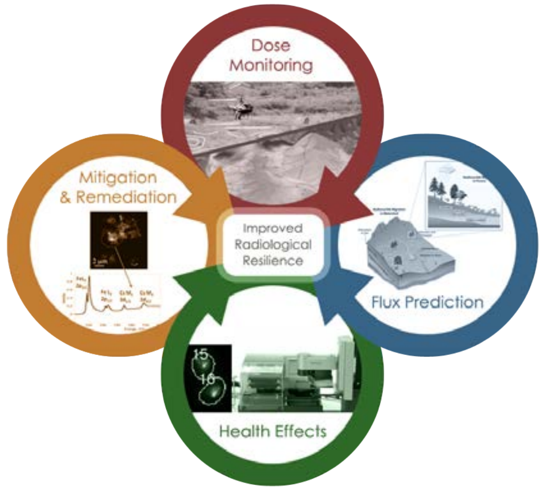

Figure 1: The four main research areas being pursued initially as part of the new Institute for Resilient Communities. The goal is to enhance the effectiveness in monitoring and predicting radiological transport in the environment, to better understand and minimize the impact of radio-isotopes in the biospheres, particularly humans, and the remediation of these radiological materials, particularly cesium.

3. STATUS AND PATH FORWARD

The aforementioned outreach and research activities will become the central pillars for the proposed Institute for Resilient Communities. Based on these established activities we will expand our outreach and research activities locally in Berkeley and with our research and community partners and organizations in Japan. Reflecting the need to work with local communities we are pursuing partnerships with cities such as Berkeley in the U.S. and Koriyama in the Fukushima Prefecture in Japan.

Complementary to the research, we will continue Radwatch with its near-realtime air monitoring and measurements of environmental and food samples as well as with Kelpwatch as part of the outreach and educational efforts. As before and reflecting the importance of transparency in any of our activities to maintain public trust, we will publish all our measurements, procedures, and findings. While the focus to-date was on gamma-ray spectroscopy that is sensitive to radioisotopes such as Cs-134 or Cs-137, we will expand our measurements to alpha spectroscopy which will allow us to measure radioisotopes such as Po-210 which are also naturally occurring, however, can also be misused as highly effective poison.

We are developing and installing a radiation dosimeter network, first across UC Berkeley campus and then across local schools. In parallel, we will make dosimeters available to these schools and will describe science projects that can be performed by the students. These projects have two objectives: 1.) Allow the students to “see” radiation in our environment and to learn important properties of radiation, e.g. the fact that it varies spatially and temporally or that it can be shielded or reduced by increasing the distance; 2.) Enable a better understanding and appreciation of fundamental concepts in science and engineering such as uncertainties associated with observations and measurements, statistics and probability, and ultimately risk. Particularly the concept of risk is becoming ever more important in our modern and technological driven global society and therefore needs to be better understood by the public. The first objective addresses specifically the fear of radiation in the public as it can not be recognized with human senses. The second objective addresses the need to enhance more broadly the science and technology literacy of citizens.

4. SUMMARY

Recent events associated with the releases of radioactive materials and the recognition of the possibility of events that are associated with the release of radioactive materials to happen in the future represent major challenges for advanced and global societies. Radiological or nuclear events due to accidents or the misuse of materials have and will have an enormous socio-economical and political impact on local and global communities. While it is possible that such an event may have significant health effects due to radiation, the psychological impact will be substantial, as observed in Japan. While it is paramount to enhance the safety and security of the currently operating and future nuclear power plants, it is also critical to enhance means in responding and recovering from a possible event to minimize the impact of such events, i.e. to increase the resilience to such events.

The Institute for Resilient Communities addresses this need by combining natural and social sciences, technology and engineering, education and outreach and involves local communities, all in a global context. It addresses the need to improve the scientific understanding of cause and impact of such events. Specifically, the transport and impact of the released radioactive materials in the geo-sphere and the bio-sphere, including humans needs to be better understood. Technologies are being developed to provide the necessary data and information to enable effective means to respond and recover from an event. This includes radiation and bio-sensor technologies as well as modeling and communication tools. The education and outreach aspect aims at minimizing the psychological effects through a better-informed public. While the initial focus will be on radiation, the goal is to establish programs to enhance science and technological literacy more broadly, including basic concepts in science and engineering. Data will be collected and made available to recognize and appreciate the world we are living in, particularly the world we can not see or feel. Local communities will be involved to effectively introduce these concepts to the public and into schools. By providing such a framework, the new institute will become a trusted resource to the public, media as well as decision makers, essential in the response to a radiological or nuclear event.

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5.5. Students' posters

- Hiroyasu Abe (U Tokyo), Ground motion prediction for regional seismic risk analysis including nuclear power station
- Ivana Abramovic (UCB, NE), Effects of inelastic neutron scattering in magnetic confinement fusion devices
- Aissame Afrouss (MPT), The account of the Fukushima Dai Ichi accident by the plant manager: A source to study engineering thinking in emergency situations
- Sophie Agulhon (MPT), On Safety Management Devices: Injunction and Order Use in Emergency Situation
- Sasha Asghari (UCB, NE), A Novel Neutron Counter for Nonproliferation
- Romain Bizet (MPT), Economic assessment of nuclear damage: A review of existing studies and their insights into mitigation policies
- Justin Larouzee (MPT), Human error and Defense in depth: from the "Clambake" to the "Swiss Cheese"
- Xudong Liu (UCB, NE), Criticality Safety Study for the Disposal of Damaged Fuels from Fukushima Daiichi Reactors
- Dipta Mahardhika (U Tokyo), Logical and Emotional Influence in a Time-Constrained Group Decision Making
- Hiromu Matsuzawa (U Tokyo), Evaluation of Optimal Power Generation Mix Considering Nuclear Power Plants’ Shut-down Risk
- Naoto Mitsume (U Tokyo), A Hybrid Finite Element and Mesh-free Particle Method for Disaster-resilient Design of Structures
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Ground motion prediction for regional seismic risk analysis including nuclear power station

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ABSTRACT
Ground motion simulation is one of techniques used to analyze seismic risk due to damage of structure and its effects on society. In this paper, the ground motion simulation using fault plane is used. Recently, ground motion simulation using fault model have been widely applied. Characterized fault model is conveniently used to model the heterogeneous slip distribution on fault plane, which divide the fault into two areas (asperity area and background area). More detailed model is needed to conduct probabilistic seismic risk assessment, which incorporate uncertainty in ground motion prediction. The model, however, is too simplified to model the complex characteristics of slip. In this paper, a stochastic model to simulate the slip distribution of fault plane is proposed for that purpose.

Key words: Seismic Motion, Random Field, Crustal Earthquake, Fault Model, Earthquake Ground Motion

INTRODUCTION
To discuss the safety of critical infrastructure such as nuclear power plants, seismic risk assessment is conducted. Usually engineered system consists of several facilities which are spatially distributed. Though the conventional risk assessment is mainly for a single facility, risk assessment for multi-facility is required. An example of spatially distributed system is a nuclear power station. In a nuclear site, several units are located. Additionally, sometimes several sites are located closely each other. For public, the information on the likelihood and possible amount of radioactive material release is needed and all the units may suffer from identical external events, multi-unit risk assessment is necessary. For that purpose, a technique to simulate spatially distributed ground motion probabilistically is needed.

Recently, ground motion simulation using fault model is widely used for ground motion simulation for a single site. In the fault model, a simplified characterized fault model was proposed and used for that purpose, and standardized method, e.g., ‘recipe’[1), is proposed. The method, however, was proposed to calculate the average characteristics of ground motion. More detailed model is needed to conduct probabilistic seismic risk assessment, which incorporate uncertainty in ground motion prediction. Therefore, in this study, a probabilistic modeling of slip distribution focusing on crustal earthquake is proposed.

A PROPOSED MODEL TO SIMULATE THE SLIP DISTRIBUTION
Fig. 1 is an example of actual slip distribution in the fault plane of West Off Fukuoka Earthquake in 2005. The spatial distribution of slip displacement exhibits stochastic characteristics. When two elements in the fault plane is closely located, slip displacement is similar, i.e., correlated. On the other hand, slip displacement is random when two elements are distant. These characteristics of slip displacement can be modeled using the spatial correlation model.

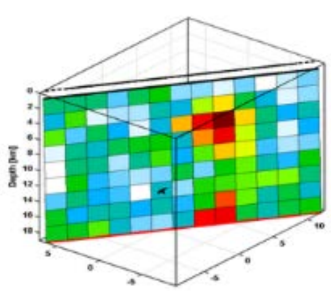

Fig. 1. Slip distribution along fault surface of West Off Fukuoka Earthquake [3), 4)]

This correlation structure of the slip distribution is analyzed. The slip displacement at each element at Figure 1 is denoted $y=\{y_1,\cdots,y_n\}$, where n is the number of element. Slip displacement is assumed to be distributed by the log normal distribution. Table I shows the average and standard deviation of logarithm of slip y in Fig. 1 obtained by the maximum likelihood estimate. Then, the correlation structure from slip distribution during actual earthquake is analyzed. Semivariogram *r* is used for that purpose. $r(Y_i,Y_j)$ is defined as follows:

$$r(Y_i,Y_j)=\frac{1}{2}E[(Y_i-Y_j)]^2 \qquad (1)$$

where, Y_i and Y_j are the lengths of slip at the *i*-th and *j*-th element respectively.

Table I. Average and standard deviation of logarithmic slip of West Off Fukuoka Earthquake

Average	Standard deviation
3.90	0.87

And, semivariogram '$r(Yi,Yj)$' is defined as follows:

$$r(Y_i,Y_j)=\sigma_Y^2\times(1-\rho_{YiYj}) \qquad (2)$$

where, σ_Y is standard deviation of fault plane and ρ_{YiYj} is the correlation coefficient between Yi and Yj .
In this study, this correlation is assumed to depend on h that is distance between two elements, and the correlation coefficient is defined as follows:

$$\mathrm{r(h)}=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}(Y(\mathbb{X}_{1i})-Y(\mathbb{X}_{2i}))^2 \qquad (3)$$

Provided that $N(h)$ is the number of pairs that fulfill (4) include $(\mathbb{X}_{1i},\mathbb{X}_{2i})$.

$$\mathrm{h}-\frac{\Delta h}{2}\leqq|\mathbb{X}_{1i}-\mathbb{X}_{2i}|\leqq\mathrm{h}+\frac{\Delta h}{2} \qquad (4)$$

where, $\varDelta$h is assumed 1.34km. Fig. 2(a) is $r(h)$ obtained from Equation (3). Fig. 2(b) shows $N(h)$ for each bin. In Fig. 2(a), fitted parabola that is determined from least -squares method is denoted.

$$r(h)=b(1-\exp(-ah^2)) \qquad (5)$$

where, b is the constant equal to the dispersion $\sigma_{Y'}{}^2$. a is estimated 0.0947, and b is 3.4819×10^3.

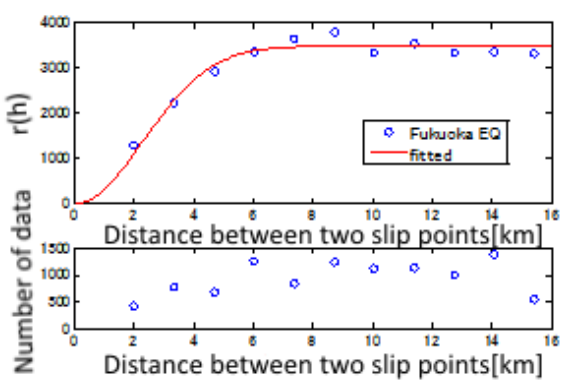

Fig. 2. Semivariogram showing spatial correlation of slip obtained from slip distribution during West Off Fukuoka Earthquake

Simulation of slip distribution in fault plane is conducted by Monte Carlo Simulation. The slip of fault plane in *i*-th element is Y_i. $Y=[Y_1,Y_2,\ldots Y_N]'$. Y follows logarithmic normal distribution. W is the normal random variable that is transformed from Y by Rosenblatt conversion as follows:

$$W = \Phi^{-1}(F(Y)) \qquad (6)$$

where $\Phi^{-1}(\ )$ is cumulative function of standard normal distribution, and $F(Y)$ is the cumulative distribution function of Y. Z is decided by random number, and W is determined from that.

$$W = \Phi_w Z \qquad (7)$$

W is determined from that. In this equation, Z is the stochastic variable vector that fulfill normal distribution, mean of 0 and standard deviation of 1. Φ_W is Eigenvector of covariance 'C_{WW}'. (8)

$$C_{WW}\Phi_W = \Phi_W \Lambda_W \qquad (8)$$

Λ_W is the square matrix, diagonal element is characteristic number and the other is 0.

$$C_{WW} = \begin{bmatrix} \rho_{11} & \cdot\ \cdot\ \cdot & \rho_{N1} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \rho_{N1} & \cdot\ \cdot\ \cdot & \rho_{NN} \end{bmatrix} \qquad (9)$$

In this equation, ρ_{WiWj} is correlation coefficient between Wi and Wj. In this study, it is premised that ρ_{WiWj} is equal to ρ_{YiYj}, and fulfill (5). So, it is premised that ρ_{YiYj} is a function of only h_{ij} which is distance between i and j.

$$\rho_{YiYj} = \exp(-ah_{ij}^2) \qquad (10)$$

Distribution in fault is simulated under the condition of $Mw6.6$ ($M_0=9.0\times10^{18}$N・m) that is same as West Off Fukuoka Earthquake.

GROUND MOTION SIMURATION USING PROPOSED MODEL

Stochastic Green's function[2)] method is used for ground motion simulation. The fault geometry and receiver location is showed in Fig. 4. S-wave velocity on surface is assumed to be 400m/s in this study.

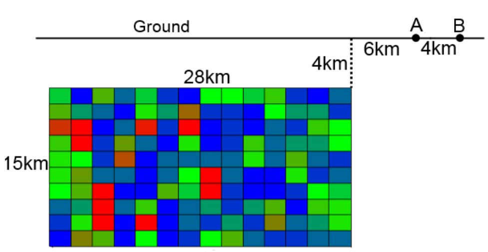

Fig. 4. Geometrical relation between fault plane and receiver locations (A and B)

In Fig. 5(a), samples of slip distribution is shown, while simulated ground motion (velocity time history) for respective case is shown in Fig. 5(b). As shown in the figure, the temporal characteristics of velocity time history are different between samples. Maximum velocity increases if large slip appear between the hypocenter and the receiver as shown in the bottom figure in Fig. 5.

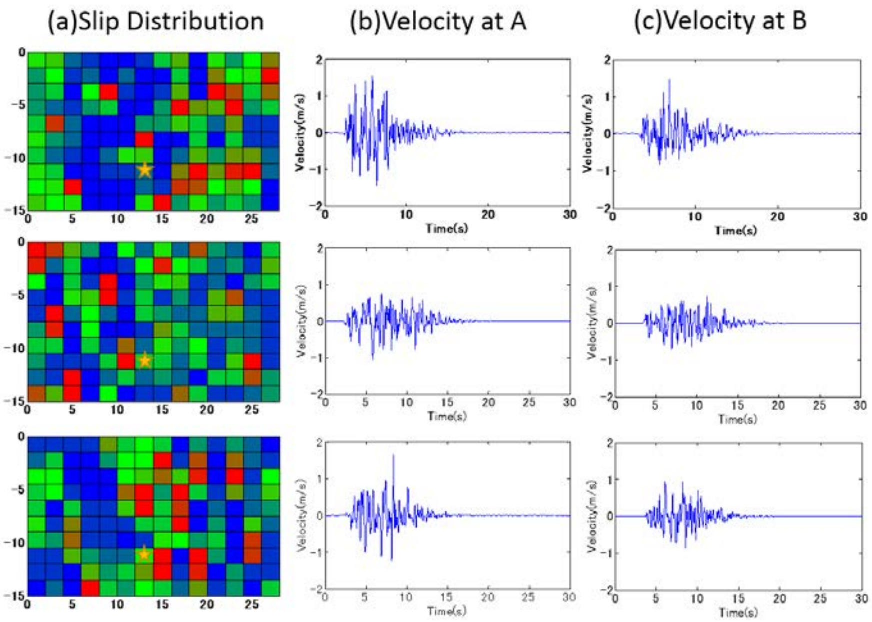

Fig. 5. Distribution slip and velocity of ground motion obtained by MCS.

The simulated slip distribution was closer to real distribution than characterized fault model. However, the long slip area is scattered than actual case.

CONCLUSIONS

Multi-unit and multi-site probabilistic seismic risk assessment is needed to respond to the public concerns about offsite emergency response. In this paper, a stochastic fault rupture model is proposed for the purpose of multi-unit and multi-site probabilistic seismic risk assessment.

The simulated slip distribution was closer to real distribution than characterized fault model. However, the larger slip area scattered than actual case. It is needed to be improved in future study. For example, it would be needed that slip distribution is modeled by a different approach.

ACKNOWLEDGMENTS

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The account of the Fukushima Dai Ichi accident by the plant manager: A source to study engineering thinking in emergency situations

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ABSTRACT
The concept of « engineering thinking in emergency situations » has been defined to make up for an epistemological lack in the field of Safety Sciences*. The institutional bodies did not take an interest in analysing the conditions in which the recovery efforts had to be carried out. The description of the accident and its representation in the accident investigation reports convey these shortcomings. The Fukushima Dai Ichi plant manager Masao Yoshida testimony may allow us address them partly. Actually, the transcription of his hearings contains essential details and information to understand the sequence of events which took place after the 2011 Tōhoku earthquake and tsunami. This article intends to show the importance of studying this narrative, in order to highlight the relations between the Fukushima accident management and the concept of "engineering thinking in emergency situations".*

Key words: Engineering thinking, extreme situation, Yoshida testimony, narrative analysis, mental representation.

INTRODUCTION

The Fukushima Dai Ichi accident is regarded as one of History's most important nuclear accidents, along with Chernobyl and Three Miles Island. Yet, the institutional accident investigation reports do not allow us to comprehend fully the complexity of the accident management by the operators. To address this problem, the concept of "engineering thinking in extreme situations" has been defined as "*engineering activities that are significantly impeded due to the lack of resources in the face of a societal emergency*" (Guarnieri, Travadel, 2014).

Masao Yoshida, the plant manager, has been heard by the Investigation Committee on the Accident at the Fukushima Nuclear Power Stations (ICANPS) on the plant's management after the earthquake and the actions undertook to deal with the accident. His account, made public in September 2014, is currently being edited in French (Guarnieri et al., 2015)[86]. The testimony enables us not only to address the silence of the reports, but to learn more about the factors affecting the decision-making and the action-taking during "extreme situations" as well. During such a situation, the actions taken by workers do not enable them to regain control of their production tool, and are regarded as responsible of an impending and irreversible damage (Travadel, Guarnieri, 2015).

This article therefore intends to demonstrate the importance of the Masao Yoshida first-hand account, and how its study contributes to the concept of "engineering thinking in emergency situations". In the first part of the article, some accident investigation reports and there content are presented. In the second part, correlations between the hearings of Yoshida and the narrative form are highlighted, and then, the significance of the manager's disclosures for "engineering thinking in extreme situations" is revealed.

THE ACCIDENT INVESTIGATION REPORTS

The first part presents the four institutional reports used in this study and the bodies that produced them. Then, it sums their content up, with an eye to analyse the representation they make of the accident.

Description of the institutional report

Following the Fukushima accident, several bodies published reports about its causes. These reports also point out the lessons that are to be learned to enhance nuclear facilities safety. This paper is based on the reports issued by the Investigation Committee on the Accident at the Fukushima Nuclear Power Stations (ICANPS, 2012); the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC, 2012); the Nuclear Energy Agency (NEA, 2013); and the American National Academy of Science (NAS, 2014). These documents have been written by two Japanese, an international and an American organisation. Obviously, they were drafted with different purposes and present different feedbacks and recommendations.

[86] The CRC – MINES ParisTech is publishing a French version of the entirety of the hearings of Yoshida. The first volume which contains the auditions of 22 and 29 July 2011 is available since March 2015. The following hearings will be gathered in the second and the third volumes. The fourth volume will be devoted to the analysis of the whole corpus.

The Cabinet of Japan has decided to create The Investigation Committee on the Accident at the Fukushima Nuclear Power Stations (ICANPS) on 24 may 2011. The ten members (researchers, judges...) are put under the direction of Yotaro Hatamura, professor emeritus of the University of Tokyo. The aim of the Committee is to suggest recommendations to limit the expansion of the damages of the accident and to prevent the recurrence of similar crises. The investigation should identify the causes of the accident and the causes of the damages it inflicted to Japan. The members of the Committee ambitioned to carry out a thorough investigation which outcome would satisfy every question about the accident, and whose results would remain valid for the next century. The final report is issued in July 2012.

The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC) has been established via a dedicated act – named NAIIC act – on 30 October 2011. On 8 December 2011, the ten members of the Commission are designated by the Diet president. Kiyoshi Kurokawa, a doctor of medicine and former chairperson of the Science Council of Japan is appointed chairperson. The nine other members are scientists, legal experts and politicians. The investigation of the NAIIC focuses on the causes of the accident and of the damage of the accident. It also reminds how the stakeholders dealt with the accident, and points out the lack of efficiency of their responses in the face of the emergency situation. Finally, it suggests measures to be applied in order to prevent another nuclear accident from happening in Japan and to mitigate its possible consequences. The final report is published in September 2012.

One of The Nuclear Energy Agency's (NEA) tasks is to strengthen the legal, scientific and technological bases of the nuclear safety in the Organisation for Economic Co-operation and Development (OECD). In September 2013, it drew up a report on the lessons learnt from the Fukushima accident. This document has been written under the direction of the Director-General Luis Echávarri. It lists the efforts made by the OECD member countries to improve safety management following the accident, and gives general recommendations based on the main lessons learned.

The American National Academy of Science published a report sponsored by the United States Nuclear Regulatory Commission in July 2014. The study has been carried out by a committee consisting of various scientists and engineers with different competencies. The committee was led by Norman P. Neureiter. The aim of the report is to summarize the multiple causes of the nuclear accident and to suggest recommendations to enhance the American nuclear facilities' safety.

The accident according to the reports

The analysis of the recommendations given in the different reports allows indentifying the flaws singled out by the institutional bodies. This therefore permits to understand the accident representation by the bodies. In this article, the notion of "representation" refers to the cognitive map of the subject, that being the entirety of causal, proximal and influence relations established, in order to understand a problem or a problematic issue (Chaxel et al.,2014).

As for the four reports, the Fukushima Dai Ichi accident is due to a lack of preparation of TEPCO and the involved institutions to deal with such an event. They reveal therefore the absence of training and of skills needed to respond to an emergency situation among TEPCO employees. They also point out the fact the communication between the workers and the authorities, and the poor coordination of the emergency response centres has not permitted to react effectively to the situation.

Furthermore, the accident could have been avoided if the state of the art and the new safety concepts have been applied, especially the concept of defence-in-depth. TEPCO and the Japanese institutions did not take out the appropriate measures to bring their facilities' safety into line with current international standards. The reports underline also the necessity for all nuclear power plants to strengthen the defence-in-depth provisions, and to consider the occurrence of beyond design basis and multi-unit accidents.

Another recommendation concerns the lack of independence of the Nuclear and Industrial Safety Agency (NISA). The nuclear regulatory body knew about some of TEPCO safety deficiencies and did not make sure the operator corrects them. The competencies, the involvement and the transparency of the NISA have been called into question. Consequently, Japan needed to deeply reform its nuclear facilities' regulation and surveillance system.

This quick overview shows that the four reports do not bring renewed reflections on nuclear accidents management. Instead, they only emphasise the need to strengthen concepts already acknowledged and to take larger margins to avoid potential accidents. New standards might be suggested and taking beyond design basis accidents into account is encouraged. To sum up, major accidents management is regarded through the organisation and the resources already available.

However, after the earthquake and the tsunami, the operators found themselves in the face of scenario that exceeds every known standard. The loss of electricity resources and the worsening of the site conditions point out the need to adapt to new and unexpected circumstances. The hearings of Masao Yoshida bring out a new consideration of the accident, giving specifications and details unfound elsewhere. His account enables a better understanding of the proceedings of the Fukushima crisis management.

THE IMPORTANCE OF YOSHIDA'S TESTIMONY

This part analyses the hearings of Masao Yoshida and shows that his testimony can be considered as a narrative. A comparison is then made between the content of the institutional reports and the disclosures of the manager, binding these information and the concept of « engineering thinking in emergency situations ».

The Yoshida testimony: A narrative of the accident

The hearings of Masao Yoshida have been carried out by the ICANPS, which interrogated several stakeholders of the accident management. The manager has been summoned five times by the Commissions, between 22 July and 22 November 2011. The transcription of these hearings has been made public on 11 September 2014[87].

The content of these hearings can be regarded as a narrative of the nuclear accident. A narrative corresponds to an oral, written, drawn or ritualised representation of real or fiction events, arranged according to a chronological organisation and following a whole consistency (Adam, 1996). Yoshida's account of life is produced during a "semi-structured interview". This kind of interview is an "*interaction close to conversation, thanks to the continuous adaptation of interrogations and interventions of the researcher to the ongoing exchange*" (Nossik, 2011). In such a narrative, the person interviewed – Yoshida – leads his discourse according to what he considers the investigator's expectations are (Brun, 2013). The semi-structured interviews also encourage the narrator to digress and tell anecdotes (Bernard, 2014).

These deviations from the main narrative plot are useful to add meaning to the story, by providing explanations and/or comparisons. In his account, via the addition of details and information, the narrator intends justifying the sequence of events: this guarantees the overall outline and the intelligibility of the narration. Yoshida selects the events he believes significant and establishes "*specific connexions to provide consistency*" (Bourdieu, 1986).

Yoshida's account is obviously based on his own memories. The facts are then arranged according to the – necessarily subjective – point of view of a major stakeholder of the accident management. Even though the main plot of the account is led by the investigators, the overall meaning is instilled by the interviewee. The manager resorts to his own representational system to build a consistency between the facts reported.

The metaphors used and the reference to his states of mind reveals the complexity and the extent of the troubles that had to be dealt with during the decision-making. It is interesting to note the deviations to the main plot since they enable us to reveal the "absences" in the official investigation reports.

The disclosures of the manager

The analysis of the manager's testimony shows correlations between the accident management and the concept of "engineering thinking in emergency situations". The information it presents, sometimes unrevealed before, can be divided into three aspects: factual, representational and operational.

The institutional reports the succession of events in the Fukushima Dai Ichi plant with an a posteriori posture. They reflect a desire of comprehensiveness and explanation of all phenomena, especially from a technical point of view. This approach makes the reports recount some of the facts as they were deduced by simulation, and give precise time-related indications. Yet, the Fukushima Dai Ichi response centre ignored about many of these phenomena until the simulations were performed. Indeed, Yoshida tells the investigators many times that he cannot recall some details or that he did not know about facts stated during the interview.

From a representational point of view, some of the reports describe the Fukushima Dai Ichi reactors one by one. As for the manager's account, it reveals that the emergency response centre had to deal with the whole site at the same time, in order to avoid the deterioration of the different facilities. In addition, the evolution of the emotional state of Yoshida shows extreme complications in the handling of the situation. This can be proven by an excerpt of the hearings. After the earthquake, the concerned employees gathered in the anti-seismic building and established an informal emergency response centre. Since the tsunami warnings, this group considered the probability of an anomaly in the reactors' cooling. However it is the loss of the electric power resources following the tsunami that causes the distress of the group[88]: "*We're so dismayed that we're speechless. For the time being, we're quiet and we're tackling administrative tasks, as the declaration of loss of all AC power, the much talked about article 10. However, as I told you a bit earlier, as we carry out these administrative tasks, emotionally, we're devastated*". The team finds itself, from this moment on, "*in the face of a catastrophe*" (Guarnieri et al., 2015).

[87] These documents are available in Japanese in the following address : http://www.cas.go.jp/jp/genpatsujiko/hearing_koukai/hearing_list.html
[88] The plant manager has to warn the authorities in case of an emergency situation, such as the loss of power resources. He then constitutes an emergency response center under his direction; in accordance with the article 10 of the Japanse act No. 156 on the Special Measures Concerning Nuclear Emergency Preparedness.

Devastation, annoyance, fear relate to an emotional anxiety which comes into play in the decision making and the action taking in an accident situation. The third aspect of the information found in the account of Yoshida is complementary to the representational one. It relates to the actions undertook in the field. The manager underlines many times the complexity faced to see the tasks through to the end. This inability to have an effect on their work tool, paired up with the lack of understanding and the impatience of their off-site hierarchy, contributes to the extreme situation undergone by the workers (Guarnieri et al., 2015). The attempts to vent the reactor 2, mentioned in few institutional reports, illustrate perfectly the gap between the field and the executives.

The analysis of the hearings permits to better take some factors inherent to the “extreme situation” concept into account. For instance, the uncertainty of the situation, the lack and inappropriateness of the available resources to deal with the accident, the social and hierarchy pressure, and the powerlessness facing the progressive decay of the facilities can be mentioned.

The factual lacks and the arrangement of facts in the reports do not convey accurately the complexity and the stakes of the crisis as faced by the workers and the onsite emergency response centre. Nevertheless, it should be made clear that the testimony is a reflection of how the manager recalls the story and depends particularly on his memory and subjectivity. Thus, the account does not necessarily correspond to the objective succession of events, as they took place in the Fukushima Dai Ichi plant following the arrival of the tsunami.

CONCLUSION

The account of the accident by Yoshida is a valuable material to understand the Fukushima Dai Ichi accident management. The testimony makes up for some factual shortcomings and clarifies some information given by the institutional reports.

The information and the disclosures available in the narrative allow to establish a link between the Fukushima accident management and the concept of “engineering thinking in emergency situations”. A more thorough analysis of this document should consequently showcase some pointers of this kind of engineering activities, performed in “extreme” conditions. The analysis of some excerpts could for example show the influence of social pressure – embodied in the repeated demands of the Japanese Government – on the operations undertook to preserve the reactors’ integrity.

The narrativisation of the nuclear catastrophe could also be studied. This research perspective should underline, for instance, the relation that Yoshida maintains with the nuclear technology, to which he dedicated his entire professional career and on which he loses control after the tsunami.

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On Safety Management Devices: Injunction and Order Use in Emergency Situation

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ABSTRACT

This paper aims to introduce two main concepts regarding safety management which are injunction and order. In a first section, those two kinds of communication for action will be defined and distinguished through responsibility repartition criterion. Indeed, while injunction device involves addressee's commitment regarding action design, order device is a less complex one in which a specific authority is responsible of order content in a specific frame while the addressee is generally only responsible of the order content execution. To illustrate those concepts potential, injunction and order contribution to face an emergency situation will be demonstrated through local field management and Headquarter relationship analysis during a crisis exercise of major magnitude in a nuclear fuel cycle industry. As a general conclusion regarding safety management, one would note that injunction use ensures decision-making robustness by subjectivity mobilization, as challenging voices multiplication participates to solid evidence emergence thanks to cross-checking practices. Secondly, the specific result of this demonstration remembers one of the Fukushima-Daiichi management lessons, meaning that in a resilient system, Headquarter tends to communicate with Local Management Team through injunction.

Key words

Emergency situation management, injunction use, management devices and relationships, order use, nuclear safety.

INTRODUCTION

According to CREAM methodology developed by Hollnagel[1], Human Reliability (HR) depends on three factors: human, technology and organization[2]. As this knowledge can possibly contribute to develop resilient systems, management devices use to overcome unexpected situations seems to be a relevant research topic to deepen. As Blau noticed, two kind of communication management can address to the people managed, depending on their "independence in the performance of [their] duty"[3] and impacting responsibility distribution. Those two kinds of communication are management devices that we would call order and injunction. Both of them are used by an authority demanding something from someone but with a different approach toward responsibility.

This contribution defines those two safety management devices called injunction and order and demonstrate their contribution to system recovery in an emergency situation. This "ongoing crisis in which conventional resources are lacking, but societal expectations are high"[4] was a particularly interesting case as explicitation processes and time acceleration effect emphasize how nuclear organizations deal with those issues.

SAFETY MANAGEMENT DEVICES DEFINITION

What is injunction?

Injunction is a communication triggering action as the addressee should adapt his behavior regarding its message (conformity). This communication comes from an authority and is both binding and relying on its addressee subjectivity[5]; as the addressee is linked to the expected action or to its aim regarding responsibility criterion. Fundamentally, injunction implies a tension between what comes from oneself (autonomy) and what is implemented by external sources (heteronomy)[6]. This phenomenon affects one's identity as no one can predict how far a subject will integrate external things to his subjectivity[7] and experience.

By saying so, one would conclude right by stating that safety injunction is not always or completely defined in time, space and form. That is why, prevention posters from Oak Ridge Laboratory dating from the Manhattan Project times are still quite relevant for any worker exposed to radiation sources, even though some military elements might have lost some sense since[8].

What is also interesting about injunction as a management device is that there is a wider array of potential issuers than in the order case. So far, three kinds of authorities have been identified as relevant to make an injunction.

The first authority observed is derived from the recognized power one has to direct someone else, such as in hierarchy case. This typical authority has been widely analyzed since management studies beginning, particularly with Henri Fayol description of administrative skills use[9].

The second authority defined comes from the legitimacy inherited from ones' function, in Weber sense[10]. So, experienced workers, specialists, inspectorate and auditors can also make injunctions. We chose here not to use the word "expert" as Blau showed that training purpose in organizations was mainly to make people experts in their respective domains; as we wanted to insist on the role idea which goes beyond knowledge.

The third authority observed results from a commitment. In this configuration, issuer and addressee are parts of the same community of interest and share an aim. That is why the issuer is legitimate to make an injunction and the addressee has to fulfill his duty as a group member. As one can guess, this is why safety culture development is encouraged in nuclear firms.

Finally, observing nuclear industry fieldwork shows that safety injunction use often implies an interesting labor division. Indeed, the issuer; or transmitter regarding its human or non-human status[11] ; fixes goals that the addressee has to reach by defining himself means such as structures, equipment, workforce, and so on. So, safety injunction strength and weakness is its capability to rely on its addressee's experience by giving him some latitude to obtain a better individual contribution to safety. However, as nuclear industry also needs precision in several quality aspects, order as a management device can also be very helpful.

What is order?

Order is a time and space framed, oral or written binding communication, coming from an authority detaining a recognized power of direction over the addressee, to which the addressee must obey. In most of the cases, this authority is responsible of the given order result. Obedience and disobedience are not related to the autonomy-heteronomy tension derived from conformism but is a matter of dependence and independence balance. As a matter of fact, obedience in the kind of relationship previously described does not impact the addressee identity in the same way as injunction.

Indeed, as there are objective things showing the addressee's dependence and as the action expected is, apparently, not related to his own willingness, the subject is generally not easily questionable for his acts. As The Grapes of Wrath novel shows[12], when an expropriated farmer asked for who he should shoot to avenge his loss, the answer done by the mended man is that he is just following the owner orders who is just following the bank orders; and so on until the causal chain vanishes in the unknown, making the farmer's quest for a convener absurd.

Furthermore, orders are often combined with injunctions. Even in organizations when orders through short communications were openly favored such as in jail or in Christian schools during XVIIIth and XIXth centuries, Michel Foucault demonstrated the existence of another purpose than getting obeyed quickly.

What was at stake was to place bodies in a little world of signals to which an only and mandatory answer is attached. So, a daily-life order can also be combined with an injunction shaping prisoners and pupils' behavior, training them to react in the exact sense defined[13]. In this case, their individual contribution to performance tends to zero.

As subjects can be both commanded (when management makes them do something using order device) and governed (which means that management guides their actions and consequently modify their behavior by injunction device use) depending on management device choice, and because power relations are generally numerous and of various kinds[14], distinguishing how one is put under pressure and to what extend regarding his responsibility can be quite necessary to face all the expectations one is addressed in a particularly sensitive moment such as facing an emergency situation.

SAFETY MANAGEMENT DEVICES CONTRIBUTION TO SYSTEM RECOVERY

Crisis organization context

In September 2014, a nuclear industry organized a major crisis exercise of 36 hours that we will not try to analyze as such. Our demonstration will only focus on something out of all simulation aspects: the relationship between local and national level to manage an emergency situation.

Crisis mode is a simplified organization designed to save time. What should be remembered about this design is that:

- Local Emergency Management Team is responsible of field response to the crisis;
- While its national hierarchy (Headquarter) informs stakeholders and takes specific decisions like internal intervention force deployment;
- As this intervention force is composed of various specialists from other entities with no previous hierarchical link with Local Management Team but who will be placed under its command during field intervention.

As we explained earlier, an authority derived from the recognized power one has to direct someone else can possibly use injunction and order management devices. As time is lacking and precision necessary to get out of the crisis situation, one could have imagined that order would have been the main device used by Headquarter to lead the Local Management Team.

However, our observations note a different result which might clarify one of Fukushima-Daiichi management lesson regarding Yoshida and Prime Minister's coordination unit[15]: injunction can be used to handle uncertainty while order contributes to accelerate the recovery process.

Recovering with injunction and order use

On the first day, a simulated tornado damaged the nuclear fuel cycle platform in the early afternoon. As no one knew exactly what were the consequences of such natural disaster on the plant, all actors tried to face the crisis in the best way they could think of. In this sense enactment phenomenon that is to say ways people find to cooperate for the moment to get to the next step in a specific occasion[16] began to appear.

During the mid-afternoon turn-over preparation conference call between Local Management Team and Headquarter, five issues were highlighted (in no preference order):

- Human assessment;
- Safety assessment;
- Production recovery conditions;
- International Nuclear Event Scale (INES) classification of the event;
- Plant workers evacuation.

As injunction use showed regarding the last point ("This needs to be addressed"); Local Management Team was clearly expected by Headquarter to solve those problems, though Headquarter also ordered "not to waste time" on INES classification.

On the field, as Local Team handles operational responsibility towards crisis management for legal and practical reasons, decision was made to prior human and safety assessment. So, rounds and competencies checking were organized to gather information on damages, assess risks and take back control on source terms. Workers evacuation was done during the night when Plant Management was sure no one would be carelessly exposed to danger.

On the second day, as reliable data were gathered, valuable technical solutions were found such as sprinkling devices and robot use to deal with the most risky situations. When it appeared that the intervention force would be sent in a relatively controlled environment, the Headquarter finally ordered to allocate the internal intervention force to spread uranium powder extraction, a relatively known action. As a consequence, the crisis exercise finished in the expected time and with no human loss due to National or Local effort for system recovery; which might not have been the case if previous decision had been confirmed to send the force right after the tornado instead of triggering its early warning mode for field checking support.

RESULTS

First, injunction effectiveness to system recovery in national and local level management relationship has been demonstrated in several ways.

Injunction use contributed to data collect organization as the National level trusted Local Management Team ability to gather adequate means to do so because of geographic position and responsibility repartition. But injunction use also contributed to recruit individual contribution to solution design such as sending a robot to a damaged building to prevent criticity peak consequences on intervention forces.

As a consequence, injunction reduced uncertainty and contributed to an effective internal force deployment through order. So this second management device could help, for its part, to solve the crisis in a clean-cut way.

Second, Headquarter injunction use in its relationship with local management allowed priority fixing, innovative choices but also, to a certain extent, contributed to limit errors due to omission or deny, as even the terrorism hypothesis has been considered. To put it in a nutshell, injunction contributed to an exhaustive situation assessment by cross-checking practices without penalizing field action.

DISCUSSIONS

Choosing wisely between order and injunction management devices during the crisis participates in effective system recovery.

If resilience is a characteristic of a system with elastic behavior which can face disturbances[17]; that is to say a system able to partly absorb human experience through contextualization without rejecting all systemic aspects; knowing more about safety injunction reception could be an important step in High Reliability Organization design.

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A Novel Neutron Counter for Nonproliferation

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ABSTRACT
The International Atomic Energy Agency (IAEA) relies on helium-3-based neutron detectors to perform critical safeguards verification activities. Yet because the supply of helium-3 has greatly diminished in the past decade, it is of international interest to develop non-helium-3 based neutron detectors. The Water Neutron Detector (WaND) provides an efficient, non-toxic, and non-flammable alternative detector method. The WaND system is under investigation for nondestructive assay of spent nuclear fuel, particularly quantifying plutonium content.

Key words: Nondestructive assay, neutron detection, water Cherenkov, IAEA, spent fuel monitoring

INTRODUCTION

Background

Without an adequate, assured supply of [helium-3] (or an effective replacement), IAEA safeguards in particular (and worldwide safeguards in general) will be significantly impaired." -- The IAEA Workshop on Requirements and Potential Technologies for Replacement of Helium-3 Detectors in IAEA Safeguards Applications

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT), entered into force in 1970, requires all signatory non-nuclear weapons states to not ``acquire nuclear weapons or other nuclear explosive devices" [1]. A major role of the International Atomic Energy Agency (IAEA) is to verify that signatory states are abiding by their NPT treaty obligations by establishing safeguards for nuclear weapons-related material. Safeguards measures are utilized to confirm that nuclear material is used solely for peaceful purposes. Neutron detection is an integral part of safeguards because it provides an effective way of detecting and identifying special nuclear material [2].

Helium-3-based neutron detectors comprise essentially all neutron detectors currently used by the IAEA, and the US has historically been a primary supplier [2]. The U.S. stockpile of helium-3 plummeted from ~230,000 liters in 2001 to ~50,000 liters in 2010 [3]. Because of the connection between the U.S. stockpile of helium-3 and the effectiveness of IAEA safeguards inspections, it is of national and international interest to develop non-helium-3 based neutron detectors.

Furthermore, the Next Generation Safeguards Initiative has identified neutron multiplicity as a priority for nondestructive assay (NDA) of spent nuclear fuel. Methods for direct and accurate measurement of plutonium content in spent fuel requiring fewer unverified a priori assumptions about the fuel matrix are needed. Such measurements would aid in quantifying shipper/receiver differences, determining the input accountability value at reprocessing facilities, and provide quantitative input to burnup credit determination for repositories [4].

Novel neutron detector

The WaND (Water Neutron Detector) [5] is a non-helium-3 based neutron multiplicity counter under development at Lawrence Livermore National Laboratory. It is an efficient, stable, non-toxic, and non-flammable solution to some neutron neutron multiplicity counting applications. Neutron multiplicity refers to the number of neutrons emitted per fission event and may be used to fingerprint special nuclear material, such as plutonium or uranium enriched in uranium-235. The advantage of using a neutron multiplicity counter is that the analysis is non-destructive, has the possibility of being done on-site, and is relatively fast. The WaND system is composed of 1 m^3 of pure 18 MegaOhm deionized water doped with 0.5% gadolinium-chloride ($GdCl_3$), contained within a stainless steel tank (121.9 cm x 91.4 cm x 119.4 cm). To protect the stainless steel tank from the corrosive water (due to the chloride content), the tank is coated with a baked-on layer of Teflon. Eight photomultiplier tubes are mounted on the top of the detector, looking into the detector volume. The inside of the tank is also lined with a 1.0 mm highly reflective (>99% in blue near UV) layer of GORE DRP material. Figure 1 shows a 3D model and a photograph of the detector.

The detection mechanism is multi-stepped. A neutron born from a fission event in the sample well must enter the water volume and thermalize. The thermalization distance is ~35mm for 1MeV neutrons. Once the neutron has thermalized, it will radiatively (n,gamma) capture on a gadolinium nucleus. Gadolinium-157 (15% natural abundance) has the highest thermal neutron absorption cross-section of any stable isotope (259,000 barns), and natural gadolinium's thermal neutron absorption cross section is 50,000 barns. After capture, the target nucleus will de-excite by emitting a gamma shower with a total energy of 8 MeV. The gamma cascade consists of roughly 3 to 4 gammas, each with an average energy of ~2 MeV [7]. The gammas then Compton scatter off of electrons in the medium, ejecting some at high energies. Electrons that are emitted with a kinetic energy above the Cherenkov threshold (250 keV [8]) will produce a ring of Cherenkov light, which is then detected by photomultiplier tubes.

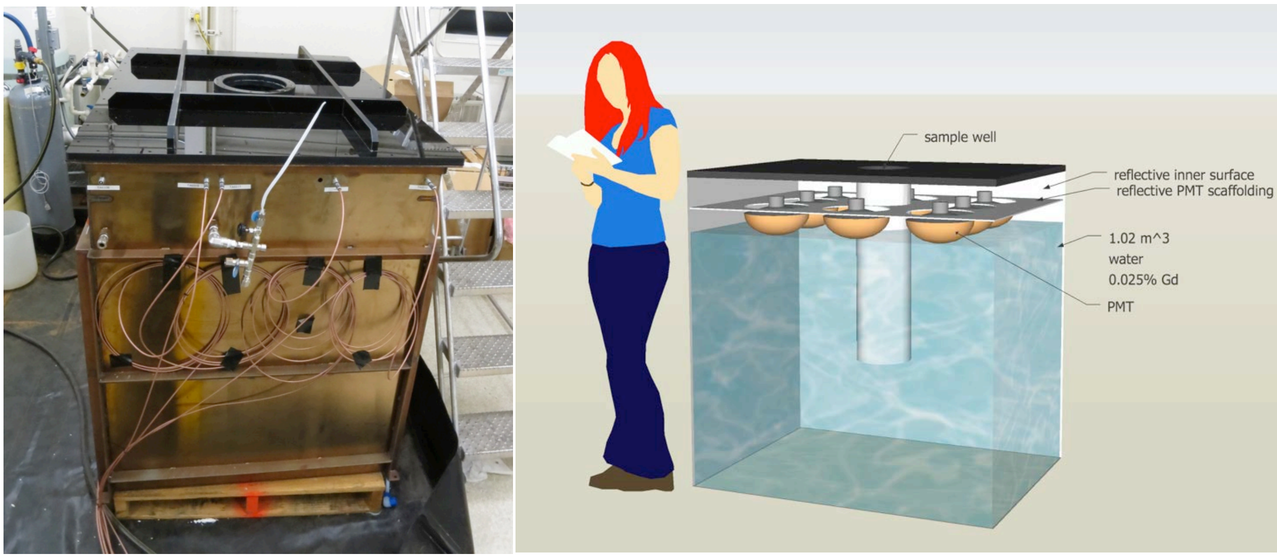

Fig. 1. A photograph (left) and 3D model created using Sketchup (right) of the WaND system. Note the person for scale.

RESULTS

Both gammas and neutrons produce a detector response in the WaND system. Figure 2 shows the spectral response of a 5.9 microCi cobalt-60 and a 0.82 microCi californium-252 source. The background is measured by performing a data run without sources. Then the background is statistically subtracted from a source run, leaving only the source contribution.

A 50 photoelectron energy cut from a background-subtracted run effectively eliminates gammas (leaving only 1 in 10^8), leaving only neutrons. The absolute neutron detection efficiency with this criteria is 28%. This translates to a sensitivity to ~20 to 30 milligrams of plutonium-240 [9].

CONCLUSIONS AND FUTURE WORK

The WaND system is currently under investigation for possible application to spent fuel monitoring. Spent fuel poses an especially difficult problem for neutron detection because the high intensity gamma field renders most detectors useless. For example, scintillator-based detector systems rely on pulse shape discrimination, placing severe limits on gamma background and neutron signal rate. Germanium or silicon-based detectors are small and susceptible to neutron damage. Boron-based systems such as BF_3 and ^{10}B tubes and planes present toxicity concerns and can be relatively inefficient. The WaND system is efficient, stable, non-toxic, and non-flammable. The effects of high gamma fields and how to mitigate them are currently under investigation. Future work includes measuring the multiplicity distribution of a plutonium source. The combination of plutonium sensitivity and gamma insensitivity creates a potential to directly measure the plutonium content in spent fuel.

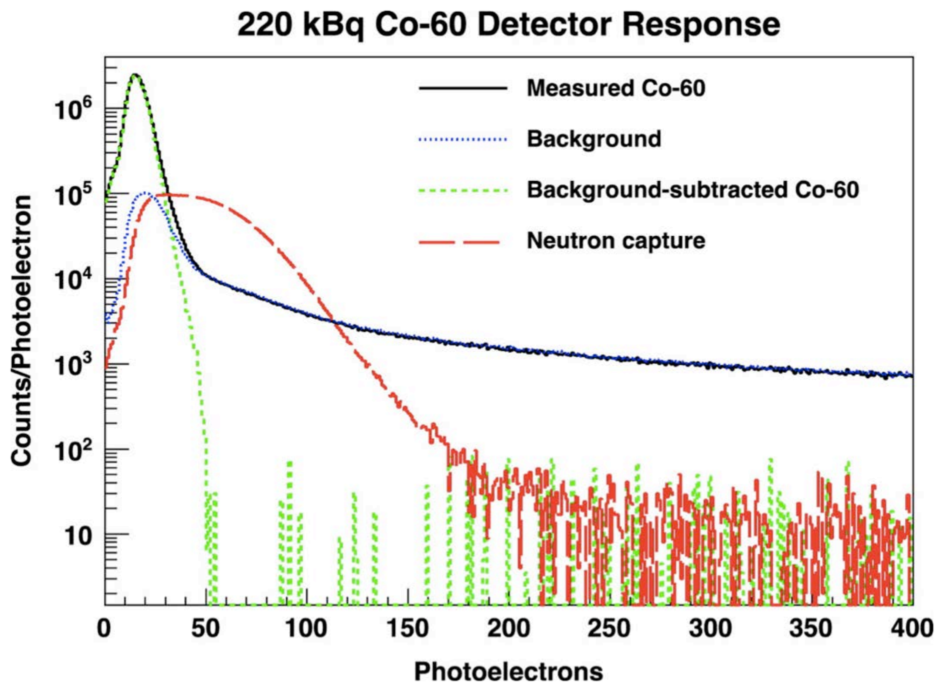

Fig. 2. Detector response to a one hour run of a 5.9 microCurie cobalt-60 gamma and a 0.82 microCurie californium-252 neutron sources [5]. The solid black line indicates a cobalt-60 spectrum with a background spectrum. The dotted blue line is a no-source background spectrum. The dashed green line shows the statistical subtraction of the cobalt-60 source and background, minus the background. This leaves the pure cobalt-60 detector response spectrum. The dashed red line shows a pure neutron californium-252 spectrum, background subtracted in the same manner.

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Economic assessment of nuclear damage: A review of existing studies and their insights into mitigation policies

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ABSTRACT

In this short paper we review the existing studies that assess the economic cost of nuclear accidents. Their results exhibit large discrepancies, and vary by several orders of magnitude. We argue that these differences are not peculiar from an economic standpoint and arise from three sources. Cost assessments have very different scopes, they use various methods to estimate the monetary values of non-monetary welfare losses, and studies based on Chernobyl's figures yield much higher costs than studies based on probabilistic safety assessments. We then argue that current research on cost assessment fails to provide guidelines for mitigation policies. This failure is due to the aggregation of costs that do not entail the same consequences for mitigation policies. Restraining the scope of cost assessments to nuclear countermeasures might provide insights on how mitigation policies should be implemented.

Key words: nuclear accidents, cost assessments, monetary valuation, mitigation policies, nuclear countermeasures.

INTRODUCTION

Risks of accidents are often quantified by the assessment of their expected costs; that is the product of a monetary loss by its probability of occurrence. In the case of nuclear power, this definition is particularly inconvenient. Estimating the probability of a nuclear disaster is subject to high uncertainties, and so is the assessment of its costs. The former issue is discussed in the companion paper by François Lévêque. This paper will focus on the latter issue.

Estimating the economic cost of nuclear damage serves two purposes. First, *ex ante* cost assessments provide decision-makers with policy guidelines regarding hazardous activities. Choosing among various technologies for electricity production, or setting efficient safety standards both are policy decisions that rely on these assessments. Second, *ex post* cost assessments allow victims to be compensated according to their losses.

Numerous assessments of the cost of a nuclear accident have been performed over the years. This paper will review some of these assessments and present their very different results. We argue that these differences are not peculiar from an economic standpoint. Similar differences are also observed in other hazardous activities, such as car accidents, oil spills or climate change. We then try to identify the origins of the discrepancies in the assessments. The uncertainty clouding results stems from three sources: existing studies have very different scope; they rely on either past data or probabilistic safety assessments (PSA); and assess the consequences of the accident and their monetary costs with different methodologies.

Second, we highlight the fact that most studies focus on damage, not on mitigation efforts, and try to produce assessments that account for as many consequences of an accident as possible. Even if this is necessary for the aforementioned goals, it fails to provide insights into how the aftermath of nuclear accidents might be mitigated. Indeed, numerous countermeasures are available and can help reduce the impact of a nuclear accident on the economy. Yet, few economic studies try to assess the impact of mitigation policies on the cost of nuclear accidents. Those who do reduce their scope to a specific nuclear countermeasure - such as land decontamination - often yield less uncertain results or clearer insights for policy-makers. Therefore, we stress the need for future research in the economics of nuclear countermeasures, which could provide guidelines for mitigation policies.

EXISTING ASSESSMENTS OF THE COST OF A NUCLEAR ACCIDENT

A review of existing studies

Assessments of the cost of nuclear accidents have been carried out since the mid-seventies and the beginning of probabilistic safety assessments. Since then, numerous studies have been published, and several reviews of these studies exist. Namely, in 2000, the Nuclear Energy Agency published a methodological review in which several cost assessments were described (1). In 2011, after the Fukushima-Daiichi accident, the German Renewable Energy Foundation performed a calculation of the adequate insurance premium that the nuclear industry would need to pay to fully cover the accident risk. This study also reviewed some existing assessments (2). The D'haeseleer report for the European commission also provides a comprehensive review of studies that assess the external cost of nuclear accidents (3). Finally, the IRSN[89] published in 2013

[89] The IRSN is France's technical support organization for the Nuclear Safety Authority (ASN).

an assessment of the cost of severe and major accidents in which other studies were reviewed (4). Those four reviews reference numerous studies and give a thorough overview of the state of the art literature on the evaluation of the costs of nuclear accidents. As we do not wish to tackle here the question of the probability of nuclear accidents, Table 1 below only presents the studies that assess the cost of nuclear accidents before weighting.[90]

Table 1: A review of existing assessments of the cost of nuclear accidents[91]

ref		Year	Health cost	Food cost	Loss of land, production and cost of mitigation actions	On-site cost	Image cost	Fleet cost	Cost of a nuclear accident (b€)
(5)	WASH 1400	1975	**x**	**x**	**x**	-	-	-	**14**
(6)	CRAC-2	1982	**x**	**x**	**x**	-	-	-	**314**
(7)	Hohmeyer	1988	1370	-	-	-	-	-	**1370**
(8)	Ottinger	1990	629	38	-	-	-	-	**667**
(9)	Ewers-Rennings 1	1991	2740	38	828	-	-	-	**3606**
(9)	Ewers-Rennings 2	1992	7815,6	307,4	179,1	-	-	-	**8302**
(10)	ExternE	1995	74,3		37,9	-	-	-	**112,2**
(11)	Eeckhoudt	2000	10,85	6,162	0,098	-	-	-	**342**
(2)	German Renewable Energy Federation	2011	**x**	**x**	**x**	**-**	**-**	**-**	**5900**
(12)	Rabl-Low	2012	10	5	100	50	-	-	**165**
(12)	Rabl-Central	2012	18,8	7,5	250	78	-	-	**354**
(12)	Rabl-High	2012	50	50	1000	290	-	-	**1390**
(4)	IRSN-severe	2013	0	9	11	10	50	44	**124**
(4)	IRSN-major	2013	27	14	110	28	180	88	**447**

Table 1 shows high discrepancies. How can one assess the cost of nuclear accidents at approximately €10 billion (5), while others announce a cost of more than a trillion Euros (9)? First, it can be noticed that all studies do not assess the same cost. Some only focus on damage to the population (health and food costs), while others try to assess the total impact of the accident on the economy. Yet, this cannot be the only cause of these differences. Indeed, even within cost sections (health, food…), there is little consensus as to which cost section represents the highest share of the total cost. The comparison between the “IRSN-major” (4) and the assessment from the German Renewable Energy Federation (2) embodies this observation: even though it only assesses health, food and production costs, the German study calculates a total cost ten times superior to the IRSN figure, which accounts for a larger panel of consequences.

The assessments of the costs of other hazards exhibit similar discrepancies

This is not specific to nuclear power: other hazardous activities exhibit the same kind of discrepancies. In 1995, Elvik studied the assessments of the cost of car accidents in twenty countries. This work was motivated by the observation of large disparities in the evaluation of this cost: while the Netherlands were evaluating the total cost of a car accident at U.S. $0.12 million, Switzerland estimated it at U.S. $2.5 million (13). This study argued that the deviation was caused by the lack of common methodology in the assessment of the cost and the consideration by only a limited number of countries of value of the lost quality of life.

The estimations of the damage caused by oil spills are also prone to large disparities. In 1995, Cohen assessed the damage of the Exxon Valdez oil spill. She claimed that the upper bound of the estimation of the damage caused by the oil spill in the first two years following the disaster was U.S. $155 million (14). In 2003, another study assessed the cost of this oil spill at approximately U.S. $2.8 billion (15). In these studies, Cohen limited her assessment to the costs incurred by southcentral Alaska’s fisheries, while Carson assessed the population’s willingness-to-pay to restore the lost passive use of the damaged environment.

Finally, the climate change literature also exhibits large discrepancies. In a review published in 2009, Tol shows that there is little agreement on the long term effects of climate change. While some authors (16) predict an overall small positive effect

[90] The cost of a nuclear accident can be weighted by an electrical output to yield an external cost or by a probability to yield an expected cost.
[91] “x” signifies that the cost section is at least partly assessed. “-“ signifies that the cost section is not assessed.

due to the heating of cold regions, others predict dramatic consequences (17). This overview highlights the fact that the uncertainty clouding cost estimates can originate from several sources.

UNCERTAINTIES AND MITIGATION POLICIES

If these discrepancies are not peculiar from an economic standpoint, it is nonetheless interesting to try and understand why they occur. In basic economic theory, costs are often defined as anything that causes a loss of welfare (18). The cost of a nuclear accident can thus be defined as the gap between the expected social welfare levels that would be achieved with and without an accident. This vagueness in the definition induces divergence in the assessments. Moreover, the consequences of an accident – direct or induced by mitigation countermeasures – are so numerous and intricate that it is impossible to be sure that all consequences have been accounted for properly. Studies differ first in their assessment of the consequences of the accidents, and then on the monetary valuation of these consequences.

Cost assessments do not speak the same language

First, it seems obvious that results will be different if the type and location of accidents assessed are different. Nuclear plants are highly sophisticated, so there is a large panel of possible accidents which do not have the same consequences. Likewise, nuclear plants are located in areas which are not equally densely populated (19). As an example from Table 1, Hohmeyer's study calculates the external cost of a hypothetical Chernobyl-like accident in the Biblis nuclear plant (Germany) in 1990. The IRSN study calculates the social cost[92] of a hypothetical DCH[93] nuclear accident in France in 2020. The scopes of these two studies are radically different. More generally, the comparison of the studies presented in table 1 is impossible because they do not stand on common definitions.

Similarly, the boundaries of a cost assessment also need to be clearly defined. In 2006, two reports on the consequences of the Chernobyl accidents were published. Their assessments of the number of radio-induced cancers differed by a factor ten. The IAEA/WHO report (20) focused on the consequences of the accident in Belarus, Ukraine and Russia, while the TORCH report accounted for all consequences across Western Europe (21). Nuclear accidents can have cross borders consequences, so it is paramount to define clearly the boundaries of cost assessment studies to fully understand their implications for public policies. As an example, Hayashi and Hughes have shown that the Fukushima-Daiichi accident had an impact on the electricity bill of households in gas-intensive countries such as the United-Kingdom or South-Korea (22). How and by whom should these impacts be accounted for?

Finally, the statistical choices in the presentation of the cost are also crucial for their comparison or their use in policy making. There is for example no consensus as to whether the cost of a nuclear accident should be presented as a distribution function or as a single number. The IRSN decided to produce a median cost so that decision makers know that there is a 50% chance for the cost of an accident to be above or below the result. Conversely, the 2011 study from the German Renewable Energy Federation provided an average maximum value in order to calculate an "adequate" insurance premium.

The aftermath of a nuclear disaster: PSA or past events?

The consequences of a nuclear accident are numerous and intricate. An accident has on-site consequences, such as casualties, highly-irradiated workers or material losses in adjacent reactors. It also causes off-site consequences, such as the release of radioactive materials in the atmosphere, the collective absorbed dose, the area of contaminated lands or the quantity of crops and cattle contaminated. The negative consequences of the countermeasures, such as psychological distress, also have to be estimated. Yet, these numerous consequences have to be assessed in order to derive their monetary value.

The source of divergence in the assessment of the consequences is twofold. First, all studies do not assess the same range of consequences. Some studies argue that health effects dominate all other effects (2) (7) (8). They thus focus on the collective absorbed dose and neglected other consequences. Other studies focus on a wider panel of effects, such as land exclusion, or image effects (tourism, regulatory changes…). Second, studies also differ in their assessment strategies. Physical consequences can be modelled by dedicated programs (MACCS, COSYMA… (23)) that rely on level-three probabilistic safety assessments; or assessed by adapting the figures derived from past catastrophes. Most studies performed in the early nineties were based on Chernobyl's figures, and find particularly high values for the total cost of the accident (7) (8) (9). More recently, another very high cost was assessed by the German Renewable Energy Foundation which happens to be also based on Chernobyl's figures. This observation raises an important question. Can we assess future accidents solely by using the consequences of past catastrophes? A preliminary answer is that we probably cannot. Relying on past figures fails

[92] The private cost of an accident is the cost incurred by the utility; the external cost is the cost that will not be incurred by the firm because either a legal liability threshold exists, or the firm is limited by the total worth of its assets. The social cost of the accident is the sum of private and external costs.
[93] The IRSN describes a Direct Containment Heating accident, which consists in a direct heating of gases within the containment vessel.

to account for the learning from past consequences, the enhancement of safety standards, and the progress in available mitigation technologies.

Converting consequences into costs requires various hypotheses and assessment methodologies

Once the consequences of a nuclear accident have been assessed, they have to be given a monetary value. Indeed, a cost is the monetary valuation of foregone welfare. Among the consequences discussed previously, some welfare losses are easily derived (cost of material losses). For other physical consequences, various hypotheses are required to bridge the gaps in our limited knowledge. Regarding health issues, we do not know precisely the effect of exposure to low doses on cancer or hereditary diseases probabilities. Regarding the environmental impact of an accident, the size of lost lands depends on the geographical spread of the radioactive materials and on the acceptable radioactivity threshold that a population can bear. The consequences on food are also uncertain since the population can react to food-bans by boycotting healthy products. The harm caused by nuclear countermeasures, such as psychological distress due to relocations, is also hard to assess. Some hypotheses substantially differ from one study to another. As an example, the excess rate of radio-induced cancer varies from 5% to 10% in the assessments presented in table 1.

Some of these welfare losses such as reduced tourism, strengthened safety standards for nuclear plants, or higher energy prices, can easily be given a monetary value. They are assessed through macroeconomic methods such as the IO-table method. Yet, all welfare losses caused by nuclear accidents are not necessarily monetary. Therefore, some methodologies have been developed in health and environmental economics in order to give monetary values to non-monetary losses. Environmental losses can be assessed by the evaluation of individuals' willingness to pay (WTP) to avoid these losses. Two families of methods allow the assessment of this WTP: the revealed-preference methods and the stated-preference methods. *Revealed-preference* methods such as the travel cost method or the hedonic pricing method, can be used for valuating environmental losses. These are hard to apply to nuclear accidents because they rely on past behaviors and thus require data (24) (25) (26). *Stated-preference* methods are based on surveys that try to elicit the willingness to pay of people to restore the environment. The contingent valuation method is often used to value the environmental consequences of rare disasters.

Regarding health costs, the human capital method calculates the economic value of fatalities or impairments by assessing the number of lost years of production and multiplying it by the average yearly production of a human being. Other methods, such as the friction cost method, exist and have very different ways of calculating those health costs (27) (28) (29) (30). This variety of methods is responsible for some of the discrepancies observed in table 1. First, a consequence can be assessed by different methods. Second, even if a cost is assessed by two studies with the same method, some aspects of the evaluation remain quite arbitrary. In the human capital method applied to the cost of radio-induced cancers, Hohmeyer assesses the cost of a death at $1 million while Ottinger assesses it at $4 million (2).

Drawbacks

Table 1 shows that the tendency over the last twenty years has been to provide an estimation of the cost of nuclear accidents which would account for as many consequences as possible. This emphasis on completeness, which is particularly stressed in the IRSN study, is indeed necessary for the goals mentioned in the introduction of this paper. *Ex ante* policy making and *ex post* compensations both need to rely on a complete assessment of the consequences of a nuclear accident, since an incomplete assessment might lead to an underestimation of the cost and entail an underinvestment in nuclear safety, a disproportionate share of nuclear power in the electricity mix, or an inadequate compensation of victims (31; 32).

This quest for completeness also has its drawbacks. First, it fosters the aggregation of numbers that differ by nature. As we have seen, all costs of consequences are not assessed using the same methodologies, and are thus not subject to the same uncertainties. Summing them up to provide a global cost of nuclear accidents propagates the highest uncertainty to the final result. Second, completeness can be detrimental to scientific rigor. Some costs currently have no corresponding assessment methods. It is the case for food bans; which are estimated in the most recent study by comparison with recent non-nuclear food bans (4). Their integration in cost assessments is thus controversial, since they don't stand on robust economic grounds. Finally, to achieve completeness, existing studies have focused on damage and consequences, and tried to identify new consequences, or "lines of cost". By doing so, most studies overlook the impact of nuclear countermeasures, which is the object of the next part of this paper.

Cost assessment fails to provide guidelines into mitigation policies

Current research on cost assessment focuses on providing more complete assessments by identifying more and more consequences of an accident. This trend is necessary, but is not adapted to mitigation policies. First, the theory of "sunk costs" (33) explains that once a cost has been incurred, it is no longer relevant for decision making regarding the future. In the case of mitigation policies, the capital losses due to the destruction of a power plant are incurred at the time of the accident. Those losses are an example of sunk costs, and should thus not enter the mitigation policy decisions. Current estimates, as they account for all kinds of losses regardless of the time at which they are incurred, cannot be used in the determination of mitigation policies. This observation raises one question: can we expect cost assessments to provide useful guidelines for mitigation policies?

Yes! Cost-benefit analysis (CBA) of countermeasures could provide at least three useful insights regarding mitigation policies. First, it was shown by the report on the consequences of Chernobyl that countermeasures are costly (20). Cost-benefit analysis could thus help determine which countermeasures are most efficient by comparing their costs to society with the valuation of the prevented damage. Second, there are numerous countermeasures that address the same harmful consequences. Some measures are substitutes (emergency relocation and confinement), while others are complements (iodine prophylaxis and confinement). Hence the assessment of their costs and benefits could help policy-makers identify tradeoffs or synergies when implementing several countermeasures. Finally, the consequences of a nuclear accident do not happen all at once. Cost-benefit analysis is thus a good tool to search for the optimal inter-temporal allocation of mitigation resources.

This kind of assessment is already carried out in other hazardous activities such as car accidents or biosecurity (34) (35). In the case of nuclear power, Munro studied the tradeoff between long-term relocation and land decontamination. As radioactive decay reduces the cost of land decontamination over time, he calculated the optimal decontamination date which occurs approximately ten years after the accident (36). Other studies also focus on particular tradeoffs between countermeasures, namely land decontamination and food restrictions (37) (38). Yet, these studies focus on multi-criteria decision making rather than on performing a CBA of countermeasures.

Existing studies that deal with mitigation only focus on long-term countermeasures. Being able to deal with emergency countermeasures is a barrier that needs to be overcome if CBA is to provide guidelines for mitigation policies. Indeed, an important tradeoff has to be solved right after the accident, and concerns the confinement or the emergency relocation of populations. A question for future research is whether CBA can deal with this emergency. Indeed, the optimal mitigation scheme cannot be determined ex ante, as it requires ex post data such as the plant impacted or the weather and its impact on the path of the radioactive materials dispersed in the atmosphere.

CONCLUSIONS

This paper raises two research questions. The first is whether assessing the cost of nuclear accidents using the figures derived from past events is a robust method. As it fails to account for safety enhancements, progress in mitigation technologies, and learning from past catastrophes; it can drive cost assessments upwards, provide pessimistic numbers and entail overinvestments in safety or an unbalanced electricity technology mix. The second question is whether cost assessment should only focus on *ex ante* policy making and *ex post* compensations. We believe that cost assessment should also be used in order to improve mitigation policies and the reduction of the cost of nuclear accidents. This could be achieved by reducing the scope of cost assessments to the cost-benefit analysis of available nuclear countermeasures.

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Human error and Defense in depth: from the "Clambake" to the "Swiss Cheese"

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ABSTRACT

Since the early 1990s, the Swiss Cheese Model (SCM) of the English psychologist James Reason has established itself as a reference model in the etiology, investigation or prevention of industrial accidents. This article focuses on the collaboration between the psychologist (James Reason) and a nuclear engineer (John Wreathall) who happened to be at the origin of the creation and evolution of SCM. This article is based on an exhaustive literature review of Reason's work and interviews of Reason and Wreathall carried out in 2014. The study suggests that the success of the model is not so much due to appropriation of the work of the psychologist by the industrial community but to a complex process of co-production of knowledge and theories. To conclude, we try to highlight ways that should encourage, in the future, these collaborative ways of working.

Key words

Swiss Cheese Model, Defense in Depth, James Reason, John Wreathall, Coproduction.

INTRODUCTION

Since the early 1990, the Swiss Cheese Model (SCM) of the psychologist James Reason has established itself as a reference model in the etiology, investigation or prevention of industrial accidents. Its success in many areas (transport, energy, medical) has made it the vector of a new paradigm of *Safety Science*: the organizational accident. A comprehensive literature review of Reason's work leads us to consider the SCM as the result of a complex (and poorly documented) collaboration process between areas of research and industry; human sciences and engineering sciences. In a dualistic premise where research and industry would be two entities interacting but still separable, this collaboration would be understood as the appropriation of research work by the industrial world. However, the complexity of the genesis of the SCM forces an overcoming of this dualism to bring out a process of "co-production" of knowledge. As part of this research, the two main "fathers" of the SCM: James Reason (psychologist and theorist of human error) and John Wreathall (nuclear engineer) met with and interviewed by the author. These meetings shed a new light on a prolific era for the Safety Sciences field. We therefore hope to keep from a retrospective bias that tends to smooth and simplify facts. This communication deals with the induced effects of the collaboration between a psychologist and an engineer in terms of models production. In the first section, we briefly present the two "fathers" of the SCM and the social and historical context in which their collaboration took place. In a second section, we focus more specifically on the effects of this collaboration over their intellectual and scientific productions. It is important to note that this article assumes prior knowledge of the SCM, its theoretical foundations and its main uses (see, for example Larouzée et al., 2014).

I/ THE FATHERS OF THE MODEL

This section presents the two fathers of the SCM. Reason a psychologist of human error and Wreathall a nuclear engineer. After presenting their backgrounds (subsection 1 and 2), we present the social and industrial context in which they were brought to meet and work to create the first version of the SCM (subsection 3).

1. James Reason, psychologist

Reason gets a degree in psychology at Manchester University in 1962. He then works on aircraft cockpit ergonomics for the (UK) Royal Air Force and the US Navy before defending a thesis on motion sickness at Leicester University in 1967. Until 1976, he works on sensory disorientation and motion sickness. In 1977 he becomes professor of psychology at Manchester University. In 1977, Reason makes a little action slip that will impact his scientific career. While preparing tea, he began to feed his cat (screaming with hunger). The psychologist confused the bowl and teapot. This was of great interest to him and he started a daily errors diary. With applied cognitive psychology methodologies, he began his research on human error. His work resulted in a taxonomy of human error (1987). After he became a referent on the issue, he was a keynote speaker in various international conferences on human error. During these conferences, he met John Wreathall, nuclear engineer, with who Reason built working relationship and "*strong intellectual communion*" (in his words). On their collaboration will be drawn the first version of the SCM. Since then, Reason kept working on human and organizational factors in many industrial fields.

2. John Wreathall, the engineer

John Wreathall studies nuclear engineering at London University, undergraduate in 1969; he gets a masters' degree in systems engineering in 1971. Later he studies an Open University course "Systems Thinking, Systems Practice" based on Checkland's models of systems. This option brings the young engineer to human factors and systems thinking. From 1972 to 1974 he works on the British nuclear submarine design which allows him to access confidential reports on HRA by Swain. From 1976 to 1981, Wreathall works for the CEGB (English energy company), first as design reviewer for control systems then as an engineer on human factors in nuclear safety. As an acknowledged expert he was brought to participate in conferences organized by NATO and the World Bank called *Human Error* (book "*Human Error*" by Senders & Moray is the only published product from the 1981 conference of the same name). After meeting Reason there, they both started professional collaborations on accident prevention models (including SCM). His interest in the human factor brought him to several leading functions where he worked on human factor. Most of his works also were funded by the nuclear industries in the USA, Japan, Sweden, the UK and Taiwan, and by the US Nuclear Regulatory Commission.

3. Meeting and collaboration, a particular context

Industrial and research community's interest for human factors is nothing new in the mid-1980s. By the 1960s, development of the nuclear industry and modernization of air transport stimulates many research programs (e.g. Swain, 1963; Newell, Simon, 1972; Rasmussen, 1983; quoted by Reason, 1990). Researches then were mostly conducted under the '*human error*' paradigm. The 1980s were marked by a series of industrial accidents (Three Mile Island, 1979; Bhopal, 1984, Chernobyl and Challenger, 1986; Herald of Free Enterprise and King's Cross Station 1987; Piper Alpha, 1988). Investigations following these accidents brought the Safety community to question the understanding of accidents solely based on operator error. In this scientific, industrial and social context, NATO and the World Bank funded many multidisciplinary workshops on accidents. The first one was held in Bellagio, Italy, 1981. It received the name of "*first human error clambake*".

At Bellagio's Clambake, Reason and Wreathall met. This fortuitous meeting led them to become (in Wreathall words) "*social friends*". Indeed, according Wreathall, "*intellectual communion was quick with Reason but also with other researchers in vogue on the issues of human error at the time. Swain, Moray, Norman*". Reason and Wreathall started corresponding and met at different conferences during the 1980s. Both took commercial projects for industrial groups such as British Airways and US NRC in which they employed each other as professional colleagues. At that time Reason was ending his taxonomy of unsafe acts. He started writing a book on human error aimed to his cognitive psychologist peers. The *Safety Culture Decade* context and choice of reducing first chapter's size brought him into writing a chapter on industrial accidents. Therefore, he intended his book to both the research and the industrial world (he progressively became familiar with thanks to his Wreathall & Co's joint missions as well as others). To communicate his new vision of *organizational* accidents, Reason called on his friend Wreathall to help to design a simple but effective model that would be included in the 7th chapter of *Human Error*. This model was to become, ten years later, the famous SCM.

II/ BIRTH AND GROWTH OF THE SCM

Section 1 has presented the two SCM's fathers, their backgrounds and the context in which they were brought to meet. This section focuses on their collaboration from 1987 (when the writing of *Human Error* begun) to 2000 (publication of the latest SCM version). We first look back at the discovery and exploitation by Reason of the nuclear field (sub-section 1). We then explicit the shift that the psychologist made from fundamental to applied research (sub-section 2). Sub-section 3 is devoted to the percolation of defense in depth into the SCM. Finally, we look at the developments which led the Wreathall and Reason's early accident model, to become, in 2000 the famous and widely used SCM (sub-section 4).

1. Reason, human error and NPPs

In the late 1970s Reason is still far from the nuclear power plant (NPP) control rooms. Yet this industrial field will be one of the most influential for its work. In 1979, the TMI incident operates an awareness of the influence of local workplace conditions on the operator's performance. If Charles Perrow sees in TMI the advent of a *normal accident*, Reason finds the first level of his taxonomy: distinction between *active* and *latent* errors. In 1985, Reason and Embrey publishes *Principles Human factors relating to the modeling of human errors in abnormal condition of nuclear power plants and major hazardous installations*. One year later, the Chernobyl disaster provides an unfortunate case study. Reason introduces a new distinction between errors and violations in his taxonomy. In 1987, he publishes an article in *British Psychological Society* bulletin devoted to Chernobyl errors' study from a theoretical perspective. In 1988, he publishes *modeling the basic tendencies of human operator error*, thus introducing an error model which allows modeling the human behaviour of problem solving (the Generic Error Modeling System, GEMS). Reason's cognitive models were then based on observations in NPPs control rooms as case study of human behavior.

The development of distinction between accidents theories based on active or latent errors and violations, is strongly linked to the development of nuclear energy and its safety culture. From 1979 to 1988, Reason uses accident investigations and gets used to the field and its culture. For all that, his productions remains designed to his peers. A turning point is met when the observation process becomes a collaborative one and that Reason's psychologist work mingles with the engineering one of Wreathall.

2. From fundamental to applied research

1987 represents a break in Reason's work (Larouzée *et al.*, 2014). After studying everyday errors for ten years, Reason holds a major contribution to his discipline with the taxonomy of unsafe acts (Reason, 1990, p. 207). He publishes the *Generic Error Modelling System* (Reason, 1987 Fig. 1.a.), a combination of his classification with the *Skill Rule Knowledge* model of Danish psychologist Rasmussen (1983). It presents the types of human failures linked with the specificities of a given activity. This theoretical cognitive model still belongs to the field of psychological research (model quoted 192 times).

The same year, Reason works on a chapter of *Human Error* dedicated to industrial accidents and designed for security practitioners. He has the backing of his friend Wreathall. Reason says he looked for a manner of "*showing people what our work was about*". Wreathall talks in these terms of the genesis of the first model "*during an exchange in a pub (the Ram's Head) in Reason's home town (Disley Cheshire, England), we have drawn the very first SCM on paper napkin. Initially, James saw the organizational accident as a series of "sash" windows opening or closing thus creating accident opportunity*". Wreathall allowed the psychologist to combine his accident theory (resident pathogens metaphor; Reason, 1988) and his error taxonomy with a pragmatic model of any productive system.

The shift over, the cognitive and theoretical model changed into a descriptive and empirical one (Fig. 1.b). The book *Human Error* received a warm welcome by both research and industrial communities (quoted 8604 times). Reason became a Wreathall & Co' director and continued his work related to industries "*he supported psychological dimensions of the reports produced by the firm. As early as 1991* according to Wreathall, *James was familiar with the engineering community and became conductor of the various works made by Wreathall & Co', especially for the American nuclear domain*". Reason will remain a part-time collaborator of Wreathall & Co' and then WreathWood Group until he retired in 2012.

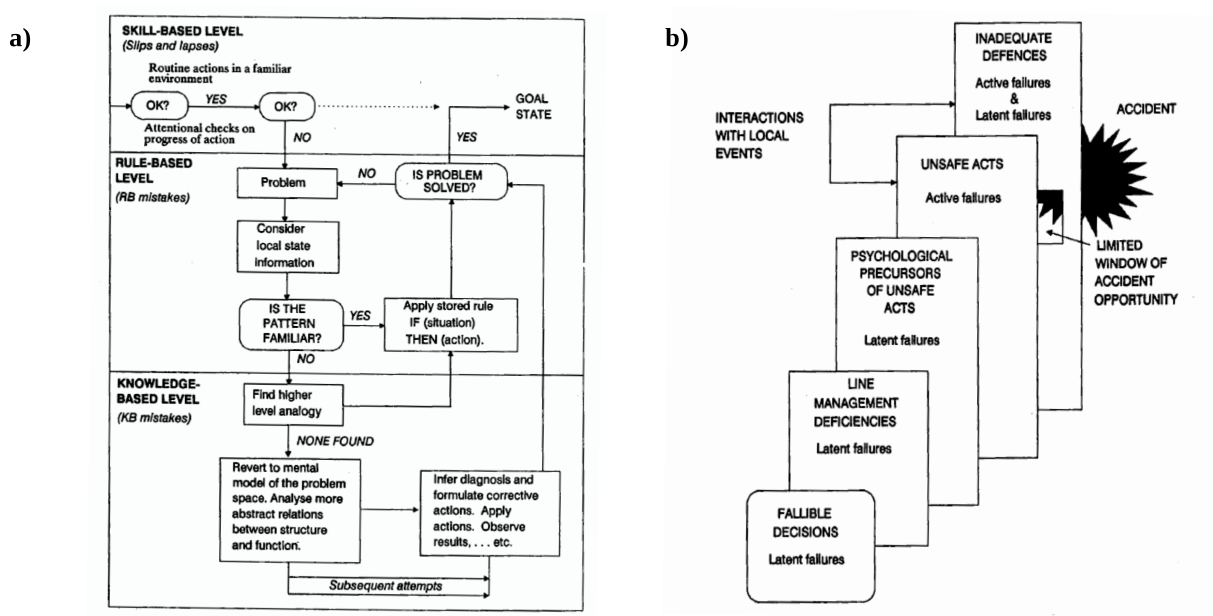

Fig. 1. Reason's taxonomy backed a) at the cognitive SRK model by Rasmussen produces a theoretical model (*on the left*); b) at the Wreathall's productive system model produces an effective descriptive and empirical model (*on the right*).

3. The defense in depth contributions

The engineer's contribution goes beyond the pragmatic modeling of a productive system. Wreathall's training and experiences with the British submarines nuclear reactor and CEGB NPPs safety gave him specific defense in depth[94] thinking.

[94] Early 1960, the military *defense in depth* concept is introduced into the US nuclear safety policies. It concerns the hardware and construction design (fuel and reactor independent physical barriers containment). The TMI incident extends it to human and organizational dimensions. In 1988, an International Atomic Energy Agency working group publishes an issue entitled

When he designed the first SCM, Wreathall chose a representation of superimposed plates. These plates evokes defense in depth's *levels of protection*. Reason then explains each plate's failure using his taxonomy and understanding of organizational accidents. The *Swiss cheese* nickname and representation is late. Still it's rooted in the first graphical choice. Wreathall's contribution overtakes engineering understanding of a system: it carries the defense in depth thinking.

Defense in depth is clearly mentioned in an early SCM version (Reason, 1990, p.208; Fig. 2.a.)[95]. It incorporates an accidental *trajectory of accident opportunity* which provides information on respective contributions of the psychologist and the engineer. On the left hand, the white plates represent the organizational (managerial level) and human failures (unsafe acts): contribution of the psychologist. On the right hand, gray plates represent defense in depth as a block (set of defenses ensuring the system's integrity): it's the engineer contribution. Human variability may confuse the engineer (which partly explains the historical *human error* understanding of accidents). On the other hand, technical and organizational sides of safety often confuse academic researchers. In the SCM, disciplines collaboration is used to display the complex interactions between humans and technology and therefore, emergent properties of system's security (Fig 2.b.). Finally, the differences in graphical complexity between the theoretical and empirical models are to be noted. In the next section, we will argue that the success of the SCM also lies in the choice to simplify the drawing in a heuristics release.

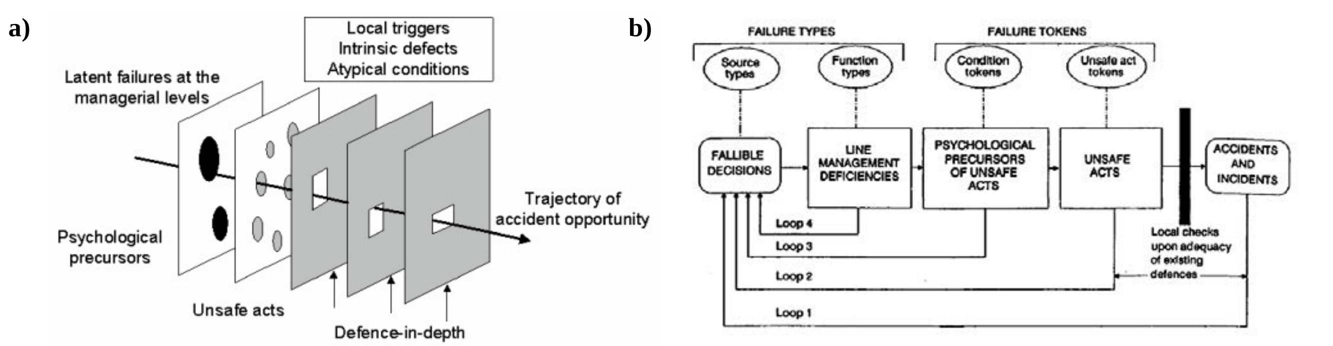

Fig. 2. a) The accident causation model published in 1990 explicitly introduced the defense in depth concept. b) A more complex representation showing the interactions between human and technical dimensions of the system.

3. SCM evolutions

Reason and Wreathall kept working together and using the SCM within Wreathall & Co's reports. A little after 1993 Wreathall suggests replacing "*latent error*" (referring to organizational failures) by "*latent conditions*". This change acknowledges the fact that efficient decision at a given time may have negative outcomes at another time or place in the system but these decisions may not be wrong at the time—they are just made under uncertainty. In addition to these semantic changes, SCM graphically evolves (over 4 times in the 1990s). Its use reached many sectors such as energy or transportation (Larouzée et al., 2014). During 1990s, Rob Lee, director of the Australian Bureau of Air Safety Investigation, suggested representing gaped barriers as Swiss cheese slices (Reason et al., 2006). The idea attracted Reason, then working on a new SCM version for the *British Medical Journal* (Reason, 2000. Fig 3). This was a landmark article (quoted 3442 times) and in 2003 Reason was appointed *Commander* of the British Empire for his work on patient safety. The SCM was born. Its simplicity and empirical pragmatism made it the vector of a new paradigm of Safety: *the organizational accident*.

Defense in depth in nuclear safety (INSAG, 1988) which establishes defense in depth as a doctrine of nuclear safety. Doctrine based on three concepts: *barriers* (implementation of physical protection systems), *defensive lines* (structural resources and organizational security), and *levels of protection* (arrangement of barriers and defensive lines according to structured objective regarding the potential event's gravity).

[95] If the original version labels *defense in depth* (Fig. 2.a.), the 1993 French translation (by an academic) changes the label for « *défenses en série* » (*serial defenses*). Loss of sense due to field sensitivities' manifestation.

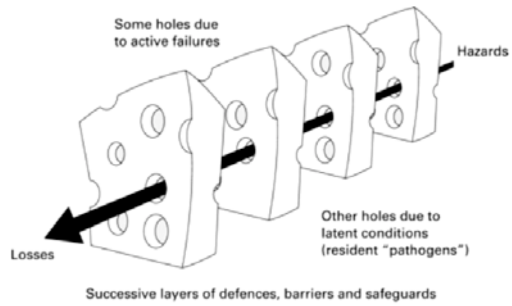

Fig. 3. SCM version where the cheese slices represent a system's defenses (Reason, 2000).

CONCLUSIONS

A detailed study of the SCM is both simple and complex. Simplicity comes from the abundance of sources. This model has been widely quoted and Reason is a prolific author (149 publications; Larouzée & Guarnieri, 2015). Complexity arises from the nature of the model's origin: a collaborative and poorly documented work between distinct but interactive worlds, research and industry. Meeting the two fathers of the SCM was a great help, it surely helps preventing from retroactive bias.

This study was guided by intuition that the success of SCM lays (mostly) in its simple graphical representation. If it is undeniable that *Swiss cheese* representation has played a role in the socialization process of Reason's work, it actually seems it has mostly caused theoretical and methodological pitfalls (Larouzée & Guarnieri, 2014). A second hypothesis was that success of the model was the result of the appropriation of research findings by industry. It emerges that it is more the appropriation of industrial experience by the academics and long term collaboration that gave the SCM its empirical pragmatism, likely to encourage its use and spread. If Reason and Wreathall's meeting was helped by a favorable social and industrial context (Safety Culture decade and human error clambakes), their collaboration stood thanks to a mutual will of convergence. We note the importance of backgrounds and early life experiences that led Reason working in aviation community and Wreathall meeting systemic thoughts and human factors early in his studies. This shared background guaranteed sensitivity and brought a common language to the two: a collaboration prerequisite. Finally, more than causing their meeting, the social demand at that time (industry funding many research programs) allowed the evolutions of the model. Through various research programs the SCM was used and shaped. The SCM will stay long in ranks of quoted and used accident models. It's time to reproduce the essence of its efficiency: cross-disciplinary background and collaboration.

ACKNOWLEDGMENTS

My thanks to Professor Reason for his hospitality, January the 7th, 2014, and to Mr. Wreathall for coming and meeting us at MINES ParisTech Centre of Research on Risk and Crises, October the 10th, 2014. Their answers provided valuable insight to our work. Great thanks to Professor Frank Guarnieri for his unconditional support and precious advices.

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Criticality Safety Study for the Disposal of Damaged Fuels from Fukushima Daiichi Reactors

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ABSTRACT
This paper summarizes our previous works on neutronics analysis for the disposal of damaged fuels from Fukushima Daiichi reactors. Three major stages have been identified for the criticality safety assessment after disposal. In order to evaluate the criticality safety for certain repository conditions and engineered barriers designs, neutronics models have been defined for different stages, and numerical results have been calculated by a Monte-Carlo code MCNP. For stages when fissile nuclides in the damaged fuels remains in the vicinity of the engineered barriers, the neutron multiplicity (k_{eff}) for a canister containing fuel debris surrounded by buffer was calculated over the leaching time. For the stage when fissile nuclides originated from multiple packages deposit in far-field host rocks, the critical masses for uranium depositions were studied for various rock types and geometries. The methodology presented in the present paper could be further improved and utilized to assist the repository system design and criticality safety assessment in the future.

Key words: criticality safety; geologic disposal; damaged fuels; Fukushima accident; radioactive waste management

I. INTRODUCTION
The accident at the Fukushima Daiichi Nuclear Power Station in March 2011 generated damaged fuel in three crippled reactors, containing nearly 250 metric tons of uranium and plutonium along with fission products, minor actinides, and other materials such as fuel cladding, assemblies, and in-core structural material[1]. The damaged fuels will have to be disposed of in a deep geological repository. For a prospective repository, a criticality safety assessment (CSA) should be performed to ensure that the repository system including the engineered barriers and far-field geological formations remains sub-critical for tens of thousands to millions of years. For various repository concepts, CSA is considered to include three major stages in a chronological order: (1) the stage before package failure, (2) the stage after package failure, while fissile nuclides remain within the engineered barriers, and (3) the stage in which fissile nuclides originated from multiple packages deposit in far-field host rocks.

This paper summarizes our previous works[2, 3] on neutronics analysis for the disposal of damaged fuels from Fukushima Daiichi reactors, during the three stages in CSA. Current understanding about the conditions of the damaged fuel is very limited, and the location and design of the repository have not been determined. Therefore, the primary objective of our study is to establish a consistent methodology to evaluate the criticality safety for certain repository conditions and engineered barriers designs. The methodology could be further improved and utilized to assist the repository system design and criticality safety assessment in the future. For stages (1) and (2), neutronics analysis for the engineered barrier region consisting of a single waste package containing damaged fuel debris, failed overpack and the buffer materials[2] will be reported in section II. For stage (3), our study on the criticality conditions for uranium depositions in geological formations resulting from geological disposal of damaged fuel[3] will be reported in section III.

II. NEUTRONICS ANALYSIS ON ENGINEERED BARRIER SYSTEM CONTAINING DAMAGED FUEL DEBRIS

II.1 Model and Assumptions
The repository is assumed to be in a water-saturated reducing environment. The neutronics model consists of a canister containing fuel debris from Fukushima Daiichi Unit 1 reactor and the buffer surrounding the canister. Because there is no current design for the disposal system for the damaged fuels, the composition and dimension of the canister and buffer are assumed based on the design for spent fuel disposal[4]. The damaged fuel is assumed to be disposed of after 50 years of cooling. The fuel composition after the accident was calculated by burnup code ORIGEN, which was reported in Ref. [1]. Gaseous, soluble, and volatile neutron absorbing nuclides in the fission products (such as Xe and Cs) might have been separated from the fuel and released during and after the accident[5]. Therefore, in this study, only physically and chemically stable, and strongly neutron absorbing nuclides in fission products are considered, which include Gd, Nd, Sm, Rh, and Eu isotopes.

The present work considers six nominal time steps for neutronics analysis: the emplacement time (t=0), the canister failure time (t= T_f), and four steps during the dissolution of debris particles (t= T_f+0.2T_l, t= T_f+0.4T_l, t= T_f+0.6T_l, and t= T_f+0.8T_l). At t=0, the canister only contains fuel debris. The failure time (T_f) of the carbon steel canister is assumed to be

1000 years. After canister failure, water fills the canister, and the canister is modeled as a porous medium with porosity of 0.3.The geometry of neutronics model for the damaged fuel debris at different time steps have been built based on our literature review on defueling process for the Three Mile Island (TMI) accident[6]. A hexagonal lattice of spherical fuel particles is assumed. The pitch distance between particles is assumed to be either (1) make particles contact each other or (2) make the particles lattice fully fill the canister. In the leaching steps, the released materials from the damaged fuel particles is assumed to be either (a) removed from the canister-buffer system, or (b) be homogeneously mixed with the corroded canister. Combinations of the above variations makes four cases: case 1a, case 1b, case 2a, and case 2b. The schematic layout of the MCNP model is shown in Fig. 1. The engineered barriers consist of a carbon-steel canister surrounded by buffer (a mixture of bentonite and silica sand). The canister is filled with spherical fuel particles in a hexagonal lattice. The unit cell of the lattice is shown in the right bottom of Fig. 1. More detailed descriptions about the model parameters can be found in Ref. [3].

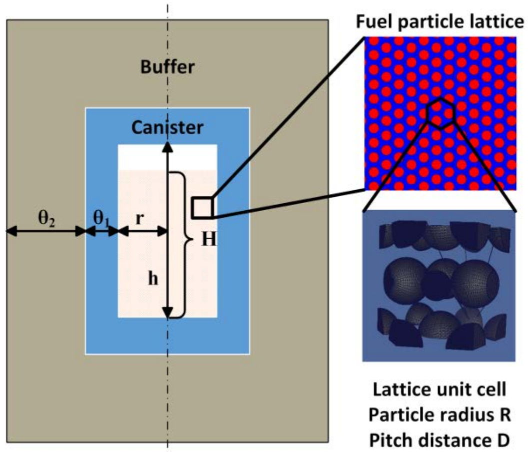

Fig. 1. Schematic layout of the neutronics model of the engineered barrier system containing damaged fuel debris.

II.2 Summary of Numerical Results

The numerical results were calculated by a Monte-Carlo code MCNP[7], and are shown in Fig. 2, where the neutron multiplication factor k_{eff} is plotted against the nominal time steps for various combinations of cases and initial loadings. Note that the time axis only represents the order of the time steps and does not represent the actual time. The failure time (1000 years) should be several orders of magnitude smaller than the leach time. The green points in three figures in Fig. 2 represent cases assuming the canister is filled with water at time zero.

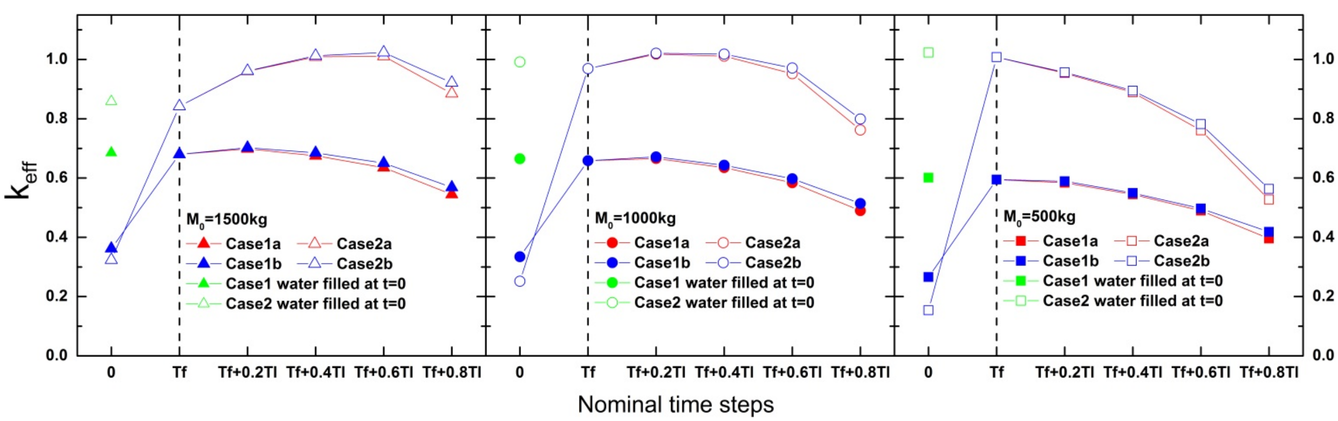

Fig. 2. Calculated k_{eff} for various cases versus time. Solid points represent case (1), hollow points represent case (2). Red points represent case (a), and blue points represent case (b). Squares, circles, and triangles represent initial loading of 500kg, 1000kg, and 1500kg, respectively.

The major findings from the numerical results include, (a) the calculated neutron multiplication factor (k_{eff}) is sensitively dependent on assumptions related to moderation, (b) the carbon steel canister plays an important role in reducing the potential for criticality, (c) the maximum k_{eff} of the canister-buffer system could be achieved after a fraction of fissile nuclides been released from the canister, and (d) under several assumptions, the maximum k_{eff} of the canister-buffer system could be principally determined by the dimension and composition of the canister, not by the initial fuel loading.

III. CONDITIONS FOR CRITICALITY BY URANIUM DEPOSITION IN WATER-SATURATED GEOLOGICAL FORMATIONS

III.1 Model and Assumptions

From previous discussions, in stage (3), a plume of uranium-bearing groundwater originated from multiple canisters containing damaged fuels could form a uranium deposition in geological formations in the far-field. The deposition could locate in either porous or fractured rock. Because the size of the uranium deposition in porous rock is of the order of the grain size of those rock is much smaller than typical neutron mean-free-path, we can consider that uranium deposition in porous rock is homogeneously mixed with rock and water in a neutronics model. For deposition in the fractured rock, two different configurations have been considered for the mixing between uranium deposition and water in the fracture (i.e. fully mixed or fully separated).

Fig. 3 shows the schematic of the MCNP model, in which the spherical core is filled with one of the three different geometries (shown right), surrounded by the one-meter-thick rock as reflector. The combination of rock, water, and heavy metal is expressed by two independent variables: void volume fraction (VVF) and heavy-metal volume fraction (HMVF). For the heterogeneous systems, the VVF is given by *b*/*d*, representing the averaged fracture volume fraction, or the fracture porosity in rock. For the homogeneous system, VVF represents the void space fraction that is filled with water and heavy metal precipitations, equivalent to the porosity of a porous rock. The HMVF is defined in a similar way, representing the volume fraction of heavy metal precipitations in the entire core. The volume fraction of the solid-phase of the rock then equals to (1-VVF), and the water volume fraction is given by (VVF-HMVF). By definition, the HMVF must be smaller than VVF, because the volume of precipitation cannot exceed the available void space in the rock.

Two types of host rocks are considered in the present study: average sandstone and magnetite-hematite-bearing pelitic gneiss containing 15% iron. For the heterogeneous systems, the fracture aperture takes values of 0.1, 0.2, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, and 10.0 centimeters. For given compositions and geometry for rock and heavy metal, calculations have been first performed for various VVF and HMVF parameters, assuming that the mass of heavy metal in the core is 250 MT, which is the total mass of the damaged fuels form three reactor cores. The discrete k_{eff} results have been used to generate a k_{eff} contour plot by interpolation. By defining a nominal sub-criticality criterion $k_{\mathrm{eff}}<0.98$, the super-critical region can be determined in the parametric space. Within the super-critical parameter range, MCNP calculations have been conducted to obtain the critical mass of heavy metal deposition. More detailed descriptions about the model parameters can be found in Ref. [2].

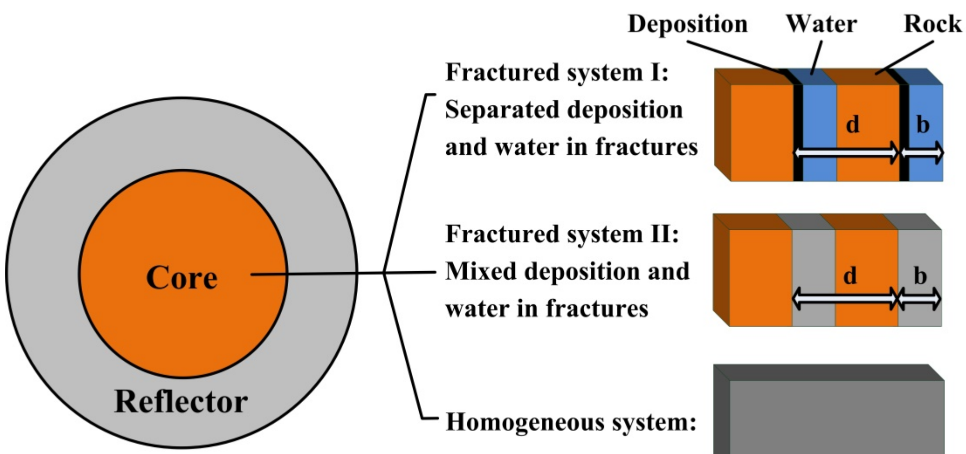

Fig. 3. Three geometries for the MCNP simulations: (1) fractured system I, (2) fractured system II, and (3) homogeneous system.

III.2 Summary of Numerical Results

The numerical results for the effective neutron multiplication factor k_{eff} for the deposition containing 250 metric tons of uranium are shown in Fig. 4 (a) and (b) for two types of host rocks. The contour line in red color, referred to as the critical contour line, indicates the nominal criticality criterion, k_{eff}=0.98. The triangular region results from the fact that the HMVF cannot be greater than VVF. In either case of rock, the k_{eff} value tends to be greater for a greater value of VVF (i.e., to the right along the horizontal axis). A maximum k_{eff} is observed as HMVF increases for a fixed VVF. If the VVF is 0.094 or smaller for sandstone (Fig. 4 (a)) and 0.265 for iron-rich rock (Fig. 4 (b)), then the uranium deposition is always subcritical. We call this threshold VVF as the minimum critical VVF hereafter. The comparison between sandstone and iron-rich rock shows importance of rock compositions. For the iron-rich rock, the likelihood of criticality event would be significantly smaller because iron strongly absorbs neutron.

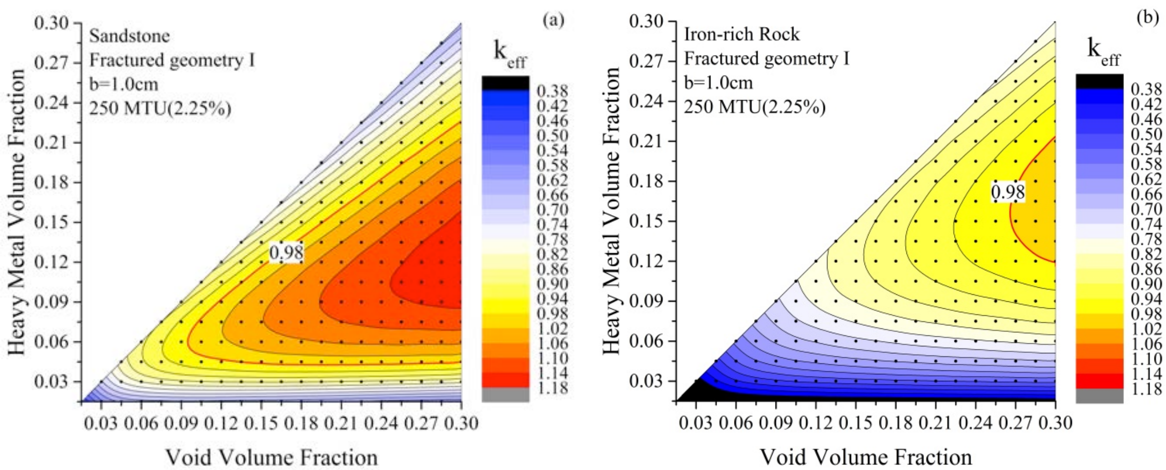

Fig. 4. (a) k_{eff} contour plot for fractured sandstone with fractured geometry I. (b) k_{eff} contour plot for iron-rich rock with fractured geometry I.

The minimum critical VVF can be found similarly for every combination of rock type, geometry, and a certain mass of uranium deposition. For both rock types with fractured I geometry, the minimum critical VVF becomes the smallest at aperture *b*=1.0 cm. Fig. 5(a) and (b) show the contour plots for the critical mass for sandstone comparing two geometries as indicated within the figures. The boundary of the plot is extracted from the red contour line from the k_{eff} results (Fig. 4 (a) and (b)). The values for critical masses are shown in a logarithm scale in unit of metric tons of uranium, and the contour lines for 1, 10, and 100 metric ton are shown in black, red, and blue, respectively.

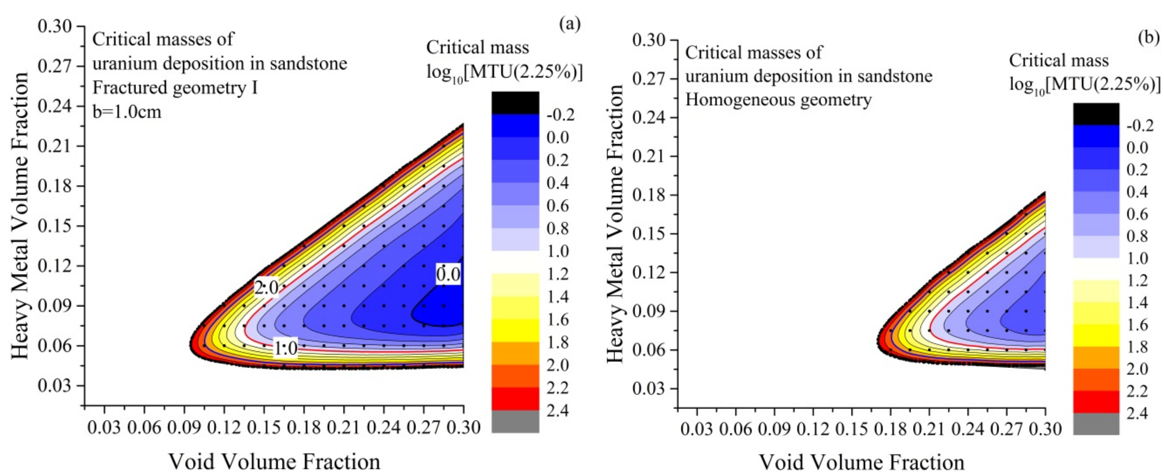

Fig. 5. (a) Critical mass contour plot for fractured sandstone. (b) Critical mass contour plot for homogeneous sandstone. The values in the figure and in the side-bar scale are logarithm of MT of uranium included in the system.

From the numerical results, we can conclude that, the k_{eff} for the deposition become greater with (1) smaller concentrations of neutron-absorbing materials in the host rock, (2) larger porosity of the host rock, (3) heterogeneous geometry of the deposition, and (4) greater mass of uranium in the deposition.

IV. CONCLUSIONS

This paper summarizes our previous works on neutronics analysis for the disposal of damaged fuels from Fukushima Daiichi reactors. Three major stages have been identified for the criticality safety assessment after disposal.

For stages when fissile nuclides in the damaged fuels remains in the vicinity of the engineered barriers, the k_{eff} for a canister containing fuel debris surrounded by buffer was considered over the leaching time. Based on literature review, the fuel debris has been modeled as a hexagonal lattice of spherical fuel particles. Based on the numerical results, the following key observations can be made: (a) the calculated neutron multiplication factor (k_{eff}) is sensitively dependent on assumptions related to moderation, (b) the carbon steel canister plays an important role in reducing the potential for criticality, (c) the maximum k_{eff} of the canister-buffer system could be achieved after a fraction of fissile nuclides been released from the canister, and (d) under several assumptions, the maximum k_{eff} of the canister-buffer system could be principally determined by the dimension and composition of the canister, not by the initial fuel loading. Future works in this area are planned to apply the present approach for damaged fuels from Unit 2 and Unit 3, to consider more modes for release from the canister, such as leaching of the damaged fuels by reducing the radius of each fuel particle, to consider buffer swelling or collapsing due to degradations, and to develop detailed models to connect the models for single canister with models for the deposition from multiple canisters. The dependence on model parameters, such as fuel particle radius, need to be further examined. We will also investigate the option of using backfilling materials to control criticality in the engineered barrier design.

For the stage when fissile nuclides originated from multiple packages deposit in far-field host rocks, the critical masses for uranium depositions were studied for various rock types and geometries. The analysis has been made for two kinds of rocks by considering a finite system with three different geometries, containing various masses of uranium. The three different geometries include heterogeneous (fractured I and II) and homogeneous systems. The exploration was performed to find optimized combinations of geometry, fracture aperture and the model parameter HMVF, to give the minimum rock porosity (VVF) for criticality. The numerical results show that: the k_{eff} for the deposition become greater with (1) smaller concentrations of neutron-absorbing materials in the host rock, (2) larger porosity of the host rock, (3) heterogeneous geometry of the deposition, and (4) greater mass of uranium in the deposition. After the present analysis, we conclude that various far-field critical configurations are conceivable for given conditions of materials and geological formations. Whether any of such critical configurations would occur in actual geological conditions remains unanswered. To answer this question, we need to extend the present study into the following directions. First, from the neutronics point of view, a more “realistic” fractured system with both the fracture orientation and size randomly distributed is suggested. Second, we need to perform the mass transport analysis to explore whether such a configuration obtained by neutronics analysis is likely to be occurred in geological formations.

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Logical and Emotional Influence in a Time-Constrained Group Decision Making

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ABSTRACT
When humans make decisions, they tend to rely on a heuristic approach, instead of considering all available facts. When humans need to make decisions as a group, this tendency also seems true. However, there are some additional mechanisms that can only be observed in the group level, which are influence and conformity. Understanding these processes and their patterns is necessary to interfere and manipulate group decision making in order to make a good group decision. This is particularly critical in emergency situations, where decision making needs to be done under time and risk pressure. This paper proposes a model of group decision making process using I-P-O model, emphasizing the influence process in the group. Besides, this paper also explains about an analysis towards group decision making experiment in laboratory setting. The discussion process was observed to find the influence pattern among the members.

Key words; Group decision making, Group conformity, Influence, Personality

INTRODUCTION
One important aspect in resilience engineering is about how organizations respond to changes that happen from either within or outside the organization. When a change happens, the organization needs to shift from its usual routine into a new action. Changing from routine into a new condition requires some decision making. In modern world, most of that decision making should be made by a group instead of a single individual. As pointed out by Stasser and Dietz-Uhler [1] even though group is far from perfect, their choice, judgment, and solutions are generally better than individuals.

Individual decision making has been studied intensively in many fields, including psychology, economics, politics, etc. [2], [3]. Group decision making, however, is relatively a newer and less matured subject compared to the studies of individual decision making. Group decision making is more complex, since it is both involving the information processing by its member individually and social process between the members. This social process is not just including information exchange between the members but also how each member influences on other members' agreement towards the group decision.

Reaching a consensus in a group decision making is not just the norm of the group, but also triggered by human's natural response against cognitive dissonance. Cognitive dissonance happens when group members discover that they do not agree with other members [4]. This is such an unpleasant state that people are motivated to take steps to reduce it [5]. Some of the steps done by the members are changing their own position (conform) or trying to change other members' position (influence). These process sometimes happens unconsciously because the nature of social influence is very complex [6, p. 221].

In this paper, the dynamics of conforming and influencing process in group decision making is observed. Even though conformity and influence are affected by many situational characteristic [6, p. 211], it is argued that in general, it can be divided into logical and emotional influence. This research aims to find the pattern of logical and emotional influence in several short decision making discussions.

THEORETICAL PERSPECTIVE
To make a good decision, group members should thoroughly and carefully consider as many information as possible relevant to the problem. When a person makes a decision as an individual, however, a heuristic approach is usually used due to human's limited cognitive ability. One often relies on simple, fast, and easy to access heuristics [7]. This situation also happens when a group makes a decision. Even though there are more resources to process information, group members still need to rely on heuristics such as other people's opinion instead of information from actual sources.

To illustrate the group decision making process and observe the social influence, input-process-output model is used. The model is explained in the following subsection.

Conceptual Model

As shown in Figure 1, the inputs consist of three entities. Personal knowledge or preference is individual's knowledge relevant to the problem being discussed, and also their personal preference regarding the decision. The difference in this part will trigger the discussion process until consensus is reached. Members' characteristic is the personal traits that will determine the dynamics of the discussion process, mainly the emotional influence. Some examples of this characteristic factors are introversion / extroversion and self-esteem [6, p. 214]. The context defines the situational characteristic of the decision making. For example, in an emergency situation, usually the group is pressured to make an unanimous decision in a short time.

In the process, members exchange information, influence, and conform to each other. In this model, information exchange is different from logical influence due to its neutral property. The information is exchanged merely for letting the others know about it. Meanwhile, "logical influence" is described as a process when a person use information or logical analysis to convince other people towards certain decision. Logical influence is used because naturally people are motivated to interpret and perceived the reality as accurate as possible [8]. Any other factors besides logical influence that can affect conformity are defined as emotional influence. Some example of this persistence of a person without providing convincing argument, or emphasizing time constraints to force the member to conform.

The output of the group decision making process are the group decision and individual view towards it. Even though the group has reached consensus, it does not mean that all members also privately agree with the decision. This will be explained in the next subsection.

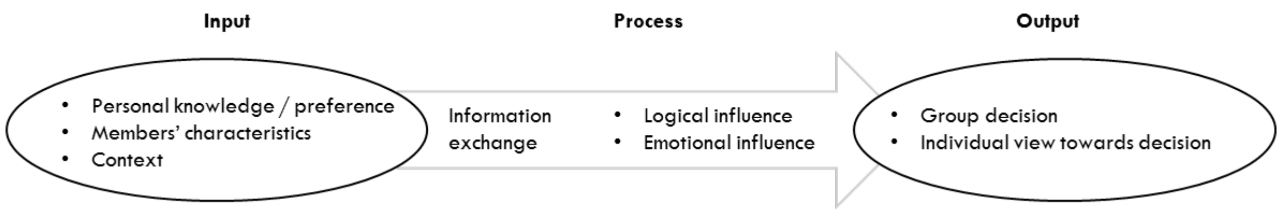

Fig. 1. The IPO model of influence in group decision making

Social Response in Group Decision Making

Like all other social processes, group decision making is involving social influences – interpersonal activities that change other people's thoughts, feelings, or behaviors. In group decision making, Nail and Macdonald [9] (as cited in [6]) pointed out that there are five social responses related to influence: compliance, conversion, independence, anticonformity, and congruence. That categorization is made based on the status of agreement between the individual decision (before and after discussion) and group decision. A group may reach consensus after the members agree with it *publicly*. However, they may or may not *privately* agree with it. If they agree both publicly and privately, it is called conversion. Otherwise it is compliance. However if they agree since before the discussion, it is called congruence. Independence is when a person disagrees with the group decision at all time. Anticonformity is when a person initially agree (or neutral) but afterward disagree with the group.

EXPERIMENT, DATA, AND ANALYSIS

Experiment Design

The purpose of the experiment is to find the pattern of logical and emotional influence in regards to three different responses of group decision making: compliance, conversion, and congruence. The data were taken from the previous research about mutual belief model [10]. In that experiment, 21 groups of size 3,4, and 5 persons were asked to give ranks to 15 items (such as oxygen, water, rope, etc) based on their priority related to a fictional story [11]. They were required to provide their own rank before discussion (IIR – Individual Initial Rank), publicly agreed rank (GR – Group Rank), and individual rank after discussion (IRR – Individual Revised Rank). In this experiment, only congruence, compliance, and conversion can be observed. Independence cannot be observed because by definition, this type of response is disagreeing with the group decision at all time, while in the experiment, the final group decision must be unanimous. For the similar reason, anticonformity cannot be observed as well. The discussion was conducted for 15 minutes, and they have to reach a unanimous decision within that time. The whole discussion process was recorded by both video and audio.

It is assumed that if the IIR between members are diverse, they will have more discussion. In the same manner, it is also assumed that if a person has higher congruence, this person is regarded as influential to the group. By using these two assumptions, all participants were then mapped based on their diversity and congruence.

From the mapping, several participants' data were chosen, and their videos were observed to find the conformity pattern in the discussion. The detail of the mapping and video observation is explained in the following subsections.

Congruence and Diversity Distribution

As mentioned previously, if a member agree to the group's decision even from before the discussion, this type of response is called congruence. By comparing IIR and GR, a score can be assigned to the degree of congruence. Next, by comparing IIR of members in a same group, a score can be assigned to the degree of diversity. The calculation is shown by the following formulas (m=id of participant, n=group size, i=item number, g=id of group where participant m is belong to, p=partner in the same group). The result of the mapping can be seen in Figure 2.

$$\text{Congruence}_m = \sum_{i=1}^{15} \left| IIR_{i,m} - GR_{i,g} \right| \qquad (1)$$

$$\text{Diversity}_m = \sum_{i=1}^{15} \left(\sum_p \left| IIR_{i,m} - IIR_{i,p} \right| \right) \qquad (2)$$

As shown in the graph, in less diverse groups, the congruence tend to be high, while in more diverse groups the congruence is more distributed. This result can be understood intuitively, as in a diverse group the "distance" between individuals and the group decision is varied, some are far, some are close. From this graph, three data were chosen arbitrarily from three different areas. The videos from these three participants were then analyzed further.

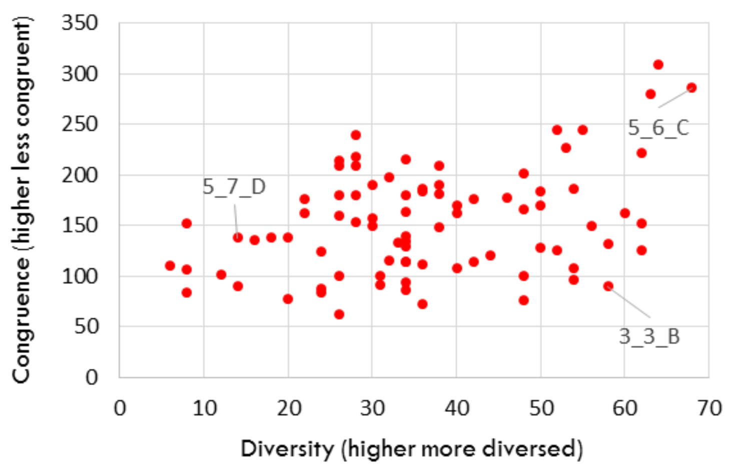

Fig. 2. Distribution of members based on congruence and diversity score

Analysis of Influence

In the current progress of the research, the video of group 5_6 has been observed. This group has been picked up first, because one of its member is located in an extreme area in the graph in Figure 2. Participant 5_6_C experienced a very diverse opinion compared to the other members and her initial answer is not so congruent from the group decision. The video was transcribed and the discussion was analyzed. The protocol analysis aims to separate logical influence and emotional influence, and to see if there is a pattern of emergence of the influence, such as time-wise emergence. For each utterance in the discussion, two tags were assigned. The first is the item related to the utterance, and the second is whether the utterance is an influence or not. If it is considered by the researcher as an influence, then it would be decided whether it is logical or emotional influence.

One example of logical argument is as follows: for the item oxygen someone says "The amount 2.5kg is not sufficient". The logical reason may be strong or weak but at least the participant shows some argument. On the other hand, an example of emotional influence is as follows: for the item pistol someone says "Pistol is really unimportant", without providing any argument. The statement that says an item is important or not is the expected decision, therefore when someone mention their preference about a decision without argument, it is considered as an emotional influence. The result of the analysis towards group 5_6 is shown in Figure 3. In the figure, one dot represents one utterance.

This group mostly discuss about compass and oxygen, 30 and 32 utterances respectively. For compass, 17 utterance was logical influence while for oxygen it was 24. The group was focusing on those two items for most of its logical influence. When looking at the distribution of IIR for each item in that group, oxygen on the other hand is the item with the least diverse IIR. Meanwhile, the item with the most diverse IIR, the heating unit, was discussed only with 5 utterances and 2 of them are logical influence.

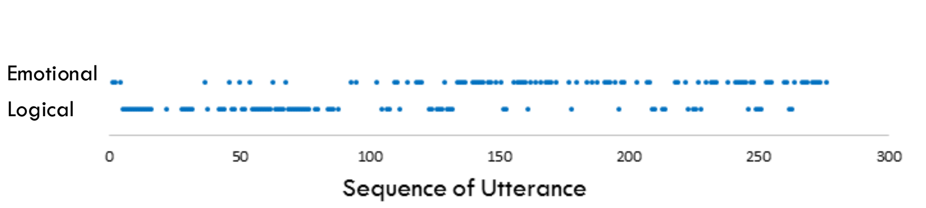

Fig. 3. Distribution of logical and emotional influence

As can be seen from Figure 3, in the first half of the discussion they intensively used logical influence, while in the latter half emotional influence was more dominant. One might think that the second half is probably the decision stage after they discussed the matters in the beginning. However, most of the other items appeared in the second half. It means that for these items they conformed to each other with few logical influence or even not at all. This happened regardless the difference of IIR of these items. One possible factor is the time pressure. Reaching the latter half they realized that they do not have much time to make a decision. At that moment, they started to use the heuristic approach by conforming or influencing other member even without a logical reason. Most of the time in the latter half, some of the members mentioned their rank for some items and then other people conformed to it, or provided alternative rank without any argument.

Another fact that was observed from the discussion is that the discussion was the domination of the discussion. The discussion was dominated by two of the members. One other member (5_6_C) almost never spoke or gave any opinion. When their IIRs were compared to the expert rank [11], this least contributive member is on the other hand, had the closest rank to the expert rank. However she did not try to influence other members to follow her rank. In some of the items, she converted or complied to the group rank. In the end the group score fell down and got further from the expert rank. The IRR of 5_6_C also became bad, and quite far from her IIR.

PRELIMINARY FINDINGS

Even though at the current stage of research the supporting data are not enough and more of the videos in the data need to be analyzed, there were several interesting findings that can lead to further investigation or elaboration. From the analysis explained in the previous section, three preliminary results were found.

The first finding is that group members sometimes do not realize what is important to discuss and what is not. Moreover, in a time-constrained decision making situation where members are pressured to make a decision as fast as possible, they may skip the orientation process of understanding the differences of the topics. As found in the analysis, they discusses more about oxygen regardless its low difference of IIR, while discussed less about heating unit regardless its high difference of IIR. This was triggered simply because oxygen was mentioned very early by one of the members, while nobody mentioned about heating unit until the middle of the discussion.

The second finding is about the pattern of logical influence and emotional influence. It is found that when the time pressure is higher (in this case, reaching the end of discussion time) members tend to use emotional influence than logical influence. Since they do not have enough resources (time) to consider all facts, they may rely on their partners' preference. When comes into this situation, whose preference will be used will depend on various things such as the members' personality.

The third finding is the effect of the members' personality on the decision. As found in the analysis, the member with the best answer is unfortunately the least contributive member. On the other hand, the answers of the dominant members were not so good. Since the group relied on the heuristic approach for most of the items, then the dominant members were more influential regardless the inaccuracy of their answer.

Human decision making behavior under stress has been studied quite extensively [12]. However, there seems to be more to study about decision making under stress for group situation. The interaction and influencing process between the members, related to time or members' personality still need to be explored further. Such studies can later improve decision making by group, particularly in emergency situation.

CONCLUSIONS

In this paper, a model of group decision making has been proposed. The model emphasizes the aspect of individual influence towards each other in making group decision. In the current stage of research, some issues were found. This paper wants to highlight that in group setting, humans also tend to rely on heuristic approach in decision making, just like in individual setting. However, there is a mechanism that was not found in individual decision making, which are influence and conformity. Further research need to be done to ensure that group decision making in emergency situation will produce a good decision.

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Evaluation of Optimal Power Generation Mix Considering Nuclear Power Plants' Shut-down Risk

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ABSTRACT
This paper develops a dynamic optimal power generation mix planning model from 2012 to 2030 considering both of the uncertainty of nuclear power plants' shut-down and cost-effectiveness employing stochastic dynamic programming and linear programming technique. The advantage of this model is that it successfully address the curse of dimensionality in stochastic dynamic programming by using approximation method, and as a result, it can consider all the possible yearly stochastic state-transitions of nuclear power plants' usage rate. By this model, the possible measures including demand response to address the nuclear power plants' shut-down risk and the expected value of additional cost to implement the measures are evaluated. Simulation results suggest the possibility that more installation of LNG CC (natural gas combined cycle) is necessary under the uncertainty of nuclear power plants' shut-down. Secondly, nuclear power plants' shut-down introduces LNG CC's capacity expansion furthermore. Finally, the assignment of the nuclear power plants' shut-down uncertainty reveals the escalation of total cost in order to implement measures against the uncertainty.

Key words
Optimal power generation mix planning, Electricity supply security, Cost, Dynamic programming, Linear programming

1. INTRODUCTION

After Fukushima nuclear power plant accident, the electricity supply security is getting more and more important. By the shut-down of nuclear power plants and thermal plants in Kanto region and Tohoku region, rolling blackout had been taken place, which was the first time after the war. In addition, electricity supply shortage in summer is concerned every year since the accident because of the decrease of supply capacity. Especially in 2012, the Japanese government issued the restriction of electricity use against the large-lot electricity users. Thus, the impact of supply capacity reduction by huge earthquake is significant. We must construct a resilient electricity supply system which can deal with such a risk, and develop an implementation plan to realize it in a long term perspective. In power generation mix planning, cost-effectiveness is very important. Since unit construction cost is very expensive and the constructed units operate over long period, it is important to decide in a relational way when and to what extent new facilities should be constructed.

Under these circumstances, quantitative analysis is desirable to evaluate those policies that ensure stable electricity supply and cost-effectiveness in a long term perspective. In this paper, simulation analysis on power generation mix planning has been done using mathematical model in order to address the above requirements. The highlight of the model is to assess what measures should be taken before and after the accident respectively in power generation mix planning, taking account into the uncertainty of nuclear power plants' shut-down. This paper also focuses on analyzing how much additional cost will be needed to implement such measures.

2. DYNAMIC OPTIMAL POWER GENERATION MIX PLANNING MODEL

2.1. Mathematical Formulation

In this paper, the authors develop a dynamic optimal power generation mix planning model from 2012 to 2030 under various constraints employing stochastic dynamic programming and linear programming technique. It treats the uncertainty of nuclear power plants' shut-down as yearly stochastic state-transitions of the usage rate. The minimization of the expected value of multi-period objective function, which corresponds to the summation of discounted annual facility and fuel cost, allows us to identify the best mix of power plants capacity. Power plants considered in this paper are thermal power, nuclear power, hydro power including pumped type, and stationary sodium-sulfur battery (NAS battery). PV, wind, biomass or geothermal is not considered. Exogenous variables about power plants are based on (Komiyama *et. al.*, 2014), and fuel price is set based on (IEA, 2013). Annual power demand is expressed by four representative load curves each of which correspond to a representative one of each season in 2012, and it does not change until 2030. Regional scope in this paper is the whole region of Japan. Problem formulation is described as follows:

<u>*Endogenous variables*</u>

J : discounted total cost from 2012 to 2030 ($), TC_y : annual total cost in year y ($/year), $Kp_{i,y}$: capacity of i-th power plant in year y (GW), $Nkp_{i,y}$: Newly constructed capacity of i-th power plant in year y (GW), $X_{i,d,t,y}$: output of i-th type of power plants in day d at time t and year y (GW), $Ks1_{j,y}$: kW capacity of j-th electricity storage facility in year y (GW), $Ks2_{j,y}$: kWh

capacity of j-th electricity storage facility in year y (GWh), $Nks1_{j,y}$: Newly constructed kW capacity of j-th electricity storage facility in year y (GW), $Nks2_{j,y}$: Newly constructed kWh capacity of j-th electricity storage facility in year y (GWh), $CS_{j,y}$: annual cost of j-th electricity storage facility($/year), $Save_{d,t,y}$: electricity demand saving in day d at time t and year y
Where: i {1: Nuclear, 2: Coal fired, 3: Natural gas combined cycle (CC), 4: Natural gas fired, 5: Oil fired, 6: Hydro}, j {1: Pumped hydro, 2: NAS battery}, d {1,2,…,D} D : number of the representative day (D = 4), t {1,2,…,T} T : number of the time steps per day (T = 24), y {0,1,…,Y-1} Y : number of the yearly steps (Y = 19)

A. *Objective Function*

Objective function is the discounted total cost considering all the possible yearly state-transitions from 2012 to 2030. Discount rate in this paper is assumed as 3%. As the initial state in dynamic programming, the existing capacity of power plants is given and assume nuclear power plants are available.

$$J = \min_{\vec{N}k_0,\ldots\vec{N}k_{Y-1}} \mathrm{E}_{\omega_0,\ldots\omega_{Y-1}}\left[\sum_{y=0}^{Y-1}\exp(-\gamma y)\times TC_y\left(\vec{K}_y, \vec{N}k_y, \omega_y\right)\right] \quad (1)$$

$$\vec{K}_y = \left(Kp_{1,y},\ldots,Kp_{6,y},Ks1_{1,y},\ldots,Ks1_{2,y},Ks2_{1,y},\ldots,Ks2_{2,y}\right) \quad (2)$$

$$\vec{N}k_y = \left(Nkp_{1,y},\ldots,Nkp_{6,y},Nks1_{1,y},\ldots,Nks1_{2,y},Nks2_{1,y},\ldots,Nks2_{2,y}\right) \quad (3)$$

$$TC_y = \sum_{i=1}^{6}\left(pf_{i,y}\times Nkp_{i,y} + \frac{365}{4}\sum_{d=1}^{D}\sum_{t=1}^{T}pv_{i,y}\times X_{i,d,t,y}\right) + \sum_{j=1}^{2}CS_{j,y} + \frac{365}{4}\sum_{d=1}^{D}\sum_{t=1}^{T}CSAVE_{d,t,y} \quad (4)$$

$$\vec{K}_{y+1} = \vec{K}_y + \vec{N}k_y - \vec{d}ec_y \quad (5)$$

$$\vec{d}ec_y = \left(decp_{1,y},\ldots,decp_{6,y},decs1_{1,y},\ldots,decs1_{2,y},decs2_{1,y},\ldots,decs2_{2,y}\right) \quad (6)$$

Where: ω_y : Nuclear power plants' availability factor in year y (ω_y = {0: Unavailable, 1: Available}, uncertainty factor in stochastic dynamic programming), γ : discount rate, $pf_{i,y}$: unit depreciation cost of i-th type of power plants form year y to the end of time period ($/kW), $pv_{i,y}$: unit variable cost of i-th type of power plants ($/kWh), $decp_{i,y}$: decommission capacity of i-th type of power plants in year y (GW/year), $decs1_{i,y}$: decommission kW capacity of j-th electricity storage facility in year y (GW/year), $decs2_{i,y}$: decommission kWh capacity of j-th electricity storage facility in year y (GWh/year).

Energy-saving through demand response is a possible measure to address supply-shortage risk by nuclear power plants' shut-down, as is the case in the summer of 2011. Hence, demand response is mathematically modelled in this model based on (Komiyama *et. al* 2014). Suppose reference price is P_0 and reference demand is $load_{d,t,y}$ on a typical electricity demand curve as shown Fig. 1, the curtailment of demand $Save_{d,t,y}$ cause the decrease of utility and it corresponds to electricity saving cost. Variable $Save_{d,t,y}$ is endogenously determined through cost minimization considering the cost competitiveness towards the power generation technology. The formulation of saving cost is as follows. This modelling depends on reference price P_0 and price elasticity. In this paper, P_0 is assumed as the shadow price of electricity demand in optimal power generation mix planning model that does not consider the nuclear power plants' shut-down uncertainty, and price elasticity is assumed as 0.1.

$$\begin{aligned} CSAVE_{d,t,y} &= \int_0^{Save_{d,t,y}} P(s)ds = \int_0^{Save_{d,t,y}} P_0 \times \left(\frac{load_{d,t,y} - s}{load_{d,t,y}}\right) ds \\ &= \frac{\beta}{1-\beta}\times load_{d,t,y}\times P_0 \times \left\{\left(\frac{load_{d,t,y} - Save_{d,t,y}}{load_{d,t,y}}\right)^{\frac{\beta-1}{\beta}} - 1\right\} \quad (\beta \neq 1) \end{aligned} \quad (7)$$

Where: β : price elasticity, P_0 : reference price, $load_{d,t,y}$: power load in day d at time t and year y (GWh).

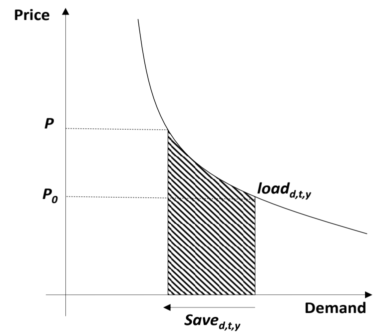

Fig. 1 Electricity demand curve and energy saving (Komiyama *et. al.*, 2014)

B. Constraints

a) Available capacity constraint of the plants

$$X_{i,d,t,y} \leq avp_p(\omega_y) \times Kp_{i,y} \qquad (8)$$

Where: avp_p : availability factor of ***i***-th type of power plants, which depends on ω_y.

In addition to this, the following constraints are considered in this paper based on (Komiyama et. al., 2014).

b) Power demand and supply balances
c) Constraint on upper and lower installable capacity
d) Constraint on load following capability of the plants
e) Charge and discharge balances of energy storage technology
f) Available capacity constraint of the battery technology

2.2. Nuclear power plants' shut-down model

In this paper, the uncertainty of nuclear power plants' shut-down is modeled as yearly stochastic state-transitions of usage rate. Suppose that *normal* state means nuclear power plants are available and *accident* state means unavailable, the state-transition probability λ from *normal* state to *accident* state is expressed through the reliability of nuclear power plants' availability R as shown equation (9). The probability λ is assumed as independent from time steps in this paper, and the mean time between disruptions (MTBD) is expressed through equation (10) and (11). The state-transition probability from *normal* state to *accident* state μ is expressed in a similar way considering the unreliability of nuclear power plants' availability and the mean time to recover (MTTR). MTBD and MTTR are assumed as 30 years and 2 years respectively in this paper.

$$\lambda = -\frac{1}{R}\frac{dR}{dy} \qquad (9)$$

$$MTBD = \int_0^\infty y f(y) dy = \frac{1}{\lambda} \qquad (10)$$

$$f(y) = -\frac{dR}{dy} = \lambda \exp(-\lambda y) \qquad (11)$$

$$\lambda = 1 - \exp(1/MTBD) \qquad (12)$$

$$\mu = 1 - \exp(1/MTTR) \qquad (13)$$

Where: λ : the state-transition probability from *normal* state to *accident* state, R : the reliability of nuclear power plants' availability, f : disruption density function, $MTBD$: the mean time between disruptions (year), $MTTR$: the mean time to recovery (year).

2.3. Calculation algorithm

To solve the model, all the possible state-transitions during the period should be considered, which needs a lot of computations and calculation is difficult due to computational constraints. To solve this problem called "the curse of dimensionality", an approximate solution method by cutting planes (Chen *et. al.*, 1999) is adopted in this paper. This method is especially for convex function, and it is available the model uses linear function technique. Equation (1) is rewritten as a recursive equation (14) known as Bellman equation, and the value function *V* can be evaluated by a linear constraint (16), which is a convex function's characteristic. Cutting planes method approximates the value function *V* by several constraints defined on sample points on the function, and it enables us to solve the multi-step problem respectively. That achieves a lot of computational saving, and can successfully address the curse of dimensionality. Fig. 2 shows the algorithm.

$$V_y\left(\vec{K}_y,\omega_y\right)=\min_{\vec{N}k_y}\left\{TC_y\left(\vec{K}_y,\vec{N}k_y,\omega_y\right)+\exp(-\gamma)\times \mathrm{E}_{\omega_{y+1}}\left[V_{y+1}\left(\vec{K}_{y+1},\omega_{y+1}\right)\right]\right\} \tag{14}$$

$$V_Y\left(\vec{K}_Y,\omega_Y\right)=0 \tag{15}$$

$$V_y\left(\vec{K}_y,\omega_y\right)\geq V_y\left(\vec{K}_y^*,\omega_y\right)+\left(\frac{\partial V_y\left(\vec{K}_y^*,\omega_y\right)}{\partial \vec{K}_y}\right)^T \vec{K}_y^* \tag{16}$$

Where: V_y : discounted total cost from year *y* to 2030 ($), $\vec{K}_y{}^*$: a sample power generation mix

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Step1. Initialization

Set $n=0$ $\forall y\in\{0,\dots,Y-1\}$ $C_y=\varnothing, S_y=\left\{\vec{K}_y^0\right\}$ (If $y=0, \vec{K}_y^0=\vec{K}^0$.)

Step2. Do the following for $y=Y-1,\dots,0$

Step2-1. Sampling

Choose sample power generation mix $\left(\vec{K}_{y,k}\right)_{k\in\{1,\dots,SN\}}$ from S_y

If $SN^*<\left|S_y\right|$, $SN=SN^*$ and choose at random. Otherwise, $SN=\left|S_y\right|$

Step2-2. Do the following for $k=1,\dots,SN$ and $\omega_y=0,1$ (If $y=0$, only $\omega_y=1$)

Step2-2a. Solve

$$z_{y,k}=\min_{\vec{N}k_{y,k}}\left\{TC_y\left(\vec{K}_{y,k},\vec{N}k_{y,k},\omega_y\right)+\exp(-\gamma)\times \mathrm{E}_{\omega_{y+1}}\left[\tilde{V}_{y+1}\left(\vec{K}_{y,k}+\vec{N}k_{y,k}-\vec{d}ec_y,\omega_{y+1}\right)\right]\right\}$$

$$\forall q\in\{1,\dots,\left|C_{y+1}\right|\}\quad \tilde{V}_y\geq\alpha_{y+1}^j+\left(\vec{\beta}_{y+1}^j\right)^T\left(\vec{K}_{y,k}+\vec{N}k_{y,k}-\vec{d}ec_y\right)\qquad y\neq Y-1$$

$$\tilde{V}_Y=0\qquad y=Y-1$$

Step2-2b. Addition

$$\text{Add }\left(\alpha_{y+1}^{\left|C_{y+1}\right|+1},\vec{\beta}_{y+1}^{\left|C_{y+1}\right|+1}\right)=\left(z_{y,k}-\left(\vec{\lambda}_{y,k}\right)^T\vec{K}_{y,k},\vec{\lambda}_{y,k}\right)\text{ to }C_y\qquad y\neq 0$$

$$S_{y+1}\leftarrow\left(S_{y+1}\cup\vec{K}_{y,k}+\vec{N}k_{y,k}-\vec{d}ec_y\right)\qquad y\neq Y-1$$

Step3. Convergence test

If the solution of **step2-2a.** at $y=0$ is not convergent, $n\leftarrow n+1$ and return **Step2**.

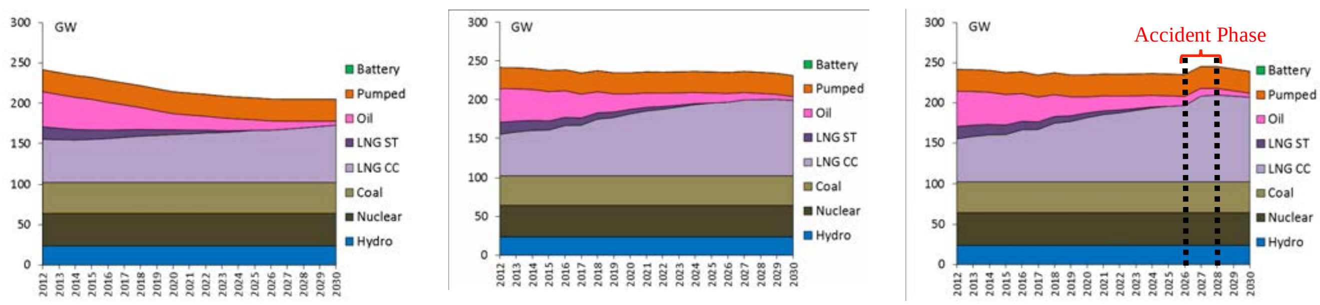
Fig. 2 Cutting planes method algorithm

Where: n : iteration number, C_y : constraint space in year *y*, S_y : power generation mix space in year *y*, SN : sampling number, SN^* : maximum sampling number, $\vec{\lambda}_{y,k}$: the shadow price of equation (5) in **step2-2**.

3. RESULTS

The algorithm shown in Fig. 2 allow us to simulate any scenarios by solving the problem forwardly from $y = 0$ to $y = Y$-1 using the approximated value function. This paper presents two representative scenarios. The first scenario (Scenario1) assumes the shut-down does not happen during the time period. In the second scenario (Scenario2), the shut-down happens in 2026 and it recovers 2028. In addition to the two scenarios, reference case in which the shut-down risk is zero is calculated.

Fig. 3 shows estimated capacity mix from 2012 to 2030. In scenario 1, the LNG CC capacity is expanded at larger scale than reference case. The uncertainty of nuclear power plants' shut-down encourages to have capacity reserve margin in preparation to the *accident* state. In scenario 2, the accident introduces LNG CC's expansion furthermore, which suggests the possibility of additional supply capacity is necessary for the next year under the uncertainty of nuclear power plants' restart.



Reference case Scenario 1 Scenario 2

Fig. 3 Estimated capacity mix from 2012 to 2030

Fig. 4 shows the comparison of the discounted total cost from 2012 to 2030. It reveals the escalation of total cost as the uncertainty of nuclear power plants' shut-down is assigned.

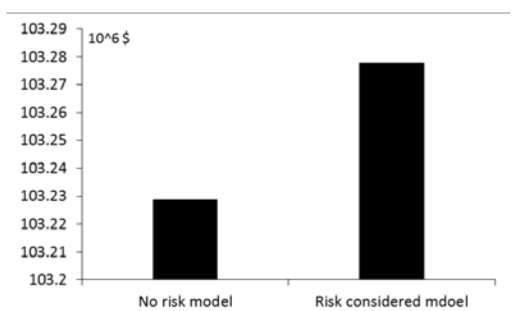


Fig. 4 Estimated discounted total cost

4. CONCLUSIONS

This paper develops a dynamic optimal power generation mix planning model from 2012 to 2030 considering both of the uncertainty of nuclear power plants' shut-down and cost-effectiveness. Simulation results show the possible measures to address the nuclear power plants' shut-down risk and the expected value of additional cost to implement the measures.

Future work consists in assessing the installable potential of distributed generators and including other kinds of risk such as fuel import disruption or thermal plants' shut-down risk since huge earthquake risk in Tokyo-Bay area, where large capacity of thermal plants exist, is concerned recently.

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A Hybrid Finite Element and Mesh-free Particle Method for Disaster-resilient Design of Structures

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ABSTRACT
The MPS-FE method, which is a hybrid method for Fluid-Structure Interaction (FSI) problems adopting the Finite Element method (FEM) for structure computation and Moving Particle Semi-implicit/Simulation (MPS) methods for free surface flow computation, was developed to utilize it in disaster-resilient design of important facilities and structures. In general free-surface flow simulation using the MPS method, wall boundaries are represented as fixed particles (wall particles) set as uniform grids, so that the interface of fluid computation does not correspond to the interface structure computation in the conventional MPS-FE method. In this study, we develop an accurate and robust polygon wall boundary method, named Explicitly Represented Polygon (ERP) wall boundary method, in which the wall boundaries in the MPS method can be represented as planes that have same geometries as finite element surfaces.

Key words
Fluid-Structure Interaction, Finite Element Method, Moving Particle Semi-implicit/Simulation Method, Mesh-free Particle Method, MPS-FE Method

INTRODUCTION

Large-scale facilities such as petrochemical and nuclear power plants, and tsunami evacuation facilities built along coastal regions are vulnerable to water-related disasters. The resulting damage to equipment and instruments has the potential to cause catastrophic harm to people and local society. However, it is economically impossible to completely prevent the effects of disasters of extreme severity. We need quantitative measures to minimize the damages and loss. Detailed numerical computations treating the disasters and damages as Fluid-Structure Interaction (FSI) problems involving free surface flow give us a measure for disaster-resilient design of important structures.

We have developed a hybrid method for FSI problem with free surface, named the MPS-FE method [1, 2]. This method adopts the Moving Particle Semi-implicit/Simulation (MPS) [3] method, a mesh-free particle method, for free surface flow computation because of its robustness in long-term analyses with moving boundaries, and Finite Element Method (FEM) for structure computation because of its high accuracy and reliability. The method combines the advantages of both methods and achieves efficiency and robustness. These two methods are coupled with a partitioned coupling approach, i.e. the conventional serial staggered (CSS) scheme [4], which can set different time step sizes for the fluid and structure computations.

The conventional MPS-FE method [1], in which MPS wall boundary particles and finite elements are overlapped in order to exchange information on fluid-structure interfaces, has difficulty in dealing with complex shaped fluid-structure boundaries, because the wall particles have to be set in an orthogonal and uniform grid manner. In addition, forces on fluid-structure interfaces are not balanced when the pressure on the walls is calculated in the conventional MPS-FE method. As the next step, we adopted existing polygon wall boundary models [5, 6], which can treat a wall boundary as an arbitrary plane, and improved the MPS-FE methods so that the fluid and structure interfaces are consistent. However, the existing polygon wall boundary models cannot satisfy the pressure Neumann or the slip/no-slip boundary conditions, so these cause instability near the boundaries and deteriorate the accuracy.

In this study, we developed a new polygon wall boundary model for fully explicit algorithms (Explicit-MPS [7]: E-MPS), called the Explicitly Represented Polygon (ERP) wall boundary model [8] to compose more accurate MPS-FE method. The ERP model is formulated such that it satisfies the pressure Neumann boundary condition and the slip/no-slip boundary condition, without requiring the generation of virtual particles or treating angled edges as exceptional cases. Moreover, the ERP model eliminates the problem of force imbalance on the boundaries, which occurs in conventional models.

ERP WALL BOUNDARY MODEL FOR EXPLICIT-MPS METHOD

Regarding the wall boundary treatments, research has made greater progress for the SPH method [9], which is one of mesh-free particle methods. The repulsive-force model [10] has been developed in order to avoid penetration of fluid particles across wall boundaries. Although the model is relatively easy to implement, it causes the instability of fluid particles near wall boundaries because the boundary conditions are not satisfied. On the other hand, the ghost (mirror) particle approach [11] is widely used to satisfy the boundary conditions on walls. In this approach, virtual particle is generated at reflectional position across the wall of each fluid particle. These mirror particles are given pressure and velocity values so that the pressure Neumann boundary condition and slip/no-slip condition are satisfied. However, this approach has several problems, including a high computational cost caused by the need to generate virtual particles, and leakage of particles at the angled edges of surfaces.

Regarding polygon wall boundary models in the MPS method, Harada et al. [5] derived the force exerted on a fluid particle from a wall from impulse-momentum relationship at the particles near the wall. This force modeling can be classified as repulsive-force model, so Harada's model has the same problem of the instability and strange behavior of fluid particles near the wall. Yamada et al. [6] focused on the E-MPS method and they proposed another formulation. Although this is a natural expansion of the MPS differential operator models, the model causes excessive pressure oscillations.

The ERP model is based on the mirror particle approach and can satisfy the boundary conditions on walls without virtual particles, and it is versatile enough to treat arbitrarily shaped boundaries and arbitrary movements. The ERP model adds a repulsive force adaptively only when the boundary conditions are not satisfied near the angled edges. The ERP model has the following characteristics.

– Wall boundaries are represented explicitly.
– Generation of virtual particles and the need to make special adaptations for angled edges are not required.
– The pressure Neumann boundary condition and the slip/no-slip condition on the walls are satisfied.

VERIFICATION OF THE ERP MODEL

To verify the accuracy of the ERP model applied to the E-MPS method quantitatively, we analyzed a hydrostatic pressure problem in a rectangular vessel. The numerical results were compared with the theoretical solution

$$\boldsymbol{p} = \boldsymbol{\rho}\, |\boldsymbol{g}| \boldsymbol{h}$$

where $\boldsymbol{\rho}$ is the fluid density, $\boldsymbol{g}$ is the gravitational acceleration vector, and h is the depth of the static water surface. The initial configuration, in which the depth of the rectangular vessel is 0.1[m] and the width is 0.04[m], is illustrated in Fig. 1. In the E-MPS computation, weak compressibility causes vertical vibrations of the fluid surface. To reach the static state as quickly as possible, we chose a relatively high value for the kinematic viscosity. The conditions used in the analysis are listed in Table I.

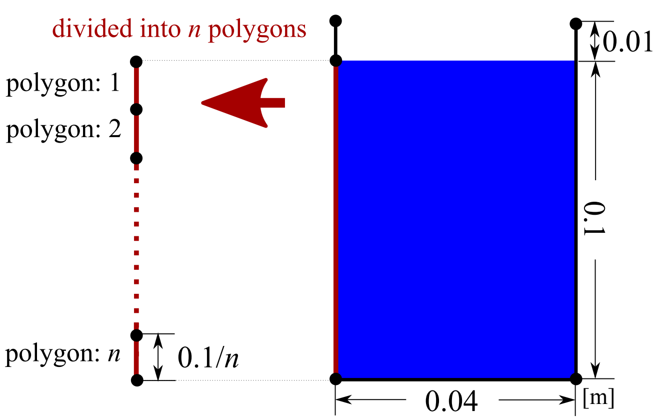


Fig. 1. Hydrostatic pressure: initial configuration

Table I. Hydrostatic pressure: analysis conditions

Time step width	5.0×10^{-5}[s]
Number of particles	4,000
Particle spacing	1.0×10^{-3}[m]
Effective radius	$2.9l^{0}$[m]
Fluid density	1.0×10^{3}[kg/m^3]
Kinetic viscosity	1.0×10^{-4}[m^2/s]
Gravitational acceleration	9.8[m/s^2]
Sound speed coefficient	9.44[m/s]
Repulsive coefficient	1.0×10^{7}[N/m^3]

Fig. 3 shows the pressures of fluid particles computed by (a) the ERP model, (b) the ERP model using only the repulsive force, (c) Harada's model, and (d) Yamada's model. These are the results at the 200,000th step, at which the pressure field can be regarded to be in a steady state. In Fig. 2, snapshots obtained by each models at the 200,000th step are shown; the pressure on the fluid particles is indicated by color (unit [N/m^2], min: 0, max: 1,000).

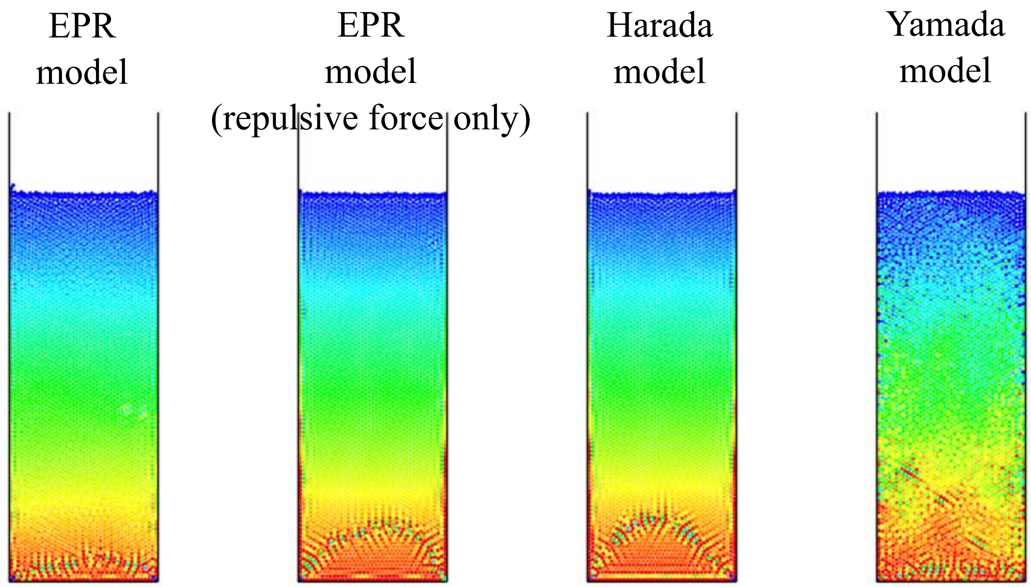
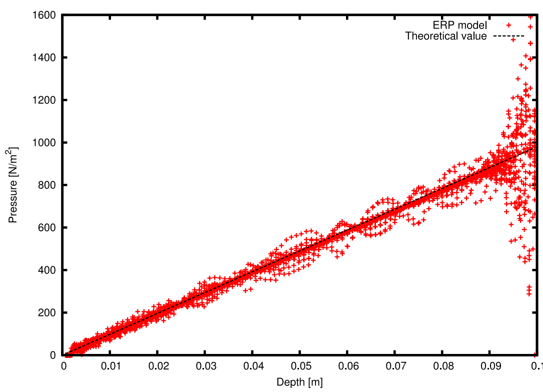
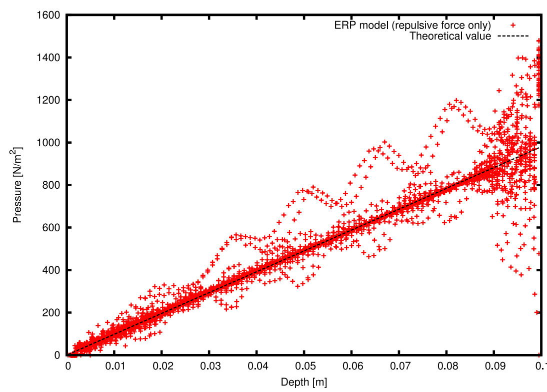


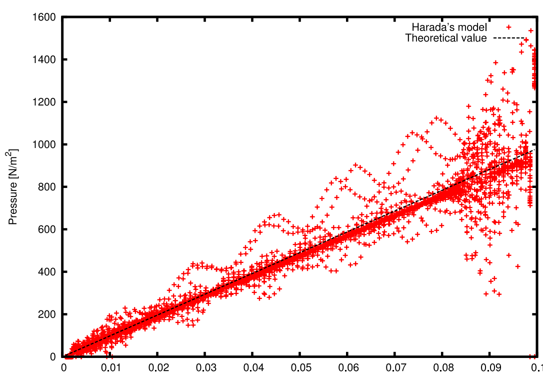
Fig. 2. Hydrostatic pressure: visualization of results



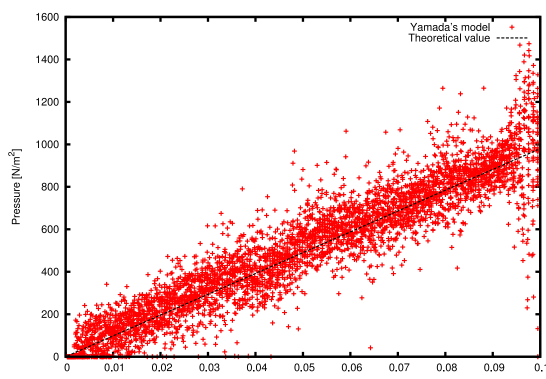
(a) ERP model



(b) Repulsive model



(c) Harada's model



(d) Yamada's model

Fig. 3. Hydrostatic pressure: Pressure on particles

As indicated in Fig. 3-(b) and Fig. 3-(c), the results from using only the repulsive force show the same tendency as those from Harada’s pressure gradient model, which is one of the repulsive force models as we mentioned. Both of the results exhibit two strange lines that indicate pressures that are higher than the theoretical values. These results indicate that the pressures on the particles in contact with polygons have not been evaluated correctly, as shown in Fig. 2. Therefore, the model using only the repulsive force encounters the same problems as are found with Harada's model. On the other hand, Fig. 3-(d) shows that Yamada's pressure gradient model results in a disturbed pressure field that has a wide dispersion compared to those of the other methods.

Unlike the existing polygon wall boundary models, the ERP model does not have the problems that occur with Harada's and Yamada's models, and it obtains a better pressure distribution that is in agreement with the theoretical solution. The results of the ERP model are also in better agreement with the theoretical solution. This is because the pressure gradient in the ERP model satisfies the pressure Neumann boundary condition, whereas the pressure gradient obtained using the existing polygon wall boundary models do not satisfy it rigorously. The results of the polygon wall boundary model involving the ERP model, however, have highly dispersed pressures near the bottom of the vessel, because the accuracy deteriorates at the angled edges of polygons. The influence of the edges can be reduced by enhancing the spatial resolution by using smaller particles.

CONCLUSIONS

In this study, we developed and verified the Explicitly Represented Polygon (ERP) wall boundary model for the E-MPS method. It can deal with arbitrarily shaped boundaries and movements, and it can accurately impose boundary conditions for free-surface flow analysis.

The ERP model is formulated so as to satisfies the pressure Neumann boundary condition and the slip/no-slip boundary condition, without requiring the generation of virtual particles or treating angled edges as exceptional cases.

For verification of the proposed model, we conducted simulations for a hydrostatic pressure problem. The results were compared with the theoretical values and the results of other models. We confirmed that the boundary conditions of the ERP method were appropriately modeled, and the E-MPS method with the ERP model can achieve adequate accuracy.

Now, we have been developing a more accurate and robust MPS-FE method applying the ERP model, and a large-scale parallel MPS-FE analysis system using the large-scale parallel code for the E-MPS method (HDDM_EMPS [12, 13]) and FEM (ADVENTURE_Solid [14, 15]). This system makes it possible to conduct robust simulations of three-dimensional fluid-structure interaction. An example is shown in Fig. 4, which is a three-dimensional simulation of dam break and an elastic column with constraints on the bottom surface.

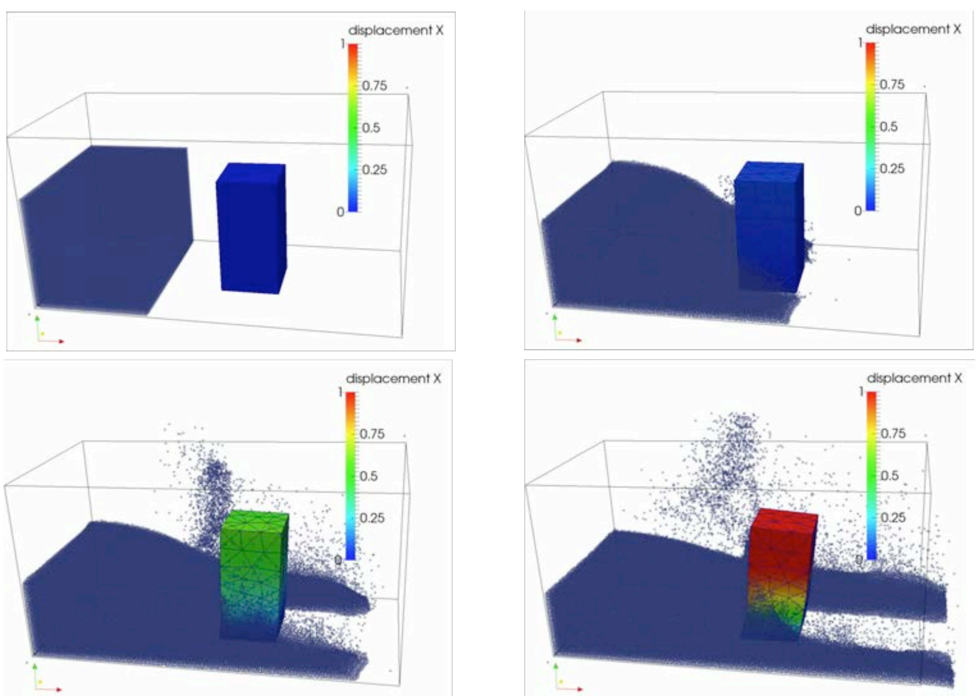


Fig. 4. Example of three-dimensional FSI simulation using the MPS-FE method

ACKNOWLEDGMENTS

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Lack of Cesium Bioaccumulation in Gelatinous Marine Life in the Pacific Northwest Pelagic Food-web

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Abstract
Bioaccumulation of cesium with increasing trophic position is well known across nearly every ecosystem for most organisms. In the marine environmental, typical (concentration ratios (Bq/kg in tissue:Bq/kg in seawater) range from 50-100 in lower trophic levels to 300-10,000+ for apex predators. Recent surveys of 7 gelatinous organisms off the coast of Oregon ranging in trophic position from 1.0 to 3.0 revealed a concentration ratio maximum of 12.5 and typical concentration ratios no higher than 4.4. The implications on human diets and ecosystem shifts for large radiocesium releases are discussed.

Introduction
Accumulation of radiocesium with increasing trophic position has been well known since the 1960s. Most radioecological assessments at that time were driven by nuclear weapons testing, and concerned with human food safety in Western diets rather than ecosystem effects, which come from trophic levels of ~2.7 (e.g. pandalid shrimp, forage fish) up to and exceeding 4+ (e.g. older large tunas) (Ruzicka, Brodeur, & Wainwright, 2007). In pelagic marine environments like those sampled in this study, the preferential retention of Cs with respect to K has been shown to increase by a factor of 2.4 per trophic step (Mearns, Young, Olson & Schafer, 1981). Recommended concentration ratios (CRs) for Cs vary by species to some degree, from 50 in crustaceans to 100 in fish (IAEA, 2004), although observed CRs in higher predators can range much higher (~200-300 in albacore, 400-500 in sharks analyzed alongside the gelatinous organisms reported here). Cephalopod molluscs, however, break this trend with CRs typically closer to 10-20.

In the years following the release of substantial quantities of Cs-137 and Cs-134 (among other radionuclides) from reactors at the Fukushima Daiichii Nuclear Power Station, this overall focus on Western diets has lead to surprises relative to expectations. For example, tea plants at the time of the release did not yet have new leaves (those harvested), eliminating foliar uptakes as a pathway. Nonetheless, some tea leaves harvested the following season still showed substantial radiocesium uptake. As gelatinous organisms are essentially wholly absent from Western diets, there has been far less study on cesium retention. Thus, there are surprises in store with regards to human dietary concentrations of radiocesium in jellyfish. It is hoped that this survey of various gelatinous organisms will help serve as a first approximation of expected outcomes in dietary jellyfish such as *Rhizostomatidae* and *Stomolophidae*.

Methods
Organisms were collected off the coasts of Oregon and Washington either directly from surface trawls or via dip nets. Collections are from 2012-2014, conducted as part of research cruises conducted by the National Marine Fisheries Service. After identification, samples were kept frozen until processed. Before radio-analysis, samples were first baked to dryness at 100°C, before being carefully dry ashed at a maximum temperature of 450°C and a maximum temperature increase of 100°C per hour. Recovery of cesium through ashing was verified to be unity, within the range of counting uncertainty ($\sigma = 4.074\%$), by processing IAEA-414 freeze dried fish tissues (Pham, La Rosa, Lee, & Povinec, 2004). Samples were analyzed for Cs-137 concentrations on a high-purity germanium γ spectrometer. The 72.5mm diameter, 68mm long closed-end coaxial detector has 70% relatively efficiency and 2.0 keV resolution [full-width at half-maximum] at 1.33 MeV and 1.0 keV at 122 keV. To account for differences in detection geometry arising from differing volumes of ash, samples of known activity were counted at various fill volumes and a weighted least-squares fit for the absolute efficiency based on the fill volume was produced. Uncertainties in count rates, mass, geometry-altered efficiency, and chemical yield (on the basis of the yield using the IAEA-414 standards) were propagated.

Results & Discussion
Initial analyses of 1000g by wet weight (standard sub-sample weight for other phyla being analyzed) yielded no detectable concentrations. Increasing this to the entire mass of each collection yielded detectable levels in only 1 of all collections despite wet weights up to and exceeding 10,000g. Table 1 reports the results of radio-analysis for the 7 collections reported here. However, the minimum detectable activity (MDA) as based on the Currie limit[96] and reported in terms of Bq/kg constrain the maximum possible bio-accumulation for these organisms to well beyond the bounds of those seen practically all other marine biota. Assuming a surface water concentration of 1 mBq/kg, 6 of the 7 samples have practically

96 The Currie limit is based on a decision level that produces a 5% false positive rate, and defines the minimum activity necessary at such a decision level to expect a 5% false negative rate.

no bio-accumulation whatsoever: MDAs for bulk samples of the salps *Salpa fusiformis* and *Thetys vagina*, the medusae *Chrysaora fuscescens* and the two individual medusa *Phacellophora camtschatica* yield CRs of just 3.6 to 4.4. The mollusc *Carenaria* featured a CR no higher than 4.4, remarkably low compared to that recommended for most other non-cephalopod molluscs of 60 (IAEA, 2004), which may be due to its dietary inclusion of gelatinous prey such as thaliacians and relative jelly-like body composition: it features only a vestigial shell a few mm in size and extremely soft translucent tissue, and by appearance outside of the water can be easily misidentified as a torn fraction of *Salpa fusiformis*.

Table 1: Activities/MDAs of analyzed organisms. Most samples consisted of bulk samples of multiple individuals. Phacellophora were large enough to analyze as individuals. MDAs calculated as the Currie limit e.g. activity for 5% false negative rate given detection limits.

SampleID	Species	Composition	Cs-137 Act Bq/kg fw	Cs-137 rel err 1 σ	Wet mass g	Collected
JP1	*Pleurobrachia sp.*	Bulk	0.0125	38.86%	3246	July 2013
JS1	*Salpa fusiformis*	Bulk	0.0044	<*MDA*	2706	July 2013
JE1	*Phacellophora camtschatica*	Individual	0.0036	<*MDA*	5726	July 2013
CAR1	*Carenaria sp.*	Bulk	0.0044	<*MDA*	871	July 2013
JT1	*Thetys vagina*	Bulk	0.0060	<*MDA*	3041	July 2013
JBig	*Phacellophora camtschatica*	Individual	0.0108	<*MDA*	10458	June 2012
C42	*Chrysaora fuscescens*	Bulk	0.0038	<*MDA*	9880	October 2013

The only sample with both sufficient biomass and bio-accumulation to be directly quantified still had resulting concentrations yielding a remarkably low CR. The small ctenophore *Pleurobrachia* had a CR of just 12.5 (σ= 38.85%), producing a total number of counts only barely above the decision level.

With regards to trophic level (Ruzicka, Brodeur, & Wainwright, 2007), these results are extremely surprising. All of these organisms, by trophic level, are at least comparable with forage fish such as sardine and smelt, with the latter having 10 times as much bio-accumulation at the maximum possible here. Further, as all but one of these are maximum levels constrained by MDAs, the actual CRs could be much lower...as ionoconformists it is not out of the question to consider a CR of 1 for the lower trophic position samples. In the case of *Phacellophora*, it occupies a trophic position above 3.0, specializing in predating on the gelatinous organisms like those sampled here. This puts it on par with young albacore and bluefin tuna in terms of trophic level, which have CRs of 200+ (Neville, Phillips, Brodeur & Higley, 2014) (Madigan, Baumann & Fisher, 2012).

One implication of this result is that, at least with regards to food safety, dietary jellyfish are likely to remain safe for consumption even in cases of substantial contamination. Drinking water standards for Cs-137 are several orders of magnitude below those for most foods owing to the much larger quantities of water consumed by a human. For example, the EPA in the US has a drinking water standard of 7.4 Bq/L (approximately 7.4 Bq/kg) for Cs-137, whereas the FDAs derived intervention level for Cs-137 in food products is 1,200 Bq/kg. Given the CRs presented here even for the highest trophic positions of gelatinous organisms, jellyfish should remain a relatively safe food product even when harvested in water well of 100 times past the safe drinking water standards.

Another implication of these results is one that has been mirrored in other areas of anthropogenic effects on marine ecosystems: jellyfish blooms. In the event of a radiocesium release of a large enough magnitude to produce population level effects in that ecosystem, the doses to gelatinous organisms can be expected to be tens to hundreds of times lower than that to crustaceans, fish and even macroalgae. Although no in-depth studies have been conducted on the radiosensitivity of gelatinous organisms, there is nothing to suggest they would be especially radiosensitive to offset this greatly decreased dose. Because of their extremely simple immune system that lacks the an equivalent “weak-link” of bone-marrow, and an intestine that is replaced directly by mitosis rather than the “weak-link” of crypt cells, the general indication is that they would show at least moderate radioresistance. One might expect, then, that ecosystem-affecting anthropogenic radiocesium releases might lead to jellyfish blooms and increased competition with forage fish much, much as been observed from anthropogenic eutrophication and apoxia (albeit for a different set of sensitivity/resistance mismatches).

Conclusion

Gelatinous organisms seem to show remarkably low retention of radiocesium when compared to their competitors in the food web. Even with 24 hour counting periods, several kilograms of sample tissue to concentrate and a relatively high-efficiency HPGe in a low-background environment, only one of all gelatinous samples collected exceeded the detection threshold for Cs-137. CRs were no higher than 4.4 and may very well have been 1.0 for some of the organisms collected. Jellyfish may thus serve as a preferential food source during periods of high levels of radiocesium contamination, and may experience more population growth due to lack of competition in the event contamination levels are sufficient to produce population level effects in the ecosystem. More work on radiosensitivity of jellyfish and the means by which they maintain such low levels of retention are needed in the future.

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RadWatch Near-Realtime Air Monitoring (Natural Radioactive Backgrounds and Outreach)

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ABSTRACT

Radioactive backgrounds establish the limit of sensitivity in detection systems for the general search scenario, and set the reasonably unavoidable dose limits for members of the public. Measurement of NORM isotopes in the air provides a unique opportunity to serve the dual goals of capturing temporal/meteorological NORM variations as well as coordinate public outreach/education of NORM exposure. The RadWatch Near-Realtime Air Monitor (RAM) stores meteorological and high resolution spectroscopy data as a function of time from six stories above UC Berkeley Campus. This data is served hourly to the public via radwatch.berkeley.edu/airsampling to demonstrate, not only the existence of NORM, but also the large variations observed in radioisotope air concentration. Clarity and transparency in this education effort are paramount, and complement the urgency of a 'realtime' system. In the future RadWatch will expand to interactive, networked devices to broaden the scope and engage the public.

Key words: NORM, Background radiation, Radon, Low Dose, Outreach

INTRODUCTION

Currently there exists a major deficit in public knowledge about nuclear technologies and nuclear science. A resilient society will include the education of the public and will be crucial to the success of nuclear technologies. The RadWatch program seeks to fill those gaps by providing data in context for background radiation measurements around the Bay Area. Here transparency and clarity measurements/data are paramount. A branch of the RadWatch activities, the Near-Realtime Air Monitor (RAM) is crucial to public outreach efforts and serves the dual purpose of providing high resolution spectroscopy data to analyze temporal and meteorological inputs on variations in the natural radioactive background.

NEAR-REALTIME AIR MONITOR DETECTION SCHEME

The air monitor that we have constructed forces 21SCFM of air through a 4" diameter HEPA filter which is continuously assayed by a high resolution gamma spectrometer (HPGe). The FPAE-102 filter collects 99.99%DOP 0.3um particles. The mechanically cooled, n-type HPGe detector has superior energy resolution and efficiency, even at ~10keV energies. The detector is sensitive in the 3keV-3000keV energy range. Spectra are reported every hour to the public to promote transparency.

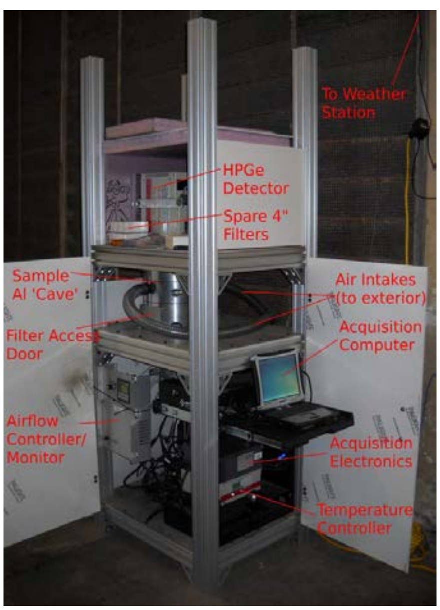

Fig 1: RAM system, acquisition and weather station electronics.

Fig 2: Weather station with 6 parameters of local meteorological data, about 25m above street level.

RADIOISOTOPES OF INTEREST

Isotopes reported by RAM are primarily selected by total contribution to the spectra. These lines are NORM materials, composed of ^{40}K, ^{238}U, ^{232}Th or their daughters. Specifically thoron and radon daughters are of interest because they provide almost ⅔ of the natural dose that healthy individuals receive. Other isotopes are of public interest after events such as Fukushima Dai'ichi which include residual fallout or TENORM. The RAM is an improvement over the previous revision of the sample based air monitors that we employed just after Fukushima. The measurements for the time period just after Fukushima were mainly focused on the detection of ^{134}Cs and ^{137}Cs, the results are provided in figure 5.

Isotope	Origin
Bi214	Naturally Occurring(U238)
Pb212	Naturally Occurring(Th232)
Tl208	Naturally Occurring(Th232)
K40	Naturally Occurring
Cs134	Reactor
Cs137	Technically Enchanced/Naturally Occurring

Fig 3.The isotopes reported by the RAM system to the web. These are significant in that they are NORM or isotopes related to Fukushima releases.

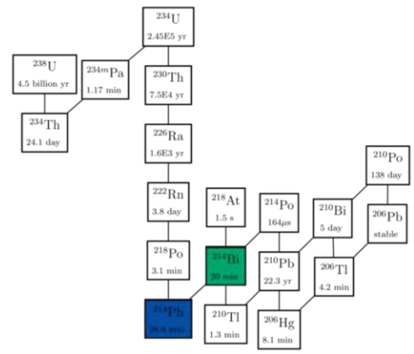

Fig 4. 238U decay chain. These decays constitute the majority of the public's dose.

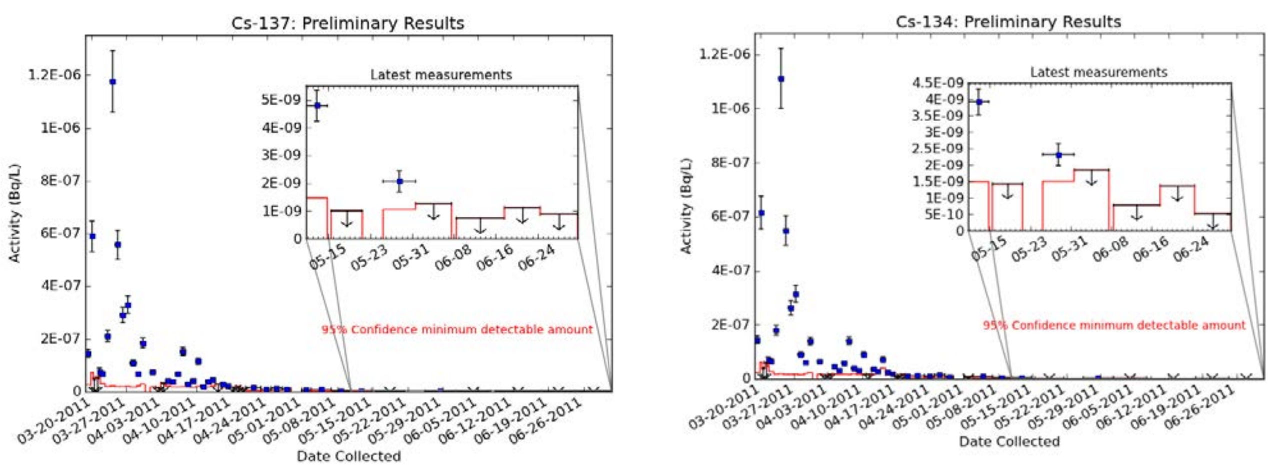

Figure 5 & 6: 137Cs and 134Cs discrete filter air sampling just after Fukushima with first revision air sampler. The RAM system would have the ability to continuously sample events of this kind, capturing the transient response.

OUTREACH (HEADING A)

Accessibility and transparency are vital to establishing trust in an outreach effort. The website allows the RadWatch activities to scale accessibility, by providing data in context about the naturally radioactive world we are living in. The strongest context for the RAM system is in the long time history over which we are tracking isotopes. In the future, a computed NORM dose-rate-variance could be used as an unavoidable dose band for putting excess dose risk in perspective. Transparency is imposed by the immediacy with which results are published, while maintaining good quality control.

PRELIMINARY RESULTS/STATUS

The air monitor provided data with a total downtime of about 72hrs over the Feb to Dec 2014 time period. A sample of this data is provided in figure 7. One can observe factors of 25 variation in certain gamma ray lines. This defines the natural band of variation for these products in the air. More work is to be done to remove systematics from the data, with the caveat that isotope selection is a bandwidth filter. Planned upgrades will help achieve the optimum time resolution for radon concentration in the air. The optimum is defined by the rate kinetics with some simple assumptions about the isotope collection.

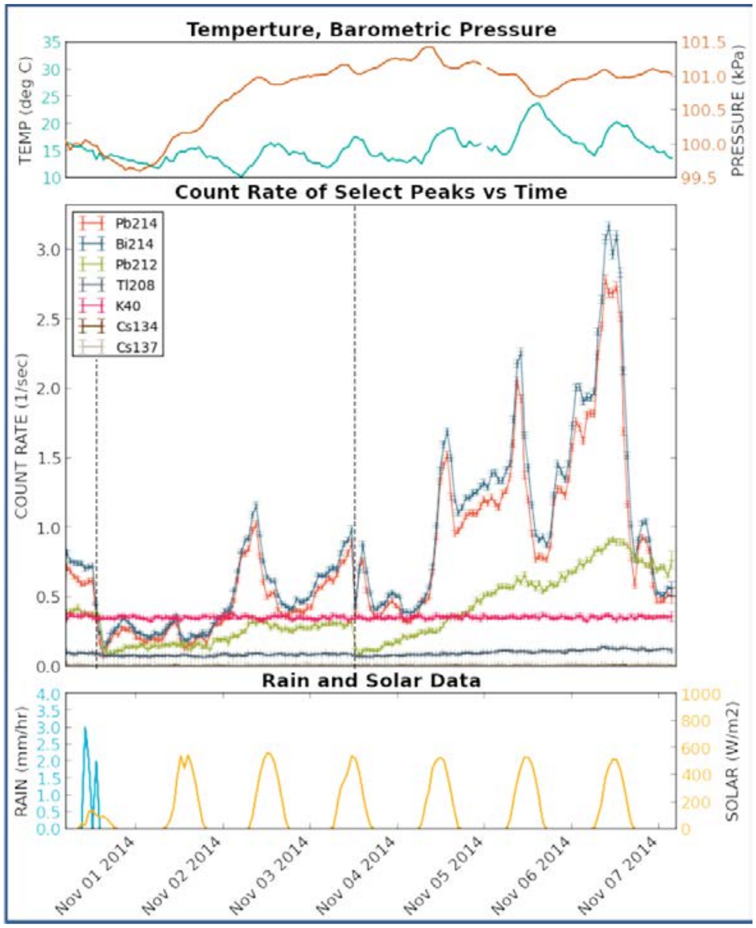

Figure 7. [Middle] Net peak counts rate for one week. The natural background lines vary by as much as factors of 25. Observation of this variance is considerable. Dashed black lines indicate the filter exchange times.[Top&bottom] Meteorological data collected from the weather station just above the monitor. Currently the air monitor is down for upgrades to allow for deduction of weather trends.

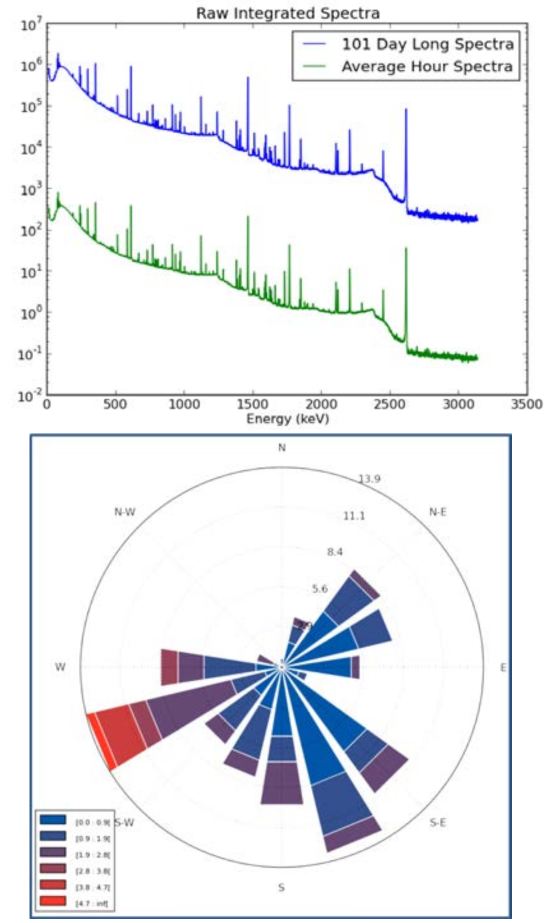

Figure 8. [Top] A wind rose measured from the weather station. The most probable direction for wind was W-SW at about 14% of the time with gusts up to 4.7m/s+. [Bottom] Integrated and average spectra from 100d period.

CONCLUSIONS

A radiologically resilient society will depend on public data provided in context and transparently. We have demonstrated the operation of a high resolution spectroscopy system with accessible data to provide the public with the facts that the world is radioactive and that they concentration of natural radioactivity in the air varies considerably. The goal of this research is to eventually calculate an estimate of current dose rate. Concentration of background isotopes in the environment are incredibly useful for putting nuclear technologies and events in context, allowing the public and scientific community to weigh the risks and benefits associated with this field.

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Incorporating Value Discussions into High Level Radioactive Waste Disposal Policy: Results of Developing Fieldwork

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ABSTRACT
The disposal of high level radioactive waste has fared no better in Japan since its legislation in 2000 than in most countries grappling with the same problem. This research aims to contribute to realizing some form of disposal in Japan, by suggesting an improved institutional scheme for policy making. A partially arrived answer to this question concerns value judgments in decisions of technology use. Historically, implementing agencies have allowed limited debate on issues of value. What would develop if those previously excluded were given a chance to have their say in issues of value concerning high level radioactive waste disposal? This question has been taken out to the field, in the form of group interviews of young citizens. Here, the details and preliminary discussion of the fieldwork are described, as a temporary result of this study.

Key words: High level radioactive waste disposal, policy making, value discussions, citizen interviews

INTRODUCTION

High Level Radioactive Waste Disposal in Japan

The disposal of high level radioactive waste has fared no better in Japan than in most countries grappling with the same problem. Since 2002, two years after legislation announced that Japan's waste would be vitrified, stored for 30 to 50 years, then disposed in a geologic repository within its territory, Japan has embarked on a process of 'local solicitation', asking municipalities to apply appropriate sites for further investigation. Compensatory money and services sparked near calls for application nationwide, but nothing appeared on official papers.

Moves to fix problems within the set framework, such as finding visual means of explaining the official position, and elaborating on the compensatory measures, have been studied and adopted in abundance. There have also been moves to shift the political weight from the localities to the national government. All have ended to no avail as of today.

Meanwhile, opposition against the present method of disposal of high level radioactive waste (and of its by-production) has been repeatedly put forth by the concerned public in the form of public comments on policy drafts and opinions gathered at public hearings. These opinions have been presented both prior to [1] and after [2] legislation, but close inspection reveals that it is hard to say they have been given a substantial response. Much of the official publications and discussion events have dismissed other methods of disposal on grounds of their presiding political and technical challenges to realization, raising agendas of the safety of geologic disposal, or what can be done for localities accepting site exploration instead.

This apparent evasion of debate occurs not necessarily because geologic disposal cannot withstand such counterarguments, but rather because the choice of geologic disposal relied heavily on top-level selection based on prior international debate and perception. This means that, in the Japanese context, it is easy to explain the chosen plan in terms of how it seemed better than other existing options, but it is difficult to break this decision down to the evaluation of respective criteria, and impossible to say whether the choice of criteria or its relative weighting was democratically warranted. Albeit mention in the present policy of securing a margin for reform for the 'future generations', doubts arise whether anyone can recognize a "betterment" coming along when there has been no attempt to substantiate what "better" actually means.

Such a history suggests, both in practicality and in theory, that more radical reconsideration of policies is due.

Overarching Aims

This research aims to contribute to realizing some form of disposal in Japan, by suggesting an improved institutional scheme for radical (re)consideration of high level radioactive waste disposal policies. The improvisation will center on problems of how decision making agendas have been limited/assigned to certain actors over time. This direction will lead further to questions such as, "*How* should the public participate?" or "What is the role of certain specialists in policy making?" which are both questions echoed from related studies [3] [4].

To reconsider institutional schemes in this view, the history of decision making on high level radioactive waste disposal will be reviewed with a mind to discern what agendas have been heretofore assigned to which actors, while consciously inquiring how agendas and actors could or should be defined. The latter query in particular is of importance, since forming an understanding of the relationship of the actors/agendas, and being able to sequence them in some manner (e.g. from the technically general to the specific, from national to local, etc.) is fundamental to understanding what is "wrong" with past policies; what has unknowingly been assigned against the order of agendas/actors at some point in time.

Research in Development: Incorporating Values into Decisions of Technology Use

This study is in process (most of the understanding arrived at this point has been formed as the author's graduate thesis [5], and is expressed in the first sub-section of the introduction), and a working hypothesis has been derived: One problem of prior institutional schemes is that citizens have been deprived of debate concerning overall value judgments of technology use, having been expected to participate in judging technical, specific issues. It follows that devising a means to ask citizens to discuss values concerning such issues would improve the present institution. This is a point shared with researchers working for the Science Council of Japan's on issues of high level radioactive waste disposal policy [6].

The grouping of actors here does not split society into experts and citizens, but rather assumes an abstract notion of citizens being those thinking as a politically independent member of society (including the vocational experts, engineers, researchers etc.), with the other end of the scale being experts, or non-"value-thinkers", those who solve the predefined problems using particular know-how. It is not necessarily that "the public's view was not considered" but that "those of the public who spoke as citizens were dismissed" or "agendas which concerned value judgments were put aside" in the debate concerning high level radioactive waste disposal policy of Japan.

This working hypothesis has been put to test. Using chances granted by funds from Tokai village, a municipality with a long relationship with the nuclear industry, a method for consulting people in matters of value regarding disposal related technology has been devised and conducted. The details are introduced in the subsequent sections.

METHODS OF INCORPORATING VALUES INTO DISCUSSION OF TECHNOLOGY USE

Objectives and Methods

The objective of the fieldwork at Tokai village is to attempt to consult people on issues of values which influence decisions on technology use (as concerns this presentation). To have achieved this, the value-laden issue needs to be defined, then the context of the technological problem conveyed, then the problem consulted. The results of the consultation can then be analyzed by the researchers and translated back into its implications for discussions of technology use. This process needs to sufficiently convey the context of the discussion, and be appropriately defined (if the issue is too abstract in terms of value, for example if people were asked to discuss political values each endorses, this would likely not work any better than asking them to talk about the appropriate thickness of the waste containers).

The method of consultation devised here takes the form of a group interview. During August 2014 to February 2015, 18 people were interviewed in various groups, each session lasting around 90 minutes. Participants were asked to relax and to discuss freely "what you think is a desirable means of 'disposal' of high level radioactive waste" without worrying about present technical limitations etc. A less than 5 minute explanation of what high level radioactive waste is, what it looks like, how much radioactivity it holds and how long that lasts, how much of it Japan has, and its present designation was given at certain timings using the figures shown (Fig.1).

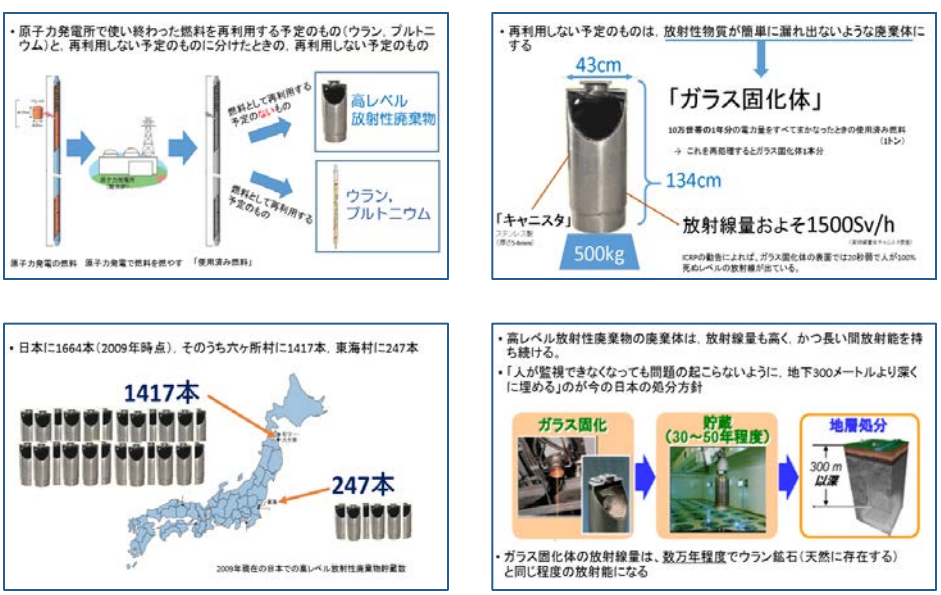

Fig.1 The 4 slides handed to participants during the actual interviews

Table I. Primary Results of the Group Interviews

Opinions*	General Implication
"It is better for the waste to be re-used"	Means to minimize the fundamental problems should be reconsidered
"It is better for the production of waste be reduced"	
"Can't the radiation be reduced?"	
"Can't the radioactivity to be shortened?"	
"Somewhere isolated from the human environment would be better for a repository"	The general idea of a geologic repository may not be far off, but other possibilities should also be evaluated in these terms
"Somewhere that has little to do with humans for years to come"	
"The waste should be stored so that the unfairness of siting is minimized"	Means to minimize "unfairness" should be reconsidered
"Monitoring of the waste should be continued for as long as possible"	Even for a repository with passive safety designs, maintaining active safety measures should be considered
"Effort should be made to be able to do something if anything happens"	
"Effort to pass on messages of the presence of the waste and of apology should be taken"	Means to pass on warnings and apologies should be reconsidered

* Revised and translated

One important characteristic of these interviews was that the targeted age group of the participants was limited to "young" people, set as being between 16 (a high school freshman) to 34-35. This target was meant as a current attempt of listening to the "future generation".

Results and Discussion

Some of the frequently observed opinions obtained through the group interviews are listed above (Table I.). Many of the participants from varying groups raised questions about reducing and re-using the waste, and some mentioned that such efforts to fundamentally ameliorate the situation should be continued after the waste has been stored in a repository. There were mixed feelings about putting hopes in future technology development, but not many were in favor of giving it up altogether. Questions about what sort of place would seem fit for the storage of waste drew answers that places isolated from the human environment and places which humans have little relation to even into the future were considered better, revealing that the general idea of a geologic repository (for storage/final disposal) may not be far off. However, it can be said that experts may have an obligation to evaluate the other possible sites on the same terms. The seabed and outer space, though controversial within the groups, was also raised as a (future) possibility. Many of the participants viewed the unfairness of siting a repository as a problem, and suggested that the sites be dispersed into <10 sites, or 47 sites –one for each prefecture. It would follow that the idea of dispersed repositories should be given a (perhaps qualitative) technical evaluation. When asked what sort of message might be left to future generations, many of the participants said a warning would be necessary, of the fact that high level radioactive waste is present, and of its storage place. Some offered to say that an apology to the future generations was due, yet others openly stated that they thought this unnecessary.

Overall, it can be said that once people started thinking about the high level radioactive waste, most did not opt for trying to have as little to do with it as possible, instead coming up with ideas about how the problematic could be reduced, what the generation could actually *do* in face of the waste.

At least 10 of the arguments held implications to the present policy in that they raised questions which had not been adequately investigated in Japan's context. These initiatives can be directly translated into 'homework' for the experts, or discussed further with citizens by giving more information about the general concerns for the ideas that the experts hold. For example, informing citizens about the technical difficulties of separating radioisotopes, or the technology level of transmutation may yield different feelings for the idea of decreasing radioactivity, or call for extra conditions on the desirability of waste re-use.

From the results of the interview, it can be said that a general background understanding of high level radioactive waste seemed to have been conveyed to most of the participants, although a more detailed explanation of the nature of radiation may have been necessary. There may also be room for improvement in the explanations to some of the technical questions raised during the interview, which could have affected the range of ideas the participant could voice, however, this point requires more trials to confirm. The setting of the issue itself can also be considered appropriate (neither too technical, nor too abstract) if we note that a certain number of opinions concerning values were obtained through this interview.

CONCLUSIONS

High level radioactive waste disposal policy has not worked out monetarily or politically as it has been designed, and a study of the criticism it has received shows that those responsible for maintaining its policy have not been able to respond to such debate due to its lack of consideration about the value judgments incorporated in issues of technology use. This understanding of the problem has been applied to fieldwork in Tokai village, where group interviews were conducted with the cooperation of young citizens, to ask for ideas on “What would be a desirable means of ‘disposal’ of high level radioactive waste”. The results centered on ideas to tackle the “fundamental” problems of the waste, such as its presence, amount, radiotoxicity and “uselessness” or “unwanted-ness”, rather than just cope with the safety risks the waste imposes. There were also opinions on what sort of environment would be best for storing the waste, which shared points in common with the present policy but also added that the “unfairness” of concentrated siting should be reconsidered. Other opinions opted for persisting in R&D and maintenance, for reducing or reusing the waste, hauling it to outer space, etc. These opinions on the desirable means of dealing with the waste hold respective implications for those with the know-how to consider how they may be realized, or to evaluate their technical feasibilities into the future so that they can be reconsidered as alternative options.

ACKNOWLEDGMENTS

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5.6. Rapporteurs

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Hybrid risk – Hybrid knowledge

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ABSTRACT
Drawing from in-depth anthropological research in the Bay Area analyzing the community of scientists, experts and other risk-conscious residents, this article emphasizes the importance of multiple forms of knowledge and reflexive approach to fully apprehend the complexity of the integrations and interactions between science, engineering and society. Building on corpus coming from Science and Technology Studies, Disasters and Risk Studies and and Geography, this article emphasis the importance of systematic approach of in the study of risk and disaster. Following this exploration will see that the rigid definition that have separated science and experience, rationality and emotion, expertise and lay perception should be recomposed in favor of a more integrated approach that takes into account the role of the different dimensions of knowledge. As a prospect for a better understanding of the complex definition of risk in the public sphere, this research also proposes a framework to think about the definition of the subject "at risk," as well as allows for reflection on the establishment of closest relation between scientific and non-scientific knowledge.

Key words: risk, knowledge, integration, expertise.

INTRODUCTION

Risk and disaster studies cross disciplinary fields from physical, engineering, social, political sciences to humanities; using multiple methodologies approaches anchored in diverse epistemologies. This multiplicity of perspectives is even complicated by the fact that academic expertise is constantly in discussion with the more operational level of policy making and, sometime also, with lay people, residents, consumers, citizens or concerned groups who are both the beneficiaries and the subjects of scientific knowledge. This difficulty to deploy the complexity of each situation has been, and for several decades now, one of the many research programs tackled by researchers in Sciences and Technology Studies (STS) which can be defined as an "*interdisciplinary field that examines the creation, development, and consequences of science and technology in their cultural, historical, and social contexts"* (Hackett, Amsterdamska, Lynch, & Wajcman, 2008). Researchers interested in the complex relations between any given space and social practices have looked at the multiples dimensions of the eruption of risk and the unfolding of disaster in the urban and non-urban environments. These studies have focused both on the socio-economic preconditions that worsen the effects of hybrid (both man-made or naturals) disasters, as well as the cultural and political parameters that influence the conditions and quality of a particular disaster response, and later on, reconstruction. Studied through the frame of socially constituted and culturally meaningful practices, theses approaches have enabled researchers to create an index of adaptation – or often mal-adaptation – between human and non-human actants (Quarantelli, 1988, 1998, 2005).

THINKING WITH THE CONCEPT OF RESILIENCE IN A SCIENCE AND TECHNOGY PERESPECTIVE

One of the key concepts that seem to have been successful in fostering discussions between the different stakeholders is the concept of resilience. Building from the researches on vulnerability which have tended to emphasis the subject as an agent, and his specific capacity – or lake of capacity - to grasp a problem, resilience studies have favored a more systematic approach (Reghezza-Zitt, 2013; Vale & Capagnella, 2005). Making explicit the divergences in mode of engagement between the two concepts helps understand the nature of this change of "paradigm", as Miller and al. recalled:

> *These different emphases are seen in two studies in Limpopo Province, South Africa […]. In the vulnerability study, the aim was to understand how different stakeholders view their vulnerability to support decision-making at the village and municipal scales in Sekhukhune District. […] In the resilience study, the aim was to establish an overall picture of system function, including qualitative system dynamics and vulnerability analysis, in the Sand river sub-catchment using resilience theory. This study made explicit the linkages between the social and ecological system on the one hand, and the time scales at which certain drivers proved more important than others. The vulnerability approach placed more emphasis on agency and on the identification of hooks for responding to adaptation and development challenges.* (Miller, et al., 2010)

These conceptual investigations are themselves often built on previous researches that have focused on the historical, social, economical and political density of specific contexts. In such approach, *"environmental risk in the city is interpreted as an outcome of the political interests and struggles over power that shapes the urban environment and society"* (Pelling, 2003: 4). These researchers have opened up the field to reflect on what Oliver-Smith has specifically termed "peril," meaning how people deal with the possibility of death, disruption or destruction of their environment, and the sequels of such events: the trauma (Caruth, 1996; Clavandier, 2004; Das, 2006). Re-opening the question of consequences of disasters on individuals and groups, they have focuses on the relations between individual personal experiences, the larger scales of social experiences and complex scientific and engineering systems. The possibilities of interactions that they opened up have made possible to conceptualize risk and disasters multi-dimensionally:

> *Disasters are both socially constructed and experienced differently by different groups and individuals, generating multiple interpretations of an event process. A single disaster can fragment into different and conflicting sets of circumstances and interpretations according to the experience and identity of those affected. Disasters force researches to confront the many and shifting faces of socially imagined realities. Disasters disclose in their unfolding the linkage and interpenetrations of natural forces or agents.* (Oliver-Smith, 1999: 26)

In more recent years, experts and lay people alike have also come to question the horizon of a world without disaster, as well as the place that disasters take in our lives (Dupuy, 2002; Latour, 2013; Neyrat, 2008; Serres, 2009; Stengers, 2009). Acknowledging that the balance between dangers and safety precautions is constantly renegotiated in contemporary societies (Lupton, 1999a, 1999b; Wiener & Rogers, 2002; Wiener, 2010), researchers have also emphasized the role of expertise in the definition of such concepts (Callon, Lascoumes, & Barthe, 2009; Haas, 1992). Here, questions related to the threat of potential disasters – coming together under the concept of "risk" – have become an extensive field of research, in which the seminal work of Ulrich Beck (Beck, 1992) has been both celebrated and criticized (Bourg, Joly, & Kaufmann, 2013; Boudia & Jas, 2007; Lash, Szerszynski, & Wynne, 1998; Latour, 2004; Wynne, 1996).[97] Beck's definition of the concept of *risk society* has marked a turn in the understanding of the questions and the diffusion of the concept outside the specialized field. But as Latour noted *"like most sociologists, Beck suffers from anthropology blindness"* (Latour, 2004: 453). Indeed, during 50 years of field work, social scientists working on that topic have shown that, when examined in detail, the conditions for the emergence the concepts of risk and/or disasters, rather than being a homogeneous set of concepts, practices, and methods as Beck as tended to present them, have *"been continually fraught with internal tensions"* (Collier & Lakoff, 2008: 8). Boudia and Jas (Boudia & Jas, 2007) additionally noted that researchers have reacted strongly to the publication of Beck's book, documenting what seemed to have been one of the blind spot of the book, i.e., citizen science, Public Participation in Scientific Research (PPSR), and the role of concerned individual in the shaping of the definition of the risk. Indeed, in the Sciences and Technology Studies literature, experts have been credited for solidifying the techno-politics of the state (Mitchell, 2002); but also criticized for creating tensions within the democratic process (Fischer, 2000) and, sometime, for not taking into account local knowledge (Wynne, 1996). But what happens when expertise is based on local knowledge (Lidskog, 2008) and when knowledge is co-produced along both expert and non-expert lines (Lane et al., 2010)? Indeed, in many recent disasters experts have become the beneficiaries of their own expertise (Atkinson & Wald, 2007; Bohy, 2013; Walde, Quitoriano, & Dewey, 2006)?

SOME INSIGHTS FROM A FIELD RESEARCH IN THE SAN FRANCISCO BAY AREA

This paper built on my own research in the Bay Area of San Francisco where I have defined the network of knowledge that, within the community of scientists and experts that I have studied, connects science and experience. When it come evaluate a risk or think about a disaster, "knowing" is a complex operation. In the academic context, it is often taken for granted that scientific and expert knowledge surpass lay knowledge and that risk will be better prevented if only residents could think more like scientists do. In this article, I want to show that, in the Bay Area, the scientists and experts who have also learnt to think as residents do, and this hybridization of knowledge has allowed tremendous improvement in disaster preparedness.

Utilizing hierarchical categories, comparing, and discussing the risks allow to envision the potential dreadful consequences of large-scale earthquake, but also re-place it in a time frame of a individual life spam. As discussed by a respondent living in San Francisco involved in risk prevention and the development of building codes:

> *With earthquakes, they're so rare and extreme that to understand them, you have to think of them in the spectrum of everyday risks, monthly risks, and yearly risks. These all get compiled together and, most*

[97] Wynne critics are mostly toward the reproduction of dichotomies *"which are key part of the problem of modernity: natural knowledge vs.. 'social' knowledge, nature versus society, expert versus lay knowledge. It's also reflects – and reinforces – a more basic lack of recognition of the cultural /hermeneutic of scientific knowledge itself, as well as of social interactions and cognitive construction generally. (…) I also thus problematize their uncritical conception of science and knowledge per se. It is important to distinguish here between their recognition of the (in recent years only) contested nature of scientific knowledge, and their uncritical reproduction of realist concept of scientific knowledge. This realist epistemology also, I argue, gives rise to an unduly one dimensional understanding of the underlying dynamics of the nature of 'risk' in the risk society"* (Wynne, 1996:45).

> *people, whether they articulate it or not, they're aware of that difference. You rarely find people that dumb that they don't understand risk in their daily life. [It] doesn't mean they always make the informed decisions, but they have an innate understanding of the rarity of things.* [D.21]

Looking at their own experience of getting prepared for the next Big One, most of the experts and scientists I interviewed gracefully admitted that they only have taken a step or two of the recommended disaster preparedness plan – but, in the other hand, they have taken a step to understand how the everyday co-habitation with the earthquake risk transform our relation to it, leaving it often to compete with other concerns and constraints. Indeed, safety measures advocated to prevent major damages in case of an earthquake concern the field of the domestic life. A space where, experts living in the Bay Area have to make the same day-to-day decisions than anybody else: choosing a house, a school for their children, or a transportation system to go to work. And like anybody else, these experts-residents also must make their decisions based on the amount of information available; evaluate a complex web of actants, and imagine — if they can — the worst for their families.

As recalled a one-time non-expert resident, now an expert in the field, the risk of an earthquake, is not, and never was, "a given"; but has been progressively instaured[98] by researches, practices and attentions: "*I'm from Massachusetts and New York State. When I moved here, it was the 1970s; [The idea of a major earthquake] wasn't in anybody's awareness."* [J.12] This ongoing instauration of the earthquake risk was not a one-way street, but rather, a slow elaboration of the capacities needed to understand both earth science and resident behavior, and many things in-between like the legacy of past and distant disasters, as well as cultural, philosophical and metaphysical questions; often in a reflective way. In this context, experts and scientists have learnt at their own expense how to be not only rational subjects but also beneficiaries of their own expertise – the one that is aware of the tensions between forms of knowledge. In the process, scientists and experts have learned to deal with, and even to respect, residents' understanding and practices: *"If it does not make sense for the people to retrofit their home, then it does not make sense by scaring them into doing it,"* [D.21] summarized one respondent, a structural engineer by training, who here echoed this common Bay Area sentiment. Moving away from the easily-taken-for-granted discourse regarding the lack of preparation and the irrationality of the residents (Geschwind, 2001; Stallings, 1995), and also taking their distances with infructuous attempts to detach irrational thinking from idealistic, "pure" scientific knowledge, these experts have accepted that several *"frames can be considered rational yet lead to radically different solutions"* (Von Winterfieldt, Roselund, & Kisuse, 2000, p. 35). And as the previously quoted respondent noted, taking this perspective open up large possibilities:

> *We need to define what is rational by what people do, rather than decide what's rational and say that they're not being rational. They <u>are</u> the definition of rational, and therefore we have to rethink what rational is [emphasis added]. [D.21]*

Opening this black box also changes preconceived narratives about people's relations to risk,[99] and in a broader sense, their understanding of individual and collective dynamics. As a respondent who has been working for 30 years in the field of hazards mitigation and long-term disaster recovery planning recalled, the process of defining priorities in the earthquake preparedness was often full of surprises:

> *We did a male survey of people in the mid 1990s. It was intended to find out why people would choose do structural retrofit in their homes, and as part of that, we wanted to see the correlation with whether or not people have done the Red Cross kind of things, like food, water, and first aid. And it turned out - as a side-line, because we also asked their age and income - that the more educated you are,[100] the less likely it was that you're going to have food, water, [and] first-aid training; and the less likely it was that you would have made the structural changes to retrofit your house, regardless of income! [Laughs] And we thought, "Okay … Somehow, when people get a lot of education, they tend to have more blind faith that the utility companies are going to come through and they're going to have food and water. And [they think] they don't need to do this, because they know that their house is going to fall on the ground and therefore*

[98] "Instauration and construction are clearly synonyms. But instauration has the distinct advantage of not dragging along all the metaphorical baggage of constructivism—which would in any case be an easy and almost automatic association given that an artwork is so obviously 'constructed' by the artist. To speak of 'instauration' is to prepare the mind to engage with the question of modality in quite the opposite way from constructivism. To say, for example, that a fact is 'constructed' is inevitably (and they paid me good money to know this) to designate the knowing subject as the origin of the vector, as in the image of God the potter. But the opposite move, of saying of a work of art that it results from an instauration, is to get oneself ready to see the potter as the one who welcomes, gathers, prepares, explores, and invents the form of the work, just as one discovers or 'invents' a treasure." *(Latour, 2011:10)*

[99] In the literal sense, see for instance Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming (Oreskes & Conway, 2011).

[100] Again, please note the change of the personal pronoun as she discusses this history.

> *they're going to fix it. Whereas the other group, which was less well-educated, was convinced that it was going back to that basic survival training." We were trying to hypothesize why this was going on, the basic survival training that they knew: that food and water were important on a day-to-day basis because they're having to deal with it weekly, as they did their budgeting. And therefore: "I need to make sure that I have set aside a little extra so that I will have food and water in case of any emergency, not just a disaster." [J.8]*

Listening to the people they interviewed, accepting to get surprised, or even challenged, and reframing their hypothesis, Bay Area experts worked in alongside the researches taking place in the social sciences that favored and validated their own approaches. Building on their own experience, experts of the Bay Area were also starting to redefine the "normal", which often is for people not living in an earthquake country, a world without hazards. Understanding that the earthquake risk overlaps situations previously though without connections – like science and experience - they framed the contours of a situated, acceptable, but moving norm of "living with earthquake", which never seems to reach a perfect and definitive conclusion.

> *Everybody expects that if there is a major earthquake, things are not going to be as normal. So, it's okay if you take three days before going back to work. If you have to spend some money to patch up cracks and repaint, that's fine. Sometimes, engineers always show you the pictures of the damage because we can always do better and prevent that damage, but most of the time we should be looking at the pictures and saying, "So what? Is that acceptable or not?"* [D.21]

Of course, following argumentation also changes the perspective of the risk itself:

> *If you imagine an event and think you can recover, you don't need mitigation. You can trade off between mitigation, responding, and recovery. That decides how we plan mitigation, which ones we prioritize, why some makes sense in some places but not others, why it makes sense for some organizations but not [for] others. The reason individuals don't do mitigation is because they understand they'll be able to recover. [D.21]*

CONCLUSIONS

The instauration of the risk is not the implementation of risk zero safety, and how could that be? - but the renegotiation about what is an acceptable level of threat that people can afford and agree upon; knowing that what can be done might never be sufficient to cope with the extent of the damage and destruction of the next Big One. Instauring the risk in defining a new norm of what is acceptable when living-with-the-earthquake, endlessly rephrasing the question: *"ask yourself if you have a risk, ask what you have at risk. Just the awareness is important* [emphasis added]*"*[D.21]. In many ways, the incapacity to think *of* the danger frames the limits of this tightrope-walking mental exercise. How, then, do experts and residents articulate the known and the unknown, and how does that articulation add another layer to the instauration of earthquake risks? In this case, knowledge is supported by the capacity to imagine the unthinkable, and to expect and accept the consequences of a large-scale earthquake. But in face of such statement, experts' open secret is that many preventive actions cannot be accomplished preemptively. In such cases, experts have to recognize that their scientific knowledge and their capacity of action to prevent damages are limited, and that a potential future earthquake can go way beyond, or be just very different, from anything they had planned for.

Instauring the risk of an earthquake is a mental exercise that allows experts to improve their knowledge about residential practices in a space of risk; and residents' capacities to define – specific and personal – knowledge of the danger that they are dealing with. This never-ending work-in-progress is continually renegotiated between residents and experts, moving the cursor of acceptability. When new building construction is planned, when a child is born, when a new scientific discovery is unearthed, when a new law is voted upon, or when the time comes to choose a new house, all of the micro-events that had previously been balanced, must be reprocessed. Experts and scientists of the Bay Area are the memory and the knowledge of the earthquake, and make sure that the rest of us never forget this invisible presence.

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