universität
wien

MASTERARBEIT / MASTER’S THESIS

Titel der Masterarbeit / Title of the Master‘s Thesis

„Emergency Response in Action: Expertise, Imaginaries, and Communication in Nuclear Crisis“

verfasst von / submitted by

Tudor Ionescu

angestrebter akademischer Grad / in partial fulfilment of the requirements for the degree of

Master of Arts (MA)

Wien, 2017

Studienkennzahl lt. Studienblatt / degree programme code as it appears on the student record sheet:	A 066 906
Studienrichtung lt. Studienblatt / degree programme as it appears on the student record sheet:	Masterstudium Science-Technology-Society
Betreut von / Supervisor:	Univ. Prof. Dr. Ulrike Felt

Acknowledgements

First and foremost I would like to thank Univ.-Prof. Dr. Ulrike Felt for her excellent supervision of my thesis and her patience with me taking so long to write it. Her feedback and ideas helped me to transform a text into a master thesis. I would also like to thank all the people from the Department of Science and Technology Studies for accepting and guiding me through this challenging and interesting master program.

Further, I would like to express my deepest gratitude to the people at the IKE, notably Walter Scheuermann, for providing me with valuable insights regarding the workings of the ABR-KFÜ collective. Last but not least, I would like to thank my friends and family for supporting me with this change of track in my lifelong course of studies.

Contents

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 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 (Felt, 2014) 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 (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2004). 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 (Hand, et al., 2001).

Nuclear accidents have inspired scholars to create an entirely new field of research. The very term “risk” seems to be an eternal buzzword that will never allow a unique definition. Event 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 (Aven & Renn, 2015). 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 (Sturgis & Allum, 2004). 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-benefit analysis, climate modelling) that are designed, on the whole, to facilitate management and control, even in areas of high uncertainty” (Jasanoff, 2003, p. 238).

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 (Jasanoff & Kim, 2009), 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 (Felt, 2016) 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.

1.1 From Controlling to Preparing for Radiological Risk

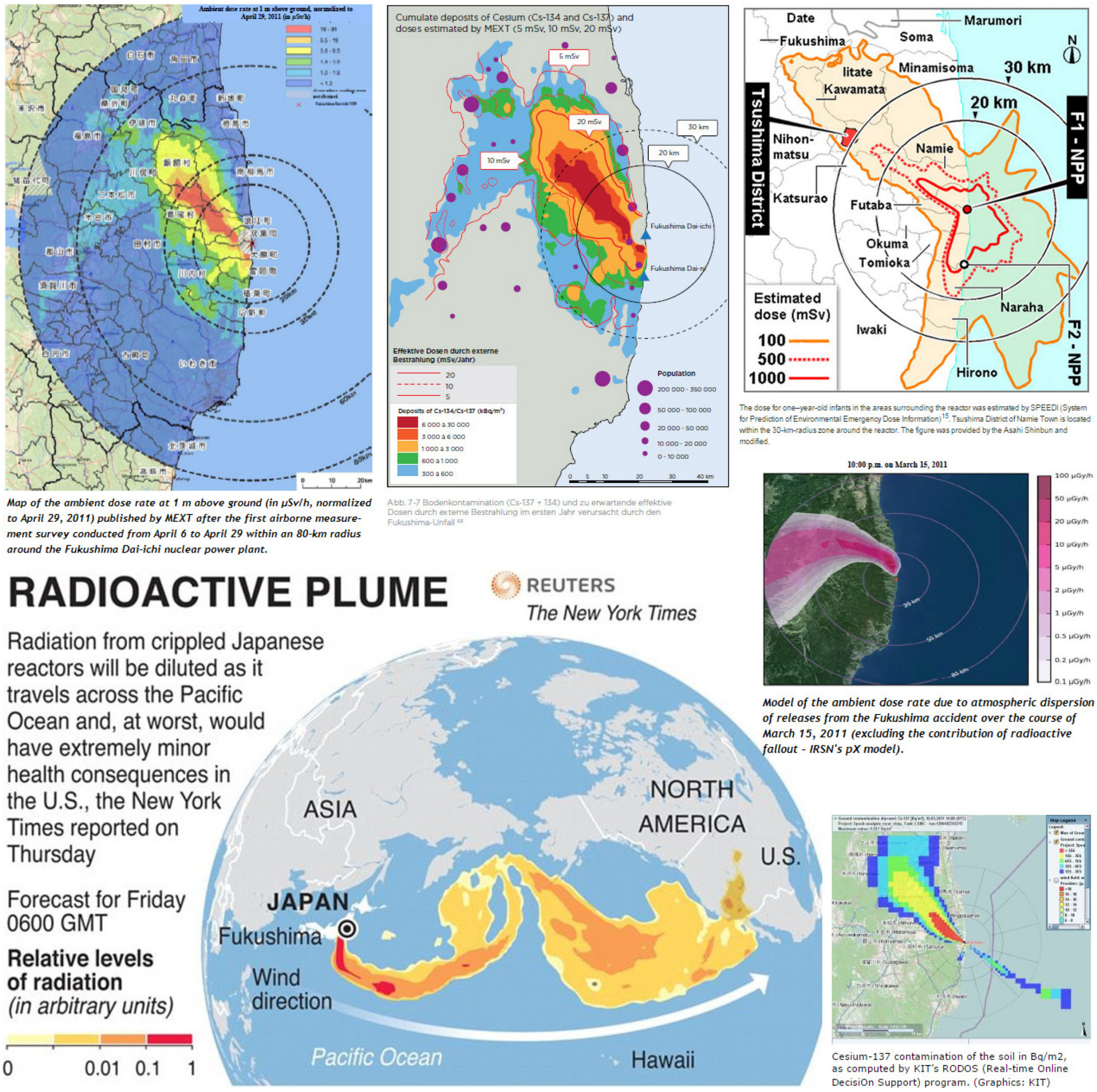
As it became clear at the political level that in a nuclear emergency radioactivity and the risks associated with it cannot effectively be controlled, in some countries (including Germany) the focus shifted from *controlling* nuclear risk to *preparing* for an eventual accident. The advent of powerful computers during the 1980s enabled the development of computer programs for atmospheric dispersion forecasting and dose estimations. 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 (Riccio, et al., 2007), discretization, and other inherent errors entailed by the numerical schemes, which implement the physical models (Christopher, 2005); as well as pure coding errors (Ionescu & Scheuermann, 2016).

The uncertainties embedded in atmospheric dispersion forecasts and dose estimations 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 estimations 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[1]; and (6) The *New York Times* reproduced by Reuters in arbitrary units.

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.

---

[1] http://www.kit.edu/kit/english/pi_2012_9010.php (as of 23.12.2014)



Map of the ambient dose rate at 1 m above ground (in µSv/h, normalized to April 29, 2011) published by MEXT after the first airborne measurement survey conducted from April 6 to April 29 within an 80-km radius around the Fukushima Dai-ichi nuclear power plant.

Abb. 7-7 Bodenkontamination (Cs-137 + 134) und zu erwartende effektive Dosen durch externe Bestrahlung im ersten Jahr verursacht durch den Fukushima-Unfall[63]

The dose for one–year-old infants in the areas surrounding the reactor was estimated by SPEEDI (System for Prediction of Environmental Emergency Dose Information)[15]. Tsushima District of Namie Town is located within the 30-km-radius zone around the reactor. The figure was provided by the Asahi Shinbun and modified.

Model of the ambient dose rate due to atmospheric dispersion of releases from the Fukushima accident over the course of March 15, 2011 (excluding the contribution of radioactive fallout - IRSN's pX model).

Cesium-137 contamination of the soil in Bq/m2, as computed by KIT's RODOS (Real-time Online DecisiOn Support) program. (Graphics: KIT)

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

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.

The present work will take a closer look at the ABR-KFÜ (*Ausbreitungsrechnung für die Kernreaktorferüberwachung*) DSNE system used in Germany by the state government of Baden-Württemberg and the thought collectives formed around the development and use of DSNE systems more generally. The day to day work of the members of these thought collectives revolves around what I have termed the *sociotechnical imaginary of preparedness.* This imaginary enables them to create different *what-if* scenarios and emergency management plans, which are rehearsed in different settings, such as regular drills and trainings as well as in public presentations and at scientific conferences. DSNE systems play an important non-human expert role in the imaginary of preparedness by providing experts, politicians, and laypersons with visual representations of risks in the form of encoded radioactivity maps. These maps are used in the aftermath of nuclear accidents to help decision makers to determine the type and the application area of protective countermeasures. The present work thus closes a gap between the STS literature on the well-established imaginaries of the nuclear age, such as the imaginary of containment (Jasanoff & Kim, 2009), and the real world experiment of nuclear displacement and cleanup currently being conducted at the Fukushima accident site (Felt, 2016), which are representative of the post-Fukushima sociotechnical imaginaries of the nuclear age.

In the following, I am going to show how the sociotechnical imaginary of preparedness emerged by means of an evolutionary process from other imaginaries of the nuclear age, notably the imaginary of containment. To this end I will consider three case studies, one of them focused around the so called "inherently safe" modular reactor—a paradigmatic example of the imaginary of containment—and two of them on different DSNE systems and the practices that emerged around them by the example of a small community of nuclear scientists—a group of which I counted myself as a member at some point. The thesis is structured as follows:

- The remainder of Chapter 1 provides a background to DSNE systems and their use in Germany.
- Chapter 2 presents a state of the art survey of the debates around the issue of preparedness in nuclear emergencies and the related imaginaries from the STS literature.
- Chapter 3 introduces the theoretical framework used for the analysis in this work as well as the research questions, methods, and materials used in the analysis.
- Chapters 4 and 5 present the results of a detailed analysis of the materials by means of the methods, theories, and sensitizing concepts summarized in chapter 3.
- Chapter 6 concludes the work.

1.2 Background on Decision-Support Systems for Nuclear Emergency Management: The Case of the ABR-KFÜ System

The operation of a nuclear power plant entails risks that cannot be solely accounted for by technical means. When local risks (e.g., location-specific natural hazards) or residual risks (i.e., hazards that are unknown or have a very low likelihood of becoming a threat and are thus left aside in the design of safety systems) materialize, accidents can occur. The first line of defense in such events is provided by the safety and recovery systems of the plant. In term, these can fail for different reasons themselves. For example, the diesel power generators of the Fukushima reactors, which are essential components of the active reactor safety system, were flooded with seawater brought in by the tsunami wave. This reduced the cooling capacity of the active safety systems of the reactors, which lead to a chain of incidents and failures and ultimately to the release of radioactive materials into the environment.

In case of important accidental releases of radioactive materials into the atmosphere, authorities are generally expected to take protective countermeasures, such as distributing iodine tablets and/or evacuate the population as soon as radiation levels reach certain threshold values. The exact processes and resources to be used to this end vary from one country to another, with some countries having very strict and well-defined procedures and organizational structures as well as especially trained personnel for such situations; while other countries relying on rather loosely defined procedures and improvisation. Germany is one of the countries where rather strict processes for managing nuclear emergencies are in place, for the execution of which, in the immediate phase of an accident, the state governments (*Landesregierungen*) are in charge. While being informed from the very beginning of an accident, as soon as the radioactive threat crosses the state border, the federal government also becomes involved in managing the nuclear emergency. In the case of an accidental release of radioactive materials, crisis task forces assigned by the state governments are called to estimate which sector(s) of the area surrounding the accident site are more severely affected by radiation. Here, atmospheric dispersion forecasts play an important role. Task force members are also required to recommend countermeasures, which are ultimately approved by the state's Prime Minister *(Ministerpräsident)*. These decisions are taken in consideration of the fact that all resources are limited and that there exists a hard time constraint for countermeasures to be taken. In these circumstances, too conservative decision may lead to costly and unnecessary actions. Conversely, rudimentary or simply erroneous countermeasures may not effectively prevent contamination of people, the environment, and livestock. In political terms these extreme cases can be regarded as issues of accountability and responsibility having political as well as possibly professional and legal consequences.

Prior to the introduction of computer codes, experts from the nuclear emergency management task forces used to carry out dispersion calculations by hand using the Gaussian plume dispersion model, which is also sketched in the official German guideline for performing such calculations (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2004). Yet after the Chernobyl accident in 1986, which coincided with the advent of more powerful and inexpensive personal computers, computer-based simulations largely replaced the manual calculations. In 1989, the first version of the ABR-KFÜ system was introduced in the German state of Baden-Württemberg. The system was developed by the Institute of Nuclear Technology and Energy Systems of the University of Stuttgart under the aegis of Fritz Schmidt, professor of computer engineering and then head of the institute's Knowledge Engineering department. Since it was very innovative for that time, it reached the international spotlight (Figure 2).

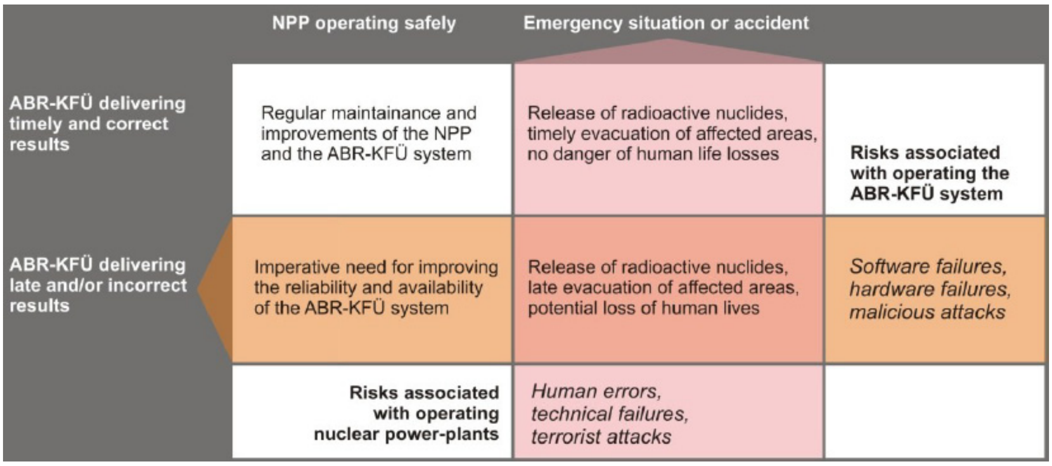
Figure 2 – 1989: Using the ABR-KFÜ system and measurement emission and meteorological data, IKE experts presented Mihail Gorbachev (then president of the UDSSR) a simulation of the atmospheric dispersion of radioactive materials from the Chernobyl accident site. The person next to the main screen is Dr. Walter Scheurmann who has been interviewed as part of the present work.

Decision-support systems for nuclear emergency management were introduced in Germany after the Chernobyl accident. Post factum atmospheric dispersion simulations revealed significant fallout of airborne radioactive materials in Germany, which, according to radiation protection experts, must have originated from the Chernobyl accident site (Ebermann & Junkert, 2011). As a consequence, the Federal Agency for Radiological Protection (BfS – *Bundesamt für Strahlenschutz*) was founded, whose main mission was to coordinate nationwide actions concerning radioactivity measurements, atmospheric dispersion forecasts, and dose estimations. As a result of these efforts, the IMIS (*Integriertes Mess-und Informationssystem zur Überwachung der Umweltradioaktivität*) integrated measurement and information system for monitored environmental radioactivity was introduced. The realization of the IMIS system was also supported by 20 additional institutions nationwide.

According to the BfS report on the Chernobyl accident, the day-to-day task of the IMIS system was (and still is) to continuously monitor the environment to detect even slight changes in environmental radioactivity nationwide reliably and fast, as well as to be able to detect long-term trends. IMIS is primarily considered an instrument of emergency preparedness by creating the appropriate bases for decisions about countermeasures to the end of protecting people and the environment in case of an incident. This is to be achieved by the IMIS system by

- Gathering information about the radioactive contamination of the environment in case of an incident;
- Reliably assessing the resulting radiation exposure for humans;
- Quickly, clearly, and simultaneously informing all parties concerned with taking countermeasures about the radiological situation.

The IMIS system was introduced in response to events that made certain risks evident (simply referred to as *risk events* in literature). The nuclear industry, which has always been a highly politicized strategic branch of a country's socio-economic system, was forced to acknowledge those risks in the wake of irrefutable evidence and, as a consequence, had to negotiate a way to continue its operations. The result of these negotiations was that the nuclear industry had to acknowledge the risk of accidental releases of radioactive materials into the environment, while delegating its management to the government-led IMIS program. Figure 3 depicts the risk delegation scheme according to which DSNE systems operate. During normal operation of the monitored NPPs, developers of DSNE systems are mainly concerned with the continuous improvement of the system. In case of an emergency, the system becomes an essential tool for preventing any harmful effects of radiation primarily upon humans. In this context, the IMIS system can be regarded as a subsystem for managing the risk of radioactive releases, which has become an inherent part of the greater technical system of nuclear power production, while not actually going to the root of the problem. Before the German nuclear phase out decision from 2011, the industry was required to financially support the IMIS as well as other decision-support and environmental radiation monitored systems operated by the local governments of the different German federal states.



	NPP operating safely	Emergency situation or accident	
ABR-KFÜ delivering timely and correct results	Regular maintainance and improvements of the NPP and the ABR-KFÜ system	Release of radioactive nuclides, timely evacuation of affected areas, no danger of human life losses	**Risks associated with operating the ABR-KFÜ system**
ABR-KFÜ delivering late and/or incorrect results	Imperative need for improving the reliability and availability of the ABR-KFÜ system	Release of radioactive nuclides, late evacuation of affected areas, potential loss of human lives	*Software failures, hardware failures, malicious attacks*
	Risks associated with operating nuclear power-plants	*Human errors, technical failures, terrorist attacks*	

Figure 3 – Risks associated with operating NPPs and DSNE systems and potential consequences.

Real measurement data are essential in validating the results of DSNE systems and data about human-caused environmental radioactivity are sparse and difficult to obtain. That is because experiments would involve actual releases of radioactive materials. For this reason, the information and data from accidents, such as the one in Fukushima, are used to simulation models.

The introduction of the IMIS system came in the wake of the moratorium on nuclear power from 1986, which stated that existing nuclear power plants were allowed to continue operation but no new ones were to be built. The nuclear industry had to also contribute both financially and operatively (i.e., by providing the system with measurement data from inside the nuclear sites) to the implementation and maintenance of the IMIS system, which operated at federal level, as well as of several state-level systems, such as the ABR-KFÜ, which were coordinated by local governments and research institutes.

Decision-support systems for nuclear emergency management (henceforth referred to as DSNE systems) are able to simulate the atmospheric dispersion of radioactive materials using input data from various sources, including nuclear power-plants, weather forecast centers, and radiological measurement stations. Figure 4 shows the architecture of the modern ABR-KFÜ system. In the left hand side of the picture, the various data sources are depicted. These data are collected in real time and stored in a central database. The central part of the picture depicts the component that generates the dispersion forecasts and dose estimations using a workflow of scientific simulation programs. The right hand side of the picture shows the users of the system, comprising the operators of nuclear power plants, local authorities, and government agencies.

The ABR-KFÜ was also used to forecast the dispersion of radioactive pollutants from the damaged Fukushima reactors. IKE experts used data provided by the German Society for Facility and Reactor Safety (GRS), the German Agency for Radiological Protection (BfS), Japan’s Nuclear and Industrial Safety Agency (NISA), Tokyo Electric Power Company (TEPCO), and the International Atomic Energy Agency (IAEA) for evaluating the possible radiological consequences of the accident. The Baden-Württemberg state government requested a dispersion simulation for the Fukushima-Daiichi site to forecast where the radioactive plume was headed and what dose rate affected populations would receive. In the lack of accurate information about the type and quantity of released radioactive pollutants, the experts were given license to make assumptions as necessary based on their experience and expertise. Hereby, the main problem was back-calculating the inventory of radioactive nuclides that would be released under various failure conditions, such as a leak in the reactor vessel, based on the very sparse available measurement data. Nevertheless, groups from different German institutes came up with similar predictions, which were judged to be realistic by GRS experts. These results were later published in the International Journal for Nuclear Power (Scheuermann, et al., 2011).

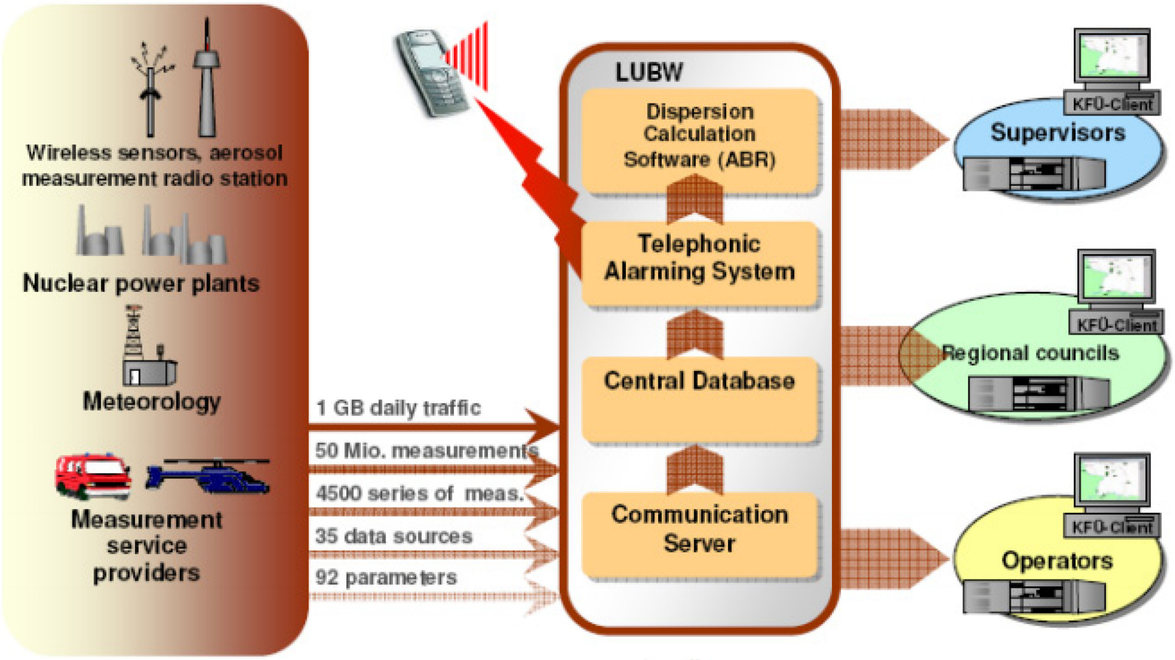


Figure 4 – System architecture of the latest version of the ABR-KFÜ system *(Wilbois, et al., 2013)*.

Simulation codes represent the heart of a DSNE system. They incorporate physical models assembling them into workflows which forecast the atmospheric dispersion of radioactive materials and estimate the radioactivity doses that the population in the affected areas might be exposed to. The simulation-based dispersion forecasting is only the core of an entire assemblage of tools, processes, expertise, regulatory guidelines, people, and data used to aid decision makers in taking appropriate countermeasures in nuclear emergencies. Figure 5 illustrates a tentative division of this assemblage into different stages (or layers). In consideration of the official German guideline for radiological protection in nuclear emergencies (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2004), from the bottom up we can distinguish at least the following five epistemic layers that find themselves in a relationship of subordination:

- **Dispersion models** are physical and mathematical models (numerical schemes) of different meteorological, fluid-mechanical, and radiological phenomena which need to be taken into account when performing dispersion and dose forecasts. Physical models have raised numerous epistemic issues motivated by the inherent uncertainty and limited possibilities for validation that come along with their development. In a safety-relevant context, such as nuclear emergency management, these issues contribute to a negative recommendation in regulatory guidelines by the IAEA concerning the use of these models in serious cases[2].

- **Dispersion simulation codes** are pieces of software implementing dispersion models. As a consequence, in order for the codes to be reliable they must be tested according to the

---

[2] https://www.iaea.org/ns/tutorials/regcontrol/emerg/emerg78.htm

requirements of the context of use, whereby safety-critical context require the strictest development and testing processes. This is seldom the case when it comes to simulation codes, which are usually developed by scientists whose concerns are scientific rather than related to the quality, reliability, and trustworthiness of the software (Ionescu & Scheuermann, 2016a; Ionescu & Scheuermann, 2016b). One method of improving the reliability of dispersion forecasts is to use an ensemble of simulation codes rather than a single one and provide a "middle-way" result (Galmarini, et al., 2004).

- **Forecast visualizations:** Dispersion simulation results are usually visualized as color-codified layers over topographical maps. The colors reflect the concentration of radioactive materials or the potential dose that persons in affected areas are exposed to. In some sense, visualizations of dispersion forecasts may be regarded as visual representations of radiological risk. When such visualizations are presented by the mass-media, they are likely to trigger emotional reactions of with readers and viewers. Airborne radioactive materials are often perceived as an invisible and seamless threat able to reach far away places. However, there is a high level of uncertainty related to the visualization of any kind of data. In the case of atmospheric dispersion forecasts, different scales and color schemes may influence risk perceptions on the part of laypersons.

- **Decisions about countermeasures:** at this stage a nuclear emergency has occurred and in countries with nuclear power an appointed crisis task force is summoned to assess the situation and decide upon appropriate countermeasures. In Germany, this task force receives dispersion forecasts automatically from a DSNE system that is in place long before the crisis occurs. Task force members have to take dispersion forecasts into consideration when deciding upon the appropriate countermeasures. One can assume that, depending on the severity of the situation, task force members will have a hard time figuring out which areas need immediate countermeasures based on the available information, which also includes dispersion forecasts. In these situations, uncertainties arise from all the previously discussed layers. The trustworthiness of dispersion forecasts is a function of the availability and quality of measured radiological and meteorological data as well as of the perceived reliability of the dispersion simulation codes. Untrustworthy results may lead to disagreement among the members of the task force while dispersion forecasts that are perceived as being trustworthy and plausible may still be wrong and lead to erroneous decisions.

- **Accountability for decisions:** this is the final stage in nuclear emergency management. As of the widely mediatized Three Miles Island accident, this stage begins days after the onset of the crisis, as soon as media and the public start putting pressure on the officials in charge of managing the crisis and may last for months or years. Post factum analyses based on richer measurement data may reveal that countermeasures taken at that time have been inappropriate, with accountable officials facing political consequences. Conversely, the countermeasures may have been too conservative, in which case the responsible officials are held accountable for excessive and unjustified spending.

- **Crosscutting concerns:** There are at least three cross-cutting concerns that must be dealt with carefully at each stage: interpreting and fulfilling regulatory guidelines, combining and putting different types of human and non-human expertise to work effectively in the decisional process, and assessing the reliability of radiological and meteorological measurement data.

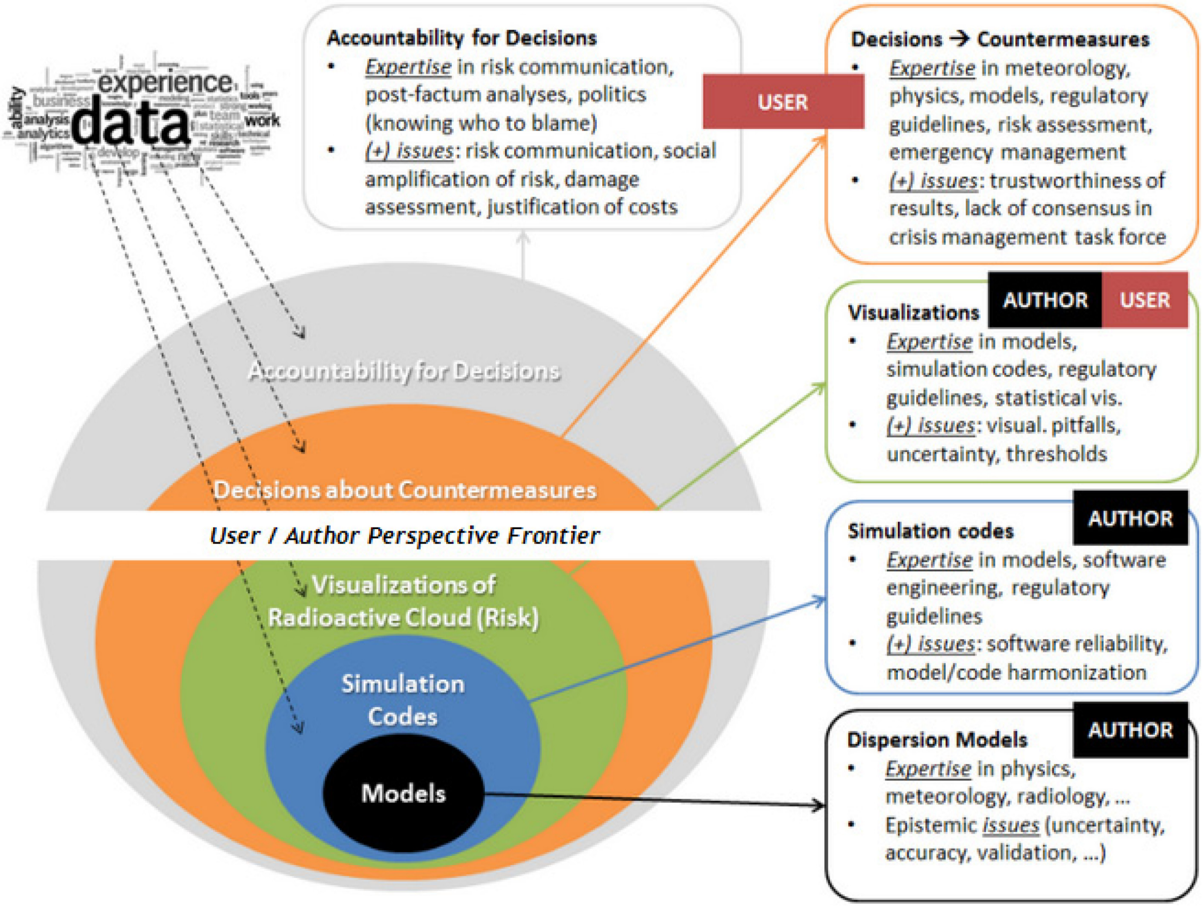


Figure 5 – The composing entities of the dispersion forecasting assemblage used to aid decision makers during nuclear emergencies.

The depiction of the different stages of nuclear emergency management from Figure 5 assumes a relationship of *embeddedness* between adjacent entities: the models are embedded in simulation codes, which are embedded in the visualizations of risk, which in term are embedded in the decision making process, and so on. Indeed, Merz observes that there is a relationship of embodiment between the simulation codes and the models, whereby the former embodies the latter (Merz, 1999).

2 State of the Art

This chapter provides a review of the relevant STS literature with respect to the sociotechnical imaginary of preparedness. While not claiming to be exhaustive, the choice of articles discussed in this chapter reveals a conceptual gap in the literature on sociotechnical imaginaries (Jasanoff & Kim, 2009), rhetorical visions (Sovacool & Ramana, 2015), and fantasies (Carper & Schmid, 2011) of the nuclear age. This gap arises from the fact that, although the authors of different studies are able to identify different imaginaries, rhetorical visions, and fantasies at work as part of the broader nuclear discourse of the last few decades, the relations between different imaginaries and rhetorical visions is often missing. As these concepts are often present in risk communication, a brief view of the latter is also provided. Finally, a review of the STS literature on the Fukushima nuclear accident will help contextualize the sociotechnical imaginary of preparedness in today's post-Fukushima nuclear reality.

2.1 Fantastic Small Modular Reactors

In recent years, small modular reactors (SMR), which are shipped rather than built on site and produce less power than a conventional reactor, have increasingly become the focus of STS scholarship (Carper & Schmid, 2011; Ramana & Mian, 2014; Sovacool & Ramana, 2015). Although they are presented as groundbreaking innovations that will solve the problems of conventional large nuclear power plants, present-day SMRs are very similar to the modular reactor designs and prototypes from the early 1980s. Back then the aim was to have a reactor that is so small in size and power that it would be able to "forgive" (i.e., tolerate) the mistakes of human operators. The HTR-Modul reactor, for example, has been licensed in Germany in 1989 and then shut down shortly after that due to a series of safety-relevant incidents. By the example of the HTR-Modul reactor, Section 4.1 looks into the emergence of the "forgiving" reactor as a sociotechnical imaginary (Jasanoff & Kim, 2009) in the wake of the Three Mile Island accident and its demise after the Chernobyl accident.

In (Carper & Schmid, 2011) the authors approach the SMR phenomenon from the angle of the imagery and metaphors used by different companies to describe this new type of reactor, which is supposed to solve several of the problems of the conventional light water reactors concomitantly:

> "A growing faction of promoters believes that these small reactors can provide solid answers to the myriad risks nuclear energy continues to face: safety, weapons proliferation, waste management, and initial capital cost. Each small reactor design offers a unique narrative of how it will remove or reduce these risks. Recurring themes include built-in capsule-like containment, passive cooling features, pledges for more effective disposal or recycling of waste, and a kind of inverse "economies of scale": advantages offered by small capital investment, standardization, and mass production" (Carper & Schmid, 2011, p. 2).

A small company called Hyperion used the term "battery" as the main marketing buzzword representing their SMR design. Carper and Schmid show that, while the term battery is technically inappropriate, it is effectively used to present a fantasy of "walk-away-safe" reactors from reasons of advertisement:

> "A battery is a static device that converts stored chemical energy to electrical energy. It arguably does not belong in the same conversation as harnessing a nuclear chain reaction, the results of which include highly radioactive materials. Images on Hyperion's Web site of buried, unattended nuclear reactors would make sense if they were merely batteries, but they are not. For this reason, more than one of the nuclear energy experts we interviewed used the term 'fantasy' in reference to such scenarios that deploy 'walk-away-safe' nuclear reactors" (Carper & Schmid, 2011, p. 6).

By contrast, large and well established companies from the nuclear industry, such as NuScale, Westinghouse, and Babcock & Wilcox, choose a more conservative message based on the idea that their SMRs incrementally build upon a well understood technology while providing key improvements over conventional reactor designs: "They are miniature versions of the world's tried-and-true light-water reactors, with substantially improved safety features." This evolutionary approach to innovation, the authors note, is tailored so as to fit well with the expertise of the members of the US Nuclear Regulatory Commission (NRC). The dialectic tension between the revolutionary design of the "forgiving" battery-like reactor and the incrementally and continuously improved reactor design reflect two distinct sociotechnical imaginaries, which are described in detail in Chapter 4 of the present work.

The term *fantasy* is also used by other scholars to describe the narratives built around SMRs, notably (emphasis added):

> "[S]cientists and technologists associated with the nuclear industry are building support for small modular reactors (SMRs) by advancing five rhetorical visions imbued with *elements of fantasy* that cater to various social expectations" (Sovacool & Ramana, 2015, p. 1).

Sovacool and Ramana note that the term "fantasies" is used in STS literature as a sensitizing concept to emphasize functional, utopian, contradictory, and selective aspects of technological innovation. One of the five rhetorical visions concerns nuclear safety: "a vision of risk-free energy would eliminate catastrophic accidents and meltdowns." This vision coincides with the main safety goal of the "forgiving" reactors from the 1980s (Weinberg, et al., 1985). The authors analyzed over 100 studies about SMRs in scientific journals such as Annals of Nuclear Energy, Annals of Nuclear Science and Engineering, International Journal of Radiation Applications and Instrumentation, Journal of Nuclear

Energy, Journal of Nuclear Materials, Nuclear Physics, and Progress in Nuclear Energy. The vision of risk-free energy identified in 60% of the total number of the analyzed papers reflects the desideratum of producing energy with perfect reliability and complete safety. Human error and potential terrorists or saboteurs are regarded as the main risks to the safety of present-day nuclear reactors. Just as in the case of the forgiving reactor, the term passive / inherent safety is often encountered in the papers as a symbolic cue supporting the vision of risk-free SMRs. In the conclusion, the authors point out three interesting features of the rhetorical visions identified in their study:

> “There are competing, at times overlapping visions, not all of them consistent, some of them part of larger visions that cut across a variety of nuclear technologies. (...)
>
> Statements about SMR commercialization present the future as a predetermined extension of current events. (...)
>
> Scientists and engineers are not immune to drama and fantasy and that they can become 'infected' with rhetorical visions—a symbolic convergence—that cause them, in their excitement, to lose their scientific precision” (Sovacool & Ramana, 2015, p. 116).

As I will discuss in chapters 6 and 7, these features of the rhetorical visions about SMRs also apply to the sociotechnical imaginaries of the nuclear age.

Ramana and Mian provide a comprehensive analysis of the available SMR designs and the promises their promoters and the promises associated with these designs (Ramana & Mian, 2014). The authors show that the 4 desiderata—cost, safety, waste volume, and nuclear proliferation risk—cannot concomitantly be minimized by either of the analyzed SMR reactors. The reason for this, the authors note, is that (emphasis added):

> “All the concerns about economic competitiveness, waste generation, avoiding catastrophic accidents and nuclear proliferation *are fundamentally social in origin*. The solution attempted by nuclear developers and vendors is to encode these priorities into the design of a specific nuclear reactor” (Ramana & Mian, 2014, p. 122).

SMRs seem to interesting mostly because of the concern about climate change and the fact that “social possibility of stopping the continued growth in energy demand let alone reducing it drastically.” In this context, SMR supporters claim that nuclear technology can help tackle the climate change problem, while having learned from the mistakes from the past and the design flaws of large conventional reactors. Fantasies and rhetorical visions about SMRs then come into play in order to project a utopian future in which SMR solve all energy-related problems of humanity while not posing any safety risks.

2.2 Risk Communication and Expertise in Nuclear Emergencies

In (Kasperson, et al., 1988) 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 (Kristiansen & Bonfadelli, 2016). 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 (Stilgoe, 2007). Post-Fukushima accounts of risk communication in nuclear crises focus more on how risk communication is performed by the different actors 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” (Kinsella, 2015, p. 2).

While being considered an accident triggered by a series of “beyond design basis” causes and failures by nuclear experts (Hirano, et al., 2012), by others Fukushima is regarded as a techno-natural disaster (Felt, 2014), a compound disaster (Chhem, 2014), or a triple disaster from “3/11” (Kinsella, 2015). 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 (see the discussion in 4.1). 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 (Kinsella, 2015).

Felt notes that techno-natural disasters help us to better understand how risks are socially perceived and acted upon (Felt, 2014). 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 thought collectives may not suffice to handle the dynamics of disaster and to mitigate the risks it entails (Felt, 2014). 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" (Fahlquist & Roeser, 2015). 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 (Felt, 2014).

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 (Fahlquist & Roeser, 2015). 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 (Beck, 1992) paved the way for more socially-sensitive approaches to understanding and modeling nuclear risk communication.

2.3 Learning from a Socio-Techno-Natural Disaster

"Disasters prompt us to seek lessons" (Pfotenhauer, et al., 2012). In the same vein, nuclear accidents prompt us to think about what went wrong and what could have been done to avoid the accident in the first place. In the aftermath of an accident, nuclear experts, government officials, social scientists, and regular people are compelled by the different media representations to participate to the global conversion about what went wrong and what can be learned. Hindsight seems to be a predominating feature of these conversations. Had they only built the protection walls higher, the accident could have been avoided—many of us thought after the Fukushima accident. Yet hindsight is unlikely to yield any real lessons that might be useful in refactoring the ways of normal nuclear operations, including regulatory systems and the complex relationship between the nuclear industry and the broader public. The Fukushima accident gave reason and material for myriad of public analyses, scientific publications, and public opinions, which all point to different aspects believed to have contributed to the causes of the accident. In this section, I attempt to review some of the STS publications that deal with that which could be learned from the Fukushima accident. The multitude of lessons learned from Fukushima, which pervade both the nuclear and academic discourses suggest that the theme of *learning* from disasters develops into a new master narrative of the nuclear.

Nuclear power has been contested in many countries—notably Germany—because of its conflicting fields of application. While the peaceful applications of nuclear power, like energy production, are presented by their promoters in a positive light, they do share at least one aspect with its military applications: Both peaceful and military nuclear applications endow the owners of the "nuclear secret" with tremendous power that goes beyond conventional means of conducting warfare and producing financial profit. As Kinsella notes, this tremendous power is often acknowledged in nuclear discourse through rhetorical mystification and the narrative of nuclear potency:

> "Nuclear science, technologies, and policies, products of human discourse, are widely portrayed as arcane, difficult, and out of the intellectual reach of ordinary people. Paradoxically, in a world where nuclear power plants and nuclear weapons are pervasive presences, the legend persists that only a gifted few can understand these products of science and technology" (Kinsella, 2005, p. 53).
>
> "Einstein's statement called attention to the potency of nuclear energy and to the urgency of our situation, and has become a commonplace of the nuclear age" (Kinsella, 2005, p. 56).

Since nuclear power has been used for great destruction during World War II, for some there is no compelling reason to believe that it will not be used for the same purposes again in future. Perhaps this is one of the main reasons why some people seem to have an innate aversion to the nuclear, be it military or peaceful.

As Jones, et al. note, during the decades leading up to the earthquake and tsunami, public opinion on nuclear power strongly diverged in Japan as well (Jones, et al., 2013). From 1945 to 1952, Japan lived under an Allied occupation headed by the US, during which public discourse fell under censorship. References towards atomic weapons and the extent of damage at Hiroshima and Nagasaki were not allowed. While Japan saw nuclear energy as a form of economic redemption, the US used this opportunity to build up influence in Asia during the Cold War. Japanese officials began promoting nuclear power in the mid-1950s with the exhibition on "Atoms for peace" held in Hiroshima. With the support of the US, pronuclear education materials started to be distributed in schools. Japanese officials started training local politicians for presenting nuclear energy to the local communities in a positive light. Reactor equipment was brought in by companies from the US, France, Canada and Australia. By the late 1960s the reliance on foreign nuclear technology started to became a significant concern. The two largest newspapers in Japan *Yomiuri* and *Asahi Shimbun* expressed their concern and disappointment regarding this matter. While there was little opposition to the first nuclear reactor in Fukushima, the opposition grew during the 1970s and the 1980s but did not manage to stop the construction of additional reactors. In this context, (Jones, et al., 2013) argue that the reactor meltdown cannot be seen merely as an extreme incident. The origin of nuclear power in global geopolitics, the nuclear politics of the United States during the Cold War of Japanese nation building, and the long-standing precarious conditions at the power plants are very important in understanding of the multiple narratives. The events at Fukushima in 2011 were entangled in complex local national and international contexts. The history of nuclear power in Japan is deeply local. That is because the central Japanese Government and TEPCO worked in tandem with local administration in order to win the support of the residents. The daily operation of the plants was made possible by workers who endured serious risks of radiation often unknowingly. The national-level narrative shaped life at the local level, but it required the compliance and compromises of the local residents and plants workers. Paying attention to the local perspective regarding nuclear power reveals several patterns. First, the greatest consequences were borne by local residents and workers. They were the only ones exposed directly to the danger and were poorly trained in radiation protection issues. Secondly, the assertion that Japanese citizens uncritically accepted nuclear power is false, as several anti-nuclear protests were held during the 1970s and the 1980s.

Many problems with the day to day operations of the nuclear industry seem to only be brought to light in the wake of an accident, with some of them being quite shocking. Gabrielle Hecht provides a compelling account of the workings of the Japanese nuclear industry by focusing on whom she calls "nuclear janitors" (Hecht, 2013). These are blue collar workers contracted by subcontractors of subcontractors of other subcontractors, who perform cleanups after accidents and regular maintenance work at NPPs. There are up to 8 levels of subcontracting in the nuclear business, as Hecht reports, which makes it difficult for anyone to follow the chain of responsibility when it comes to the health of these workers. There is no reliable information about the dose received by these workers, as they often tend not to wear their dosimeters while doing their work. This is because regulations stipulate a maximum dose that each worker is allowed to receive per year. And once this dose is reached, the worker is often fired. The dose thus represents a valuable currency in this industry. The maximum allowable dose for one nuclear janitor was raised from 25 mSv to 250 mSv during the early cleanup works at the Fukushima NPP, which shows that the value of this currency depends on the circumstance.

The complex history of the nuclear, its social implications, and the root causes of accidents cannot be explained by technical means alone. As Pfotenhauer, et al. observe, "it is impossible to separate the social and technical features in a complex operation such as Fukushima" (Pfotenhauer, et al., 2012, p. 1). Confronting the commonly held belief that Fukushima was primarily caused by political interference with technology, Pfotenhauer, et al. note that "political values and interests are continually part of nuclear operation" (Pfotenhauer, et al., 2012, p. 79). The authors further recommend that regulatory bodies be international rather than national and suggest that the IAEA assume the role of licensing nuclear power plants, thus growing out of its current advisory statute. The authors point out that the modelling culture practiced by the experts of nuclear organizations often breeds hindsight when it comes to assessing the root causes of accidents:

> "Had the models been correct and correctly followed, the story goes, the disaster might have been averted through the incorporation of more robust defenses into the original reactor design" (Pfotenhauer, et al., 2012, p. 80).

In the lack of empirical data, modelers thus need to rely on extrapolation and coherence assumptions. The authors further note that the modeling of complex sociotechnical systems should incorporate sociotechnical assumptions and draw on Alvin Weinberg's observation that the number of data points is too small for nuclear systems safety models to be accurate.[3]

On one reading of (Pfotenhauer, et al., 2012), one might imply that the modeling of complex sociotechnical system would actually entail building a model of the world itself—something held by most modelers to be unfeasible and thus bad modeling practice. Models are supposed to represent a reductionist view upon the world. Models can only work well in a controlled environment and under certain simplifying assumptions. However, models are also used in post factum analyses to better understand what happened during accidents such as Fukushima. In this case, incorporating sociotechnical assumptions is not a thing of the impossible since the modeler actually knows how society reacted to certain stimuli occasioned by the course of the accident; and the response of the authorities. To this end, modelers may go as far as to regard the Fukushima evacuations and cleanup works as a real-world experiment (Felt, 2016). One aspect of this real-world experiment concerns the reordering of space, which entails a redistribution of agency and a reconfiguration of power relations.

Felt focuses on displacement as one of several possible modes of reordering space (Felt, 2016). The Fukushima evacuations entailed the displacement of people from their homes and properties. Part of the cleanup works entailed the displacement of vast amounts of contaminated earth, which was transported away from the evacuation zone in an effort to restore agricultural land and to allow people to return to their communities as soon as possible. These displacements were facilitated by the use of maps, which redefine space in terms of its distance from the power plant. Through mechanical objectivity these maps divide the space surrounding the nuclear power plant into concentric circles, with the innermost circle representing the evacuation zone. Felt further notes that, farmlands and villages were redefined as irradiated zones and "people were reconceptualized as 'at-

---

[3] It must be noted however that, as it later turned out, Weinberg might have acknowledged the lack of empirical data for validating nuclear safety models to the end of promoting the "inherently safe reactor" (Weinberg, et al., 1985)—an apogee of scientism—and not necessarily to argue for a more socially-sensitive way for the nuclear industry to conduct their business.

risk-subjects' expected to behave in specific ways" (Felt, 2016, p. 8). Through the use of radiation maps, the location of a person becomes analogous to the risk of exposure to radioactivity, which entails the transformation of living space and peoples' homes in evacuation and health hazard zones. The temporal dimension of the map, which is usually obscured by the perception of static maps as stable representations, reveals itself in times of crisis as a continuously changing diagnosis of the past and prognosis of the future. Thus, as Felt notes, while "[i]ntended to promote certainty, to represent a stabilized order, maps unwillingly became part of a narrative of change and uncertainty" (Felt, 2016, p. 11). Furthermore, radiation maps caused an ontological redefinition of space—from one of living, leisure, and agricultural productivity to a risk zone. Perhaps for these reasons, the official radiation maps published by the Japanese authorities were challenged by participatory radiation maps generated using personal Geiger counters and publicly available web-based technologies (Plantin, 2015).

In their effort to clean up the evacuation zone as quickly as possible, a layer of earth from the surface of the soil was scratched off and put into plastic bags. Scraping huge amounts of earth was seen as the only possible way of restoring the initial purpose of the land, which was agricultural. However, as Felt notes, "it has remained unclear where this 'matter' could have its place in Japanese society" (Felt, 2016, p. 18). As Felt further notes, the effort to displace this earth to the end of decontamination can be interpreted as an effort to re-stabilize the sociotechnical imaginary of containment and control of the nuclear. In this new imaginary, the very notions of containment and control have been challenged by the continuous redefinition of space through maps and displacement:

> "Once the nuclear had moved out of the confinements of the reactor, new types of spaces were ceded to it, evacuating people and hoping that the nuclear could be temporarily contained in these new spaces and controlled through continuous measurement. These continuous spatial adaptations thus played an essential role in attempting to restabilize the nuclear imaginary—therefore moving to the core of the real-world experiment" (Felt, 2016, p. 20).

Felt's account of the real world experiment conducted at the Fukushima evacuation zone, with its abandoned areas and scratched earth surface, reveals a dystopian techno-cultural space, at the center of which stands the nuclear power-plant itself. "An orange blinking streetlight is actually the only sign that would allow the assumption of an inhabited space" (Felt, 2016, p. 20). Ironically, electricity is still part of this otherwise socially deserted space. The presence of the cleanup workers (or "nuclear janitors") suggests that the entire space around the NPP actually became part of it; for the same type of instrumentation, radioactive protection suits, risks, and hazards are now to be found inside as well as outside of wracked reactors. With that ontological change of the meaning and uses of space, the sociotechnical imaginary of nuclear containment and control was extended to a scale previously unattempted. The scraping of the contaminated earth also represents an attempt at erasing the memory embedded in that space since the memorable images of the contaminated zone under cleanup will be remembered instead. The scars of the displacements have turned the space around the Fukushima accident size into a material and symbolic medium for new collective (traumatic) memories.

2.4 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 (Plantin, 2015). 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 (Plantin, 2015). 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. Palin 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 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, Palin 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 (Sethi, 2016), some scholars suggest that preparedness should leave room for improvisation (Schmid, 2016). 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" (Sethi, 2016, p. 262).

In the remainder of this work, I will attempt to show how the *sociotechnical imaginary of preparedness* emerged, stabilized, and is being practiced and rehearsed on different occasions as well as how it relates to other imaginaries of the nuclear, such as the *imaginary of continuous improvement*. The next section provides some details about the ways in which this work contributes to the existing corpus of STS literature.

2.5 This Work's Contribution

The present work aims to bridge a gap in STS literature concerning the relations between rhetorical visions and fantasies as sensitizing concepts; and the sociotechnical imaginaries of the nuclear age. To this end, I will draw upon three case studies. The first one is mainly based on a historical account of a German "inherently safe" reactor design, which received relatively little attention in STS literature until now. This case study reflects a paradigmatic case of the sociotechnical imaginary of containment and, at the same time, a paroxysm of techno-science in the post Chernobyl decade. The second case study is focused on the sociotechnical imaginary of preparedness, which—I contend—is best reflected by the beliefs and practices of thought collectives formed around the development and use of decision-support systems for nuclear emergency management. The third case study provides an overarching account of the history of the German nuclear community in the three decades following the Chernobyl accident from 1986. The three case studies are represent different sociotechnical standing points. While the proponents of inherently safe reactors claim that radioactivity can effectively be contained within a graphite sphere the size of a tennis ball under any imaginable circumstances that to the complete understanding of the laws of physics and chemistry, the imaginary of preparedness actually acknowledges the opposite; that is, in case of a nuclear accident, radioactivity has escaped from all reactor containment structures and may do so in future as well. However, the imaginary of preparedness nurtures a belief that is not so far from the imaginary of containment: While radioactivity may escape the reactor containment, its health and environmental impact can be effectively controlled using a set of appropriate tools and practices. Once revealed, the complex relations between the imaginaries of containment and preparedness analyzed in the context of the German nuclear community in the past three decades will also help to shed more light upon what Florian Bayer has termed nuclear science-technology-society relationships (Bayer, 2015, p. 12).

While not having been an explicit goal of the analysis from the upcoming chapters, one of the outcomes of the present work is an alternative model of nuclear risk perception that challenges the social amplification of risk model (Kasperson, et al., 1988). 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" (Hecht, 2013) and the victims of evacuations (Felt, 2016) 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 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 (Miller, 2003).

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 (Scheuermann, et al., 2011).

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 estimations will be. However, most of the

    times, accurate dose estimations 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.*
    - 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[4] 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" (Jasanoff, 2003) that promise command and control over technology (Felt, 2016). 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 (Beck, 1992). 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 culture (e.g., nuclear scientists and engineers) and people living in different local communities and cultures maintain their complex indirect relationship with "the nuclear."

---

[4] Jasanoff makes a similar observation with respect to technical risk management more generally (Jasanoff, 2003, p. 224).

3 Research Design

This chapter starts with a review of the STS theories and sensitizing concepts that will be used in the analysis from the upcoming chapters. Then, it introduces the research questions, the materials, and the methods used to perform the analysis.

3.1 Theoretical Framing and Sensitizing Concepts

3.1.1 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" (Giddens, 1999, p. 3) in Giddens' understanding and (2) "a systematic way of dealing with hazards and insecurities induced and introduced by modernization itself" in Beck's view (Beck, 1992, p. 21). 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[5] 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 (Jasanoff, 1988). 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" (Beck, 1992, p. 50).

These surges of technological rationalization and changes in work and organization are in a sense *co-produced* (Jasanoff, 2004), 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

---

[5] The Fukushima techno-natural disaster contradicts Beck's observation on this particular matter.

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 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[6] 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

---

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

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.

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 (including the IMIS and ABR-KFÜ systems) clearly have their own limitations. *Normal accidents* (Perrow, 2011) 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.

In the course of this work, I will show how different practices of organized irresponsibility (Beck, 1992) have become indispensable in preparing for nuclear emergencies, the latter of which are the products of what Perrow refers to as normal accidents. As these practices stand at the core of *thought collectives*, which are composed of nuclear *organization men*[7] and emerged around decision-support systems for nuclear emergency management, the next section will briefly introduce these sensitizing concepts.

3.1.2 Thought Collectives and the Organization Man

Drawing from Kant's thesis that *a priori* knowledge always precedes individual experience, microbiologist Ludwik Fleck coined the term *thought collective* (Fleck, 2012) to denote a community of persons mutually exchanging ideas or maintaining intellectual interaction. According to Kant, the act of learning about nature from our own experience is only possible if we know something before experiencing anything. A priori knowledge plays an active role in cognition insofar as one might never know the difference between the picture of the world produced by our forms of perception and categories of thought; and that which truly exists independently of our cognitive acts. Fleck used the idea of *cognitive a priori* as a starting point for his theory about the collective mental differentiation of individuals. The members of a though collective both adopt a certain way of perceiving and thinking; and transform it continuously, whereby this transformation happens both in their minds and in the interpersonal space within the thought collective itself. Fleck also notes that a thought collective is

---

[7] The term refers to Willian H. Whyte's "The Organization Man" discussed in section 3.1.2.

likely to develop a certain *thought style* reflecting the members' way of perceiving and thinking as well as interpersonal relationships within the collective. Fleck calls *collective mood* that which holds the thought collective together by strengthening the ties between its members and makes them act in a certain way.

The group of people formed around the German ABR-KFÜ DS-NEM system is a good example of a multidisciplinary thought collective. While the members of the ABR-KFÜ working group have different backgrounds, ranging from meteorology, physics, and engineering to computer science, the frequent meetings (about 8 per year) brought them closer together from an epistemic point of view over the past 15-20 years. These interactions ultimately led to the emergence of a particular thought style and a specific collective mood within the group. An essential element that contributed to the formation of this thought collective is the common purpose of developing and improving the ABR-KFÜ system as well as planning and drawing conclusions from regular exercises held jointly with the Ministry of Environment and NPP operators. Moreover, the group is united by the shared responsibility assigned to them by the government of Baden-Württemberg as a consequence of the division and delegation of responsibilities in large sociotechnical systems described by Beck. In order to be prepared for an effective response, the members of the ABR-KFÜ group meet regularly at a frequency of about 6-8 times a year, usually at the Institute of Nuclear Technology and Energy Systems (IKE) in Stuttgart. Besides the members of the institute's scientific staff (including professors, PhD students, and other long-term employees) with assigned responsibilities with respect to the system, representatives of the Ministry of the Environment of Baden-Württemberg are also present at these meetings.

To better understand the workings of the ABR-KFÜ collective, Fleck's theory can be complemented with W.H. Whyte's *Organization Man* (Whyte, 2013)—a book considered one of the most important sociological and business studies of the 20th century. Looking through a sociologists' lens, Whyte provides a compelling description of the impact of mass organization on American society. In doing so, Whyte also showed how the American belief in the perfectibility of society was shifting from one of individual initiative to one that is achieved at the expense of the individual.

Considering that before the German nuclear phase-out decision from 2011 corporations from the nuclear industry represented the main financial supporters of the ABR-KFÜ collective, its members became themselves "organization men." Knowingly or unknowingly they acted at the command of the overarching organizations that provided financial support for research through long term contracts. With the ministry of the environment being also part of this constellation, the ABR-KFÜ thought collective still acts like an organization within other organizations. Although each of its members worked for diverse organizations—including the university, the government, and large private companies—until 2011 the group's activities were funded by public and private organizations affiliated one way or another with the nuclear industry. In this constellation, long term projects, such as the development of the ABR-KFÜ DSNE system, became possible.

The ABR-KFÜ collective can thus be regarded as a group of agents working within different host organizations, submitting themselves to what W. H. Whyte calls the *Social Ethic* of the organization. According to Whyte, the Social Ethic is determined by three interrelated pillars:

- *Scientism,* "the promise that with the same techniques that have worked in the physical sciences we can eventually create an exact science of man" (Whyte, 2013, p. 23).
- *Belongingness,* stating that the primal loyalty of the human being should be to a group larger than family, within which one can attenuate his conflicts and tensions.
- *Togetherness*, which is the belief that groups, especially groups meeting face to face, are able to come up with new ideas, and that ad-hoc collaboration renders leadership useless.

Belongingness and togetherness are perhaps the most appropriate denominators for describing the ABR-KFÜ collective, while scientism makes its presence felt mostly within the broader vision held by its members. This vision entails that the precise temporal, spatial, and radiological characteristics of a radioactive plume can be forecasted and that people can effectively be moved around over large geographical areas (i.e., evacuated) in a nuclear emergency in order to avoid contamination. A lost sense of belongingness is perhaps what makes it so difficult for nuclear experts to accept the German nuclear phase-out decision. Togetherness appears to be the reason why the ABR-KFÜ collective’s take on how to organize and prepare for nuclear emergency response contrasts with the IAEA recommendations—a comparison which will be presented in detail in a later chapter.

In the upcoming chapters, I will explore the ways in which the ABR-KFÜ thought collective is glued together by specific practices, technoscientific beliefs, and relations with different organizations affiliated with the German nuclear industry. In doing so, the aim will be to identify some of the defining features of the organization man in the members of the ABR-KFÜ collective, notably scientism and belongingness. The following section will introduce three sensitizing concepts, which are central to the practices of the ABR-KFÜ group.

3.1.3 Knowledge Objects, Non-Human Experts, and Expertise

The core of the ABR-KFÜ DSNE system, which is central to the everyday work of the ABR-KFÜ collective, is represented by a series of scientific simulation programs (or codes) linked together to form a workflow. Merz refers to simulation codes implementing physical models as *knowledge objects* (Merz, 1999). They embody different meanings and functions which can be used in different application contexts. In the case of nuclear emergency response, these knowledge objects are expected to also be used in a safety-critical context. One of the main properties of simulation codes, as knowledge objects, is that they submit themselves to the “black box” paradigm. That is, the user can only control the inputs (i.e., simulation data and parameters), while assuming that the outputs (i.e., results of the simulation) are trustworthy and reliable. In this context, the user has little or no control over what actually happens inside the knowledge object. That is because the internals of a simulation code is the realm of its creator(s), who might not be available all the time for eventual clarifications.

The fact that experts refer to the computation programs of the ABR-KFÜ system as “legacy codes” further complicates the matter. Legacy codes are old computation programs, whose authors are usually no longer available from different reasons. Organizations often choose not to create completely new versions of these legacy codes due to the high costs entailed by such endeavor. Moreover, older simulation codes are considered more reliable than newer ones because it is assumed that the former underwent several revisions and error fixing phases during their useful life. Problems with legacy codes, notably the question about their reliability, are widespread within the modeling and simulation community and there is no simple solution at hand. Merz observes that there is a relationship of embodiment between the simulation codes and the models, whereby the former embodies the latter. Merz also makes a clear distinction between the author and user role with respect to simulation codes. Authors and users of simulation codes have very different concerns when interacting with them. In the case of DSNE systems, these two distinct perspectives contribute fundamentally to the ways in which different actors interpret and apply regulatory guidelines, combine different types of expertise into the simulation codes and the decision-making process, and assess the reliability of the measurement data.

Merz and Knorr-Cetina (Merz & Knorr Cetina, 1997) analyzed knowledge objects in more detail in an attempt to describe how physicists actually think when inferring mathematical models about physical phenomena. In crisis situations, there is too little time to rethink these models and often simplifying assumptions according to the situation at hand are made instead. This is where the black-boxing principle becomes problematic. Because of the black-boxing of the entire simulation workflow, the ABR-KFÜ DSNE system becomes rather autonomous from an epistemic point of view. There are application contexts in which there is no time to analyze the plausibility of the results in the same way as experts would do during the verification and validation phases of a normal development process. Due to its epistemic autonomy, the system itself becomes something of a *non-human* expert and thus a special member of the ABR-KFÜ thought collective. As a non-human member of the crisis task force, the ABR-KFÜ DSNE system provides a type of expertise that emerged from a process of translation (Callon, 1984). This process was occasioned by the act of delegating part of the risk of operating an NPP to the ABR-KFÜ collective.

In Germany, nuclear emergency task forces are composed of government officials (decision makers), developers and trained regular users of DSNE systems, and DSNE systems as non-human experts. This gives birth to a particular cocktail of expertise that emerged from the practices of a well-established thought collective (Felt, 2014). Drawing upon the table of expertise by (Collins & Evans, 2008), human experts in the task force bring their *specialist tacit knowledge.* Decision makers must possess interactional expertise because they have to understand the specialists’ arguments. *Lower levels of specialist expertise* are implemented in the simulation codes, while the tendency is to also embed as much specialist tacit knowledge into these codes as well. These codes can turn meteorological and radiological data into visualizations of risk. Specialist users and authors are able to interpret these visualizations and assess their plausibility. Decision makers will finally also make use of what Collins and Evens call *transmuted expertise* (a form of meta-expertise) to make judgments about the specialists and their recommendations. The overall result of all activities of the ABR-KFÜ thought collective can be regarded as mostly "routine expertise," that is learning how to tackle well-known problems by using a predefined collection of tools, techniques, and approaches shared by all members of the thought collective (Felt, 2014). Also, as Felt notes, the members maintain well-entrenched communicative relations with actors internal (e.g., government representatives) and external (e.g., members of the broader atmospheric dispersion modeling community) to their thought collective.

Considering that the members of the ABR-KFÜ thought collective are representatives of their own local communities (Stuttgart, Karlsruhe, etc.), they are likely to also possess local knowledge about the environment they live in. This type of knowledge is commonly referred to as lay expertise (Wynne, 1992; Epstein, 1995)—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” (Kinsella, 2004, p. 85). As citizens of their own local communities, the members of the ABR-KFÜ collective are likely to possess a form of latent lay expertise. This epistemic source provides them with insights about the practical contexts in which they prepare for and carry out nuclear emergency response actions in their own communities. However, by being part of an organizational thought collective for over 15 years, their lay expertise may have been outclassed by the allegedly more reliable and accurate scientific expertise they gained while developing the ABR-KFÜ DSNE system. How much latent lay expertise actually flows into the practices of the ABR-KFÜ is an interesting question in itself.

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.
>
> [...]

> 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" (Kinsella, 2004, p. 85).

Public expertise thus represents a participatory approach to overcoming the deficit model in public understanding of science (Sturgis & Allum, 2004). 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 technoscientific 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.

In the course of this work, I will analyze how simulation codes as knowledge objects, DSNE systems as non-human experts, and emergency response planners as human experts work together to prepare for real nuclear emergencies. The next section introduces a sensitizing concept that captures the essence of the technoscienfic beliefs and practices of the ABR-KFÜ group in their day-to-day operations.

3.1.4 Sociotechnical Imaginaries

Jasanoff and Kim coined the concept of *sociotechnical imaginaries* by deriving the idea of collective imaginaries from technoscientific imagination, which—according to histories of scientific and technological discovery—"appears primarily in the creative minds of individual scientists and engineers" (Jasanoff & Kim, 2009, p. 122). Considering that the capacity to imagine and to project positive goals while trying to attain them is an essential constitutive element in both political and social life, imagination in fact gives birth to systems of meaning, which allows for collective interpretations of reality, thus inducing social order. Furthermore, technoscientific imaginaries embed ideas about how science and technologies should meet public expectations and, in doing so, they actually define the publics that are relevant to them. For these reasons, Jasanoff and Kim argue, technoscientific imaginaries are at the same time "social imaginaries", which encompass visions of a "good society."

Differentiating them from master narratives and media packages (Gamson & Modigliani, 1989), Jasanoff and Kim provide a first definition of imaginaries along the following lines:

> “Imaginaries are instrumental and futuristic: they project visions of what is good, desirable, and worth attaining for a political community; they articulate feasible futures. Conversely, imaginaries also warn against risks or hazards that might accompany innovation if it is pushed too hard or too fast. In activating collective consciousness, imaginaries help create the political will or public resolve to attain them” (Jasanoff & Kim, 2009, p. 123).

Furthermore, sociotechnical imaginaries

> “[…] are associated with active exercises of state power, such as the selection of development priorities, the allocation of funds, the investment in material infrastructures, and the acceptance or suppression of political dissent”.
>
> “[...] operate for us in the understudied regions between imagination and action, between discourse and decision, and between inchoate public opinion and instrumental state policy” (Jasanoff & Kim, 2009, p. 123).

Jasanoff’s and Kim’s example imaginaries of the nuclear formed around the ideas of “containing the atom” and “atoms for national development” project positive future visions of technoscientists harnessing the otherwise dangerous forces of nature present in “the atom” and putting them to work for the good of societies. However, Felt (Felt, 2015) shows by the Austrian example that sociotechnical imaginaries can also be based on negative feelings of “keeping technologies out”. Felt notes that this “imaginary of the absent” helped shape the nationhood of Austria after the difficult period experienced by Austria after the end of World War II.

In *Dreamscapes of Modernity*, Jasanoff revises the definition of sociotechnical imaginaries as a result of an entire collection of case studies by several STS scholars (Jasanoff, 2015). The now more mature definition of sociotechnical imaginaries substantiated by this collection of case studies goes along the following lines:

> ‘[Sociotechnical imaginaries] are collectively held and performed visions of desirable futures’ (or of resistance against the undesirable), and they are also ‘animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology.’ Unlike mere ideas and fashions, sociotechnical imaginaries are collective, durable, capable of being performed; yet they are also temporally situated and culturally particular. Moreover, as captured by the adjective ‘sociotechnical,’

> these imaginaries are at once products of and instruments of the coproduction of science, technology, and society in modernity" (Jasanoff, 2015).

The ABR-KFÜ collective nurtures such a sociotechnical imaginary in which DSNE systems play a central role. This imaginary projects neither a desirable future nor resistance against the undesirable but rather something in between the two. In fact, it is the fusion of a vision of resistance and a belief in the capacity of the technoscientific field of atmospheric dispersion modeling and radiological protection to protect the population against the consequences of nuclear accidents. This vision represents the *raison d'être* of the ABR-KFÜ collective, in the creation and reinforcement of which reflection upon the roles and responsibilities of each member of the group plays an important role. The rehearsal of roles, responsibilities, and methods within the group during exercises held jointly with the ministry of the environment and different NPP operators is equally important. These drills may be regarded as the generators of a broader imaginary about how things are supposed to work during a real emergency, ranging from technical aspects, such as the measurement of the concentration of released radioactive materials, to the most likely reactions of the population in the case that the evacuation of larger localities becomes imperative.

From a temporal perspective, the imaginary nurtured by the ABR-KFÜ thought collective is situated in the three decades which have passed from the Chernobyl accident in 1986. From a cultural point of view, it is shaped by deeply rooted cultural reflexes of the space in which it is being performed. In Germany, one of the cultural reflexes, recognizable in the day-to-day work of the members of the ABR-KFÜ collective, is that of continuously improving technical systems to the end of ensuring the safety, security, and comfort of the people living in their own local communities. From a sociopolitical point of view, the imaginary of preparedness is coproduced by technocracy—with its mishaps, normal accidents, and means for protection against them—and the social and political reactions to normal accidents.

Chapters 4 and 5 provide a comprehensive analysis of the sociotechnical imaginary of preparedness as one of several post-containment imaginaries of the nuclear. As part of this analysis, I will explore how the imaginary of preparedness emerged, how it stabilized as well as the ways in which it is being rehearsed by the ABR-KFÜ collective in the wake of the Fukushima accident. The next section introduces two sensitizing concepts, which will help shape some of the limits and pitfalls of the sociotechnical imaginary of preparedness, which have become more evident after the Japanese socio-techno-natural disaster from 2011.

3.1.5 The Limits of Representation and Technologies of Humility

As a paradigmatic normal accident, Fukushima was considered by nuclear experts (Hirano, et al., 2012), (USNRC, 2011) 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 (Felt, 2014). 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” (Kinsella, 2012). Drawing on Heidegger’s notorious essay “The Question Concerning Technology”, Kinsella justifies this statement by arguing that *(emphasis added)*,

> "[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*" (Kinsella, 2012, p. 253).

Kinsella thus adheres to the position that it is common practice in the technoscientific community to “focus on the known at the expense of the unknown” (Jasanoff, 2003) 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” (Kinsella, 2012)—a point that Jasanoff also makes with respect to what she calls “technologies of hubris” (Jasanoff, 2003).

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” (Jasanoff, 2003, p. 104).

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” (Jasanoff, 2003, p. 224). 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 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 technoscientific apparatus around them (thought collectives and methods of forecasting, prediction, and dose estimation), 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" (Jasanoff, 2003, p. 238).

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 ABR-KFÜ thought collective, 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 members of the collective 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 ABR-KFÜ thought collective:

> "*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” (Jasanoff, 2003, p. 241).

> “*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 failure in a given case is more or less unambiguous, its causes may be open to many different readings” (Jasanoff, 2003, p. 242).

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 thought collectives 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 collectives 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.

The analysis from the upcoming chapters will help place DSNE systems on a spectrum between technologies of hubris and humility more accurately. In so doing, I will explore how the “limits of representation”, which are often expressed in official reports in terms of missing measurement data, ineffective emergency planning, and organizational failure, become the main source of uncertainty in real nuclear emergencies as well as one of the main drivers of political accountability in the aftermath of accidents.

3.2 Research Questions

As a sensitizing concept, *sociotechnical imaginaries* have been initially proposed in relation to nuclear technology; the sociotechnical imaginary of containment describes one of the first imaginaries of the nuclear age in STS literature (Jasanoff & Kim, 2009). A series of case studies (Jasanoff, 2015; Bayer, 2015) have built upon the seminal work by Jasanoff and Kim, thus paving the way for a more elaborate theoretical framework. The present work aims at contributing to the theoretical framework on sociotechnical imaginaries by addressing a series of research questions, which help describe some of the German post-containment imaginaries of the nuclear. These post-containment imaginaries emerged in the three decades following the Chernobyl accident from 1986 in a complex technopolitical context. Their main common feature is that, unlike the imaginary of containment, they do not take reactor safety as granted. Instead, each of them is built around a particular sociotechnical solution (sometimes more technical than social) for eliminating or mitigating the safety risks of conventional nuclear reactor designs, such as the classic PWR (pressurized water reactor).

The German discourse around the three major nuclear accidents as well as the developments within the nuclear communities following each of these accidents produced a range of narratives, discursive frames, rhetorical visions, and fantasies on the past, the present, and the future of nuclear technologies. As a result of these developments, the imaginary of containment has been challenged not only by anti-nuclear activists and a large number of laypersons but also by members of the nuclear community itself. It must also be stressed that, perhaps for the first time in the history of nuclear science and technology, the public opinion on nuclear safety issues and the perceptions of the nuclear accidents by laypersons have played a significant role in shaping the German post-containment sociotechnical imaginaries of the nuclear. At the techno-political level, the post-containment imaginaries of the nuclear helped to cope with the fact that radioactivity cannot be effectively contained, a belief held by most nuclear experts before 1979 and shattered by the immediate realities of the TMI and Chernobyl accidents. In this context, DSNE systems emerged as part of a fallback strategy for coping with the failure of active reactor safety systems. DSNE systems, which represent an important tool for compensating the lack of reactor safety, reflect both a paradigmatic shift in nuclear risk management and a process of reordering the German technopolitical culture in the nuclear domain, which started in 1986 with the moratorium on nuclear energy and ended in 2011 with the German nuclear phase-out decision. Taking these observations as a starting point, the thesis revolves around the following research questions:

- **RQ1:** What kind of post-containment sociotechnical imaginaries of the nuclear emerged after the TMI and Chernobyl accidents and how did they stabilize—if that is indeed the case?
    - **RQ1.1:** How have they being rehearsed in formal and informal settings?
    - **RQ1.2:** How do they relate to the imaginary of containment and to each other?
    - **RQ1.3:** How have they been represented in different reports on the Fukushima nuclear accident?
- **RQ2:** How did DSNE systems become an important nuclear risk management technology in Germany?
    - **RQ2.1:** What kind of thought collectives and practices developed around them?
- **RQ3:** How do the post-containment imaginaries of the nuclear and the thought collectives and practices that developed around the creation and use of DSNE systems influence each other?

- **RQ4:** How did the Fukushima accident reshape the post-containment imaginaries of the nuclear and the community of nuclear experts in Germany?

To address these questions, the present work draws on three case studies. The first case study follows the history of a particular German reactor design, which was claimed to be “inherently safe” by its proponents (chapter 4.1). The second case study revolves around the creation and use of DSNE systems as well as the thought collectives and practices that developed around them (chapter 4.2). The third case study represents an overarching account on the history of the German community of nuclear scientists and engineers by the example of the Institute of Nuclear Technology and Energy Systems (IKE), affiliated with the University of Stuttgart in Germany (throughout chapters 4 and 5). By observing the reordering of the German technopolitical culture following the Chernobyl and Fukushima accidents, these case studies helped to identify some key features of the post-containment imaginaries of the nuclear, which might also be generalized for other sociotechnical imaginaries. The analysis in chapters 4 and 5 uses a wide angle of analytical approach, which helps to substantiate the main characteristics of the post-containment imaginaries of the nuclear in a series of historical and organizational contexts.

3.3 Materials and Methods

To pin down the post-containment sociotechnical imaginaries of the nuclear I have mostly focused on a small community of scientists and engineers united under the umbrella of the Institute of Nuclear Technology and Energy Systems (IKE) in Stuttgart, Germany. As I have been myself a member of that community for about four and a half years until early 2012, my views may be biased. This and the fact that I did not think to write about that community at that time and thus never asked for informed consent is why I have decided not to use analytical auto-ethnography (Anderson, 2006) as a research method. Instead, I chose to use methods, materials, and situations that are accessible to outsiders of the community as well. Nevertheless, it was impossible for me not to use some of the things I have learned and experienced during my time at the IKE when drawing the conclusions of this work. That is because, at some point, the results of informal unintended interviews and participant observation became a part of the particular mindset that influenced my views on the matters I analyzed in this work. However, to reassure the reader that the conclusions of this work are based on prodigious analysis and reflection, I must confess that my views have changed to a great extent between 2013, when I started working on the analysis, and 2016 when I handed in the thesis. Whereas in the beginning of this research, I tended to view the German nuclear phase-out decision as an act of injustice towards the professional community of nuclear scientists and engineers who found themselves struck by a decision seemingly taken out of the blue, by the time I had systematically analyzed the German “inherently safe reactor” case and the narratives that dominated the German nuclear discourse throughout the years between Chernobyl and Fukushima, I realized that things are much more complex than I previously thought. Nevertheless, I still believe that a student who chose to study nuclear engineering during the 1990s or 2000s (possibly because her mother or father also worked for the nuclear industry), is not to blame for the mishaps and political entanglements of the nuclear industry and for not having been skeptical about the internal workings of its steeply hierarchical and somewhat Kafkaesque bureaucracy, the representatives of which probably promised her a well-paid life-long job during the taster week of the nuclear engineering study program. Today, that student is likely to have already changed her field of work or to be facing unemployment in a foreseeable future.

Jasanoff recommends a series of research methods for studying sociotechnical imaginaries (Jasanoff, 2015). Drawing on those recommendations, to answer the research questions proposed in section 3.2, I chose to use the following materials and methods:

- *Comparative analysis* between the US and the German versions of the various imaginaries of the nuclear at different points in times. As Jasanoff notes, the comparison of culturally-shaped versions of a sociotechnical imaginary can be carried out by considering case studies on the same aspects from different countries (Jasanoff, 2015). Comparative studies are more likely to reveal interesting features of the imaginaries being studied than studies focusing on a single country. Furthermore, Jasanoff also recommends comparing the same issues at different points in time. This approach has shown to be very effective in studying nuclear issues. One reason for why comparisons in time and space are useful in studying nuclear issues is because disruptions, such as the Fukushima accident, have produced profound changes in the technopolitical culture of different countries like Germany, while having less important technopolitical effects in other nuclear countries like Japan and the USA.

  I have used comparative analysis for showing how inherently safe reactors have been received by the nuclear community in Germany and in the USA. Also, I have compared three thought collectives that developed around atmospheric dispersion modeling practices.

- *Document analysis* (Bowen, 2009) of regulatory guidelines and policies as well as of domain-specific scientific papers supports the comparative study of sociotechnical imaginaries (Jasanoff, 2015) because it helps to understand the regulatory culture and the main features of the relevant sociotechnical imaginaries in the countries being studied. The analysis of post-factum institutional reports on the Fukushima accident helps to identify the public expectations with respect to the sociotechnical imaginary of preparedness.

  Document analysis is used throughout the analysis and is the main method used in Chapter 5, section 5.2.

- *Participant observation* (Atkinson & Hammersley, 1994) of the thought collectives revolving around the imaginary of preparedness and *interviews* with members of those collectives help to understand how sociotechnical imaginaries are being articulated and rehearsed by their supporters as well as how (if) they stabilize in a given socio-cultural space, such as a country, or within a professional community.

  As a member of the ABR-KFÜ collective, I participated in many of its meetings and attended the Harmo.org conferences. The results of these observations pervade the analysis from chapters 4 and 5. A formal interview with one of the members of the ABR-KFÜ crisis task force stands at the basis of the analysis in Section 4.2.

- *Grounded theory* (Corbin & Strauss, 1990) helps to pin down the main characteristics of the different German imaginaries of the nuclear age by comparatively analyzing and coding official documents (such as guidelines for crisis communication and institutional reports on the Fukushima accident) as well as participant observation notes and interview transcripts. The goal of the method is to ultimately create the basis for a new theory by analyzing the concepts and categories resulted from coding the data. One of the main rules of grounded theory, which differentiates this method from other qualitative research methods, states that data collection and analysis are interrelated processes.

  The analysis was structured in three main steps. In the first step I looked into the history of the inherently safe “forgiving” reactor concept. This preliminary analysis suggested that the sensitizing concept of sociotechnical imaginaries applies well in this case.

  In the second step I have collected data through interviews, participant observation, and by selecting relevant documents for the analysis. Hereby I mainly focused on the development and use of DSNE systems before and after the Fukushima accident. The choice of DSNE systems as the central element of the analysis was based on my previous involvement with the ABR-KFÜ project as well as on the intuitive feeling that DSNE systems are made of aggregated knowledge objects, which act as non-human experts supporting nuclear emergency response planning and decision-making. The analysis of the data suggested that the work and practices of the members of the ABR-KFÜ collective builds upon a sociotechnical imaginary of nuclear preparedness.

  Finally, in the third step, starting from the observation that the sociotechnical imaginary of preparedness pervades the practices of the ABR-KFÜ thought collective, I have identified its main features as well as some features of other imaginaries of the nuclear by analyzing the data collected in the previous steps. The analysis revealed that the imaginary of preparedness emerged through an evolutionary process facilitated by disruptive events which led to what one might call “mutations” of well-established imaginaries of the nuclear, such as the imaginary of containment. These mutations happen whenever disruptive risk events, like nuclear accidents, or major geopolitical changes, such as the fall of the Iron Curtain, occur. The sociotechnical imaginaries of the nuclear age are thus intrinsically linked with the different modes of risk perception, mitigation, and valorization in modern society. Sociotechnical imaginaries can be identified and described by studying thought collectives and the different technologies and methods used by the members of these collectives. I have described the concepts, which emerged during the analysis by applying grounded theory, as generic features of the sociotechnical imaginaries of the nuclear in Chapter 6. These features complement the concepts described in (Felt, 2015), notably emergence, stabilization, and rehearsal, which define sociotechnical imaginaries. In grounded theory terms, the two new categories revealed by the analysis are different genres of sociotechnical imaginaries and disruptive risk events.

4 German Post-Containment Imaginaries of the Nuclear

This chapter analyzes the emergence of several German post-containment sociotechnical imaginaries of the nuclear by the examples of the inherently safe reactor designs and DSNE systems.

Although the effects of the fallout caused by the Chernobyl accident from 1986 are still being researched today, radioactivity measurements have shown that the South of Germany (Bavaria and Baden-Württemberg) were among the regions in Europe most affected by radioactive fallout and washout. The accident was kept secret by the Soviets for an entire week until Swedish researchers measured unusual concentrations of radioactivity in the atmosphere, which turned out not to be caused by Swedish reactors. In Western Europe the news of the accident was represented by the media in very different ways from one country to another. While, for example, in France, public televisions claimed that, due to a high pressure front, the invisible radioactive threat was stopped right at the French border, in Germany media tended to exacerbate the effects of fallout and washout, thus contradicting some politicians' claims that nobody was in real danger[8].

Although minimized by most members of the German nuclear community, the Chernobyl fallout had a devastating effect upon the local nuclear industry. In a sense this accident represented the beginning of the end for the German nuclear industry. In a first step, this happened because of a division of opinion among the experts in the field. Some regarded the accident as a product of the totalitarian Soviet regime. Others claimed that the graphite-based technology was to blame and that such an accident would never occur in Germany. Another group of nuclear experts took an unorthodox position and claimed that such accidents were going to happen on a regular basis in the foreseeable future, considering that the safety culture created and nurtured by the promoters of the classic pressurized water reactor (PWR) was based on gradual improvements inspired by "mishaps", such as the Chernobyl accident. The latter group formed in Germany around Dr. Günter Lohnert, a SIEMENS employee around the time the Chernobyl accident occurred. Lohnert, a nuclear physicist who obtained his PhD in the United States, had picked up on a new paradigm in nuclear engineering aimed at creating an inherently safe reactor, which would make accidents such as the one at Three Mile Island impossible. Inherent safety was based on passive safety elements, which—as opposed to active safety elements—would prevent radioactivity from being released from a damaged nuclear reactor without the need of human intervention and active cooling of the reactor. Since it is both interesting and relevant with respect to the political decisions that ultimately lead to the German nuclear phase out, section 4.1 presents a detailed account of the case of inherently safe reactors in Germany.

In the aftermath of the Chernobyl accident, the nuclear industry negotiated a continuation of the operation of nuclear power plants in Germany in spite of the moratorium on nuclear energy issued by the social-democrat government right after the accident. As a result of these negotiations, the industry had to support the development and operation of DSNE systems at both the state and the

---

[8] Karambolage 375 – December 2015: http://sites.arte.tv/karambolage/de/das-archiv-tschernobyl-karambolage

federal level. While the financial support came from the big players in the industry, the money was to be administered by the ministries of the environment from each Land in West Germany. The actual development of the systems was carried out by different research institutes in cooperation with software companies. DSNE systems were thus put in place to help protect the population in case of a future accident in Germany or in one of its neighboring countries. The introduction of the DSNE systems thus represented the recognition by the German nuclear industry of the real risk for a serious accident to occur in Western Europe and a transfer of accountability from the industry to the government. A detailed account of the emergence and usage of DSNE systems in Germany is provided in section 4.2.

After a long period of political back and forth regarding nuclear power, in 2010 the nuclear industry obtained a preliminary victory—the lifetime extension of a series of reactors, which were due for decommissioning in just a few years from then. This wave of optimism, which was sometimes referred to as the *Ausstieg aus dem Ausstieg* (phasing out the phase-out) in German media, was ended abruptly by the Fukushima nuclear accident from March 2011. While there was not much to do for German nuclear experts other than to monitor the situation in Japan and analyze the scarce emission data that was gradually being published by the Japanese authorities, DSNE systems were used to create powerful images of the invisible radioactive cloud travelling from Fukushima to the rest of the world. These images were picked up by many newspapers around the world, which set up impromptu e-learning websites linked to from the front pages of online newspapers, such as the Frankfurter Allgemeine Zeitung in Germany and The New York Times. Chapter 5 provides an analysis of the immediate reaction of the German nuclear experts at the IKE to the Fukushima accident.

The latest dramatic episode in the history of the German nuclear industry happened when, in the late spring of 2011, the Christian-Democrat government lead by Angela Merkel government announced the plan to phase-out of all reactors by 2022. Consequently, the nuclear industry's support for DSNE systems was cut off. Nevertheless, DSNE systems continued receiving financial support from public funds. For a period of about 3-4 years they received in fact more funding than before in order for experts to integrate the lessons learned from the Fukushima accident into the systems. Thus, DSNE systems became financial working horses for institutes such as the IKE—with all other subfields of nuclear science no longer being funded or subsidized at all. In this context, many nuclear experts changed their professional field completely, while some refocused on dispersion forecasting, dose estimation, and the emerging research field of *source term back-calculation*, which aims at inferring the general characteristics of the radioactive release term based on radioactivity measurements alone. Section 5.3 provides an account of the current situation in German nuclear research in the post-Fukushima era.

4.1 Reactions to Three Miles Island: The Forgiving Reactor

The Three Mile Island (TMI) nuclear accident of 1979 was arguably the first event of its kind to evoke widespread media attention and exposure (Friedman, 2011). It also made clear for both scientists and laypersons that nuclear technology entailed serious risks which had to be addressed immediately. In response to this new way of perceiving nuclear power, which was until then regarded as relatively safe, the concerned US governmental bodies and the community of nuclear experts had to take a stance regarding the causes of the accident as well as what could be done to avoid such “mishaps” in the future. The results were such that on the one hand, the National Science Foundation initiated and funded a program for the reassessment of the very discipline of risk analysis (Miller, 2003). On the other hand, experts began to think about what could be done to prevent any conceivable accident in the future. The lessons learned from the TMI accident provided the motivation and starting point for what was to become a paradigm shift in the field: *inherently safe reactors*.

According to the US Nuclear Regulatory Commission’s (US-NRC) report on the TMI accident[9], the failure that eventually led to the partial core meltdown occurred in the secondary cooling system of the pressurized water reactor. The main feedwater pumps stopped working thus interrupting the secondary cooling system, which triggered the automatic reactor shutdown procedure. A series of failures followed, including that of the pressure valve, which had to be opened but would not close back again and thus allowed contaminated water to exit the reactor pressurizer. Initially the failure of the valve led to a loss of coolant accident, but due to another failure, the control room instrumentation did not indicate that the pressure valve would not close back again. For this reason, the operators in the control room were unable to correctly assess the situation and took a series of inappropriate measures, which eventually caused a partial core meltdown. As a result, radioactive materials were released into the environment. The release of radioactive materials had a big psychosocial impact on the resident population in the areas affected, although according to the report, no serious injuries or cases of illness caused by radiation were recorded afterwards. Three Mile Island is a paradigmatic case of a “normal accident” (Perrow, 2011).

Experts in the field concluded that the main cause of the accident was not to be found inside the reactor core itself but in the equipment that was installed to protect the core from a meltdown: the active safety systems. Considering that these systems rely on the correct functioning and reliability of equipment such as pumps, valves, sensors, and countless pipes, it is impossible to provide guarantees that accidents will never occur simply because all these individual components have certain failure probabilities themselves. Moreover, 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 problem, a previous reactor safety study of the US Atomic Energy Commission (U.S. Nuclear Regulatory Commission, 1975) pledged for the introduction of so called “subjective probabilities” which were embedded in widely used Probabilistic Risk Analysis methods. In other words, where failure probabilities of complex systems could not be effectively

---

[9] “Backgrounder on the Three Mile Island Accident”, United States Nuclear Regulatory Commission, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html.

determined because of missing data or intractable calculus, they would be replaced with experts' assessments of those probabilities—a process identified by Carolyn Miller as the conversion of *ethos* into *logos* (Miller, 2003).

As a result of the lessons of the TMI accident and the shortcomings of various probabilistic risk assessment methods, the experts envisioned a reactor that would need no active safety systems for preventing the release of radioactive materials into the environment at all, regardless of the postulated accident type and scenario. If the decay heat produced by the reactor core could be effectively removed prior to a radioactive release or a core meltdown, the public's confidence in nuclear energy shattered by the TMI accident would be restored. At the same time, a reactor not posing any safety risks would be perceived by the broader public as a "forgiving reactor" (Weinberg & Spiewak, 1984) and a new start for atomic energy would be possible. The adjective "forgiving" referred to the ability of the reactor to tolerate faults. Refocusing on the safety of nuclear reactors rather than their efficiency paved the way for a very ambitious project, which in some sense can be considered utopian. To some members of the US nuclear community, the "forgiving reactor" represented an illusory escape from the potential fatality of their *métier*, which was brought to light by a seemingly impossible event—the TMI accident.

Even when the reactor is shut down safely (i.e., the fission reaction is stopped), decay heat, which represents about 8% of the nominal thermal power of the reactor, will continue to be produced for days and weeks. Therefore conventional reactors must be cooled for as long as decay heat is still produced by the fission products inside the core. The ambitious goal to create an inherently safe reactor could thus be achieved by controlling the decay heat without the help of active safety systems. And so the concept of an *inherently safe reactor*, which would be endowed with technological means of controlling the decay heat, was born. Wineberg and Spiewak, two of the most prominent US nuclear scientists at that time, defined an inherently safe reactor as one "whose safety depends not on the intervention of humans or of electromechanical devices but instead depends on *immutable and well-understood laws of physics* and chemistry" (Weinberg & Spiewak, 1984, p. 1399).

According to its proponents, the "forgiving" inherently safe reactor would have to be smaller than conventional pressurized water reactors in order to produce a manageable amount of decay heat. However, from an economic point of view, the loss in power would be compensated by the fact that there would be no need for active safety systems, as the reactor would safely shut down and manage the decay heat by itself. Small reactors could then be installed close to large cities and wherever else needed. Thus, from an economic point of view, the reduced power would be compensated by the proximity to cities, which would secure their energy needs in a clean and safe way. In order for inherently safe reactors to be financially feasible, it was necessary for regulatory authorities like the US-NRC to loosen their demands over safety features such as a high pressure containment cell or earthquake proofing. To make their case even stronger, the proponents of inherently safe reactors calculated that in a world with a projected 5000 pressurized water reactors, there would be a core meltdown every other year. Therefore, inherent safety was not only an option but a prerequisite for ensuring the continuity of the nuclear industry in the first place. In a way, by criticizing the other reactor types existing at that time, the promoters of new inherently safe reactor designs (two of which were preferred by experts, namely the Process Inherently Ultimate Safe and the modular High-Temperature Gas reactors) somewhat replaced the old dream of “energy too cheap to meter” by proposing a new one that I would call “energy too safe to raise concerns”.

To summarize the experts’ argument: Inherently safe reactors do not need any safety systems, be they active or passive. They could lead to and perhaps are the only viable solution for enabling what has tentatively been called a “Nuclear Renaissance” (Weinberg, et al., 1985)—a return to the status-quo from the 1950s, when nuclear energy was seen as the most promising energy source for the future. Any other reactor design would just lead to the continuation of the ineffective regulatory philosophy of incrementally improving the safety of existing reactors. With the worldwide number of reactors believed to grow continuously and fast, any reactor design that is not inherently safe will ultimately result in a future meltdown at a global frequency of every couple of years.

4.1.1 Attempts at Establishing the Sociotechnical Imaginary of the “Forgiving Reactor”

The notion of a “forgiving reactor”—an anthropomorphism of the more common technical term “fault-tolerant reactor”—reflects a compelling sociotechnical imaginary: a system that is able to forgive the mistakes of the experts in charge of its creation and its safe operation. The Christian precept of forgiveness provides the link between the properties of a technology and the features of an entire society. Thus, the call for forgiveness resonates beyond the boundaries of the technology, reaching deep into collective conscience. The imaginary asks people to forgive the mistakes of the nuclear experts, which led to the TMI accident, just as the new inherently safe reactors will forgive the mistakes of their creators. From a social perspective, the imaginary projects a forgiving and thus fault tolerant society perhaps in line with the developments toward more tolerance in American society from the late 60s and early 70s.

As far-stretched as it may seem, it is reasonable to believe that, considering its profound meaning in a mostly Christian society as the American one, the precept of forgiveness used to characterize inherently safe reactors was meant to sensitize the public just as much as it was meant to persuade other nuclear experts of the unique features of a new technology. Also, less evident, is the ability of the word “forgiving” to unconsciously remind of popular idiomatic expressions, such as “forgive and forget”. This helps frame media discourse, which is known for its ability to shape public opinion (Gamson & Modigliani, 1989), such that the readership be compelled to forget the mistakes and mishaps of different industries. If the responsibility for a given mishap is diffuse, reminders and calls to innate social behavior, such as the ability to forgive and forget, can be implanted in the media discourse. The turn to affect facilitated by the use of anthropomorphic metaphors, such as the forgiving reactor, in media discourse is one of the recurring tactics used to sensitize audiences. While these media tactics appear to work for the target audience and readership of the respective TV channels and newspapers, they also provide an excellent opportunity for anti-nuclear activists, who only need to remind their audiences about the nuclear industry's covered-up or downplayed mishaps.

The imaginary of the forgiving reactor was the product of a small group of people, formed around high-profile nuclear scientists like Richard Weinberg, who repeatedly expressed their concerns about the safety of conventional light water reactors, to establish a new sociotechnical imaginary. However, the result of these efforts can be regarded as a mere extension of the imaginary of containment (Jasanoff & Kim, 2009). The latter, as Jasanoff and Kim show, is based on the idea that the forces of atom which proved their destructive capacity during WWII can effectively be contained within a strong container or shield and thus leveraged for energy production and other peaceful applications. This idea was notoriously expressed in Dwight D. Eisenhower's "Atoms for Peace" speech (Eisenhower, 2003) before the United Nations from 1953. After the TMI accident, with the emergence of the forgiving reactor concept, the imaginary of containment received a face lift but did not change in essence. In fact, it was reinforced since the passive safety systems aimed at providing an additional impenetrable shield against radioactivity. The TMI accident clearly showed that at least a partial core meltdown was possible and that the active safety systems of the TMI plant could neither effectively contain the radioactivity nor prevent the loss of face for the nuclear industry. Therefore a better, inherently safe technology based on the complete understanding of the laws of physics and chemistry was seen as the only one capable of preventing any further loss of face for the nuclear industry.

While several inherently safe "forgiving" reactor designs were proposed around the beginning of the 1980s, one of them best reflects this reinforced imaginary of containment: the German Pebble Bed Modular Reactor (PBMR). The next subsection presents this case in point.

4.1.2 Inherently Safe Reactors in Germany

In Germany, nuclear power has never been far from the top on the list of public issues, and almost all citizens have an opinion on the topic. A strong anti-nuclear movement has played a key role in German politics since long before the Chernobyl accident, and antinuclear protests have been frequent and dramatic, sometimes marked by violence. When the much feared radioactive cloud finally arrived from Ukraine in 1986, the German public reacted with fear, partly due to the alarmist coverage the accident received in German media (Ionescu, 2012; Fahlquist & Roeser, 2015; Park, 2016). Following this public reaction, the German federal government issued a moratorium on nuclear energy, which stated that no new nuclear power plants were to be built on German territory while existing ones could still be operated until the end of their lifespan.

As both human error and technological failure were identified as principal causes of the Chernobyl accident, the industry-affiliated German nuclear scientists started working on a strategy that was to eventually lead to a rescindment of the moratorium. For those scientists, the human error component of the problem was not at issue thanks to the imaginary of a strong and disciplined German safety culture compared to the allegedly propagandistic and careless Soviet one, as the latter was perceived during the Cold War. However, such an argument was not strong enough to convince public critics because human error could intuitively never be entirely excluded. For these reasons, the experts' attention was drawn to inherently safe reactor designs, one of which was being developed by the German company Siemens/Interatom under the aegis of Günther Lohnert.

In the High Temperature Modular Reactor (HTR-Modul) design the key to inherent safety is represented by its fuel elements, called pebbles (Reutler & Lohnert, 1983). These are graphite spheres the size of tennis balls containing a large number of coated particles. Each coated particle is itself a smaller sphere of less than 1 mm in diameter, which contains a tiny core of nuclear fuel surrounded by four layers of carbon and carbide shielding. Particles and pebbles are designed in a way that, in principle, prevents the reactor core temperature from exceeding the melting point of the coating. This approach makes a core meltdown theoretically impossible because the small amount of uranium contained in a coated particle cannot yield enough energy to produce dangerously high temperatures even in an uncontrolled chain reaction. In a reactor that uses this type of fuel, pebbles are moved in a cycle from the top to the bottom several times until their potential is expended. According to its designers, the reactor does not need a pressurized containment building because the pebbles are small containment structures themselves; nor would it need additional active or passive safety systems, such as water pumps and valves.

Co-owning the patent on the HTR-Modul, Lohnert approached the research community to rally help for producing proof in favor of its inherent safety features. In cooperation with colleagues from the Jülich National Research Center, where an experimental version of the HTR-Modul had been running since 1968, scientists wanted to prove that the temperature inside the reactor core would under no conceivable circumstances reach a temperature higher than 1600°C, a temperature at which the carbide coating of the nuclear fuel would deteriorate and thus cause a core meltdown. The temperature could be controlled, as the designers claimed, through a precise sizing of the tiny uranium core in each coated particle. In 1983, after a preliminary successful experiment, it was claimed that when heated up to 1600°C for up to 1000 hours, none of the particles lost their integrity. When heated up to 1800°C, one percent of the particles cracked within the first 100 hours of the experiment. This also showed that it was possible to precisely identify the thermal breaking point of the particle coating. In the final section of the study, the authors argued that the experiment was statistically significant, in spite of the rather small number of particles tested compared to the over five billion particles used in a HTR-Module. The authors concluded the study (Lohnert, et al., 1988, p. 263) with the following statement, which exhibits an overly confident rhetorical style:

> "From these calculations we conclude that any hazardous radiation dose to the environment can be excluded if the maximum fuel element temperature stays below 1600°C. It goes without saying that the HTR-Module, having a power output of 200

> MW, inherently limits its maximum fuel element temperature below this value, regardless what accidents might be postulated."

For the reactor designers there was no need for additional proof. The experiment showed that inherent safety was possible and that the laws of nature, represented in this instance by the temperature, could effectively be kept under control regardless what accidents might be postulated. This one experiment, however, was insufficient for proving the inherent safety to the German nuclear regulatory authority and the public; since in the world of science, in order to gain credibility, there must be a means for experimental results to be replicated. In the following years, a number of other experimental results and simulation studies on the same topic were published. Because experiments were very costly and it was very difficult to effectively measure different physical quantities, such as the temperature inside the reactor core, an irradiation-based stress testing method for the spherical fuel elements (regarded as essential inherent safety features of the HTR-Modul) was developed (Mehner, et al., 1990). In addition, much work aimed at determining the behavior of the pebbles in the AVR reactor, notably the maximum attainable temperature under different circumstances, was carried out using complex computer simulation codes. Other experiments and simulations were carried out in order to determine the consequences of air and water ingress accident scenarios. All these studies supported the idea that the HTR-Module was indeed inherently safe thanks to its specially designed spherical fuel elements.

Yet in spite of these promising results, the AVR reactor was shut down in 1988 by the German regulatory authorities due to a series of deficiencies and safety-related reactor incidents, which were not made public at that time. A long-classified report for the state government of North Rhine-Westphalia, which was declassified[10] in 2011 as a rather late consequence of the German Environmental Information Act of 1994 (*Umweltinformationsgesetz*), revealed an unacceptable risk of so-called super-criticality, which can lead to an uncontrolled fission reaction and ultimately to a core meltdown. In a report by the Jülich Research Center from 2008, the alleged inherent safety of the HTR-Modul was reassessed (Moormann, 2008). More precisely, the report stated that the coating of the spherical fuel elements would be unable to retain radioactive metallic fission products and called for the development of a new fuel element capable of retaining all fission products. Rainer Moormann, the author of the report and a longtime member of the HTR-Module group, concludes with the following statements:

> "Previously a superior safety behavior of pebble bed reactors was claimed compared to other nuclear systems including an allegedly catastrophe free design. According to the above presented arguments there are doubts, whether this depicts reality" (Moormann, 2008, p. 33).

---

[10] Parts of this report are reproduced in (Deiseroth, 2016).

Roughly twenty-five years after the HTR-Modul was first claimed to be inherently safe, the Moormann report showed that the ambitious goal of fully understanding and controlling the “immutable laws of physics and chemistry” as set by the initial proponents of the inherent safety concept was far from being attained.

The THTR-300 reactor at Hamm-Uentrop, which started operating in 1983, had a similar history. This reactor used the same type of TRISO fuel elements (pebbles) and served as a prototype for testing them. Due to the numerous incidents registered in its short lifetime, the German regulatory authorities decided to shut the reactor down in 1989.

4.1.3 Dumping[11] the Forgiving Reactor to Africa and China

With no future prospects in Germany, the proponents of the HTR-Module turned to other markets. Before long, in South Africa a company called Eskom started a development project based on a modified version of the HTR-Modul design called the Pebble Bed Modular Reactor (PBMR) under Lohnert’s supervision. The AVR was portrayed to the South African public as an “unqualified success” (Thomas, 2009). Meanwhile, as the future of nuclear energy in Germany did not look too bright during the 1990s, the nuclear community began to reconsider its options. The holy grail of inherently safe reactor designs was not to be attained in Germany, but it seemed to have a better chance in South Africa. In 1997, Lohnert was appointed Director of the Institute of Nuclear Technology and Energy Systems (IKE) at the University of Stuttgart and gained his professorship accordingly. Now officially part of the academic nuclear science community, Lohnert designed a new research agenda for the institute with a strong focus on the PBMR and other high temperature reactor designs. However, during the early years of the decade the PBMR project was stalling because of financial reasons, and was eventually abandoned in 2008. The PBMR/HTR-Modul designers thus found themselves on the look for other potential markets again. Around the mid-2000s, the Chinese government announced their intention of building a commercial reactor based on the design, and Lohnert was invited to work as a consultant for the project. The Chinese had already built a small copy of the AVR in 1992, which began operating in 2003. For his merits in helping the country develop nonproprietary nuclear reactor technology, Lohnert received the Chinese Friendship Award in 2009, the highest distinction a foreign citizen can be granted by the Chinese government[12].

An article from 2004 published in the former Swiss technoscience magazine FACTS covers the success story of the Chinese HTR-10 reactor in a rather jubilatory manner (Klose & Reiss, 2004). The narrative is focused on the opportunity for the German HTR reactor technology to become an export hit in the wake of the exponential growth in energy demand (a common narrative in pro-nuclear

---

[11] The Intergovernmental Panel on Climate Change (IPCC) defines “technology dumping” as “[t]ransfers to developing countries of older technologies whose environmental performance is lower than that of average technologies used in developed countries” (Bert Metz, 2000). I am using the term with respect to “safety performance” rather than “environmental performance.”

[12] “Prof. G. Lohnert erhält den Chinesischen Staatspreis 2009”, Institute of Nuclear Technology and Energy Systems, http://www.ike.uni-stuttgart.de/aktuelles/archiv/preis_lohnert.html

media representations) of the Chinese economy forecasted at that time. The article also recounts the TMI accident and Lohnert's contribution to the mitigation of the accidents consequences as well as the problems with the Hamm-Uentrop reactor in the voice of the security expert Wolfgang Kröger—then safety surveyor at the Jülich research center. The article ends with the following quote from Kröger *(emphasis added)*:

> "It would be a mistake to inconsiderately give up nuclear technology for all times. Yet for being successful, it is crucial for the population to *tolerate* the facilities. Without this prerequisite it will not be possible to enforce a reactor in future as well" (Klose & Reiss, 2004, p. 67).

The idea that the population must tolerate nuclear technology in order for the latter to survive represents the social component of the sociotechnical imaginary of the fault tolerant, "forgiving" reactor. The imaginary of the forgiving reactor, invoked in Kröger's statement, subtly hints towards the intertwinement and co-production of technoscience and society: the technology's tolerance of human errors must be met with tolerance on the part of society. In the lack of this sociotechnical contract, neither technology nor society will thrive, as (energy) demanding times lie ahead.

Looking back at the Chernobyl accident, which took place in a country having a totalitarian regime (like today's China), one finds that the population's "tolerance" for different technologies in these countries may well be mistaken with the inability of the population to raise an opposing voice or simply ignorance on the part of a population confronted with more stringent everyday shortcomings. In this context, it is reasonable to regard the technological transfer of the German HTR reactors to Asia and Africa as a technology dumping rather than the adoption of a ground-braking technology by a visionary government. In the absence of a working democratic system, the sociotechnical imaginary of the forgiving reactor becomes less social than technical, and thus more technocratic.

From a decommissioning point of view, the imaginary of small modular reactors spread around the country according to local energy demands (Carper & Schmid, 2011) threatens to be a financial disaster for local communities. That is because the decommissioning of a nuclear reactor is often more expensive that its construction and the problem of a final disposal nuclear waste still remains to be solved[13]. Also the problem of who is liable for the decommissioning is unclear, both in China and in Germany. The FACTS article quotes the collective voice of city managers from the whole of China asking "How much are the things [reactors] supposed to cost?" (Klose & Reiss, 2004, p. 65). There are at least two possible versions of this question: With or without decommissioning and waste disposal? Yet it remains unclear from their question, which of the two answers the Chinese city managers hope to get.

---

[13] The Swiss documentary "Die Reise zum Sichersten Ort der Erde" follows Charles McCombie, one of the most renowned expert on nuclear waste disposal, around the world in his unsuccessful search for a final nuclear waste disposal location: http://www.diereisezumsicherstenortdererde.ch/

4.2 The Sociotechnical Imaginary of Preparedness

In Germany, the Chernobyl accident from 1986 has led the social-democrat lead German government from that time to issue a moratorium on nuclear energy production. The moratorium stated that new NPPs could no longer be built on German ground while the operation of existing NPPs was allowed until the end of their lifetime. The rationale behind the moratorium lay in *compromise* and *preparedness.*

While the risks associated with operating NPPs were proven real, the technology was considered a necessary compromise for bridging the decades to come until some novel, less risky technology would reach the brake-even point (i.e., the ability of a power-plant technology to produce more energy and energy than required for its mere operation). The compromise thus consisted of a commitment to continuously improve the safety of existing operational NPPs while searching for alternative solutions. The conservative *imaginary of continuous improvement* attracted most German nuclear experts, who did not stand behind the imaginary of the forgiving reactor (a generation IV technology). What is important about this imaginary of continuous improvement is that it acknowledges the possibility of radioactivity breaching out of the containment building; and that this risk needs to be addressed through active and passive safety systems. In doing so it shifts the emphasis from the containment of a physical force (radioactivity) to the management and mitigation of risk. While risk cannot be effectively contained (not even within the realms of an imaginary) it can be minimized through continuous improvement of safety systems. Also, risk can be diluted when it crosses from one epistemic boundary to another. This epistemic crossing of boundaries is illustrated by the sociotechnical risk transmutation process discussed in section 2.5.

Focusing on risk rather than physically containing radioactivity under all circumstances apparently provides more levers for limiting the effects of realized risks. Experts and systems can work together towards minimizing risks at all levels in the risk chain. Solutions for mitigating the effects of realized risks can also be specially tailored for each type of risk. This way, it is hoped that, overall, both the risk and the effects of realized risks can be diluted over time and as radioactivity reaches farther out, provided that continuous technological improvements are installed regularly and methods targeting each stage of the risk chain are developed. By contrast, the forgiving reactor is designed to address first level risks only (i.e., technical failures leading to accidents).

The notion of risk thus becomes the epistemic focal point in the post-Chernobyl period when it comes to dealing with reactor safety and nuclear accidents. In this context, risks functions as a currency (Beck, 1992) insofar as it guides investments into the development of systems specialized in the management and mitigation of risk. The ability to manage and mitigate risk represents the substance of *preparedness*. Unfortunately, both the imaginary of preparedness and that of continuous improvement leave the impression of “organized irresponsibility” (Beck, 1992) since they divide responsibilities for managing risks among several loosely coupled agencies without providing any tangible guarantees that these risks can be effectively mitigated by any of these agencies at every stage of the sociotechnical risk transmutation process.

4.2.1 Nuclear Emergency Response

In the fall of 1986, perhaps motivated by the Soviet authorities' failure to communicate about the accident early enough to enable an appropriate international protective response, the International Atomic Energy Agency (IAEA) negotiated the signing of the "Convention on Early Notification of a Nuclear Accident"[14] by all IAEA member countries. The convention states that, in the event of a nuclear accident, the responsible state must immediately provide the IAEA and other potentially affected states "with such available information relevant to minimizing the radiological consequences in those States, as specified in article 5." Among other essential pieces of information like the time, location, and nature of the accident, the convention requires the communication of the foreseeable development of the nuclear accident, the general characteristics of the radioactive release (i.e., what is nowadays referred to as the source term), current and forecast meteorological data, off-site protective measures taken or planned, and the predicted behavior over time of the radioactive release.

With the IAEA early notification convention, nuclear emergency response becomes one of the main levers of preparedness. In case of a nuclear accident, in the country responsible for the accident as well as in other potentially affected countries, government-assigned specialized task forces are called upon to manage the crisis. These task forces must use the data provided by the state in which the accident happens in the best possible way to the end of taking effective countermeasures for which they will be held accountable. Considering that most IAEA member countries have never experience a nuclear accident and perhaps never will, preparations for a real accident are usually taken on the basis of scenarios derived from the accidents that happened in other geographical, political, and socio-cultural contexts. To cope with missing accident experiences, nuclear emergency preparedness experts also need to draw upon hypothetical scenarios anchored in the specificities of the local nuclear facilities, regulatory systems, physical environments, local communities, and culture in their own countries.

4.2.2 Epistemic Sources for Nuclear Preparedness

In practical terms, preparedness mostly depends on three epistemic sources: (1) Experience and data gained in real accidents, (2) regular exercises (called drills) which are also based on the imagination of the emergency preparedness experts, and (3) computer simulation. The experience and data gained in real accidents is the most valuable of the three sources, yet limited and expensive. The cost is not only financial but also social and political, since those in charge of carrying out emergency response actions are also those who are most likely to be held accountable for any mistakes. Responsibility thus breeds accountability and the two, as collective traits of technopolitical culture, may vary extensively from one country to another. The Chernobyl accident has been perceived in Western countries as a badly

---

[14] https://www.iaea.org/publications/documents/treaties/convention-early-notification-nuclear-accident

managed covered-up nuclear emergency. The Cold War circumstances made it easy to blame the Soviet authorities for their sloppiness. The Fukushima accident also triggered lively debates about the Japanese way of managing the disaster and the entangled relationship between the Japanese government and the nuclear industry of that country. This complex institutional relationship is believed to have produced a flawed regulatory system (Bundesamt für Strahlenschutz, 2012). The local technopolitical culture thus plays an important role when it comes to responsibility and accountability for the consequences of nuclear accidents. As Jasanoff, Kim, and Sperling note (Jasanoff, et al., 2007), in Germany the (techno)political culture is rather corporatist, which hints toward a similar entanglement between government and industry as in Japan.

The second important epistemic source for nuclear emergency response is represented by regular drills and imagination. Here again, local cultural specificities are likely to lead to different understandings of the role and goals of drills in the larger emergency preparedness context. In Germany, annual drills involving NPP operators and local authorities are compulsory. In Baden-Württemberg and other German federal states, every year another NPP is chosen for a two day accident simulation. Sometimes several exercises take place within one year. Preparations for these drills are extensive and follow precisely defined goals and priority. Example goals and priorities include (Wilbois, et al., 2009):

- *Biblis (September 2008)*: During a simulated incident in the Biblis NPP the main focus was on the exchange of data between authorities of the affected German federal states, notably Baden-Württemberg, Rheinland-Pfalz, and Hessen. The Biblis NPP is currently being decommissioned.

- *Fessenheim (November 2008)*: The focus was on the use of the computer simulation environment (DSNE system), the collaboration, and the synchronized exchange of information between the French IRSN and the German experts. The IRSN provided the source term of the hypothetical leak of radioactive materials. Another goal was to test the collaboration between the "Groupe d'Intervention Robotique sur Accidents" (INTRA) and the "Kerntechnische Hilfsdienst GmbH" (KHG). These analogous organizations are in charge of carrying out real-time field measurements using mobile measurement units. The Swiss “Nationale Alarmzentrale” (NAZ) was also involved in the exercise.

- *Neckarwestheim (February 2009)*: In this drill the focus was on the facility itself in the context of a hypothetical leak from the second block of the NPP at Neckarwestheim (in 2011 this one was shut down as a consequence of the Fukushima accident). Being focused on the actual reactor facilities, the exercised emphasized the collaboration between the German agencies in charge of taking emergency response actions. These are the prime-minister's office "Regierungspräsidium" (RP) in Stuttgart, the Ministry of the Environment, the NPP operator, the KHG, and the "ABC-Erkunder"—mobile terrestrial measurement units carrying out radioactivity and meteorological measurements, which are usually part of the local (voluntary) fire-fighting departments (Figure 6).

Figure 6 – Picture of a mobile terrestrial measurement task force next to a vehicle carrying measurement apparatus. The sign "Bevölkerungsschutz" reflects the responsibilities assigned to the members of the team by the Interior Ministry[15].

The summaries of these drills provide excellent insights into the performative dimension of the imaginary of preparedness. As Jasanoff notes (Jasanoff, 2015), socio-technical imaginaries imply agency and exercises such as the ones summarized above are meant to roll-out agency in the absence of the actual threat. In this sense, some aspects of the drills are of special interest. The preparations are remarkably precise. The type and location of the imagined accidents is well-known long before the exercise. The actors do have enough time to prepare thoroughly. The collaboration and information exchange between different agencies is carefully synchronized. This perfect orchestration is characteristic of the exercises carried out before the Fukushima accident. Emergency response agencies involved in the drills must correlate their actions which requires and intensive exchange of information between them. In contrast to the actual course of events occasioned by the Fukushima accident, this perfect orchestration seems rather artificial and reveals some of the cultural traits and reflexes of the participants to the exercises, which nurture the imaginary of preparedness. These are (1)

---

[15] Source: http://www.of-stadtmitte.de/bilder/berichte/gefahrstoffzugausbildung30052013/Gefahrstoffzug_Ausbildungsdienst_30052013_4.jpg

a strong belief in the usefulness of planning and preparations, (2) the practice of gradual improvement (from one exercise to another), and (3) rehearsal as a means for improving preparedness.

While being perfectly legitimate and useful, this particular practice of preparedness is reminiscent of the usual preparations for theatrical performances. In this context, the fictitious audience is likely to play an important role in these exercises. The fact that drills are carefully planned, as do most things in Germany, is natural from a cultural anthropology point of view. As Edward T. Hall notes, people are unable to think outside their cultural system and logic (Hall, 1989). While the logic of the drills is based on preparedness, improvement, and rehearsal, the logic of accidents might be very different, requiring a great deal of improvisation. Yet, as Hall further notes, humans are unable to evaluate the effectiveness of their own cultural reflexes with respect to dealing with a particular situation or problem unless they are confronted with the logic of another culture. This is why some decisions taken in nuclear emergency response situations might be perceived as mistakes by experts from other countries. That is because acting according to the logic of the accident in the context of one's own culture of preparedness is difficult to explain to outsiders. The logic of accidents can only be fully understood post-factum, which leads to hindsight (Felt, 2014).

Finally, computer simulation represents the third main source of knowledge for managing nuclear emergencies. When radioactive materials are released into the environment, they disperse according to the laws of fluid dynamics in water an in the atmosphere. Provided that emission and meteorological data are available, atmospheric dispersion simulation programs can be used to forecast the trajectory and concentration of substance (of any type) present in the atmosphere at any given location and time after the release. Before the introduction of computers, dispersion calculation used to be carried out manually by experts. Atmospheric dispersion simulation codes (henceforth referred to as dispersion codes for succinctness) represent the core of any DSNE system. After the TMI accident, dispersion codes created and used to deal with any kind of air pollution since the 1950s were adapted for the case of radioactive materials. The first atmospheric dispersion model is based on the Gaussian law of dispersion. That is, due to atmospheric turbulence, a fluid will disperse in all directions equally such that the concentration of substance has a Gaussian distribution is space. Since wind will carry away some of the substance, the resulting plume has the shape of a cone, as illustrated in Figure 7.

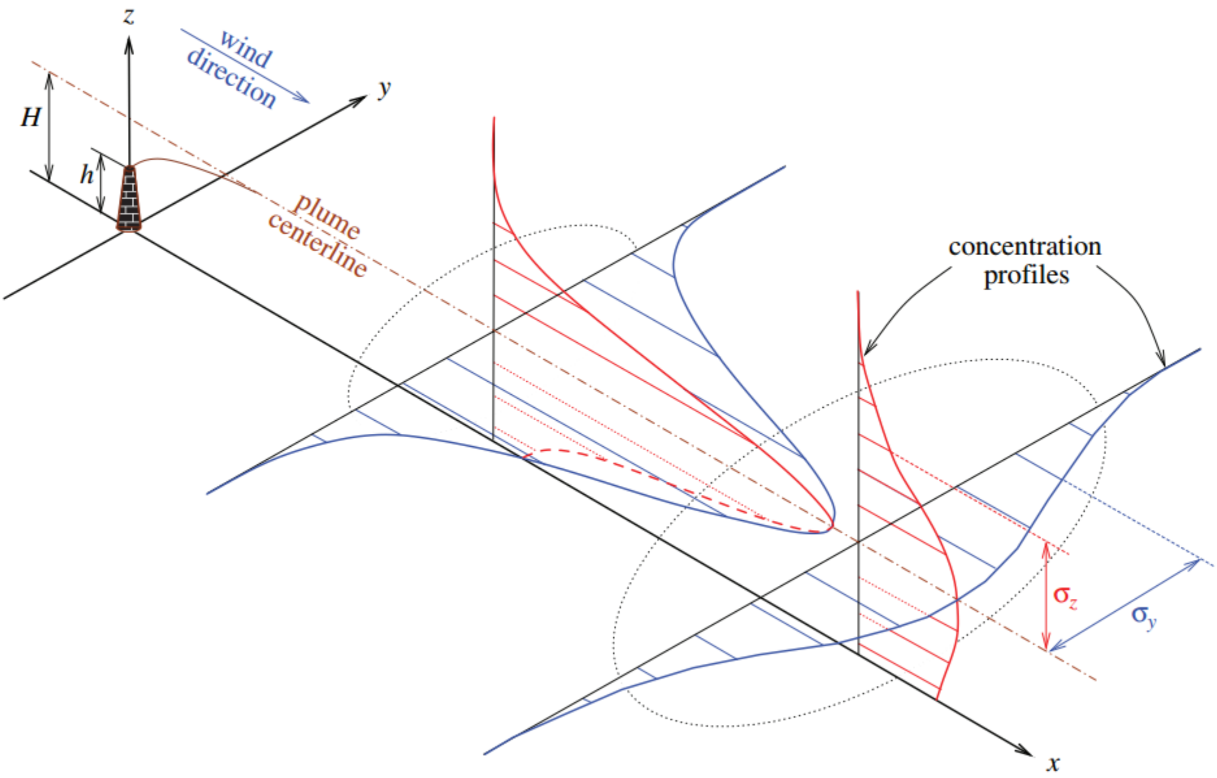


Figure 7 – The Gaussian Plume atmospheric dispersion model *(Stockie, 2011)*.

Radioactive materials will decay and release energy-laden alpha (Helium nuclei), beta (electrons and positrons), and gamma (photons) particles, which spread at approximately the speed of light in all directions. Gamma radiation will also reach the ground. Some of the radioactive materials will fall out due to the force of gravity and another fraction of the released substance may be washed out by rain. After the Chernobyl accident, radioactive materials were washed out by rain, which triggered an important wave of psychosocial discomfort in West-Germany at that time.

From an epistemic point of view, atmospheric dispersion forecasts provide compelling visualizations of risk, albeit reflecting strongly simplified abstractions of reality. In the context of the imaginary of preparedness, dispersion forecasts also provide a means for supporting collective imagination. Dispersion forecasts aggregate various human and computer-generated imaginations about radioactive clouds travelling across possibly vast territories. These imaginations are unified within a single color-coded image, which has the advantage of visibility over the mental representations of individuals about the physical phenomenon being visualized. Being the product of the collective effort of numerous experts provides dispersion forecasts higher legitimacy and trustworthiness than individual predictions and imaginations in a real nuclear emergency. Yet, whenever accurate measurement data are not available, DSNE systems will produce false forecasts, which adds to the inherent uncertainty embedded in the dispersion models. In real emergencies, concerns about the uncertainty that lurks in both the input data and in the simulation models may crystallize in the minds of the experts from the nuclear emergency task force. These concerns, which might impede members of the task force from taking the best possible decisions, provide a rationale for the imaginary of preparedness and all the activities and practices of the ABR-KFÜ thought collective. In this context, learning how to trust dispersion forecasts and how to make decisions in the presence of uncertainty in the input data and in the dispersion models implemented by the DSNE system in stress situations becomes a core practice of preparedness in the ABR-KFÜ group.

***

Sections 4.2.3 through 4.2.7 are based on the insights obtained from an interview with the head of the Department of Knowledge Management and Engineering at the Institute of Nuclear Technology and Energy Systems (IKE) at the University of Stuttgart. Over the past 25 years, the IKE has been contracted by the Ministry of the Environment of Baden-Württemberg to develop and maintain the simulation engine of the ABR-KFÜ DSNE system. Dr. S.[16] is also a permanent expert advisor to the nuclear emergency task force.

4.2.3 The Role of DSNE Systems for Nuclear Emergency Management in Germany

In Germany, the individual state governments are in charge of taking immediate countermeasures in nuclear emergencies. On the long term, the federal government takes over this responsibility. In Baden-Württemberg, the crisis cell or emergency task force (called “Krisenstab” in German) is formed by employees of the Environment Ministry and supported by expert advisors. The crisis cell communicates with the operators of NPPs. The names of the members of the crisis cell are usually not made public. In real emergencies, the crisis cell makes recommendations to the political branch of the local government (in BW: *Regierungspräsidium*), which is in charge of implementing the countermeasures.

The NPP operators must provide emission data from on-site measurement stations. Other measurement values are collected by measurement stations maintained by the Environment Ministry. In addition, the Federal Office for Radiation Protection provides helicopters endowed with mobile emission measurement devices. Such helicopters were also used around Fukushima since on-site measurement devices had been destroyed by the tsunami wave. A company called KHG is also prepared on call to provide mobile measurement services as well as to distribute iodine tablets if needed. Iodine tablets are distributed to the population when a high amount of radioactive iodine is released from an NPP. They prevent the radioactive iodine to be absorbed by the thyroid gland. The crisis cell has four subunits:

- Unit N – Nuclear Protection Unit
- Unit K – Coordination unit (infrastructure and telephones)

---

[16] The abbreviation “Dr. S.” will be used throughout the text to refer to the interviewee, who informed me about the workings of the workings of the nuclear emergency task force and the regular activities of the ABR-KFÜ collective.

- Unit T – Technical unit concerned with assessing the technical situation of the affected NPP and the course of the accident
- Unit S – Radiation protection unit, which assesses the radiological situation with the help of the DSNE system, experts, and different measurement units.

Unit N is the one that takes the final decision upon the recommendations which are forwarded to the team in charge of implementing the countermeasures. Finally, the Minister of Environment announces eventual countermeasures. However, this has never occurred in Germany.

The members of the crisis cell are regular employees of the Ministry of Environment. The 12 members of Unit S are either natural scientists (i.e., physicists, chemists, etc.) or engineers. Unit N is composed of administrative staff and politicians. Unit K is formed by administrative staff and logistics specialists. Finally, the members of Unit T are also natural scientists or engineers. In total the crisis cell is composed of about 40 people. The technical experts from the crisis cell stay on their job for a long time whereas the politically-assigned members are usually affiliated to the governing party.

The composition of the crisis cell reflects the model of science advisors assisting politicians in the decision making process. The crisis cell and the decision making process are hierarchical and clear. This is likely to avoid confusion and decisional deadlocks in real emergencies, although, hypothetically, opposition to orders cannot be ruled out. The composition of the crisis cell—with experts having permanent positions and politicians temporary positions—reflects the fact that the responsibility for eventual unfortunate decisions is strictly of a political nature.

4.2.4 DSNE Systems as Non-Human Experts in Nuclear Emergency Management

The ABR-KFÜ DSNE system, with its current architecture, was first introduced in 1990 as a reaction to the Chernobyl accident. The financial support of the system came in form of different research grants for PhD students until 1997. Afterwards, the Environment Ministry started supporting the system financially. Prior to its introduction, the data acquisition and the atmospheric dispersion modeling software were not coupled and so the dispersion simulation programs needed to be fed with data manually. The SSK guideline for the expert advisor for radiation protection (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2004) is older than the ABR-KFÜ system and was initially used to carry out dispersion forecasts manually. SSK guidelines are not legally compelling and thus there are no legal consequences if experts choose not to follow it in greatest detail.

The main purpose of the ABR-KFÜ system is to automate and speed up calculations and data transferring tasks that initially could have been carried out manually. To do so, it had to encompass the expertise of those people who used to carry out these calculations manually, i.e., atmospheric physics and dispersion models, meteorology, radiology and nuclear science, and mathematics. With the advent of more refined models (i.e., Lagrangian particle model) and powerful computers, the simulation programs became complex to such an extent that it would be impossible to carry though an entire simulation by hand, with would require millions of individual calculations. In other words, the programs currently are able to do in a few minutes what a single person would be able to accomplish in weeks or months. For this reason, DSNE systems have become irreplaceable non-human experts, the development of which follows the scientific advancement and new empirical insights gained through experiments and during the assessment of the effects of real accidents.

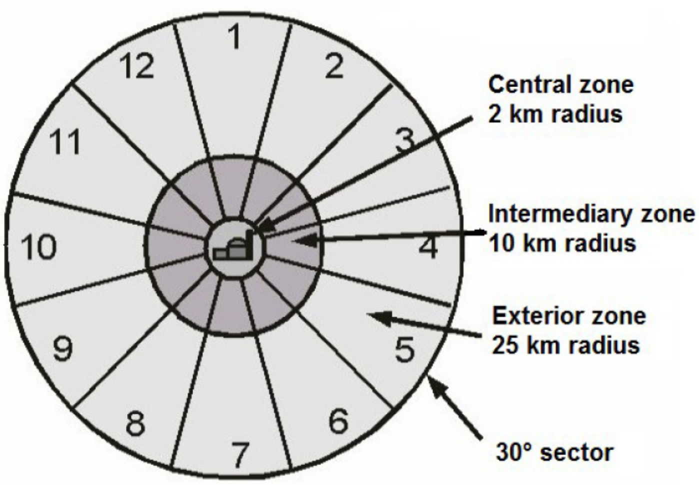


Figure 8 – The division of the monitored area into sectors and radial discs as defined by the German Federal Office for Radiation Protection *(Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2004)*.

In a real emergency, the DSNE system is either triggered automatically when measured emission values exceed a certain threshold or when the NPP operator signals a dangerous technical incident. When such an alarm is triggered, the crisis cell assembles (in approximately 1-2 hours) in the building of the Ministry of Environment. The first dispersion forecasts are used to take decisions upon eventual countermeasures in the monitored area around the affected reactor(s). The monitored area is divided in 12 sectors around each NPP, as shown in Figure 1. This division is based on the Gaussian plume model for atmospheric dispersion, according to which in steady wind conditions, the radioactive plume takes the shape of a cone with the origin near the release site (see 4.2.1). The area, for which the local authorities are in charge, is a disc having a 100 km radius. There are basically 4 possible recommendations that the crisis cell can make for each sector:

- Stay inside the house
- Take iodine tablets
- Temporary evacuation
- Permanent evacuation

In addition, a 2-5 km zone around the emission point is evacuated regardless of the amount of released substances, if an event qualifies as an accident. When time and space are taken into consideration, the complexity of the task of making recommendations for each sector of the monitored area explodes. For evacuations, there exist contingency plans and the actions are coordinated by local authorities from each locality. Police may assist the evacuation process.

Assessing the trustworthiness of dispersion forecasts in a real emergency is perhaps the most difficult task of the members of the crisis cell. There is a certain confidence is the DSNE system on the part of the members of the crisis cell, yet there also exists an awareness of the fact that they entail a certain level of uncertainty. The main concerns are with the temporal course of events, the affected sectors of the monitored area, the uncertainties in the source term, and the uncertainties in the meteorological data. Simulation programs are usually considered reliable, which is the result of constant validation and verification work. Nevertheless, plausibility checks and mental assessments are performed by the members of Unit T (note that the dispersion forecasts are primarily performed, assessed, and translated into recommendation by the members of Unit S, so Unit T performs an independent cross-check). Under these circumstances, consensus upon the recommendations for countermeasures in usually reached relatively fast. This is due to the experience and competence gained by all members of the crisis cell during regular trainings and drills.

From an epistemic point of view, there are at least two main differences between the experts from the crisis cell and the DSNE system, as a non-human expert. First, the former can quickly adapt to a new modeling requirement that may become relevant in the course of an accident, while the latter cannot. For example, the ABR-KFÜ system was not able to carry out dispersion simulations with several emission phases and, after the Fukushima accident which revealed the need for such a feature, it had to be tweaked by its developers impromptu so as to allow this type of simulation. This has now become a standard feature of the system. In other words, the non-human expert is unlikely to adapt to a new situation and can only be made to do so by human experts in a variable amount of time. For this reason, the term “knowledge objects” introduced by Merz captures the epistemic inertia of simulation codes (Merz, 1999). Second, the non-human expert cannot meaningfully check its own results on the fly by default. That is, it cannot validate its own calculations without external assessments. In safety-critical software running in airplanes and vehicles, such assessments are performed automatically by means of specialized design patterns (Ionescu & Scheuermann, 2016b). In the case of DSNE systems, the experts from the crisis cell have to perform plausibility checks and assess the trustworthiness of dispersion forecasts.

Human and non-human experts thus find themselves in a relation of interdependence. While the use of DSNE systems has become commonplace, just as Latour’s door hinges (Johnson, 1988), they depend on constant fostering by human experts. In a sense, DSNE systems as non-human actors have become the obligatory passage point (Callon, 1984) for data and decisions in nuclear emergencies and the network of actors has stabilized around them. For the members of the crisis cell, it is currently unconceivable to not use a DSNE system for managing a nuclear emergency.

4.2.5 Issues of Communication, Media Representation, and Participation in Nuclear Emergency Management

Because a nuclear accident with serious consequences has never occurred in Germany, the entire emergency response planning is based on an imaginary involving an entire range of governmental and non-governmental institutions as well as the people residing in the affected areas. This imaginary is rehearsed through trainings and drills yet none of these preparatory activities involve the public. The members of the crisis cell are aware of the fact that the drills and trainings would be more useful if the public would be involved in them. This way, the imaginary would become somewhat more realistic and procedures could be improved. How this can be practically realized remains an open issue. Nevertheless, in Germany, there exists a guideline published by the SSK that prescribe how the crisis communication should be organized in order to improve the effectiveness of countermeasures (Strahlenschutzkommission, 2007). The guideline recommends that each institution which has got something to do with nuclear science and engineering, including research institutes, should prepare and rehearse their own process for communicating with the public in case of a nuclear emergency. These processes are to be taken seriously by each of these institutions in order to be able to provide an effective orchestrated response in the case of a real emergency. The guideline further specifies how communication with other public institutions and the media is to be conducted using official statements, press declarations, press conferences, interviews, on site visits of the damaged facility, discussion rounds in TV and radio shows, etc. All of this is accompanied by a set of rules for effective communication as well as a set of measures for assessing the effectiveness of the communication. Besides the inter-institutional communication channels and the media as a risk message relaying tool, the document specifies the possibility of organizing direct public encounters between risk communicators and people from outside the usual organizations directly concerned with nuclear emergency response issues.

There are two basic assumptions that pervade the content of the document and thus reflect the mindset of its collective author. The first one reflects a deficit model:

> “The scientific fundamentals necessary for assessing the risks arising from exposure of radioactive material are not an integral part of the general education of the population. Accidents during which radioactive substances are released or may be released can cause anxiety in the population, which can stand in the way of an orderly implementation of countermeasures.”

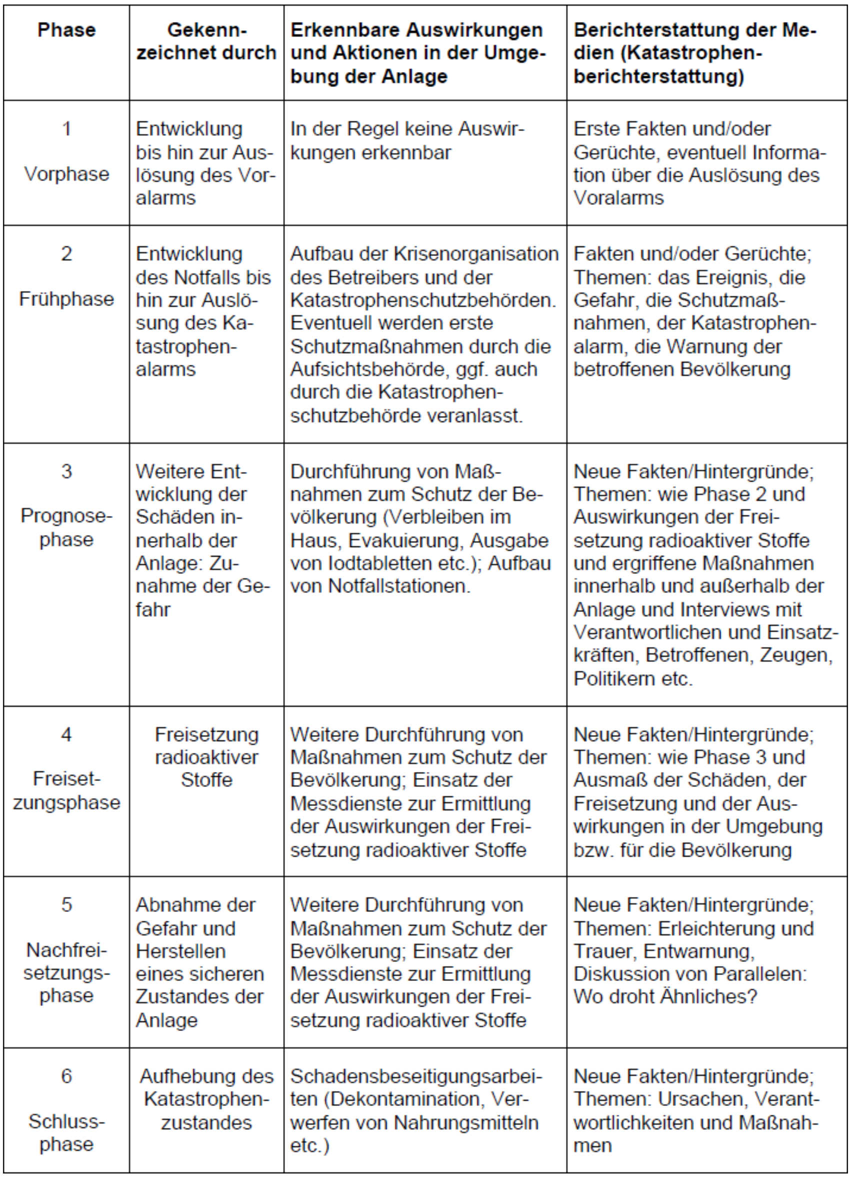
The communication guideline aims at coping with this deficit of knowledge on the part of the population in the context of the need for orchestrated actions by the accident stakeholders to the end of mitigating the accident’s effect in an orderly way. Part of this action must be to fast-forward on making the effects of radioactivity on humans clear to a wide audience by means of an impromptu knowledge transfer. For example, at the time of the Fukushima accident, some German newspapers created compelling e-learning portals in order for people to have access to a carefully selected knowledge base, which the authors believed to help readers better understand technical issues in a relatively short time (Ionescu, 2012).

In line with the deficit model and concerned with the typical media representations of nuclear emergencies, Dr. S. points out another problem which is likely to appear during nuclear accidents: the communication of eventual countermeasures. According to Dr. S., the population does not easily grasp the fact that the meteorological situation is variable and therefore areas and communities that are not affected at some point might be at a later time. If people would participate in the drills, they would presumably see how the radioactive plume or cloud changes route, which would enable them in real situations to accept this variability and cooperate much better. As the Fukushima accident showed, the media will be first to communicate the radiological situation on a wide scale. According to Dr. S., the content of these first broadcasts is likely to be based on the first communiqués of the crisis cell and will be exaggerated so as to give it an anti-nuclear flavor. Dr. S. also considers that nowadays the media fails to report in a realistic fashion about radioactivity. In this context, the problem of the credibility of the first source emerges. The aspect of credibility together with the temporal variability of the radiological situation poses the greatest issues both in terms of logistics and communication. The actual assessment of the radiological situation does not pose a major problem in spite of the uncertainties of the models and the input data. These insights show that within the imaginary of preparedness a deficit model is at work: the public should be able to understand the variability of the radiological situation and other bits and pieces of scientific facts about radioactivity. Dr. S. further suggests that public participation to trainings and drills might improve the effectiveness of nuclear crisis management and consequence mitigation procedures.

The second strong assumption present in the guideline for public communication during nuclear emergencies is that accidents themselves are likely to obey an orderly course, with a precise beginning and an end. Table 1 illustrates the phases which are believed by the authors of the document to be typical for nuclear accident to go through. The table is introduced with the following remark:

> “An emergency at a nuclear installation can 'announce' itself by means of an initial fault or can be suddenly triggered by a single event; whereas the case that a malfunction or an incident precedes the emergency is more likely.”

Table 1 – Alleged phases of a typical nuclear accident (Strahlenschutzkommission, 2007).



Phase	**Gekenn-zeichnet durch**	**Erkennbare Auswirkungen und Aktionen in der Umgebung der Anlage**	**Berichterstattung der Medien (Katastrophen-berichterstattung)**
1 Vorphase	Entwicklung bis hin zur Auslösung des Voralarms	In der Regel keine Auswirkungen erkennbar	Erste Fakten und/oder Gerüchte, eventuell Information über die Auslösung des Voralarms
2 Frühphase	Entwicklung des Notfalls bis hin zur Auslösung des Katastrophen-alarms	Aufbau der Krisenorganisation des Betreibers und der Katastrophenschutzbehörden. Eventuell werden erste Schutzmaßnahmen durch die Aufsichtsbehörde, ggf. auch durch die Katastrophen-schutzbehörde veranlasst.	Fakten und/oder Gerüchte; Themen: das Ereignis, die Gefahr, die Schutzmaß-nahmen, der Katastrophen-alarm, die Warnung der betroffenen Bevölkerung
3 Prognose-phase	Weitere Entwicklung der Schäden innerhalb der Anlage: Zunahme der Gefahr	Durchführung von Maßnahmen zum Schutz der Bevölkerung (Verbleiben im Haus, Evakuierung, Ausgabe von Iodtabletten etc.); Aufbau von Notfallstationen.	Neue Fakten/Hintergründe; Themen: wie Phase 2 und Auswirkungen der Freisetzung radioaktiver Stoffe und ergriffene Maßnahmen innerhalb und außerhalb der Anlage und Interviews mit Verantwortlichen und Einsatz-kräften, Betroffenen, Zeugen, Politikern etc.
4 Freiset-zungsphase	Freisetzung radioaktiver Stoffe	Weitere Durchführung von Maßnahmen zum Schutz der Bevölkerung; Einsatz der Messdienste zur Ermittlung der Auswirkungen der Freisetzung radioaktiver Stoffe	Neue Fakten/Hintergründe; Themen: wie Phase 3 und Ausmaß der Schäden, der Freisetzung und der Auswirkungen in der Umgebung bzw. für die Bevölkerung
5 Nachfrei-setzungs-phase	Abnahme der Gefahr und Herstellen eines sicheren Zustandes der Anlage	Weitere Durchführung von Maßnahmen zum Schutz der Bevölkerung; Einsatz der Messdienste zur Ermittlung der Auswirkungen der Freisetzung radioaktiver Stoffe	Neue Fakten/Hintergründe; Themen: Erleichterung und Trauer, Entwarnung, Diskussion von Parallelen: Wo droht Ähnliches?
6 Schluss-phase	Aufhebung des Katastrophen-zustandes	Schadensbeseitigungsarbeiten (Dekontamination, Verwerfen von Nahrungsmitteln etc.)	Neue Fakten/Hintergründe; Themen: Ursachen, Verantwortlichkeiten und Maßnahmen

The table provides a back-to-back comparison of what can be observed in an around an affected reactor in case of a “well-behaved” emergency and the expected typical media representation of that information, as it transpires from the source through official and unofficial ways. The table entries for the phases 3 and 6 illustrate some important features of the German sociotechnical imaginary of preparedness. Phase 3 is called the prognosis phase, during which the radiological situation is forecasted (presumably with the help of DSNE systems) and decisions upon countermeasures are implemented. In this phase, the media is expected to “play along” by supporting the work of the experts. The official line of communication is to be reiterated in broadcasted interviews with the people in charge of carrying out the countermeasures as well as with politicians and witnesses. The imaginary of preparedness thus counts on a helpful, selfless mass media that will diligently reiterate the information emitted through official communication channels, while trying to complement it with reinforcing testimonies of the people in the field and witnesses. In the last phase of the accident, while different emergency task forces are effectively cleaning up after the accident, the mass media becomes the scene of public debate and judgment about the accident's causes, the actors responsible for it, and the countermeasures that have been taken to mitigate the accident's effects. Again, this expectation is one of total collaboration on the part of the mass media, which is now granted power of judgment.

The German imaginary of preparedness thus assumes a controllable physical and social world order, with accidents and the mass media obeying predefined courses of action. Moreover, the media is expected to serve the purposes of limiting damage and reestablishing sociotechnical consensus. Unfortunately, the Fukushima accident showed that many of these expectations will not be met. Nuclear accidents are more likely to develop suddenly, to have a much longer than expected phase 4 and to never reach phase 6. Instead, they may linger on for years in what resembles to be phase 5 in Table 1. In the era of the new media, information sent though unofficial channels and uncontrollable social media platforms, like Twitter and Facebook, is likely to reach the population much faster than conventional media and be more persuasive than the official "Katastrophenberichterstattung" (disaster reporting). Also, part of the commercial mass media will diligently work to prove everything that is being done to mitigate the crisis wrong. Newspapers around the world will be full of atmospheric dispersion forecasts showing how radioactivity is about to reach the farthest corners of the planet, whereas NGO (non-governmental organization) activists are likely to factually counter the public statements of official representatives of the crisis task force.

4.2.6 Concerns of the Task Force Members Regarding the Use of DSNE Systems

Since dispersion forecasts depend themselves on emission and meteorological data as well as computer simulation programs, a series of concerns emerge rather naturally. The main concern is with the reliability of the data, which is usually provided by NPP operators and national weather services (in German the DWD – Deutscher Wetterdienst). If the measured or forecasted data are flawed, so will the dispersion forecast be. However, measured emission data are usually considered reliable and in Germany the network of measurement stations for radioactivity is dense, whereby only high-quality devices are used. Measured wind speed and direction, atmospheric pressure, and temperature data are also fetched from a large number of weather stations and are usually considered reliable. Problems may occur when measurement data are not available for different reasons (e.g., a sparse network of measurement devices or defective devices due to other meteorological events). Also, decision makers are interested in longer term forecasts in order to prepare suitable countermeasures, in which case weather and emission forecast data are used. In either case, the members of the crisis cell are the ones in charge of assessing the trustworthiness of emission and meteorological forecasts, as well as of dispersion forecasts.

Another concern is of epistemic nature: how reliable are the computer simulation programs and data preparation software tool chain (e.g., on the part of the weather service) considering that they are based on software implementations of numerical schemes for complex physical models for atmospheric dispersion? It is well known from the specialized literature (Ionescu & Scheuermann,

2016) that computer programs can only be made asymptotically error free with considerable financial efforts and a high level of software engineering expertise. Furthermore, the physical models themselves are generally subjected to a small number of validation experiments based on well-known datasets (e.g., European Tracer Experiment). In this context, the members of the crisis cell must carefully take into consideration all these concerns under the pressure of a real nuclear emergency. Other concerns of the members of the crisis cell in a real emergency include:

- Reaching consensus concerning the radiological situation and the countermeasures needing to be taken,
- Logistical aspects of allocating appropriate and sufficient resources and coordinating countermeasures,
- Communicating the radiological situation and decisions upon countermeasures to public audiences,
- Ensuring the effectiveness of the implementation of countermeasures in the field,
- Adapting countermeasures to the dynamics of the accident and to the changing weather conditions,
- Maintaining a continuous and consistent channel of communication with the people residing in the areas affected by radiation, and
- Accountability for erroneous decisions entailing possibly harmful effects both in terms of resources and health.

4.2.7 Communication Channels and Preparatory Activities of the ABR-KFÜ Collective

Figure 9 summarizes the main communication channels and preparatory activities of the ABR-KFÜ working group. Besides the regular exchanges with a large research community and the continuous flow of new research results facilitated by the HARMO conferences and a number of specialized scientific journals (e.g., Atmospheric Environment, Environmental Modelling and Software, etc.), the ABR-KFÜ group also considers the newest developments in numerical simulation and software engineering, which are essential for meeting the performance and reliability requirements for a safety-critical software-based decision-support system. Regular exchanges with other government agencies, such as the BfS, the GRS (*Gesellschaft für Anlagen- und Reaktorsicherheit*), and the Swiss ENSI, are also part of the group’s responsibilities, besides the continuous reviewing of the regulatory guidelines for radiological protection[17] to the end of keeping the ABR-KFÜ system aligned with them. Perhaps for cultural and geographical reasons but also because of the radioactive washout from Chernobyl, the ABR-KFÜ collective has more contacts with their Swiss colleagues at ENSI than with experts from other parts of Germany, with the exception of the federal institutions like the BfS the society for facility and reactor safety (GRS).

---

[17] General Recommendations for the Remote Monitored of Nuclear Power Plants: http://www.verwaltungsvorschriften-im-internet.de/bsvwvbund_12082005_RSII51703134.htm

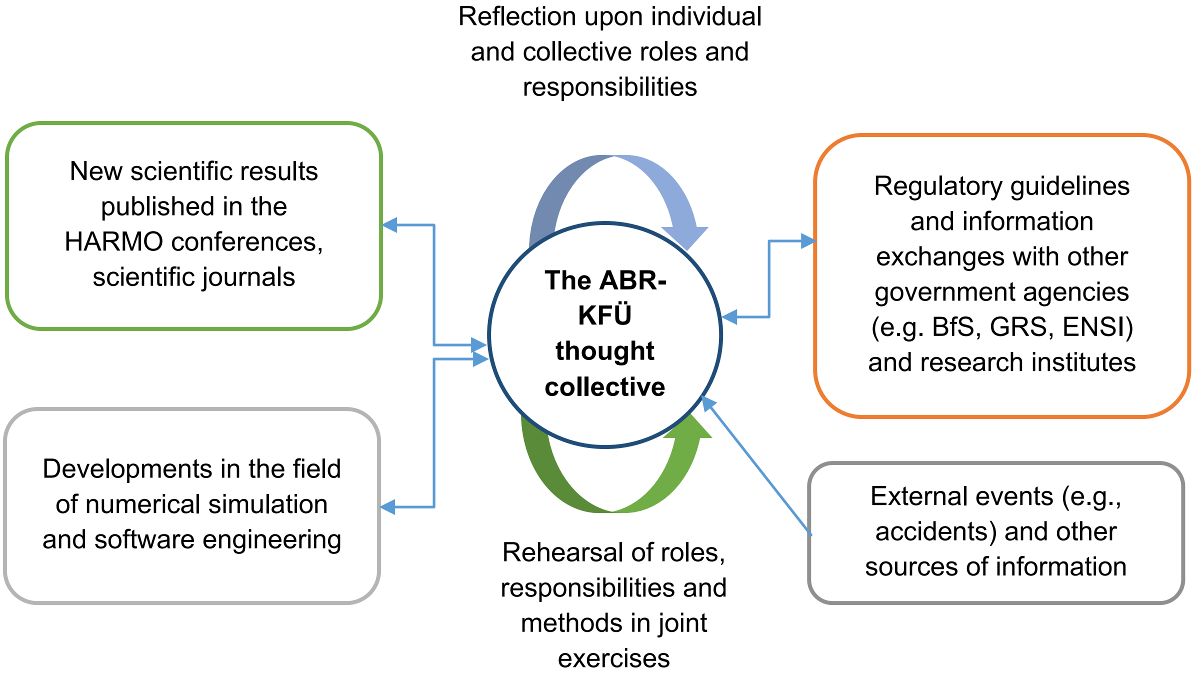


Figure 9 – The main communication channels and reflexive activities of the ABR-KFÜ thought collective.

A special type of inputs to the group's activities comes from external sources and events, such as institutions analogous to the BfS from other countries, especially in times of crisis. The Fukushima accident was the latest risk event, which from a scientific point of view can be regarded as a valuable empirical source of data for validating atmospheric dispersion models. Moreover, due to the controversies around the Fukushima evacuations, the members of the ABR-KFÜ collective began to reconsider some of the procedural aspects of the regular exercises of emergency management held jointly with the NPP operators. For the first time in the group's history the possibility of engaging members of the public in these exercises was considered, albeit informally. While dispersion forecasts may be considered relatively accurate with respect to their spatial distribution (provided that reliable measurement data are used) it also became clear to the experts from the ABR-KFÜ group that the temporal dimension of the course of events at Fukushima made it very difficult for emergency managers to plan and implement appropriate countermeasures. As a result, the concept of *cloud arrival time* (i.e., the time that the radioactive plume or cloud takes to arrive at a certain location, depending on the weather situation and regardless of the concentration of transported pollutant) is now considered as a new parameter to be computed by the ABR-KFÜ system for every point of the area being monitored.

4.2.8 Harmonizing Knowledge Objects: The Harmo.org Initiative

The use of dispersion models to forecast the dispersion of radioactive materials in nuclear emergencies gave birth to a more or less homogenous community of experts, including physicists, meteorologists, engineers, mathematicians, chemists, and radioprotection scientists. Each of these categories of experts brings with them a particular type of expertise and imaginary about the way in which radioactive materials disperse and their radiological impact upon the population and the environment. These different views on the matter are reflected in the often divergent results of the simulation codes implementing different atmospheric dispersion models developed by different institutions around the world. The local “modeling culture” thus seems to be embedded in the dispersion models and simulation codes. This inherent diversity of atmospheric dispersion models has troubled the atmospheric dispersion modeling community and decision makers likewise ever since the Chernobyl accident.

The lack of agreement between the predictions of the different dispersion models and implementations thereof during the 1986 Chernobyl accident made the International Atomic Energy Agency (IAEA) recommend the review and inter-calibration of the models for the short-ranged and long-ranged atmospheric transport of radioactive nuclides. Moreover, the creation of a database for model validation studies was suggested since there were few measurement data sets which could be used for validating the entire chain of dispersion simulation programs, from wind field generation to dose calculation. In response to this situation several dispersion forecasting experiments[18], such as ATMES, ETEX, and ATMES-II, have been carried out. The resulting data were made publicly available and validation studies with different dispersion models followed. Surprisingly enough, these studies did not reveal any consistently inadequate modeling approaches among the ones being evaluated and it was impossible to identify an approach which was more successful than others[19]. As a result of this effort to standardize dispersion forecasts, many members of the dispersion modeling community gathered under the umbrella of the “Initiative on ‘Harmonisation within Atmospheric Dispersion Modeling for Regulatory Purposes.’" As stated on the *harmo.org* website, the *raison d’etre* and goals of this community are based on the following considerations *(italics added)*:

> "In 1991, a European initiative was launched for increased cooperation and *standardisation of atmospheric dispersion models* for regulatory purposes. A 'new generation' of models is emerging with physically more justifiable parametrisations of dispersion processes. A need was felt for these new models to be developed in a well-organized manner and turned into practical, *generally accepted tools fit for the various needs of decision-makers*.
>
> On this background it was decided to organize a series of workshops to promote the use of new-generation models within atmospheric dispersion modeling, and in general *improve 'modeling culture'*. The subsequent activities have now been going on for more than 20 years, and have developed to a series of succesful international conferences."

The wish to standardize dispersion models and simulation codes or knowledge objects (Merz, 1999) expressed in the aims and scope of the Harmo initiative reflects the struggle to bring different

---

[18] See http://rem.jrc.ec.europa.eu/etex/ for more information on these experiments.

[19] https://rem.jrc.ec.europa.eu/etex/7.htm

knowledge cultures to a common denominator. The Harmo experts regard the result of this effort as an improved modeling culture. In other words, diversity is only acceptable insofar as it adheres to a community standard, which is being continuously negotiated and revised within this expert community. The standardization of atmospheric dispersion models also reflects the wish to harmonize various imaginaries of preparedness. These prerequisites seem sufficient for the emergence of a new thought collective with its own politics of expertise, the goal of which is that of speaking truth to power by means of “generally accepted tools fit for the various needs of decision-makers.” The members of the Harmo collective thus appear to work very closely to national governments and the nuclear industry in each country. Improving the trustworthiness of dispersion forecasts in view of their use by decision makers is one of the two main goals of the initiative. Trustworthiness of dispersion models is to be achieved through scientific soundness checks, model validation, guides to using models, quality assurance of model development, reference problems, comparability of input/output formats, proper exchange of expertise, etc.

The achievement of the aforementioned goals appears to depend on the use of typical bureaucratic means, such as the organization of regular meetings, in which people are pointed to the proper research directions and "good practices" and diverted from alleged "bad practices." In such a setting, leaders can more easily distinguish themselves from the other members of the community and, at the same time, gain more credibility. The harmonization of the dispersion models also entails the harmonization of opinions within the thought collective.

4.2.9 Aggregating Knowledge Objects: The ENSEMBLE Project

Another prominent approach to increasing the trustworthiness of dispersion modeling results is represented by ensemble modeling systems. The ENSEMBLE project (Galmarini, et al., 2004) funded by the European Union aims at creating a super-DSNE system encompassing over 20 different dispersion simulation codes developed by independent institutions around the world. In this approach, model diversity and disagreement between simulation results is regarded beneficial (i.e., the more diverse the models, the better). In an emergency situation, the ENSEMBLE system would run these dispersion simulation codes in parallel and produce an aggregated median result, which is considered more reliable than the results of each individual simulation code. Ensemble modeling and simulation systems were first used in meteorological forecasting. Basically, there are two types of ensemble approaches based on either varying inputs or varying models. The ENSEMBLE system follows the second method.

Air-quality dispersion models predict the median concentration for a given set of conditions (i.e., an ensemble average usually produced by a meteorological preprocessor). Ensemble systems produce aggregated results consisting of the individual results produced by each of the models participating in the ensemble. The aim is to reduce the model bias of the ensemble with respect to the bias of each participating model. The bias is computed as the mean of the deviations between the result produced by a dispersion model and reality. It is commonly considered that bias is solely due to internal modeling errors caused by wrong physical models, erroneous parameterizations, software faults, etc. In other words, if we think of individual dispersion models as of knowledge objects, then the ensemble system is an aggregating oracle that proves all models wrong. However, the oracle says, I can leverage the wrongness of each knowledge object to produce a less wrong result.

After initial successes, which drew with them more scrutinizing eyes from the Harmo.org community, the ENSEMBLE developers realized that the oracle may be improved by identifying tuples of 2 or more knowledge objects that tended to produce similar results, which is commonly referred to as model redundancy. That is, models which tend to exhibit similar bias are considered to be redundant in the ensemble. By having such models in a model ensemble, the weight of a particular type of bias may overweigh the bias of the other models, which is likely to puzzle the oracle. Since the oracle only knows how wrong a knowledge object is (and not how right it may be), it needs opinions that are wrong in different ways in order to produce a better result. Thus, one is better off eliminating redundant models from the ensemble from the very beginning because otherwise they would bias the oracle's aggregated result more than any other knowledge object participating in the ensemble.

If this discussion sounds complicated, it is because ensemble modeling is indeed a complex endeavor. It also relies on the efforts of many scientists and software developers, whose work may end up deemed "redundant" because of the statistics of bias. The ENSEMBLE initiative's credo contrasts with the Harmo initiative's goals due to the model redundancy problem. While the Harmo community aims at producing more similar dispersion models, the ENSEMBLE system welcomes model diversity. Nevertheless, the two initiatives share the common goal of reducing the bias of atmospheric dispersion forecasts used by decision makers in managing nuclear emergencies and other pollution problems.

4.2.10 Three Subgenres of the Sociotechnical Imaginary of Preparedness

This subchapter proposes a comparative analysis of three thought collectives, whose activities are strongly influenced by the sociotechnical imaginary of preparedness. The aim of this exercise is to point out important common as well as distinctive features of the beliefs and practices of the three collectives to the end of identifying the different *subgenres of the sociotechnical imaginary of preparedness* in which each of these thought collectives are grounding their activities. Wikipedia defines a genre as a type of communication in any mode with socially-agreed upon conventions developed over time. A subgenre is a subordinate within a genre. While genres and subgenres are usually associated with literature, music, and other forms of art or entertainment, genres can also be rhetorical, communicative, or functional. Genres establish by conventions which change over time as new genres are constantly invented and deprecated ones are discontinued. Genre dynamics thus reflects an evolutionary process, which also appears to be the case with the sociotechnical imaginaries of the nuclear.

Concern	**Harmo.org**	**ENSEMBLE**	**ABR-KFÜ**
Model uncertainty and trustworthiness of results	Achieving improvement by reaching scientific consensus and harmonizing model validation and verification methodologies	Improved by statistical result aggregation and elimination of model redundancy; belief that aggregated results are better than individual simulation results	Leveled-out by expert opinion, mental assessments, regular trainings and drills, situational assessments, and improvisation
Modeling culture	Top-down; policy-oriented; discouraging diversity; centralized; annual meetings; transparent (Harmo.org website)	Bottom-up; encouraging diversity; decentralized; transparent (scientific publications)	Expert-driven, developed within the thought collective; attendance of Harmo.org, IAEA, and other conferences by both experts and politicians; non-transparent
Accountability and responsibility for decisions	Advisory role only; diffuse responsibility; financial accountability (i.e., for spending money on research topics considered important)	Shared with developers and operators of simulation codes and DSNE systems from participating countries	Accountability is mostly political; responsibility is shared by experts and politicians; limited precisely defined jurisdiction
Reliability of input emission and meteorological data	Reliance on experimental data (e.g., ETEX); focus on source term back-calculation (due to unreliable source term from Fukushima); fitting of models to the data	Reliance on ensemble weather forecasts (i.e., varying input data to the end of obtaining the most probable weather situation); not specifically aiming radioactive materials	Reliance on German Weather Service, emergency measurement units (KHG), and NPP measurement stations; conscious distinctive treatment of measured and forecast weather and emission data
Crisis communication	Post-accident analyses; focus mostly on non-crisis communication	Internet-based, data exchange-driven between participating	Reliance on official guidelines, political decision markers, and

		institutions; focus on which dispersion forecasts to take into consideration	other institutions (e.g., GRS, Federal Gvt.)
Learning from accidents	Learning from previous accidents; tracer experiments (e.g., ETEX); joint exercises with experts from different countries	Tracer experiments; collaboration with institutes, which developed the dispersion simulation codes integrated into the ENSEMBLE system	Learning from previous accidents (notably Fukushima); focus shifted from the spatial dispersion to the temporal dispersion of radioactive materials
Effectiveness of countermeasures	Radiological considerations; modeling of decision-support processes	Outside of the project's scope	Reliance on local authorities; regular drills not involving population; collaboration with federal authorities
Funding of research activities	EU and state-supported; spent on model development and evaluation, conferences and meetings, release experiments; direct access to local state governmental funds; possibly lobbying	EU-supported; funding spent mostly for technical and scientific research topics (e.g., integration of simulation codes into DSNE system); advisory role for the European Commission	Industry and state-supported; spent on technical and scientific research, collective-building, improving coordination and communication with other institutions and key actors (e.g., NPPs)

The Harmo and the ENSEMBLE initiatives appear to have contradictory goals. While the former tries to harmonize modeling culture, which would lead to more similar models, the latter regards model diversity as a way to improve the trustworthiness of aggregated dispersion forecasts. The main concerns of the Harmo and ENSEMBLE thought collectives are also quite different from the concerns of the ABR-KFÜ collective. In this context, the table below provides a comparative classification of the preferred approaches of the Harmo.org, ENSEMBLE, and ABR-KFÜ thought collectives with respect to the main concerns expressed by any of the three collectives. This comparison is aimed at providing additional insights into how the imaginary of preparedness is constructed by different thought collectives having members of different cultural and professional backgrounds. The way in which the three collectives address the different concerns listed in the first column of the table arguably reflect some of the defining features of the underlying subgenres of the sociotechnical imaginary of preparedness which stands at the basis of each of these thought collectives. In the Harmo and ENSEMBLE cases, the information in the table resulted from the author's own considerations and analysis of the two collectives as an external observer rather than an insider.

To improve the trustworthiness of atmospheric dispersion forecasts, the Harmo.org initiative fosters a consensual collective imaginary of preparedness grounded in a harmonized modeling culture. This modeling culture is carefully inoculated, rehearsed, and stabilized through regular meetings. The Harmo collective is organized like an emerging scientific community with a top-down policy-oriented philosophy, whose aim is to establish itself on the basis of the noble yet lucrative goal of "speaking truth to power". The responsibility for the advice that Harmo offers to political decision makers appears to be diffuse, since consensus is the product of averaging over different opinions. Accountability for the research moneys spent on model validation and harmonization is measured in terms of new experimental data sets and the degree to which they are used for validation and verification purposes. In this sense, the proceedings of the Harmo.org annual meeting also serve the purpose of providing an account for the money being spent on research (notably tracer experiments and validation studies). There are only two accepted model validation kits, which (ironically) recommend two completely different validation and verification philosophies, which echo the tense debate between scientists and engineers regarding the validation and verification of computer-based climate and forecasting models[20]. This reflects a struggle for gaining more influence within the community by some experts over others, a detail which usually remains hidden to the eye of an external observer. Since the Harmo meetings are regularly attended by decision makers from the ministries of the environment from different countries, the influence gained by imposing one validation methodology over another is likely to bring upon not only scientific but also political influence.

---

[20] https://judithcurry.com/2011/09/25/verification-validation-and-uncertainty-quantification-in-scientific-computing/

The ENSEMBLE system fosters a modeling culture in which model diversity is encouraged. Consensus, which improves the trustworthiness of the results of the system, is achieved through statistical means. This approach is founded on the belief that aggregated results are better than individual model results, which makes the imaginary of preparedness of the ENSEMBLE thought collective quite different from the one of the Harmo community. The ENSEMBLE system and the subgenre of preparedness imaginary it projects also tend to reflect the geopolitical and cultural aims of the European Union: aggregated diversity. This makes it essentially a bottom-up and decentralized approach. Yet, as critics of the pan-European political and administrative constructs like to point out, aggregated diversity induces bureaucracy. In the case of the ENSEMBLE system, bureaucracy requires of the various experts involved in the project the alignment of data formats and other parameters of the atmospheric dispersion models participating to the ensemble. The desire to eliminate model redundancy automatically reduces the influence of some models, while favoring others. Hence, the ENSEMBLE system replaces the type of harmonization practiced by the Harmo community with one dictated by the rules of statistics. Responsibility for the eventual advice given to decision makers by the ENSEMBLE system is difficult to pin down since, even if the results of the ENSEMBLE system may be less wrong that any individual model results, in an unfortunate event they might still be wrong on an absolute scale. Hence, the responsibility stays with the providers of the models, while statistics appear to obscure it. An objective analysis of why the ENSEMBLE model may produce wrong results in a real emergency might be impossible to carry out in a transparent way. Accountability for the research money spent is provided in form of research papers published in high ranking journals (e.g., Atmospheric Environment, Environmental Modeling and Software, Physics and Chemistry, etc.).

The ABR-KFÜ thought collective is the one closest to the actual decision makers compared to the other two (Harmo and ENSEMBLE). The particularity of this system is that the actual requirements to it are formulated by experts and non-experts from within the government of Baden-Württemberg. This way, the trustworthiness of results is improved by a very close cooperation between experts (including the developers of the system) and decision makers as the actual users and main stakeholders of the system. The dispersion models used in the ABR-KFÜ system are quite old although they are being updated continuously. The modeling culture, which is rather conservative, is the result of a long cooperation between the IKE, the Ministry of the Environment, and a large private software company. Representatives of these organizations regularly attend the Harmo.org conferences and are usually well received as presenters there. A special emphasis within the collective is put on testing the ABR-KFÜ DSNE system, especially after the Fukushima accident. This makes this collective's approach to developing the ABR-KFÜ DSNE system one of engineers, rather than of scientists. The close cooperation between the developers and the decision makers as the users of the system yields a special relationship between responsibility, trustworthiness, and accountability within the ABR-KFÜ thought collective. The responsibility for countermeasures is lived by the members of the collective (notably decision makers) through a culture of continuous improvement of the trustworthiness of dispersion forecasts through (1) testing, (2) following the developments within the scientific community, and (3) a tight collaboration between the users and the developers of the system. The imaginary of preparedness nurtured by the ABR-KFÜ collective appears to be based on a deeply rooted (engineering) practice of continuously improving technical systems. Continuous improvement also provides for accountability by creating new requirements (both scientific and software engineering-related) and tests aimed at verifying the fulfillment of those requirements.

In conclusion, the comparison between the three thought collectives reflects very different approaches to the problem at stake. These approaches are based on what could be called *subgenres of the sociotechnical imaginary of preparedness*. While the Harmo.org collective bases their efforts on a belief that a harmonized modeling culture is best for improving preparedness, the ENSEMBLE collective encourages a diverse modeling culture while betting on ensemble statistics (e.g., aggregates scores like percentile values and concepts like model redundancy). The ABR-KFÜ collective is one that regularly rehearses the imaginary of preparedness in different settings, ranging from project meetings to exercises involving the NPP operator and decision makers. The imaginary of preparedness practiced by the ABR-KFÜ community appears to be the strongest of all the three being compared here and reflects the cultural imprint of the region and its past experiences, notably the washout from the Chernobyl accident. This collective seems to live accountability and responsibility through the imaginary of preparedness it practices. The tight collaboration between the developers and the users of the system as well as the mix of expertise and political power reflects an effort to continuously improve an imperfect yet essential tool—the ABR-KFÜ DSNE system. While learning to handle uncertainty in the atmospheric dispersion models implemented by the DSNE system and trying to continuously improve it, the members of the ABR-KFÜ collective believe that the system will be vitally useful in a real emergency.

4.2.11 DSNE Systems, Technologies of Hubris or Humility?

DSNE systems 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." (Jasanoff, 2003, p. 238)

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 the imaginary of preparedness in regular meetings, trainings, and drills the ABR-KFÜ thought collective is 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 ABR-KFÜ collective and the broader technoscientific community formed around DSNE systems to answer 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" (Jasanoff, 2003, p. 239). 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. Notably, the ENSEMBLE project relies on advanced statistics to narrow down the space of possible decisions that ultimately need to be taken by human actors. The HARMO community and the ENSEMBLE systems analyzed in this work 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. The complex interplay between the technologies of hubris encompassed by DSNE systems and their seemingly humble purpose as cornerstones of the imaginary of preparedness reflects the fact that the roots of this imaginary can be found in older imaginaries of the nuclear age, which were predominantly motivated by hubris at the expense of reasonableness and humility.

In order to better understand the roots of what seems to be a rather hubristic technocratic belief, the sociotechnical imaginary of preparedness practiced by the ABR-KFÜ thought collective needs to be contextualized in the German culture and history. There are at least two historical events that are relevant to the imaginary of preparedness, which have also attained an almost mythological dimension in Germany. The first one we shall refer to is the Chernobyl accident from 1986, which has been represented by the German mass media in a rather alarmist style. The second one is depicted in one of Theodor Storm's novels called *The Rider on the White Horse*, which is telling with respect to the German cultural reflex of continuously improving technical systems as well as the socio-cultural tensions this reflex creates within a German local community around 1800.

In Germany, after the Chernobyl accident, a moratorium on nuclear energy was passed which conditioned the operation of the existing power plants to the creation of a system for continuously monitored nuclear power plants and the environmental radioactivity. This conditioning produced what is arguably the world's densest network of radioactivity monitored stations. The map in Figure 10 showing the EURDEP (European Radiological Monitored Platform)[21] radioactivity monitored grid in Europe is telling with respect to the feelings of the Germans when it comes to radioactivity.

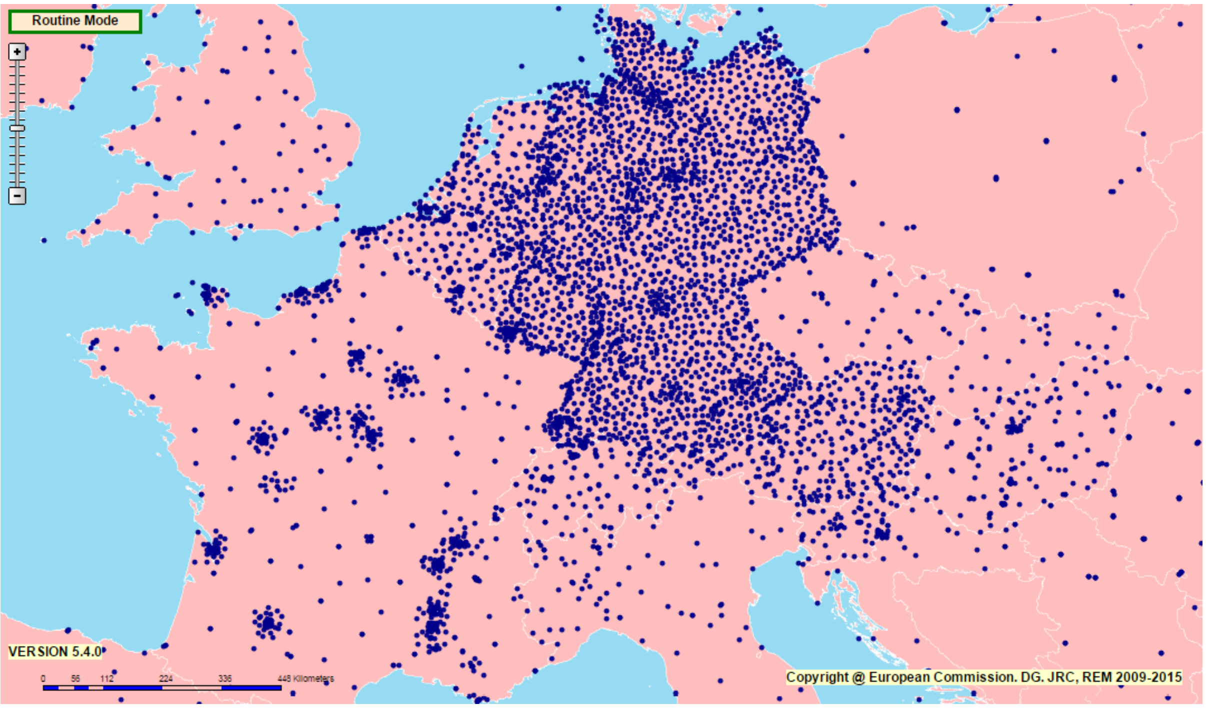


Figure 10 – EURDEP map of radioactivity monitored stations in Europe.

The combination of the radioactive cloud from Chernobyl and having nuclear power plants of their own ground gave birth to a particular compromise concerning nuclear energy in Germany. At the core of this compromise there was the IMIS system, to which analogous state-level systems were added. The IMIS and other DSNE systems in Germany, including the ABR-KFÜ system, convey a certain feeling of defensive preparedness in light of a constant hazard, which is also suggested by the map of the EURDEP network of radioactivity monitored stations. If one didn't know where Germany starts and where it ends but, instead, knew that Germans are rather fearful of radioactivity, one would probably be able to draw this country's borders only by looking at the EURDEP map. Germany has the densest network of radioactivity monitored stations in Europe, being only seconded by Austria. Yet, unlike the Austrian case, where the anti-nuclear movement referred to the surrounding countries having nuclear power plants to

---

[21] https://eurdep.jrc.ec.europa.eu/Basic/Pages/Public/Home/Default.aspx

emphasize the Austrian exceptionalism through keeping risky technologies out, in Germany the imaginary of preparedness allowed continuing the operation of NPPs on German ground. Also, it addressed the problem of the uncontrollability of operational NPPs in neighboring countries like France, Belgium, and Switzerland.

The two constitutive elements of the German sociotechnical imaginary of preparedness facilitated by DSNE systems are (1) the ability to provide early warnings about dangerous amounts of radioactive materials being released and transported into densely populated regions and (2) preparing for countermeasures through laborious planning and regular exercises (i.e., drills) involving local and federal agencies in charge of making decisions about countermeasures and the operators of nuclear power plants. While not directly involving the population in these drills, the imaginary of preparedness tacitly plays a tactical game of moving entire populations around dispersion forecasting maps. Much like in the case of the Austrian imaginary of keeping technologies out, the German imaginary of preparedness takes shape and is being reinforces through cycles of rehearsal and stabilization. However, the rehearsals take place at different levels and at different times than in the Austrian case. While on the part of the members of the crisis task force, the imaginary is being rehearsed at least once a year during drills, on the part of members of the public the rehearsals are occasioned at a small and informal scale during so called yearly "information days" organized by institutes such as the IKE in Stuttgart and when accidents nuclear accidents happen. Moreover, as Felt notes, the repeated display of maps, such as the one of the radioactivity measurement grid and of atmospheric dispersion forecasts are one way of stabilizing an imaginary through rehearsal (Felt, 2015).

In its current form, the imaginary of preparedness projects a future in which both experts and laypersons regularly prepare for the unexpected. This imaginary has not surprisingly emerged in the rather risk-averse German society (Goebel, et al., 2013), whose attitudes towards science and technology seem ambiguous. On the one hand, people in Germany are technology enthusiasts but, on the other hand, prefer to live in a society without second-order risks, as defined by Beck (Beck, 1992). Nevertheless, technological innovation is seen rather positively, provided (1) innovation cycles are frequent and gradual, that they do not pose additional risks, (2) they are supported by a critical mass, and (3) they are provably better than the technologies being replaces by improving some process or, simply, by making life easier. In this context, the imaginary of preparedness becomes the indispensable counterpart of a continuous, gradual, and culturally embedded process of technological improvement. This tension between risk averseness and the drive for innovation also transpires from one of Theodor Storm's novels inspired from a Germanic saga from Schleswig-Holstein.

In Storm's *The Rider on the White Horse* we find an incipient proto-imaginary of preparedness as well as a mythological early warning symbol: the rider on the white horse himself. The novel's main character Hauke Haiens, who has a passion for mathematics and becomes a dam builder, insists that the only way to protect the village community located along a water shore is by building a new dam, which entails very high costs. The idea is supported by the dike master and in spite of the strong opposition of the villagers, who rely on the early warnings of the rider on the white horse the dam gets to be built. The mythological rider on the white horse is allegedly spotted on the old dam each time a heavy storm approaches. However, because Hauke forbids the villagers to carry through one of their ancient rituals of burying a living dog under the joining point of the old and new dam, when a heavy storm eventually hits the village, the men from the village destroy the joining point of the two dams, thus allowing the village to be flooded completely.

While a proto-idea of early warning transpires from the magical appearances of the ghostly rider on the white horse, Storm's novel is also telling with respect to the tensions between the drive for technological improvement at high costs pushed by the experts of that time and the mythological beliefs of the villagers. The novel shows that these tensions are older than one often believes. The now established imaginary of preparedness has arguably alleviated these tensions by encompassing a broad compromise, which allows the paradigm of technological improvement to continue operating at the sociotechnical level while meeting social expectations of early warnings when unavoidable disasters occur. When it comes to disasters in densely populated countries, such as Germany or Japan, a clear differentiation between natural and technological disasters becomes impossible. That is because natural disasters are not only perceived as a direct threat to humans but also as a threat to the technologies that are in place to protect or serve human needs. Ironically, the insufficiently high tsunami protection walls at the Fukushima nuclear power plant are somewhat reminiscent of the sabotaged dam from Storm's novel. While the parameters of large sociotechnical systems always need to be negotiated between different human agencies, these negotiations become irrelevant in the wake of the physical forces of nature.

From a socio-cultural perspective, the two historical events—one real and one literary—established themselves in German collective conscience as something that might be called a sociotechnical myth. The function of this myth is at once explanatory, stimulative, and cautionary; for it explains the circumstances in which a techno-natural disaster could occur and stimulates its remembrance. In doing so, it warns people in a timeless manner that similar disasters can happen in similar circumstances; and, as any myth does, it also states that not dealing with this eventuality will draw upon people and their social structures even more trouble. The socio-cultural reflex of the German people combined with the immediacy of the Chernobyl accident provided a substantial rationale for a sociotechnical imaginary of preparedness supported by oracles in the form of DSNE systems, which represent modern "riders on white horses." This rationale for preparedness, which should be understood in the German socio-historical space, is strongly tight with responsibility and accountability. The protestant ethic (Weber, 2002), which transpires from Storm's novel, asks of people to assume responsibility for their actions at all times. On the one hand, decision makers and all representatives of the ABR-KFÜ thought collective live their work-related responsibility through the filter of the protestant ethic’s self-normativity. On the other hand, the protestant ethic also encourages people to be successful (including financially), which is also God’s wish for people.

In large modern organizations accountability and success prevail over responsibility which may lead to tensions within decision making groups. As Whyte notes, in the US the protestant ethic was largely replaced by the organization’s ethic after World War II (Whyte, 2013). As part of this transformation, people at work no longer followed their own success goals freely but rather succumbed to the rule of organizational hierarchy. The incentives for personal development were reduced to the possibility of climbing the hierarchical ladder within the organization’s bureaucracy. This led people to distance themselves from the protestant ethic and corporate accountability largely replaced responsibility as a work ethic principle. The imaginary of preparedness thus encompasses the German myths of disaster, the protestant and the social (organizational) ethics altogether. The myths of disaster ask for preparedness in the form of early warnings and oracles that help to sort out uncertainty. The protestant ethic induces work responsibilities which urge the members of the ABR-KFÜ thought collective to regularly train for and continuously improve emergency response plans and actions. Finally, the organizational ethic, which nowadays pervades most large German public and private institutions, asks for accountability on the part of decision makers for the countermeasures taken during a real nuclear emergency.

For what it's worth, the novel provides an explanation for why a sociotechnical imaginary of preparedness based on a proto-idea of early warning by means of DSNE systems—or the “rider on the white horse” warning of imminent disasters—prevailed over preparedness through continuous improvement—or building higher dams to protect against future disasters. In the end, the relevant actors and stakeholders chose the solution that promised the highest protection with the least effort and change in terms of the well-establish technopolitical order of the German socio-cultural space.

5 DSNE Systems in Action: Emergency Responses to the Fukushima Accident[22]

The March 2011 Fukushima nuclear accident unfolded in an era of new media. Unlike the case of Chernobyl, people around the world followed this accident in real time thanks to the Internet. News channels and newspapers invited dozens of experts in nuclear technology to provide public explanations of what was occurring at Fukushima. Yet, even these experts had a hard time understanding exactly what was happening; the facts surrounding the accident were sparse and often seemed to get distorted on the way from Fukushima. Seeking to provide accurate and reliable explanations of the events, the invited experts often had to assemble their own expert teams to elaborate a coherent story prior to their broadcasts. Some television producers had backup experts on hold in case the scheduled experts changed their minds about going on air. Unfortunately for public audiences, the multitude of explanations that emerged created more confusion than clarification. After only a few days, the media seemed to have forgotten about the greater disaster related to the earthquake and the devastating tsunami that followed it. Instead, they were focused primarily on sorting out facts about the nuclear accident and the likelihood and consequences of an invisible radioactive plume arriving in various parts of the world. The Fukushima nuclear accident also represented an opportunity for DSNE systems developed after the Chernobyl accident to be used in a real emergency. For the imaginary of preparedness, Fukushima represented a moment of rehearsal for the well trained emergency response routine.

Being concerned that no one benefited from this stream of inconsistent information that threatened to become sensationalism, nuclear experts worldwide felt a need to address concerned publics in ways that bypassed newspapers and television. Groups of experts from various research institutes with a focus on nuclear technology chose to give local public presentations on the topic. This allowed them to address, directly and coherently, people who were interested in hearing more than just a few (often conflicting) phrases on TV and instead wanted to learn about the technology that was failing before their eyes. It was hoped that this approach might help people make their own judgments about the possible consequences of the accident. By the example of the Fukushima reactors, nuclear experts primarily explained why and how the reactors failed. Yet, as the IKE's public presentation from March 24, 2011 showed, the pressure and the questions of the audience actually pushed experts to unfold a series of emergency response strategies, which could be considered if a similar accident happened in Germany or in a neighboring country. These public presentations represent one of the communication channels recommended by the SSK guideline for public communication in nuclear emergencies (Strahlenschutzkommission, 2007).

---

[22] The analysis and the text of the sections 5 and 5.1 strongly build on a paper that I have published in 2012 in the journal "Environmental Communication", Vol. 6, Iss. 2: (Ionescu, 2012)

In theatre, before the premiere of a piece, there is a final rehearsal of the play, which takes place in the presence of a public audience. Although this public rehearsal is basically an exercise, the audience puts additional pressure upon the actors. In this context, directorial advice during the play is usually omitted and the public rehearsal practically becomes a *de facto* premiere of the play. IKE's presentation on the Fukushima accidents presents all the features of a public rehearsal of the imaginary of preparedness. The following section provides an account of IKE's public presentation from March 24, 2011 from the perspective of a participant to the event. Section 5.2 then provides an analysis of four reports by different institutions dealing with the atmospheric dispersion of radioactive materials from the damaged reactors and the emergency response actions that were taken by the Japanese authorities.

5.1 Rehearsing the Imaginary of Preparedness: IKE's Public Presentation on the Fukushima Accident

During the first two weeks after the accident's onset, experts worldwide were having difficulties assessing its severity without accurate data regarding the state of the damaged reactors and how much nuclear fuel was stored at the plant. Without that information, one cannot assess the impact of a worst-case scenario. Such a scenario would involve a complete meltdown of the cores of all six reactors, which some experts considered improbable but not impossible. IKE experts were using data provided by the German Society for Facility and Reactor Safety (GRS), the German Agency for Radiological Protection (BfS), Japan's Nuclear and Industrial Safety Agency (NISA), Tokyo Electric Power Company (TEPCO), and the International Atomic Energy Agency (IAEA), which were insufficient for evaluating the possible consequences of the accident without a high level of uncertainty. Despite that uncertainty, the Baden-Württemberg state government requested a dispersion simulation for the Fukushima-Daiichi site to forecast where the radioactive plume was headed and what dose rate affected populations would receive. The experts were given license to make assumptions as necessary based on their experience and expertise. The main problem was back-calculating the inventory of radioactive nuclides that would be released under various failure conditions, such as a leak in the reactor vessel, based on the very sparse available measurement data. Nevertheless, groups from different German institutes came up with similar predictions, which were judged to be realistic by GRS experts.

Despite opposition by some IKE experts, Dr. Jörg Starflinger, the institute's new director, decided to make these results public as part of an informative presentation on the situation at Fukushima. The presentation's main purpose was to discuss the technology and safety systems of the reactors and the causes that led to their failure, based on verified information available at that time. Another goal was to explain radiological terms that were being used extensively and sometimes erroneously in the media. The public presentation was scheduled for March 24, giving the IKE experts about a week to prepare.

On the afternoon of March 24, attendance in the University's second-largest amphitheater exceeded all expectations. The room was far too small to accommodate the 500-person audience. Concerns about disruptive anti-nuclear protesters marching in quickly dissipated. Although the audience consisted largely of university faculty, staff and a few students (school was out of session), many people from the broader Stuttgart community were present as well.

The presentation comprised three parts. The first part outlined the events from the accident's onset through March 24, providing construction details for the reactors at Fukushima and defining technical terms such as decay heat. The second part discussed the strategy used for cooling the damaged reactors, described the course of a generic core meltdown for that reactor type and the possibility of radioactive releases, and presented the IKE experts' dispersion simulation results from March 12 to March 24. These results were later published in the International Journal for Nuclear Power (Scheuermann, et al., 2011). The final part discussed the consequences of exposure to radioactivity and its environmental impacts. A 60-minute question and answer session followed, during which people in the audience asked, among other questions, how such a severe error (exposed diesel generators) could be made in the design of a nuclear power plant, whether or not sea water would corrode the reactor vessel, whether radioactivity levels can be accurately computed rather than measured, and whether it was safe to travel to Japan in the following weeks. Arguing that the scientists were not there to respond to political provocations, the discussion moderator rejected the only hostile question—an action applauded by the audience. Some people asked for a follow-up presentation, which indeed took place on May 4 in Stuttgart's city hall attended by some 250 citizens (Spaeth, 2011).


By courtesy of Andreas Piater

The Audience (~500) and the Experts

Figure 11 – Impressions from IKE’s public presentation from March 24, 2011.

The public rehearsal of the imaginary of preparedness facilitated by IKE’s public presentation from March 2011 was a display of effective crisis communication inspired from the official guideline for how to communicate during a nuclear emergency (Strahlenschutzkommission, 2007). Before the accident, nuclear experts in Stuttgart would have never expected such a large audience to attend a technical conference on nuclear technology without any hostile interferences. To give just one example, the annual conference of the German nuclear community (KTG – *Kerntechnische Gesellschaft*)[23] enjoys police protection against anti-nuclear protesters. In this context, the successful and undisturbed course of IKE’s public presentation was made possible

- *By (temporarily) restoring trust in nuclear experts* – IKE’s public presentation filled a void of trust and expertise that existed in the minds of people from the Stuttgart community, fostered by confusing media coverage of the Fukushima accident in the absence of accurate information. Although TEPCO and the Japanese authorities have been blamed for a lack of transparency in managing the crisis, it must be stressed that data are extremely difficult to collect in a severely damaged nuclear reactor; in practical terms the missing information did not exist. Understanding

---

[23] http://www.ktg.org

and interpreting the information that was publicly available, on the websites of official organizations such as the IAEA or the German GRS, required a level of knowledge and competence in nuclear science that members of the public typically do not have.

- *By reverting to the deficit model* – With the immediate threat represented by the televised Fukushima accident, people around the world were now eager to learn some things about nuclear technology. Newspapers and television assumed a teaching role for their audiences in a process resembling a distance learning or e-learning activity. The *Frankfurter Allgemeine Zeitung*, for example, developed an online glossary for nuclear science (Lotz & Mattes, 2011) as well as compelling computer simulations aimed at explaining the causes and showing the course of the Fukushima accident. However, effective e-learning systems allow direct interaction between students and instructors; without two-way communication with the instructor, one may have a difficult time grasping the concepts taught. That feature was missing from the impromptu Fukushima e-learning system. Compounded by chronic public distrust of the media, the Fukushima distance learning system failed, which paved the way for the direct engagement between experts and laypersons.

- *By engaging in a public exchange between nuclear experts and laypersons* – The success of IKE's public presentation demonstrated that in crisis situations there is a role for more direct public engagement. University experts assumed that role in their own communities, helping people acquire knowledge required for understanding what was happening and providing a key feature missing from the improvised Fukushima e-learning system. The presentation's unexpectedly high attendance and positive audience response further suggest that people may trust experts from their community more than those who communicate through the media. Farell notes that in general "the public has no compelling reason to believe one expert over the other" (Farrell, 1993). The direct encounter on March 24 provided Stuttgart's public with a reason to trust local experts, improving their relationship by reverting to deeply rooted communal ties, thus reassuring audience members and serving as an effective model for crisis communication. Starflinger's intervention as the new IKE director also produced a long-awaited demonstration of the institute's value, turning him into a public figure and a highly sought expert on nuclear science and technology (Spaeth, 2011).

- *By helping laypersons draw the line between nuclear technology and nuclear science* – Another aspect demonstrated was the ability of members of the public to differentiate between nuclear science and technology. The public presentation had a reassuring effect on the members of the

> audience in a way that is perhaps similar to a doctor's opinion for a hypochondriac patient. People found the contact to nuclear experts from their community useful during the crises, while nuclear energy technology remained unwelcome in Germany. Nuclear science was thus embraced as a valuable aid for coping with an ongoing and extensive crisis. The ambiguity of the relationship among public communities, nuclear science, and nuclear technology arises from the fact that nuclear science was both called upon to create the technology at the heart of the crisis, and to remedy the effects of sociotechnical failure—a paradox that has noted with respect to science more generally (Beck, 1992).

Yet after this successful public rehearsal, the actual "play" got canceled through the German nuclear phase-out decision. Thus, half a year after the Fukushima accident, the IKE returned to its usual routine. The decisions of the German, Swiss, and Belgian governments to phase-out nuclear energy within the next 20 years (considered overly populist by some) have become bitter occasional discussion topics for IKE's experts. In their opinion, governments made these decisions without thorough analyses of the accident's causes and the actual safety of nuclear energy facilities in their own countries. Student interest in nuclear technology at the University of Stuttgart has also dropped compared to previous years. Public interest in IKE analyses of the accident and talks has diminished as well. All of this may indicate that the success of IKE's first presentation was primarily due to immediate fears of contamination from the radioactive cloud from Japan and the question of the safety of German nuclear power plants. With the phase-out decision already taken by the German government, public interest in nuclear technology topics soon plummeted.

From a risk communication point of view, the explicit risk message conveyed by the IKE experts through the public presentation from March 24 belongs to a genre that Lundgren and McMakin refers to as *care communication* (Lundgren & McMakin, 2013), that is, communication about risks that are already known to the audience and for which scientifically determined management procedures exist and are accepted by the audience; and therefore it is informative rather than persuasive. Considering the tremendous psychological impact of the Chernobyl accident upon the German public, the Fukushima accident also called for what Cole & Fellows refer to as *crisis communication* (Cole & Fellows, 2008), although the radiological threat was not imminent for Germans. Unlike in the case of, for example, Hurricane Katrina in which risk communicators reverted to several risk communication strategies to address an imminent and local risk, in the case of the Fukushima accident the risk event happened thousands of kilometers away from Germany, which gave the IKE experts the opportunity to present the result of their own independent analysis of the events unfolding at the Fukushima accident site. Considering that, as Fischhoff notes (Fischhoff, 1995), "[c]ommunication often begins before a word is said," the interesting fact about IKE's public presentation is that, while the IKE experts presumably intended to give an informative presentation about the status of the damaged reactors in Fukushima and the possible radiological consequences of the accident, they also managed to tacitly communicate about another risk; that is, the risk of dissolution faced by the German nuclear community in view of the traditionally very tense political debates on nuclear issues. In turn, this yielded the risk of not being prepared for dealing with future nuclear crises in the lack of nuclear experts in Germany. Thus, the actual risk message here encompassed two types of concerns, which appear to have motivated the presentation from the very beginning: (1) concerns about the accident's technical and radiological consequences and (2) concerns about the communicators' own professional future considering the accident's potential consequences—be they technical, radiological, or political.

During and after the public presentation, the IKE experts also became something that came close to what Rickard calls "informal risk communicators" (Rickard, 2011); that is "service workers who relay risk information to public audiences, though often outside of their formal job descriptions." The purpose, message, and genre of the presentation could be placed somewhere on a spectrum between "technical rationality" and "cultural rationality". Also, the presenters shared most of Rickard's features of informal risk communication, notably they had a "complex understanding of a given risk, founded on both cultural and technical meanings" and were perceived as average members of the public, who enjoyed more trust from the part of the audience than public officials might have (Rickard, 2011).

The public presentation organized by the IKE experts also helped improve the communication strategy by bringing it to the level of direct encounter between risk communicators and laypersons. Fischhoff calls this type of encounters the seventh development stage in risk communication, having the following leitmotiv on the part of the risk communicators (Fischhoff, 1995): "All we have to do is make them partners." According to Fischhoff, members of the public do want and often can fill more active and constructive roles. By making interested members of the public partners in risk management, risk communicators are more likely to improve their own communication strategies. Fischhoff further notes that such partnerships are important for creating the human relations needed to damp the social amplification of minor risks.

5.2 Representations of Risk in Official Post-Fukushima Reports

Atmospheric dispersion simulations produced by DSNE systems can be regarded as visual color-coded representations of radiological risk. When being thus represented, risk finds itself somewhere in the middle of the risk transmutation process described in chapter 2.5—approximately between the risk for radioactive materials to be released into the environment from a damaged reactor and the risk for people residing in the affected areas to receive a dangerous dose of radiation. Atmospheric dispersion forecasts thus feed the worries of both experts and laypersons.

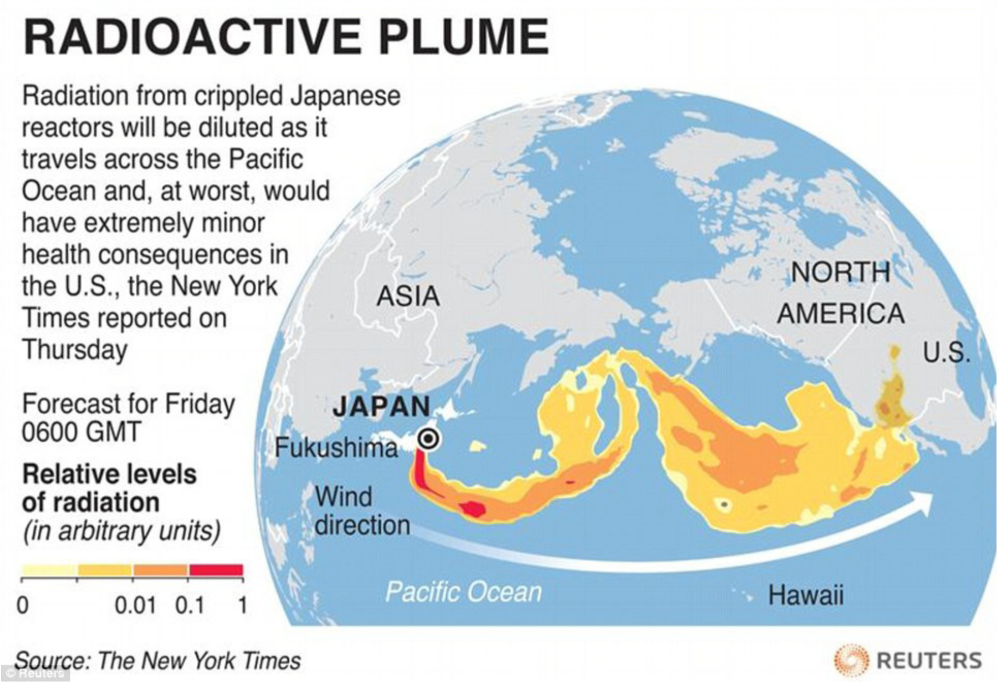


Figure 12 – Visual Representation of the Fukushima radioactive plume by the New York Times.

The international mass media presented atmospheric dispersion forecasts from the Fukushima plant that apparently reached the shores of the Western United States, as shown in Figure 11. What is striking about this representation of risk is that the visual is in stark contrast with the textual description. While the image shows a massive plume imminently reaching the shores of the US, the description states that the visual color codes represent "arbitrary units" and that—thanks to dilution—the effects of the plume is US is negligible. Yet, the emotional effect is already achieved by the image, regardless of the description. This example shows how the mass media exploited the accident for its own purposes of impressing audiences and readerships by any means. Reproducing an atmospheric dispersion forecast in arbitrary units can only be regarded as a theoretical exercise with little informative value.

In spite of being outpaced by the mass media, numerous specialized institutions around the world published reports dealing with the causes, the course, and the radiological consequences of the accident. Especially the radiological consequences of the accident were assessed by reverting to one form or another of evaluating the decaying radiological risk in terms of (potentially) contaminated areas, the dose received by the population in the affected areas, the risk of developing diseases as a consequence of that dose, the health effects from consuming contaminated foods, etc. The following sections provide an analysis of some of these reports with emphasis on to the evaluation of the radiological consequences of the accident and the nuclear regulatory system in Japan. In addition, the official report of an independent commission appointed by the Japanese Diet provides useful insight into how accountability is brought in connection with the use of DSNE systems and how decaying radiological risk also transmutes responsibility into accountability at the organizational level.

5.2.1 IAEA Recommendations and the Japanese Diet's Report on the Fukushima Nuclear Accident

The IAEA Textbook for Regulatory Control of Nuclear Power Plants contains the following recommendation concerning the use of DSNE systems in real emergencies:

> "IAEA recommends that initially decisions concerning protective action not be based on dose projection models because of the great uncertainties associated with their use. Early in a severe emergency, IAEA recommends that decisions on countermeasures be based on very simple criteria that rely on observable data (EALs and OILs). However, for long-term emergencies involving large atmospheric release resulting in large areas of contamination, a computer-based support system may be very useful. [...]
>
> There may be large uncertainties with projections of doses before and during a release.
> Therefore early in an event protective action decisions are based on simple observable criteria (e.g. indications of core damage), or operational intervention levels. Tools such as RODOS should be used to reassess the initial decisions and for further decisions when more time and information are available" (IAEA, 2002, p. 286).

This recommendation contrasts with the ABR-KFÜ collective's approach to emergency response. In the German experts' approach, DSNE systems represent non-human experts built around knowledge objects, whose "opinions" in form of dispersion forecasts are considered from the very beginning of the decision making process. The requirements to the system state that, in a real emergency, the first atmospheric dispersion forecast results should be available within minutes from when the alarm has been triggered. This divergence of opinion between the IAEA and the ABR-KFÜ experts is also reflected in the expectations of the independent commission appointed by the Japanese Diet to report on the Fukushima accident (The Fukushima Nuclear Accident Independent Investigation Commission, 2012). In the subsection entitled "Chaotic evacuation orders" the evacuation is described as follows:

> "Evacuation orders were repeatedly revised as the evacuation zones expanded from the original 3-kilometer radius to 10 kilometers and later, 20 kilometers, all in one day. Each time the evacuation zone expanded, the residents were required to relocate. Some evacuees were unaware that they had been relocated to sites with high levels of radiation. [...]

> The fact that some areas within the 30-kilometer zone suffered from high radiation levels was known after the System for Prediction of Environmental Emergency Dose Information (SPEEDI) data was released on March 23. But neither the government nor the nuclear emergency response headquarters made a quick decision to evacuate residents from those areas; it was only one month later that they were evacuated" (p. 38).

This suggests that the emergency task force initially followed the IAEA recommendations concerning the 3-5 km evacuation zone (IAEA, 2002). Then the IAEA recommends further evacuations based on measurement data from so called "hot spot" zones in which high levels of radioactivity can be measured. While the evacuation measures do not contrast with the IAEA recommendations, the dynamics of the countermeasures taken—with the extension of the evacuation zone for two times within a single day—were perceived by the members of the reporting commission (and presumably by the public as well) as having been conducted in a chaotic manner. The report continues with a very harsh assessment of the use (or misuse) of the SPEEDI DSNE system (italics added):

> "*Lack of preparation for a nuclear disaster*
>
> [The] government also failed to assume a severe accident or a complex disaster in its comprehensive nuclear disaster drills. As the scope of the drills expanded, they lost substance, and *were performed for cosmetic purposes, rather than to develop preparedness*. The irrelevant drills were lacking instruction in the necessity of using tools such as the radiation monitored information from SPEEDI. Though it was applied in the annual drills, participants found the drills useless at the time of the accident.
>
> The Emergency Response Support System (ERSS) and the SPEEDI system are in place to protect public safety. The environment monitored guideline assumption is that ERSS predicts and forecasts the release of radioactive substances and release data, and SPEEDI predicts and forecasts the spread of radioactive materials based on ERSS. Public safety measures, including those for evacuation, should be planned based on the use of these systems. [...]
>
> *The system failed.* The emission data could not be retrieved from ERSS, and the government was unable to use the SPEEDI results in planning protection measures and fixing evacuation zones. A few weeks later, NSC released an estimation of the plume of radioactivity at the time of the accident. Though the NSC's estimation was created by reverse analysis based on long-term

> monitored data, the public mistakenly believed that it was made with data from the time of the accident which the government had ignored or failed to release. This resulted in further public distrust" (p. 38).

These paragraphs reveal nuclear emergency preparedness in Japan to be at the level of an expectation rather than a practice, which is in stark contrast with the German safety culture. The commission regards this with *retrospective* normativity[24]: If the evacuations and other countermeasures were to be effective, the drills have to have been taken seriously. This kind of attitude on the part of the commission is justified by considering that preparedness for nuclear emergency response was not trained and rehearsed. The public expectation concerning nuclear emergency preparedness is also justified, considering that the Japanese usually train regularly for earthquake and tsunami emergency response. Thus, we can deduce from this assessment that a sociotechnical imaginary of nuclear preparedness emerged in Japan only after the Fukushima accident. Before that, preparedness was the product of an entangled bureaucratic construct of different technocratic organizations. The ingredients for its emergence appear to have been an existing culture of preparedness with respect to other types of natural disasters (e.g., earthquakes) and the public expectation that authorities and corporations should work together to enable preparedness. As in the German case, the Japanese sociotechnical imaginary of preparedness emerged only after a disruptive event with direct influence upon the population residing in those countries (the washout from Chernobyl accident for Germany; the contamination and evacuations occasioned by the Fukushima accident in Japan).

The expectation that after this terrible accident authorities will prepare more effectively for nuclear emergency response also reflects the acknowledgement that radiological risk can escape the boundaries of the reactor containment and thus must be dealt with on another level. While being lower than within the proximity of the reactor itself, radiological risk has a much higher psychosocial impact upon the population as it reaches farther out and transmutes into different types of risk (e.g., contamination of foods and water). There must be agencies in place able to meet the public safety expectations on many levels, reaching from risks associated with food and water consumption to the long-term effects of radioactivity and the relations with other potentially affected (neighboring) countries. Hence, the report also shows that sociotechnical imaginaries of preparedness develop in response to unfolding processes of radiological risk transmutation. Such processes ask for accountability and responsibility on other levels than previously considered, thus reaching beyond the nuclear regulatory framework.

---

[24] Finlay defines retrospective normativity as a type of normative sentences which are "ascribed to a time later than the event-time of the means" (Finlay, 2010, p. 73). As opposed to hindsight, retrospective normativity makes stronger claims by using a more precise structure of phrasing, as in "If Macbeth was to become king, he had to have killed Duncan." (Finlay, 2010, p. 70)

The National Diet of Japan
The official report of
The Fukushima Nuclear Accident Independent Investigation Commission
Executive summary

Die Katastrophe im Kernkraftwerk Fukushima nach dem Seebeben vom 11. März 2011
Beschreibung und Bewertung von Ablauf und Ursachen
Fachbereich Sicherheit in der Kerntechnik
Bundesamt für Strahlenschutz

REPORT
IRSN
Enhancing nuclear safety
Fukushima, one year later
Initial analyses of the accident and its consequences
Report IRSN/DG/2012-003 of March 12, 2012

The Impact Fukushima 11032011
Radiological Effects of the Nuclear Accidents in Fukushima on 11 March 2011

Figure 13 – Cover page artwork, from left to right: Japanese, German, French, and Swiss. The artistic structure of the cover pages—with the German and Swiss having a dark background, and the Japanese and French a light one—might also reflect the confidence in vs. the vulnerability of each country's regulatory system.

5.2.2 Technopolitical Reports on the Radiological Effects of the Fukushima Accident

The BfS report. The German BfS published a report (Bundesamt für Strahlenschutz, 2012) mostly focused on analyzing how the Japanese nuclear regulatory system is structured and how it reacted during the Fukushima crisis. In many points, the BfS report finds that the Japanese nuclear regulatory system is inefficient due to unclear relationships between the ministry of economy and different regulatory agencies. Also, the report finds, some of these agencies appear to have redundant duties, which are likely to lead to confusion in real emergencies. Concerning the contradictory official communiqués issued during the accident by these agencies, the report concludes by citing experts that communication failed because authorities failed to apply the single voice principle.

What is also noteworthy about this report is that many of the conclusions it reaches are in line with the ones of the IAEA, which is always pointed out in the text:

> "The analysis of the organizational structure of the Japanese regulatory system exhibits potential for optimization. [...]The IAEA reaches similar results in the report of the Integrated Regulatory Review Service (IRRS) mission to Japan in 2007 (IRR07) with respect to the Japanese regulatory structure. The report reminds us of the clarification of the roles of NISA and the NSC and, furthermore, the clarification of the independence of NISA from ANRE. [...] In addition, it provides a reason for the difficulties to respond swiftly to the disaster by the existing structures."
> (p. 87)

This leaves readers with the impression that the BfS report attempts to make a point concerning the inefficiency of the Japanese regulatory system compared to the German one. In a sometimes condescending tone, the authors reveal what appear to be striking inefficiencies of the Japanese regulatory system, while not explaining how it is done in Germany. This lack of comparative explanation is backed by referenced to IAEA reports, which makes the text seem like one written for the insiders of the German nuclear regulatory system and not for a wider audience. Hence, the impression is one of a defensive yet self-confident attitude with respect to the questions raised in Germany after the Fukushima accident regarding the safety of German reactors. However, considering that the BfS report was published in 2012, one can also sense the resignation of the authors in the face of the nuclear phase-out decision taken by the German federal government shortly after March 2011.

Regarding the organization of the emergency response, the BfS report states:

> "The organizational structure of the authorities involved in managing a nuclear crisis—NISA as the primary regulatory body, NSC as an external consultant, the regional government and the corresponding offices and ministries for environmental measurement—reveals an unclear distribution of tasks and responsibilities. Thus, according to an assessment by the Japanese government, an adequate reaction to such a nuclear catastrophe was not possible. The IAEA reaches the same conclusion. [...] It was only four days after the onset of the catastrophe that a joint crisis task force was assembled by the government and TEPCO. Some of the mentioned difficulties might have been avoided through the earlier set up of this task force." (p. 88)

In Germany, this joint crisis task force is established within one hour after a nuclear emergency alarm is triggered.

The BfS report also includes a cultural reference to the historical flooding markers and tsunami warning stones in the Tohoku region. The presence of this picture in such a report seems to have a twofold purpose. On the one hand, the picture is used to argue that the walls of the Fukushima plant could have been built higher because information about past tsunami wave heights was available long before the power plant was built. Hence, in expert terms the fact that the walls were too low represents a reactor design flaw. On the other hand, considering that these stones represent pieces of collective cultural memory, the BfS actually expresses critique with respect to the inability of the Japanese to transfer the imaginary of preparedness from one application to another, i.e., from tsunamis to reactor safety and radiological protection. This critique is reminiscent of the plot of Th. Storm's novel The Rider on the White Horse.

As opposed to the Japanese one, the German imaginary of preparedness appears to be embedded in collective cultural memory and in social order. This embedding entails a certain conscience on the part of both experts and laypersons that technical systems are interrelated and that the failure of one technical system may lead to failure in other systems. Moreover, as it transpires from Storm's novel, failure in technical systems also reverberate upon social order. By using the reference to the Japanese warning stones, the BfS report actually points out that, in the perception and practice of the Japanese regulatory system, at the time of the Fukushima accident preparedness lacked a social dimension. This means that the social component of the sociotechnical imaginary of preparedness enables the transfer of widely used practices of preparedness for risk mitigation from one type of risk to another.

Figure 14 – Historical flooding markers and tsunami warning stones in the Tohoku region *(Bundesamt für Strahlenschutz, 2012)*. The warning stones, like Th. Storm's Rider on the White Horse, represent a reminder of historical events of mythical importance: great tsunamis produced great devastations.

The IRSN report. The French IRSN (Institute for Radiological Protection and Nuclear Safety), which is placed under the joint authority of the Ministries of Defense, the Environment, Industry, Research, and Health, published an extensive report one year after the Fukushima accident (IRSN, 2012). This report dedicates a large section to the presentation of atmospheric dispersion forecasts by the IRSN itself, which are compared to the official atmospheric dispersion simulation results published by the Japanese authorities.

The IRSN published estimates about the Fukushima source term on March 22, 2011. The report emphasizes the lack of measurement data and the need to rely on estimation techniques stemming from own research complemented by field information from the Japanese authorities. While carrying out their own atmospheric dispersion forecasts, the IRSN also conducted a validation of their estimates using measurement data from Japan. The French experts thus appear to have been very eager to validate their own atmospheric dispersion models on the basis of this new important data point provided by the Fukushima radioactive releases.

The report first points out that, while the results of different estimates of the atmospheric releases (i.e., the source term) made by the IRSN and other institutes around the world were inconsistent, they were within the same range of values. Then, the authors engage in what appears to be academic competition, stating that:

> "Altogether, IRSN estimated the radioactivity released for 73 radionuclides (135, counting their radioactive progeny), making this the most extensive source term ever published." (p. 48)

While doing so, the authors mainly compare their own work with (Stohl, et al., 2011) and disagree with some of the findings of that study. Then the report continues with the presentation of an extensive validation study based on the Fukushima measurement data targeting their own regional (several hundred to several thousand kilometers) and local (up to a few tens of kilometers) scale models.

The IRSN report reflects the concerns of the French nuclear experts faced with the real eventuality of an accident happening at one of the over 59 French nuclear reactors still in operation. Much like the German ABR-KFÜ collective, the IRSN experts used the Fukushima accident to rehearse the imaginary of preparedness, the central point of which seems to be a DSNE system as well. Unlike the BfS report, the IRSN report does not analyze the nuclear regulatory system in Japan. The report's strong focus on atmospheric dispersion modeling and preparedness aided by DSNE systems as well as the fact that, unlike the German reports, it is written in English also reflects the ambitions of the French experts to be recognized as leaders within the scientific community that developed around atmospheric dispersion modeling for regulatory purposes.

The ENSI report. The Swiss Federal Nuclear Safety Inspectorate (ENSI) also published a report (ENSI, 2011) in December 2011 focusing on the radiological impact of the Fukushima nuclear accident. The Swiss report is neutral with respect to the Japanese regulatory system and does not rely on any other atmospheric dispersion forecasts than those published by the Japanese authorities during and after the "hot phase" of the accident. The missing focus on preparedness from the Swiss report is also explicable through the fact that the Swiss did not have a DSNE system in place at the time of the accident. After 2010, the Swiss ENSI evaluated a series of DSNE systems, including the ABR-KFÜ and RODOS (Ehrhardt & Weis, 2000), in view of installing one of them for monitoring the Swiss reactors. At the time of the Fukushima accident, these negotiations were still ongoing but shortly after the accident, the Swiss opted for the RODOS system.

The Swiss report stands out from others by dedicating an entire chapter to the effects of the Fukushima releases upon the Swiss population. This evaluation is performed by comparison with the radioactivity levels recorded after the Chernobyl accident, stating that:

> “The radionuclide concentrations measured in Switzerland were below the detection limits of the automatic alarm measurement networks (NADAM, MADUK and RADAIR), and they were 1’000 to 10’000 times lower than the concentrations measured in Switzerland after Chernobyl.
>
> Primarily, it was possible to determine increased concentrations of Iodine-131 in the air close to ground level with the help of sensitive measuring equipment. Other radioisotopes originating from Fukushima such as Cesium-134 and Cesium-137 were also detected in lower concentrations. I-131 occurred in particulate form and also in gaseous form, in concentrations that were up to five times higher. [...] The radioactivity from Fukushima that was detected in Switzerland was harmless to the health of the population. Since mid-April 2011, the concentrations of all isotopes from Fukushima in the air in Switzerland have declined.” (p. 66)

The ENSI report thus aims at reassuring the Swiss population that there are experts and means for emergency preparedness and radiological protection in place. It must be noted, however, that the Swiss topography makes it quite difficult for atmospheric dispersion models to provide accurate and reliable forecasts that can aid emergency response task forces. This is perhaps why the ENSI mostly relies on measurement data to provide information about the radiological situation.

5.3 German Nuclear Scientists in the Post-Fukushima Era

Bureaucracies have no soul, no memory, and no conscience.

– Edward T. Hall, Beyond Culture

The Fukushima accident in March 2011 left the German nuclear science community stupefied. Many experts had harbored the feeling that another accident would end the nuclear era in Germany, and that feeling was about to be confirmed. The German government ordered the shutdown of the nine German reactors built before 1980 immediately after the first phase of the Fukushima accident. On March 27th, a traditionally antinuclear Red-Green (socialist-environmentalist) coalition won the state elections in the highly industrialized Baden-Württemberg for the first time in history. Although this event cannot be attributed solely to the Fukushima accident, one cannot deny the accident’s contribution to the outcome of the elections. The Federal Government decided that the nine German reactors shut down immediately after the accident would never go back online. Soon after that, the Christian Democrat government returned to the previous plan to phase out nuclear energy by 2022 as expressed in the moratorium of 1998 by the socialist government of that time. A federal "Ethics Commission for Secure Energy" was appointed to evaluate the impact of this decision. The commission's report regarded a nuclear phase-out as a possibility, albeit at the high cost of increased dependence on energy imports and the loss of a few gross domestic product points (Ethikkommission Sichere Energieversorgung, 2011). What the commission's report did not mention was how the knowledge in the field of nuclear technology would be preserved in future, with consideration to the long-term outcome of the specific scientific community in Germany facing the end of their road.

The German nuclear science community thus received its symbolic death sentence in the voice of a federal government consisting of a coalition of parties which had traditionally been supportive of nuclear technology. This had a deep emotional impact on a group of people whose profession had abruptly become undesirable in their own country. German nuclear experts also found that their government took the phase-out decision in the absence of a definitive analysis of causes of the Fukushima accident as well as a thorough reassessment of the actual safety of nuclear energy facilities in Germany (Ionescu, 2012). Twenty five years after the Chernobyl accident, through the nuclear phase-out decision the German nuclear community was undermined once again because of a highly unlikely and unexpected event that occurred thousands of kilometers away from Germany. Yet this time, the Fukushima boiling water reactors were based on a similar technology as the one used in some of the German reactors. Perhaps this rationale combined with the *kairotic* (Miller, 1994) political decision of removing the nuclear issue from the public agenda in future elections is what led to the German nuclear phase-out decision.

These technopolitical decisions might not be properly understood in the lack of a larger historical context. The tense negotiations between the nuclear industry and the German regulatory bodies developed long before the Fukushima accident in the context of an international anti-nuclear political movement. The Green Movement emerged in West Germany in the early 1970s, when support for nuclear energy was strong due to the recent oil crisis. It was militating against both civil and military nuclear power. The 1979 Three Mile Island accident significantly contributed to the movement’s rise and the birth of the Green Party in the early 1980s. Ever since, the party has grounded a substantial part of its political program in anti-nuclear protest. Growing German public resentment toward nuclear technology peaked with the 1986 Chernobyl accident, which received a rather alarmist media coverage (Ionescu, 2012). In response to the Chernobyl accident, the Social Democratic Party, which had supported nuclear energy previously, changed its policy and passed a resolution to abandon nuclear power within 10 years. In 1998, the Green-Red (Green Party-Social Democratic Party) coalition government changed the law to allow the eventual phase-out of nuclear power, an act known as the moratorium on nuclear power. Despite the consistent public opposition to nuclear power, in 2010 the new Christian Democrat government led by Angela Merkel announced the intention of extending the lifespan of reactors by 14 years for those built after 1980 and by eight years for all others. After a long period of frustration and isolation caused by the hostile public opinion on nuclear energy, this lifetime extension decision was received by the community rather enthusiastically. They were hoping for a nuclear renaissance. This moment provided nuclear scientists with an opportunity for psychological relief and for getting out of their hiding place. Nuclear scientists believed that a favorable decision concerning the lifetime extension of reactors would open the way for their social redemption. This optimistic mood was quickly reversed by the nuclear phase-out decision from 2011.

In a newspaper article (Jansen, 2015) from February 2015 about the last concert of the "Camerata Nucleare"—the German nuclear industry's classical music orchestra—the German industry-friendly newspaper FAZ (Frankfurter Allgemeine Zeitung) makes an attempt at sensitizing readers concerning the discomforting fate of a misfortunate branch of the German industry. The author of the article reveals his motivation for writing this article in an answer to a reader comment on the newspaper's website:[25]

> "Perhaps [the orchestra] is something as trivial as a sports club. Perhaps it is a bit more, considering that its fate is so tightly linked to the demise of the nuclear industry. I believe in the latter; this is why I have written the text."

According to the article, the Camerata Nucleare was founded in early 1986 to the end of improving the reputation of the nuclear industry through music and disbanded 28 years later. In their last concert they played Schubert's "Unfinished Symphony." This metaphor nicely captures the psychosocial shock of German nuclear experts.

Yet as unfair as the phase-out decision seems, the current, post-Fukushima status of nuclear scientists (not all the employees of NPPs[26]) is not very different from that of their peers from other branches of science, which do not have too many practical applications in Germany. The main aspect that changed for the nuclear science community is that financing no longer comes almost unconditionally from a flourishing industry as it used to before the Fukushima accident. Instead, research funds must be obtained from international collaborations and European organisms, such as the Euratom agency. This requires nuclear scientist to submit to a different bureaucracy than the well-known one of the German nuclear industry and regulatory system.

In a 2015 documentary entitled "Tabu Kernforschung"[27] the Austro-Swiss-German TV Channel 3Sat portrays the German community of nuclear scientists as victims of the phase-out decision from 2011. Toward the end of the show, the ABR-KFÜ DSNE system is put on display showing a simulated release from the French Fessenheim NPP. With the wind blowing from the West—a typical situation for that part of the world, Dr. Scheuermann explains—the radioactive cloud enters German territory within minutes.

---

[25] http://www.faz.net/aktuell/wirtschaft/unternehmen/orchester-der-atomindustrie-die-unvollendete-13414118.html

[26] Most employees from the NPPs will be able to keep their jobs during the planned decommissioning of the plants. However, NPPs no longer hire new personnel and the upper management networks have most likely broken down and lost political influence.

[27] http://www.3sat.de/page/?source=/wissenschaftsdoku/sendungen/183536/index.html

The message conveyed by this image is clear: even if German reactors will be shut down, financial support for DSNE systems and nuclear emergency preparedness should not be stopped considering that the French have no official plans to decommission their reactors in the near future. The show ends with Dr. Starflinger, the head of the IKE, stating that

> “if nuclear science, including financial support and teaching, is developing into an orchid-like domain, then it would be nice if we got a proper orchid greenhouse. This means there must be a small protected area within which the orchids will be able to flourish.”

Dr. Starflinger’s call for the protection of the emerging minority of nuclear scientists is justified in the documentary by the fact that, in future nuclear scientists will be needed for decommissioning the German NPPs, for providing expertise in reactor safety for other countries operating NPPs, and for finding solutions to the nuclear waste problem. In the documentary, this point of view is shared by other interviewees from the old generation of German nuclear scientists, notably Prof. Dr. Hans-Josef Allelein from the Jülich National Research Center.

Dr. Marco Ricotti, an Italian researcher, remarks that the German resistance to nuclear power is “a cultural problem” and that a simpler technology is more likely to be accepted by the population if properly explained to laypersons. According to Ricotti, such a technology may well be represented by small modular reactors endowed with passive safety systems, which make a core meltdown impossible. Ricotti’s observation concerning the cultural problem of the resistance to nuclear power is to the point. As Edward T. Hall notes, “[…] Western philosophies and beliefs are pictures in men’s minds as to the nature of what is” (Hall, 1989). The Western logical system documented and explained by Socrates, Plato, and Aristotle is the mere product of the Western culture. Due to the focus on “what is” in the absence of real access to what really is (see for example Plato’s Allegory of the Cave) the result is a logical system based on words and conventions created by a particular culture. These conventions may or may not be shared by other cultures. Projecting this line of thought upon the case of the divide between supporters and opponents of nuclear technology may be the key to understanding why the latter are often considered irrational by the former.

In Western philosophy, as Hall further notes (Hall, 1989), the irrational is logic’s counterpart. Since Western logic is based on culturally-specific words and conventions, it is quite natural that laypersons do not really understand the details of a safety argument concerning a particular reactor technology. What people understand very well is that accidents have happened and simple Western logic dictates that they may happen in future as well. In this context, many nuclear experts hold the belief that if laypersons understood the technology better, they would start believing in the benefits of technology in question and forget about the risks. However, what nuclear experts themselves do not seem to understand is that conventions based on pictures of reality are not shared by all members of a particular culture, not to speak of members of other cultures.

Indeed nuclear experts are raised within a particular organizational culture, starting perhaps as early as high-school. Some nuclear experts "to be" may also have relatives working for the nuclear industry in their families. When they start studying nuclear engineering in universities, students are exposed to a rather unilateral view of the world—something that comes close to indoctrination. By the time they start a PhD or work in a NPP, their cultural formation is complete and unlikely to change very much within that organizational culture. For nuclear experts, neutrons and atoms will always behave in the way they were thought in school. The imaginary of containment and other imaginaries reinforce this belief. On the other hand, the imaginaries of the opponents of nuclear power are based on remembering and reminding others about accidents; and reiterating the major risks entailed by the technology, notably the nuclear waste problem and the safety issues. Hence, the logics used by the two sides appear to be totally different, which leads to a cultural gulf between the two sides.

What makes the nuclear experts' side weaker in this cultural confrontation is perhaps what Kinsella calls "the limits of representation" (Kinsella, 2012) with respect to nuclear power. On the one hand, it is impossible to *see* what exactly happens in a nuclear fuel element, like the TRISO particle, at the moment when an uncontrolled reaction starts or the structure of the fuel element is compromised. One the other hand, the models that describe different aspects of reactor physics are so complex that only a handful of people can fully understand them. Naturally, this give rise to a steep and multi-layered bureaucracy of knowledge, in which very few people truly have a holistic understanding of the workings of a nuclear reactor in the greatest details. The essential gaps and spaces in knowledge and understanding of the reactor among the members of the bureaucracy of nuclear expertise are compensated by trust in superiors and belief in imaginaries, such as the one of containment. In a similar way, the imaginary of preparedness is used to fill what might be called "the representation gap" in the attempt of mapping the inherently continuous process of radiological risk transmutation (from technical to social risks) to some of the inherently discrete human organizational structures, such as corporations and regulatory bodies. The perceived impression of this representation gap is one of organized irresponsibility (Beck, 1992).

Ricotti's solution to the cultural problem that he identifies in the 3Sat documentary is based on the deficit model: Laypersons should learn more about nuclear technology to convince themselves of its viability. This, however, would translate into creating a new layer at the very bottom of the bureaucracy of nuclear expertise, with everyone interested in nuclear issues becoming a member of that layer. The members of the bottom layer would have just enough knowledge in the field to accept whatever they are being told by higher-ranked experts. Kinsella's notion of "public expertise" hints towards such a layer of knowledgeable laypersons, albeit granting them more agency and the right to follow their own interests. By contrast, Ricotti's expectation is that public experts would automatically see the advantages of the technology as soon as they would understand more about it, thus excluding them from the real conversation from the very beginning. And yet, even if this hypothetical layer of public experts existed, the breaches within the community of nuclear experts occasioned by different accidents and incidents would repeatedly create opposition within the community of nuclear expertise itself. This has happened a number of times already, notably the shattering of the imaginary of containment caused by the TMI accident in 1979, which gave rise to the imaginaries of the forgiving reactor standing in competition with the imaginary of continuously improving reactor safety.

As opposed to the bureaucratic apparatus of the nuclear community, the opponents of nuclear technology do not seem to be organized into a steep hierarchy. A flat hierarchy and simple tactics like remembrance and reiteration is what makes the anti-nuclear movement effective in counteracting the arguments of nuclear organizations. One such illustrative argument often invoked by nuclear experts is that of the alleged irrationality of anti-nuclear protesters. This argument is based on the quantitative comparison of risks. For example, one would often hear nuclear experts saying that the risk of getting cancer from the radioactivity dose to which a person might be exposed in the vicinity of a nuclear power plant is many factors lower than the risk for that same person to die in a plane crash. In this context, these experts have a hard time understanding why most Germans don't have a problem with taking airplanes but seem to have a major one with having NPPs in their own country. Yet, according to the logic of anti-nuclear activists, which is deemed irrational by nuclear experts, one can always choose not to get on board of an airplane and use some other means of transportation instead, whereas ordinary people do not have much saying when it comes to the construction of a NPP.[28] To understand the logic of nuclear experts in this case, one must first understand some basic statistics and the physics of radioactivity. Yet more importantly, one must also believe that the laws of physics will work as described in textbooks and explained by experts on numerous occasions—something that not all people are willing to do.

---

[28] The Austrian referendum on nuclear power from 1978 represents perhaps the exception from this rule.

6 Conclusion

So far the analysis from the previous chapters showed *that* sociotechnical imaginaries (STIs) have played a significant role in (1) the formation and identification of the community of nuclear experts, (2) in the construction and consolidation of the bureaucracy of nuclear expertise, and (3) in the achievement of social acceptance of a technology that was designed for military purposes. The different events and aspects of the German history of nuclear science and technology covered by the analysis also helped to reveal *how* sociotechnical imaginaries have influenced the German nuclear community, composed of experts, politicians, industry representatives, power-plant workers, and professors or students of nuclear science and technology. In doing so, some of the key features of the sociotechnical imaginaries of the nuclear age can be identified and described in more details. These features have enabled sociotechnical imaginaries to shape the nuclear community as well as public opinion on the matter over several decades.

STIs provide a performative discursive link between technology and society through which people can identify themselves with different aspects of a particular technology. To achieve their goal, imaginaries often aim at stimulating deeply engrained human emotions and behaviors. The imaginaries of the nuclear age were called upon to bridge the rationality gap that emerged between anti-nuclear protesters and nuclear experts. Thus, STIs provide a means for achieving consensus in the context of existing sociotechnical dissentions. Yet the way to achieve consensus is never precisely defined and thus subject to continuous rhetorical negotiations (Kinsella, et al., 2013). For this reason, some imaginaries always compete with others, being endorsed by different parties with different economic, political, and personal interests. In doing so, they are inherently political considering that human interests are diverse and often conflicting. From this perspective, STIs undergo at least one of the steps of the sociology of translation (Callon, 1984)—"interestment". In order to gain momentum, imaginaries must co-interest a critical mass of people, both experts and laypersons. Pfotenhauer et al. observes that "political values and interests are continually part of nuclear operation" (Pfotenhauer, et al., 2012, p. 2). The sociotechnical imaginaries of the nuclear have also reflected the political values that pervaded both the social and technical practices of the thought collectives formed around a particular technology during normal operation.

In addition to the agendas of their proponents, there is another phenomenon at work that renders sociotechnical imaginaries performative and appealing to experts, politicians, and laypersons—sometimes even to the masses. This phenomenon appears to be that of an evolutionary competition between contemporary imaginaries which takes place at all times. In this competition, battles are sometimes won by hazard and other times through a long process of stabilization. In the former case, a disruptive event, such as a "normal accident" or a major shift in technopolitical order, may render one imaginary obsolete (or extinct) while establishing another one in its place. In the latter case, new genres and subgenres of the same imaginary may emerge rather seamlessly over a longer period of time. In the end, it may become difficult to trace the original in contemporary imaginaries. Figure 14 represents an attempt at illustrating a possible phylogeny of the German imaginaries of the nuclear. In this depiction, each generation is defined by the time between two disruptive events, which may lead to significant structural changes of imaginaries through a mechanism that resembles the one of genetic mutations.

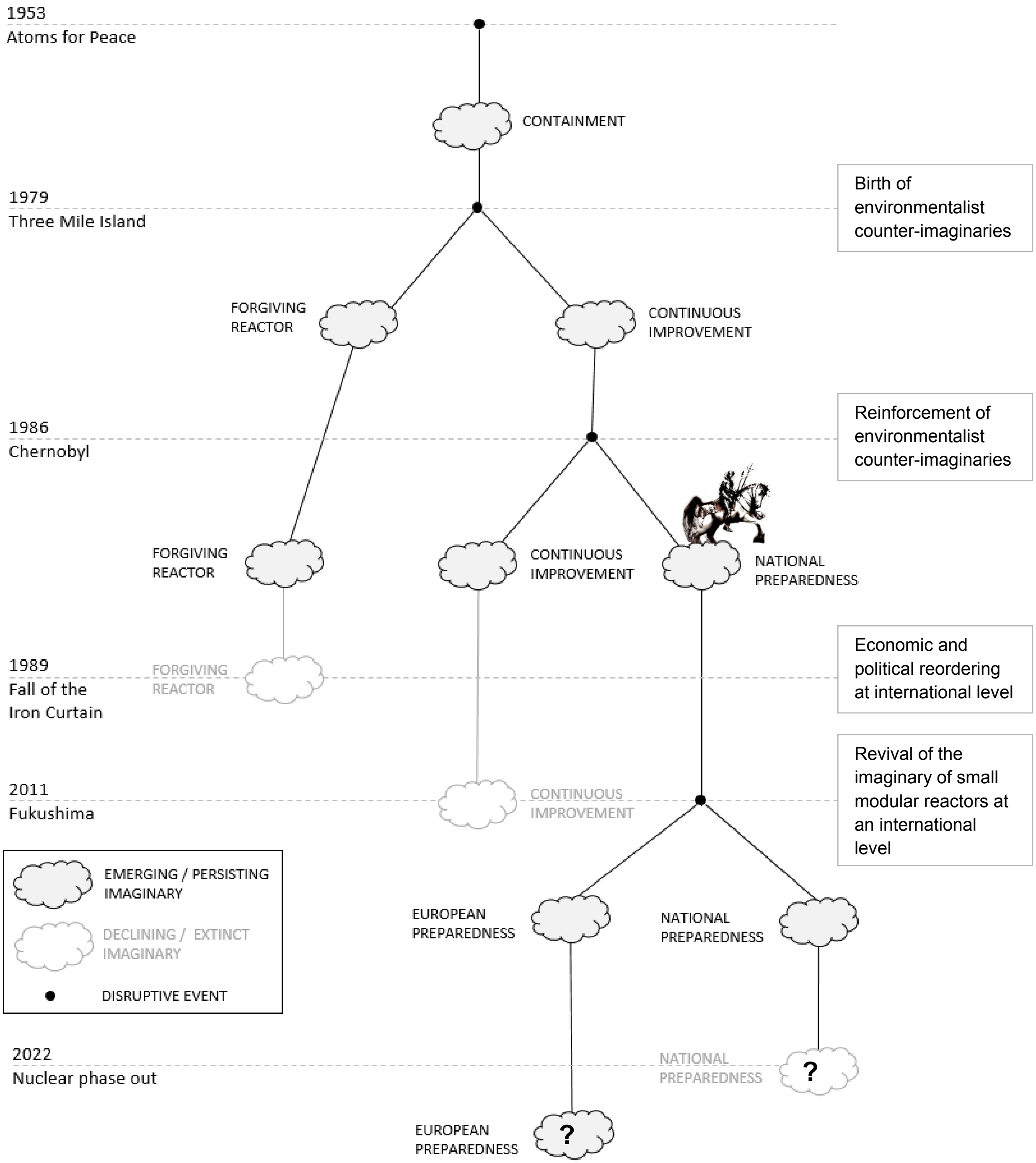


Figure 15 – A phylogeny of the sociotechnical imaginaries of the nuclear age.

The phylogeny of the German imaginaries of the nuclear era helps to identify a series of key features of sociotechnical imaginaries more generally. By analyzing the tree in Figure 14 and considering the different accounts presented in the course of this work, the following features of sociotechnical imaginaries became apparent:

> *First generation imaginaries are products of technocracy.* The imaginary of containment was arguably the product of the post war scientific establishment that helped win the war thanks to the Manhattan project. It resulted from the technocratic reflex of continuing a military-style social order based on large technical systems that worked to solve all problems of humanity. Thus, the imaginary of containment imposed the vision, the goals, and the logic of their creators upon post-war America. In doing so, the imaginary of containment helped to induce a social order based on large organizations that stood behind large sociotechnical systems and had the saying in many political matters. In doing so, this imaginary contributed to the organization-oriented social ethic that emerged in the flourishing era of the organization man (Whyte, 2013) and defined generations to come.
>
> *First generation imaginaries reflect a strong optimistic wish associated with the use of a particular technology; while later generation imaginaries also encompass increasing collective anguishes caused by the failed fulfillment of the original wish.* This slow transformation of wishes into anguishes is often depicted in some of the ancient and modern myths of the Western world (Prometheus, Sisyphus, Faust, Frankenstein, etc.) as a fundamental trait of humanity. In the nuclear case, the wish to find peaceful uses for nuclear power was grounded in a firm belief that radioactivity can be contained, which gave birth to the sociotechnical imaginary of containment. The Three Mile Island and Chernobyl accidents gave birth to the second generation imaginaries of forgiveness and continuous improvement. In technical terms, the imaginary of the forgiving reactor meant fault tolerance, while in social terms it meant acceptance and oblivion. The imaginary of continuous improvement was its direct competitor and reflected a confident yet cautious belief that only the continuous improvement of the technology will prevent radioactivity from becoming a fatal threat in future. The imaginary of national preparedness, which appeared after the Chernobyl accident, appears to have weakened after the Fukushima accident. That is because, with the German nuclear phase-out decision taken, the nuclear industry no longer agreed to finance projects like the ABR-KFÜ. Following the source of financial support, preparedness is now envisioned at European level.

Later generation imaginaries are co-produced by technoscience and society. Disruptions represent opportunities for society to challenge widespread technoscientific credos and to cut to the bone of technocratic establishments, like the nuclear industry. Moments of disruption can lead to governments resigning, large corporations being tried, and scientific disciplines disappearing or losing important branches. As a result, a new generation of sociotechnical imaginaries may emerge from a failing one. A good example for this phenomenon is provided by the imaginaries of the forgiving reactor, continuous improvement, and preparedness. From these three, the imaginary of preparedness was the co-produce of technocracy and society. The other two failed while aiming to touch social chords but ending up being technocratic in essence. Preparedness thus appears to be a co-produced sociotechnical imaginary resulting from the negotiations following the Chernobyl accident between the nuclear industry, the German government, and the German civil society, notably the anti-nuclear movement.

They are determined by local and organizational culture. The way the inherently safe reactor concept, which lay at the core of the imaginary of the forgiving reactor, was received in the USA and Germany shows that sociotechnical imaginaries are very much influenced by the cultures in which they are supposed to exist. While in the USA, the issue of inherent safety was one of cost, in Germany the forgiving reactor met a strong resistance both in civic society and amidst the community of nuclear experts. The forgiving reactor had a competing imaginary grounded in the deeply rooted cultural practice of continuously improving technical systems instead of searching for a silver bullet. The imaginary of continuous improvement ultimately won the evolutionary battle, which lead to the demise of the forgiving reactor in Germany. The Fukushima accident also showed that preparedness is understood very differently in different countries. While the members of the ABR-KFÜ thought collective strongly believed in the usefulness of DSNE systems in real nuclear emergencies, the Japanese authorities have failed to use them effectively—possibly by following the IAEA recommendations. It was only in the Japanese Diet’s report and some media representation that the expectations concerning the use of DSNE systems in real emergencies came to light as an expression of hindsight. These expectations turned out to reflect the imaginary of preparedness the way it is practiced in Germany rather than how it is being described in the IAEA recommendations and how it has been enacted by the Japanese authorities during the Fukushima crisis. Last but not least, the German imaginary of nuclear preparedness seems to be influenced by the functional image of “The Rider on the White Horse” as a proto-imaginary of early warning against techno-natural disasters.

They may never stabilize through rehearsal if disrupted by an external risk event (e.g., accidents). Disruptive events can cancel the stabilization process of sociotechnical imaginaries. Even though the Fukushima accident has been used by many groups of experts around the world to rehearse the imaginary of preparedness using DSNE systems, the positive effects of these rehearsals turned out to be ephemeral in some cases. After the IKE's public presentation from March 25, 2011 the ABR-KFÜ system became the working horse of the institute. Yet with the nuclear phase-out decision taken corroborated with the political changes that the March 2011 elections in Baden-Württemberg brought, the imaginary of preparedness began to lose ground. There were increasing questions about whether it would be possible at all to manage a nuclear crisis comparable to the one that took place in Japan without losing the credibility of the public. While in Germany, DSNE systems are still considered useful in such emergencies, the government of Baden-Württemberg decided to start using the simulation components of the RODOS system financed and endorsed by the European Union and the German federal government instead of the ABR-KFÜ system. With this change of attitude, the imaginary of preparedness can be said to have moved from a national and local to a federal and European level. The practices within the emerging RODOS-KFÜ thought collective will most likely be different from the ones of the ABR-KFÜ collective considering the scale of the two projects. While the ABR-KFÜ resulted from a grassrooted development that addressed the expectations of the local communities in Baden-Württemberg in terms of political accountability and responsibility, the RODOS system brings with itself a community of hundreds of users and other stakeholders from dozens of countries.

They are fascinating and addictive. The sociotechnical imaginaries of the nuclear have fascinated entire generations of engineers and laypersons. If was only after a strong anti-nuclear movement emerged that this fascination began to pale. The German nuclear phase-out decision also revealed that for some, sociotechnical imaginaries are not only fascinating but also addictive. Even today, many nuclear experts refuse to accept that the German nuclear era is nearing its end. Some of them are in denial while others have moved on and found jobs in other fields but still considering the phase-out decision unjust. It is not difficult to be fascinated by an imaginary such as the one of preparedness. It suffices to believe in the capacity of models to predict the future, which—in technical terms—translates into forecasting the spatial and temporal flow of airborne trace species. The resources reserved for real emergencies are themselves fascinating: high-tech measurement units in red fire fighting vehicles and helicopters; dosimeters planted all over the country; powerful computers that are always available to produce dispersion forecasts whenever an emergency is triggered; the institution of the "Krisenstab"—the task force formed of experts and politicians endowed with the necessary authority to carry through protective countermeasures;

and the idea that the members of this task force and all other members of the ABR-KFÜ thought collective serve their communities. A stabilized imaginary thus induces addiction, which is also caused by financial dependency on endowments from the nuclear industry and the government. Cut these apron strings loose and you end up with many members of the ABR-KFÜ thought collective experiencing withdrawal symptoms. The orchids are in denial.

They are endemic: after (apparent) extinction in one techno-cultural space, they may reappear in the same or another one. Only a few years after the Fukushima accident, small modular reactors (SMR), which are almost identical to the HTR-Modul in design, are once again receiving considerable attention in scientific literature (Carper & Schmid, 2011) and in the media (Carrington, 2015). With the UK and US planning to build the first SMRs as a response to the unprecedented global energy market challenges, the informed reader is ridden by a *déjà vu* sensation: small inherently safe reactors will flexibly be installed wherever electricity is needed. There will be no need to worry about safety or costs since SMRs will be mass produced and their small power of less than 300 MVe will prevent them from melting down. The imaginary of the forgiving reactor seems to be endemic in the US and the UK as it reappeared in the form of small modular reactors only 20 years after the HTR-Modul and PBMR projects have failed in Germany and South Africa. In both cases, the sparking idea came from the United States and was exported to other countries, which from different reasons shut down the projects. It remains to be seen whether SMRs will produce a different outcome in the countries pursuing them.

6.1 Concluding Remarks and Outlook on the Imaginary of Preparedness

While the *sociotechnical imaginary of preparedness* draws upon other imaginaries of the nuclear age, it is simultaneously an imaginary of compensating the loss of trust and momentum of other imaginaries, including the imaginary of containment and continuous improvement of reactor safety systems. This work showed how the sociotechnical imaginary of preparedness emerged in the German nuclear community, society, and culture. Within that particular socio-techno-cultural space *it* reflects a particular mindset focused on risk control and minimization and on the continuous improvement of technical systems. *It* depends on the nuclear industry just as much as the other imaginaries of the nuclear age did but seems to better adapt to post-accident perceptions of technoscience and changes in nuclear regulatory policies than other imaginaries. With the German phase-out decision taken in 2011, *it* has lost some of its national, community-centered character. Today, preparedness for nuclear emergencies is envisioned at the federal level in Germany and at the transnational level in Europe. Thus, in the lack of financial support from the German nuclear industry the imaginary of preparedness was pushed up the ranks of European bureaucracy and politics. While today consensus that local, federal, and European authorities must prepare for nuclear emergencies still prevails, it is not clear anymore who should pay for nuclear emergency management trainings, drills, and the development of DSNE systems in future. This also depends on the future of nuclear energy in Europe. Without strong commitments regarding the future of nuclear energy in Europe, the sociotechnical imaginary of preparedness is more likely to take a path of decline, along with the nuclear industry.

Up until now, Perrow's observation concerning "normal accidents" has proven to be correct. In this context, the role of DSNE systems within the global imaginary of preparedness is 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. This trend is reflected by the German case, where emergency response has already shifted from the national to the federal level. At the same time, by "partnering with the public" (Sethi, 2016) and possibly more emphasis put on improvisation rather than trained preparedness (Schmid, 2016), people could be guided directly and more effectively towards safety in a nuclear emergency. A culture of improvisation, as Sonja Schmid notes (Schmid, 2016), may indeed improve on well trained "reliable" emergency response plans. Next generation imaginaries of preparedness might assimilate improvisation as an additional technique for emergency response along with DSNE systems, regular drills, and reliable planning. But is improvisation itself a trained ability or an innate talent? [29] 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 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.

6.2 Reflection on the Sociotechnical Imaginaries of the Nuclear in Relation to Other Sensitizing Concepts

The observation that the different imaginaries of the nuclear follow an evolutionary process allowed to identify some of their key features, which can be related to the existing theoretical frameworks on sociotechnical imaginaries, rhetorical visions, and fantasies. In this sense, I contend that the sociotechnical

---

[29] Japanese Zen masters argue that every talent can be trained if the apprentice follows the Zen way (Hall, 1983).

imaginaries analyzed in this work draw upon rhetorical visions and fantasies of the nuclear, which eventually become pivotal elements of these imaginaries. To give just one example, the imaginary of the forgiving reactor embeds the fantasies and rhetorical visions of small modular reactors. In doing so, at least three of the features of sociotechnical imaginaries identified in this work match features of the SMR fantasies identified by (Sovacool & Ramana, 2015):

Features of the SMR fantasies according to (Sovacool & Ramana, 2015) *and* (Ramana & Mian, 2014)	*Features of the sociotechnical imaginaries of the nuclear age*
There are competing, at times overlapping visions, not all of them consistent, some of them part of larger visions that cut across a variety of nuclear technologies.	Imaginaries are in a constant evolutionary competition whereby some imaginaries survive by hazard and other times through a long process of stabilization.
Statements about SMR commercialization present the future as a predetermined extension of current events. SMR fantasies are selective and choose what aspects history to highlight and leave out potential challenges to their vision as if they simply did not exist.	Disruptive events may render one imaginary obsolete while establishing another one in its place. If imaginaries survive through a long process of stabilization, new genres and subgenres of the same imaginary may emerge rather seamlessly over a longer period of time.
Scientists and engineers are not immune to drama and fantasy and that they can become 'infected' with rhetorical visions—a symbolic convergence—that cause them, in their excitement, to lose their scientific precision.	They are fascinating and addictive by design. The sociotechnical imaginaries of the nuclear age have fascinated entire generations of engineers and laypersons.

In the conclusion of their article (Sovacool & Ramana, 2015) on SMR fantasies and rhetorical visions, Sovacool and Ramana ask a rhetorical question of their own:

> “Why does a technical paper on, say, alkali-metal thermal-to-electric static converters—electronic components that help generate electricity without rotating machinery—have to start with a statement on the energy challenges of 'populations in underdeveloped countries and in small remote communities,' move on to discussing the details of how some reactors may be 'factory-assembled and shipped by rail or on barge' and then cover the possibility of using these reactors for desalination” (Sovacool & Ramana, 2015, p. 115).

I would add to the answer provided by the authors in their paper that the proponents of new technologies need to acknowledge the social implications of *inherently risky technologies*—to use Kinsella's term (Kinsella, 2012). What is being acknowledged is that new technologies always pose new sociotechnical risks, which need to be addressed, one way or another. Yet, as Kinsella observes, when it comes to representing sociotechnical risks, the analysts reach the limits of representation (Kinsella, 2012). From this reason, the fantasies and rhetorical visions embedded in sociotechnical imaginaries are aimed at either obscuring some risks or filling in for lacking representations of those risks. This mechanism can be illustrated by relating the different sociotechnical imaginaries of the nuclear age to different stages in the sociotechnical risk transmutation process:

Stage in the sociotechnical risk transmutation process	*Obscuring risk*	*Filling in for lacking representations of risk*
There is a certain risk for a reactor incident (e.g., a severe reactor failure) to lead to a nuclear accident.	The imaginaries of the **forgiving & small modular reactors** promise that all types of failures can effectively be dealt with thanks to the inherent safety and fault tolerance of the reactor.	The imaginary of **containment** promises that radioactivity (and thus risk) can be effectively contained within the reactor core.
During a nuclear accident, there is a certain risk for radioactive materials to be released into the environment.		The imaginary of **continuous improvement** promises to mitigate this risk through both active and passive safety systems.
If 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.	The imaginaries of **forgiving & small modular reactors** deny the existence of these risks in the context of SMR operation.	The imaginary of **preparedness** promises that protective countermeasures (e.g., sheltering, evacuation) can preemptively be taken on the basis of atmospheric dispersion forecasts and that adequate treatment can be provided (e.g., intake of iodine tablets) on the basis of dose estimations.
Provided that radioactive materials have reached a populated area, there is a certain risk of exposure at different levels.		

Let us briefly return to Kinsella's remark concerning the limits of representation: "If 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" (Kinsella, 2012, p. 252). Going beyond design basis by means of fantasies and rhetorical visions thus appears to be one of the rhetorical devices used to stabilize the sociotechnical imaginaries of the nuclear. While rhetorical visions and fantasies represent the utopian (Sovacool & Ramana, 2015) wish of their creators, “normal accidents” represent the brutal negation of that very wish.

Considering that the sociotechnical imaginaries of the nuclear reflect the utopian wishes of their creators, when negated they might also tell something about the risks they attempt to obscure. Hence, I believe one can go beyond the limits of representation of risk by negating sociotechnical imaginaries. In this sense, negated imaginaries could be used in a similar way as stochastic models: Take one imaginary (e.g., small modular reactors), negate it (e.g., SMRs might not be as safe and cost-efficient as their promoters claim them to be) and then ask questions and devise scenarios by drawing on, for example, Jasanoff’s questions of humility: What is the purpose, who will be hurt, who benefits, and wow can we know? (Jasanoff, 2003) After a number of such thought experiments, the “thinkers” might come up with a scenario similar to the one that unfolded at Fukushima. The grass-rooted practice of negating sociotechnical imaginaries has arguably produced a series of counter-imaginaries that draw upon the culturally and psychosocially rooted ambivalence of myths and fantasies. One need not be trained in a particular way to negate a sociotechnical imaginary; for this is what any layperson able to escape the trap of gullibility is likely to do instinctively, especially if they are directly concerned by the issue at stake.

7 References

Anderson, L., 2006. Analytic autoethnography. *Journal of contemporary ethnography,* 35(4), pp. 373-395.

Atkinson, P. & Hammersley, M., 1994. Ethnography and participant observation. *Handbook of qualitative research,* 23(1), pp. 248-261.

Aven, T. & Renn, O., 2015. An evaluation of the treatment of risk and uncertainties in the IPCC reports on climate change. *Risk Analysis 35,* pp. 701-712.

Bayer, F., 2015. *Nuclear Energy Futures: the Appropriation of the "Atomic Age" in post-war Austria,* Vienna: Universität Wien.

Beck, U., 1992. *Risk society: Towards a new modernity.* s.l.:SAGE.

Bert Metz, O. D. J.-W. M. S. V. R. a. L. V. W. M. (., 2000. *Methodological and Technological Issues in Technology Transfer,* Cambridge: Cambridge University Press.

Bowen, G., 2009. Document analysis as a qualitative research method. *Qualitative research journal,* 9(2), pp. 27-40..

Bundesamt für Strahlenschutz, 2012. *Die Katastrophe im Kernkraftwerk Fukushima nach dem Seebeben vom 11. März 2011: Beschreibung und Bewertung von Ablauf und Ursachen,* Köln: BfS.

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2004. *Leitfaden für den Fachberater Strahlenschutz der Katastrophenschutzleitung bei kerntechnischen Notfällen.* München-Jena: Elsevier Urban & Fischer.

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 2005. *Allgemeine Verwaltungsvorschrift zu §47 Strahlenschutzverordnung: Ermittlung der Strahlenexposition durch die Ableitung radioaktiver Stoffe aus kerntechnischen Anlagen oder Einrichtungen,* Berlin: Bundesregierung.

Callon, M., 1984. Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. *The Sociological Review,* 32(S1), pp. 196-233.

Callon, M., 1984. Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St Brieuc Bay. *The Sociological Review 32,* pp. 196-233.

Camus, A., 1955. *The myth of Sisyphus, and other essays, trans. Justin O'Brien.* New York: Vintage.

Carper, R. & Schmid, S., 2011. The Little Reactor That Could?. *Issues in Science and Technology,* 27(4), pp. 82-89.

Carrington, D., 2015. George Osborne puts UK at the heart of global race for mini-nuclear reactors. *The Guardian*, 24 November.

Chhem, R. K., 2014. *Radiation Medical Science Center, Fukushima Medical University.* Fukushima, Radiation Medical Science Center, Fukushima Medical University.

Christopher, J., 2005. Review of code and solution verification procedures for computational simulation. *Journal of Computational Physics,* Volume 205, pp. 131-156.

Cole, T. W. & Fellows, K. L., 2008. Risk communication failure: A case study of New Orleans and Hurricane Katrina. *Southern Communication Journal,* 73(3), pp. 211-228.

Collins, H. & Evans, R., 2008. *Rethinking expertise.* Chicago: University of Chicago Press.

Corbin, J. & Strauss, A., 1990. Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative Sociology,* 13(1), pp. 3-21.

Deiseroth, D. F. A., 2016. *Whistleblowing im nuklear-industriellen Komplex.* pp. 67-74. ed. Berlin : Berliner Wissenschafts-Verlag.

Ebermann, L. & Junkert, A., 2011. *The 1986 reactor accident in Chernobyl.* Salzgitter: Bundesamt für Strahlenschutz.

Ehrhardt, J. & Weis, A., 2000. *RODOS: Decision Support System for Off-site Nuclear Emergency Management in Europe: Final Project Report,* Karlsruhe: Forschungszentrum Karlsruhe.

Eisenhower, D. D., 2003. Atoms for Peace. *IAEA Bulletin,* 45(2), pp. 62-67.

ENSI, 2011. *Radiological Effects of the Nuclear Accidents in Fukushima on 11 March 2011,* Brugg: Swiss Federal Nuclear Safety Inspectorate ENSI.

Epstein, S., 1995. The construction of lay expertise: AIDS activism and the forging of credibility in the reform of clinical trials. *Science, Technology & Human Values,* 20(4), pp. 408-437.

Ethikkommission Sichere Energieversorgung, 2011. *Deutschlands Energiewende – Ein Gemeinschaftswerk für die Zukunft,* Berlin: Bundesregierung.

Fahlquist, J. N. & Roeser, S., 2015. Nuclear energy, responsible risk communication and moral emotions: a three level framework. *Journal of Risk Research,* 18(3), pp. 333-346.

Fahlquist, J. N. & Roeser, S., 2015. Nuclear energy, responsible risk communication and moral emotions: a three level framework. *Journal of Risk Research,* 18(3), pp. 333-346.

Farrell, T., 1993. *Norms of rhetorical culture.* New Haven: Yale University Press.

Felt, U., 2014. *Knowledge claims and forms of expertise in the context of a techno-natural disaster.* Fukushima, Radiation Medical Science Center, Fukushima Medical University.

Felt, U., 2015. Keeping Technologies Out: Sociotechnical imaginaries and the formation of a national technopolitical identity. In: S. Jasanoff & S. Kim, eds. *Dreamscapes of modernity: sociotechnical imaginaries and the fabrication of power.* Chicago-London: The University of Chicago Press, pp. 103-125.

Felt, U., 2016. *Living a Real-World Experiment: Post-Fukushima Imaginaries and Spatial Practices of 'Containing the Nuclear',* Vienna: Pre-print; Published by the Department of Science and Technology Studies, University of Vienna.

Finlay, S., 2010. Normativity, necessity, and tense. A recipe for homebaked normativity. *Oxford studies in metaethics,* Volume 5, pp. 57-85.

Fischhoff, B., 1995. Risk perception and communication unplugged: Twenty years of process. *Risk analysis,* 15(2), pp. 137-145.

Fleck, L., 2012. *Genesis and development of a scientific fact.* s.l.:University of Chicago Press.

Friedman, S. M., 2011. Three Mile Island, Chernobyl, and Fukushima: An analysis of traditional and new media coverage of nuclear accidents and radiation. *Bulletin of the Atomic Scientists,* 67(5), pp. 55-65.

Galmarini, S. et al., 2004. Ensemble dispersion forecasting, Part I: concept, approach and indicators. *Atmospheric Environment 38,* pp. 4607-4617.

Gamson, W. A. & Modigliani, A., 1989. Media discourse and public opinion on nuclear power: A constructionist approach. *American journal of sociology 95,* pp. 1-37.

Giddens, A., 1999. Risk and Responsibility. *The Modern Law Review,* 62(1), pp. 1-10.

Goebel, J., Krekel, C., Tiefenbach, T. & Ziebarth, N., 2013. *Natural disaster, policy action, and mental well-being: the case of Fukushima,* Berlin: German Institute for Economic Research.

Hall, E. T., 1983. *The dance of life.* Garden City: NY: Anchor Press.

Hall, E. T., 1989. *Beyond Culture.* 2st ed. New York: Anchor Books.

Hand, D. J., Mannila, H. & Smyth, P., 2001. *Principles of data mining.* Cambridge: MIT Press.

Hecht, G., 2013. Nuclear Janitors: Contract Workers at the Fukushima Reactors and Beyond. *Asia-Pacific Journal: Japan Focus,* 11(2).

Hirano, M. et al., 2012. Insights from review and analysis of the Fukushima Dai-ichi accident: Fukushima NPP accident related. *Journal of Nuclear Science and Technology,* 49(1), pp. 1-17.

IAEA, 2002. Regulatory control of nuclear power plants Part A (Textbook). In: *TRAINING COURSE SERIES No. 15.* Vienna: s.n., p. 286.

Ionescu, T. B., 2012. Communicating in Germany about the Fukushima accident: How direct encounter beat media representations. *Environmental Communication: A Journal of Nature and Culture,* 6(2), pp. 260-267.

Ionescu, T. B., 2013. Connaissance socialement robuste : le jeu des perles de verre et les modes à la mode. *Alliage,* Volume 72, pp. 102-115.

Ionescu, T. B. & Scheuermann, W., 2016b. Improving the Reliability of Decision-Support Systems for Nuclear Emergency Management by Leveraging Software Design Diversity. *Journal of Computing and Information Technology,* 24(1), pp. 45-63.

Ionescu, T. B. & Scheuermann, W., 2016. Improving the Reliability of Decision-Support Systems for Nuclear Emergency Management by Leveraging Software Design Diversity. *CIT. Journal of Computing and Information Technology 24,* pp. 45-63.

Ionescu, T., Laurien, E. & Scheuermann, W., 2014. *Improving the Reliability of Deci-sion-Support Systems for Nuclear Emergency Management using Software Diversity Methods.* Varna, HARMO.org.

Ionescu, T. & Scheuermann, W., 2016a. Architecting safety-critical decision-support systems for nuclear emergency management. *it-Information Technology,* 58(1), pp. 49-60.

IRSN, 2012. *Fukushima, one year later: Initial analyses of the accident and its consequences,* Paris: IRSN (Institute for Radiological Protection and Nuclear Safety).

Jansen, J., 2015. Die Unvollendete. *Frankfurter Allgemeine Zeitung*, 20 February.

Jasanoff, S., 1988. The Bhopal disaster and the right to know.. *Social Science & Medicine,* 27(10), pp. 1113-1123.

Jasanoff, S., 2003. Technologies of humility: citizen participation in governing science. *Minerva 41,* pp. 223-244.

Jasanoff, S., 2004. *States of knowledge: the co-production of science and the social order.* s.l.:Routledge.

Jasanoff, S., 2015. Future Imperfect: Science, Technology, and the Imaginations of Modernity. In: S. Jasanoff & S. Kim, eds. *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power.* Chicago-London: The University of Chicago Press, pp. 1-33.

Jasanoff, S. & Kim, S. H., 2009. Containing the atom: Sociotechnical imaginaries and nuclear power in the United States and South Korea. *Minerva 47,* pp. 119-146.

Jasanoff, S., Kim, S. H. & Sperling, S., 2007. *Sociotechnical imaginaries and science and technology policy: a cross-national comparison. NSF Research Project,* Cambridge: Harvard University.

Johnson, J., 1988. Mixing humans and nonhumans together: The sociology of a door-closer. *Social problems,* 35(3), pp. 298-310.

Jones, C. F., Shi-Lin, L. & Kyoko, S., 2013. Narrating Fukushima: Scales of a nuclear meltdown. *East Asian Science, Technology and Society,* 7(4), pp. 601-623.

Kasperson, R. E. et al., 1988. The social amplification of risk: A conceptual framework. *Risk analysis 8,* Volume 2, pp. 177-187.

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

Kinsella, W. J., 2004. 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, pp. 83-95.

Kinsella, W. J., 2005. One hundred years of nuclear discourse: Four master themes and their implications for environmental communication. *Environmental communication yearbook,* Volume 2, pp. 49-72.

Kinsella, W. J., 2012. Environments, risks, and the limits of representation: Examples from nuclear energy and some implications of Fukushima. *Environmental Communication: A Journal of Nature and Culture,* 6(2), pp. 251-259.

Kinsella, W. J., 2015. *Being "Post-Fukushima": Divergent Understandings ofSociotechnical Risk.* Tokyo, United Nations University Institute for the Advanced Study of Sustainability.

Kinsella, W. J., Kelly, A. R. & Kittle Autry, M., 2013. Risk, regulation, and rhetorical boundaries: Claims and challenges surrounding a purported nuclear renaissance. *Communication Monographs,* 80(3), pp. 278-301.

Klose, R. & Reiss, S., 2004. Atomkraft, ja bitte!. *FACTS*, 21 October, pp. 64-67.

Kristiansen, S. & Bonfadelli, H. K. M., 2016. Risk Perception of Nuclear Energy After Fukushima: Stability and Change in Public Opinion in Switzerland. *International Journal of Public Opinion Research,* Volume edw021.

Kuhn, T. S., 1962. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Lederberg, J., 1972. Freedoms and the Control of Science: Notes from the Ivory Tower. *The. S. Cal. L. Rev,* Volume 45, p. 596.

Lohnert, G. H., Nabielek, H. & Werner, S., 1988. The Fuel Element of the HTR-Module, a Prerequisite of an Inherently Safe Reactor. *Nuclear Engineering and Design,* 109(1), pp. 257-263.

Lotz, J. & Mattes, A., 2011. Von Becquerel bis Strahlenkrankheit. Frankfurter Allgemeine. *Frankfurter Allgemeine Zeitung*, 15 March.

Lundgren, R. E. & McMakin, A. H., 2013. *Risk communication: A handbook for communicating environmental, safety, and health risks.* New York City: John Wiley & Sons.

Mehner, A. W. et al., 1990. Spherical Fuel Elements for Advanced HTR Manufacture and Qualification by Irradiation Testing. *Journal of Nuclear Materials,* 171(1), pp. 9-18.

Merz, M., 1999. Multiplex and unfolding: Computer simulation in particle physics. *Science in context,* 12(2), pp. 293-316.

Merz, M. & Knorr Cetina, K., 1997. Deconstruction in a thinking' science: Theoretical physicists at work. *Social Studies of Science 27,* pp. 73-111.

Miller, C. R., 1994. Opportunity, Opportunism, and Progress: Kairos in the Rhetoric of Technology". *Argumentation,* 8(1), pp. 81-96.

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

Ministery of the Environment, Climate Protection and the Energy Sector Baden-Württemberg, 2011. *Remote Monitoring of Nuclear Power Plants Baden-Württemberg.* [Online] Available at: http://www.lubw.baden-wuerttemberg.de/servlet/is/2912/kfue_flyer_engl.pdf?command=downloadContent&filename=kfue_flyer_engl.pdf
[Accessed 6 February 2014].

Moormann, R., 2008. *A Safety Re Evaluation of the AVR Pebble Bed Reactor Operation and Its Consequences for Future HTR Concepts,* Jülich: Forschungszentrum Jülich, Zentralbibliothek Verlag.

Park, D. J. W. W. &. P. J., 2016. Beyond Disaster and Risk: Post-Fukushima Nuclear News in US and German Press. *Communication, Culture & Critique,* 9(3), pp. 417-437.

Perrow, C., 2011. *Normal accidents: Living with high risk technologies.* s.l.:Princeton University Press.

Pfotenhauer, S. M., Christopher, F. J., Krishanu, S. & Sheila, J., 2012. Learning from Fukushima. *Issues in Science and Technology,* 28(3), pp. 79-84.

Plantin, J. C., 2015. The politics of mapping platforms: participatory radiation mapping after the Fukushima Daiichi disaster. *Media, Culture & Society,* 37(6), pp. 904-921.

Powell, R., 1990. *Nuclear deterrence theory: The search for credibility.* Cambridge: Cambridge University Press.

Ramana, M. V. & Mian, Z., 2014. One size doesn't fit all: Social priorities and technical conflicts for small modular reactors. *Energy Research & Social Science,* Volume 2, pp. 115-124.

Reutler, H. & Lohnert, G. H., 1983. The Modular High-Temperature Reactor. *Nucl. Technol.,* 62(1), pp. 22-30.

Riccio, A., Giunta, G. & Galmarini, S., 2007. Seeking for the rational basis of the Median Model: the optimal combination of multi-model ensemble results. *Atmos. Chem. Phys. 7,* pp. 6085-6098.

Rickard, L. N., 2011. In backyards, on front lawns: examining informal risk communication and communicators. *Public Understanding of Science,* 20(5), pp. 642-657.

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

Schmid, S., 2016. *Chernobyl, Fukushima, and preparedness for a "next one".* [Online] Available at: http://thebulletin.org/chernobyl-fukushima-and-preparedness-next-one [Accessed 1 6 2016].

Schmid, S. D., 2016. What if there's a next time? Preparedness after Chernobyl and Fukushima - A European-American response. *Bulletin of the Atomic Scientists,* 72(4), p. 260–261.

Sethi, M., 2016. *Partnering with the public for better preparedness.* [Online] Available at: http://thebulletin.org/chernobyl-fukushima-and-preparedness-next-one [Accessed 1 6 2016].

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

Sovacool, B. K. & Ramana, M. V., 2015. Back to the future small modular reactors, nuclear fantasies, and symbolic convergence. *Science, Technology & Human Values,* 40(1), pp. 96-125.

Spaeth, B., 2011. Joörg Starflingers fulminanter Einstieg. *Transmitter*, 5, pp. 18-19.

Stilgoe, J., 2007. The (co-) production of public uncertainty: UK scientific advice on mobile phone health risks. *Public Understanding of Science,* 16(1), pp. 45-61.

Stockie, J. M., 2011. The mathematics of atmospheric dispersion modeling. *Siam Review,* 53(2), pp. 349-372.

Stohl, A. et al., 2011. Xenon-133 and caesium-137 releases into the atmosphere from the Fukushima Dai-ichi nuclear power plant: determination of the source term, atmospheric dispersion, and deposition. *Atmospheric Chemistry and Physics Discussions,* 11(10), pp. 28319-28394.

Strahlenschutzkommission, 2007. *Leitfaden zur Information der Öffentlichkeit in kerntechnischen Notfällen,* Bonn: Geschäftsstelle der Strahlenschutzkommission.

Sturgis, P. & Allum, N., 2004. Science in society: re-evaluating the deficit model of public attitudes. *Public understanding of science 13,* pp. 55-74.

The Fukushima Nuclear Accident Independent Investigation Commission, 2012. *The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission,* Tokyo: The National Diet of Japan.

The National Diet of Japan, 2012. *The official report of Executive summary The Fukushima Nuclear Accident Independent Investigation Commission,* Tokyo: The National Diet of Japan.

Thomas, S., 2009. The Demise of the Pebble Bed Modular Reactor. *Bulletin of the Atomic Scientists*, 22 June.

Tokonami, S. et al., 2012. Thyroid doses for evacuees from the Fukushima nuclear accident. *Scientific Reports,* Volume 2.

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.

U.S. Nuclear Regulatory Commission, 1975. *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants,* Washington, D.C.: US NRC.

U.S. Nuclear Regulatory Commission, n.d. *Reactor Safety Study: An Assessment of Accident,* s.l.: s.n.

USNRC, 2011. *Recommendations for enhancing reactor safety in the 21st century: The Near-term Task Force review of insights from the Fukushima Dai-ichi accident,* Washington, DC: U.S. Nuclear Regulatory Commission.

Weber, M., 2002. *The Protestant Ethic and the Spirit of Capitalism: and other writings.* s.l.:Penguin.

Weinberg, A. M. & Spiewak, I., 1984. Inherently Safe Reactors and a Second Nuclear Era. *Science,* Volume 224, pp. 1398-1402.

Weinberg, A. M., Spiewak, I., Phung, D. L. & Livingston, R. S., 1985. The Second Nuclear era: a nuclear renaissance. *Energy,* 10(5), pp. 661-680.

Whyte, W. H., 2013. *The organization man.* s.l.:University of Pennsylvania Press.

Wilbois, T. et al., 2009. SIM-NOT: Einsatz von Simulationen im radiologischen Notfallschutz. In: R. Mayer-Föll, A. Keitel & W. Geiger, eds. *Kooperative Entwicklung wirtschaftlicher Anwendungen für Umwelt und Verkehr in neuen Verwaltungsstrukturen, Phase IV 2008/09.* Karlsruhe: Forschungszentrum Karlsruhe (FZKA 7500), pp. 71-80.

Wilbois, T. et al., 2013. Remote monitoring of nuclear power plants in Baden-Wuerttemberg–From measurement to emergency protection. *Radioprotection,* 48(5), pp. S95-S102.

Wynne, B., 1992. Misunderstood misunderstanding: Social identities and public uptake of science. *Public understanding of science,* 1(3), pp. 281-304.

Abstract

The complex socio-techno-natural disaster at Fukushima provided an important occasion for an international display of emergency response and nuclear crisis communication in action. While being only one of several such occasions, the Fukushima nuclear accident revealed that current public expectations concerning the management of a nuclear crisis and the actual implementation of emergency response actions do not meet. On the one hand, the technologies, organizational structures, and guidelines designed for managing nuclear emergencies by relevant government agencies are based on experiences from the past, notably with the Chernobyl accident from 1986. On the other hand, the Fukushima accident showed that nuclear emergencies do not follow a foreseeable course of events. These insights ask for rethinking nuclear emergency response in a broader sociotechnical context rather than in a strictly technocratic one.

Decision-support systems for nuclear emergency management (DSNE) currently represent one of the core technologies used by government-appointed crisis task forces around the world in nuclear crises. They are based on forecasting the atmospheric dispersion of the radioactive substances eventually released from damaged nuclear reactors by means of computer simulations. Atmospheric dispersion forecasts are used by the members of emergency task forces for supporting decisions about evacuation priorities and other protective countermeasures. In addition to using DSNE systems, crisis task forces must effectively communicate the radiological risk situation to the public and implement the most appropriate countermeasures in order to protect the population against the effects of radiation.

The present work aims to complement the existing STS literature on sociotechnical imaginaries by analyzing some of the post-containment sociotechnical imaginaries of the nuclear, which emerged after the Three Mile Island and Chernobyl accidents. Further, it examines how DSNE systems became an important nuclear risk management technology in Germany and how the post-containment imaginaries of the nuclear and the thought collectives and practices formed around DSNE systems influenced each other. Finally, the analysis explores the ways in which the Fukushima accident reshaped the post-containment imaginaries of the nuclear and the community of nuclear experts in Germany. To address these research questions, the thesis is built around three case studies. The first case study follows the history of a particular German reactor design claimed to be “inherently safe” by its proponents. The second case study revolves around the creation and use of DSNE systems as well as the thought collectives and practices that developed around them. The third case study represents an overarching account on the history of the German community of nuclear scientists and engineers by the example of the Institute of Nuclear Technology and Energy Systems (IKE), affiliated with the University of Stuttgart in Germany.

The results of this research show that, in addition to the technopolitical agendas of their proponents, there is another phenomenon at work that renders sociotechnical imaginaries performative and appealing to experts, politicians, and laypersons. This phenomenon appears to be that of an evolutionary competition between contemporary imaginaries which takes place at all times. In this competition, battles are sometimes won by hazard and other times through a long process of stabilization. In the former case, a disruptive event, such as a “normal accident” or a major shift in technopolitical order, may render one imaginary obsolete while establishing another one in its place. In the latter case, new genres and subgenres of the emerging imaginary may develop seamlessly over a longer period of time. The observation that the different imaginaries of the nuclear follow an evolutionary process allowed to identify some of their key features, which can be related to the existing theoretical frameworks on sociotechnical imaginaries, rhetorical visions, and fantasies. The thesis also provides an outlook on the sociotechnical imaginary of preparedness and the ways in which it could benefit from public participation and improvisation in addition to rigidly defined emergency response plans.

Abstract (Deutsch)

Die komplexe „soziotechnologische Naturkatastrophe“ in Fukushima bot eine wichtige Gelegenheit der Demonstration internationaler Anstrengungen von Notfallmaßnahmen und angewandter Krisenkommunikation im nuklearen Bereich. Der Atomunfall von Fukushima war zwar nur einer von mehreren solchen Anlässen, doch er zeigte, dass die derzeitigen Erwartungen der Öffentlichkeit an das Management einer Atomkrise und die tatsächliche Umsetzung von Notfallschutzmaßnahmen nicht erfüllt werden. Einerseits basieren die Technologien sowie die organisatorischen Strukturen und Leitlinien, die für die Bewältigung von nuklearen Notfällen durch die zuständigen Regierungsbehörden entwickelt wurden, auf Erfahrungen aus der Vergangenheit, insbesondere aus dem Unfall von Tschernobyl aus dem Jahr 1986. Auf der anderen Seite zeigte der Unfall von Fukushima, dass nukleare Notfälle keinem vorhersehbaren Verlauf folgen. Diese Erkenntnisse verlangen ein Umdenken im Rahmen der Reaktion auf nukleare Notfälle nicht nur in einem streng technokratischen Zusammenhang, wie bisher, sondern in einem breiteren soziotechnischen Kontext.

Systeme zur Entscheidungsunterstützung für das nukleare Notfallmanagement (DSNE) stellen derzeit eine der Kerntechnologien dar, die von staatlich berufenen Krisenstäben weltweit in Nuklearkrisen eingesetzt werden. Sie basieren auf der anhand von Computersimulationen ermittelten Prognose der atmosphärischen Ausbreitung radioaktiver Stoffe, die aus beschädigten Kernreaktoren freigesetzt werden. Atmosphärische Ausbreitungssimulationen werden von den Mitgliedern des Krisenstabs zur Unterstützung von Entscheidungen über Evakuierungsprioritäten und andere Notfallschutzmaßnahmen eingesetzt. Zusätzlich zu dem Einsatz von DSNE-Systemen müssen die Mitglieder des Krisenstabs die radiologische Risikosituation der Öffentlichkeit wirksam mitteilen und die am besten geeigneten Schutzmaßnahmen ergreifen, um die Bevölkerung vor den Auswirkungen der Strahlung zu schützen.

Die vorliegende Arbeit zielt darauf ab, die STS-Literatur über soziotechnische Imaginäre um die Analyse einiger „post-Containment“ soziotechnischer Imaginäre der Nuklearära, die nach den Three Mile Island und Tschernobyl Unfällen entstanden sind, zu ergänzen. Des Weiteren wird untersucht, wie sich DSNE-Systeme in Deutschland zu einer wichtigen Technologie zur Unterstützung des nuklearen Risikomanagements entwickelt haben und wie sich die „post-Containment“ Imaginäre der Nuklearära sowie die entstandenen Gedankenkollektive und Praktiken im Bereich der Benutzung und Entwicklung von DSNE-Systemen gegenseitig beeinflusst haben. Abschließend wird untersucht, wie der Fukushima Unfall die „post-Containment“ Imaginäre der Nuklearära sowie die Gemeinschaft deutscher Nuklearexperten umgestaltet hat. Um diese Forschungsfragen zu beantworten wurden drei Fallstudien herangezogen. Die erste Fallstudie behandelt einen speziellen deutschen Reaktorentwurf, der von seinen Befürwortern als "inhärent sicher" bezeichnet wurde. Die zweite Fallstudie beschäftigt sich mit der Entstehung und Nutzung von DSNE-Systemen und der dazugehörigen Gedankenkollektive und Praktiken. Die dritte Fallstudie gibt einen Überblick über die Geschichte der Gemeinschaft deutscher Atomwissenschaftler und -ingenieure am Beispiel des Instituts für Kernenergetik und Energiesysteme (IKE) der Universität Stuttgart.

Die Ergebnisse dieser Arbeit zeigen, dass zusätzlich zu den technopolitischen Agenden ihrer Befürworter ein weiteres Phänomen existiert, das soziotechnische Imaginäre performativ und für Experten, Politiker und Laien interessant macht. Dieses Phänomen deutet auf einen kontinuierlich stattfindenden evolutionären Konkurrenzkampf zwischen zeitgenössischen Imaginären hin. In diesem Wettbewerb werden Kämpfe manchmal durch Zufall und andere Male durch einen langen Stabilisierungsprozess gewonnen. Im erstgenannten Fall kann durch ein disruptives Ereignis wie ein "normaler Unfall" oder eine bedeutende Verschiebung der technopolitischen Ordnung ein Imaginär

entstehen, während es ein anderes an seiner Stelle etabliert. Im letzteren Fall können sich neue Genres und Subgenres des aufkommenden Imaginärs über einen längeren Zeitraum nahtlos entwickeln. Die Beobachtung, dass die verschiedenen Imaginäre der Nuklearära einem Evolutionsprozess folgen, ermöglichte es, einige ihrer Schlüsselmerkmale zu identifizieren, die mit den existierenden Theorien über soziotechnische Imaginäre, rhetorische Visionen und Phantasien in Zusammenhang stehen. Die Arbeit gibt auch einen Ausblick auf die mögliche Weiterentwicklung des soziotechnischen Imaginärs der Notfallschutzbereitschaft und auf die Art und Weise, in der es neben den starrdefinierten Notfallplänen auch von der Beteiligung der Öffentlichkeit und Improvisation profitieren könnte.

Curriculum Vitae

Higher Education

2013 – 2017	M.A. Science-Technology-Society, University of Vienna
2007 – 2013	Doctoral Program (Dr.-Ing.), Universität Stuttgart, Germany
2005 – 2007	M.Sc., “Politehnica” University of Bucharest
2000 – 2005	Dipl.-Ing., “Politehnica” University of Bucharest

Work Experience

2015 –	Senior Software Architect, Siemens AG, Austria
2012 – 2014	R&D project manager, TTTech Computertechnik AG, Austria
2007 – 2012	Research Assistant, Institute of Nuclear Technology and Energy Systems, Stuttgart
2006 – 2007	Software Developer, TTTech Romania SRL