Rethinking Nuclear Risk in the Post-Fukushima Era

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Key-words: nuclear risk, Fukushima disaster, risk society, radiation maps, emergency response.

Abstract
The paper discusses some issues concerning the different types of risks entailed by the civil uses of nuclear technology around the turn of the millennium. This discussion is meant as an introduction into a broadly studied topic revived by the Fukushima accident from 2011. As we shall see, some important theoretical strands from the field of Science and Technology Studies (STS) and elsewhere concerning nuclear risks have their roots in observations about the Chernobyl nuclear accident from 1986 and the less severe accident at Three Miles Island from 1979. These accidents, along with other technological crises have inspired scholars, including Ulrich Beck, Charles Perrow, Brian Wynne, Sheila Jasanoff, and William Kinsella – to name but a few – to shed a different light upon technological failure. The results of the work of these scholars were turned into social theories and sensitizing concepts about technological risk, expertise, and techno-political regimes, which have influenced the way we think about nuclear and other risks today. In the next section, we introduce some of these theories and concepts to set the stage for a discussion of different models for conceptualizing and communicating risk before proposing one of our own. We then briefly discuss radiation maps in light of what Jasanoff termed "technologies of hubris and humility" and provide an outlook into future topics of potential interest in relation to nuclear risk.

1. Introduction

Safety has always been one of the main concerns of the designers and the operators of nuclear power plants (NPPs). And yet the outspoken need for major improvements in this area seems to have been predominantly motivated by the occurrence of the three main nuclear accidents at Three Miles Island (TMI), USA in 1979; at Chernobyl, Ukraine (then part of the UDSSR) in 1986; and at Fukushima, Japan in 2011. Technologies for improving nuclear safety have followed a similar evolution as the concerns with safety itself, albeit with a considerable delay. While being mainly a technical concern before the TMI accident (the first to be widely mediatized), as safety

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issues increasingly became public, they became social concerns as well. After all, how is one supposed to live in the vicinity of a NPP when we know they are liable to failure? This failure liability revealed by the TMI accident meant that the safety of NPPs could no longer be regarded from a technical perspective alone. NPPs are large technical systems that operate in a given socio-cultural context. Hence, their operation implies a social contract. To make matters more complex, the Fukushima nuclear accident has been characterized as a techno-natural disaster[1] thus adding another dimension to the sociotechnical perspective on nuclear safety.

From a physics and engineering point of view nuclear safety is concerned with preventing radioactive materials from being released into the environment. Such releases happened in all three major accidents, although at different levels. In case of a radioactive release, in order to assess who is at risk of being hurt, experts in radiological protection agree that it is necessary to assess the potential dose for the affected population. Radioactive materials can contaminate environments and can irradiate people from the sky (gamma cloud radiation). Thus, decision makers are interested in precise forecasts concerning the short, medium, and long term risks for the affected population by means of measurement and estimation. Such assessments bear high uncertainty since they essentially represent assessments of an entire forward-dependent chain of risks. From a technical point of view, when a potential risk is identified, attempts are made to quantify that risk by means of statistical probabilities. In term, the uncertainty associated with some predictions also needs to be quantified. Some statisticians regard uncertainty estimations as one of the most remarkable achievements of modern science.[2]

Nuclear accidents have inspired scholars in risk research for decades. The very term "risk" seems to be an eternal buzzword that will never allow a unique definition. Even today high level scientific institutions like the Intergovernmental Panel on Climate Change (IPCC) use the terms "risk" and "uncertainty" in ways considered inappropriate by other well-established risk researchers.[3] These tensions seem to be motivated by the fact that the term risk can also be understood in a more social than technical sense, and vice-versa. A risk expressed in technical terms by means of quantifiable probabilities may as well reflect subjective rather than computational assessments made by a wide variety of actors, notably by those considered to find themselves at the allegedly uneducated end of the deficit model.[4] Before 1979, risk was predominantly being treated through practices and methods, which Jasanoff termed *technologies of hubris*:

> "To reassure the public, and to keep the wheels of science and industry turning, governments have developed a series of predictive methods (*e.g.*, , risk assessment, cost-

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[1] Ulrike Felt, *Knowledge claims and forms of expertise in the context of a techno-natural disaster*, 25-27 Jul 2014 2nd FMU-IAEA International Academic Conference, Fukushima, Radiation Medical Science Center, Fukushima Medical University.

[2] David Hand, Heikki Mannila, Padhraic Smyth, *Principles of data mining*, Cambridge, MIT Press, 2001.

[3] T. Aven, O. Renn, *An evaluation of the treatment of risk and uncertainties in the IPCC reports on climate change* in "Risk Analysis", vol.35(4), 2015, pp. 701-712.

[4] Patrick Sturgis, Nick Allum, *Science in society: re-evaluating the deficit model of public attitudes* in "Public understanding of science", vol.13, 2004, pp. 55-74.

> benefit analysis, climate modelling) that are designed, on the whole, to facilitate management and control, even in areas of high uncertainty."[5]

This type of risk treatment did not raise too much public attention before the TMI accident. However, the two major nuclear accidents from the 20th century showed that, contrary to what nuclear experts have always claimed, when accidents occur radioactivity cannot be effectively retained within the nuclear reactor. Radioactivity reaching out of the sealed reactor containment also showed that the methods used to assess the risk of incidents and accidents systematically understated those risks. More importantly, nuclear accidents shattered the sociotechnical imaginary of containment,[6] allowing radioactive materials and thus risk to trespass the thoroughly controlled boundaries of the reactor containment building (the imaginary of containment claimed the contrary).

Felt notes[7] that the space contaminated by radioactivity released from NPPs into the environment is implicitly handed over to "the nuclear" for decontamination works. Public and private communal space, which might have been inhabited, farmed, and used for other purposes by laypersons before the Fukushima nuclear accident had to be forcefully handed over to experts dressed in white overalls and Geiger counters during and long after the accident. The no-entry zone around the Chernobyl reactor site, still in force 30 years after the accident, is also telling in this respect. On the occasions of the TMI, Chernobyl, and Fukushima accidents this seizure of communal space by the nuclear was more easily represented in the media than any kind of information from within the NPP – a protected corporate environment completely sealed off from the public. Thus, nuclear accidents revealed that radioactivity, nuclear risk, and the authority of "the nuclear" cannot be effectively contained within the legal and physical boundaries of the affected nuclear power plant.

As it became clear at the political level that in a nuclear emergency radioactivity and the risks associated with it cannot effectively be controlled, in some countries (including Germany) the focus shifted from *controlling* nuclear risk to *preparing* for an eventual accident. The advent of powerful computers during the 1980s enabled the development of computer programs for atmospheric dispersion forecasting and dose projections. Today, such programs, which fall into the broader class of scientific simulation software, are being used regularly by experts and decision makers in different countries to assess the risks of contamination by radioactive materials accidentally released from a NPP. In this context, it is worth noting that scientific software is known to entail a number of additional sources of uncertainty related to physical model uncertainty[8] discretization, and

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[5] Sheila Jasanoff, *Technologies of humility: citizen participation in governing science* in "Minerva", vol.41, september 2003, p. 238.

[6] Sheila Jasanoff, Sang-Hyun Kim, *Containing the atom: Sociotechnical imaginaries and nuclear power in the United States and South Korea,* in "Minerva", vol. 47, 2009, pp. 119-146.

[7] Ulrike Felt, *Living a Real-World Experiment: Post-Fukushima Imaginaries and Spatial Practices of 'Containing the Nuclear',* Pre-print; Published by the Department of Science and Technology Studies, University of Vienna, Vienna, 2016 in https://www.researchgate.net/publication/305471505_Living_a_Real-World_Experiment_Post-Fukushima_Imaginaries_and_Spatial_Practices_of_Containing_the_Nuclear

[8] Riccio, A., Giunta, G. & Galmarini, S., *Seeking for the rational basis of the Median Model: the optimal combination of multi-model ensemble results* in "Atmospheric Chemistry and Physics", vol.7, 2007, pp. 6085-6098.

other inherent errors entailed by the numerical schemes, which implement the physical models[9]; as well as pure coding errors.[10]

The uncertainties embedded in atmospheric dispersion forecasts and dose projections were reflected by the discrepancies between the different visual representations of the Fukushima radioactive plume (or cloud) published by various scientific, governmental, and media organizations around the world.

Figure 1 shows (in clockwise order) six different atmospheric dispersion forecasts and dose projections at different times and in different units (re)produced (1) by the French *Institut de radioprotection et de sûreté nucléaire* (IRSN, 2012) and (2) by the *Eidgenössisches Nuklearsicherheitsinspektorat* (ENSI, 2011) in their reports on the Fukushima nuclear accident; (3) by researchers from Japanese universities in a *Nature* article using the Japanese SPEEDI system (Tokonami, *et al*., 2012); (4) by IRSN researchers using their own models (IRSN, 2012); (5) by Karlsruhe Institute of Technology (KIT) researchers using the RODOS system[11]; and (6) The *New York Times* reproduced by Reuters in arbitrary units.

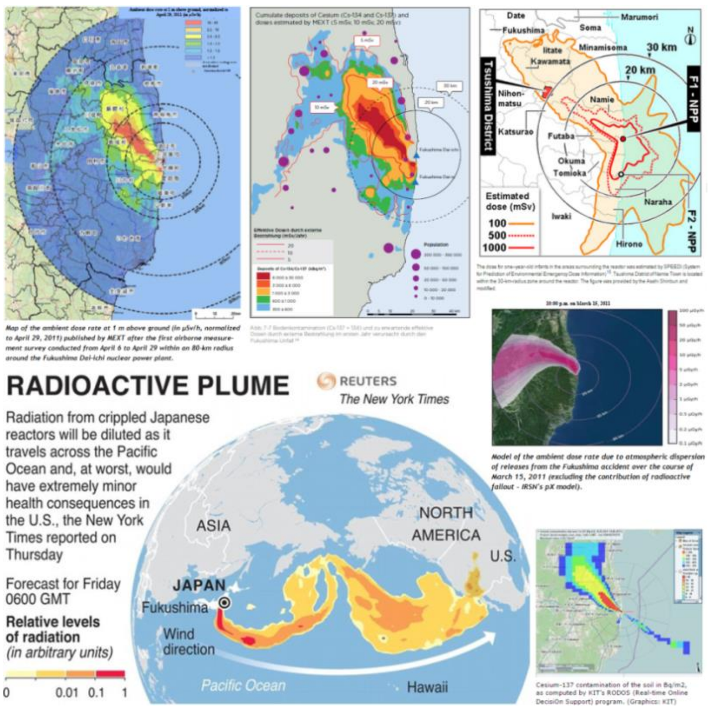

Figure 1 – Different visualizations of the radioactive plume from the damaged Fukushima reactors.

[9] Jon Roy Christopher, *Review of code and solution verification procedures for computational simulation* in “Journal of Computational Physics”, vol. 205, 2005, pp. 131-156.
[10] Tudor B. Ionescu, Walter Scheuermann, *Improving the Reliability of Decision-Support Systems for Nuclear Emergency Management by Leveraging Software Design Diversity* in *CIT. Journal of Computing and Information Technology*, vol. 24, no.1, 2016, pp. 45-63.
[11] http://www.kit.edu/kit/english/pi_2012_9010.php (as of 23.12.2014).

While the first two forecasts published by IRSN and ENSI are mere reproductions of what the Japanese Ministry of Education (MEXT) published at different times after the onset of the accident, the other depictions exhibit major qualitative and quantitative differences. IRSN's and KIT's own simulations seem very simplistic, possibly from modelling reasons. The third forecast produced by Japanese researchers exhibits the classic method of representation of concentration maps using isopleth lines, which is harder to grasp for non-experts, as opposed to the other very colorful representations. The New York Times picture shows how infinitesimal quantities of airborne "radiation" represented in arbitrary units of measurement may cross the Pacific Ocean, reaching American shores within an unspecified amount of time but with a deadline on "Friday at 0600 GMT". The lower part of the description is inspired from the descriptions of the forecasts produced by scientists, which all specify a point in time and a measurement unit. However, the time and the units are both arbitrary and thus of no other meaning than either a purely theoretical or speculative one.

In countries having nuclear energy production facilities, including Germany and Japan, atmospheric dispersion forecasts are used as an aid in the decision-making process by government agencies in charge with taking counter-measures in case of radioactive releases. In Germany, for example, each state government has a designated task force for managing nuclear emergencies composed of experts and non-experts (often politicians). Decision-support systems for nuclear emergency management (DSNE) systems encompass emission and meteorological data measurement networks, atmospheric dispersion simulation and dose estimation programs as well as complex forecast visualization and interpretation tools in the context of a nuclear emergency. They have become non-human experts acting amidst nuclear crisis management task forces around the world.

Against this background, the paper discusses some issues concerning the different types of risks entailed by the civil uses of nuclear technology around the turn of the millennium. This discussion is meant as an introduction into a broadly studied topic revived by the Fukushima accident from 2011. As we shall see, some important theoretical strands from the field of Science and Technology Studies (STS) and elsewhere concerning nuclear risks have their roots in observations about the Chernobyl nuclear accident from 1986 and the less severe accident at Three Miles Island from 1979. These accidents, along with other technological crises have inspired scholars, including Ulrich Beck, Charles Perrow, Brian Wynne, Sheila Jasanoff, and William Kinsella – to name but a few – to shed a different light upon technological failure. The results of the work of these scholars were turned into social theories and sensitizing concepts about technological risk, expertise, and techno-political regimes, which have influenced the way we think about nuclear and other risks today. In the next section, we introduce some of these theories and concepts to set the stage for a discussion of different models for conceptualizing and communicating risk before proposing one of our own. We then briefly discuss radiation maps in light of what Jasanoff termed "technologies of hubris and humility" and provide an outlook into future topics of potential interest in relation to nuclear risk.

1.1. Conceptualizing Nuclear Risk

1.1.1. The Risk Society and Normal Accidents

Much of the public and scholarly discourse about nuclear power and accidents relates one way or another to the notion of risk. During the 1980s sociologists Anthony Giddens and Ulrich Beck coined the term "risk society" denoting (1) "a society increasingly preoccupied with the future (and also with safety), which generates the notion of risk"[12] and (2) "a systematic way of dealing with hazards and insecurities induced and introduced by modernization itself" in Beck's view.[13] Following Beck, the risk society, which allegedly replaced industrial society, has at least two major implications. It is a society that is secured against natural catastrophes[14] while social risks are considered to be tractable (or calculable), which leaves the impression of controllable security. However, Beck notes, the risk society produces numerous other risks, which are not tractable in time and space and for which there is no guaranteed form of assurance. Nuclear technology is one example of a technology that promised to solve one of the most stringent problems posed by industrialization and the exponential growth of the world population: energy consumption. Chemical plants have also led to what the nuclear industry would call "mishaps", such as the accident at Bhopal in 1984, when 500 thousand people were intoxicated with methyl isocyanate.[15] Genetically modified crops also exhibit some of the second order risks that Beck identifies.

Beck defines modernization as:

> "Surges of technological rationalization and changes in work and organization, but beyond that includes much more: the change in societal characteristics and normal biographies, changes in lifestyle and forms of love, change in the structures of power and influence, in the forms of political repression and participation, in views of reality and in the norms of knowledge."[16]

These surges of technological rationalization and changes in work and organization are in a sense *co-produced*,[17] since technologies, such as nuclear power, are made by people working in different political structures and economic organizations deeply embedded in Western society. But these technologies start influencing the political structures and economic organizations the very moment that the possibility of their practical implementation crystallizes out of the wish or drive for modernization itself. Hence, risk can be regarded as an expression of the aguish associated with the possibility of the wish *not* being fulfilled or not without bearing a potentially high cost. Some

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[12] Anthony Giddens, *Risk and Responsibility* in "The Modern Law Review," vol.62(1), 1999, p. 3.
[13] Ulrich Beck, *Risk society: Towards a new modernity*, London, SAGE, 1992, p. 21.
[14] The Fukushima techno-natural disaster contradicts Beck's observation on this particular matter.
[15] Sheila Jasanoff, *The Bhopal disaster and the right to know* in "Social Science & Medicine", vol. 27(10), 1988, pp. 1113-1123.
[16] Ulrike Beck, *op.cit.*, p.50.
[17] Sheila Jasanoff (ed.), *States of knowledge: the co-production of science and the social order*, London, Routledge, 2004, pp.1-13.

technologies may thus end up being more harmful than beneficial, in which case they become highly risky.

The duality of the term risk is also reflected by different idioms of the English language, such as *something being risky, risking one's life or health, taking risks, assuming a risk*, etc. While the first two examples reflect a certain anguish induced by the negative connotation of the notion of risk, the third expression also suggests the potential for an extra gain by taking certain risks. The fourth expression suggests a process of rationalization, since the assumption of a risks is the result of a process of assessment and quantification as well as one of balancing the potential benefits versus the potential losses. The term risk thus encompasses the dynamics generated by the opposite forces of the *wish* for quick and important wins and the *anguish* of potential loss, both of which are deeply embedded in human nature. Their socio-economical counterparts are benefit and cost. Nowadays, any technology may be regarded as risky by the broader public unless the contrary is proven in an irrefutable way.

The rationalization of basic material needs and natural hazards, which have typically posed existential risks for individuals living in the industrial and preindustrial societies, gave birth to second order risks, which are being addressed in a reflexive way by the risk society. Some of these second order risks were generated by the very technologies called upon to solve the problems of the industrial society itself. Interestingly, as part of this reflexive process of technology assessment and reassessment, technological risks are usually addressed through newer, often even more complex technologies aimed at quantifying, confining, and ultimately neutralizing them. Beck refers to this reflexive process as *the rationalization of rationalization*. Beck later observed[18] that, "[i]n principle, the risk of nuclear power is only acknowledged when alternative energies are available. Otherwise, this risk continues to be disowned or downplayed."

Science and technology, as pillars of the risk society, are more and more confronted with the risks created by the products of scientific and technological innovation. This allegedly leads to a generalized uncertainty and a certain resistance against hazards on the part of society. Beck also points out that this situation leads to what he calls a certain type of irresponsibility or incompetence (Germ. *Unzuständigkeit*), that is a division of responsibilities and competencies oriented towards functionally different subsystems, thus leading to the absence of a holistic responsibility for, say, an entire large technical system, such as a national nuclear energy production system. While there are experts concerned with the safety of reactors as well as experts concerned with the nuclear fuel cycle, the decommissioning of used nuclear fuel, etc. these concerns and responsibilities are rather disjoint. Beck further notes that, while the different actors in charge of the many subsystems focus their efforts upon internal affairs within the subsystems they are part of, the global appearance is in effect one of "organized irresponsibility" since the risks of modernization are not to be ascribed to singular causes. This is to say that large technical systems and the risks they entail cannot be effectively controlled by reductionist risk management technologies since these are likely to leave out different sources of hazard.

[18] Ulrich Beck, *Im Dialog*, 17.02.2013: https://www.youtube.com/watch?v=hPPNPPSMj6c

Considering the example of the nuclear industry, the entire process of acknowledgement, negotiation, and finally delegation of risks shows how the reflexive risk society deals with existing risks and produces new ones, since decision-support systems for nuclear emergency management clearly have their own limitations. *Normal accidents*[19] thus revive the debates within research communities that reach beyond reactor safety issues. Normal accidents, which according to Perrow are caused by multiple and unexpected failures in tightly coupled large sociotechnical systems, help to better understand collateral phenomena, such as the spread of radioactive materials, as well as the social dimensions of a nuclear crisis. Perrow argued that some technologies are so complex and thus vulnerable to rapidly-developing failure modes that they reach out of the limits of human control. Accidents caused by failure in inherently complex systems, such as nuclear power plants, can be somewhat reduced in scale and frequency but never be fully eliminated. Perrow's conjecture that normal accidents are impossible to prevent and thus will keep happening in future is probably what motivates governments to use DSNE systems.

1.1.2. Lay Expertise

This type of knowledge is commonly referred to as lay expertise[20] − a form of expertise embedded in local practices and culture that ordinary citizens possess. As Wynne and Epstein showed, when citizens are directly concerned by issues that require or involve scientific expertise, they demonstrate the ability to identify the flaws in expert discourses and to provide alternative explanations and solutions for the issue(s) at stake by drawing on local and intuitive knowledge. Lay expertise thus consists, among others, of "important insights regarding the practical contexts that give meaning to expert discourse."[21] Kinsella proposes a model for enabling ordinary citizens and experts to overcome the apparent incompatibility of lay and professional perspectives:

> "To counter monolithic technocratic decision making, or better yet, to engage in productive collaboration with technical specialists, members of the public must have reasonable fluency in the language(s) of science. Here, I call this fluency *public expertise*. The ideal form of public expertise is technical competency acquired and used directly by affected citizens. Such competency need not, and cannot, replace the more specialized knowledge of technical or policy professionals, but it can provide members of the public with an adequate foundation for genuine dialogue with these specialists.
> [...]

[19] Charles Perrow, *Normal accidents: Living with high risk technologies*, Priceton, Princeton University Press, 2011.

[20] Brian Wynne, *Misunderstood misunderstanding: Social identities and public uptake of science* in "Public understanding of science", vol. 1(3), 1992, pp. 281-304; Steven Epstein, *The construction of lay expertise: AIDS activism and the forging of credibility in the reform of clinical trials* in "Science, Technology & Human Values", vol. 20(4), 1995, pp. 408-437.

[21] William J. Kinsella, *Public expertise: A foundation for citizen participation in energy and environmental decisions* in S. P. Depoe, J. W. Delicath & M. F. Aepli Elsenbeer (eds.) "Communication and public participation in environmental decision making", Albany, SUNY Press, 2004, p. 85.

> If expertise consists of understanding particular kinds of problems comprehensively, in all their relevant dimensions, then it must incorporate the local knowledge and evaluative contexts that ordinary citizens provide. In this respect, members of the public are experts, too, with their own forms of special knowledge"[22]

Public expertise thus represents a participatory approach to overcoming the deficit model in public understanding of science.[23] According to Kinsella, interested members of the public need not acquire the same depth of technical knowledge as specialists because this would make them specialists themselves rather than representative members of the public. Instead, they only need to possess a working vocabulary of specialized terms and concepts as well as an overall understanding of how technical reasoning operates. This basic technical knowledge, Kinsella notes, would allow people to follow evolving policy issues in a rapidly changing contemporary society. Kinsella's model of public expertise is compelling because it suggests that one can understand techno scientific policy issues only by understanding the expert discourse around it. This kind of discourse is often constructed around master narratives and sociotechnical imaginaries. By distilling the true intentions of all the actors who contribute to policy decisions from expert discourse, ordinary citizens would be able to better protect their own interests. However, the model of public expertise implies that ordinary citizens are, to some degree, already versed in critical analysis by the time they engage with expert discourse. Thus, it may favor more articulate people having higher lexical and analytical skills to the detriment of others who might possess genuine lay expertise as well.

1.1.3. The Limits of Representation and Technologies of Humility

As a paradigmatic normal accident, Fukushima was considered by nuclear experts[24] to have been triggered by a series of "beyond design basis" failures. The complications that led to these failures arose from the fact that, as Felt notes, it was a techno-natural disaster.[25] Such a disaster had never occurred before in the history of nuclear technology. In this context, Kinsella notes that, "[i]f Fukushima was beyond its engineering design basis, it was also beyond the 'limits of representation' for a sociotechnical system that has exceeded its creators' vision of control."[26] Drawing on Heidegger's notorious essay "The Question Concerning Technology", Kinsella justifies this statement by arguing that *(emphasis added)*,

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[22] *Ibidem.*
[23] Patrick Sturgis, Nick Allum, *op.cit.*, pp. 55-74.
[24] Masashi Hirano, Taisuke Yonomoto et al., *Insights from review and analysis of the Fukushima Dai-ichi accident: Fukushima NPP accident related* in "Journal of Nuclear Science and Technology", vol.49(1), 2012, pp. 1-17; U.S. Nuclear Regulatory Commission, 1975. *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, Washington, D.C: NRC.
[25] See Ulrike Felt, *Knowledge claims and forms…*
[26] William J. Kinsella, *Environments, risks, and the limits of representation: Examples from nuclear energy and some implications of Fukushima* in "Environmental Communication: A Journal of Nature and Culture", vol.6(2), 2012, pp. 251-259.

> "[i]t would not be true to Heidegger's argument to say that this [totalizing] scientific world picture [seeking to represent all existing phenomena] denies the reality of phenomena it cannot represent. Rather, such phenomena are fundamentally inconceivable within the scientific framework: they cannot and need not be denied, *because they cannot be imagined*".[27]

Kinsella thus adheres to the position that it is common practice in the techno scientific community to "focus on the known at the expense of the unknown"[28] because the unknown cannot be imagined. Kinsella also stresses that there are limits to the calculability in quantitative risk analysis and that "computational models of physical systems are inherently incomplete and therefore insufficient for regulatory decision-making"[29] – a point that Jasanoff also makes with respect to what she calls "technologies of hubris".[30]

Drawing on Beck, Perrow, and other STS scholars, Jasanoff notes that

> "[r]isk … is not a matter of simple probabilities, to be rationally calculated by experts and avoided in accordance with the cold arithmetic of cost-benefit analysis. Rather, it is part of the modern human condition, woven into the very fabric of progress."[31]

Being "part of the modern human condition", risk must be a notion for which not only experts in nuclear technology must have a feeling but also laypersons. Yet experts tend to quantify risk as if it were a tractable and additive quantity that can be dealt with by statistical methods. For example, even if the failure probabilities of specific components, such as a pipe or a pump, could be determined by probabilistic analysis, quantifying the risk of a concomitant failure of several components in a cooling system comprising hundreds of components would pose considerable difficulties. To deal with this kind of problems, in the 1970s the US Atomic Energy Commission introduced so called "subjective probabilities" which were embedded in widely used probabilistic risk analysis methods (U.S. Nuclear Regulatory Commission, 1975). Where failure probabilities of complex systems could not be determined because of missing data and intractable calculus, they would be replaced with experts' assessments of those probabilities.

Jasanoff further notes that, "[c]ritically important questions of risk management cannot be addressed by technical experts with conventional tools of prediction."[32] Yet it seems that these tools of prediction are so appealing to both experts and (to some extent) laypersons that they are still being used as primary tools of risk management. The methods implemented by DSNE systems are either based on statistical inference about risk or are being validated using statistical methods. According to the current standards in

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[27] *Ibidem*, p.253.
[28] Sheila Jasanoff, *Technologies of humility: citizen participation in governing science* in "Minerva", vol.41, september 2003, pp. 223-244.
[29] William J. Kinsella, *Environments, risks….*, pp. 251-259.
[30] Sheila Jasanoff, *Technologies of humility: citizen…*, pp. 223-244
[31] *Ibidem*, p. 224.
[32] *Ibidem*.

the scientific community, the validation of scientific simulation codes enables their authors and users to make claims of objectivity concerning the results produced by these codes, provided that the input data used is indeed reliable and accurate (*e.g.*, data from measurement experiments). From this perspective, DSNE systems, including the entire techno scientific apparatus around them, expose some of the features of what Jasanoff calls *technologies of hubris*:

> "To reassure the public, and to keep the wheels of science and industry turning, governments have developed a series of predictive methods (*e.g.*, risk assessment, cost-benefit analysis, climate modelling) that are designed, on the whole, to facilitate management and control, even in areas of high uncertainty. These methods achieve their power through claims of objectivity and a disciplined approach to analysis, but they suffer from three significant limitations."[33]

DSNE systems could indeed be localized on a spectrum between technologies of hubris and technologies of humility. On the one hand, they use "[p]redictive methods [which] focus on the known at the expense of the unknown, producing overconfidence in the accuracy and completeness of the pictures they produce". Within the community of radioprotection experts, the "peripheral blindness toward uncertainty and ambiguity", as Jasanoff puts it, is complemented by a kind of intuitive improvisation, which is somewhat similar to subjective probabilities. The end users and creators of these systems usually have a feeling of not being able to do much more about uncertainty other than to improve the keenness of their sense for it, in addition to keeping up with the state of the art in the scientific fields of dispersion forecasting and radiological protection.

On the other hand, one of the main goals of DSNE systems can be related to the defining questions of Jasanoff's technologies of humility: *Who will be hurt and how can we know?* Arguably, the first part of the question is being addressed by the very existence of these systems, whereas the second part is addressed by the continuous effort to improve them. Yet, there are at least two additional fundamental problems pointed out by Jasanoff with respect to predictive methods in general, which also concern the members of the community of radioprotection experts:

> "*Vulnerability*. Risk analysis treats the 'at-risk' human being as a passive agent in the path of potentially-disastrous events. In an effort to produce policy-relevant assessments, human populations are often classified into groups (*e.g.*, most susceptible, maximally exposed, genetically predisposed, children or women) that are thought to be differently affected by the hazard in question. Based on physical and biological indicators, however, these classifications tend to overlook the social foundations of vulnerability, and to subordinate individual experiences of risk to aggregate numerical calculations."[34]
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> "*Learning*. [...] The capacity to learn is constrained by limiting features of the frame within which institutions must act. Institutions see only what their discourses and practices permit them to see. Experience, moreover, is polysemic, or subject to many interpretations, no less in policy-making than in literary texts. Even when the fact of

[33] *Ibidem*, p. 238.
[34] *Ibidem*, p. 241

failure in a given case is more or less unambiguous, its causes may be open to many different readings."[35]

The categorizations used in DSNE systems do indeed work with well-defined age groups (e.g., infants, children, minors, adults, etc.), geometrically symmetrical areas of vulnerability (*e.g.*, monitored areas having the shape of concentric discs around the nuclear power-plants), and only a few types of countermeasures that are to be recommended and implemented for entire age groups and areas (*e.g.*, evacuation, staying inside the house, ingesting iodine tables). Also, due to the closed nature of the research groups that develop and maintain DSNE systems, the learning process which occurs mainly (but not only) after major incidents is not likely to lead the members of these groups to completely new perspectives upon the problems at stake. Here, a participatory approach might pave the way towards a more profound and socially-sensitive reflection upon the ambiguities of interpretation through civic deliberation. The polysemic nature of the experience of many individuals could thus be turned into useful feedback within a more flexible participatory DSNE framework.

1.1.4. Risk Communication and Expertise in Nuclear Emergencies

In the study *The social amplification of risk: A conceptual framework*[36] the authors note that risk events, such as nuclear accidents, undergo a series of transformations when communicated to and perceived by the public. This process resembles to some extent the transmission and amplification/attenuation of electromagnetic signals. In a similar manner, the risk perceived by ordinary people, can be amplified by the mass media, or different non-governmental organizations. Conversely, governments and local authorities tend to understate the gravity of risk events in their official communications, perhaps fearing unpredictable public reactions such as collective panic. This process can be thought of as one of attenuation and represents the counterpart of the amplification of risk. The multitude of studies about the media coverage and representations of the Fukushima accident challenge the social amplification model of risk communication, which was the product of the Chernobyl accident. With few exceptions, notably that of Germany, public opinion about nuclear energy returned to levels recorded before the Fukushima accident only a few months after the usual burst of salience of nuclear topics in the media, which is typical for every major nuclear accident and any other type of disaster.[37] This suggests that the social amplification of risk is a temporary side-effect of the co-production of media representations and public concern on different issues in science and technology.[38] Post-Fukushima accounts of risk communication in nuclear crises focus more on how risk communication is performed by the different actors

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[35] *Ibidem*, p. 242

[36] R.E. Kasperson *et al.*, *The social amplification of risk: A conceptual framework* in "Risk analysis," vol. 8(2), 1988, pp. 177-187.

[37] Silje Kristiansen, Heinz Bonfadelli,Marko Kovic, *Risk Perception of Nuclear Energy After Fukushima: Stability and Change in Public Opinion in Switzerland*, in "International Journal of Public Opinion Research", vol.30 (1), 2016, pp. 24-50.

[38] Jack Stilgoe, *The (co-) production of public uncertainty: UK scientific advice on mobile phone health risks* in "Public Understanding of Science", vol. 16(1), 2007, pp. 45-61.

involved in the nuclear emergency management at different times during the crisis as well as on the effects of the communication on regulatory policy, nuclear organizations, and publics in different countries.

Because the duration of a nuclear emergency is impossible to predict, risk communication in such situations is extremely challenging. Not only is it difficult to predict the duration of nuclear emergencies and to devise appropriate emergency response plans but also to classify them as mere accidents, disasters, or catastrophes, as Kinsella notes:

> "Typically, we expect that we can learn from 'accidents' and move on, incorporating incremental improvements. 'Disasters' pose greater challenges and call for more extended reflection, perhaps leading to more substantial changes in policy and practice.
> The term 'catastrophe' suggests something more profound. In the English language, and consistent with its original Greek meaning, early uses of the word linked two key ideas: fundamental, irrevocable change; and an inevitable culmination of a process that was implicit from a phenomenon's origin and has unfolded over time." [39]

While being considered an accident triggered by a series of "beyond design basis" causes and failures by nuclear experts,[40] by others Fukushima is regarded as a techno-natural disaster,[41] a compound disaster[42] (Chhem, 2014), or a triple disaster from "3/11."[43] At the same time, for the German nuclear industry, it is reasonable to say that *it* was a catastrophe; that is because the nuclear phase-out decision taken by the government shortly after the onset of the accident brought an irrevocable change in an entire field of science and business. This change was indeed the inevitable culmination of a lengthy process that has seen many episodes of hubris and deceit amidst the German nuclear community Today, one can observe the entire global nuclear community "being post-Fukushima" – a state requiring a more intense preoccupation with sociotechnical risks rather than strictly technical ones.[44]

Felt notes that techno-natural disasters help us to better understand how risks are socially perceived and acted upon.[45] Techno-natural disasters also represent challenges to our knowledge systems and to the authority of experts and their expertise. Here, risk communication can be seen as a mediator between risk perception and the actions taken to mitigate those perceived risks in accordance with the expertise available at the time of the unfolding disaster. In this context, Felt notes that routine expertise acquired within closed groups may not suffice to handle the dynamics of disaster and to mitigate the risks it entails.[46]

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[39] William J. Kinsella, *Being "Post-Fukushima": Divergent Understandings of Sociotechnical Risk*, in "Fukushima Global Communication Programme Working Paper Series" no.18, 2015, Tokyo, United Nations University Institute for the Advanced Study of Sustainability, p. 2.
[40] Masashi Hirano, Taisuke Yonomoto et al.,*op.cit.*, pp.1-17.
[41] Ulrike Felt, *Knowledge claims and forms….*
[42] Rethy K. Chhem, *Radiation Medical Science Center, Fukushima Medical University*. Fukushima, Radiation Medical Science Center, Fukushima Medical University, 2014.
[43] William J. Kinsella, *Being "Post-Fukushima…*, p. 2.
[44] *Ibidem.*
[45] Ulrike Felt, *Knowledge claims and forms….*
[46] *Ibidem.*

Fahlquist and Roeser also observe that "[c]ommunication about nuclear risks is treacherous territory [...] requiring not only considerations about effectiveness, but also about ethical legitimacy."[47] Experts often restore their ethos post-factum by reverting to hindsight. This process is based on the technocratic belief that, if the proper information were available in an emergency situation, appropriate solutions could undoubtedly be found.[48]

In its first historical phase, which started approximately after the Chernobyl accident from 1986, nuclear risk communication was regarded as one type of education whereby the public was to be informed about risk estimates under the assumptions of a deficit model being at work in the public's understanding of science.[49] In this phase models like the social amplification of risk (Kasperson, *et al*., 1988) were interesting presumably because they treated risk communication as an exact science. Ulrich Beck's redefinition of risk as a global currency[50] paved the way for more socially-sensitive approaches to understanding and modeling nuclear risk communication.

1.1.5. Maps, Emergency Plans, and Improvisation for Preparedness

Radioactivity maps are central technical artifacts used to prepare for and manage nuclear emergencies. They are visually compelling, color-coded, geospatially-bounded representations of the risks entailed by airborne radioactive particles released during nuclear accidents. Such maps have repeatedly been the subject of controversies in the wake of the Fukushima accident.[51] Plantin provides a detailed analysis of the ways in which online maps facilitated a certain mode of participation in assessing the radiation situation after the tsunami and the consequent nuclear disaster at Fukushima.[52] Several maps created by amateurs attempting to locate radiation appeared online, primarily based on the Google Maps API. These maps represented a complement for that which could not be accomplished by amateurs using other participatory media platforms such as Twitter and blogs in a general sentiment of distrust in the government and lack of standards for amateur monitoring. These maps aggregated multiple sources of data and were used to verify government measures as well as to correlate the results with alternative and crowd-sourced data. In this context, amateurs decided not to rely only on the information distributed by the government and to produce new data for verifying official radioactivity measurements. Plantin notes that two types of participation became evident during these mapping activities: (1) participation as data extraction, where laypersons either monitored data using Geiger counters or extracted and republished data from official websites and (2) participation as data aggregation, where maps where used to display and compare radiation

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[47] J.Fahlquist, S. Roeser, *Nuclear energy, responsible risk communication and moral emotions: a three level framework* in "Journal of Risk Research", vol.18(3), 2015, pp. 333-346.
[48] Ulrike Felt, *Knowledge claims and forms….*
[49] J.Fahlquist, S. Roeser, *op.cit.*, pp. 333-346
[50] See Ulrich Beck, *op.cit.*
[51] Jean Cristophe Plantin, *The politics of mapping platforms: participatory radiation mapping after the Fukushima Daiichi disaster* in "Media, Culture & Society", vol. 37(6), 2015, pp. 904-921.
[52] *Ibidem.*

measurements from official or crowd-sourced venues. The results of this participatory work by amateurs complemented the shortcomings of TEPCO's and the Japanese government's own efforts to cope with the lack of official radiation readings. While TEPCO did not provide real-time monitoring, in Japan radiation monitoring is facilitated by a sensor network called *System for Prediction of Environmental Emergency Dose Information* (SPEEDI). However, the sensors in the Miagy and Fukushima prefectures were knocked down by the tsunami, which prevented them from reporting data. Moreover, the website of SPEEDI was barely accessible in the first days after the tsunami due to heavy load.

In this difficult context, Plantin notes, the New York Times reported in an article from August 8, 2011 that the Ministry of Education, Culture, Sports, Science and Technology (MEXT) did not communicate the SPEEDI data do the government, giving the poor quality of the measurements as a pretext. The same article also criticised the lack of experience by government agencies using the complex SPEEDI data and the fact that the government was also suspected of withholding information since the beginning of events. The official readings which were eventually published online were in a read-only and not machine-readable format and used a multitude of norms for radiation measurements, which generated a heterogeneous panel of readings. As a reaction to this situation, individuals attempted to address this lack of information by creating their own digital maps. In the end, these maps were created by multiple actors, including individuals as well as for-profit and non-profit organizations. Some maps were created by web-industry companies (*e.g.* Yahoo!), designers, scientists, hackers, and anonymous individuals.

In practical terms, the first solution to address the lack of available data was to monitor the radiation levels from scratch using Geiger counters. Several individuals and organisations possessing Geiger counters published real-time readings on their websites. As Geiger counters quickly became out of stock in stores and online, people willing to monitor the levels of radiation had to find alternative means to do so, such as creating do-it-yourself (DIY) measurement devices – something that was harshly criticized by radiation protection efforts around the world. The voluntary body Safecast played a key role in these monitoring efforts. They worked closely with the Tokyo Hackerspace to create DIY Geiger counters that would eventually scale up to create an independent radiation-sensing network. In addition to a fixed sensor network, they produced radiation readings with local teams on foot and by car in order to create an exhaustive map and to regularly update the readings. Another way in which individuals located data was by extracting the published official readings in order to generate structured data files. Such activities are more commonly referred to as "web scraping."

For most people, an urge to prepare seems to be the reflexive response to risk situations. Consequences of the lack of preparedness are depicted in countless musical, literary, and other cultural accounts of disastrous events. However, the responsibility for organizing preparedness in society and the ways in which preparedness is to be enacted before, during, and after a risk event are still subjects of controversy and periodic reconsideration. While most nuclear emergency managers argue that preparedness should be based on detailed planning and orchestration,[53] some scholars suggest that

[53] Manpreet Sethi, *What if there's a next time? Preparedness after Chernobyl and Fukushima - an Indian response* in "Bulletin of the Atomic Scientists," vol. 72(4), 2016, pp. 262-264.

preparedness should leave room for improvisation.[54] Within a single paragraph, which talks about the ways in which the negative perceptions of nuclear power can be addressed in future, Sethi – a senior fellow of the Indian Council of Social Science Research – reveals two distinct sociotechnical imaginaries (continuous improvement and preparedness – discussed in chapters 4, 5, and 6 of this work); an instantiation of the deficit model (improvements can be communicated to the public); and one post-Fukushima narrative of the nuclear (learning from disasters):

> "There are three primary ways to address this issue. First, the safety of reactor operations can continually be improved. Second, better emergency preparedness and response can be instituted. Third, improvements on both fronts can be communicated to the public. Both the Chernobyl and Fukushima disasters rendered important lessons along all three of these dimensions – but the focus here is improved disaster preparedness since the 1980s"[55]

2. An Alternative Nuclear Risk Model

We present an alternative model of nuclear risk perception that challenges the social amplification of risk model.[56] This alternative model is based on the observation that the risks of radioactivity undergo a series of transmutations, which closely follow the decay chain of radioactive nuclides. Unlike the social amplification of risk model, which assumes that risk is amplified by different agencies *(e.g.*, the media, government agencies, etc.) at different stages in the risk communication process, the proposed model builds upon a phenomenological basis of the same process. The proposed model assumes that there exists an indirect material relationship between radioactive nuclides as risk agents and nuclear experts or laypersons as risk perceivers. The perceived risk is then the product of the indirect relationships with radioactivity maintained by different actors (*i.e.*, nuclear experts, decision makers, and laypersons) in very different ways, which only become direct, and for some even material, when nuclear accidents occur. Hecht's "nuclear janitors"[57] and the victims of evacuations[58] are the most notable exponents of those who have unwillingly experienced the direct material relationship with radioactivity. During the normal operation of NPPs, the indirect relationship of most experts and laypersons with "the nuclear" is mediated by different nuclear organizations. In this context, conscious and unconscious practices of collective and individual remembrance of different catastrophic events from the past also plays a major role.

What the TMI and Chernobyl accidents revealed, among many other things, is that, as radioactivity reaches farther out of the reactor containment building, the risks

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[54] Sonya Schmid, *Chernobyl, Fukushima, and preparedness for a "next one"*, in https://thebulletin.org/roundtable/chernobyl-fukushima-and-preparedness-for-a-next-one/ [Accessed 1 6 2016].
[55] Manpreet Sethi, *op.cit.*, p.262.
[56] See R.E. Kasperson *et al*., *op.cit.*
[57] Gabrielle Hecht, *Nuclear Janitors: Contract Workers at the Fukushima Reactors and Beyond* in "Asia-Pacific Journal: Japan Focus", vol.11(2), 2013, pp.1-13
[58] See Ulrike Felt, *Living a Real-World Experiment: Post….*

associated with it undergo a process of transmutation, which is somewhat analogous to the decay chain of radioactive nuclides. The byproducts of an uncontrolled chain of radioactive decay are unstable radionuclides which are invisible to the eye, airborne, weather-driven, and terrifying for people and the mass media. When it happens outside the controlled environment of a nuclear reactors, this transformation implies an incommensurable amount of uncertainty. The following simplified radioactive release phases illustrate the transmutation of risk and radioactivity as it reaches out of expert control due to increasing uncertainty:

1. *There is a certain risk for a reactor incident to lead to a nuclear accident.*
   - The assessment of the probability for a nuclear accident to occur bears a high level of uncertainty and methods for computing it include subjective probabilities.[59]

2. *During a nuclear accident, there is a certain risk for radioactive materials to be released into the environment.*
   - The assessment of the amount and types of released materials bears a high level of uncertainty because it depends on the exact assessment of the level of technical failure inside the reactor and the safety systems.[60]

3. *Provided that radioactive materials have been released into the environment, there is a certain risk for them to reach certain populated areas in a certain amount of time.*
   - Here, the uncertainty is entailed by the need for assessing the meteorological dispersion conditions, such as wind speed and direction, temperature, turbulence conditions, etc. As a rule of thumb, the more time passes and more measurement data become available, the more accurate dose projections will be. However, most of the times, accurate dose projections can only be performed months or even years after the initial release of radioactive materials into the environment.

4. *Provided that radioactive materials have reached a populated area, there is a certain risk of exposure at different levels (**i.e.**, some people may be in their houses, other outside on the streets or in their cars).*
   - Here, the uncertainty arises from the unpredictable behavior of people, which is likely to also depend on the degree to which they are informed about the radiological situation.

5. *Finally, there is a certain risk of developing cancer after having received a high radiation dose.*

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[59] C.R. Miller, *The presumptions of expertise: The role of ethos in risk analysis* in "Configurations", vol.11(2), 2003, pp. 163-202.

[60] W. Scheuermann *et al.*, *Modeling consequences of the accident at Fukushima* in "International Journal for Nuclear Power", vol.56(6), 2011, pp. 325-331.

In radiation protection terms, given a certain dose of radiation there is a probability *p* for *1* in *Y* people to develop cancer. If *p = 1* and *Y = 1000,* this does not necessarily mean that 1 person will definitely develop cancer and all the other ones will not. Perhaps 10 will develop cancer or none. Probabilities only add up when referring to an entire population, not a limited sample. So, there is uncertainty involved in this step as well, which is usually quantified by the statistical confidence level.

There are at least three remarkable things about this risk transmutation process:

- At a physical level, going from an earlier to a later stage *(i.e.*, point 1 to point 5 in the listing above) makes risk become more obscure and diffuse to the analyst. This leads to more uncertainty when attempting to quantify it.
- From an organizational and social point of view, going from an earlier to a later stage in the decay chain, risk tends to exit the boundaries of organization, reaching farther out into the public realm and the environment. This makes later stage risks much harder to conceal from public attention than early stage risks.
- At social level, the effects of a realized later-stage risk, such as a person becoming ill from exposure to radioactivity, have a much greater cultural impact upon people than early stage risks, such as the failure of a safety-critical system in a reactor because people can more easily relate to illness than to any other technicality of a nuclear power plant.

These three observations suggest that in the process described above, as soon as radioactive materials are being accidentally released into the environment, technical risks – such as a valve not working properly – transmute into social and individual risks – such as communities facing evacuation and individuals becoming ill from radioactivity. Due to the phenomenon of transmutation, the risks of radioactivity are not treatable using the same class of methods at every stage of the process illustrated before[61] which has led to major disagreements between risk perceptions by nuclear experts and laypersons in the past. In this context, emergency preparedness is based on what Jasanoff calls "technologies of hubris"[62], that promise command and control over technology.[63] Each of these technologies is tailored for one of the stages of the risk transmutation process sketched above without taking into consideration the sociotechnical phenomena that facilitate the transmutation of one type of risk into another. For this reason, the technologies of nuclear emergency preparedness, including radioactivity maps and other heuristic dose estimation methods, contribute to what Beck has identified as "organized irresponsibility" in managing nuclear risk.[64] This form of organized irresponsibility breeds disagreements between risk perceptions by nuclear experts and laypersons. Discrepancies also occur in the ways in which people exposed to nuclear organizational

[61] Jasanoff makes a similar observation with respect to technical risk management more generally in Sheila Jasanoff, *Technologies of humility:* p. 224.
[62] *Ibidem* pp. 223-244.
[63] See Ulrike Felt, *Living a Real-World Experiment: Post-Fukushima.*.
[64] See Ulrich Beck, *op.cit.*

culture (*e.g.*, nuclear scientists and engineers) and people living in different local communities and cultures maintain their complex indirect relationship with "the nuclear."

3. Radiation Maps – Technologies of Hubris or Humility?

Radiation maps represent key non-human experts within the imaginary of preparedness. Their primary purpose is to help protect people and the environment against radioactive contamination. Yet, paradoxically, considering that radioactivity dispersion forecasts represent compelling visualizations of risk, the seemingly humble purpose of DSNE systems appears to be achieved by using what Jasanoff has termed *technologies of hubris*:

> "To reassure the public, and to keep the wheels of science and industry turning, governments have developed a series of predictive methods (*e.g.*, risk assessment, cost-benefit analysis, climate modelling) that are designed, on the whole, to facilitate management and control, even in areas of high uncertainty."[65]

The risk assessment methods embedded in DSNE systems require constant training and rehearsal in order to complement predictions by non-human experts with human expert opinion and interpretation. When rehearsing emergency response protocols radioprotection experts are constantly concerned with the defining question of what Jasanoff has termed "technologies of humility": *Who will be hurt and how can we know?* The technologies used by the members of the techno scientific community formed around DSNE systems aimed at answering this question, however, appear to be based on "[p]redictive methods [which] focus on the known at the expense of the unknown, producing overconfidence in the accuracy and completeness of the pictures they produce."[66] The multitude of atmospheric dispersion forecasts of the Fukushima radioactive plume published in the mass media and different official reports convey an image of completeness and accuracy, while differing to a great extent both qualitatively and quantitatively from one report to another. Whereas it is in the nature of individual atmospheric dispersion forecasts to leave the impression of completeness and accuracy, the comparison of different forecasts produced by different systems reveal a tendency for overconfidence in models and modeling practice and artificial consensus based on statistical aggregation. Dose projections rely on advanced statistics to narrow down the space of possible decisions that ultimately need to be taken by human actors. DSNE systems exhibit such tendencies at the expense of a participatory approach which, according to Jasanoff, would make for a more humble and possibly more effective approach to solving difficult sociotechnical problems.

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[65] Sheila Jasanoff, *Technologies of humility…*, p. 238.
[66] *Ibidem*, p. 239.

4. Outlook

Up until now, Perrow's "normal accidents" prophecy has proven correct. Every few decades a new accident shatters the trust in nuclear technology. The latest accident at Fukushima happened in an era dominated by computer technologies, notably the Internet, and was caused by a series of techno-natural interactions never imagined before by reactor designers and nuclear safety experts. Simulation-based dose projections have played a significant role during the accident, while not providing clear answers to decision makers. The mass media pushed dose projections (or radiation maps) into the public realm. These visualizations of radiological risk reached an audience perhaps much broader than their creators had ever imagined. The "innovative" character of the Fukushima accident calls for rethinking current risk generation, propagation, and communication models, such as the well-known "social amplification of risk" model, in the light of new "techno-natural" actors and nuclear preparedness regimes affecting the production and communication of risk. In this sense, we proposed an alternative model for conceptualizing nuclear risk focused on the description of the different stages at which risk needs to be assessed, prevented, and mitigated. Our risk transmutation model is primarily aimed at explicating the different socio-technical boundaries at which technical risks are turned into other forms of risk, which are no longer in the control of the organizations generating them. Thinking of risk in terms of transmutation – that is, a process by which one type or risk is qualitatively transformed into another one – rather than amplification constitutes a thread worth following in nuclear risk research in the post-Fukushima era.

The role of DSNE systems in nuclear emergency management is also likely to increase with every future nuclear accident. Due to the increasing digitalization of society, more weight is likely to be put on globally-networked software-based early warning systems. The current trend in nuclear preparedness is characterized by a gradual movement from locally-flavored and loosely integrated practices towards globally integrated and coordinated systems for nuclear emergency response. In this context, by "partnering with the public"[67] and possibly more emphasis put on improvisation rather than trained preparedness,[68] people could be guided directly and more effectively towards safety in a nuclear emergency. A culture of improvisation, as Sonja Schmid notes,[69] may indeed improve on well trained "reliable" emergency response plans. But is improvisation itself a trained ability or an innate talent? [70] And can it be combined with the local expertise of ordinary citizens? These and other open questions need to be answered in order to leverage the benefits of improvisation and public participation in nuclear emergency management. The practices of nuclear preparedness can also be extended by incorporating lay expertise as an additional epistemic source. Kinsella's model of public expertise could be used to convey the lay expertise of interested citizens to the nuclear emergency response task forces on the basis of a shared understanding of the issues at

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[67] Manpreet Sethi, *Partnering with the public for better preparedness*, in https://thebulletin.org/roundtable/chernobyl-fukushima-and-preparedness-for-a-next-one/ [Accessed 1 6 2016].
[68] See Sonya Schmid, *op.cit.*
[69] *Ibidem.*
[70] Japanese Zen masters argue that every talent can be trained if the apprentice follows the Zen way (Hall, 1983).

stake. Also, these exchanges could be facilitated by involving members of the public in the regular trainings and drills as well as in designing more flexible decision-making processes, which should also take into consideration lay expertise.

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