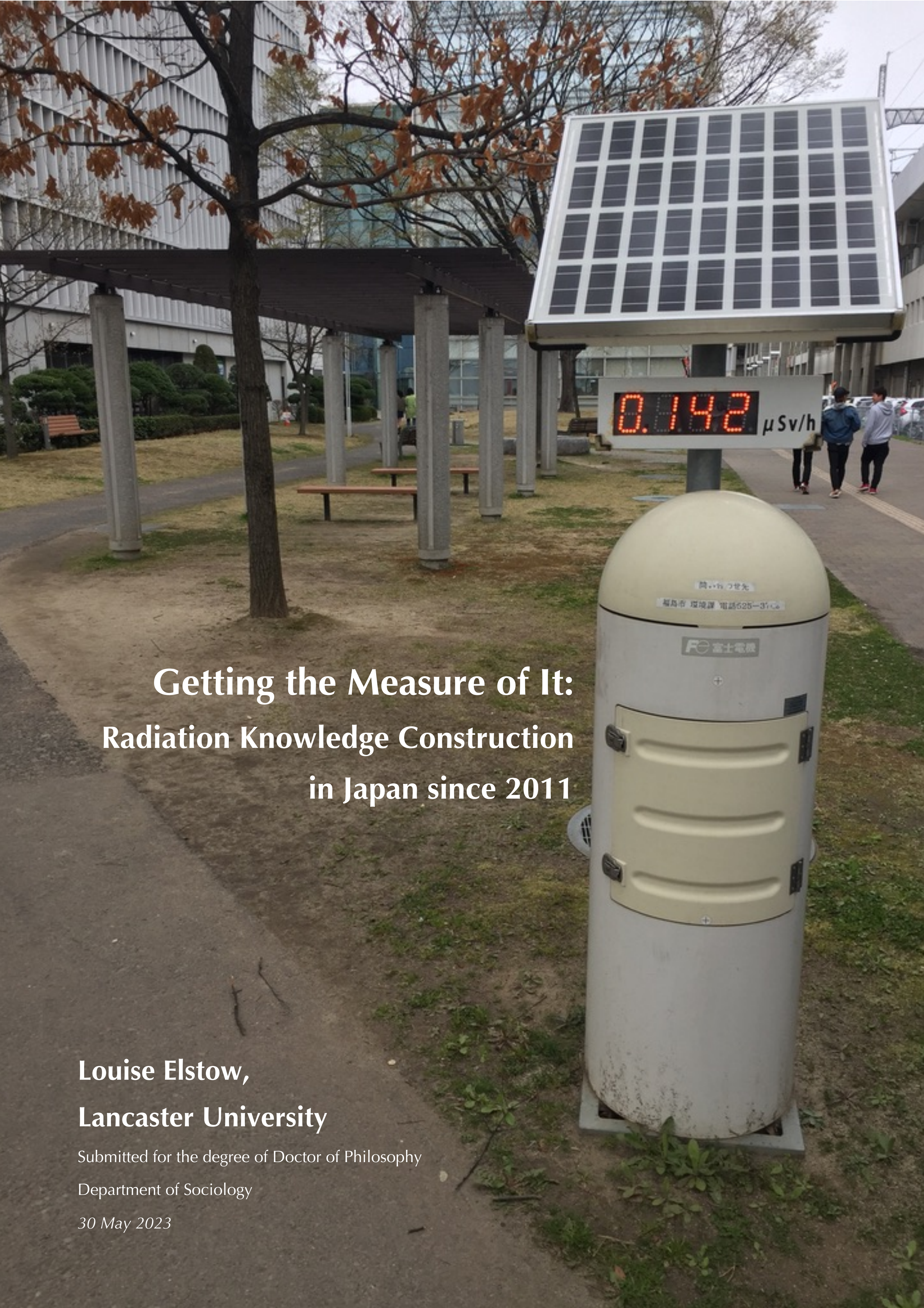

Getting the Measure of It:
Radiation Knowledge Construction in Japan since 2011

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Image on Front Cover: A fixed radiation monitoring post situated next to Fukushima City railway station.

Declaration: This thesis is my own work and has not been submitted in substantially the same form for any other award. Parts of chapter 1 were published in Elstow (2022), in particular the opening section (1.1. Noticing and 1.4 'What's it for?').

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Front matter

Abstract

Getting the Measure of It: Radiation Knowledge Construction in Japan since 2011

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Since the Fukushima Daiichi nuclear power plant meltdown in March 2011, in which environments, foods and bodies were contaminated with radioactive isotopes, many devices have made knowledge about radiation.

This thesis overlays concepts such as assemblages, qualculations, comparisons, and syncretism to provide a multidimensional, layered way of thinking about scientific knowledge making in contamination emergencies. Based on ethnographic data from Japan gathered between 2018 and 2022, including two periods of fieldwork in Japan in 2018 and 2019, I demonstrate multiple heterogeneous socio-material entities come together to construct radiation knowledge in different places, times and for different purposes. I contend that human and nonhuman actors are active in the process of radiation knowledge creation, performing different roles and functions in the assemblage. I argue these actors influence what else is in assemblages, where and when they operate, and what happens when they come into contact with alternative assemblages operating in the same spaces and times. However, not all actors have equal agency in this. I highlight tensions between knowledge-making communities – the questions they seek to answer, the resources they have access to, and the extent to which they seek to align their practices with others. I also assert that nonhuman actors, such as emergency plans, legislation, standards, thresholds and guidance documents simultaneously stabilise and constrain knowledge making opportunities. Stabilisation and constraint occur across multiple dimensions – spatially (where knowledge is made), temporally (when it is made) and practically (how it is made).

As well as contributing to social science debates about the sociality and materiality of collective knowledge making practices in general, my findings are directly relevant to professionals charged with planning for and responding to contamination events. It suggests a new way of thinking about knowledge making in emergencies which acknowledges the multiplicity of knowledge making assemblages, their opportunities and limits in different places and times, and how they operate alongside other knowledges and practices.

Keywords: Knowledge production, qualculation, syncretism, radiation, Fukushima, measurement, devices, assemblages

Data Access Statement: Data are available on request from the Author. l.elstow@lancaster.ac.uk

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I would like to dedicate this thesis, and the pursuit of making sense of the things around us, to Karolina and Viktoriia Sorokina, Oleksandr (Sasha) Lisovyi and to the people of Ukraine, who continue to struggle to make sense of what is going on around them and why this is happening.

Glossary of terms and abbreviations

The following table includes a list of key terms and abbreviations used in this thesis.

In full	Abbreviation	Description / explanation
'triple disaster', '3.11'	n/a	Terms to describe the incident that began on 11 March 2011 and included an earthquake, tsunami and nuclear disaster. In Japan is it commonly referred to as 'The Great East Japan Earthquake'.
Actor-network theory	ANT	A way of thinking about how networks of entities shift and relate to one another.
Alternative Dispute Resolution	ADR	One of the three routes for compensation as a result of the Fukushima Daiichi Nuclear Power Plant disaster – the remaining two routes being normal litigation or a standardised form via 'Direct Compensation' managed by TEPCO.
Anshin 安心	n/a	Japanese: A more subjective notion of safety. One of my participants noted that the best translation was 'peace of mind'
Anzen 安全	n/a	Japanese: A more a scientific, more objective and technical means of describing safety or security.
Chemical, Biological, Radiological and Nuclear	CBRN	This abbreviation is used to describe an incident involving contaminating materials. Sometimes the term hazmat incident might be used. In the UK CBRN is used in military and civilian settings to describe malicious intent, whilst hazmat is non-malicious. In military settings it was previously referred to as NBC or CBR.
Citizen Radiation Measuring Organisations	CRMOs	An umbrella term coined by Aya Kimura to describe citizen groups engaged with radiation measuring and monitoring after the Fukushima nuclear power plant disaster.
Citizens' Collective Data	CCD	An anonymised citizen group making, collecting and publishing radiation data
Codex Alimentarius Commission	CAC	An organisation created in 1963 by Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) to develop food standards, guidelines and codes of practice.
Consumer Affairs Agency	CAA	Japanese Government Agency
Detection, Identification and Monitoring	DIM	An abbreviation used in the UK to describe predominantly fire-service capabilities and equipment designed to detect, identify and monitor hazardous materials.
Disaster STS	DSTS	An academic sub-field of STS concerned with the subject of disasters.
ETHOS in Fukushima	ETHOS	A risk communication program after the Fukushima nuclear accident – organised by the ICRP and other international, predominantly radiological organisations. It was modelled on similar projects in Chornobyl.
European Nuclear Safety Regulators Group	ENSREG	ENSREG's role is to help to establish the conditions for continuous improvement and to reach a common understanding in the areas of nuclear safety and radioactive waste management. Expertise from national nuclear safety, radioactive waste safety or radiation protection regulatory authorities and European Union / European Commission.
Food and Agriculture Organization	FAO	Agency of the United Nations that leads international efforts to defeat hunger
fūhyōhigai風評被害	n/a	Japanese: Harmful rumours or damage through rumours – used frequently in relation to the Fukushima disaster both as a justification for not releasing information and as a means of de-legitimising concerns held about radiation levels.
Furekonフレコンバッグ	n/a	Japanese: 'Flexible container'. Large black bags into which contaminated soil and materials were placed, prior to temporary storage and processing.
Gaman 我慢,	n/a	Japanese: patience or endurance

Geiger Müller Tube / Geiger Counter	G-M Tube	A particular kind of radiation measuring device.
Government of Japan	GoJ	n/a
Gray	Gy	A unit of absorbed radiation equal to the dose of one joule of energy absorbed per kilogram of matter, or 100 rad.
Health and Resilience in Disasters	HeaRD	A project to bring together academics from British and Japanese institutions working on the consequences of disasters, in particular Fukushima.
History and philosophy of science	HPS	n/a
Hormesis	n/a	The idea that some toxic substances (including radiation) might have a beneficial effect at very low levels. Contrast this with LNT.
Hot zones / hot spot	n/a	A particularly contaminated area
Intensive Contamination Survey Areas	ICSA	Areas where municipalities take the initiative in decontamination work, and the national government takes financial measures and technical measures to assist these municipalities. https://www.env.go.jp/en/chemi/rhm/basic-info/1st/pdf/basic-1st-09-01.pdf
International Atomic Energy Agency	IAEA	An intergovernmental organisation which seeks to promote the safe, secure and peaceful use of nuclear technologies.
International Commission on Radiological Protection	ICRP	The primary body in protection against ionising radiation, created by the 1928. As an independent, non-governmental organisation they produce internationally recognised recommendations and guidance relating to ionizing radiation and radiation protection.
International Nuclear and Radiological Event Scale	INES	Established by the IAEA, the INES is a scale used for rating events that result in a release of radioactive material into the environment and in the radiation exposure of workers and the public.
Japan Atomic Energy Agency	JAEA	Japan's nuclear research and development institute
Japan Nuclear Energy Safety	JNES	An incorporated administrative agency established in 2003, is an expert organization with the mission to ensure safety in the use of nuclear energy.
n/a	JML	Japanese maximum permissible levels of radiocesium in food (JMLs),
Josen/除染	n/a	Japanese: decontamination
Lateral Flow Device / Test	LFD / LFT	A kind of device for detecting the presence of a virus, and commonly used to detect COVID-19 in asymptomatic individuals.
Linear-Non-Threshold	LNT	A model used in radiation protection to estimate the cancer risk caused by ionizing radiation – it assumes that there is no level below which ionising radiation is so negligible it is 'safe'. See also *Hormesis*.
Madei までい	n/a	Japanese: A local expression in Fukushima. It has been translated as 'politely' or 'with sincerity'. It is linked to a sense of appreciation for a slow way of life and taking one's time.
Mainichi 毎日	n/a	Japanese: every day, daily
Mendokusai: めんどくさい	n/a	Japanese: troublesome, bothersome
Met Office	n/a	The Met Office is the national meteorological service for the UK, providing critical weather services and climate science.
Ministry of Agriculture	MoA	Japanese Government department
Ministry of Economy, Trade and Industry	METI	Japanese Government department
Ministry of Education, Culture, Sports, Science and Technology	MEXT	Japanese Government department
Ministry of Environment	MOE	Japanese Government department – in a nuclear emergency it is responsible for compensation and prevention of health impairment caused by pollution,

		and countermeasures against environmental contamination with radioactive materials
Ministry of Health, Labour and Welfare	MHLW	Japanese Government department
National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission	NAIIC	Commission to investigate the background and cause of Fukushima Daiichi nuclear disaster formed by statutory law enactment by Diet of Japan on 7 October 2011.
Not Detected	ND	ND is used to show that radiation level is sufficiently low that the device measuring it is not able to detect it. This does not mean that there was no radiation present. ND differs according to the sensitivity of the measuring device.
Nuclear Emergency Response Headquarters	NERH	Japanese government organisation which sits under the Cabinet Office temporarily established in the event of a nuclear emergency. General coordination of nuclear emergency response measures and post-accident measures
Nuclear Regulation Authority	NRA	Established after the 2011 triple disaster, as an external organization of the Ministry of Environment. In peacetime its role is to ensuring safety of nuclear facilities. This separated regulation of the nuclear industry from promotion of the nuclear industry which had previously been combined.
Office for Nuclear Regulation	ONR	UK regulator of the nuclear industry
Personal Dosimeters	n/a	A personal dosimeter is a small device portable device used for measuring and sometimes recording radiation dose. Different models exist using different technologies – including photoluminescence and film. Examples found in use in Fukushima included Quixel Badges, MyDose Mini, the eDose, Glass Badges and D-Shuttles.
Pile	n/a	A colloquial term for an early design nuclear reactor, because these were made of 'piles' of graphite and uranium blocks
Polymerase Chain Reaction	PCR	A technique used to "amplify" small segments of DNA – one of the main kinds of COVID tests used in the UK.
Public Health England	PHE	Dissolved in 2021 during the COVID pandemic, PHE was previously an agency of the UK Government Department of Health and Social Care in England –to protect and improve health and wellbeing and reduce health inequalities
Radiation	n/a	The emission of energy as electromagnetic waves or as moving subatomic particles, especially high-energy particles which cause ionization.
Radical Interpretations of Disasters	RADIX	RADIX was created in 2001 as a "Home for Radical Interpretations of Disaster and Radical Solutions". Founders of the RADIX Disaster Studies Manifesto and Accord
Radiation Protection	RP	The protection of people from harmful effects of exposure to ionizing radiation, and the means for achieving this.
Science and Technical Advice Cell	STAC	A locally sourced group of subject matter experts who support local level emergency management in the UK.
Science and Technology Studies	STS	A branch of social sciences with an interest in the interactions between science, technology and social systems.
Scientific Advisory Group for Emergencies	SAGE	Provides scientific and technical advice to support UK government decision makers during emergencies.
Social studies of scientific knowledge	SSK	Emerging in the late 1970s, SSK examined how scientific knowledge itself was socially shaped or constructed
Social construction of technology	SCOT	A strand of academic work interested in the social construction of technology and technological artifacts.
Source (term)	n/a	'The types, quantities, and physical and chemical forms of the radionuclides present in a nuclear facility that have the potential to give rise to exposure to ionising radiation, radioactive waste or discharges.' https://www.onr.org.uk/new-reactors/uk-abwr/reports/ri-abwr-0001.pdf

Special Decontamination Areas	SDAs	Areas where the Japanese national government directly conducts decontamination work after Fukushima. https://www.env.go.jp/en/chemi/rhm/basic-info/1st/pdf/basic-1st-09-01.pdf
Tokyo Electric Power Company	TEPCO	The owner and operator of the Fukushima Daiichi Nuclear Power Plant
United Nations Development Programme	UNDP	UN department aiming to achieve the eradication of poverty, and the reduction of inequalities and exclusion
Whole Body Counter	WBC	A device for measuring the total amount of radiation inside a human body.
World Health Organization	WHO	Agency of the United Nations responsible for international public health

Table of Contents

PART ONE: BACKGROUND READINGS

Figure 1: A fixed radiation monitoring post installed by Iitate Village

1 Introduction

1.1 Noticing

The first time I visited Fukushima prefecture was in 2018, seven years after the devastating earthquake, tsunami and nuclear disasters of March 2011. As I will explain in more detail shortly, I was interested finding out more about in the radiological aspects of what is variously called the 'Great East Japan Earthquake (and Tsunami)', the 'Triple Disaster' or sometimes just '3.11'. I remember seeing my first fixed radiation monitor – a white oversized bollard with a red LED screen and solar panel attached to a pole on the top (Figure 2). It was in the middle of the train station car park in Koriyama City, a city which although not affected directly by any kind of legal requirement to evacuate as a result of nuclear contamination, still had elevated radiation levels compared to pre-2011 figures. As I left the station and saw Fukushima Prefecture for the first time, I must admit I was a bit excited, thrilled even, to finally be there and to spot a radiation monitoring post for myself. At last, I was able to see with my own eyes how much radiation there was in this potentially contaminated place I had heard so much about.

Figure 2: The first radiation monitoring post I encountered in Koriyama City train station car park (June 2018).

Fixed radiation monitoring posts provide written traces or radiation levels, on their screens and in government databases, enabling different judgements about radiation to take place in different spaces and by different people. The posts convert invisible radiation into visible numbers, to which I (and others) could then attach meaning about the radiological contamination of my surroundings, based on an understanding of what those numbers meant. The monitoring post was also a marker to me as an outsider, of what it meant to be contaminated. It meant I was in the right place; I had arrived in Fukushima and not, for example, Kyoto or Tokyo.

At first I did not know what to make of the number I saw on the screen (0.182 μSv/h). What did that mean? What do I do with that information? Over time, however, I learned a quotidian way to note and pay attention to the numbers on the screens I saw and to the range of devices themselves. There was not so much excitement as the frequency with which I saw the monitors rendered them into a familiar sight. However, I registered the number on the screen, much in the same way as I might note the price of fuel in petrol station forecourts in the UK – glance and move on. I started to know typical ambient dose levels in different parts of Fukushima

Prefecture, to expect higher levels in Iitate or Yamakiya than I would do in Fukushima City or Suetsugi. I found that residents in parts of the prefecture with typically higher radiation levels since the disaster might tolerate a general level of radiation not considered acceptable elsewhere in the prefecture.

I also noticed some devices measured radiation in subtly different units which account for different aspects of radiation: some displayed measurements in different and, initially at least, unfamiliar units of measurement: Grays and others in Sieverts. Although in Fukushima's case, because of the specific characteristics of the radionuclides (radioactive particles) involved, measurements in Grays and Sieverts are broadly equivalent, having to navigate different measurement units and different scales was easily confusing (I explain these challenges more clearly in section 1.3). I was told that some devices initially displayed measurements in nanograys (one billionth of a Gray), which alarmed people by showing readings in triple digits, making them look much larger than the numbers shown on other devices measuring in μGy/h (micrograys per hour) or μSv/h (microsieverts per hour). To address this, the measurement units painted on the side of the screen were taped over and the device was reset to μGy/h, thus moving the decimal place over to a less concerning location.

Figure 3: The fixed radiation monitoring post measures 0.17 microsieverts per hour whilst a handheld monitor reads 0.10 microrems per hour. How do these numbers and units relate to each other? Is one right or wrong? What are they telling me?

I learned to compare and to pick up on larger fluctuations from these general baseline figures in each town. On various occasions, I held different hand-held devices next to the fixed radiation monitors to compare readings and saw a degree of disparity in the readings. This was a standard occurrence according to several people I spoke to – professional- and citizen-scientists, as well as government officials. It was up for debate as to which of the devices was 'right' and which were inaccurate. One participant told me a common approach amongst the anti-nuclear side was to choose the higher figure so as not to underestimate risk. There were contrasting views on how to judge accuracy: whether this should be judged on the number of data points, the time elapsed since the last measurement, the people doing the monitoring, the device they used or the method of using the device. There is a rich array of approaches to, motivations for and results emerging from radiation measuring and radiation monitoring activities.

Figure 4: In Commutan Fukushima (Communication Building of the Centre for Environmental Creation, Fukushima prefecture, a centre for local residents to learn more about radiation), a cloud chamber makes visible radioactive particles as they pass through and cause a disturbance.

1.1.1 Messy radiation

As my first encounters with radiation monitoring posts in Koriyama City showed me, radiological contamination, a form of toxicity and a potential source of harm, is a messy object (Law and Singleton, 2005). By *messy* I mean that the means by which radiation is made visible, tangible and sens-able are not singular, nor is there an ultimate truth about radiation waiting to be discovered and unearthed. Echoing Beck's observation that hazards like nuclear risks 'require the 'sensory organs' of science – theories, experiments, measuring instruments – in order to become visible or interpretable at all' (Beck, 1992: 27), Svetlana Alexievich observed the failure of 'our entire inner instrument' to be able to see, hear or touch radiation (1999: 20). The messy object of radiation contamination is multiple and constructed via the very systems and mechanisms that we have to determine what's out there (Kuchinskaya, 2011, 2012, 2014). Supporting this view, Liboiron et al. note that 'toxicity is not given in advance by nature but is stimulated, constructed, rehearsed and contested through a myriad set of social, epistemological, historical, economic, material, biological and governance systems and structures' (2018: 334). That is, that toxicity (in this case radiological contamination as opposed to chemical) is created by the tools and processes we have for knowing it is there.

Measuring and monitoring radiation requires technical tools like whole body counters, Geiger Muller tubes or scintillation detectors. These are some of Beck's *sensory organs of science*. They generate data, typically in numerical forms, which are displayed on dials and screens for collection and interpretation. The monitoring posts conform to Bruno Latour's description of *inscription devices* as 'any set-up […] that provides a visual display of any sort in a scientific text' (Latour, 1987: 68), and which produces 'a written trace that makes the perceptive judgment of the others simpler' (Latour, 1983: 161). The data and numbers produced by the devices of radiation measuring and monitoring are 'immutable mobiles' (Latour, 1987) able to travel between spaces, communicating information about rice produced in a field in Fukushima to a potential consumer in Tokyo, or communicating the internal contamination of residents from Date City in Fukushima to conference of scientists in Vienna. Radiological contamination itself, does not always travel to the same place that data about it does. Data is also not enough to come to a judgement. We need ways of interpreting what the data means in order to determine what action to take, if any.

The human body makes for a poor radiation sensor. It is not able to detect the presence of radiation through the usual bodily senses such as sight, smell or taste. Radiation's invisibility to the human senses makes it ideal as a case study into the making and technologies of scientific knowledge in disasters. There is no unmediated way of looking at radiation. *The central concern of this PhD is how scientific knowledges about contamination are made, made sense of and used after contamination disasters.* Taking as a given that there is no unmediated way of looking at radiation contamination, that there are always technical devices and methods of data gathering and interpretation involved, I applied various concepts from social science theory, STS in particular, to my data. My data concerns the tools and processes of scientific knowledge making about radiological contamination after the 2011 nuclear disaster in Fukushima, Japan. My project tackles questions about radiation knowledge and sense making, familiar to those accustomed to Science and Technology Studies (STS) enquiries into scientific endeavours. Such questions include, how is scientific information made? Who or what makes scientific information? How is scientific information made available and to whom? What are the spatial and temporal dimensions of scientific knowledge making? And finally, how does one begin to understand and make sense of the numbers created by scientific inscription devices?

The thesis has three sections. The first introductory section, *Background Readings,* includes Chapters 1 to 3. It establishes the reason for, intentions of and framework for the project. The remainder of Chapter 1 provides an overview of key background details about the Fukushima Nuclear Disaster and the main radiation protection steps taken as part of the management of the radiation contamination released. Chapters 2 and 3 set out the relevant literature for the study and its methodology respectively. I am able to provide and expand on the logic for a more detailed structure of the thesis at the end of Chapter 3, having established the kinds of the themes and issues which the rest of my thesis goes on to explore and address. Part Two, *Making and Doing* incorporates Chapters 4 to 7, which introduce my empirical data alongside concepts from Science and Technology Studies (STS) as a means of working with those issues and questions. I conclude in Part Three, *Making Sense,* by summarising the overarching points of the chapters and the thesis as a whole and also by expanding on the implications of these points for professionals dealing with the consequences of contamination emergencies.

1.2 Introducing Fukushima

The following section introduces and summarises key details about the Fukushima nuclear disaster in terms of its radiation protection response as it forms the core site of exploration for the thesis. This is becauser disaster, which started on 11 March 2011 when an earthquake triggered a tsunami off the coast of Japan, transformed the status of radiological contamination knowledges in Japan and around the world[1]. I acknowledge that the act of distilling the myriad of happenings into a snapshot of key actions, maps tables and events since March 2011, makes tidier[2] and hides complexity behind these topics, something which STS is normally at pains to open up. However, I present this summary not as the subject of my analysis, but as a broad backdrop for the analysis of radiological knowledge making that is. Providing the summary here situates the reader with some of the key dates, actions and terms of the disaster, relevant to all empirical chapters but without disrupting the flow of the chapters themselves.

1.2.1 The Triple Disaster

The earthquake, tsunami and nuclear disaster that began Japan in March 2011 marked the start of intense inspection of bodies and environments in the affected areas. What came to be known colloquially as the ‘triple disaster’, ‘3.11’, or more commonly in Japan ‘The Great East Japan Earthquake’ (a term which can also include the tsunami and nuclear disaster), started with a magnitude 9.0 (IAEA, 2015: 1) earthquake off the north-eastern coast of Japan’s largest island Honshu on 11 March 2011. Around an hour after the earthquake the first of several tsunami waves, some reaching well over 10 metres in height, struck a long stretch of the Tohoku region, to the north of Tokyo. The waves’ power was concentrated on the prefectures of Fukushima, Miyagi to the north of Fukushima and Iberaki to its south. Damage caused by the waves and earthquake disrupted the power supply to five nuclear power stations along the same coastline: Higashidori, Onagawa, Fukushima Daiichi, Fukushima Daiini (Daiichi’s sister plant) and Tokai Daiini.

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[1] As I write this, participants in Japan are trying to source radiation monitors to send to Ukraine, in response to the uncertainties created by Russian troops invading Ukrainian nuclear sites including Chornobyl.

[2] A common term found in the title of many Japanese Government guides about radiation is ‘basic’, which simultaneously smooths out the complexities of radiation knowledge production, whilst hinting at its complexity. Examples include the recently published *‘BOOKLET to provide basic information regarding health effects of radiation’* (MoE, 2022). The ‘*booklet’* is split into two volumes with Volume 1 concentrating on the ‘basic knowledge’ and Volume 2 on the ‘accident at TEPCO’s Fukushima Daiichi NPS and Thereafter’. Volume 1 alone is 280 pages long.

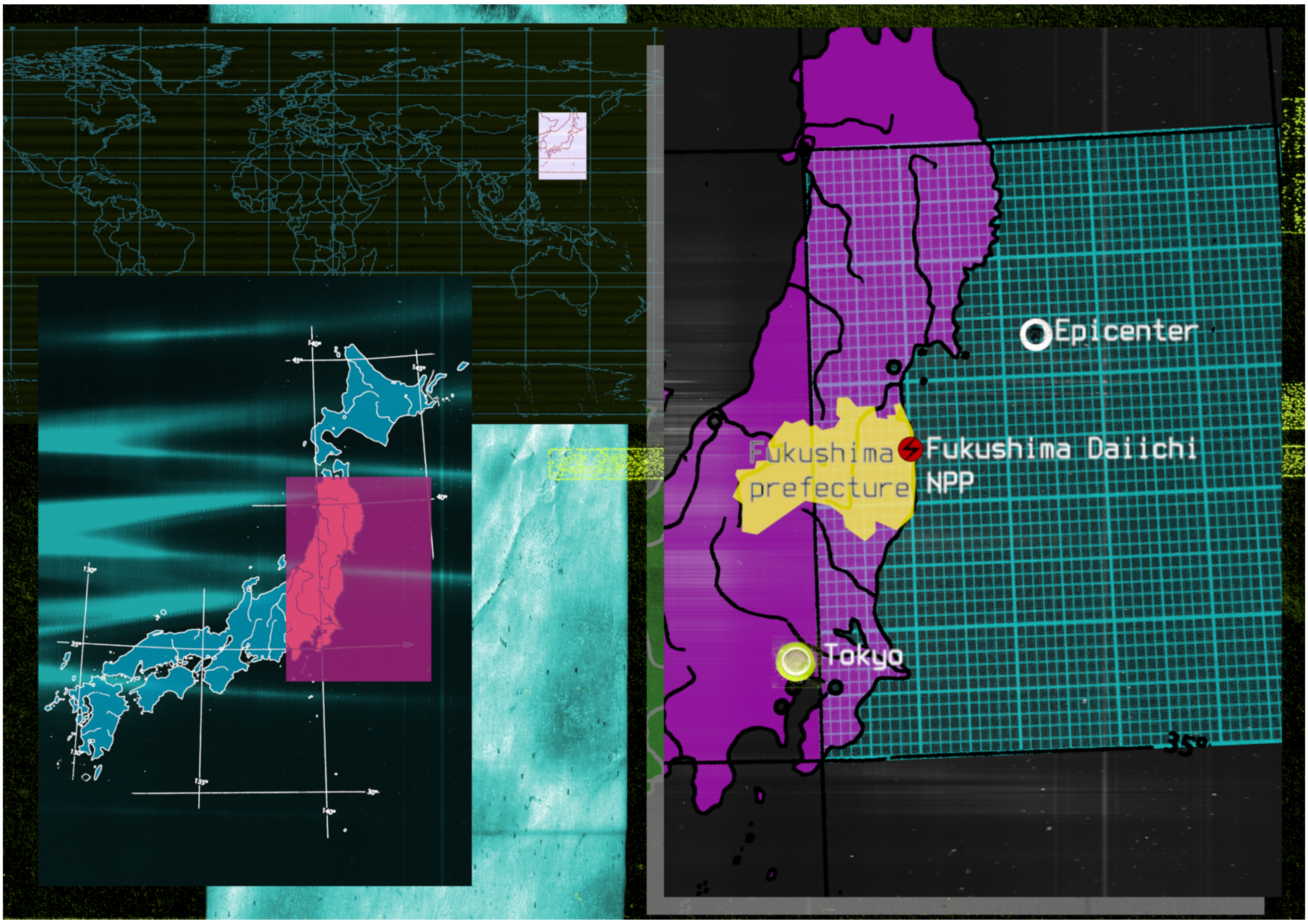


Figure 5: Map of Japan showing the epicentre of the 11 March 2011 earthquake, Fukushima Daiichi Nuclear Power Plant and the Prefectural boundary. Credit: KETHER CORTEX.

Although the reactor units at the four other power stations were all able to be shut down safely, at Daiichi the consequences were catastrophic. There, the combination of severe damage from flooding and the earthquake, coupled with a lack of on-site power, ultimately resulted in the loss of cooling function at the three working reactors that were in operation at the time of the earthquake (reactors 1-3) (Acton and Hibbs, 2012; MoE, 2022b). Over the following days this led to overheating in the reactors, the melting of nuclear fuel, the breaching of the three containment vessels and subsequently also to hydrogen explosions at reactors 1, 3 and 4 (IAEA, 2015; Wakeford, 2021). As a result, the Fukushima nuclear incident had the dubious honour of joining the 1986 chornobyl[3] nuclear disaster which occurred in present day Ukraine, by registering as Level 7 (the highest) on the International Nuclear and Radiological Event Scale (INES)[4] of the International Atomic Energy Agency (IAEA).

Radioactive contamination from Fukushima Daiichi Nuclear Power Plant was dispersed across huge swathes of Fukushima as well as several other neighbouring prefectures, including Ibaraki to the south, Tochigi to the south west and Miyagi to the north (Ministry of the Environment (MoE) – Government of Japan, 2019). Thousands of people were evacuated or took the decision to evacuate from their homes; some have still not been able to or chosen to return (IAEA, 2015). Although some contamination was carried out to sea by prevailing winds, a significant amount was deposited inland as the plume moved and tracked in a north westerly direction over inhabited areas, farmland and forests (Wakeford, 2021). Further direct releases of radioactive water into the oceans occurred and continued for several years after the initial event (Kumamoto et al., 2015) and are the subject of ongoing concern (Japan Today, 2022; Japan Times, 2022).

[3] I use the Ukrainian spelling for Chornobyl as opposed to the more common Russian spelling Chernobyl unless this is in quoted text.
[4] https://www.iaea.org/resources/databases/international-nuclear-and-radiological-event-scale

In the days, weeks and to some extent even months after the disaster, little was known about where contamination had been deposited, how much there was or what impact this might have on health long-term. Government information about radiological contamination was slow to emerge (National Diet of Japan, NAIIC, 2012; Reiher, 2016). In those first months, acknowledging the paucity of publicly available Japanese government data, many citizens, activist groups and international organisations began to undertake their own measuring and monitoring, both to address a continuing dearth of granular data as well as to counter a lack of trust in the limited information being disseminated centrally (Hemmi & Graham, 2013; Kimura, 2016a, 2016b; Kenens et al., 2020, along with several of my own interviewees fieldnotes; e.g, fieldnotes July 2018 and interview on 16 July 2018).

Dose Limits — **ICRP Recommendations and Responses of the Japanese Government**

	2007 Recommendations of the ICRP		Responses at the time of the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS
Occupational exposure	Rescue activities (Volunteers who have obtained the relevant information)	When benefits for other people outweigh the rescuers' risks, dose limits are not applied.	Special Provisions of the Ordinance on Prevention of Ionizing Radiation Hazards (Ministry of Health, Labour and Welfare) The emergency exposure dose limit was temporarily raised to **250 mSv** from the conventional level of **100 mSv** (from March 14 to December 16, 2011). The Ordinance on Prevention of Ionizing Radiation Hazards was partially amended to raise the exceptional emergency dose limit to **250 mSv** (enforced on April 1, 2016).
	Other emergency activities	1,000 mSv or 500 mSv	
Public exposure	Emergency exposure situations	The limit is to be set within the range of **20 to 100** mSv/year.	e.g. Standards for evacuation in Deliberate Evacuation Areas: **20 mSv**/year
	Reconstruction period (Existing exposure situations)	The limit is to be set within the range of **1 to 20** mSv/year.	e.g. Additional exposure dose to be achieved in the long term: **1 mSv**/year

mSv: millisieverts

Source: Prepared based on the 2007 Recommendations of the ICRP and the Special Provisions of the Ordinance on Prevention of Ionizing Radiation Hazards (Ministry of Health, Labour and Welfare: MHLW)

Table 1: ICRP Recommendations and the comparable responses by the Japanese Government. Reproduced from MoE (2019, March 31)

The responses to the radiological contamination emergency in Fukushima called extensively on scientific and technical tools to sense and make sense of contamination released. Estimates about exactly how much and what was released into the atmosphere varied:

> [T]he Japanese government estimated the source terms for 131I and 137Cs to be 160 PBq [petabecquerel] and 15 PBq, respectively (RJG, 2011). The Nuclear Safety Commission of Japan (NSCJ) estimated […] 150 PBq and 12 PBq, respectively (NSCJ, 2011). Masson et al. (2011) estimated that 153 PBq 131I and 13 PBq 137Cs were released, whereas other researchers reported the total emission of 137Cs to be as high as 13–35.8 PBq (Chino et al., 2011; Stohl et al., 2012). (Aliyu et al., 2015: 224)

The estimates differ as a result of 18rojecrent assumptions built into the models used to calculate both what was inside the reactors at the time and the way the models are built. In total, 73 isotopes –135 including their radioactive progeny – were released as a result of the Fukushima Daiichi incident (Aliyu et al, 2015: 214). The bulk of this was iodine 131, which has a half-life of 8.02 days, caesium 134 (half-life of 2.06 years), caesium-137 (half-life of 30.07 years) and to a lesser degree strontium 90 (half-life of 28.78 years). Because of the short half-life of iodine 131, within a few months the risk was exponentially reduced. This meant that the main focus of decontamination and other control mechanisms was on the two kinds of radioactive caesium (isotopes) released.

The central feature of many protective actions is to reduce dose rate (the amount of radiation a body is exposed to) down to a certain level. Although countries are able to determine their own maximum thresholds for additional exposure (excluding medical treatments and background radiation), most countries (including Japan (IAEA, 2015)) follow the recommendations set out by the International Commission on Radiological Protection (ICRP). The ICRP recommendations (ICRP, 2007) differ depending on whether the individual is a radiation worker or member of the general public, and also the situation at the time –e.g. whether the release is an emergency, part of a controlled situation or part of existing exposure. Since 1950s the ICRP recommendations have been based on a Linear-Non-Threshold (LNT) model, which assumes that there is no safe level of radiation exposure, no matter how small (Abe, 2015).[5] Table 1 sets out how the ICRP recommendations were applied to the Japanese situation.

The main protective actions in response to the nuclear disaster included evacuations, food controls and decontamination, which are all supported by different regimes of measuring and monitoring radiation and which are now described in brief.

1.2.2 Evacuation zones

It is estimated that around 160,000 Fukushima prefecture residents were displaced by the nuclear disaster (although not from the same date or for the same duration). 11 municipalities near the damaged power station – Okuma Town, Futaba Town, Tomioka Town, Namie Town, Kawauchi Village, Naraha Town, Katsurao Village, Iitate Village, Tamura City, Minamisoma City and Kawamata Town – were subject to formal evacuation orders resulting in around 86,000 evacuees. In addition, many more people living outside the mandatory evacuation areas also evacuated; 26,000 left 'for fear of being evacuated at a later stage' and 48,000 people chose to leave (IRSN, 2016).

The boundaries of the zones have changed over time – initially extending rapidly in the first two days based on distance from the site (at first 3km, then 10 km, and then 20km from the site), then extending again around six weeks later in April, based on data about where the plume had travelled (see the table in Figure 7 and map in Figure 7). This meant that areas to the south of the plant were less likely to be contaminated than areas further away but to the north west where the contaminated particles had been deposited by weather patterns. Evacuation zones were formalised in March 2012 based on radiation levels (Nuclear Emergency Response Headquarters, 2012a, 2012b).

The *Difficult-to-return-to-zone*[6] included the most contaminated areas expected to have annual integrated doses over 50mSv (Nuclear Emergency Response Headquarters, 2011). Entry is strictly controlled, and no overnight

Evacuation-Designated zones : About 2.7% of the whole Fukushima Prefecture area (Apr 1 2017)	
Difficult-to-Return zone	・Annual integrated doses are over 50mSv. ・Entry is prohibited with some exceptions. ・Lodging is prohibited.
Restricted residence zone	・Annual integrated doses are between 20 and 50 mSv. ・Entry is permitted, and business operation is partially permitted. ・Lodging is prohibited with some exceptions.
Evacuation order cancellation preparation zone	・Annual integrated doses are below 20 mSv. ・Entry is permitted, and business operation is permitted. ・Lodging is prohibited with some exceptions.

Figure 6: Designated evacuation zones and descriptions. Source: Fukushima Prefecture (2019)

[5] Various models for radiation health risks have been proposed and contested from different angles. Some (e.g. Busby, 2011) have argued (this has subsequently refuted) that the LNT model underestimates the risk from low doses, whilst others have suggested that below a certain level, radiation can have a positive health effect (e.g. Doss, 2013; Vaiserman, 2010). This is based on hormesis effects. Others yet have called for an integrated LNT-Hormesis model (Kaminski et al. 2020).

[6] The names of the different zones can be translated into different things when translated into English from Japanese (even by the same organisation), which can make understanding transitions of areas from one to another, and also how these relate to the decontamination categories quite challenging.

stays are permitted. In the *Restricted residence zone* annual integrated doses are expected to be between 20 and 50mSv. Although entry is permitted into these areas, overnight stays are still prohibited.

In the *Evacuation order cancellation preparation zone* annual integrated doses are expected to be below 20mSv, certain kinds of business activities can be undertaken, and entry is permitted. Residents are allowed to go to their homes to undertake maintenance and get them ready for returning, although lodging overnight is not allowed. By April 2017 all zones had been lifted, except for those in Futaba Town and Okuma Town closest to the power plant, and sections of the 9 other municipalities designated as 'difficult-to-return' zones because of the high rates of radioactive contamination present.

The government established a long-term goal to reduce radiation levels to 1mSv annually, however the criteria for reopening evacuated areas (Cabinet Office, Japan, 2016), involved discussions between the national government (Nuclear Emergency Response Headquarters) regarding the need for the following three points to be met:

1. Cumulative dose estimated by air dose rate: 20mSv or less per year
2. Mandatory infrastructure which is necessary for daily life such as electronic, gas, water and sewer services, public transportation and communication network, etc is restored OR services which relates to daily life such as medical, nursing, postal service are restored AND decontamination operation in children's living environment is improved enough
3. Consultation with prefectures, municipalities and residents

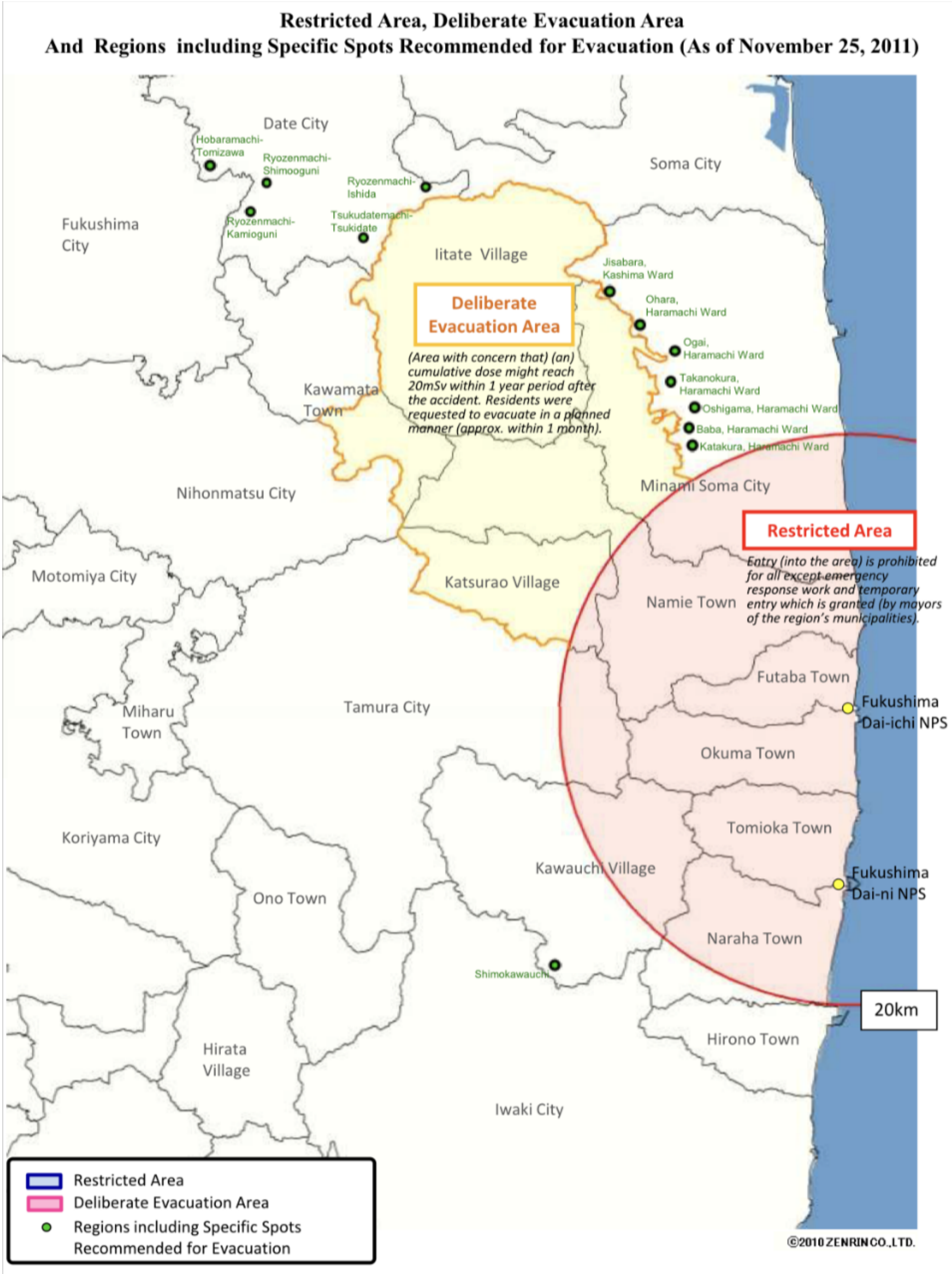


Figure 7: Ministry of Economy, Trade and Industry (METI), Government of Japan Map issued on 25 November 2011: https://www.meti.go.jp/english/earthquake/nuclear/roadmap/pdf/evacuation_map_111125.pdf

1.2.3 Food Controls

International guidance on food standards is set by the Codex Alimentarius Commission (CAC), made up jointly by the World Health Organization (WHO) and the United Nations' Food and Agriculture Organization (FAO) and based on the views of the International Commission on Radiological Protection (ICRP). In Japan radiation dose limits for food are set at 1 mSv (millisievert) annually (Consumer Affairs Agency (CAA), Japan, 2013). After the Fukushima Daiichi disaster the Ministry of Health, Labour and Welfare (MHLW) set provisional regulation values for radioactive caesium on 17 March 2011 in order to control the consumption of potentially contaminated foods and to prevent them from entering the food market. Subsequently these were revised again after deliberations by MHLW, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the CAA. The revised limits set out in the Food Sanitation Act have been in force since 1 April 2012 and were stricter.

Provisional limits established 17 March 2011	
Category	Provisional limits (Bq/Kg)
Drinking Water	200
Milk, dairy products	
Vegetables	500
Grains	
Meat, eggs, fish, etc.	

→

Legal limits enacted on 1 April 2012	
Category	Limit (Bq/Kg)
Drinking Water	10
Milk	50
General foods	100
Infant foods	50

Table 2: Table showing provisional and confirmed limits of radioactive caesium in different foods. Source: Reproduced from CAA (2013) 'Food and Radiation Q&A'.

The tables are provided in Becquerels per kilogram and relate to the amount of radioactive caesium (137 and 134) in the food, because caesium isotopes were the main radioactive materials released during the accident. 'Becquerels' are a measure of how radioactive something is (how many disintegrations per second), whilst 'Sieverts' is a unit of measurement for how much the radiation affects human tissue. This is because different kinds of radiation disintegrating at the same rate have more or less of an impact on human tissue. The calculations used by the Japanese Government indicated that even by consuming food and water at the maximum levels prescribed, an individual would be very unlikely to be able to exceed 1mSv per year additional dose as a result of consuming food contaminated with radioactive caesium (CAA, Japan, 2013).

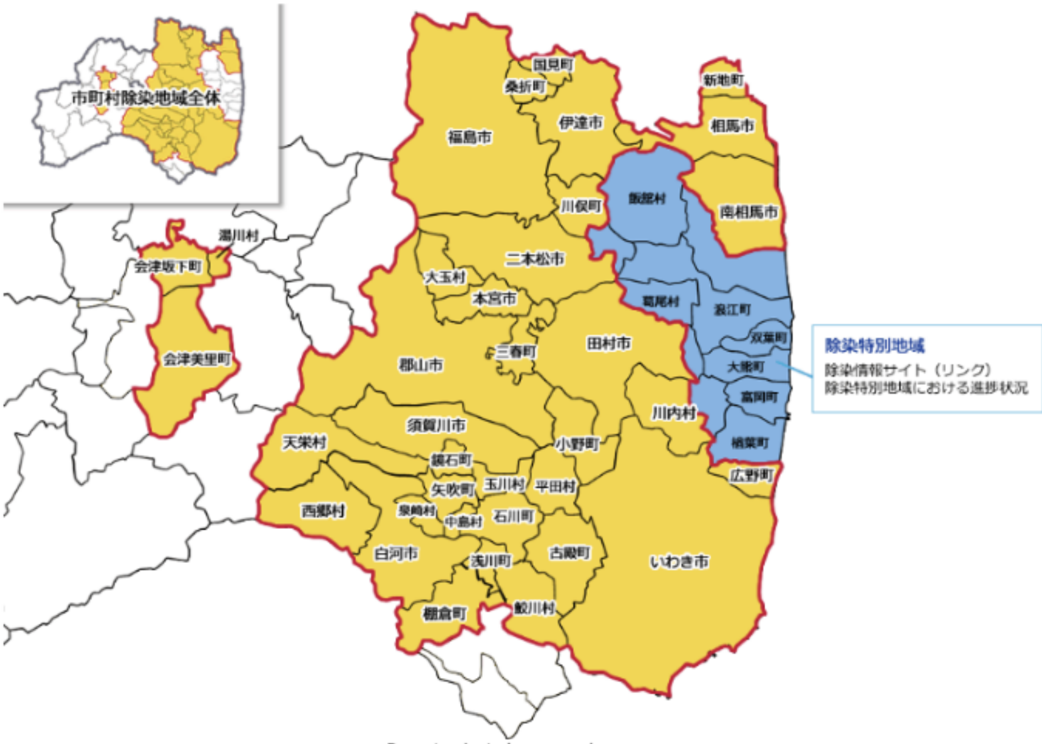
In order to determine food contamination measurements, various food monitoring centres have been established, by local communities, food and farming cooperatives and also by the prefectural government.

1.2.4 Decontamination

Decontamination reduces 'the amount of radiation received in the living areas by removing radioactive materials or by burying them underground' (Fukushima Prefecture, 2021). Environmental radiation levels are reduced using one or more of three methods. Contaminated soil and vegetation in homes, schools and farms etc. is removed (via washing, scraping, brush cleaning) and then stored before being taken away from areas where people are living, and remaining contamination is blocked by covering it with 'uncontaminated' soil (for example via reverse tilling which brings cleaner soil up closer to the surface, or by bringing in 'clean' soil from other parts of the prefecture) (MoE, 2013). Not everywhere is deemed suitable for decontamination or included in the decontamination guidelines. Almost all of Fukushima's forested mountains are excluded from the decontamination arrangements, a source of criticism from some who claim that these areas act as a reservoir for re-contaminating, in particular, residential and educational areas (Greenpeace, 2021). Mountains and forest cover around 70% of Fukushima Prefecture (ibid).

Areas designated as 'Special Decontamination Areas' (SDAs) aligned with the most contaminated parts of Fukushima Prefecture – e.g. the Difficult to Return to areas, where integrated doses were likely to stay above 20mSv for a long time as well as areas within 20km of the site (MoE, 2019). Responsibility for decontamination in these areas falls to the National Government. Areas with ambient radiation levels above 0.23μSv/hr (roughly equating to 1mSv per year – see later discussion in Comparators about this threshold) were designated as Intensive Contamination Survey Areas (ICSA). Decontamination in these areas, which covered a large area –including parts of Ibaraki, Gunma, Chiba, Saitama, Tochigi, Miyagi and Iwate prefectures – falls to the local municipality.

According to Japanese Government, decontamination had been completed in all areas except the Difficult-to-Return areas by 19 March 2018 (MoE, 2022c). It is estimated over this time that a mammoth 17,000,000m^3 soil (MoE, 2019) has been generated for processing as a result of decontamination work. This is the equivalent of over 4 times the volume of Wembley Stadium in London. Around 70,000 decontamination workers and volunteers have been scraping away the top layer of soil, leaves, mud and other detritus into large black bags (*furekon* – meaning flexible container), each around the size of a 'hot tub' (one cubic metre) and weighs around one tonne when filled (Wynn Kirby, 2019: 10). One village alone had created 2.3 million bags of waste (Fieldnotes, 28 June 2019). These were then stacked like neat ziggurats, visible in hundreds of temporary storage areas around the Prefecture awaiting processing and sorting. Around 1600 drivers and their vehicles make return trips every day to move the *furekon* between temporary to intermediate and on to long term processing and storage facilities (McCurry, 2019), in a seemingly endless effort to 'recycle' the waste in order to get rid of it (Wynn Kirby, 2019).



Decontaminated zones and summary

Legend	Zone name	Agency	Summary
: Light blue	Special decontamination area	National Government	The "former planned evacuation zones" where the annual integral dose may exceed 20 milisievert (mSv) and the "former warning zones" located within 20 km of the Fukushima Daiichi Nuclear Power Station.
: Red frame	Priority contamination survey area	Municipality	Municipality including areas where the annual additional exposure dose exceeds 1 mSv
: Brown	Municipalities where the decontamination plan is in effect	Municipality	Municipality where a decontamination plan was drawn up and is in progress

Figure 8: Map and table of decontamination zones and what they mean. Source: Fukushima Prefecture website, accessed 9 August 2022 https://www.pref.fukushima.lg.jp/site/portal-english/en02-03.html

1.3 Units of measurement for radiation

The metrology of radiation is worth expanding on briefly here because it is one of the initial hurdles to overcome when becoming familiar with the territory of radiation knowledge. The following information has been summarised from CDC (2020) and also 'Fukumoni' Radiation Monitoring Newsletter (Fukushima Prefecture –Radiation Monitoring Unit, March 2021).

Internationally (aside from the United States, which uses an older system, called the conventional unit), radiation is measured and weighed using the System Internationale (SI) which is based on the metric system (CDC, 2020). For many people, units of measurement for radiation are not familiar to them and therefore discussions about radiation can be confusing. This is because not only are there different measurement units (sometimes describing the same thing) there are also many different scales of unit. It is easy to conflate or mix them up. Different units of measurement are used depending on what aspect of radiation is being measured (ibid). The following table sets out the old and new units of measurement for radiation and how they relate to one another.

<table>
<tr><th>Thing being measured</th><th>Conventional Unit</th><th>SI Unit</th><th>Boxing Analogy</th></tr>
<tr><td>Emitted radiation
The amount of radiation being given off, or emitted, by a radioactive material.</td><td>Curie (Ci)
1 Ci = 37 billion (37 X 109) disintegrations per second</td><td>becquerel (Bq)
1 Bq = one disintegration per second</td><td>The number of punches thrown</td></tr>
<tr><td rowspan="2">Radiation Dose
The radiation dose absorbed by a person (that is, the amount of energy deposited in human tissue by radiation).</td><td>Rad</td><td>gray (Gy)</td><td rowspan="2">The power of the punch</td></tr>
<tr><td colspan="2">100 rad = 1 Gy</td></tr>
<tr><td rowspan="2">Biological Risk
The biological risk of exposure to radiation. A unit of measurement for how much the radiation affects human tissue. Sometimes called dose equivalent / equivalent dose.
It takes into account the type of ionizing radiation (alpha and beta particles, gamma rays, and x-rays) because this determines its ability to transfer energy to the cells of the body. Therefore, each type of radiation is assigned a Quality Factor (Q) rating. E.g. alpha is more damaging and has a higher Q.</td><td>rem
[roentgen-equivalent-man]
rem = rad x Q.</td><td>sievert (Sv)
Sv = Gy x Q</td><td rowspan="2">Damage caused by the punch (different bits of the body are more vulnerable)</td></tr>
<tr><td colspan="2">100 rem = 1 Sv</td></tr>
</table>

Table 3: Table of radiation measurement units, based on CDC (2020) and (Fukushima Prefecture – Radiation Monitoring Unit, March 2021).

The second complication for understanding a radiation measurement is scale. Prefixes are used as a scientific shorthand for very large or very small amounts within the same unit of measurement. Each unit in the table below is 1000 times smaller/larger than those either side. I have included the prefixes that I observed in use the most in relation to Fukushima radiation.

Prefix	Equal to	How much is that?	Abbreviation	Example
nano-	1 X 10-9	0.000000001	n	nSv, nanosievert –one thousandth of a microsievert.
Micro-	1 X 10-6	0.000001	µ	µSv, microsievert –one thousandth of a 24roject24vert.
Milli-	1 X 10-3	0.001	m	mSv, millisievert –one thousandth of a sievert.
Kilo-	1 X 103	1000	k	kCi
mega-	1 X 106	1,000,000	M	Mci
giga-	1 X 109	100,000,000	G	GBq
tera-	1 X 1012	100,000,000,000	T	TBq
peta-	1 X 1015	100,000,000,000,000	P	PBq

Table 4: Table of prefixes, abbreviations and terms used in radiation measurements, based on CDC (2020)

Comparing radiation measurements relies on being able to make the numbers commensurate first – which means knowing what is being measured, the unit of measurement and the scale of the number.

1.4 What to make of (radiation's) numbers – 'What is it for?!'

In May 2019 I accompanied three scientists from the National Institute of Advanced Industrial Science and Technology (AIST) to Iitate Village in Fukushima Prefecture, northwest of the Fukushima Dai'ichi Nuclear Power Plant. The evacuation orders put in place after the nuclear disaster in 2011 had been lifted in Iitate in 2017. Our visit concerned the network of around 80 fixed radiation monitoring posts around the village.

Posts installed by the national and prefectural governments from 2012 onwards were augmented with monitors installed by village authorities in 2016. The monitoring posts installed by the village provide additional points of data, alongside which data from the government-installed posts can either be validated, contested, or complimented. It is often possible to determine, by looking at a device, whether it is a national, prefectural, or local government monitor according to the model used, however, semi-standardisation of the designs (each includes a body housing the monitor itself, a solar panel and a display screen) suggests the potential for comparison across space and time between data from the various posts. Our intention was for the scientists to scope out the monitoring posts' situations to investigate discrepancies between measurement data provided by ground-based monitoring posts and a second set of data generated by aerial surveys. The scientists' work was a first step towards informing a future standard that stipulated the requirements for situating fixed radiation monitoring posts outside a nuclear installation.

Figure 9: A government installed fixed radiation post –it was here that we discussed: 'What is it for?!'

In the afternoon, we stood in front of a prefectural government monitoring post (see Figure 9). The post was sited adjacent to a road, in front of a rice paddy and opposite a farmhouse. The screen displayed 0.929mSv/hr (microsieverts per hour). One of the scientists used a hand-held radiation measuring device called a Hitachi Aloka Survey Meter, to do a quick survey of the area just around the fixed monitor. Looking at the device from the road, the Aloka read 3.6mSv/hr 1m to the right, 1.1 mSv/hr 1m to the left and on the road immediately to the front 0.3 mSv/hr.

The two scientists and I discussed what the particular monitoring post we stood next to might mean for people living in the farmhouse opposite. The younger scientist suggested, 'The monitoring post is only correct *right* here. But people see it, those people in the farmhouse over there see it every day and think that it applies to all areas.' When I asked why that was a problem, the scientist paused before continuing, 'So the problem is...... what *is* this?! What is it *for*?! [......] if people know that this monitoring post is unique, it is not a problem, but most people don't know.'

What the scientist seemed to be getting at was the situated and contextual nature of the information being produced by the monitoring post, and what this meant in the context of a group of radiation monitoring posts, installed by different government agencies and connected to a wider network of knowledge dissemination including a central and publicly accessible website displaying data from NRA posts. The displayed number on the post we were looking at might be technically 'accurate' (e.g. the device was calibrated correctly and set up as per manufacturer's instruction) but that accuracy did not necessarily extend very far in a practical sense when being operationalised and this was not clear to those viewing the screen.

The scientist's observation calls into question also what it might mean if this number differs from the one shown on a post half a mile away, from a measurement produced by aerial monitoring device or even an Aloka Survey Meter one step away from the post. What does it mean if the instruments start to fail? How long should such monitoring continue? When is enough data enough? What other information does a person need to make sense of the data displayed on the screen? How long was a reading valid for? How does this reading compare to other historical data and where is that accessed? How important is it to have a monitoring system in place nearly ten years after the initial disaster? After all, by this point the farmhouse had been re-occupied and surely its residents knew their local radiation levels by now. The summaries of the details about the Fukushima nuclear disaster and the subsequent protective measures put in place to manage the contamination problem, also raise various questions and observations about knowing and making sense of contamination via 'the organs of science' that are worth highlighting here and which this thesis explores in more depth in due course.

First, that knowing about radiation contamination is an active process of judgement, often involving quantitative measurement and derived by different groups of individuals using different methods and devices. I explore these considerations throughout the thesis but devices of radiation measurement in particular in Chapter 4 and the process of making judgements in Chapter 6. Second, the numbers of radiation produced by these devices and methods can be bewildering, as I showed in the earlier tables in section 1.3. Consider for example trying to make sense of the quantity of radioactive fission products released in those first few days in March 2011. International agencies and researchers' assessments coalesce around 150-160 PBq (Peta Becquerels or 1,000,000,000,000,000 Becquerels) of radioactive iodine-131, and 12-15 PBq (and up to 35 PBq) of caesium-137 (Aliyu et al. 2015). Radiation's numbers often include units of measurements and scales unfamiliar to most people – peta Becquerels and 17 million tonnes of contaminated waste for example. As well as Becquerels there are also Sieverts, Grays and Rems (in different magnitudes of size, including peta, nano, micro, milli), half-lives and more. Each unit of measurement expresses a particular property of radioactivity and sometimes these can be only subtly different. Making sense of radiation numbers involves understanding what property the units are concerned with and being able to relate the number to something else. Third, that some frame of reference is needed to put the information provided into context. The frames of reference that are used might be comparisons with something we are familiar with – a recognised standard or a case with which we are familiar (e.g. Chornobyl) or a specified standard. I examine comparisons in more detail in Chapter 5. Fourth, that the data produced must be made into some kind of representation which is part of rendering the situation knowable – the data about the radiological situation is translated and transmitted elsewhere to be used in some way by particular groups – put into tables, maps, guidance and so on. Fifth, that radiation measurements have temporal and spatial dimensions to them – they relate to particular times and spaces. I discuss radiation monitoring in practice and as practiced by different groups, in different situations and to different ends, in Chapter 7 in particular.

This research project expands on and develops these observations in the chapters that follow by putting them into conversation with concepts from Science and Technology Studies (STS), which I outline when reviewing the literature in the next chapter. I focus on several key concepts which are explained in more detail at the start of each empirical chapter.

1.5 My interest in radiological contamination

It is worthwhile here noting my own interest in radiological contamination and how I came to be interested in this topic, as this situates my thesis and also my particular research commitments. The release of radiological materials from Fukushima Daiichi Nuclear Power Plant in 2011 prompted inter alia, the decontamination of vast tracts of land, widespread food restrictions and extensive evacuations. These are consequences of nuclear incidents that I am well versed in as a result of my professional work as a disaster planner[7]. Disaster planners make plans and preparations for imagined futures involving things going wrong – floods, fires, terrorist attacks and nuclear incidents. These are also things we hope will never materialise. Prior to, and very much as a prompt for beginning my PhD research, I was working on an emergency management improvement project at Sellafield nuclear installation in the North West of England. The project was formed as a direct consequence of a European Nuclear Safety Regulators Group (ENSREG) Stress Test at Sellafield[8]. All European nuclear installations underwent this test after the Fukushima disaster to determine whether site plans for radiological incidents were fit for purpose.

The27rojectt I was involved in from 2013-2015 concerned the management of large 'off-site' emergencies – where contamination is released beyond the boundaries of the Sellafield site. If contamination goes 'over the fence'[9], then this triggers actions by various multi-agency partners because there is a potential for harm to humans, animal life and the environment in the local and wider community. Our role was to make sure Sellafield's plans for an off-site emergency were adequate in light of the lessons from Fukushima. Our plans were intended to dovetail with other local and national plans which described the response to the incident as it related to the local and national community. These plans covered things like decontamination, casualty management, evacuation, the provision of public information and advice, the distribution of stable iodine and warning and informing the public about protective actions. This collective work involved drawing up documented plans which would be underpinned by scientific knowledge about any contamination involved. Much of this information was not determinable in advance of any given accident occurring, due to the complexities of the many ways in which any incident on site might unfold. 'Science' would therefore be called on at the time of an incident to provide answers about which isotopes would be involved, how they behave when out in the wild, where they might go, the harm they might cause (to people, animals and the environment). This information would inform decisions about how to protect people, animals and the environment from radiological harm now as well as in the future.

The possibility of a contamination incident with wide-reaching consequences was a very real one at Sellafield and the surrounding parts of Cumbria. The region has an interesting and entangled relationship with the nuclear industry and also contamination in general[10]. A major fire in one of Sellafield's reactor piles[11] in 1957, when the site was known as 'Windscale' rather than Sellafield, was one of the world's first publicised major nuclear incidents (Arnold, 2016; Wakeford, 2007). Then in 1986 the rural and mountainous area surrounding Sellafield was affected by fall-out from the Chornobyl nuclear power plant disaster settling on higher grounds (Wynne, 1989, 1992). In 2001 the same area was subsequently also impacted by the 'fall-out' of another kind; this time

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[7] Many job titles are used interchangeably to describe what I do professionally – disaster manager, emergency planner, emergency management officer, resilience officer, contingency planner etc. For the sake of ease, I will use the generic term disaster planner. Although this is not a common term in the UK professionally (for reasons not best covered here, 'disasters' are things that are not seen as happening in the UK – they happen elsewhere), the term is easily understood at an international level. I have worked as a disaster planner in the public, private and voluntary sectors since 2007, including as a guest lecturer at several academic institutions. My work has involved planning and preparing for Chemical, Biological, Radiological and Nuclear (CBRN) incidents in the UK and abroad, as well as training, testing and exercising responders managing CBRN consequences.

[8] https://www.ensreg.eu/EU-Stress-Tests and https://www.ensreg.eu/node/272/

[9] A euphemism used in the nuclear industry to mean something outside the nuclear site's boundaries.

[10] In 2021 and 2022 I helped organise a small series of events, (funded by the with Centre for Science Studies) colleagues from Lancaster University called 'Nuclear Futures' which explored these complex relationships with nuclear things. The events which included a psychogeography writing workshop, an exhibition and an 'In-conversation' online discussion with participants, brought together a range of people from different backgrounds to examine the complex local relationships with nuclear things in the North West of England. Participants included technical specialists, artists, sociologists, physicists and emergency management specialists. More information and the recorded discussion are available on the Centre for Science Studies website: https://wp.lancs.ac.uk/sciencestudies/2022/05/16/nuclear-futures-in-conversation/

[11] A colloquial term for an early design nuclear reactor because these were made of 'piles' of graphite and uranium blocks (USNRC, 2021). https://www.nrc.gov/reading-rm/basic-ref/glossary/pile.html

from the management of a Foot and Mouth Disease outbreak, which led to the deaths of millions of sheep, cattle and other farm animals and had a devastating effect on the farming and tourism industry (Anderson, 2002). I was influenced by institutional reports and writing about the long-term social and human consequences of the Chornobyl disaster in present day Ukraine and Belarus (UNDP, 2002; Petryna, 2013; Kuchinskaya, 2014; Alexievich, 1999) as well as social science research on the human consequences of the 2001 animal disease Foot and Mouth (Convery et al., 2008). I saw a tension between the timescales we were planning for at the site, which were measured in hours and days, in contrast to the timescales and impacts of forms of contamination that I noted in these books and reports. These impacts required a more persistent attentiveness measured in years and decades.

Driven by this tension between what my colleagues and I were collectively planning for and the potential realities of what such an incident would involve, I began my PhD research project at Lancaster to investigate the ongoing impact of the nuclear disaster in Fukushima in October 2016, whilst continuing to work as a disaster planner alongside my academic research, and of course throughout my own and the world's response to and ongoing recovery from COVID-19.

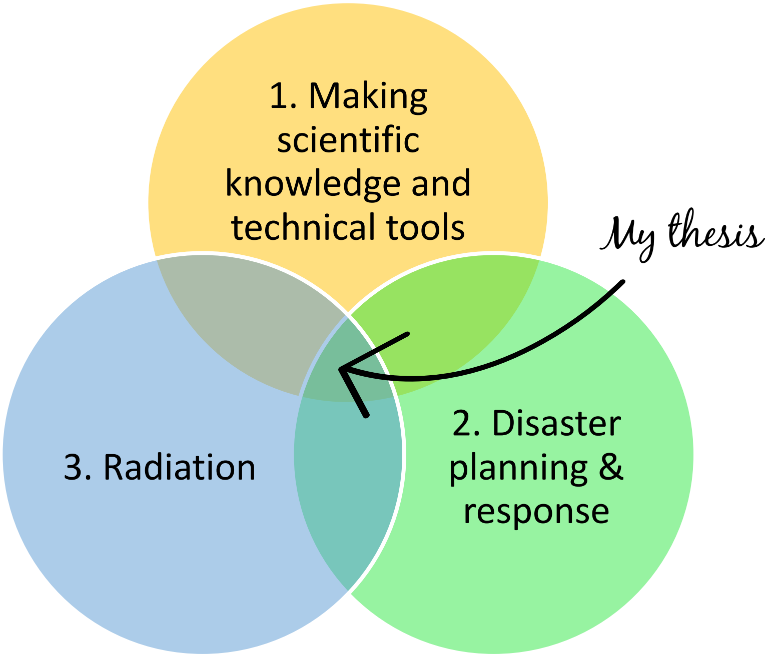
In this thesis, I will overlay concepts such as assemblages, qualculations, comparisons, and syncretism to provide a multidimensional, layered way of thinking about the making and use of scientific knowledge in contamination emergencies. I demonstrate how multiple heterogeneous socio-material entities come together to construct radiation knowledge in different places, times and for different purposes. I contend that human and nonhuman actors are active in the process of radiation knowledge creation, performing different roles and functions in the assemblage. I highlight that they influence what is in these assemblages, where and when they operate, and what happens when they come into contact with alternative assemblages operating in the same spaces and times. However, I argue that this agency is not afforded to all actors equally. I highlight tensions between different knowledge-making communities – the questions they seek to answer, the resources they have access to, and the extent to which they want or need to align their practices with others. Furthermore, I show the stabilizing work that nonhuman actors, such as emergency plans, legislation, standards, thresholds and guidance documents simultaneously do within knowledge making practices. I assert that stabilization occurs spatially (defining where knowledge making occurs), temporally (defining when different knowledge making is possible) and practically (defining who or what is involved or excluded from the process and how practice occurs).

As well as contributing to social science debates about the social and materiality of collective knowledge making practices in general, my findings are directly relevant to professionals charged with planning for and responding to contamination events. The thesis suggests a new way of thinking about knowledge making in emergencies which acknowledges the multiplicity of knowledge making assemblages, their opportunities and limits in different places and times, and how they operate alongside other knowledges and practices.

In the remaining two chapters of this introductory section, *Background Readings*, I establish the academic, epistemological and methodological position of the research. In Chapter 2, I set out the relevant literature against which I position the thesis, and in Chapter 3, I describe the methodological and methodological choices underpinning the study.

2 Researching Fukushima

This project examines how scientific facts and knowledge are created and used in response to major contamination disasters generally. I have chosen to look at radiation because, as mentioned previously, it is not discernible without 'organs of science' and 'inscription devices' acting as mediators, translating invisible harm into some kind of output that humans are able to decipher and make sense of. The major contamination of Fukushima provided therefore a valuable opportunity to explore more widely how scientific knowledges are made in response to major contamination events. There are three overarching dimensions to my field of study: (1) the making of scientific knowledge, (2) the formally recognised and less formal responses to disasters, and (3) radiological contamination. My thesis sits at the intersection of academic endeavours into these three dimensions.



The following chapter establishes relevant literature from a number of different, and at times overlapping fields to provide background to the research topic itself. It also works to establish some of the methodological and epistemological constraints of the thesis. As suggested by the diagram above, there is no neat linear route through the relevant fields of literature. I am most interested in the making of scientific knowledges and the technical tools of science. Therefore, I primarily concentrate on the texts represented by the orange area above, but I specifically highlight the overlaps with those in the blue and green areas. First, I show how Science and Technology Studies (STS) approaches the study of the making of scientific facts and the creation and use of technical devices, such as radiation monitoring devices. I then examine how disaster studies typically investigates and studies 'disasters' of different kinds and contrast this with how the STS subfield of 'disaster STS' approaches the same kinds of issues. I then go on to briefly examine sociological investigations into other radiation disasters, before finally examining social science considerations of radiological aspects of the 2011 triple disaster. In doing so, I establish the need for further research at the intersection of these domains, the making of scientific knowledges about radiation as a consequence of the nuclear disaster at Fukushima Daiichi Nuclear Power Plant. It is in this complex space that my thesis operates.

2.1 Researching knowledge production

The central concern of this thesis is how knowledge about radiation is constructed and utilised by different groups and individuals. Social scientists have long been preoccupied with the collective making of science and scientific facts, as well as other knowledges and knowledge making communities. Science and Technology Studies (STS) for example engages with the construction and consequences of science(s) and technology(ies) within the specific contexts in which they are historically, culturally and socially defined and created (Felt et al., 2017). The central concerns, concepts and methods associated with STS developed alongside and overlaps with ideas from the social studies of science (SSK), actor-network theory (ANT), the social studies of technology (SCOT), and the history and philosophy of science (HPS) (Fischer, 2016).

Scholars working in these broad and interlinked fields are interested not just in the impacts and social structures of engineering and science, but also their products – scientific facts, technologies and objects. They also grapple with questions about scientific methods, how scientific facts become established, stabilised and remain credible, how expertise is defined and operates, and the nature and construction of the technologies and devices of science. Underlying all of them is the idea that science and technology are inseparable from social relations and practices. STS scholars frequently work to highlight the complexity woven into seemingly mundane interactions between science, technology and society by 'opening up the black boxes of science and technology; breaking down artificial boundaries that separate science, technology, and society; and opening up new possibilities for imagining and implementing alternative sociotechnical arrangements' (Miller, 2017: 910). A central tenet is to show how 'it could be otherwise' and to allow space for imaging what that would involve (Woolgar & Lezaun, 2013: 322, Woolgar, 2012).

2.1.1 Science as social

Science has been established the product of the collective practices of scientists who themselves have social cultures (Merton, 1973[1942]). Drawing on Kuhn (1962), some scholars have traced connections between the interests of different groups and the kinds of knowledge they created (e.g. Barnes, 1974, 1977; Barnes & Shapin, 1979; Bloor, 1976; Collins, 1975; Shapin,1979, 1982). Others (e.g. Harry Collins,1985; Shapin & Schaffer, 1985) studied controversies and showed scientific knowledge is the outcome of negotiations between actors. Hacking (1983) highlighted that science is not only about knowing (representing) and but also about doing (intervening). Numerous works (including Barad 2003; Biagioli 1999; Callon 2007; Latour 1986; Law and Singleton 2000; Mol & Law 2004; Shapin & Lawrence 1998) have explored the complexities of how science is 'done' in different contexts and situations. Rather than seeing scientists as 'disembodied intellects making knowledge in a field of facts and observations' (Pickering, 1995:6) and the job of science being to unearth, and then objectively and faithfully represent facts out in the world, some scholars have suggested science is 'knowledge relative to particular culture' (p.5). If this claim is correct, then scientific knowledge about radiation (in an emergency or otherwise) is not just out there, waiting to be found, but it is created relative to particular groups of scientists (and other interested parties), their constellations and their interests. Scientific knowledge is 'shaped in interaction between the world on the one hand and the culture of science, including its methods, on the other' (Law, 2017: 33). Making sense of 'complex cognitive system[s] requires more than just enumerating the components. It requires also understanding the organization of the components', their social organisation (Giere, 2002: 292) and performative forms of knowledge making (Salter, Burri & Dumit, 2017).

Technical instruments, spaces, signs, symbols and processes become important objects of enquiry alongside the social when considering scientific knowledge making about radiation.). Pickering delineates between what he calls 'scientific culture', i.e. 'the field of resources that practice operates on and in', and 'practice', which he defines as 'the acts of making (and unmaking) that [scientists] perform in the field' (ibid, p.3). This is a useful distinction to make as it highlights that *practice* has a temporal aspect to it, which *scientific culture* (the network of resources) lacks. I build on this distinction within my own work, by engaging not only with the sociotechnical resources that come together to produce science, but also the practices by which they are produced and the spatial and temporal situations in which this takes place throughout the whole thesis. Aligned to concepts from actor-network theory, Hacking identified fifteen kinds of resources, which include ideas, things and marks, and which effectively constitute Pickering's *culture*, that scientists draw on in the production of knowledge. By identifying the multiplicity of these resources, he began to highlight the patchiness, multiplicity and heterogeneity of the practices through which scientific knowledge is produced (Hacking, 1992). Stabilised forms of science are stable not just because they are underpinned by particular theories but because of heterogeneous 'cultural packages' (Pickering, 1992:8) – i.e. constellations of scientists and their attendant resources - operating to produce certain knowledges.

Scholars working on actor-network theory (ANT), including Bruno Latour, Michael Callon and John Law stressed that convergence of the scientific fact and technological objects was such that they were inseparably technoscientific. Their work identified science as 'a practice of creating heterogeneous networks of actors, inscriptions, theories as well as scientific instruments and other artifacts' (Rohracher, 2015: 203). In his article on the Scallops of St. Brieuc Bay, Callon (1986) famously made the case that any analytical symmetry should be applied not just to humans but also to nonhuman actants (i.e. to anything with agency to change things). As I demonstrate later in the thesis, engaging with the technoscientific objects of radiation knowledge production provided an explanation for and way of working with the multiplicity of technoscientific devices I came across. It also gave me tools for thinking through the relationships between the whole device (and indeed where boundaries are drawn) and their constituent parts. It also informs my investigations into tools as they are used in practice, as well as their human and nonhuman elements.

2.1.2 Expertise and knowledge makers

Another important focus for scholars investigating knowledge production are the producers and knowers of knowledge, the extent to which different knowledges are produced and recognised by others and who is able to make knowledge. Brian Wynne's (1992) seminal essay examines the relationship between lay and expert knowledges coming into contact with one another. He showed that Cumbrian sheep farmers struggled to have their own lay expertise and practices about hill farming recognised as legitimate by government scientists in the face of radioactive contamination from Chornobyl. He highlighted the power relations and politics at play in the construction of knowledge practices of radiation; farmers' lay expertise was ignored by the scientists, which led to a mistrust by the farmers in what was being said to them by the scientists. The kind of politics between scientists and lay people, was 'about meanings, concerns, relationships and forms of life' (Wynne, 2008: 23) and therefore the production of radiation knowledge would always create a tension between different actors, given their multiple concerns and interwoven relationships.

Much academic attention has been paid to the making and knowing of scientific facts outside the formal structures of scientific institutions and, in particular, by the citizenry. Different names have been used to describe these activities, the people producing them and what it is they produce. Labels include 'citizen science', 'citizen generated data' and 'citizen sensing' (Fiorino, 1990; Irwin, 1995; Bonney et al., 2016; D'Ignazio & Zuckerman, 2017; Heigl et al., 2019; Ottinger 2010, 2017, 2022). Attempts have been made to create a typology of participatory characteristics (Wiggins & Crowston, 2011) or to examine the different caveats and implications of using the different terms (Eitzel et al., 2017). I discuss citizen participation in radiation knowledge making in greater detail later on in this chapter, but the main point that I want to highlight is that the makers and users of knowledge about radiation cannot be reduced to either scientists or citizens, experts or lay people.

Offering a more complex consideration of reliable expertise, Uygun Tunç argues that a scientific expert is a 'reliable informant in a scientific domain', and when asked questions about matters in that domain they are able to answer 'competently, honestly, and completely' (2022:1). Being reliable 'goes beyond one's individual competence' (ibid), by requiring the knower to reach back into collective knowledges (and therefore infrastructures, devices and practices). I take this to mean that to be an expert is situated (aligned to Donna Haraway's (2007) ideas about situated knowledges) and relative, as well as dispersed between distributed various locations and individuals. This is useful in that it moves debate away from some traditional dichotomies which delineate between oversimplified visions of expert and lay knowledges and opens up space for thinking more widely about who (or what) influences the kinds of knowledges produced and in operation in different spaces.

2.1.3 Communities of collective knowledge making

Many human and non-human entities have to come together to enable science to get done. Since the 1980s various empirical studies have examined what scientists actually do in practice in localised settings, rather than in logical assumptions about the practices of idealised notional scientists (Pickering, 1992). Any investigation into the 'truth'-finding machinery of the natural sciences should be concerned with 'what its features are […], of how these features hang together, and of how they connect, if they do, to […] "social relations"' (Knorr Cetina, 1991: 107). Social scientists in Laboratory Studies moved into the places where knowledge was being made (e.g. Latour & Woolgar 1979; Knorr Cetina, 1991; Fujimura, 1987). Traweek's classic (1988) *Beamtimes and Lifetimes* studied high energy particle physicists at the Stanford Linear Accelerator Centre, Knorr Cetina's (1999) later made comparisons between particle physicists and molecular biologists, and Mody (2002) researched the construction of contamination and cleanliness in clean rooms belonging to different groups of materials scientists. Scientific facts were shown to be created rather than purely observed and as such they are constructed socially as well as technically in laboratory settings (Latour & Woolgar, 1979; Fujimura, 1987). Laboratory practices can therefore be world-shaping through the scientific facts they create (Latour, 1983). Furthermore, in producing knowledge alongside technical devices and tools, scientists themselves become part of the social machinery that produces facts and knowledge. A scientist becomes 'a technical device in the production of knowledge' (Knorr Cetina, 1992:119).

Scholars also differentiate not just between just science and non-science, but between the plurality within scientific knowledge making communities (Kastenhofer & Molyneux-Hodgson, 2021). Such works attempted to account for the interactions between different combinations of social structures, infrastructures and technologies and the influence of these on the kinds of science(s) and scientific knowledge produced. Various scholars have explored the distinctions between the sciences in different fields and disciplines and different countries, highlighting national scientific styles (Jamieson, 1997), 'ways of knowing' (Pickstone, 2001) and 'styles of scientific reasoning' (Hacking, 2002).

The notion of *epistemic cultures* (Knowrr Cetina, 1999) is a useful concept to springboard from in this research project in that it highlights the multiplicity and complexity in knowledge making entities. These are 'amalgams of arrangements and mechanisms – bonded through affinity, necessity, and historical coincidence – which, in a given field, make up how we know what we know'' (p.1). Whilst epistemic *infrastructures* support knowledge production (for example tools and devices, methods and rules for knowledge production), epistemic *cultures* are the acknowledged and tacit skills and competencies needed to create knowledge; and epistemic *practices* are the actions that make objects knowable (Knorr Cetina, 1999). Collectively these epistemic cultures, practices and infrastructures embody and routinise norms about the world (Knorr Cetina, 1999). The production of scientific knowledge about radiation contamination is therefore likely to be the result of one or more communities of knowledge making operating simultaneously. Practices may develop in ways which 'challenge and change the established infrastructure and culture' (Gustafsson & Lidskog, 2023: 1).

An epistemic culture approach maintains that what counts as data, how research entities are manipulated and ordered in the course of research and how scientists (or indeed anyone engaged in the production of knowledge) organise themselves and their practices, will all differ according to the specific epistemic culture in question. Knorr Cetina highlighted that some scientists go through a process of isolation and separation, disentangling the objects 'seen' by their technical devices from the real world and (re)constructing them in a more controllable environment in representative form. In this thesis I approach this process of separation, ordering and judgment making through the lens of 'qualculation', a concept which deals with the process of making 'quality-based rational judgements' (Cochoy, 2008: 15). I expand on this concept empirically and theoretically in Chapter 6.

Using ideas from actor-network theory, the notion of 'boundary objects' (Star & Griesemer,1989) which bridge gaps between different knowledge cultures, and 'standardised packages' which make streamlined activities more 'doable' between different levels of organisation (Fujimura, 1987), Fujimura examined how different 'social worlds' (1992) linked up and related to one another. Each 'social world' is concerned with a particular problem, along with methods and tools by which to solve it. The particular grouping that might constitute a 'social world', a network of actors or an amalgamation, might be neatly bounded already along disciplinary or geographic lines (for example physicists working Japanese Atomic Energy Agency (JAEA) or within a laboratory run by local citizens), but it need not be constrained by this when applied elsewhere to other more dispersed groupings (such as groups of mothers concerned about radiation levels in school meals).

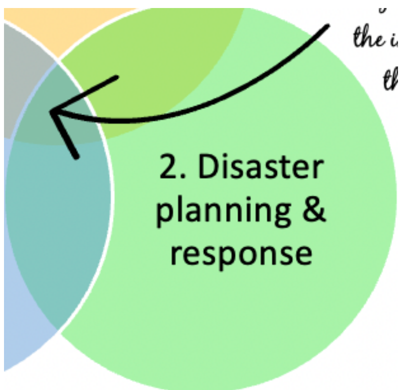
Knowledge production within any knowledge culture is defined and influenced, not only by scientific disciplines and fields, but are shaped by technologies, historical contexts, social machinery and organisational structures and so on. Feminist scholars have highlighted that it is important to note who is represented by those charged or able to make or interpret scientific facts and knowledge. Developing out of second-wave feminist critiques of the production and use of science and technology after the Cold War, in particular reproductive technologies (Adrian et al., 2018), feminist STS scholars fundamentally question who benefits and whose knowledge counts in the making and use of science and technology (Star, 1991). They have amongst other things highlighted that the experiences of women are not necessarily reflected in the products of male-dominated science (Harding, 1991) and have pushed for acknowledgement of the situated and partial perspectives of the knower (Haraway, 2007). Recent STS works have taken these agendas forward using intersectionality, in which inequality and oppression is seen as fundamentally related to often overlapping categories such as race, class and gender (Weldon, 2008; Fishman et al. 2017), as a framework to examine how discrimination and privilege are created (Strathern et al., 2019). Issues of epistemic (in)justices (Fricker, 2007) subordinate knowledge making, whose knowledge counts and the situatedness of the knower are all very relevant in the production of scientific knowledge about radiation.

More current debates on knowledge construction and expertise have developed these influential ideas further and taken them into different settings outside laboratories. Researching Australian feminist influencers online, Kanai & Zeng highlights that in social media knowledge cultures, knowledge is hierarchically 'constructed contested, and accorded legitimacy' through 'complex classed, racialised and gendered dynamics' (2023:1). In the context of the production of environmental assessments, Gustafsson and Lidskog show that the makers of knowledge 'generate ways to understand and navigate the world, both for those who create and those who receive the assessment report', rather than passively transmitting information about the world (2023:1). Smith, reflecting on the Grenfell Tower disaster of 2017, shows that *failure* can become both an object of knowledge and an instrument for its formation', formed by erasures and reminders at the Tower site, as well as the parameters of knowledge solidifying processes like the inquiry parameters (2023: 151).

This thesis builds on and contributes to these continuing debates about knowledge production practices, distributed knowledges, epistemic (in)justices and knowledge production collectives.

2.2 Researching Disaster

Having stated that my interest is in the use of scientific information production in major contamination disasters and emergencies, in this next section I start by defining what might be meant by 'disaster'. I then explore the intersection between scientific knowledge making and technologies in disasters.



2.2.1 Defining disaster

Social science researchers and those working in the field of disaster have acknowledged various problems associated with traditional definitions and framings of disasters (Easthope, 2022; Montano, 2021; Law and Singleton, 2004; Oliver-Smith, 1999; Quarantelli, 1987, 1998), as well as the implications for research questions and practice. Defining disasters is problematic. This is because definitions have boundaries which in/exclude different things (people, hazards, locations, impacts) in or from a situation. Technological inventions of the twentieth and twenty-first centuries, including nuclear power and weapons, have challenged classic understandings of disasters as 'acts of God', or as 'natural' as opposed to 'man-made' (Sagan, 1995). For the last fifty years at least, there have been questions raised about whether any kind of disaster can be defined as 'natural' at all (O'Keefe et al., 1976). Key concepts in modern disaster research including hazard, risk, vulnerability, and resilience all emphasize the interconnectedness of hazards, risks and social structures (Kelman, 2018; Albris et al., 2020). So, what counts as a disaster or not might be seen 'to a greater or lesser extent a social calculus' (Smith, 2006). Disasters have social roots (Tierney, 2007, 2012).

The framing of disasters as distinct bounded events with beginnings, middles, endings and discernible phases (in particular in emergency plans) has also come under scrutiny. The kinds of Aristotolean rules of drama do not apply in all disasters and particularly not those involving radiation, which 'violate all the rules of a plot' (Erikson, 1991: 37). When, for example, is a radiological disaster technically over? Categorising something as a disaster can also be a political move. For example, being able to declare something officially as a 'disaster' (or emergency / catastrophe / crisis etc.) can be used as a mechanism for accessing special funds or being able to take extraordinary measures (Tierney, 2007). The very essence of disasters relates to the way that they contravene shifting social norms and expectations; 'they are exceptions to expectations and understandings enabled by the norms' (Petersen et al., 2017: 313). There are therefore numerous pitfalls when engaging with the definition of disaster. Fortun et al. (2017: 1004) suggest that a productive definition highlights:

> [F]ailures of diverse, nested systems, producing injurious outcomes that cannot be straightforwardly confined in time or space, nor adequately addressed with standard operating procedures and established modes of thought.

In this project I have stated that I want to directly address the making of scientific knowledge about radiation in a contamination disaster. I will therefore use the terms 'disaster' and 'emergency' interchangeably, acknowledging that official documents may delineate between different defined 'emergencies' or 'disasters', for their own purposes (e.g. because doing so acts as a trigger for different kinds of responses, provides access to additional funding, or is needed in order to authorise legislative changes for example). These definitions of disasters and phases of disaster might differ to the ways in which individuals affected by the 'disaster' in question delineate between them (Easthope, 2018).

Another way of categorising disasters is to think about the source of harm which may be realised. In my thesis I am working with radiological contamination from a nuclear disaster, typically grouped alongside chemical and biological hazards as forming Chemical, Biological, Radiological and Nuclear (CBRN) threats or hazards. Radiological contaminants and hazards arising from 'radiological' materials are sometimes further distinguished from 'nuclear' hazards caused by a nuclear detonation (Centre for the Protection of National Infrastructure (CPNI), 2021). Another line of categorisation arises from the intent behind the incident: some organisations (such as the CPNI and most responding agencies in the UK) distinguish between CBRN incidents, deemed to be malicious intent, and non-malicious 'hazmat' incidents. I use the term 'contamination' event as a generic umbrella term for any disaster or emergency whether malicious or not and including any kind of contaminant. Section 2.3 examines in more detail discussions about radiological contamination in the social sciences.

In light of the above, where I use the terms 'disaster' or 'emergency' with respect to my field sites, I mean that the uncontrolled release of contamination (chemical, biological or radiological) into a public area or into the environment, with major impacts for example on the population and/or the environment and/or other actors/sites. Whilst I appreciate that my working definition is not perfect, I want to be able to differentiate between an event on the scale of a major pandemic or a reactor meltdown, from the minor escapes of contaminants on a day-to-day basis in say institutional facilities designed with that control in mind. This is precisely because large-scale events are likely to precipitate major interventions by public health officials and emergency response organisations.

2.2.2 Intersecting disasters and science/technology

This next section establishes how the application of STS concepts and approaches to the subject of disasters differs from or complements more the slightly older field of 'disaster studies', a field 'dominated by the natural sciences' (Guggenheim, 2014: 3). Disaster management was the field of study which informed my own working life up to the start of my PhD project, having encountered it during my Masters degree in Risk, Crisis and Disaster Management. In my degree, many of the texts I read, such as Charles Perrow's *Normal Accidents* (1999), *Accident and Design* (Hood & Jones, 1996) and *Learning from Disasters* (Toft & Reynolds, 2005) and case studies, such as the Halifax explosion, the Bhopal chemical disaster and the Zeebrugge ferry disaster, involved management considerations for socio-technical disasters. Disaster studies has been described as comprising a range of 'unwieldy and disparate bodies of knowledge', which includes studies on the 'psychosocial aspects' of disaster, alongside 'the management of disaster by official bodies, risk, risk communication and legal process' (Easthope, 2018: 5). Such perspectives tend(ed) to separate the human (social) consequences from the nonhuman (management tools and technical devices) of disasters.

Social science more broadly has always been interested in subjects such as industrial accidents, suicide, poverty (Fortun et al., 2017: 1005) and the injustices of wars, famines and diseases (Calhoun, 2004: 373). The sociology of disaster has been described as 'the sociological or social scientific study of the social structure adjustment preceding and following the precipitating event or disaster agent' (Fischer, 2003: 96) (note again the need to manage the definition of disaster – are they interested in a 'precipitating event' or the cause of the disaster?). Many social science studies of disaster have focussed for example on exploring what individuals and organisations do in stressful environments, how people view risks and how they respond in the event of an incident (Quarantelli, 1987; Frickel & Fortun, 2012). Tierney (2007, 2012), Fischer (2003) and Calhoun (2005) provide useful overviews of such enquiries into disaster, including more recent work on disaster risk reduction and governance.

It is argued that disaster research could be better integrated into sociological theory and research (Calhoun, 2004; Tierney, 2005). STS offers one way to do this (Fortun & Frickel, 2012), by challenging some of the entrenched ways of viewing and researching disasters in more traditional disaster research, as I shall explain below. This has implications for the methods used to investigate disasters and also the kinds of questions asked by social science researchers themselves.

STS has typically focused on the social, historical and structural conditions that produce disaster vulnerability and systems of governance, as well as thinking about how 'science and technology simultaneously produce risk in modern industrial societies and provide tools to assess and manage it' (Fortun et al., 2017: 1004). I now provide an overview of some of the directions taken by social scientists in and around STS who have engaged with disasters, who, whilst acknowledging that some might not necessarily define themselves as STS scholars, might still work with an STS sensibility and/or STS concepts.

Investigations into the technoscientific aspects of disaster have engaged with a broad range of topics. Some have focused on the institutional and organisational configurations that produce risk, such as those that produced the Challenger space shuttle disaster (Vaughn, 1996) and the 'catastrophic risk' from the Deepwater Horizon disaster (Lakoff, 2010). Kim Fortun's (1998, 2001) work on the 1984 Union Carbide chemical disaster in Bhopal, India foregrounded the reconstruction of environmental health science and their links to legal developments. Fortun also stressed that attempts to depict the Union Carbide disaster as an isolated occurrence, highlights the ways that disasters refuse to be 'stablized' or contained spatially or temporally (2001: 10). She introduced the concept of 'enunciatory communities' as a means of showing how new subject positions and social formations were provoked into being by the disaster (Fortun & Frickel, 2012: 4). Elsewhere, the purpose of arrangements for responding to emergencies, and the written plans and documents that supposedly support them have been challenged. Clarke (1999) for example, highlighted the 'fantasy' nature of official documents, such as emergency plans for evacuating Manhattan after a nuclear strike. He and Birkland (2009) have argued that emergency plans, after-action and post-exercise reports are largely unworkable in practice but instead offer political legitimacy. Deville builds on this further to suggest that 'training and exercises become the primary focus of organisational activity over and above responding directly to disasters' (2021: 95). Others have challenged the very idea of being able to measure elements of disaster because such activity involves categorisation and boundary-making, which are themselves socio-political processes (Fortun, 2004). Frickel and Vincent (2007), for example, examined water monitoring practices after Hurricane Katrina and found that only some chemicals are being monitored and only then in some locations. Such monitoring practices made chemical contamination 'real' in some places but invisible elsewhere – they were defined by the scope of the very processes put in place to locate them. This is a problem not just for natural sciences but for the social sciences as well – the elements of a disaster that we want to monitor and pay attention to can make a disaster real in some places but invisible and unobserved elsewhere.

A smaller nascent subfield of STS, Disaster STS (DSTS), has only recently begun to apply questions and concepts from STS to disasters. Fortun and Frickel make the case for DSTS because 'by paying close attention to the complex ways in which disasters and technoscience are mutually constructed and conditioned, DSTS can make a significant contribution to the development and elaboration of STS theory and methods' as well as of course contributing to how disasters and those impacted by them are researched (Fortun & Frickel, 2012, *The Promise and Challenge of DSTS*, para 6). Lines of enquiry in Disaster STS, they suggest, would pick up on existing STS interests including ongoing concerns with risk (Jasanoff 1986, 1994), forms of collective expertise (Knorr Cetina, 1999; Traweek, 1988), the ways different contexts produce and legitimate different knowledges (Shapin & Schaffer 1985; Allen, 2007), and the role of scientific authority and expertise (Wynne, 1992, 1996; Shackley & Wynne, 1996). The call to arms to DSTS scholars came just after the 2011 Great East Japan Disaster. Therefore, the Fukushima nuclear disaster has been well served by STS scholars (which I expand on later).

In more recent years, platforms such as the Disaster STS Network[12] have been established to link 'researchers from around the world working to understand, anticipate and respond to disaster, fast and slow'. As well as engaging with issues around the Anthropocene (de la Bellacasa, 2015; Liboiron et al., 2018; Fortun et al., 2021), the digitisation of environmental sensing technologies (Gabrys, 2016) and environmental (in)justice (Jeon, 2019; Schütz, 2021), the science-technology- society-policy interfaces in disasters, fast and slow, have been made visible by STS scholars. The COVID-19 pandemic provided a wealth of subject matter with very real dimensions and implications. The pandemic was shown to have exacerbated existing inequalities in scientific laboratories (Jeske, 2022), the messiness and negotiability of COVID tracing algorithms (Liu, 2022) and 'what it means for policy making to be 'led by the science' when the best available science is provisional and uncertain' (Evans, 2022: 53).

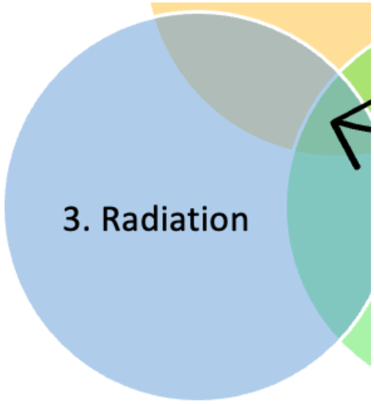
Key themes from STS in general underpin the kinds of questions *Disaster* STS scholars [could] ask about 'disasters' and the methods that are used to investigate them. Two areas of questioning suggested by Fortun and Frickel (2012) are of specific relevance to my research. These are:

- 'What STS concepts and theory can contribute productively to DSTS?'
- 'What kind of science, knowledge, and expertise emerges, and is utilized, in the wake of disaster?
- What is noteworthy about who becomes involved in knowledge production in the wake of particular disasters? Have particular government agencies or universities played significant, perhaps unexpected, roles? What knowledge production roles have social science and humanities scholars played? Citizens and workers? What has constrained the involvement of different social groups?'

My project is specifically interested in engaging with STS concepts and working with them to build a relationship between to the radiation assemblages, devices, knowledges and practices of Fukushima and my own professional practice. As a result, this thesis is a response to that call for action to work with sociological theory alongside a case study of disaster. The application of STS theory and concepts to 'disaster' (whether overtly *Disaster STS* or just STS as applied to 'disasters') directly takes up the suggestion of exploring 'What STS concepts and theory can contribute productively to DSTS?' (Fortun & Frickel, 2012). Furthermore, I am also addressing the second bullet point which asks: 'What kind of science, knowledge, and expertise emerges, and is utilized, in the wake of disaster?' (ibid). This thesis therefore offers a contribution to the debate on how working with STS concepts in relation to data from Fukushima can contribute productively to (D)STS. The specific research questions this project addresses are set out more definitively in section 3.4.3.

[12] https://disaster-sts-network.org/about

2.3 Researching Radiation



The consequences of radiological contamination have been explored in many different ways from a social science perspective. In this section I concentrate predominantly on four themes emerging from this work – radiation as matter out of place, nuclear things as exceptional or normal, the health impacts of radiation and representations of radiation risk.

Mary Douglas famously framed dirt or pollution as *matter out of place* (1966). She argued that beliefs about pollution draw physical boundaries between the moral and the immoral, reflecting particular social orders. With its links to nuclear technologies, radiological contamination can be seen as one particular kind of 'dirt' that might be cast as acceptable in some places (nuclear establishments, nuclear weapons, medical treatments, background radiation and as we shall see the forests of Fukushima) but unacceptable – i.e. 'out of place'– in others. Bloemen suggests that the 'reality status' of radiation '– as dangerous, desirable, risky, polluting or natural – arises in a process of competition, conflict and negotiation among different actors: scientists, publics, politicians and members of industry' (2013: 11). She also demonstrated that 'when and for whom radioactive matter comes to be considered 'out of place' reflects value orientations rather than facts' (ibid). Radiation and its out-of-place-ness is socially (and sociotechnically) constructed.

Gabrielle Hecht considers radiological things from another perspective. Her (2012) exemplary ethnography on uranium mining in various spaces in Africa and beyond probes what it means for something to be 'nuclear' – be that a nuclear worker, a nuclear state or a nuclear object. She suggests that 'nuclear' things are able to subvert the normal processes and procedures expected of something that can do harm, by adopting *exceptional* or *banal* framings. Nuclear things are either so exceptional that they do not need to be governed or restricted by normal conventions for safety or inspection – they are above standard processes – or they are made to become so banal, that they slip under the radar unnoticed. Sonja Schmidt (2019a, 2019b) drew on tensions between exceptional or banal nuclearity in her STS-orientated work by examining the positions of the safety and security communities. Security communities draw on the exceptional status of nuclear technologies, whereas they are routinely normalised by the safety community, into something controllable. Similarly, Joseph Masco's ethnographic work *The Nuclear Borderlands* (2006) highlights similar framings at work in relation to the Manhattan Project to develop and maintain nuclear weapons in the US. Official discourses alternated between the apocalyptic terror of nuclear war, and the banalisation of the weapons that might bring that about.

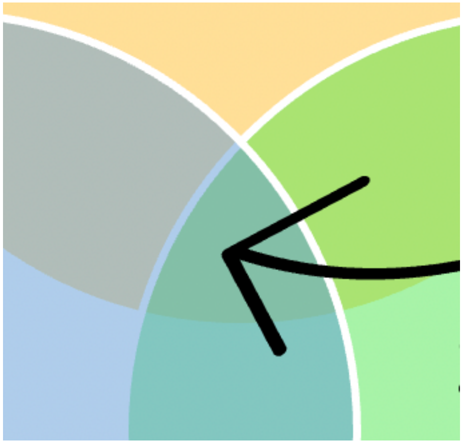
The health impacts of radiation have also been extensively explored. Stawkowski (2017) for example examines science and policy's role in legitimising or dismissing concerns about the health impact of radiation in the former nuclear test site in Semipalatinsk in Kazakhstan. Rather than being legitimised by the state, citizens' concerns are 'framed as a case of 'radiophobia' or the irrational fear of radiation. […] constructed as a mental disorder located inside the head of its victims rather than in the public domain' (2017:357). Adriana Petryna (2013) invoked the notion of 'biological citizenship' to describe how citizens utilised their health status in order to navigate the complex network of institutions set up to provide welfare and care for those affected by the disaster. The organisational structures of these systems were inextricably linked to building of the new Ukrainian state in the years immediately after the Chornobyl disaster. Without easy access to data about personal doses, citizens were obliged to use their own biology in order to assert claims for financial support, medical support and political status. Petryna revealed the logics that citizens applied and the things that they paid attention to or ignored in order to maintain their biological citizenship.

Olga Kuchinskaya's work examines the making visible of health effects of radiation after the Chornobyl disaster (2011, 2012 and 2014) and latterly after Fukushima (2019).

> [Radiation] is not directly perceptible and […] radiation danger and possible health effects have to be "articulated," that is, recognized, explicated, and established as risks […]. Radiation is not "visible" to lay people living on the contaminated areas without this work of articulation. (Kuchinskaya, 2011: 406)

The invisibility of radiation to the human body[13] and the need for technologies and representations to articulate this has also been explored. Kuchinskaya used Star's concept of the politics of representation (Star, 1995) as a lens by which to assert that radiation is being made 'twice invisible'. The politics of formal representations – standards, thresholds, and visual mapping – lies in what 'keeps slipping away' behind layers (bureaucratic or representational) of other things' (Star, 1995: 93). Kuchinskaya develops arguments around the politics of data and radiation representation matters. She argues that 'the production of in/visibility is relative: some discourses, practices, and conditions render hazards more visible, while others, in comparison, render hazards less visible and potentially even non-existent as a social issue' (2019: 873). Initially not 'visible' to the human senses, radiation is then actively excluded from certain official practices relating to how it is depicted and represented in maps, charts and tables of information.

2.4 Researching Fukushima



The social sciences, including STS but also sociology and anthropology, have engaged significantly with various aspects of the Fukushima nuclear disaster (and tsunami and earthquake) since 2011. Initial work focused areas such as citizen's experiences of evacuation and being evacuees (Gill et al., 2013). Tom Gill, Birgitte Steger and David Slater were proponents of 'urgent' (Gill, 2014) accounts of the disaster, advocating the use of local researchers more sensitive to local customs and from a practical perspective, more likely to be closer to the disaster itself and therefore more able to act quickly. US anthropologist David Slater was interested in capturing the voices of those directly affected and often forgotten in historical accounts and formal reports of disaster. Along with over 100 students from Sophia University in Tokyo where he is based, he collected oral narrative interviews directly from participants. Over 300 stories were eventually captured on video through semi-structured interviews under a project called Voices from Tohoku[14]. Many others concentrated on topics such as science communication (Tanaka, 2015; Shineha & Tanaka, 2018), discourses of nuclear and energy politics (Hirakawa & Shirabe, 2015; Mikami, 2015), as well as longer-term aspects of the ongoing disaster, including the management and construction of contaminated waste (Wynn-Kirby, 2019) and contamination as toxic pollution (Stolz, 2018; Onaga & Wu, 2018). Lindee put into conversation current medical research programmes into the long-term effects of radiation on the human body in Fukushima, under the auspices of the Fukushima Health Management Survey, with similar research projects on survivors of the atomic bombs of Hiroshima and Nagasaki (Lindee, 2016). In doing so, she shone a light on how various sciences can or should

[13] This idea was challenged by a radiation worker who spent 40 years in and around radioactive fields in Chornobyl, who said 'The most common truism about radiation is that humans cannot sense it […] but that is not true. With a dosimeter, you can hear radiation. With a camera, you can see it. If the levels are high enough, you can taste it on your tongue. It tastes metallic.' (Kupny, in Brown, 2017: 40). Nevertheless, aside from tasting it, these statements continue to support the proposition that a device is needed to act as an intermediary.
[14] https://tohokukaranokoe.org/

engage with disasters. In tracing the biomedical effects of radiation from Hiroshima and Nagasaki, Lindee's experts needed to 'draw on their own political status' (as a result of their citizenship) in order to be able to make claims about biological and radiation risk that were taken seriously (2016, 193). In contrast to Lindee's experts, Petryna's biological citizens sought to establish their biological citizenship status in order to gain access to resources and state support (2016).

This next section provides an overview of key debates and the themes in social scientific research based on data from post-2011 Fukushima, but with a particular focus on research engaging with the themes of radiation measuring and monitoring, and the construction of scientific knowledge. As might be expected with a topic that grapples directly with scientific and technological issues, many (although not all) of the authors below refer to concepts, methodological concerns and ideas familiar to STS scholars. However, given the inter/intra-disciplinary nature of much STS work, references to STS texts and ideas are frequently positioned alongside (or even within) texts and ideas from other or related disciplines, such as sociology, political science and anthropology (Felt et al., 2017: 3).

A rich strand of social science research has addressed the (often gendered) politics of the nuclear disaster, drawing attention to the silencing of women, including mothers, concerned about radiation and the impact it was having on their families, by local and national structures in place to manage the response (Slater et al., 2014). Hiroko Kumaki explored what it means 'to live well in a time, place, and ecology where toxicity has become the very fabric of everyday life' (2020). Aya Kimura's work on the food monitoring activities of mothers is particularly important as it demonstrated that women's efforts to position themselves as mothers as a means to legitimise their concerns, actually undermined their power in official discourse, resulting in their voices being dismissed more easily (Kimura, 2016a, 2016b, 2019a). Taking up radiation monitoring as a scientific endeavour was one of the ways that those women countered this dismissal. Cousin's builds on these themes alongside the production of ignorance and denial in public narratives of radiation risk (2021).

Yuko Fujigaki's edited book, *Lessons from Fukushima: Japanese Case Studies on Science, Technology and Society* (2015) highlighted events at Fukushima Daiichi from the perspective of Japanese STS scholars. The book was a partial answer to a call, issued just months after the events began, for STS perspectives on the nuclear disaster (Fujigaki & Tsukuhara, 2011) and sets out to address the three main questions: 'How are the nuclear power plants embedded in political, economic and social contexts in Japan? Under what kinds of relationships between science, technology and society are such accidents produced? In addition, how are these relationships constructed historically?' (Fujigaki, 2015: xi). Alongside research outlining the historical context of Japan's relationship with the nuclear industry, topics of discussion included the Monju nuclear power dispute (Kobayashi & Kusafuka, 2015), Minamata disease (Sugiyama, 2015), and Itai-itai disease (Kaji, 2015). For many outside Japan, this was the first time these issues had been made broadly accessible in English-language literature (Abe, 2017).

STS scholar Togo Tsukahara later observed that Japanese 'STS-ers' had proven not to be effective at all 'in dealing with the problems occurring between science, technology, and society' in the face of the national disaster (Tsukahara, 2020: 333). According to Hitoshi Yoshioka this was for a number of reasons, including because they preferred to remain on neutral territory rather than cover 'socially controversial' topics, they were unable to become 'interested parties', they were not scientifically or professionally knowledgeable enough to be critical, they remained too 'distant' from the scientists and engineers they were researching, and they were unable or willing to challenge authority in particular the government (Tsukahara, 2020: 332).

It is clear from the extensive amount of STS literature produced about Japan, although not necessarily by Japanese 'STS-ers', that STS has taken up the metaphorical gauntlet to expose highlight the 'problems occurring between science, technology and society' and to challenge the hierarchies of power that influence those interactions. That said, I do think that as evidenced by the extensive literature on citizen radiation monitoring efforts, that there is often a focus by STS researchers to frame the narrative around exclusion (e.g., citizens being excluded from producing data that might be acceptable to formal institutions) or around dichotomy (e.g., citizen produced data sitting entirely separate to data produced by governments and institutions). My own research project addresses this in a number of ways. Firstly, my own position as someone with an existing professional interest in and experience of disasters gives me a relatively unique perspective amongst STS scholars researching contamination disasters. In addition, in my research I get 'close to' rather than distance myself from the makers of scientific radiation knowledge in order to challenge some of the conceptual frameworks that inform disaster planning.

2.4.1 Radiation and citizen(s)/science

The Fukushima nuclear disaster has arguably been a catalyst for and helped energise academic interest in citizen engagement in the measuring, monitoring, and production of scientific data about radiation. Morita et al. (2013) describe the work of citizens to produce a radiation map, in terms of 'civic infrastructure', pointing out that emergent groups come together to address technoscientific failures by established institutions. Also tackling the construction of scientific knowledge, Tessa Morris-Suzuki (2014) examined the notion of uncertainty and the gap between how this was perceived by scientists and scientific institutions in contrast to those affected by Fukushima disaster, noting that citizen science offered a way of bridging the gap. In the following years much social science research has been conducted into the nature, make up and consequences of direct participation by citizens in 'science,' in particular in radiation measuring / monitoring activities from different perspectives. Having identified the varied backgrounds and activities of citizen radiation measuring groups that sprang up around Japan after the disaster, Kimura coined the abbreviation CRMOs (Citizen Radiation Measuring Organisations) (2016a), a term which has been used subsequently by Kenens in her work on the historical and situated context of the citizen science movement in Japan (2020; Kenens et al. 2020, 2022a, 2022b).

Sternsdorff-Cisterna uses the concept of scientific citizenship to explore how citizens' relationships to state generated data changed as a result of their own food monitoring practices (2015). Engaging with an STS proclivity for the democratising potential of citizen science (Irwin, 1995; Mayer, 2013; Bonney et al., 2016), Kuchinskaya (2019) compared citizen approaches to monitoring radiation in Belarus after Chornobyl with those of a citizen radiation monitoring group established after Fukushima. In doing so she raised broader questions about how citizen science data sensing practices make 'environmental hazards in/visible' (p. 872). Tam showed that in contrast to state dosimetry, which was 'leaky, impermanent and continually renegotiable', citizen produced data could be seen as 'enlivening' in producing new relations between villagers and the other organisms they shared that space with (Tam, 2020: 3).

Contestation of citizen generated data is a major theme. The contested nature of both the methods (Brown et al. 2016), and technical tools (Abe, 2015) used by citizens and the products of their labours, have been examined (Berti Suman et al., 2020; Berti Suman, 2020, 2021). In contrast, Saito and Pahk (2015) note that the poor inroads by citizen generated data into public policy might have been less to do with accuracy of methods and devices and more to do with the way that policy making is done in Japan, a situation not necessarily addressed by current public participation endeavours in Japanese nuclear energy policy making (Saito, 2021). Many of the issues and questions being asked here reflect quests by citizens to get recognition for their data within official narratives or to for it to drive policy decisions (Gabrys et al., 2016, Gabrys, 2019; Ottinger, 2010, 2017 & 2022) and incorporating citizen science into disaster response taking place in wider research into environmental contamination and citizen science more generally (Ottinger & Sarantshin 2017; Freitag et al., 2016). Maxime Polleri even suggests that collaborations between citizen scientists and government agencies or institutions to produce data, or with respect to governments using citizen generated data might be framed as 'conflicted' (2019).

A notable contrast to the sustained focus on efforts by citizens to participate in the production of knowledge about radiation is Makoto Takahashi's scrutiny of expert claims to authority in relation to civilian radiation exposure (2019). Rather than looking at grass roots radiation monitoring practices, his work considered the practices and performances – in particular improvisation –that 'experts' made to perform authority. Aya Kimura (2019) added to the discussion further by highlighting the case of ETHOS in Fukushima, which although a product of ICRP and various other European agencies, was hailed (by those institutions) as a model participatory risk communication project because of its engagement with local residents and stakeholders. Much of the literature that describes the ETHOS project frames it primarily around those community links and community voices (Ando, 2016; Lochard et al., 2019). Using critical and feminist literatures Kimura notes instead that the project 'portray[s] the reduction of government/industry responsibility as morally defensible, and the decision to stay in Fukushima as a free choice made by hopeful and determined citizens' (Kimura, 2019: 98).

I am ambivalent about the term 'citizen science' (Irwin, 1995) precisely because I am aware that the term has been used in different ways to describe 'scientific' activities undertaken with different levels of citizen involvement. Natural scientists tend to use 'citizen scientists' as a name for volunteers who collect or analyse data as part of scientific enquiry, often as part of a project directed by professional and salaried scientists (Silvertown, 2006). STS scholars on the other hand use the term citizen science to describe grass roots scientific activities driven by citizens themselves (Lave, 2012). I do not wish to enter the debate on a correct term for this, not least because this debate is being taken up elsewhere and in particular in relation to Fukushima (see Kenens et al, 2020 and Kimura, 2016).

In relation to academic research addressing citizen science activities in Fukushima (many of which were outlined above), MK Tam (2020) challenges the ways those studies frame some networks of knowing and making meaning about radiation. He asserts that:

> At best, work from these authors reinforced the panoptic character of the state and the incapacitation of citizens; at worst, they represented the data practices of the citizenry as weak versions of science that were eventually ignored or co-opted by the state, downplaying the potential of the more flexible and technology-backed participation that prevailed after the disaster. I saw something different during my fieldwork: I met individuals who used dosimeters to create their own 'monitoring systems' to challenge expert rationality […]and groups that contended with the state over representations of the fallout, rendering the official science of radiation more temporary and fragile. (2020:15)

Accounts that render citizen science as 'weak' downplay their potential to disrupt official versions of what is happening. In Tam's work, there is agency in non-official science weakening the dominant position of official science and making it more fragile. I add to Tam's criticism of some of the existing literature on citizen and official data practices by suggesting that the narrative in these accounts of citizen science is often binary or too simplistic, pitting citizen science constantly against state or 'official' science. Many of the studies about making radiation data that I referenced earlier treat both citizen science and more formally acknowledged organisational kinds of science either as two distinct poles between which there is little overlap, or as a linear scale – professionals on one end and citizens on the other, each individual holding a static position on the scale. Depicting the making of science in emergencies only from the perspective of *citizens* vs the *professionals* or as combative (e.g. Polleri's 'Conflictual Collaboration' (2019)) obscures the interconnections and overlaps between different individuals and groups 'doing' science in emergencies and how this is made (im)possible over time. A polarised account of science in emergencies mean the focus of research can become stuck on identifying 'how can citizen science become acceptable to the professionals?', or 'how can we communicate [professional] science in contamination emergencies [to publics]?' or 'can the accuracy of the devices and methods that citizen scientists use be trusted?' or similar. By continuing to analyse radiation monitoring activities as being done only by groups of only citizens or only scientists, researchers risk re-performing the very boundary making practices which hold the two groups apart from each other.

Thinking more broadly about the makers of science in contamination emergencies means that I can ask different questions about knowledge making. I can also apply these questions to situations where farmers are doing science in concert with decontamination workers, school teachers are thinking about science alongside parents, city planners are engaging with radiation science alongside local businesses etc. This allows me to think more about how is science *done* in contamination emergencies: what assemblages come together to make knowledge about radiation, how does is knowledge making get done, what kinds of questions we might ask during contamination emergencies, and where and when is knowledge about contamination created? Citizens and professional scientists are no longer opposed, but part of a bigger, and more complex ecology of entities coming together to make scientific knowledge in particular spaces answer particular questions on behalf of specific people.

My thesis starts from the position that a range of different actors are required to participate in activities that might be described as 'science', some of them are salaried professionals, others have studied radiation measurement for years, others have practiced it for years and so on. My own work brings side by side STS insights and works these into the practical experience of responding to disaster (whether professionally or personally). My interest lies not in trying to tidy up the activities of citizens so that they are a distinct range of categories, but in seeing how these activities related to living with radiation work alongside each other (and others).

2.4.2 Between measuring and monitoring

I now make clear what I mean by radiation monitoring and radiation measuring. In my data I found the two terms are used relatively interchangeably or together as if describing a homogenous activity. Many devices and practices associated with radiation knowledge making are doing both measuring and monitoring, however the terms invoke different characteristics.

I take *radiation measuring* to be a one-off activity, whereby a device is used to generate, inscribe and present a reading in a standard unit of measurement. For example, fixed radiation monitoring posts display the most recent ambient dose rate measurement on the small screen at the top of the device. I use the term *radiation monitoring* on the other hand to mean the ongoing and repeated measuring of a given item over a period of time. All monitoring involves an element of measurement; it also involves elements of comparison and repetition. Measuring and monitoring have different temporal characteristics. Monitoring suggests a broader interest in trends over time and relationships between multiple data points and measurements. It speaks of persistence, both of the activity itself and of the contamination being monitored, as well as attentiveness and judgement. Measuring is the act that generates a single or multiple measurements, but monitoring is about continued attentiveness to what is happening with that data over time and in relation to other things like data from other places, other times, other things and compared against specific cases or against thresholds and standards.

I delineate between radiation measuring and monitoring because of the temporal and complexity differences between them. Measuring is useful in that it provides discrete points of data which may be of significance in and of themselves, but monitoring is a conceptually more intricate way of understanding radiological contamination. *Radiation monitoring* provides, over time, a build-up of an experiential baseline, formed from past and current conditions, from which future conditions might be judged. Monitoring helps identify changes, patterns and trends which may be of concern and involves paying attention to them. Undertaking monitoring indicates care and concern. It points to a potential future in which action might be taken to address concerns identified. A single data point produced by the monitoring post we stood in front of might be enough to encourage a person or organisation to take a particular decision or action at a given time or with short term implications (e.g. don't enter this place now, or don't eat this bunch of wild vegetables picked today), or the data might be part of longer term monitoring over a longer time period for that area, or a greater geographic area. Monitoring is more likely to be linked with bigger decisions with longer-term impacts, in which case it is important to understand the contextual nature of the individual data points being produced.

Both measuring and monitoring, however, contain embedded notions about what is to be measured, why and how. These are fixed in the technical devices that we use, in the measurement units chosen and the assumptions built into the device in use, that translate what it 'sees' into an output that we can 'read'. For example, in the very early days, those working with X-rays did so unaware of the serious biological effects that high doses of radiation could cause. They had no way of measuring the strength of the radiological field around the instruments they were using; scientists used the skin reddening caused when a hand was placed directly in the X-ray beam to calibrate their instruments (Meinhold et al., 1995: 116). These days dose rates, which tell us about the potential of harm being caused to human bodies are based on generic theoretical human bodies – phantoms – calculated using computational models that represent a human body and different organs. There is for example a male phantom called 'Golem' (Zankl & Wittmann, 2001) who is 176 cm tall and weighs 69 kg and a female phantom called Laura is 167cm tall and she has a body mass of 59kg (Zankl et al. 2018). The ICRP has official computational models for both a reference male and a reference female and 140 modelled organs (Zankl et al., 2018) – they do not have names and their key stats are slightly different. So even individual data points therefore never really stand alone as neutral entities, they are linked to particular devices, methods of calculation inside the devices, methods for employing those devices and so on.

Having set out the key fields of academic work that this project is situated within, and before engaging with my data, the next chapter explains my methodology and the reasoning behind it.

3 Method and Methodology

The central goal of this thesis is to explore how scientific knowledges about contamination are made, made sense of and used after contamination disasters. This chapter sets out both the ways in which I conducted the research and analysis in order to address this question, as well as my reasons for choosing to do so. It proceeds in four parts: 'Introducing the methodology' reflects the methodological concerns of the research project; 'Research design' describes the practical design of the project; 'Doing research – Realities' focuses on the realities of doing research in the field; and 'Finding complexity and then focus' brings the strands together to provide an overview of the themes, questions and concepts used in the structure of the thesis.

3.1 Methodology

As noted by Guba and Lincoln, 'Methodology is inevitably interwoven with and emerges from the nature of particular disciplines (such as sociology and psychology) and particular perspectives (such as Marxism, feminist theory and queer theory)' (2005: 192). In order to situate this discussion about methodology, I would like to delineate between 'method' and 'methodology'. Whilst 'method' relates to the *how* of research conduct, 'methodology' can be equated to the 'world view' or 'inquirer stance' of the researcher (White et al., 2009). In writing about feminist methodology, Liambuttong writes 'that the process of research is as important as its outcome' (2007: 10).

My research design is positioned in relation to, and underpinned by, concepts and methodological considerations from Science and Technology Studies (STS) and broader sociological perspectives outlined in the previous chapter. For example, STS offers various concepts for thinking about the objects of social scientific research and present ideas for thinking about not only the technical devices used in emergencies, but also the practices and spaces involved. This includes thinking about objects as actor-networks (Callon and Latour, 1981; Latour, 1993, 2005; Law & Singleton, 2005; Mol and Law, 1994; and Callon, 1986), as complex and messy objects (Law & Singleton, 2005) and as political (Winner, 1980). STS researchers have also highlighted how scientific tools, as technical artifacts, are constructed and gain stability through specific scientific practices (Clarke and Fujimura, 1992), in specific places (Latour & Woolgar, 1986), and that scientific information systems privilege specific perspectives and values (Gieryn, 1983; Bowker & Star, 1999). This drew me to think about the material aspects of radiation monitoring as a central part of the social aspects, as well as my own boundary making and defining position as a researcher carrying out the project. Any methodological approach taken would require me to be reflexive about my own position within the research. I also wanted to gather data on multiple sites of radiation monitoring, not just those sites associated with formal structures of scientific endeavour.

Some of the key tenets that drive STS research in general and which therefore drive my own research in particular, can be summarised as:

> The situatedness of knowledge, the (social) constructivist approach to understanding science and technology in the making, an emerging attention to practices of knowledge and technology making, the realization that what we perceive as science is the outcome of complex boundary work, as well as the very idea that natural and social orders have to be seen as co-produced: all were presented as starting to form important basic understandings driving STS research. (Felt et al., 2017: 7)

Taking a constructivist position (a social science view that scientific knowledge is *constructed* within different scientific communities) means that whilst I don't dispute that radiation is a 'real' thing out there in the world, I see the 'reality' of that radiation, as facilitated by and 'derived from community consensus regarding what is "real," what is useful, and what has meaning (especially meaning for action and further steps)' (Guba & Lincoln, 2000: 197). My thesis adopts a social constructivist approach to science and technology making in which actors (for STS, human and nonhuman alike) have agency. This involves a commitment to the principle of methodological symmetry. Symmetry equates to 'evenhandedness' and setting 'aside given in advance categorical boundaries, even notions of truth or falsity, when investigating facts or things in the making' (Jasanoff, 2017: 269). The social constructivist also considers [technological and scientific] artifacts to be underdetermined, meaning that they have interpretive flexibility (Feenberg, 2017: 640). The final function of the artifact is never settled, it receives closure only through social interactions.

STS-informed research is typically conducted using ethnographic methods, participant observation, incorporating or investigating images and representations, exploring cases and controversies, semi-structured interviews and documentary analysis. This follows a methodological approach in STS which places value on observations of what is done and said, rather than reported behaviour, actions or opinions. This position, in which both the practices of science along with the inscriptions of science are valued as sources of data, has practical methodological implications for my project which I discuss in due course in the rest of the chapter.

My own research project followed these traditions and applied them to the study of scientific knowledge making in post-Fukushima Japan. I chose to undertake a combination of an ethnography, which included participant observation, note taking, photography and documentary analysis, augmented by semi-structured interviews, as a method of data gathering that aligned to my methodological commitments. The next section explains why an ethnographic method was suitable for the subject I was examining.

3.1.1 Ethnography

Ethnography is described as 'the art and science of describing a group or culture' (Fetterman in Wall, 2015: 1). Doing an ethnography involves getting actively involved and participating in a group's activities. This allows the ethnographer to gain an insider perspective and a practical appreciation of decisions to be made, as well as the physical and emotional implications of doing that work or having that experience. An ethnographer appreciates that what someone says does not always match up with what they have reported they do and that participating in the 'doing' provides rich data not always available via other data collection methods. The researcher produces detailed and comprehensive accounts (often using thick description) of different social phenomena, based on a rich array of different kinds of data; not only handwritten notes of observations, but also photos, digital recordings, interviews and documentary information (Kramer & Adams, 2018, Reeves et al., 2013). Part of the methodological challenge of an ethnography is being able to bring these multi-modal data sets together in analysis and to produce the written account, the ethnography (Dicks et al., 2006). The main tool involved in data gathering and analysis is the ethnographer themselves.

Historically, anthropologists tended to use it to study 'exotic' groups of people outside the researcher's home country. Polish anthropologist Bronislaw Malinowski is said to have 'invented' classic ethnography, having spent time on the Trobriand Islands doing fieldwork learning about the Trobrianders (Mitchell, 2011: 3). Along with anthropologists, sociologists later adopted the method to use ethnography closer to home, to explore unfamiliarity on familiar and in some cases mundane or quotidian locations such as hospitals (Mol, 2002), the street (Whyte, 1993); Bourgois, 2002), homes (Belmonte, 1979 [2005]) and workplaces (Burawoy, 1979). Both groups have used ethnography to 'make the unfamiliar aspects of their respective groups familiar for others' (Kramer & Adams, 2018: 2). Over time the focus of ethnographic research shifted from whole societies to smaller sub-groups of society and to more contemporary problems closer to home, such as homelessness and immigration, and then later on to study professional groups (Reeves et al, 2013: 1367).

Nowadays the ethnographic method is used in various academic fields including healthcare, education and organisation studies. STS for example, has a long history of ethnographic research in relation to the interaction of techno-scientific things with society and many of the classic texts introduced in the previous chapter are ethnographies (for example Latour & Woolgar, 1986; Mol, 2002; Law & Singleton, 2005). This is because STS research and ethnographic methods are ideally suited due to ethnographic methods being serendipitous, open-ended and flexible, allowing the researcher to effectively 'follow their nose'. Mitchell notes that 'in practice, ethnographers tend to let context drive not only their descriptions but also their research questions and methodological practice' (2011: 3). In contrast, other methods (such as structured interviews, questionnaires and surveys or experiments for example) can have inbuilt assumptions in them about the structure of social enquiry which foreclose ways of thinking or responding not already known about or anticipated by the research designer. Ethnographic methods are suited to exploring the messy reality of the world at large. Because ethnography involves watching and participating in what people do and say in a real-life context and over an extended period of time, it is well suited to the study of scientific knowledge making taking place in concert with technical devices, because these kinds of objects are made *through* practice (about which more later in Assemblages). It is also possible to build rapport with participants and to go back and question, challenge or observe things multiple times. An ethnographer is able to overhear and observe sayings and doings as they happen and is also more likely to be able to see the social context of the sayings and doings, rather than treating these things as happening in isolation and as distinct away from context. Hammersley asserts that:

> [T]he nature of the social world must be *discovered;* that this can only be achieved by first-hand observation and participation in 'natural' settings, guided by an exploratory orientation; that research reports must capture the social processes observed and the social meanings that generate them. (Hammersley, in Mitchell, 2011: 3))

Although I do not subscribe to the idea that I would 'discover' a social world by conducting an ethnography (I am part of the construction of any such social world I discover by the very fact that I am part of designing how it has been 'found' or put together), the 'exploratory orientation' of ethnography was central to my project.

Figure 10: Children on a radiation workshop in Tokyo in August 2018 use different monitors to look at surface radiation levels of different materials

3.2 Research practicalities

The following section sets out how, aligned to my methodological position, I designed my research.

3.2.1 Fieldwork

I collected data predominantly during two periods of fieldwork in Japan. My first fieldtrip was supported by the Japan Society for the Promotion of Science (JSPS, Award SP18107). It involved a 10-week trip between June to August 2018. During this period, I was kindly hosted by Japanese STS scholar, Professor Yuko Fujigaki at Tokyo University, whose help and support provided a stable basis for the rest of my field work in Japan. The second was a four-month trip from March to August 2019. This fieldtrip was financially supported by the Research Support Training Grant associated with my ESRC stipend, and I was hosted by Assistant Professor Mikihito Tanaka from Waseda University, whom I had met the previous year via Professor Fujigaki. The purpose of this second visit was to collate more granular data relating to my research questions – in particular the practices and devices of radiation monitoring. In addition, I later added to my data with follow up conversations, and through participation in events commemorating the anniversary of the 2011 Triple disaster[15] as well as ongoing engagement with academics in conferences and professionals in a working capacity.

3.2.2 Multi-sited ethnography and following things

A central idea of my project is that my object of study cannot be found in any one single location. Since the late 1980s, ethnographers had begun to see the benefit of undertaking multi-sited ethnographies across a variety of locations and space-times. '[M]ore complex objects of study,' it was argued 'cannot be accounted for ethnographically by remaining focused on a single site of intensive investigation' (Marcus, 1995: 95). Such multi-sited ethnographic work is well suited to STS research because it focuses on objects that might not be clearly bounded or defined, or might be distributed across a range of different spaces. In doing so it also disrupts traditional dichotomies of the global/local or lifeworld/system (ibid). The approach denies the inherent geography of any phenomena of interest and is thus an invitation to follow phenomena however or wherever they might manifest or lead. Marcus describes multi-sited ethnography as involving 'tracing the circulation through different contexts of a manifestly material object of study (at least as initially conceived), such as commodities, gifts, money, works of art, and intellectual property' (Marcus, 1995: 106). In my case the manifestly material objects I intended to follow (at least initially) were different kinds of radiation monitoring device and their representations. In this sense, my work has similarities to 'Follow the thing' a social science method in which a particular product is followed through its supply chain 'to understand interconnections and to explore and expose complexities, vulnerabilities, and injustices' (Sodero et al., 2021: 2). It has been used to follow things like papayas (Cook, 2004), and blood products (Sodero, 2018). My project diverges from this however, because there is no single item to follow through the process. If anything, *radiation* or *radiation knowledge* is the thing I follow, and part of what I establish is how to think about 'the object' that creates it.

A multi-sited ethnographic approach suited my own (at the time) loosely defined object not least because it meant speaking to and observing a range of different stakeholders who had an interest in and practical experience of making radiation knowledge via radiation measuring and monitoring. I was not beholden to any single easily defined object (e.g., a particular kind of radiation monitor), nor was I limited by only observing science in the making in one kind of site (e.g. a government run food monitoring station), or with just one kind of group (e.g. only citizen groups, or professional scientists, or lawyers etc). This supported my commitment to being symmetrical and allowing space for all configurations of the 'object'.

3.2.3 Semi-structured Interviews

I was able to benefit from the 'relatively unstructured' nature of data collection and interpretation in ethnography (Hammersley & Atkinson, 2019: 3). An ethnography does not always align itself, methodologically speaking, to the conduct of interviews, because of the limiting potential of fixed or strict interview schedules. However, in my project semi-structured interviews served various purposes. From a practical point of view, asking someone for an interview is relatively straightforward and has a fixed time commitment for both parties. As I had not been to Japan before, the purpose of my first research visit was to learn more about the 2011 disaster and its management directly, as well as to become more familiar with Japan as a whole. I was aware of what had taken place only from academic and emergency planning literature. Setting up interviews with many different people meant that in a relatively short time, I had met a range of different stakeholders, got a relatively good overview of the figurative landscape and through the initial interviewees got the chance to meet other people they knew.

I overcame the limiting nature of the interview schedule by making it semi-structured. I had a list of questions to draw from, but I was also able to follow up on anything unanticipated or to not use any given question if it would have seemed out of place. I quickly found that a) what I wanted to ask each participant varied each time, as they were involved in very different activities and b) that what was of most interest in conversation might not

[15] https://safecast.org/safecast10/

have been prompted by one of my pre-scripted questions. Sometimes the most interesting avenues of conversation emerged only once the recording device was turned off.

What was useful on the first field trip was that I asked interviewees to bring with them some kind of representation of radiation (e.g. a map, or a chart) that they had been involved in producing. The structure of the interview meant that we could use this object to start to talk more about radiation monitoring and it seemed to make participants more confident as they were talking me through something they were familiar with. In this sense I was constructing the interview as a space for socio-material interactions that included printed slide decks, scribbles on note paper, radiation monitoring devices and potentially contaminated wild garlic, to name a few. Michael's notion of '*coagents'* (2004: 10) – combinations of humans and nonhumans that order and disorder interactions – is useful here. The interviews I had with individuals gained additional dimensions because of the interactions of those nonhuman agents within our discussions. This notion of human and nonhuman entities is similar to some of the discussions I begin to elaborate on in Chapter 4 – Assemblages.

3.2.4 Meeting Participants and Finding Opportunities for Participation

My method for meeting participants was quite organic, such is the nature of ethnographic work – one cannot predict in advance the opportunities for meeting with different people that one is subsequently presented with. I adopted a snowball technique after contacting individuals initially suggested to me by people familiar with the situation. I took up offers as and when they presented themselves, and only turned down such opportunities if I already had a commitment. As a result, I found myself in a number of situations that I would not have been able to actively plan for in advance, but which were critical to my thesis!

Figure 11: (l) My host Professor Fujigaki from Tokyo University and Yan Jin my office colleague and translator (August 2018). (r) Hiroko Aihara on one of our visits to Fukushima (August 2018)

I am indebted to Professor Yuko Fujigaki (Figure 11) and Professor Mikihito Tanaka (Figure 12) for their initial help identifying key individuals with whom I could speak to about radiation. Professor Fujigaki introduced me to Hiroko Aihara (Figure 11), a journalist born and raised in Fukushima City. Having worked as a local newspaper staff writer for 20 years, including covering the 2011 nuclear disaster from the point of view of the local people, Ms. Aihara was very well connected to local communities in Fukushima as well as to institutional and governmental organisations. She helped facilitate many of my first meetings in Fukushima, before I was more established and could find my own way around. Professor Fujigaki also put me in touch with some carefully selected contacts that she had in academia who might be able to point me in the right direction towards interesting avenues for my research. Many of the rich conversations that this research is built upon emerged from these initial contacts and the contacts that they put me in touch with. One of these contacts was Professor Tanaka who kindly supported my second visit to Japan in 2019.

Additionally, in April 2019 I was able to join a 4-day conference, the Health and Resilience in Disasters (HeARD) Project, coordinated by Sudeepa Abeysinghe from University of Edinburgh in coordination with academics at Fukushima General Hospital in Minamisoma and Fukushima Medical University in Fukushima City. There, I established contact with a number of academics working on the Fukushima disaster from a legal, health, communication and community work perspective (see Figure 12). Through these contacts I was invited to join various activities and events in Fukushima. This included spending a weekend on a farm learning about farming practices (and concerns) after evacuated areas reopen, speaking to local lawyers about their Fukushima cases, foraging for wild mountain vegetables, visiting the research institute where one of the key radiation monitoring devices in use by the public was partly designed and meeting local people that they routinely work with when doing their own research. The conference also led to another conference in Edinburgh in December 2019 and a book Health, Wellbeing and Community Recovery in Fukushima (Abeysinghe et al, 2022), both of which I contributed to.

Figure 12: The HeARD Symposium in Fukushima, April 2019. Sudeepa Abeysinhe is immediately to the left of me in the photo as you look at it, and Professor Mikihito Tanaka from Waseda University and my host in 2019, is next to her half crouched down.

My extended period in Japan, and continued contact since then with some of my participants, has meant that I have been able to build relationships with people in a way that might not have been possible if I had met them only once. I found that as people got to know me and build rapport, participants would offer opinions and information that they might not have done had our relationship only been based on a relatively short and singular interaction such as a one-off interview. I was often also able to observe the context and enactment of what they reported in interviews taking place in practice in front of me.

Figure 13: I joined a group of Japanese scientists and farmers learning together in Fukushima about farming, foraging and science (May 2019)

In my second fieldtrip, I was kindly offered space at the office of a citizen radiation monitoring group, Safecast, in the Shibuya area of Tokyo. I had met the Safecast team on my first visit in 2018 (see Figure 14). Their offer was particularly beneficial for me because of the kinds of people and environment it put me in touch with. It was not uncommon for international researchers and journalists to come to speak with the Safecast team about radiation monitoring, and this kind of background conversation was a helpful stimulant to my own thinking. Moreover, because of the international make-up of the Safecast team, including permanent members based in Japan as well as interns from around the world, it was a logistically practical and academically engaging place to be based. I could not be more thankful for the time and effort Azby Brown, Joe Moross, Sean Bonner and Pieter Franken put into helping during the project.

Figure 14: (l) I was welcomed by the Safecast team. Joe Moross, me, Pieter Franken and Azby Brown from Safecast (August 2018). (r) I spent many hours and had the opportunity to meet academics, students, journalists, scientists, activists, makers and more in the Safecast offices in Shibuya, Tokyo. (June 2019)

I could easily have made my thesis focus just on Safecast, given the amount of time I spent at their office and in their company. However, I wanted my own research to provide more than one perspective on the situation and not to focus on one organisation who themselves have been the subject of many academic works (such as Hemmi & Graham, 2014; Wynne, 2017; Abe, 2015; Brown et al., 2016; Kuchinskaya, 2019). I suspect this is a result of how accessible and welcoming they are to researchers. Nevertheless, I wanted instead to open up my research to other participants and other perspectives, therefore the resulting PhD involves many different voices, places and spaces.

3.2.5 Data collected

During my research I gathered multiple types of evidence, described in the table below. As well as collecting examples of formal representations, I conducted semi-structured interviews with a range of individuals from a variety of organisations involved in the creation and dissemination of scientific information about radiation. I attended a number of meetings, tours, a conference, workshops and training sessions. Having multiple kinds of data meant that I was able to triangulate information from transcripts of formal interviews and notes from participant observation, visits and tours and informal conversations. However, the volume and variety of data format presented further challenges for me in terms of using these multi-modal data both within data analysis and also incorporating them within the thesis itself (Dicks et al., 2006).

Data	Method of collection
Field notes	A full list of activities undertaken in as part of this research is provided in the Appendix. During participant observation, informal conversations, visits, trips, tours and talks I took notes (and photos, see below) of the situation and my responses to it. Notes were typed up contemporaneously and included in Atlas.ti for analysis.
Interview transcripts	I undertook 33 formal semi-structured interviews in total. A full list of interviews undertaken in as part of this research is provided in the Appendix B: Research Activities. All interviews recorded in English (or English and Japanese) were subsequently transcribed and included in Atlas.ti for analysis.
Physical materials	Alongside field notes from participant observation activities, I was also given various presentations, maps, learning aids and books by my participants. In many cases these illustrated or accompanied their discussions with me. Each of these were labelled according to the date that they were given to me so that they could be attributed to the right individual. In some cases I was unable (due to weight constraints flying back to the UK) to take all of the paperwork with me. In these instances, some of the less directly linked artefacts were scanned using a PDF app on my phone and brought back virtually. I collected and was given various materials by participants. This ranged from books, leaflets, photographs, posters, maps and charts. I also made my own radiation monitoring device and continue to use it outside Japan to generate data and upload this onto an interactive radiation map.
Photographs	I took over 1000 photographs during the two fieldtrips. I was also kindly given permission to use various photos of fixed radiation monitoring posts taken by Joe Moross.
Other documentary texts	I also reviewed academic journal articles, formal reports by international organisations and government agencies, and grey literature on radiation monitoring practices, compensation, evacuation, decontamination and so on.

Table 5: Data collected during this project

3.3 Doing research – realities

The following section outlines some of the practical realities and ethical challenges I encountered conducting my fieldwork.

3.3.1 Ethical approval

My research is about investigating the construction of a thing that might cause harm (radiological contamination), involves empirical data gathering with direct participants, is predicated on the traumatic events of 2011 and involves going into an area which to varying degrees continues to be 'dangerous' to human health. Various ethical issues needed to be addressed before, during and after data collection. These ethical considerations concerned both me and also my participants. Ethical approval was granted by the Lancaster University Faculty of Arts and Social Sciences and Management School Research Ethics Committee (FASS-LUMS REC) prior to fieldwork in Japan in 2018. Approval was again sought and gained in 2019 prior to my second field trip. I was asked during the ethics process how I could demonstrate that I would not be putting myself in unnecessary harm during the field trip and had to account for what I would do to keep myself safe if I visited the contaminated areas. There was a certain irony to this; my planned research intended to explore just how one might go about determining, via scientific information, whether and to what extent something is contaminated and potentially harmful to you. I eventually settled on a response to the effect that I would stay in the publicly accessible zones and would only travel in excluded areas under the guidance of an expert (which I did). It was the construction of this very knowledge and expertise that I was questioning. How do people go about determining what is safe and whose advice one can trust?

Figure 15: A well-known scientist teaches the children of another scientist about foraging for wild vegetables in Yamakiya. After measuring the amount of radiation contamination present, anything that is under 100Bq/Kg is eaten by the group. What doesn't get eaten goes to a lab for 'science'.

3.3.2 Reflection and care

There is a need for broader forms of ethical engagement when in the field, beyond university guidelines and processes. During data gathering I was constantly attuned to the potential for ethical issues to arise. Although where possible these had been anticipated during the formal ethical approval process, opportunities arose throughout my fieldwork which required reflection and care.

3.3.2.1 Anonymisation vs pseudonymisation

Although all of my data is anonymised, I have read several social science articles describing encounters with radiation monitoring organisations which have not done this. When I spoke to people in Japan, they were surprised to read in my participant information sheet that I would anonymise participants, as it did not seem to be a common thing to do. It caused me to reflect on who was benefitting from anonymisation (or at least pseudonymisation) and whether it was actually potentially obscuring or hiding certain voices, who might want to be heard. One participant (Hayakawa-san) was very specific about being identified: 'Everyone knows about my maps and my Twitter account anyway, it would be pointless anonymising me!' Another person noted generally, 'oh it's ok, no one in Japan will read your research because it is going to be in an English journal.' Even where names are obscured in some way, I have found that it can be very easy to identify or guess at least who the researcher spoke to from the locations they mentioned, the activities they describe and the words that their participants used. This highlighted to me how difficult anonymisation was in practical terms, if the words, the location and the activities all leave a clue. This further highlighted issues around the diversity of people that I was speaking to. If I was able to guess at people's identities, it suggested that researchers are all dipping into the same small pool of participants and whether they representative of the Fukushima population as a whole. Therefore, whilst I use pseudonyms and have tried to obscure the identity of individuals, I appreciate that in some cases there are ethical considerations, as anonymity is not always possible, nor always wanted or even an unambiguous good.

3.3.2.2 Going native

On one occasion, I was in Fukushima City helping to run a radiation workshop for school children from Japan and France. Afterwards, I went for dinner with the organisers. During our conversation over dinner, one of the group referred to me as a 'Radmonitor' – i.e. a volunteer with them. Their definition of a volunteer is anyone who generates data and uploads it onto their website, which by that time I had done. Until that point, I had just been a researcher with an interest in radiation monitors, but now I was not sure where I stood. Would I be able to be impartial? Was this problematic? Would this mean I would side with their side of the story? Had I 'gone native'? I decided that actively engaging in participant and participatory observation is being part and experiencing the doing required for an ethnography. Nevertheless, I was mindful not to present myself as a 'Radmonitor' to other participants in my project. Furthermore, me being a 'Radmonitor' to them did not preclude me speaking to a range of different organisations about other kinds of radiation practices and devices.

3.3.2.3 Timeliness

In recent years, there have been increasing calls for scholars involved in the study of disasters to do so more ethically (see the RADIX Disaster Studies Manifesto and Accord)[16]. Some concerns relate to the demands placed on people already in precarious positions having been through (or continuing to live in) the consequences of disaster. Others relate to the privileged role of the saviour researcher parachuting in to discover things that were already apparent to those in those places and situations. Partly supporting, but also partly contradicting these concerns, is Gill's request for more urgent ethnography (2011) in Fukushima. He asks explicitly for social scientific work to continue as a means of helping archive personal and first-hand accounts that are prone to erasure by memory loss and the structural obscuring of memory by official accounts of what happened. He advocates for the conduct of this research to be done by those already in country where possible, so as not to overburden limited resources available and also, as noted in the manifesto, to ensure that cultural sensitivities are accounted for in the research process. Although neither a native nor long term resident in Japan (as is the case with Slater and Gill), I argue that my research has value to add, despite being generated as an outsider. There is value to add by having an outsider perspective. My own research adds value precisely because it adheres to STS sensibilities around the unbounded nature of disasters and their timescales. It is an act of remembering – remembering that for many people the disaster is ongoing and may never be over.

Another concern highlighted in Gill's article 'Radiation and Reason' (2014), and informally through various conversations in Japan, is that of researchers being parachuted in for short periods of time. An article would come out by a researcher based overseas and eyebrows would be raised if the individual did not show sufficient in-depth knowledge of the situation on the ground. It became very important to me to demonstrate in my conversations with participants that I was well informed and willing to listen to them. Indeed, part of the reason for the initial field trip was to get settled in Japan, a country I had not been to before, to learn some of the basic customs as well as learn more about what had happened in 2011 (and in the intervening years). The second visit was informed by and built upon relationships and information gleaned from the initial field trip, and helped form the eventual refined research questions I was seeking to answer.

3.3.2.4 Research fatigue

My research fieldwork began over seven years after the 2011 triple disaster began in Japan. During this time many but certainly not all of the challenges facing affected communities would have improved. A repeated concern held by me and also amongst academics that I spoke to in Japan, was of research fatigue; that the people I contacted to be research participants would feel like they had already given up much of their time to researchers like me. Crucially, I was not directly asking people to tell me about their experiences in the disaster itself, I was asking about radiation monitoring practices that they were a part of since then. Nevertheless, some people did start to tell me some stories relating to the disaster, although this tended to be in a personal capacity, rather than during any kind of interview process. When I raised concerns about this to Hiroko Aihara, the journalist who helped me to organise some of my first visits to Fukushima, she believed that some people would appreciate being asked about their activities and that this kind of disclosure and the ability to have their story heard was also not always available to everyone. I therefore approached participants cautiously, often meeting them in their existing activities (or by way of an introduction through someone with whom I had already established a relationship) before carefully assessing their openness to

[16] https://www.radixonline.org/manifesto-accord

opportunities for interview. A benefit of participant observation is that I was a participant in activities that they were already involved with.

3.3.3 Positionality

3.3.3.1 Researcher Abroad

As a researcher in a new and unfamiliar country, I was dependent on various forms of assistance during my fieldwork to see me over cultural, procedural and linguistic hurdles in my position as a British, female and non-Japanese speaking researcher in Japan. I depended on a network of people who supported me personally or professionally, as individuals or institutionally (e.g. my hosts, the organisers of HeaRD, my funding bodies, the ESRC and the Japan Society for the Promotion of Science (JSPS)) to navigate the new terrain. Often the people who were helping me functioned as 'culture brokers' (Eide & Allen, 2005). Culture brokers need not be professional translators, but rather 'can be anyone with an interest in the particular community' (Jones and Boyle, 2011: 110). These are people who act as 'links between individuals or groups who are culturally different, (who) bring people together and reduce misunderstanding and conflict' (Eide & Allen, 2005: 4).

Similar to the points that I will make in Chapter 6 about human roles in the construction of knowledge, it is worth noting that these culture brokers also functioned as *gatekeepers*, by influencing my access to the resources that I needed to be able to conduct my research (Sixsmith, Boneham, and Goldring, 2003). The relationship between gatekeepers and researchers can be complex as they are able to 'facilitate, constrain or transform the research process by opening and/or closing the gate' (Sanghera, & Thapar-Björkert, 2008: 543). Gatekeeping in my case included access to research funds (not only how much but also determining what this was made available for), access to certain field site locations, access to certain participants and access to certain tools and data. Because most of my initial interactions were facilitated by gatekeepers, my access to sources of data and participants was limited to immediate contacts known by those assisting me. As I became more familiar with my new environment and met more people from different networks, I became more independent and eventually built and maintained relationships with multiple culture brokers and groups. Through these I was offered access to a variety of participants and participant observation opportunities that were not immediately available to me from the start. One or two individuals, in particular, from Safecast, were extremely useful in putting me in touch with the right people because they were very well connected themselves.

Many, although not all of my participants were Japanese. Some of them spoke very good English and others spoke either a little or no English at all. All participant information was provided in English and Japanese beforehand and participants were offered a translator if they did not feel confident speaking to me in English. On one or two occasions, the interviews were a bit of a mish-mash between English and Japanese. I relied heavily on both multiple human and online translation and interpretation apps to see me over spoken and written linguistic challenges between English and Japanese. My translator was for the most part an academic colleague of mine from Tokyo University who was also researching about the nuclear industry (in France) and was familiar with Japanese customs.

Translation between languages is not a neutral objective activity. It involves interpreting and assigning meaning to words and phrases (Gawlewicz, 2019) in both languages, in my case English and Japanese. In my research translation involved an understanding not just of everyday Japanese and English, but also concepts and scientific terms specifically related to radiation protection or to the management of the Fukushima disaster. Sometimes a direct word for word translation was not possible and the translator also had to include some kind of context or explanation for what a term meant (Choi et al., 2012)[17]. There are always choices to be made by the interpreter about the symmetry of the translation and its equivalent meaning, but this is also limited by the vocabulary (cultural and linguistic) of the person translating or interpreting (Jones and Boyle, 2011). The act of translation from Japanese to English will have involved an element of reduction and representation on the part

[17] I have faced similar issues translating between English and German. Translation involves a certain amount of ontological representation and decision making. For example, calling something an 'ambulance' in English in the UK says something not only about the vehicle, but also its purpose and the kinds of people, skills and equipment that one might expect to find within it. The direct translation in German is 'Rettungswagen' (often abbreviated to RTW), but an 'RTW' is not necessarily the equivalent assemblage as 'Ambulance', as the purpose of the vehicle, the number, types and skills of the people operating it and the equipment do not overlay one-for-one.

of the translator, who would have sought to parse and then represent what was said to them in a way that I could understand and that was also within their vocabulary.

The false notion that it is ever possible to translate objectively and neutrally from one language into another, with the translator merely *transmitting* or *reproducing* one language into another (Wong & Poon, 2010), aligns to points that I noted about the ability of scientists in the production of scientific knowledge to neutrally and objectively represent elements of the world out there as scientific knowledge. Acknowledging the potential for reduction and simplification within my own data, undertaking any kind of systematic content or discourse analysis which really focussed on pauses, specific choices of words, sentence structure and syntax was not appropriate for the data that I had. I determined instead that thematic analysis was more suitable, as it allowed broader themes to emerge across a large dataset. This is because I draw not only on transcribed interviews, but also grey literature, photos and my own ethnographic notes and observations. Often it is the piecing of multiple stories, quotes and images that brings the data to life.

Interestingly, although language was sometimes a barrier, it might also have afforded me other privileges not immediately obvious from the outset. A Japanese-speaking researcher from the UK noted to me once that he was envious of my position as an outsider 'Gaijin' (foreigner) in Japan. He reflected that as non-Japanese-speaking researcher, Japanese people were likely to be more lenient towards me and might be more open to me in our conversations than they were to him. One of my participants underlined this by telling me a particular story, because if it did make it into my research, this would not be published in Japanese. Translation and interpreting therefore hold a potential, not just for loss and reduction, but also for different kinds of opportunity and productive discussion.

3.3.3.2 Emergency Planner

The epistemic cultures (Knorr Cetina, 1999) and goings-on that I was seeking to examine (people doing radiation measuring and monitoring) were not entirely removed from those that I encountered in my professional life. I have taken part in exercises where people were monitored through a sports hall in Cumbria to see if they were contaminated. I had worked with fire fighters who use Detection, Identification and Monitoring (DIM) equipment to detect, identify and monitor unknown contaminants in incidents. I had also worked on plans for transferring contaminated casualties from 'hot zones' through decontamination and onwards to hospitals. Nevertheless, the measuring and monitoring work was not being done by me directly and therefore the overlap was not complete. In addition, the context was different as my research site was in Japan rather than the UK.

My simultaneous position as a researcher in the field of radiation monitoring and also practicing emergency planner is somewhat unique. I can see that there is a productive tension between how emergency planners see, do and act on things, which might contrast to ideas in STS about how knowledge is constructed and acted on. For example, STS scholars might put more emphasis on the performative aspects of plans and exercises, or they might question the authority of the technologies of governance (plans, procedures, hierarchies, tools – such as detection, identification and monitoring DIM equipment) that are in place around emergency management, in ways that emergency planners like me might take for granted without question. Conversely, I also understand the frames of reference for professional emergency planners, how they might approach a particular issue and the typical route that emergency plans go through to become 'live' documents, in a way that perhaps an STS scholar might not. My position as an emergency planner was also useful in terms of engaging with participants. I was able to explain the potential real-life applicability of the information that they were providing me with. I was not 'just' a researcher, but also someone who could potentially contribute to different emergency plans in the future.

STS offered me a way to think not just about the social structures in disasters, or just about the technological tools of disaster management, but also to think critically about the established modes of thought and practice about engaging with science and scientific tools in disasters. By putting contrasting epistemological frameworks into serious dialogue with each other and *staying with the trouble,* my work is to look 'athwart' (Hustak & Myers, 2012: 77) at the ways the making of science in contamination emergencies is done, by whom and where. Looking *askance* might be productive way of highlighting different aspects of these encounters, missed by more traditional logics (Hustak & Myers, 2012)

Working with STS concepts has been a particularly enriching activity, although not without its difficulties. This is because STS is about challenging stabilized things. STS is about opening the box, taking the lid off and examining complexity, destabilizing things that took a lot of effort to stabilize. STS was unsettling for me because it forced me to (re)consider what was involved and who was impacted by the professional plans I was making and work I was doing. STS made me question the value or harm in what had always just been 'the way we do emergency management in the UK' to me. Before starting my PhD, my ideas of what might be good practice in emergency management were relatively certain, whereas I now want to question everything, consider why and how those pillars of emergency management have come to be and think about how things could be different.

3.4 Finding complexity and then focus

At our initial meeting in June 2018, Hiroko Aihara asked what I was most interested in seeing. I naively said that I wanted to see 'the place' where food monitoring was done. The way I phrased it suggested my understanding was that there was only one kind of place where this might happen and she laughed at me, declaring that there are many places and many people doing food monitoring – which ones do you want to see? Community groups, farmers, fishing community, local government and more. This was my first inkling into the complexity of the radiation monitoring situation.

In an ethnography it is customary to generate categories for interpreting data during the analysis phase rather than the data collection process, which makes data analysis a bit of an iterative process. Refining my data and my thinking began in my first fieldtrip. I started by charting the deployment of different kinds of scientific information after the 2011 nuclear disaster in Fukushima Daiichi, by collating different types of formal representations issued to citizens, including maps of contamination, instructions for decontamination, guidance on thresholds for radiation levels in food or how to prepare food safely (Elstow, 2018).

Although my thesis has now coalesced around assemblages and practices of radiation knowledge construction in the write up, this is not where my thesis began. Initially, I had intended to investigate the formal representations of Japan's radiation contamination, following on from Susan Leigh Star's work (1995), as well as key points arising from Kuchinskaya's work on the politics of radiation representation after the Chornobyl nuclear disaster (2014). I wanted to analyse the maps, tables and charts of radiation and I was also interested in the specific technological devices of radiation detection, measurement and monitoring. I wanted to say more about radiation detectors, scintillators, whole body counters and online maps that I was finding out about in Fukushima, but I was not sure how to approach this other than providing some kind of technical description of the devices.

It became apparent that I could not speak about both of these things (the technical tools of production, and also the representations of radiation) in the same space (the thesis) without engaging with how data generated by these technical tools is connected through social practices which determine how the devices are used, how data is generated and how it is then manipulated and arranged in order to make different representations of radiation. When I returned to Japan the second time my focus was much more specifically on the practices and devices of radiation monitoring and less so on the representations that were generated at the end of the process. The representation of radiation data was intrinsically linked to the technical tools and devices that produce the data they are constructed from.

3.4.1 Data analysis

I initially read through my notes and transcripts and looked through the photos and bags of physical materials to form an overview of the data together. I then highlighted points and observations which seemed most important in order to draw together links and connections between different data sources. These were input into a mind-mapping tool, to see if I could identify any themes. The resulting spider's web of points (see Figure 16) was altogether still too vast to work with. It was clear that I needed to be more discerning and concentrate on a more focused range of themes.

I had to read and re-code my data several times in order to identify new potential themes. This was made all the more challenging by having so many different kinds of data. My focus on measuring and monitoring practices and devices had provided a rich seam in my data – who was measuring and monitoring what, why, how, with

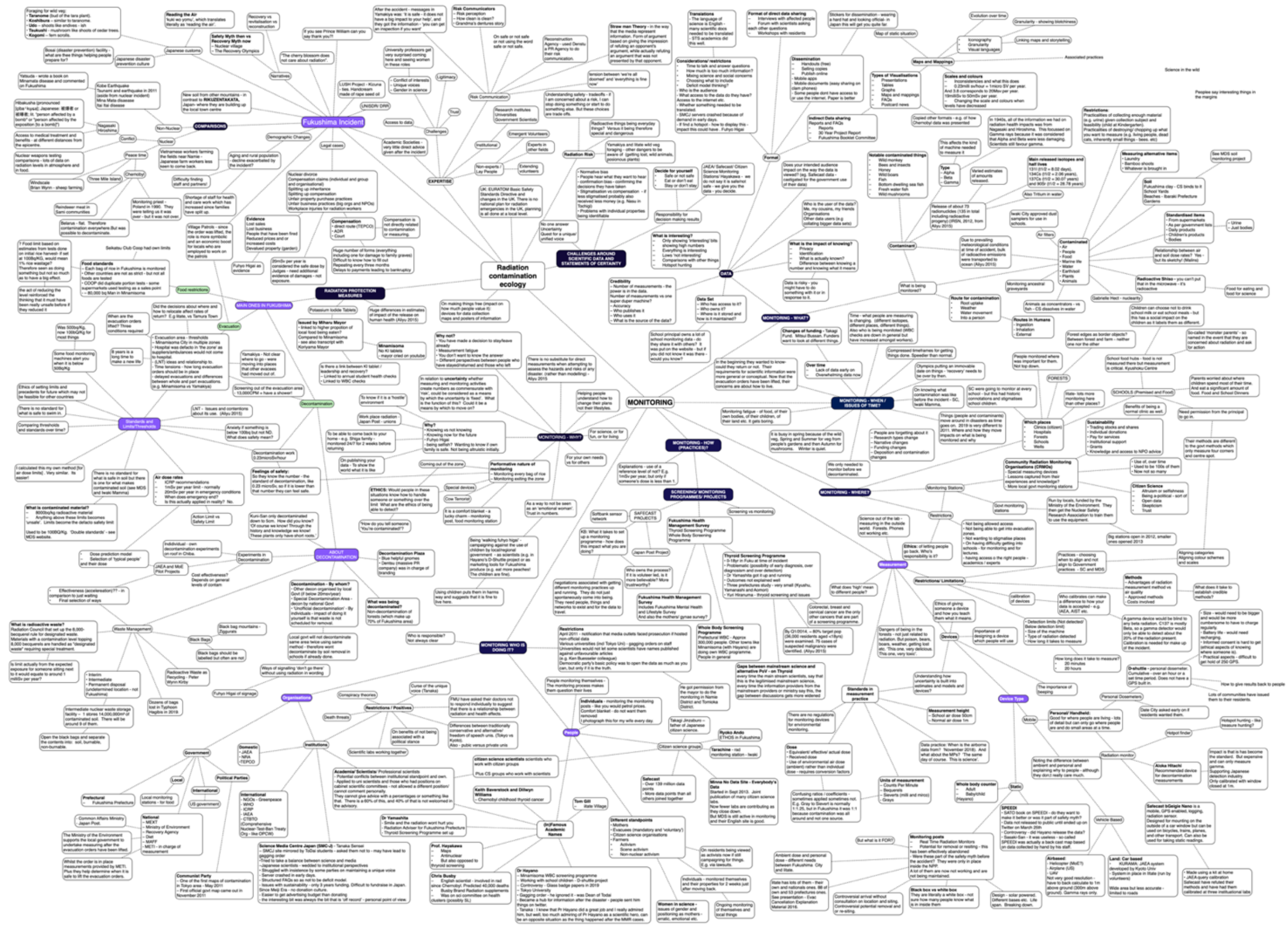


Figure 16: My initial mind map of key data points – this is intentionally too small to be legible here, however it gives the impression of the amount of data I was trying to wrangle.

what and when etc. I was led therefore to think more carefully about tools, representations and sense making taking place all together, rather than as separate activities that could be neatly boxed away.

Text-based information such as typed up notes from visits, informal conversations and participant observation, and transcripts from formal interview were input into Atlas.ti, a qualitative data analysis software which facilitates the storage and coding of different kinds of qualitative data. I reviewed my dataset again, concentrating on data that related solely to radiation devices and measuring and monitoring practices and then looked for analytical concepts from that could help me to think through what I was seeing. My findings and observations have been validated by discussing them with participants during and after fieldwork. I have also presented different aspects of the thesis at academic conferences, as I was developing my arguments.

The next section describes how I identified themes within my data which underly the rest of the written thesis.

3.4.2 Questioning

Data analysis in an ethnography involves interpreting 'meanings, sources, functions, and consequences of human actions and institutional practices, and how these are implicated in local, and perhaps also wider, contexts' (Hammersley and Atkinson, 2019:3). Finding a way to make sense of my data was at times overwhelming because there was just so much of it and there were so many different potential avenues to take. Let me outline in brief my analytical conundrums, as this will establish why the concepts I go on to use in the thesis are beneficial analytical tools to work with.

Consider for example this fixed radiation monitoring post.

I wondered where the device itself began and ended – the boundaries were unclear (Barad, 2007). Was my object of study the radiation measuring device right inside the casing, or did my object include the casing itself? Did I need to also include the fact that any one post was only partly useful on its own (i.e. radiation levels would be made visible to those who could read the screen) and was made more useful to a wider audience because it connected via a cable to a network of other monitoring posts and these connected to an online interrogatable map of radiation monitoring posts. So, should the boundary around my device also include the network, and the other radiation monitoring devices?

On the following pages I have included several photos of various models taken either by me or Joe Moross. These (mostly) white posts are omnipresent in Fukushima Prefecture. I did not have a good way of making sense of what I wanted to say about them all.

How should I think about these devices? Why are there sometimes two monitors next to each other? Why are some of the posts on a concrete plinth or on blocks, and others on the ground or a metal frame? Why are there different models? Why are some in cages? What does the little screen say? What unit of measurement does it use? Why are some in Gray and others in Sieverts? Why are they in these locations? Who uses them? What do they use them for? Who is responsible for them? What happens if they break? They were technical, they were everywhere, they were different. Different models had been installed by different agencies. Sometimes there were two posts side by side. Some posts were in different measurement units. Sometimes they were working, sometimes they weren't (the screen of the one in the photo above has been taped over). Some were sited on concrete plinths, others had vegetation growing up inside them. I needed a route through the data to make sense of it.

I also was not quite sure how to tackle the fact that there was no one actively manipulating these posts on a day-to-day basis. There was no one holding them, moving them around or turning them on and off like there were with other models of radiation monitor that I saw in use. They had been put into position and were passively 'monitoring' ambient radiation levels. So, if I wanted to talk about people doing radiation monitoring, then who was 'doing' it with these monitoring posts? And what about the people involved in providing the funding for the devices in the first place, the people who installed and maintained them, the residents and locals who looked at the radiation levels displayed on the screens or online? What should I do with them?

Another problem I had with them was that they just displayed data on the screen. I started to wonder how people go about interpreting what that data meant to them. Data on its own is not enough; we have to have means of translating and interpreting what this data then means. These monitoring posts rarely provided anything other than a data point in time – i.e. a single reading on the screen. In the absence of any additional or very limited information, how do people make sense of the different radiation data available?

Figure 17: Radiation monitoring posts were visible all over Fukushima Prefecture – on the side of roads, in the centre of villages and in school yards..

What seemed more interesting to me was to think about these different technical tools when they were put into action, in practice. I was not just interested in the technical tools, but in a bigger group of things that also included the spaces they were operating in, the times they were operating in, the different human and nonhuman actors that were active alongside these devices and the practices that the devices and their generated data were involved in.

Figure 18: Some fixed monitoring posts were caged, others were not.

Figure 19: This collection of photographs (and those in Figure 18) of fixed radiation monitoring posts (credit: Joe Moross) highlights the challenge of knowing what to do with the information they provide and what to make of them.

3.4.3 Themes and Refining the Research Questions

I identified a number of themes in my data and which are at the core of the thesis.

The first theme that I identified was the heterogeneity, multiplicity and the difficulties of drawing boundaries around the technical radiation monitoring devices I had found. I identified that the radiation monitoring posts I was seeing everywhere were operating as parts of assemblages for constructing radiation knowledges. These devices are more than technical tools; they are connected to people, to practices, and to getting things done. A second theme that I homed in on was that because these technical devices and associated practices produce a lot of quantitative data, there is a lot of calculative work, in particular comparison, being done to make sense and to operationalise the data. A third theme I noted was that the practices of radiation – measuring and monitoring and calculating – do not just 'happen' in isolation. They take place alongside and in relation to other practices – sometimes practices of radiation monitoring and sometimes other practices. I needed a way to examine how these practices worked alongside each other. And finally, a fourth theme also emerged from the data around temporalities and spatialities of radiation monitoring and knowledge making. I wanted a way of critically examining which radiation knowledge making practices took place where, who was doing (or was able to do) the knowledge making and what kinds of knowledge were being produced.

Clarity on these themes meant I was then able to refine my research questions as follows:

1. How are assemblages of radiation knowledge created, defined and negotiated?
2. What kinds of calculative work takes place in creating radiation knowledge?
3. How and when do radiation knowledge assemblages produce knowledge and meaning from radiation data?
4. How and where do different radiation knowledge making practices work together?
5. How might STS concepts help disaster management, public health and radiation protection professionals think differently about the making and use of science in contamination emergencies?

In section 2.2.2 I noted two sets of questions for DSTS research. This project's research questions provide a refined way of contributing an answer towards them.

3.4.4 Structure and Research Questions

Having settled on several key themes running through my data, I identified concepts from STS literature which provided starting points templates for thinking about these themes, and by which I would be able to extend and contribute to discussions about the making and use of scientific knowledge in contamination emergencies.

Chapter	Research Questions
4: Assemblages	How are assemblages of radiation knowledge created, defined and negotiated?
5: Comparisons	What kinds of calculative work takes place in creating radiation knowledge? How and when do radiation knowledge assemblages produce knowledge and meaning from radiation data?
6: Qualculation	
7: Syncretism and Coherence	How and where do different radiation knowledge making practices work together?
8: Conclusion and implications	How might STS concepts help disaster management, public health and radiation protection professionals think differently about the making and use of science in contamination emergencies?

The first section ***'Background Readings'***, has presented an overview of the research project as whole. Chapter 1, ***Introduction***, provided an overview of the project and background behind the study. It also acquainted the reader with some of the key events the Fukushima Nuclear disaster, including the main protective actions taken. In Chapter 2, ***Researching Fukushima***, I set out key literatures relating to the social scientific studies of scientific knowledge making in disasters, radiological contamination events and the Fukushima Nuclear disaster. In Chapter 3, ***Method and Methodology***, I reflected on the methodological and methodical considerations behind the project as it was conducted.

Section two, '***Making and Doing'***, comprises the main body of the thesis and is made up of four chapters. Chapter 4, ***Assemblages,*** provides the theoretical framework underpinning the subsequent three empirical chapters. Assemblages situates the analysis of radiation knowledge production as examined in the thesis more squarely with STS concepts including Actor-Network Theory (ANT), objects, networks, assemblages, agencement, and devices. Using examples of measuring and monitoring devices called Glass Badges and D-Shuttles, I establish that radiation measuring and monitoring practices and tools are assemblages constituted by material and social elements which, acting together, do things. Assemblages sets the groundwork for the remaining four chapters, which all relate back to the notion of socio-material assemblages, and also to each other, in one way or another. The ordering was one of many possible ones.

Having shown the complexity of the tools we use for knowing radiation in Assemblages, Chapter 5, ***Comparisons,*** narrows things down again. I examine one particular calculative practice used in radiation knowledge making – comparison. The chapter works with the notion of a particular kind of 'comparator', developed by Deville et al. (2016), to examine comparative assemblages I found in my data. I also examine the function of key comparative benchmarks in Fukushima by looking closely at the making of 0.23μSv/hr, a common comparator I saw in my data from Fukushima.

Continuing to think about calculations and judgements, but this time more broadly, Chapter 6, ***Qualculations,*** addresses the general calculative process by which data is generated and an outcome or decision is made. In other words, how do we go about knowing what we know about radiation? Qualculation (Cochoy (2002) in Callon & Law, 2005: Cochoy, 2008) is a process which can apply to both qualitative and quantitative judgements. I apply the concept to three examples from my data in which a qualculation was not achieved (nonqualculation) and in doing so begin to develop a greater understanding about what it means and what it takes to make judgements in a contamination emergency. I establish that there are certain roles that need to be performed in the qualculative process and also that there is a temporal dimension to (non)qualculation, which changes over time.

In Chapter 7, ***Syncretism and (Non)Coherence,*** I use the concept of syncretism (Law et al., 2013) as a means to explore what happens when different knowledge making practices come together in the same space. I establish that there is an ecology of multiple radiation monitoring practices taking place simultaneously. I examine how and when coherence might need to be achieved (or avoided) and think about the implications for this in contamination events.

The final chapter, ***Conclusion and Implications,*** concludes the thesis. It begins by summarising the main findings of each empirical chapter and also looks at them together to discern implications for those responsible for drawing up plans to respond to contamination events.

3.4.5 A note on images

I have, where possible, sought to include many (but certainly not all) of the images that I gathered. This fulfils two functions. First of all, I selected the images on the basis that they add to the richness of my data by providing visual clues to the situation and (nonhuman) materiality of the radiation measuring and monitoring devices I mention. Secondly, they continue to underpin the multiplicity of radiation measuring and monitoring devices I encountered in the field. Where possible I have included images that relate directly to the section of text they are adjacent to. Some images add to the vibrancy of multiple points, and therefore are distributed within the text more generally. In keeping with my point about the interconnectedness of the chapters and the difficulties I had in marshalling interwoven ideas into a linear format, the same can be said for the photos. All images are my own unless I explicitly state otherwise.

PART TWO: MAKING AND DOING

4 Assemblages

4.1 Introduction

Being able to measure and monitor radiation depends on having access to, being able to use and also being able to interpret data generated by a radiation detection or measuring device. Prior to the unplanned releases of radiologically contaminated materials from Fukushima Daiichi in 2011, the vast majority of people in Japan had very little reason to need nor want to know about radiation levels in their bodies, in the environments around them or potentially in their foods. Measuring radiation is not typically part of every-day life for the majority of people. One consequence of this is that radiation measuring and monitoring equipment tends to reside in spaces and places (such as university departments, medical institutions and industrial facilities) with a pre-existing interest in the radiological. Unsurprisingly then, immediately after the disaster, only a limited number of people and organisations were able to measure radiation, in part because radiation measuring and monitoring devices that were available were not necessarily accessible organisationally (e.g. 'at the household level' (Weston, 2017: 89)), geographically (e.g. Whole Body Counters were only available in certain locations (Hayano et al., 2014)), or financially (e.g. the cost of buying the equipment was 'prohibitively expensive for most people and community groups' (discussion with radiation monitoring group member, 2019) to everyone who would have liked to use them (IAEA, 2015). Furthermore, some existing devices failed (e.g. a network of radiation sensors, called SPEEDI, around the Dai'ichi site on the coast was damaged by the earthquake and tsunami (NAIIC, 2012)) and the supply of new devices was unable to meet increased demand (Ishikawa, 2020). SPEEDI was intended to be the lynchpin of Japanese government scientific decision making in the event of a nuclear incident, as 'SPEEDI outputs were regarded as "scientific evidence" and were directly referred to in the decisions on protective actions' (Sugawara & Jaraku, 2018).

In the intervening months and years the situation has changed. Nowadays, there are many kinds of tools used in Japan to get to know about radiation and its interaction with human bodies and human lives. I observed and heard about a myriad of technical tools during my fieldwork. My data was full to the brim with references to devices, as these examples highlight:

> Gamma rays from a very wide area are measured from this device. It measures at a height at 300m, so the result must be converted to those on the ground at 1m height. (Formal interview, 27 July 2018)
>
> They put the device for measuring on a car, and it is published on the Fukushima Prefecture's website. (Formal interview, 8 August 2018)
>
> So they use a hot spot finder, it has a GPS function in the device, they walk through the playground and the detector can get the air dose and plot the data on the map. (Formal interview, 9 August 2018)
>
> We had a working device! […] And we drove it around the Imperial Palace, because we thought that if we can drive it around the Imperial Palace then we are fine. (Formal interview, 15 August 2018)

From these examples I started to observe complexity in devices. Devices (in this sense, the literal technical tools or instruments) that are central to the production of (scientific) data are linked to ways of doing monitoring (walking around the playground and plotting data on a map), involve representation and translation (it measures at 300m and is then converted to 1m above ground level), include technical specifics about the functionality (it has a GPS function on it), information about how the resulting data and knowledge is distributed (it is published on the prefecture's website), as well as other material things (cars, palaces, playgrounds) and work (making a working device, plotting on maps, publishing on websites) that is required to make up the 'device'. Devices are therefore complicated things to investigate. This chapter therefore explores the question, how are devices and assemblages of radiation knowledge created, defined and negotiated?

In my profession, discussions about radiation measuring and monitoring equipment are the purview of technical specialists. As Lucy Easthope points out 'The CBRNE [Chemical, Biological, Radiological, Nuclear and Explosive] world is the most macho and militaristic of all our fields' (Easthope, 2021: 145). I had felt that I was not able to usefully contribute to conversations about devices used in contamination emergencies because I could neither resort to describing them by functional or technical specification, nor did I have any other ways of engaging with what they were or how they were used in practice. But in relation to detection, identification and monitoring equipment[18], the who, how, why, when and where is just as, if not more interesting to me than the what. The ‘what’ is easily answered with technical specifications. The ‘who, how, why, when and where’ is for me less concrete or fixed, and much more relational and multiple.

I therefore begin this chapter by introducing two kinds of personal dosimeter which have been used in Japan since the 2011 disaster: Glass Badges and D-Shuttles. The brief descriptions I provide initially are written in a way that might be reproduced by professionals describing such devices: weights, measures, functionality. Then, as the chapter progresses, I introduce concepts about devices from STS which extend these descriptions into new dimensions and offer tools for thinking about and working through what a device is and does. In doing so, I hope to open out the potential for the kinds of discussions (and who might be part of those discussions) that could be had, by technical specialists, by other professionals and for other groups and individuals who want to work with devices to measure and make decisions about radiation.

Figure 20: A kind of personal dosimeter –the MyDose mini which I came across on two occasions

4.1.1 Personal Dosimeters

Personal dosimeters are a particular kind of device designed to be worn on the body in order to calculate the equivalent dose of radiation that that body receives over a given period of time. They are typically used in environments where radioactive sources are controlled, for example nuclear installations or medical settings. They help the wearer and their employer monitor cumulative dose or highlight unusual deviations in radiation levels which might be associated with an uncontrolled source or release. After the Fukushima Daiichi disaster,

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[18] sometimes referred to as DIM

personal dosimeters were used to determine the kinds of doses that individuals were getting by living and working in different parts of the potentially contaminated landscape.

Although many different personal dosimeters are available (e.g. Quixel Badges, MyDose Mini and the eDose), Glass Badges and D-Shuttles are particularly noteworthy because they were used extensively in government surveys and scientific research on the affected communities after the disaster. Coincidentally, but perhaps not insignificantly, both are manufactured by Chiyoda Technol. Corporation. They do however tell very different stories.

4.1.2 Glass Badges

Glass Badges (GBs) are small passive radiation monitors which measure the cumulative external dose from photons, beta and neutrons (Juto et al., ND). Their name comes from the fact that they contain a thin layer of silver-activated phosphate glass, which produces two fluorescence sites when exposed to ionising radiations. When excited with ultraviolet rays in a reader, these sites generate fluorescence, which is called radio-photoluminescence and this can then be assessed to determine effective dose (Maki et al., 2016). GBs are typically worn on the body over a period of up to three months and then collected back in for analysis at a central location. Once handed back in they are partly dismantled in order to assess the effective dose and produce a reading. This processing takes place in large volumes at service centres, which handle up to two thousand badges in a seven-hour window (Juto et al., ND).

Around in some form since 1953 (Juto et al., ND), they are popular in the nuclear industry because the measurements can be repeated and because exposure information can be erased by a process called annealing (Maki et al., 2016), meaning the devices can be reused over and over. This is in comparison to say, film badges, which are also common in the nuclear industry, but work by the radiation reacting with light sensitive film. The

Figure 21: Photo of children holding glass badges, source: Japan Resilience System. https://japan.resiliencesystem.org/fukushima-children-receive-radiation-meters

darker the film the more radiation the film has been exposed to. However, the film can only be processed once and needs to be replaced after use. The film itself can be kept on file and remains a permanent record of exposure. Although they are one of the cheapest personal dosimetry devices and have been around since at least the 1960s, I am not aware of any surveys of resident populations in Fukushima which have used film badges.

In Japan around 300,000 radiation workers have used Glass Badges since 2001 in industrial settings (Maki et al. 2016). It is not surprising then that this device was initially one of the most common to be used for personal dose measurements in Fukushima (and to a limited degree elsewhere in Japan), as they were already available and in use. Since the disaster, GBs have been used by a number of municipalities to routinely collect data about residents' exposures in contaminated areas, which were either deemed insufficiently contaminated to warrant evacuation or where evacuation orders had subsequently been lifted. Several municipalities still offer a service whereby residents can loan a device on demand (such as Minamisoma City (2022)). Because of their prominence one of my participants noted that many people use the term Glass Badge endures as a short-hand for any kind of personal dosemeter.

However, as a device for generating data and knowledge about the exposure situations of an individual, a GB is not ideally suited to making sense of the exposure situation of residents. This is because residents behave differently to radiation workers. Unlike nuclear or hospital workers they move around different places, which means they might be exposed from various sources and directions. Radiation workers might be expected to be exposed to a single known source emitting radiation from one direction and be in a controlled working environment. Additionally, the calculations in the processing of GBs (and indeed all personal dosimeters), which relate the exposure of the device to the exposure of the person wearing it, are based on assumptions about the size of the body wearing the device (e.g., an adult body) and where the radiation might be coming from (e.g., a single source). Another issue arises from the granularity of the data, or rather lack of it. The GB produces just one reading for the whole period that it has been issued for, which can provide a broad idea of dose, but is unable to discern when or where the dose was received.

4.1.3 D-Shuttles

D-Shuttles are a kind of electronic personal dosimeter. Electronic personal dosimeters have been in use since the 1980's (Wernli, 2016: 5), and also includes devices like the MyDose Mini, which I saw in use in Fukushima, but less frequently. Electronic personal dosimeters are able to say more about individual exposure than Glass or Film Badges, in that they can record cumulative dose over specific intervals, e.g., every 10 minutes or every hour. Some of them also have screens built in so that readings can be displayed and are visible.

The D-Shuttle is a small white oblong object that sits inside a pouch that hangs on a lanyard around the wearer's neck. Shown in Figure 23, the small white monitoring device is similar in size, weight and shape to a cigarette lighter.[19] Hidden inside the smooth blank casing is a semiconductor capable of detecting (and then recording) gamma radiation from caesium 137. The battery life is such that the manufacturers claim it should last up to a year without needing to be replaced, but the consequence of wanting a long battery life is that there is no display screen on which to view the readings. Once the period of observation is over, the wearer hands the D-shuttle back in for reading in one of two adjunct devices. The first option is to slot the D-Shuttle into a smaller reader which enables some of the data to be displayed on a small screen (e.g., accumulated total dose, and the last day's dose or the last hour's dose). The second option involves a much larger reader that also connects to a laptop using an 'optical communication adaptor' (formal interview with developer of the D-Shuttle, 2021). This adaptor, shown in Figure 22 below allows all the data from the device to be downloaded and printed off. The name D-Shuttle specifically references the shuttling between users and makers for reading and battery replacements.

[19] It weighs only 23g and measures 68mm in length, 32mm in width and 14mm in depth

Developed independently by scientists at the National Institute of Advanced Industrial Science and Technology (AIST) and then commercialised by Chiyoda Technol. in the months after the disaster, they were specifically designed with residents in mind. Discussions about what might make a suitable device began in May 2011. The developers had three development targets: the device had to be reliable and able to measure radiation dose with high accuracy, it had to be easy to use (not just in the home) and it had to provide a means for checking daily radiation dose. The developers also compared functionality of other kinds of devices – glass badges, film badges and another kind of electronic personal dosimeter. They specifically wanted something which was reusable, had a good battery life, was portable, could be checked by users or on a laptop and was able to measure very low levels of radiation. Unlike film and glass badges which have a lower measurable exposure dose limit of 100μSv, the D-Shuttle is able to detect down to 0.1μSv. No other device was capable of all of these things at the same time.

D-Shuttles became available for use first in March 2013 after three different prototypes were tested.

Figure 22: D-Shuttle Readers. (l) The main link connecting the device inserted into a reader with a laptop display. (r) The smaller reader

Subsequently they have been used by a relatively small number of scientists administering specific surveys of cohorts for research purposes (Naito et al., 2015, 2016, 2017; Naito & Uesaka, 2018; Nomura et al., 2020; Tsubokura et al. 2015, 2017, 2018: Adachi et al., 2016; Hara et al., 2016; Tsujiguchi et al.,2019). Although there is no location identification technology inbuilt in the D-Shuttles, they are often combined with written diaries or external GPS trackers, which enables the readings to be aligned to a place in time. Elsewhere I found that one small coastal community in the south of the prefecture had also purchased their own D-Shuttles as well as readers for their residents (formal interview, 23 July 2019).

Having introduced two devices for making radiation knowable, Glass Badges and D-Shuttles I will now outline different social scientific concepts for thinking about objects and devices. I will examine the usefulness of these concepts using the cases of GBs and D-Shuttles throughout in order to situate the rest of the thesis in relevant theory, to demonstrate why this is useful and finally to use the discussion to prompt certain kinds of questions about devices which are subsequently addressed in later chapters.

Figure 23: You can see me (on right) wearing my allocated D-Shuttle on a green lanyard, whilst learning to split dahlia tubers in a previously evacuated part of Fukushima Prefecture. At this weekend event, scientists and their families learned about farming in Fukushima, and the farmers learned more about contamination on their farms and the surrounding areas.

4.2 Devices of knowledge production

There are multiple ways of treating technical objects like personal dosimeters, each of which prompts different follow-on questions and lines of investigation.

As I have shown in my initial descriptions of Glass Badges and D-Shuttles, one way of describing an object is to acknowledge its physical, tangible dimensions (Law & Singleton, 2005). However, doing so isolates the material elements of the object from the social. This fails to account for the places they are used, how they are used, the things they are doing (or not doing) or the different things interacting with them. D-Shuttles and Glass Badges for example are interconnected with other objects – people, methods of use, and other devices that help read, process or disseminate the data they generate. Defining an object in terms of tangible dimensions often means defining what they are made of or what their constituent parts are. But where do boundaries lie around the component parts of a device? What counts as an object/device? What is included? Is the D-shuttle 'device' just the white radiation detector? Or should we also include the green lanyard which holds it around my neck or the reading component? Was I part of the device? What counts as a device or 'apparatus' is not always easy to define or even delineate (Barad, 2006).

Conversely, some objects have been productively defined by what they are not rather than what they are. For example, an absence of an emergency response is what defines waiting on standby (Deville, 2021) or a presence and then absence of alcohol dependency is what defines the object alcoholic liver disease (Law & Singleton, 2005). D-Shuttles and Glass Badges can tell us something about these absences and presences of radiation contamination in bodies, foodstuffs and in the environment. But their ways of working (e.g. different levels of detection sensitivity, differing abilities to provide data breakdowns over different time periods, different ways of accounting for location) means that they might say different things about where, when and what the absences and presences are.

Objects can also be considered in relation to the practices they are 'enacted' through (Woolgar & Lezaun, 2013), and potentially enacted *through them*. The term 'ontological politics' (Mol, 2000) has been used to describe the 'practices and processes by which entities are brought into being and sustained' (Woolgar, 2012: 53). For example, medical diseases as objects, such as atherosclerosis (Mol, 2002) and alcoholic liver disease (Law & Singleton, 2005) have been observed by STS scholars as being enacted in different ways in different medical settings and by different kinds of clinicians. Not only this, but that the objects are different depending on the ways they are enacted. Objects can 'inscribe social relations, record actions and materialise past practice' (Lorimer, 2010: 317). Objects require human practices and human practices require objects. Objects also require other objects to work, as infrastructures and as resources for example (Shove, 2016)

Objects can also be thought about in the context of what they do. Devices in particular – allow 'action at a distance' (Lorimer, 2010: 317). For example, the production of data about residents' doses generated by Glass Badges and D-Shuttles in theory at least allowed local municipalities, the prefectures or the national government to take action to address the potential for individual exposures through different kinds of radiation protection mechanisms. Objects can be treated as a particular kind of nonhuman actor, they have agency in the world and do work – in the case of personal dosimeters, they can inform decisions about where someone can live, how long they work in a given place and what activities they do there.

STS offers a number of potentially useful concepts for examining technical devices which incorporate a lot of the complexity I have started to unpack in the preceding paragraphs above. These concepts helped me think beyond the physical object immediately in front of me and its technical descriptions of functionality and dimensions, and to extend analysis out into a wider physical and social world.

I now highlight some key concepts in order to establish a way of working with devices of radiation knowledge production, which incorporate the complexity I observed in my data. Treating devices in this way underpins the kinds of questions that I go on to ask and introduces the sensibilities that I display in the rest of the thesis.

4.2.1 Networks and Actors

Actor-network theory (ANT) (Callon & Latour, 1981; Latour, 1993, 1996, 2005b; Law, 2003b; Mol & Law, 1994; Callon, 1986), introduced briefly in Chapter 3, is a useful way to start to engage more expansively with objects. ANT encourages the exploration of 'the strategic, relational, and productive character of particular, smaller-scale, heterogeneous actor networks' (Law, 2008: 145). ANT has been described as:

> [A] disparate family of material-semiotic tools, sensibilities, and methods of analysis that treat everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located. It assumes that nothing has reality or form outside the enactment of those relations. Its studies explore and characterize the webs and the practices that carry them. Like other material-semiotic approaches, the actor network approach thus describes the enactment of materially and discursively heterogeneous relations that produce and reshuffle all kinds of actors including objects, subjects, human beings, machines…...(Law, 2008: 141))

An object is an entity in a more or less stable network of things; it is the connections, interactions and relationships between the entities (objects) in a given domain which form the network. Engaging with radiation knowledge making objects such as a D-Shuttles and Glass, requires thinking about all of the other relevant entities (inside and outside the 'device') in the network– a resident, a pouch, a scientific survey, a scientist or doctor, protocols for when and how to wear the D-shuttle and when to give it back for processing, a reading device, a laptop, a space in which to communicate the results of the survey etc.

This project has ANT 'sensibilities' (Law, 2008: 141). At the heart of ANT is the idea that all entities – human or nonhuman – which might be relevant to a given context should be included in an analysis of it (Law & Singleton, 2005). ANT therefore suggests that grappling with how radiation measuring and monitoring devices do work in the world involves engaging with the entities that make up these devices (i.e. what are they actually formed of and by), as well as thinking about the networks that they are part of (i.e. other larger networks of practice and material devices). Each network of actors, when working together, can be considered its own 'actor' or thing held together. But this actor can also be broken down into sub-actors, or the actor might also be a part of another bigger network of things. The level at which analysis takes place impacts on what is in the network. Part of the challenge therefore is defining the boundary around the network being analysed. It is always possible to keep on extending things further and further, or breaking them down into smaller and smaller constituent parts. The different things that could be included as an object of analysis are potentially endless and the interest lies in the specific entities that come together at any one time and the ways that they relate together.

Figure 24: Some organisations found innovative ways to disseminate their data. Not only online, or verbally, but also via 'postcard news'. The organisation who produced this one about the rates of contamination in well-known brands of milk, had produced 83 of these and sent them to 500 people. They told me 'it's much more effective than the internet for transferring our ideas, so I like it.' (Fieldnotes, 18 July 2018).

John Law describes the characteristics of ANT as having:

> [S]emiotic relationality (it's a network whose elements define and shape one another), heterogeneity (there are different kinds of actors, human and otherwise), and materiality (stuff is there aplenty, not just "the social"). There is an insistence on process and its precariousness (all elements need to play their part moment by moment or it all comes unstuck). There is attention to power as an effect (it is a function of network configuration and in particular the creation of immutable mobiles), to space and to scale (how it is that networks extend themselves and translate distant actors). (Law, (2008: 146)

This is relevant to radiation knowledge production because it underlines the material as well as social aspects of devices. Objects (devices) are held together by the relationships between them. This holding together is however, 'precarious' and it can easily come 'unstuck'. There is also an element of power and social dynamics in the creation of networks (Foucault, 1979) and seemingly stable things in them. One of the consequences of more stable elements of the network is that they can travel to 'distant' places and 'extend themselves'.

This kind of ANT description of objects, actors and networks outlined above is aligned with what I could see in my data about D-Shuttles, Glass Badges and other the networks of radiation knowledge production. The object networks I was observing were at times unstable and precarious – they were subject to change. They exhibited multiplicity – the things that make up the objects I was observing were many and varied – it was not possible to examine one static thing, and finally they were relational – the different entities that formed part of the actor-networks shaped and were shaped by each other as they worked together. Having an ANT sensibility means I must therefore pay just as much attention to the human as nonhuman elements of my devices. It means treating human actors (actors) and nonhuman actors (actants) symmetrically, acknowledging concepts like big and small are relational effects, and that the social and the technical are embedded in one another (Law, 2008: 147).

4.2.2 Assemblages and Agencement

Two additional related terms – assemblage and agencement – work well alongside ANT networks and objects approaches to analysis of radiation measuring and monitoring devices in my data. This section elucidates these terms and uses them in relation to D-Shuttles and Glass Badges in order to demonstrate the non-permanence and precarity of the assemblage as well as provoking an interest in what the assemblage is doing when it is brought together.

First introduced by French philosophers Deleuze and Guattari, 'assemblage' has been summarised as 'a particular collection of objects, bodies, practices and affective relations through which this ordering takes place' (Lorimer, 2010: 317) and 'a mode of ordering heterogeneous entities so that they work together for a certain time' (Müller, 2015: 28). Assemblages are about the particular moment in time when a constellation of things comes together. This hints at precarity and the changing nature of such constellations and the relationships between their constituent parts.

Assemblages order the world, but they also have 'inertia' (Lorimer, 2015: 10). Inertia can suggest potential for staying still, for durability or for resistance to change. Actor networks and assemblages can linger in places and

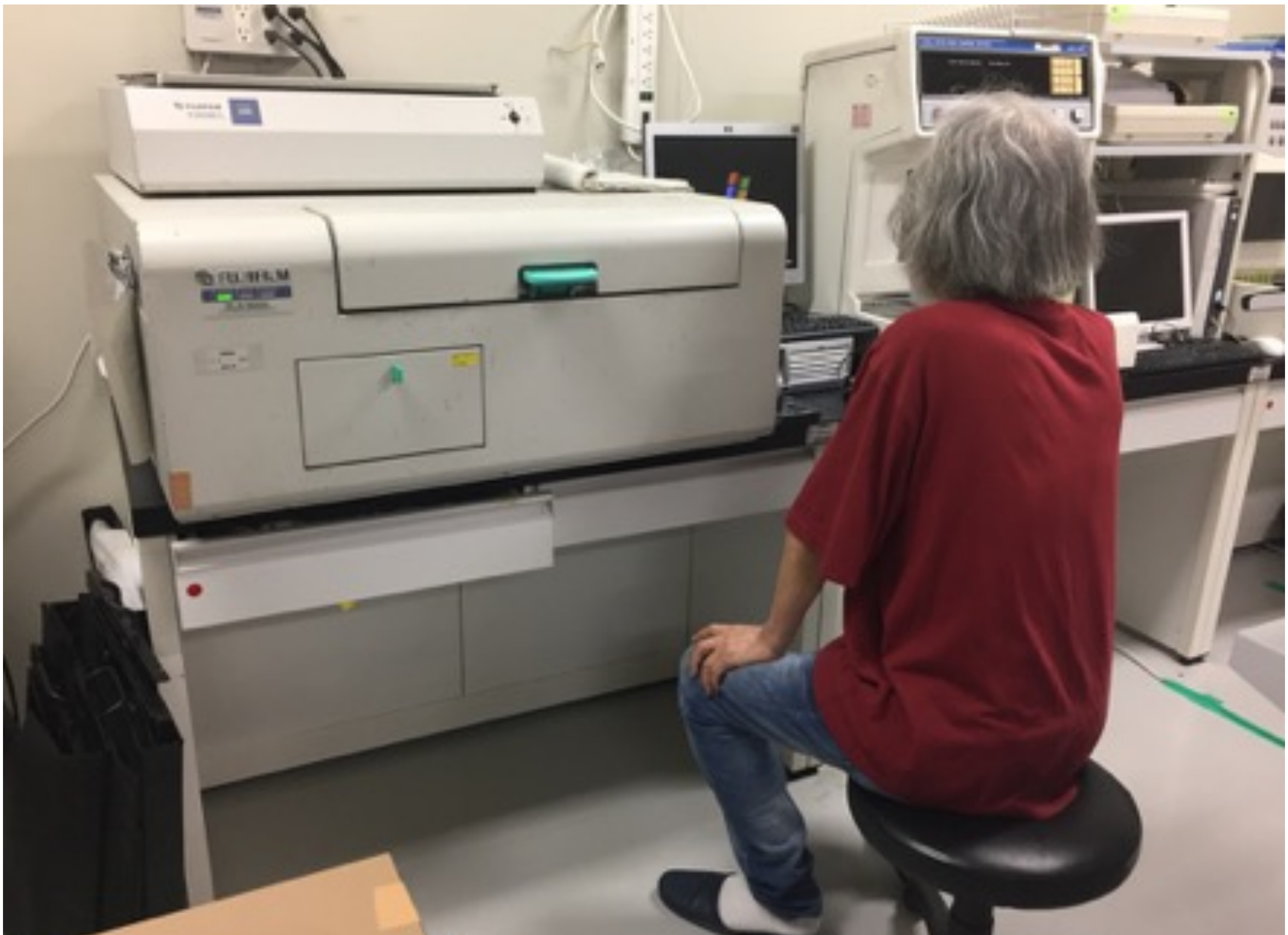

Figure 25: In a university laboratory, a scientist puts the plates into this machine to process images (a bit like an old photo printer) of a contaminated 'thing' using autoradiograph technology. This technique makes radiation visible without numbers.

in doing so order knowledge production over time. Parts of the assemblage can be a bit 'sticky' – the material elements of assemblages which are fossilised in technologies such as radiation monitors and written documents or legal instruments have a certain durability to them. The assemblage is never the same; it is always being made and remade. In this way, assemblages are also 'haunted by pasts, groove present practice, and serve to anticipate different futures' (Lorimer, 2015: 10). Today's contamination monitoring devices used in civilian settings to monitor uncontrolled releases of radiation in Fukushima are 'haunted' by devices and practices originating amongst devices and practices for keeping radiation workers, and not affected populations, safe. Before the disaster, the idea that there may be a need to distribute thousands of radiation monitors to civilian populations was not anticipated in IAEA or ICRP guidelines. Prior to D-shuttles being available, the Glass Badge assemblage which enabled the calculation of personal dose had gained relative stability, even in civilian settings even though it was not ideally suited to them. The development of the D-Shuttle destabilised the use of Glass Badges by municipalities after Fukushima because different bodies and ways of doing knowledge creation were incorporated into or expelled from the assemblage. Personal dosimeter assemblages groove present behaviours by shaping what individuals do and where they go, as well as contributing to people's understandings of what future exposures might look like. They also, then, have anticipatory potential.

In the original text, Deleuze and Guattari used the French word 'agencement', a synonym for 'arrangement', 'fitting', or 'fixing'. When first translated into English it became 'assemblage'. However, there are subtle tensions between 'assemblage' as a description of a final state, and 'agencement', which relates to the process of connecting together (Gharardi, 2016). Others continue to use 'assemblage' but acknowledge that this term conveys process and is therefore 'potentially unstable' (Lorimer, 2015:10) and that 'it operates not as a static term but as a process of putting together, of arranging and organising […] encounters and relations' (Dewsbury, 2011: 150). The dynamic aspect of assemblages, something that is 'becoming with' rather than static, has been highlighted by Haraway (2008) who also uses the idea of a knot (2003) to convey 'cohesion without a prior assumption of collective solidarity' (Gan & Tsing, 2018: 103). There are many similarities between working with assemblages (or agencement) and working with the concept of actor networks (Law, 2008). The takeaway about an *assemblage* however, is that it is less about fixed constituent parts, 'and more about what it can do, what it can affect and bring about' (Dewsbury, 2011:150).

The concept of an assemblage articulates 'the "stuff of politics": the material ecology of bodies, technologies, texts, and other materials through which knowledge is produced and ordering takes place' (Lorimer, 2015: 40). As I established above, the material elements of radiation measuring and monitoring devices are many and varied, and can comprise maps, scientific and technical instruments, soil, human bodies, animal bodies, vegetation, databases, diagrams, medical instruments, government policy documents, international conventions, standards, pens, phones, internet connections and more. If these are the 'stuff of politics' then it is important to investigate which things have power and agency to influence and govern what radiation knowledge production is doing (the kinds of questions it is answering), who it is doing it for and the order that is being created by these assemblages. If 'assemblages allow certain actors to speak for, commodify, govern, and thus shape the world, often in conflict with other representations' (Lorimer, 2015: 10), then what kinds of representations of radiation knowledge assert dominance, and in which kinds of locations, and which stakeholders are involved? Whether asserting dominance is the only potential outcome for multiple (potentially noncoherent) practices coming together is a question addressed in the Syncretism and (Non)Coherence chapter.

Using assemblages thinking alongside D-Shuttles highlights the dynamism in the technical tool. A D-Shuttle does not operate alone; it requires material objects (lanyards, computers, calibration machines, cables and readers etc.) and social/human elements (humans to wear the devices, scientists to read the devices, local governments to distribute the devices, instructions on the correct way to wear the devices etc.) to come together in specific places and times. Thinking about D-Shuttles and Glass Badges as assemblages requires paying attention to what the device is doing when these entities come together.

4.2.3 Devices – patterns and doings

Whilst the concepts of actor networks and assemblages provide ways of examining the tools radiation knowledge production in terms of their socio-materiality and dynamic constitution, neither addresses fully how to engage with what my devices (instruments, tools or apparatus) were *doing* in the world. Materiality implies that the physical properties of a device have consequences for how it is used (Schmid, 2019a). Devices are not just objects; devices are particular *kinds* of objects which *do* things. The purposeful nature of the doing is key to differentiating between just any kind of object and an instrument which has been 'designed in order to fulfil a predetermined general goal' (Stengers, 2011: 192). For example, in economic sociology market devices are 'devices that produce or 'render' markets through processes of attachment and detachment, entanglement and disentanglement' (McFall, 2009: 268). Specific groups of 'objects, devices, settings and materials acquire explicit political capacities' which 'enact material participation as a specific public form' (Marres & Lezaun, 2011:489), for example in relation to climate change (Marres, 2012). So, devices can do things like render markets and shape public participation. My empirical devices are *doing* measuring and monitoring radiation.

Devices are specific kinds of socio-material assemblages which make and do different things (Law & Ruppert, 2013). Socio-technical devices 'assemble and arrange the world in specific social and material patterns', they are 'patterned teleological arrangements' (Law & Ruppert 2013: 230). Anything that holds a group of things together coherently and even briefly is a 'patterned arrangement' (p232). The elements in these arrangements are many and varied, materially heterogeneous and could consist of a variety of bits of kit, people and inscriptions working together and doing things (p231). Law and Ruppert's 'devices' then align with ideas about assemblages and networks, but their specificity about devices being 'patterned teleological arrangement[s]' is particularly useful and worth exploring in more detail alongside my two examples.

The nature of the device articulated in the paragraph above fits the broader definition of 'assemblage' already discussed earlier in the chapter, but the patterning and doing of devices warrants further exploration. 'Patterned' suggests that devices are put together in a specific way including consistent themes and ideas – there is repetition in the arrangement, but there are also patterns in the ways that 'devices assemble and arrange the world' (Law & Ruppert, 2013: 230). However, rather than thinking of devices as 'perfectly crafted working arrangements', devices should be thought of as 'rough and ready assemblages' (p.232), implying an ad hoc throwing together of elements for the specific task at hand that might disperse at any moment. We are invited to trace 'the patterning of relations as these pass through –and order– different kinds of materials, human, social and otherwise' (p.231). This radically challenges us to focus not on the internal in/consistency of a material object, but on patterns of relationships between entities in the arrangement.

It is important to see where the patterns are and how they contribute to the coming together device. Finding different arrangements that do similar kinds of things is, therefore, as interesting as finding when the 'same' arrangement changes or does something new. For example, looking at the patterns across different assemblages that do individual dose calculation (not just D-Shuttles and Glass badges, environmental monitoring data and behaviour surveys), is just as interesting as thinking about the patterns and implications of a new version of the D-Shuttle being developed for astronauts in space (which is called the D-Space). Due to advances in technologies in the last few years, screens are no longer so draining on battery life and therefore screens are included on the D-Space directly. This in turn means that the smaller reader required for reading basic data collected by the D-Shuttle is not needed for the D-Space. Conversely the cost of each individual device has increased.

Devices are teleological, they 'do social work […] in patterned ways that are multiple and diverse' (Law & Ruppert, 2013: 230); that is, devices order and reorder things by feeding into diverse chains of action. Some scholars have argued that objects are designed things whose function is built into the object itself, embedding particular kinds of knowledge and jurisdictions over spaces, such as the workplace (Bechky, 2003). We are reminded of the influence on the tool of its user(s) and of the thing that is being 'done' by the tool –'a tool is never neutral. A tool can be passed from hand to hand, but each time the gesture of taking it in hand will be a particular one' (Stengers, 2005: 185). Looking at what devices do can tell us about embedded knowledges of both their designers and their users.

Advocates of technology as socially determined believe that '[w]hat matters is not the technology itself, but the social or economic system in which its embedded' (Winner, 1980: 122). However, a theory of technological politics 'takes artifacts seriously' and as such invites us to pay 'attention to the characteristics of technical objects and the meaning of those characteristics' (p123). Artifacts can have politics embedded in them in different ways. The way most pertinent to our discussion here is that the design or arrangement of a given artifact (or assemblage) can become 'a way of settling an issue in a particular community' (p123). In the context of thinking about the devices of scientific knowledge construction in emergencies, it is important to consider technologies are 'ways of building order' (p127), that have material durability. Our initial choices fix the materiality of the assemblage, and assemblages establish frameworks of public order (Winner, 1980).

Devices are influenced by and can exert influence on other actors, and they ‘embody both physical traits and shared meanings’ (Jarrahi & Sawyer, 2018:3). This embedded and embodied knowledge is the basis of relationships between actors in a network, in that the objects help actors to ascribe meaning and make sense of their surroundings (Jarrahi & Sawyer, 2018:3). ANT would assert of course that it is impossible to separate the object from the actor, the object *is* the actor network, but nonetheless, practices, knowledges and politics are embedded in devices. For example – the design of the D-Shuttle forces the user to continue to interact with a reading device to generate a reading and the manufacturer to replace the battery. The design of Glass Badges is embedded with assumptions about how (i.e. knowingly) and when (predominantly in controlled environments) human bodies interact with radioactive sources.

What a device is actually doing is not always obvious. The physical devices (Glass Badges and D-Shuttles) are part of assemblages *doing* a particular thing – they are creating particular kinds of knowledge about radiation. However, whilst some of the things that are being done by devices are relatively plain to see and are 'written on the package’ (Law & Ruppert, 2013: 230), devices are often doing additional things which might only be in small print on the box, or not even on the box at all. An analysis of devices might be minded to ‘go looking for agendas that are not obvious and that are nonetheless embedded in their practices’ (p230). Glass Badges and D-Shuttles are doing many other things in terms of ordering the world. They are creating relationships between residents, scientists and local governments, providing peace of mind, influencing future radiation protection concepts and more. These things are not necessarily ‘bad’, or rather the ability of ascribing a right or a wrong ‘doing’, but they are third order doings that might not be immediately obvious. Looking in more detail about what radiation knowledge producing devices are doing has the potential to highlight other undervalued, obscure or hidden work being done by these assemblages.

Whilst devices might do many things, multitask and enact multiple effects, these doings are not necessarily centrally coordinated (Foucault, 1979). There may be very limited intentionality and coherence behind devices and the work they do or how they are used. The fluid composition of the assemblage can complicate a designer’s ability to pre-determine how they are used in practice. One person pointed out to me the

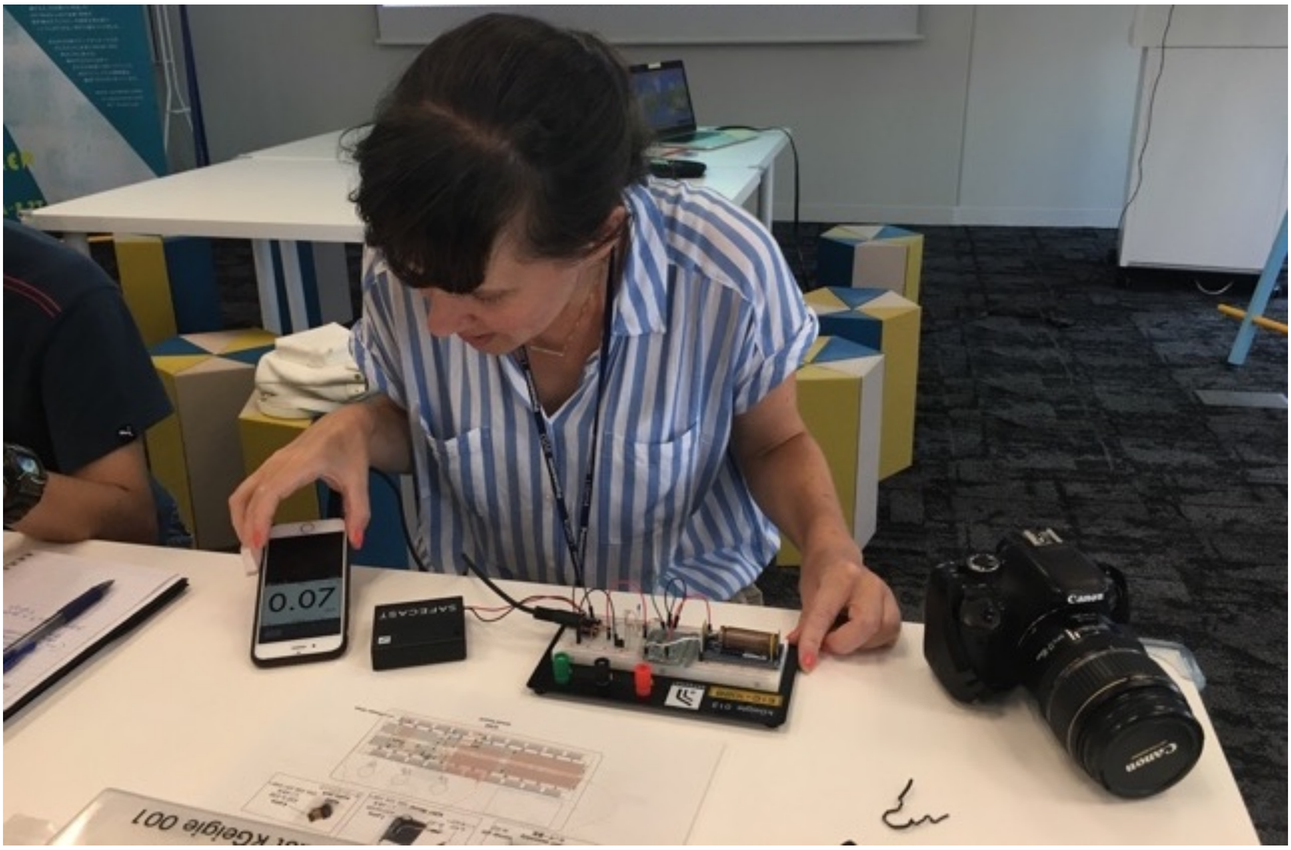

Figure 26: Learning how to make a simple radiation monitor that hooks up to my mobile phone to show the reading on my phone screen (August 2018). Am I part of the assemblage?

troublesome nature of some of the residents who had been allocated Glass Badges and were perhaps not using them in the manner the scientists approved of: 'Many people do not wear them [….] we do not know what people do with their glass badges – the mayor trusted people too much, but they are '*Mendokusai'* – farmers and children are *troublesome*!' (formal interview, 27 June 2019).

Troublesome farmers and children led to another entity entering the Glass Badge assemblage – detailed instructions were provided with the device for school children about when and where (not) to wear them. Rather than being 'perfectly crafted working arrangements', devices in practice are then 'messy patchworks or assemblages […] any claims of perfection by their authors need to be treated with a pinch of salt. They need to be understood as accounts of devices as they were conceived rather than practised' (Law & Ruppert, 2013: 232). The disjuncture between what is conceived and what happens in practice is highlighted neatly in this comment about Glass Badges:

> The [sponsor of] the D-shuttle project in Miyakoji, initially envisioned deriving the overall dose distribution by aggregating the participating residents' data. However, this plan to draw and publish dose distribution had to be dropped due to the small number of applicants and because many did not wear the D-shuttle during their daily activities, but chose to place the dosimeter in a certain location and measure the dose of the location. (Miyazaki, 2017: 114s)

So, the precise assemblage of the device is quite flexible or 'malleable' (Law & Ruppert, 2013: 235), undergoing constant tinkering as different entities enter or are ejected from the assemblage. In the case above the assemblage itself did not come together in the way that it had been envisioned: both the number of residents and their behaviours changed the outcome of the assemblage.

The boundaries that are set around devices, and which determine what is included and what is not, are 'an analytical and political matter' (Law & Ruppert, 2013: 233), and so investigating who is setting boundaries of radiation knowledge making assemblages and how these boundaries are being set offers a way of thinking about agency, power and governance in contamination events. The boundaries themselves are also inchoate, they are not permanent defences, but malleable and fluid. They are not the same all of the time, in all circumstances or indeed for all people. STS researchers have previously highlighted how scientific tools, as technical artifacts, are constructed and gain stability through specific scientific practices (Clarke & Fujimura, 1992), and that scientific information systems privilege specific perspectives and values (Bowker & Star, 1999). It follows, therefore, that epistemic groups will establish varied boundaries around their radiation measuring device depending on their questions, interests and agendas, and that the scientific tools they use to work with stabilise through practice and use. What counts as a valid part of the assemblage for a member of the public might vary considerably from what needs to be included or excluded from the perspective of scientists, who have particular cultures of knowing and doing that influence what they see as appropriate ways of constructing scientific facts (Latour & Woolgar, 1979). Some residents were said to have placed their D-Shuttles onto specific items or left them in specific places, because they were interested in radiation levels in those places (formal interview, 27 June 2019). This placement disrupted the ability of scientists to speak to the habits of the residents being monitored through the D-Shuttles. The scientists would have preferred these places to be left out of the assemblage as noted here because it conflicted with notions about proper ways of doing science:

> Many Date city residents who received glass badges did not wear them outdoors and simply sent them back to the local government office every 3 months after receiving replacements […] In other words, it is not known how many of those glass badges were never worn outside during those 3 months. (Tao et al., 2019: 161).

Having considered different social science approaches to defining and thinking about objects in general and devices in particular, I now take stock of how using these concepts could be beneficial when applied in greater detail to my case.

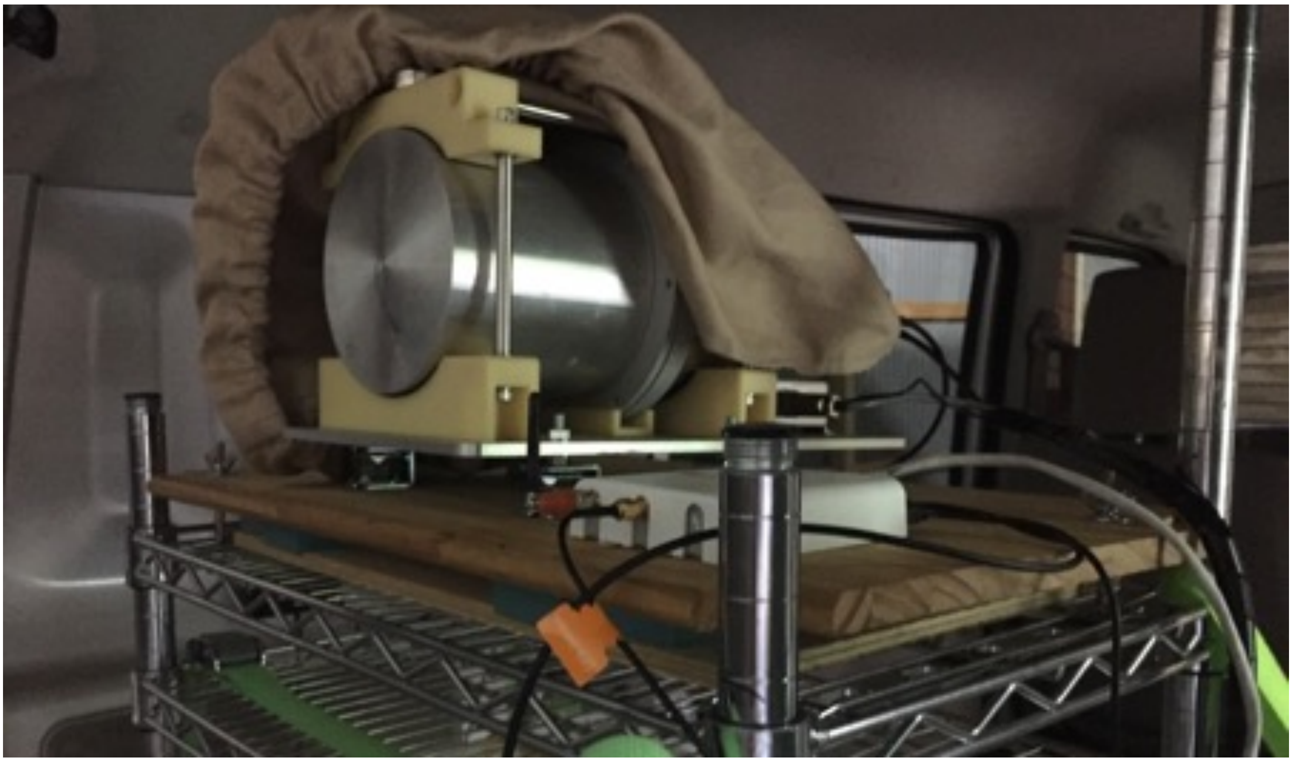

Figure 27: One village monitoring group used this monitoring device. It was installed in a shared van and the villagers took turns to drive around the village collecting data. The device was supplied by an organisation in Japan normally associated with high energy particle acceleration.

4.3 Conclusion

Investigating radiation measuring and monitoring tools as networks, assemblages and devices opens up lines of enquiry and sensibilities to issues which might be otherwise be overlooked in approaches to the analysis of radiation measuring and monitoring devices and practices based on technical specs. This is because using a networks, assemblages and devices approach:

- Holds the physical tool (the measuring device) as inseparable from the practices associated with it and through which it is enacted.
- Considers entities to be the effects of actor-networks and assemblages
- Considers what entities make up assemblages and how they relate to each other
- Prompts questions about the boundaries around devices (as patterned teleological arrangements) and who is making them and investigates the entities which are included and excluded from assemblage
- Asks who has influence over the assembly of assemblages and what agency different stakeholders have in influencing the assemblage and what it does
- Is interested in how assemblages change over time, how and when this happens
- Wants to know what the assemblages are doing, beyond the obvious
- Is curious about patterns in device assemblages
- Is interested in the spaces (both literal and figurative) that assemblages operate in

Putting my data from Japan into dialogue with the concept of radiation knowledge production as a device (a socio-material assemblage that is relational, multiple and that does things) in this broader sense is helpful. All aspects of radiation measuring and monitoring devices like D-Shuttles and Glass Badges become implicated when we start to examine the assemblage. Examining radiation measuring and monitoring devices in the context of being multiple, heterogeneous and relational is at odds with the kinds of technical descriptions of devices typically found in radiation protection, public health and emergency management narratives and planning documents. These tend to foreground technical accuracy, specific methods for use and functionality.

This ‘devices as assemblages’ positioning also supports my commitment to not privileging any one group or type of individual doing radiation monitoring. It also allows me to work through some of the human multiplicity within the assemblages of radiation knowledge production.

Giving consideration to radiation measuring and monitoring equipment and practices as socio-technical-material assemblages that do things (rather than just making radiation visible, measurable or knowable), provides a space to think more broadly about how we might engage with the tools and techniques of making contamination visible and monitorable in the aftermath of a contamination event. An ANT-sensitive/assemblage approach that acknowledges relations and practices helps one see how it is that we have come to have the devices and measuring and monitoring arrangement that exist. This can be useful for professionals, governments, planners, because it gives insight into how things have come to be. This can be used as explanation for what exists, but also can be used in a kind of future-looking orientation, by thinking ahead to how current assemblages may pan out in the future. Remembering that artifacts have politics (Winner, 1980), and that the future is always speculative, it may still be interesting to think about that kinds of pathways that may exist in a more purposeful manner.

Following these lines of enquiry leads to new questions about radiation knowledge producing assemblages, which could include: where are the boundaries created around radiation monitoring devices? Who is able to define boundaries, and compile or stabilise parts of the assemblages? How do the different entities in radiation knowledge producing assemblages (physical tools, distribution networks, academic practice, medical practice, thresholds and standards, and so on) relate to each other? What kinds of work are being done with the radiation knowledge producing assemblages? What kind of calculative work is being done through radiation knowledge producing assemblages? What part does time play in relation to the constitution of and enactment of radiation measuring monitoring? The rest of the empirical chapters take forward these concepts to address in more detail the questions that they prompt.

5 Comparisons

5.1 Introduction

At the end of a visit to the evacuated parts of Fukushima in 2019, I noted in my fieldnotes about being monitored as we left the bus for the final time having come out of the 'red zone', which was designated as most contaminated. The car park became a quasi-border crossing for people entering and exiting:

> The people monitoring our shoes and the bus wheels were also part of a performance designed to make us feel safe and to continue the functioning of the 'Red Zone' as a place of potential danger. When we had our shoe soles monitored, it became almost a game:
>
> > 'I got 71- what did you get?'
> >
> > 'I was 103!!'
> >
> > 'What do these numbers mean?'
> >
> > 'What do we do with this information?'
>
> Once we had all been monitored, we were told that if we had had over 13000 (no one mentioned what unit this was) we would have to take off our shoes. (Fieldnotes 17 April 2019)

The numbers provided us with information, but it was not clear what they meant ('what do these numbers mean?') or what we should do as a result ('what do we do with this information?'), before being informed that 13,000 was the point at which further action needed to be taken ('take off our shoes').

In Fukushima, radiation readings are displayed in numerous places in the tangible and digital worlds. Numbers and measurements are nonhuman parts of radiation knowledge making assemblages that make their way onto screens on the side of the highway, on the front of town halls, inside administrative buildings, in buses, and in public parks, and also into pamphlets, onto food labels, onto maps, tables and charts. Radiation's numbers are implicated in algorithms in devices, in data generation and visualisation, in thresholds and government policy. They also make it into acts of meaning making (Figure 31). Numbers *about* radiation permeate and influence the ways in which we come to understand what radiation *is*, how much there is out there and in us and what that means.

There are many ways in which I might have examined radiation's relationship to numbers and numbering. This chapter is rooted in a tradition of work on numbers and comparisons within social sciences (in particular STS) and is interested in how some numbers work in acts of comparison. Social scientists have in recent decades taken an interest in numbers and what they do in different circumstances. Underpinning many of these works are broad concerns about numbers' objectivity, ideals of quantification and statistics (Hacking, 1990), and their capacity for representing truth and generating power and trust (Porter, 1995). Others have taken these concerns further and raised questions about numerical accuracy and referentiality (MacKenzie, 1999), audit cultures (Power, 1997) or how equivalence is achieved – the sociology of quantification and commensuration (Espeland and Stevens, 1998, 2008). STS in particular has investigated the power and work of numbers in a diverse host of domains (Lippert & Verran, 2018) including education settings (Gorur, 2018; Holtrop, 2018), medical devices (Klausner, 2018), supermarkets (Lave, 1988; Cochoy, 2008), water (Verran, 2010, 2013) and in environmental politics and carbon accounting (Asdal, 2008, Lippert, 2018), to name but a few. The common ground for much of this work is to challenge 'the illusion that the world can be neutrally represented and accessed by measurement' (Holtrop, 2018: 77). This is of immense interest to me as a person with a professional interest in disaster and emergency management, given the prevalence of numbers, numbering and quantification in the field of radiation monitoring and other contamination events.

Figure 28: On leaving the bus at the end of our tour of the restricted parts of Fukushima, we were all monitored as we left the vehicle. What was a 'good number'? What was too high? What would happen if we had 'too much'?

I address comparisons and the numbers they are associated with specifically because they seemed from my conversations with participants to be a common and important way of making sense of the data they encountered or made themselves. Furthermore, comparisons appear to underpin nearly all meaning making about radiation in Fukushima; hearing phrases such as 'oh the levels are quite low here' or 'there's a hotspot over there' was very common during my fieldwork and were linked to decision making about what to eat, where to live and so on.

Social science discussions about comparisons emphasise different types of comparisons and how they might be constructed. This chapter engages specifically with the concept of *comparator,* both in the traditional sense of being a benchmark against which a case is contrasted, as well as the more recent contributions in the form of 'social science comparator' outlined by Deville, Guggenheim and Hrdličková (2016a). I first establish what both terms mean and how they relate to each other. I differentiate between the more traditional and the newer and more complex comparators, by calling the former 'benchmark-comparators' and the latter 'assemblage-comparators'. Assemblage-comparators are an example of a radiation knowledge making device and as such comprise various human and nonhuman entities. Continuing the notion of assemblages established in the previous chapter, this chapter examines nonhuman elements within, and also created by, assemblages making comparisons about radiation.

This chapter provides an initial response to two research questions which will continue to be answered in chapter 6: 'What kinds of calculative work takes place in creating radiation knowledge?' and 'How and when do radiation knowledge assemblages produce knowledge and meaning from radiation data?' I work with the concept of assemblage-comparators and the *assembling the comparator process* offered by Deville et al. to show that examining the construction of cases for comparison is crucial in accounting for the work that thresholds and standards do within comparative acts. I use this insight to examine one well-known example

(0.23μSv/hr) to show how it came to be and why it provokes and interferes in understandings about radiation in the way that it does. This example demonstrates how thresholds have an active and stabilising part to play in comparisons and knowledge making, acting concurrently as both as benchmark-comparators and as assemblage-comparators. I begin my analysis by setting out some of the key tensions and challenges in research about acts of comparison, before unpicking the concept of comparators in more detail.

5.1.1 STS and comparisons

Comparison can be viewed as the practice of 'bringing material together and putting it in conversation' (Deville et al., 2016a: 106). Comparison is active; STS has demonstrated the creativity and liveliness present in comparing, an activity involving many human and nonhuman parts that come together in an assemblage that creates a comparison. The dynamic act of bringing together things which might otherwise not be related has been referred to by Stengers and Verran as 'comparison as participant' (Verran, 2011, Stengers, 2011) and Verran makes the case for 'the liveliness of comparison as itself a participant in collective action' (2011: 64). Comparison is a socio-material act, involving 'a range of actors (human and nonhuman), practices, and tools' (Deville et al. 2016b: 19). This means that comparison shares many of the same features highlighted in my earlier chapter on assemblages and devices.

Comparative cases are the entities that are put into relation with each other in the comparison. Making comparative cases involves boundary making (Gieryn, 1983, 1999) – defining implicitly or explicitly what is included or excluded from the things being put into relation with each other. The process of constructing comparative cases involves defining how the two cases relate, the common qualities in the things that are being compared, 'common causal mechanisms or common events' (Steinmetz, 2004: 390). This establishes commensurability between the cases (Steinmetz, 2004). Commensuration is 'the translation of different qualities into the same metric' and it is critical to how we 'make sense of the world' (Espeland & Stevens, 1998: 314). Comparison is about establishing similarity whilst looking for difference. The person (or as we shall see, socio-material assemblage) that is doing the comparison between cases does so on the basis that they share common traits on one level, whilst anticipating that there is a potential for difference on others. The act of putting cases into comparisons with each other therefore already establishes a relationship between them.

Comparison as a *scientific method* has been the subject of much debate in the latter part of the twentieth century regarding its suitability as a tool for social scientific endeavours, and what forms of comparison might be considered legitimate (Krause, 2016). Initially conceived in the social sciences as a means to aid scientific rigour in line with the natural sciences, comparisons were thought to be an excellent mechanism by which to highlight similarities and differences (Deville et al., 2016a: 20). However, comparison as method began to be criticised for its links to colonialism and othering, particularly in anthropology, a concern which extended into other disciplines in the 1980s. At that time various challenges unsettled the stability of claims that comparison was a suitable method for representing social life in social science research. Comparisons don't just happen, they are constructed. Feminist, post-colonialist, STS researchers argued that it was simply not possible to compare things meaningfully, because of the settings in which the comparisons were generated (Strathern, 1988), because of the relationships between the researcher and their subject matter, and the fact that the researcher is never a neutral tool – their work is situated and they have values and biases (Haraway, 1988). There were questions about whether it was even possible to make certain research entities commensurate to enable comparison (Jensen, 2020, Steinmetz, 2004). There remain concerns about whether analytical concepts can truly be extracted from empirical settings and the extent to which comparison is reductionist (Robinson, 2016). Despite the challenges associated with comparison in the latter twentieth century, there have been recent moves in STS to re-engage with comparison as a social science research method in a pragmatic way by acknowledging the criticisms of comparison as a tool, without entirely dismissing it outright as a valuable research method if approached reflexively (Deville et al. 2016c; Scheffer & Niewöhner 2010; McFarlane & Robinson, 2012). For example, Tim Choy's (2011) work on environmental activism in late 1990s postcolonial Hong Kong, is itself an 'ethnography of comparison', working to establish how activists, policy makers, scientists and laypeople make connections with each other, specifically by *comparing comparisons* (Rademacher, 2013: 682).

Comparisons are said to be 'omnipresent and inevitable' in all social science research (Deville et al., 2016a: 100), which makes it unsurprising to have noted acts of comparison in my data about radiation's numbers and to engage in my own acts of comparison as a method of analysis. I am however, most interested in focusing on analysing acts of comparison as found *in* my ethnographic data. I noticed people making comparisons and using comparison to make meaning out of radiation's numbers. Rather than using comparison as a tool for interpreting my data, I use STS tools to examine what is going on in these acts of comparing. Empirical STS work on comparison has focused on comparison in medical settings (Mol, 2002), amongst scientists (Knorr Cetina, 1999; Stengers, 2011) and also in social scientific STS work itself (Deville et al., 2016), to name but a few. Mol's work is particularly useful here in that she examines specific situations in which comparisons are made and looks at the consequences of comparative work. Tim Choy's (2011) and Casper Brun Jensen's (2020) work on ecologies of comparison, are useful because they evoke a sense that any single act of comparison is operating amongst a wider ecology of other acts of comparison and other calculative acts created by assemblages. They all relate to and are informed by one another.

Sticking with my commitment to avoid reaffirming dichotomies between professional or lay expertise, I am more interested how comparisons are being made and what this construction involves in terms of resources and its constituent parts, than I am about any one group of people doing comparison. Tracing the resources and constituent parts of comparisons (assemblages) is useful because the entities that make it into or are excluded from comparative assemblages influences meanings made from the comparison. As I develop in my later chapter on qualculations, the assemblages of radiation knowledge production include many different human and nonhuman actors, therefore it was not necessary to try to identify whether one kind of actor made specific kinds of comparisons. As a result I do not limit myself to one kind of person uttering a comparison - scientist, mother, citizen scientist, nuclear activist - nor are the comparisons in my data limited to those generated by academic research projects. I am interested instead in the assemblages of comparison. How do these nonhuman devices come to be, how do they work in practice and what are consequences of that work?

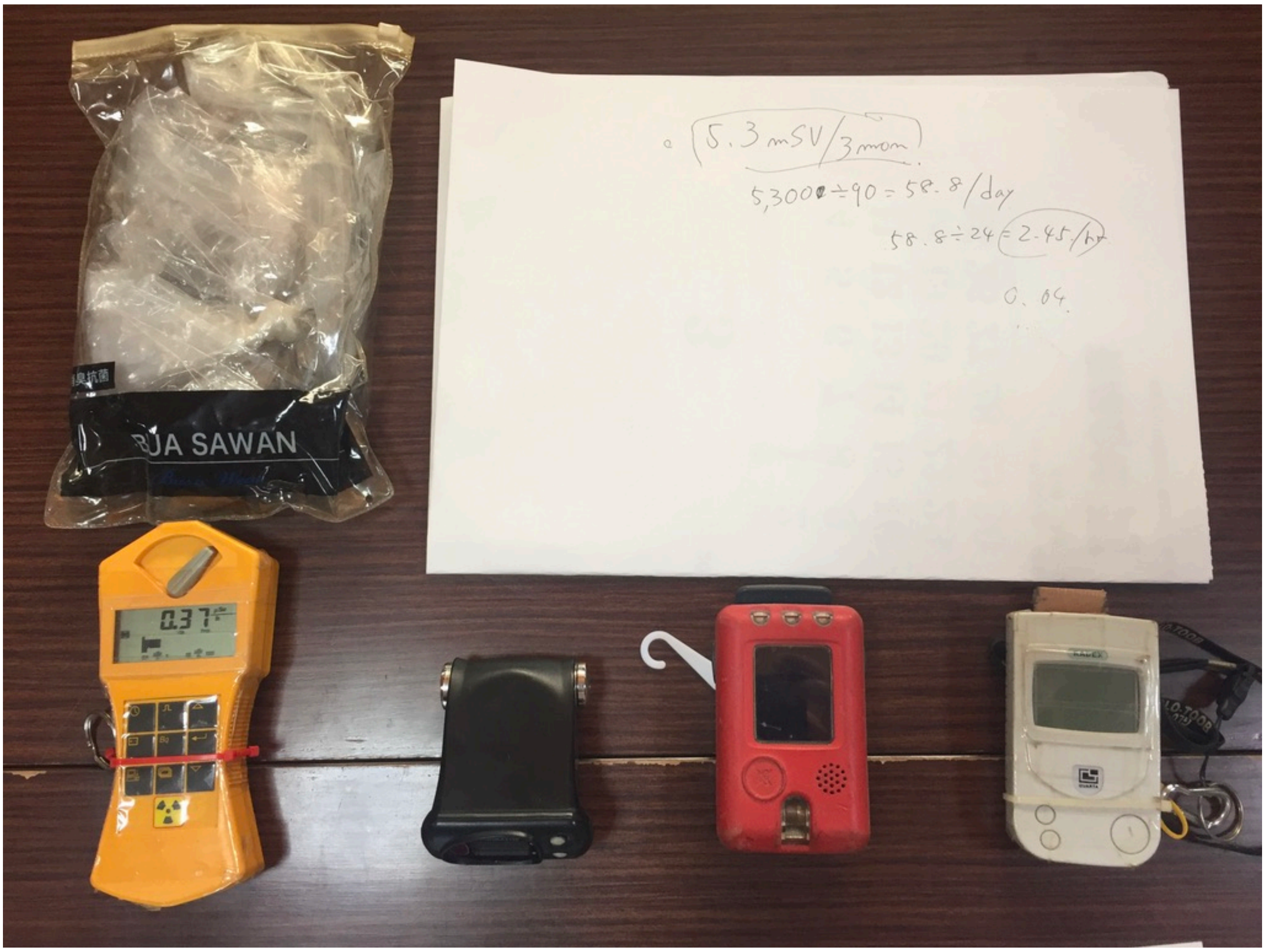

Figure 29: One of my participants had multiple hand-held monitors that he loaned out to friends and family. He had been monitoring radiation since the accident in Chornobyl. He showed me his own calculation for an acceptable limit - not 0.23 (see section 5.2).

5.1.2 Comparators

Social science has offered various names for different kinds of comparisons and comparators. Monika Krause, for example, offers for example the *asymmetrical comparison* in which the comparative cases are not equally attended to, the *hypothetical comparison* in which comparative cases exist only theoretically or are imaginary, and the *undigested comparison* in which the comparison does not fully 'assimilate' into 'the author's conceptual framework' (Krause, 2016: 61). Deville et al. describe comparisons that they find in their data as *circulating comparisons, field comparisons* or *found comparisons* (2016b). A subtly different version of '*field'* comparisons are '*existing'* comparisons. These are 'comparisons that are made not by scholars in the interests of generating analytical or conceptual insights, or deepening their understanding of a situation, but 'found' comparisons, in the field' (Robinson, 2016: 315). The examples of comparisons I am working with mostly closely align to this kind of description. However, my focus is on the devices of radiation knowledge making. I am therefore more interested in the makers and making of comparisons than on the kinds of comparisons being made. Deville et al. (2016b) offer a productive way of engaging with what and how comparisons are brought purposefully into conversation in a *constructed* manner, continuing the idea of a device being an assemblage that does something. I now examine the notion of a comparator to show how I can put this into use in relation to radiation knowledge making.

A traditional comparator is commonly understood as something against which something else is compared – I will refer to this as a ***benchmark-comparator***. If someone were to say that their son was tall for his age, the comparator could be a generalised idea of or specific notion of the standard height for a boy of that age. They might use a medical chart with a range of average heights for given ages or reference the heights of other boys in their son's class or in their family at that age. The choice of comparator (a chart of representative statistics, a reference group of boys now, or a reference group of historical boys in the family) is the guide used to determine whether the parents judge that their son is tall for his age. A comparator in this sense is a benchmark which has 'the quality of being both *fixed and known* that allows the act of comparison to take place' (Deville et al., 2016a, italics in original). As I shall demonstrate, comparators operating as benchmarks are constituted with varying degrees of *fixed-ness* and *known-ness*.

In their work on comparing comparisons, Deville et al. offer another version of a comparator as a means to talk about the assemblage that is *doing* comparison. They use their own research, a multi-year comparative research project comparing emergency preparedness activity in three different nation states, as an example of such a comparator. Their 'social science' comparator is 'not a single thing, but an assemblage of researchers, funders, and research technologies – including entities such as databases and software, legal regulations and theories, and methods' (p. 101). They take inspiration from an electronic component called a comparator, which actively arbitrates in the comparisons that it makes by 'provoke[ing] relations between previously uncompared inputs' (p. 100). This second kind of comparator – which I shall refer to as an ***assemblage-comparator –*** intervenes in the comparisons that it helps create but is also affected by the world around it. As with any assemblage, the makeup of any assemblage-comparator can be heterogeneous, very complex and subject to change.

In my own data, it was clear then that radiation monitoring devices are material nonhuman entities within assemblages doing comparison. An example of this is found in Figure 31. The first image is of a fixed radiation monitoring post in a public park in Iwaki City in Fukushima. This post is actively embroiled in comparison. Not far from it is a sign (in the second photo), produced by the local municipality, which includes a map of the park. The right side of the sign includes hand drawn reading from the five monitoring posts inside the park grounds, taken at different times. Together, the park-user, sign and monitoring post become part of an assemblage comparator, making comparisons about radiation levels in the park. It should also be noted here, that providing this kind of additional information was not common. Most fixed radiation monitoring posts, as is visible in many of the photos included in this thesis, stand in relative isolation. If there *is* another post nearby, it is likely to be obsolete, not working and therefore not able to provide a point of comparison so easily.

Figure 31: Most fixed radiation monitoring posts are just 'there', but this one in Iwaki City in Fukushima also comes with additional information about other nearby posts and also historical readings that facilitate comparison (August 2018)

Deville et al. distinguish instead between two kinds of assemblage-comparators. They contrast their own *social science* assemblage-comparator, which is primarily used to create comparisons in order to understand differences between cases, with field comparisons from within their ethnographic data. They suggest that assemblage-comparators of field comparisons are distinctly different from those creating comparisons in social science projects. Conversely, field comparators, 'often have a transparent political agenda' (Deville et al., 2016: 121). Whilst social science comparators are cumbersome and laboriously constructed, field comparators are agile; 'mobile, adaptable, and quick' (p. 125), operating with 'minimal justifications invoking norms of empirical proof and theoretical rigour' (p. 121). The social science comparator must conform to various forms of specialist ethnographic and academic standards and justifications. Human actors in field comparators are untroubled by needing 'to read extensive amounts of background literature' and are not required 'to justify what their *tertium comparationis* [common ground for comparison between cases] is, nor to write a research proposal that justifies why a comparison makes sense' (p. 121). Field comparators need not rely upon 'troublesome' academic infrastructure, invoking instead 'any comparison they like, often without the need to justify it or to calibrate a comparator first' (ibid.). Rather than ascribing the same amount of attention to describing each case and explaining the similarities and difference from a *seemingly* neutral position as a researcher, Deville et al. found that their field comparators employed a relatively simplistic form of comparison frequently creating binary judgements –better/worse, yes/no, higher/lower etc. Field comparators might be more likely than social science comparators to produce 'asymmetrical comparisons' (Krause, 2016: 58), because they take their own case 'as fully known and understood, while the other [case] provides a standard to enable the comparator to make a judgement against it – based on a simple set of assessments' (Deville et al., 2016: 121).

The field comparisons I found in my data were at times agile, adaptable and quick, but elsewhere had taken time to develop (even if quick to deploy) and they could be just as complex as those made in social science projects. I suggest therefore that both kinds of comparator are assembled according to the same process, and also that there are a number of characteristics by which that construction of comparators might be described. The analysis by Deville et al. falls short of explicitly stating that whilst all comparators might be assembled using the same process, the characteristics and boundaries around what is in/out of the assemblage, the speed with which it can be brought together, the forms of justification it requires and the audience for the comparisons being constructed might all but subtly or drastically different. Whilst they imply this, I would like to be explicit that this is the position I take.

The infrastructures, justification, norms and rigour that each assemblage works towards might be different, but they are still observable. As I will demonstrate in the following sections, the comparators I encountered in the field did rely on infrastructures, their cases were justifiable, and they were invoking norms of rigour. I assert that there are multiple, perhaps indefinite combinations of comparator-assemblages which might come together to do comparison, and that it should be possible to apply the same kinds of reasoning to all kinds of comparators. It is unnecessary and unhelpful for my analysis to try to sort comparators out into specific types. This is because my own 'existing' comparisons were located in conversations, in academic reports, in presentations, in pamphlets and so on. Trying to categorise the assemblage-comparators that produced them would draw boundaries around different kinds of human actors in those assemblages, based on who they are [in the

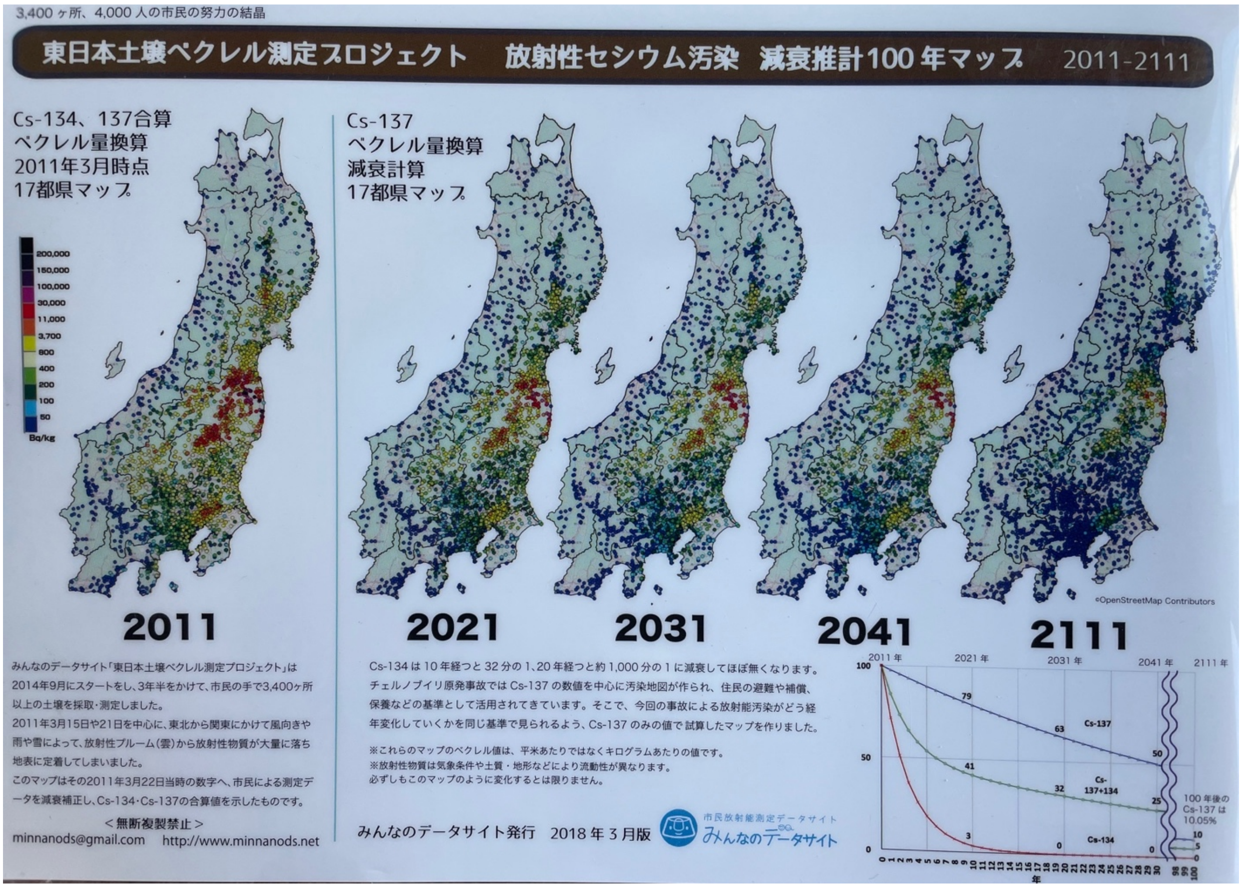

Figure 32 Some field comparisons in my data were verbal, others were more visual. Here a citizen radiation monitoring group has modelled the rate of contamination in soil, based on their collated measurements from across Japan. They show 2011 in comparison to projected future years

following Qualculations chapter I show that what they do in the device is more important]. Taking all assemblage-comparators as being heterogeneous draws attention to other ways of examining them without reinforcing and reproducing boundaries around lay and expert knowledge. One way is to look at how comparative cases in my data to pay close attention to how they are constructed and where patterns in that construction arise.

5.1.3 Assembling radiation knowledge comparators

The process for ***assembling the [assemblage-]comparator,*** includes gathering together the different parts of the comparator, giving it data and things to incorporate into the comparison (*feeding the comparator*), and finally calibration – the 'ongoing mutual adjustment – of each, to each other, as well as to our technologies, and our research objects' (Deville et al., 2016: 108). Because comparison is about putting different entities into relation with each other, calibration allows the comparator 'to be able to comparatively connect research entities that it was not able to connect before' (ibid). This interpretation of a comparator adheres to the notion of *lateral* comparisons, in which comparisons found in ethnographic data are treated symmetrically alongside and inform the very comparisons found in 'academic, practice and policy domains' (Gad & Jensen, 2016: 190).

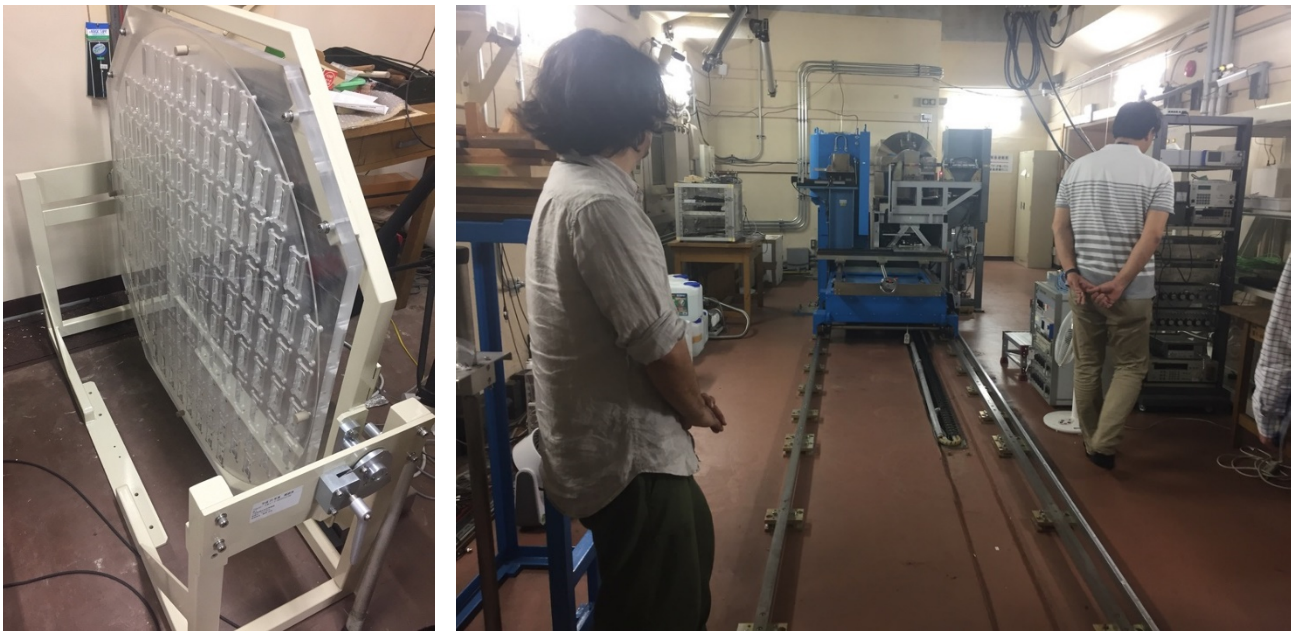

Figure 33: At a national institute in Japan, two different pieces of equipment are used to calibrate radiation monitors. (r) The extremely radioactive 'source' inside the shielded blue housing is used to direct a known amount of radiation from a specific distance which is adjusted by rolling it forwards or backwards along the rails. (l) A custom-made piece of equipment which can hold multiple D-Shuttles at one time at a defined distance from the source.

Taking seriously the idea of an assemblage-comparator means acknowledging that where they exist, benchmark-comparators (e.g. a specific kind of comparative case which acts as a known and fixed yardstick for judgement) are also part of the wider assemblage-comparator. This is means that some special cases can be ***both*** benchmark-comparator ***and*** part of the assemblage-comparator. Before I demonstrate the implications of this double work using a very specific benchmark-comparator, I need to show how comparative cases (which do not work as fixed and known benchmarks) are constructed by an assemblage-comparator.

A critical part of assembling the comparator involves the comparators' choices about how to frame, define and otherwise bound the cases they are putting into relation with each other. In my data I determined that this framing and defining for radiation-related comparisons centres on establishing the common grounds between the cases based often on three aspects. Commensurability between cases involves explaining the main entity being compared (measured) directly, along with location and temporal aspects. Consider the following conversation with a 'local mediator' about a presentation slide, which included a table of data about levels of contamination in spinach in different locations:

> Participant B: [A]t that time our government provided so many data, but without visualisation, it was very difficult for the people to acquire real situation.
>
> Participant A: So [participant B] was trying to get official data and to make it useable by the public to help them make decisions.
>
> Participant B: Yes. So officially maybe local businesspeople in Tamura City decided to stay here by seeing this data at that time.

LE: And how did you choose spinach? Why spinach and not carrots?

Participant B: Because he believes that spinach should be [a] representative vegetable. It is representative because at that time, spinach was the focus by many people because there was the news in Chiba Prefecture, where very high concentrations in spinach were found at that time. By seeing this chart people notice that the situation changed – at least in terms of spinach.

LE: And are these different…what are these things down the side [of the table]? Are they locations?

Participant B: Yes, locations

LE: And they are the same, always the same order?

Participant B: Yes. So, trend data, so people can compare. (Formal interview, 16 July 2018),

The entity being measured might be a physically tangible item such as soil, a human body, or urine, or it might be the somewhat more nebulous such as ambient air.In this example, spinach is the focus and it seems to act as a stand in for all kinds of vegetables that one might conceivably grow at home and which might be contaminated with radionuclides. It is given as a 'representative vegetable' through which comparisons and therefore decisions about radiation levels might be made on behalf of other unspecified vegetables or foodstuffs which have not made it into the table. Spinach is determined to be the most suitable stand-in because of particular concerns about radiation levels in spinach that were circulating in the news at the time. Spinach therefore had meaning for the people who might be working with that data. Time and place are also present, albeit receding into the background a little. Spinach, a stand-in for other potentially contaminated foods in Tamura City in Fukushima, is put into relation with spinach from other locations listed on the table, such as Chiba Prefecture. Time is brought in by the repeated act of comparison and the repeated production of the tables, and it is through this that 'trends' appear. These kinds of comparative tables help people 'make [official data] useable' and to help members of the public 'make a decision'.

This kind of comparative case construction (placing data about spinach from different locations next to each other on a table) brings the comparative measurements literally together into one place (as opposed to their original geographic locations) and puts them into conversation with each other. Residents watching the presentation and receiving this information might either be given a judgement about what this means for spinach in general, or they could potentially put the table of data in conversation with their own spinach measurement data. Noting this potential for residents to act with the data in the table to make their own comparisons reminds us that the assemblage is never fixed – residents (humans) and their own data (nonhumans) can be added to the assemblage. The table is a nonhuman element of the comparator, doing work to establish the boundaries and details of the comparative cases. This is another point about comparative cases that don't operate as benchmarks – they need time and effort to set out. It is also useful to note that no single case is special amongst the data set of locations and spinaches – they are treated equally in the table. It is hard to imagine any single measurement being so memorable that it is used without explanation in other comparisons, except perhaps for spinach in Chiba which had received a lot of attention in the media due to high levels of contamination found in test samples (Hey, 2011). For non-benchmark cases, we need to be reminded about the basis and boundaries of the comparison every time and no single case is particularly important.

Although often commensurability between cases was established through careful description or depiction of the case, including details about the entity, location and temporal aspects, did not always happen. I found many other examples in my data in which the producer or verbaliser of the comparison relied on particular benchmark cases which required or were offered alongside very little additional explanation. The use of well-known benchmark cases meant that comparisons could be deployed with relative speed and ease, with only minimal additional information at the time. It is tempting to think therefore that they operate in the manner of the 'field comparisons' observed by Deville et al, for example in use by Japanese disaster management professionals. Deville et al. observed that these field comparisons 'operate with minimal justifications invoking norms of empirical proof and theoretical rigour' (2016b: 121). I establish in the following section how it is that benchmark cases are able to do this, and the alternative forms of proof, rigour and justification that they might demonstrate instead. I also demonstrate the benefits of using such benchmark cases as a means of explaining their prevalence in my data.

5.2 Thresholds in comparison

In social science comparative research, the cases being compared are often described symmetrically (Deville et al. 2016), in that meaning is made about both cases when they are put into relation with one another. Elsewhere, meaning is made about Case A, because it is put into relation with a fixed and stable Case B, a benchmark, which appears to be static. Thresholds and standards are typical benchmarks – they operate in comparisons as a stand-in case, a stand-in comparator. My argument is that thresholds and standards function as benchmark-comparators by providing apparently simple and stable cases that can be easily used in comparisons. Other comparative cases have to be crafted and carefully explained on every occasion in order to give meaning to the comparison they are part of. However, the readiness and simplicity suggested by standards and thresholds obscure their complexity. Standards and thresholds may not be as simple, stable or fixed as they first suggest.

In this section I look at how thresholds and standards function in acts of comparison. I begin by examining how they work by appearing 'fixed' and 'stable' and find that *fixedness* and *stability* is not a permanent feature across thresholds and standards at all times. I then examine one iconic threshold which is used in Japan and use this to demonstrate how thresholds function simultaneously as calibrating parts of the assemblage-comparator alongside their dual-function as a benchmark-comparator. This observation is used to explain the ubiquitous use of one well known threshold, 0.23µsv/hr, which I found in my ethnographic data from Fukushima.

5.2.1 Thresholds and comparators

I begin with an example from my data. In this example I observe that in order to make a judgement about the radiological contamination in different kinds of plants and what that means, I needed a fixed point of departure and that the baseline I chose to base my judgement on altered the judgements I was likely to make.

In 2018 I walked around a farm in Iitate village with three scientists and a husband and wife, Mr and Mrs Fujiwara, who cultivated the land. As we walked around the farm Mrs Fujiwara talked to me about the vegetables she was growing and their different relationships to radiation over the years. We first came across mountain hosta:

> The plants are very healthy looking and about 3 times the size of hostas that slugs love to eat in the UK. I had never realised that humans can eat them too. We snap off stalks and eat them raw whilst going about our science business; monitoring. Later on, over lunch Mrs Fujiwara produces a jar of pickled hosta, which we try with our meal. They are ND [Not Detected], she tells me. They always have been, even in 2011. The ferns next to the hostas on the other hand were around 3500 Bq/Kg in 2011 but have gone down to about 20Bq/Kg now. (Fieldnotes, 16 May 2019)

In this example, I am part of the comparator, along with my notebook, my camera and my research questions amongst other things. Mrs Fujiwara is feeding my physical body literally with pickled hostas, and my assemblage-comparator figuratively with data about hostas. In this example however, unlike the spinach that was 'representative' of other kinds of vegetables to the people of Tamara City, my understanding about hostas was only of limited and very specific value in relation to other hostas or other vegetables. These hostas were not a representative vegetable (like the spinach we encountered in section 5.1.3) for other vegetables on the farm, because the level of contamination they contained varied so much depending on where in the farm they grew. I could not transfer understanding about one kind of vegetable to other vegetables growing in the same space or the same kind of vegetable growing nearby. My understanding of the radiological situation at the farm was being calibrated according to which species of plants growing on the farm I took into consideration (hostas, ferns or wild garlic), which bit of the plant I measured (some plants store radiation in particular parts such as the seeds, roots or leaves) and where on the farm I looked for data. Some cases therefore do not easily translate as useful cases for comparison elsewhere. Some cases have only very specific comparative value in the comparison they are drawn into.

Other cases can be applied to multiple comparisons. Knowing that the hostas that we were eating were ND (Not Detected) is a good illustration. ND was a common inscription that could be seen or heard in reference to measurements relating to vegetables, bodies and soil etc. In those conversations and tables of data ND represented a notion of *low*, *minimal* or even *no* contamination found. But it is more flexible than that. ND actually means that the level of contamination in the pickles was *below the detection limit of the device doing the measuring*. The device could not detect any contamination, rather than there was no contamination to detect. Not only does ND not mean zero contamination, the specific level of where ND sits also depends on the sensitivity of the device being used. Although ND suggests something that is fixed, its stability is difficult to pin down in anything except a rough sense of *not much contamination*. ND works as a stable but also flexible benchmark-comparator.

As a human part of an assemblage-comparator, I incorporated the nonhuman government threshold for food contamination into the assemblage and used it to calibrate my comparison. In the first year after the disaster, the threshold for contamination in food was set at 200Bq/Kg for water and dairy products or 500Bq/Kg for other foodstuffs such as vegetables, grains and meats etc. (CAA –Government of Japan, 2013). Then, in April 2012 this was reduced to 100Bq/Kg for most general foods and even lower for drinking water, infant food and milk. Therefore, when the current threshold came in April 2012, Mrs Fujiwara's ferns would have gone overnight from being 7 times the limit to 35 times the limit. Food that measured 400Bq/Kg went overnight from being safe/consumable/sellable to being dangerous/unfit for consumption/contaminated. It is understandable therefore that changes to policy thresholds can disorientate meaning-makers by changing the ground beneath their feet, because the stability of the comparative device has been shaken. Some standards and thresholds therefore can be fixed, but not stable benchmark-comparators.

Thresholds function to calibrate the assemblage-comparator::

> This is the data from 1990s – before the incident. […W]e get the result of the rice, which is 5Bq. Which is under the standard which is 100Bq. However, compared to the data from 1990, this says 0.03, if you compare to decades before the incident, it is much much higher. So we provide this kind of information. […] This clinic cannot judge if it is safe or not. Because it depends on the people's age and situation since the disaster. We provide this kind of information to help this kind of decision making. (Formal interview, 8 August 2018)

In this example, the speaker references a standard (100 Becquerels per kilogram – a limit for contamination in food), against which the 5Bq (per Kg) measurement appears to register as 'safe' to the comparator – in this case members of the public, the clinic staff who measure the rice, the various funding streams and processes in the clinic etc. The speaker then offers a second comparison which instead contrasts the 5Bq against the levels of contamination in rice in 1990. The inference is that, if viewed relative to current food safety standards, the rice would effectively be OK to eat, but if looked at relative to previous historical results, before there was an obvious hazard, then the level of contamination in the rice is not acceptable. They then distance the clinic from making a statement about whether either comparator renders the 5Bq/Kg in the rice safe or not, because the context of the individual's wider life situation must be considered. The assemblage-comparator is calibrating itself. This quote shows that how and which comparative cases are constructed influences how the comparison might be 'read' or understood by the individual engaging with it. It also underscores how active the assemblage-comparator is in pulling together the different parts of the cases in relation to one another. Citizens visiting a radiation monitoring clinic might simultaneously understand the rice to be safe because it is below a recognised standard, unsafe because it is still higher than it was before the disaster, or either safe or not safe depending on other external factors not accounted for in the comparison. Thresholds can therefore sometimes be used to calibrate how an assemblage-comparator does comparison. For example, there is less work to be done to know what 5Bq/Kg means, if you know that that is lower than 100Bq/Kg, the point at which food is not saleable for consumption.

5.2.2 Common thresholds in use in Fukushima

Having shown some of the work that thresholds are doing in comparisons I set out more explicitly some of the common thresholds that emerged in my own data about Fukushima. This demonstrates that although the specific example examined in detail below is perhaps the most frequently heard (0.23μSv/hr), other thresholds are circulating and doing the same kind of work.

Many thresholds circulate in Fukushima in relation to radiation; Table 6 on the next page highlights those most frequently found in my data. There are many other locally specific and personally defined thresholds also in place (Elstow, 2022: 51-54), however I have concentrated on those which are enshrined in law, public policy or international convention. Each of these thresholds has a story to tell in terms of why it has been set at that particular level, who was involved in the setting of the threshold, when the threshold came into effect and how its boundaries are defined. Thinking back to the idea of 'field comparators', the politics of which were highlighted by Deville et al. (2016a), such histories are of interest because they point to a particular kind of political motivation behind many institutionalised thresholds that might be present only in specific circumstances, and which might be lost as the threshold is adopted into different comparators assemblages over time. In addition, some thresholds are calibrated and constructed in relation to each other – as in the relationship between 1mSv/year, 100Bq/Kg and 0.23μSv/hr.

The origins of established legal limits for food would be worthy of further inspection, given the complex arrangement of national and international organisations involved in establishing them (see table below). However, I now focus my attention on 0.23μSv/hr, which has an equally if not more interesting background. It was one of the most commonly used thresholds in the comparisons that I investigated. I will now explain its origins and how it first emerged as a policy tool in decontamination practice, before weighing up the kind of work that thresholds might be doing in comparisons and the potential logic for this.

Figure 34: Thresholds are critical not only for determining whether something is categorised as needing contamination, but they also determine who is responsible for decontamination activity, how the waste is processed and where the waste eventually ends up.

Category Category	Threshold	Set by	Other notes
Annual additional effective dose for members of the public	1mSv/year under normal circumstances 20mSv/year in emergency conditions	ICRP Publication 60, 1990, and supported by Publications 109 and 111[20].	Although this threshold guides many other thresholds, it is an international recommendation only. Countries are at liberty to establish their own limits. Radiation workers are not included - they have higher limits.
Drinking Water Baby food and milk General food stuffs	10Bq/Kg 50Bq/Kg 100Bq/Kg	Enshrined in law: Food Safety Basic Act and Food Sanitation Act. Food Safety Commission of Japan, in coordination with Codex Alimentarius Commission [CAC] (a joint organization of the World Health Organization [WHO] and the Food and Agriculture Organization of the United Nations [FAO]), which establishes international food standards on the basis of the view of the International Commission on Radiological Protection (ICRP). (CAA – Government of Japan, 2013). 'Japanese maximum permissible levels of radiocesium in food (JMLs), an index for taking measures were set in consideration of the released radionuclides, aligning with the [CAC]'s 1 mSv/year intervention exemption level' (MAFF – Government of Japan, 2022: 4)	The current limits for radioactive caesium were set so that radiation dose from food is not to exceed 1 mSv (millisievert) annually. And that this would relate to no more than 100mSv lifelong additional effective dose. Provisional limits established initially (from 17 March 2011 until 1 April 2012) for radioactive caesium where actually much higher (i.e. not as restrictive) –500Bq/Kg for most food, 200Bq/Kg for water, milk and dairy products.
Contaminated waste	Below 8000bq/kg	Enshrined in law: The Act on Special Measures Concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the NPS Accident Associated with the Tohoku District-Off the Pacific Ocean Earthquake that Occurred off the Pacific Coast of the Tohoku Region on March 11, 2011. Effective January 2012.	Designation as suitable for processing under Waste Management and Public Cleansing Law –essentially 'not contaminated waste' This threshold also links back to 1mSv/yr (Nagasaki, 2015: 299)
Decontaminatio n zones	0.23μSv/hr which is taken to equate to 1 to 20 mSv/year as stipulated in the Act.	Enshrined in law as with 'contaminated waste' above. Methods described MoE – Government of Japan Decontamination Guidelines (2nd Edition) (2013).	See explanation below for more detail on this.

Table 6: Table of thresholds relating to radiation commonly found in post Fukushima Japan

[20] Both 109 and 111 were part of a consultation in 2019. The draft noted that 'Levels should be within or below the Commission's recommended 1–20-mSv band taking into account the actual distribution of doses in the population and the tolerability of risk for the long-lasting existing exposure situations, and would not generally need to exceed 10 mSv per year' (ICRP, 2019: 4). The wording of this was softened when the final version of the new publication 146 was released in 2020: 'For the long-term phase, the reference level should be selected in the lower half of the recommended band of 1–20 mSv per year for existing exposure situations, taking into account the actual distribution of doses in the population and the societal, environmental, and economic factors influencing the exposure situation' (ICRP, 2020: 16).

5.2.3 Constructing 0.23µSv/hr

In August 2012 the Act on Special Measures[21] was introduced by the Japanese Ministry of Environment (MoE) as a major legal instrument to manage the consequences of the nuclear disaster. The MoE aimed to establish the long-term goal of decontamination to be the reduction of contamination levels maintaining an additional annual dose of no more than 1mSv as recommended under the ICRP guidelines (ICRP, 1990). According to the Japanese decontamination guidelines: 'any area where the radiation dose is 0.23µSv/hour or higher [is designated] as an "intensive contamination survey area." […]If the results of such investigation and measurement, etc. show that the area has a radiation dose of 0.23µSv/hour or higher, such area shall be designated as a decontamination zone subject to a decontamination plan.' (MoE – Government of Japan, 2013: 1-3). Ostensibly then, 0.23µSv/hr was a device to categorise decontamination area status. However, decontamination teams used it to determine if decontamination work was needed in the first place and, once decontaminated, whether additional rounds were required to bring radiation levels down further. Although MoE documents also point out that '0.23µSv/h is not the decontamination target, but designation criteria for the ICSA' (MoE – Government of Japan, 2018: 3), in an everyday practical sense, that is exactly what it became – the yardstick by which decontamination was determined to be completed or outstanding.

The next section asks how the threshold for decontamination activities came to be set at 0.23µSv/hr, given that the Japanese Government was aiming for something that would result in no more than 1mSv per year additional dose, in line with the ICRP recommendations. How *did* 1mSv/yr (this is the same as 1000µSv per year), become 0.23µSv per hour? One way of calculating an hourly threshold would be by dividing 1mSv by the number of hours in a year (8760 hours –24 x 365). Doing so shows a much lower hourly rate however, 0.11µSv/hr.

A simple hourly rate calculation

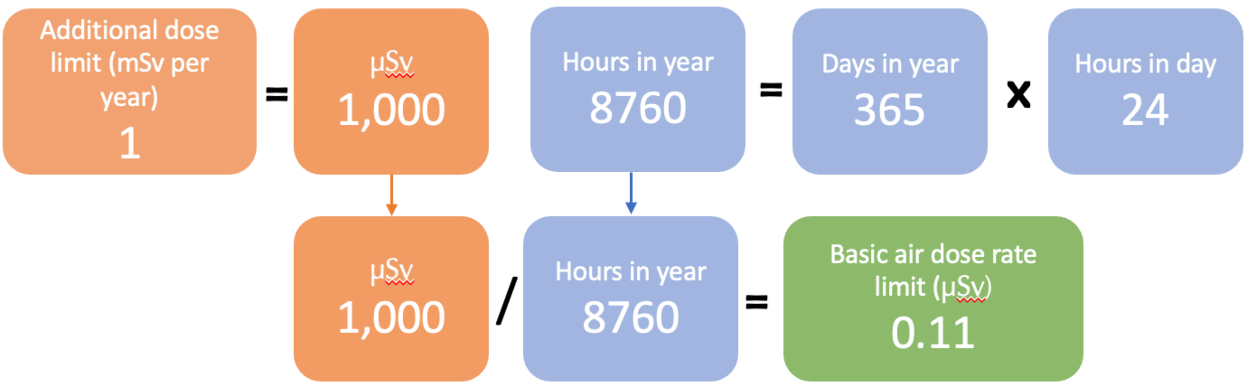

Figure 35: A simple hourly rate calculation

Conversely, multiplying the hourly threshold set by the MoE – 0.23µSv by 8760 hours generates an annual figure of just below 2015µSv (which is just over 2mSv per year). Using this kind of calculation suggests the Japanese method clearly exceeds the 1mSv threshold established under the IRCP recommendations and takes a bit more explaining to understand. One organisation to point this out specifically has been Greenpeace who provide their readings relative to both 0.23 and 0.11.

> [T]he Japanese government calculation […] assumes that citizens spend an average of 8 hours per day outside and takes account of shielding from radiation while inside a wooden house. This is considered a likely underestimate due to many citizens in rural areas spending more than 8 hours per day outside. [Our] Greenpeace calculation of annual human dose rates [is] based on radiation measurements taken at 1 meter, and represent an adult's exposure over one full year (a total of 8,760 hours) at that specific location. (Greenpeace, 2021: 14 An example of both thresholds is included on p21.)

[21] Formally known as The Act on Special Measures Concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District-Off the Pacific Ocean Earthquake That Occurred on March 11, 2011.

The next few paragraphs unpick the gap between 0.11 and 0.23, by first looking how background radiation is accounted for in the calculation, then addressing the other assumptions within the MoE calculation and what is involved in constructing the threshold. A similar and even more complex calculation was created when the Government decided that a 20mSv/yr threshold was an appropriate tool for determining whether or not to (re)open schools in Fukushima in April 2011 (see Appendix E: The calculation behind the threshold set for the reopening of schools in Fukushima). For more information see MoE, Government of Japan (2011).

The MoE methodology for 1mSv per year uses a constant assumed natural background rate of radiation as 0.04μSv/hr, based on an average 0.37mSv per year terrestrial dose (background radiation levels from natural ground-based sources such as granite bedrock) for all parts of Fukushima.

How 0.37mSv per year becomes an hourly rate of 0.04μSv:

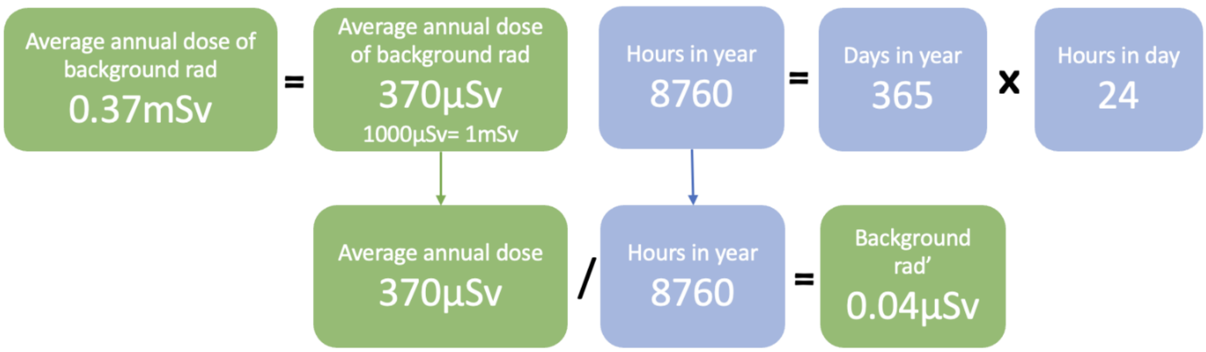

Figure 36: How 0.37mSv per year becomes an hourly rate of 0.04μSv

Natural background radiation varies according to location and therefore setting the rate as a constant across the affected area may over or under-account for the local specifics. It is not uncommon for devices to be calibrated to 'ignore' background radiation when producing readings, however the choice of what is a suitable background allowance is down to the individual organisation and I have noted differences. For example, the Glass Badge manufactured by Chiyoda Technol Corp. that I introduced in Chapter 4 subtracts 0.54 mSv/year from any readings produced. This figure was generated by averaging the 'values of the 20 Glass Badges with a 35 days measurement time placed at Oarai, Ibaraki Prefecture, Japan, before the disaster' (Tsubokura et al., 2015: 5/10)[22]. My first point here is that background radiation levels are not a given, they are chosen and incorporated (or not) into the assemblage. Linked to this is my second observation, that background radiation can be embedded in the physical device or in calculations, but sometimes it is not acknowledged at all in either – background radiation is still radiation after all.

Two further factors are embedded in the remaining 0.19μSv/hr (0.23μSv minus background radiation –0.04μSv). These two factors are based around an assumption that an individual would not be outside being fully exposed to the radiation all of the time. The MoE calculation assumes that an average person spends 8 hours outside every day and that for the remaining 16 hours a day, they would be inside a building, and that the building would provide 40% shielding from the radiation outside.

[22] The choice of Orai, Ibaraki Prefecture seems somewhat obscure unless you take into account this was probably for pragmatic reasons given it is where Chiyoda Technol is based, and the Glass Badge was designed well before the 2011 disasters.

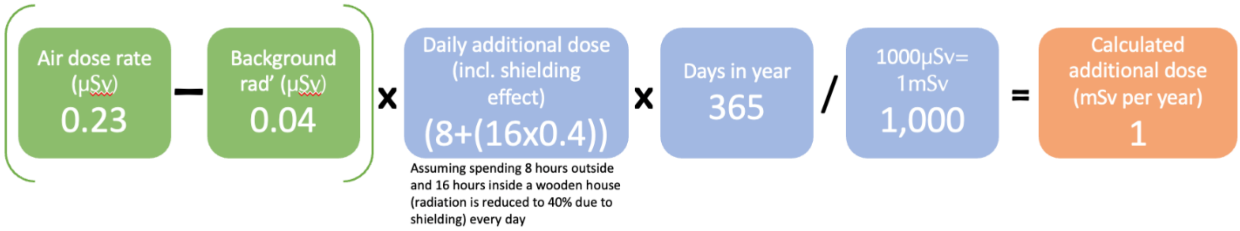

Figure 37: Calculation for 0.23 including assumptions, figure adapted from Naito & Uesaka (2017)

When added together over the course of the year, this assumed behaviour would elicit no more than the 1mSv annual effective dose as recommended by the ICRP based on the following calculation.

My intention is not to defend or challenge the suitability of the 0.23μSv/hr as a threshold, but rather to highlight the complexity present in what seems like a simple, albeit quite specific (to two decimal places) numerical threshold. In arriving at this calculation, the MoE are simultaneously alluding to an internationally recognised threshold, whilst maintaining a threshold twice what it might have been otherwise. This is relevant to thinking not only about what goes into an assemblage-social science comparator (the assemblage is 'shifted' to use Deville et al.'s terminology by international conventions and decontamination practices), but also seems to align to potential political motivations of Deville et al.'s 'field comparator'. The immediate consequence of this manoeuvre, purely from a decontamination perspective is to reduce both the area of land categorised as requiring decontamination, and the impact of that work economically, temporally and financially. I will not dwell on this given that the focus of this chapter is on how this threshold is co-opted into comparisons outside decontamination and why that might be.

In choosing 0.23μSv/hr as representative of an annual 1mSv dose, the MoE ossify certain assumptions about the way people might live in Fukushima, which are not universally applicable. For example, many people in Fukushima are farmers and are likely to spend over 8 hours outside every day, particularly in the Spring, Summer and Winter months where there is a lot of work to be done (Greenpeace, 2021). Another aspect that has been challenged is whether a typical building in Fukushima actually affords 40% shielding (Greenpeace, 2021) and whether shielding applies uniformly for the 16 hours spent indoors, given the construction methods in Japan in rural areas involve wooden buildings as well as concrete construction. Rarely are these assumptions (or the potential variation in different assumption options, such as why choose 40% shielding and not a higher or lower rate) made obvious when 0.23 is deployed.

The calculation solidifies a single notion of how residents in Fukushima live. When 0.23μSv/h (often shortened to just '0.23') is brought into a comparison as a benchmark-comparator, it might not always act as a suitable stand-in for how individuals live all the time. A family for example may choose to avoid going to visit their grandparent's farm for the weekend because the area around the farm exceeds 0.23μSv/hr. It is a matter of personal judgement whether this is the right decision or not, however, 0.23 does not necessarily represent their anticipated dose throughout the year and is arguably an inappropriate benchmark for judgement. For the same grandparents who might be working in those fields, 0.23 might more closely represent their way of living in that farm. Because benchmark-comparators are included in infinite complex assemblages making comparisons, there is no fixed mechanism for determining the judgement they arrive at. Ambiguity and ambivalence are therefore an interesting outcome of assemblages.

It is easy to say that the threshold was never designed to be used at an individual level, it was designed to assist in the designation of categories for decontamination. This logic applies if the threshold is only used to make judgements in the context of decontamination work. However, my own data showed that 0.23 was used as a generic rule of thumb by which to designate an area as being safe or not safe to be in for any length of time. How else were people expected to make sense of the ambient dose rates shown on screens on buses, written on signs or displayed on fixed radiation monitoring posts?

The extension of 0.23 into other areas of life was acknowledged by two scientists from the Japan Atomic Energy Agency (JAEA) when I spoke with them in Tokyo in 2018.

Participant A: So this 20mSv was […] a very conservative assumption or assignment for the basis of the evacuation order area. […] But another standard is the 1mSv. If it exceeds 1mSv then they cannot return home, but the evacuation order can be lifted [if the levels are] less than 20mSv. So there is a big gap between the two numbers. And based on such a simple assumption, 16 hours and 8 hours, then it corresponds to 0.23mSv per hour, which corresponds to 1mSv per year. People believe this value. But the regulatory authorities think that individual dose should be used for people to decide this decision.

Participant B: Anyway, the assumption that 0.23mSv per year corresponds to 1msv per year, is too conservative as a result. Actually, if the radiation level is around 0.2mSv the received dose is much smaller than 1mSv. So I must say, I cannot say that the decision was properly carried out. We could not help that because we did not have enough knowledge at the time. […]The number 0.23 made very significant effect for people. Maybe they have considered and even now many people consider 0.23 corresponds to 1mSv, so if there is any area around their houses that is higher than 0.23 then they are considering its very dangerous, but it is not really…..1mSv is not enough, how can I say……

He points me towards a JAEA report (Miyahara et al., 2015: 38), from which I read out: "It is emphasised that 1mSv per year is not derived as a clear distinction between safe and dangerous or that it will be achieved only by decontamination. It is a reference level to effectively implement protection actions." (Formal interview, 27 July 2018).

The two individuals deemed the calculations to be far too 'conservative' and were keen to distinguish between the threshold as it was intended for use (by government officials to designate areas to be subject to decontamination plans) in contrast to how the number was being used elsewhere (e.g. in daily decision making by citizens). As it transpired, personal dose surveys and individual dose monitoring did subsequently appear to show that a 0.23μSv/hr exposure rate was unlikely to generate an individual dose anywhere near 1mSv per year dose rates (Tsubokura, 2015) and so 0.23μSv/hr was perhaps conservative.

So, what might be the benefit of building these kinds of assumptions into the threshold calculation? Yes, the process makes the calculation more complicated, but it is also doing something else which is quite important at a governance level. By choosing a more complex calculation, which built in various assumptions about the living habits and background radiation present in Fukushima, the MoE were able to meet the threshold set by the ICRP –1mSv per year, but is also more than the hourly rate suggested by a simple calculation (e.g. 0.11μSv/hr). A lower threshold would have increased the total area to be decontaminated, and for each region meeting the designation, additional decontamination work would be needed to bring levels down to threshold. This highlights that there was work and effort in putting together the assemblage-comparator in order for it to be deployed. The assemblage also needed to be calibrated in order for the benchmark-comparator to align with political aims and limits. In the following paragraphs I provide further examples of how the threshold was used in conversational practice to show how thresholds function and add value in acts of comparison.

5.2.4 0.23μSv/hr in comparisons

When I first arrived in Japan and was trying to get to terms with different monitoring systems and the groups, technologies and methods associated with them, I did not fully understand the significance of 0.23μSv/hr, but it came up time and again in conversations with nuclear research institutions, academic scientists, citizens and government officials. It is a very specific comparator that has emerged from the situated response to the radiological situation in Japan and which has come to be applied to all kinds of situations, not just those involving decontamination by government workers. In addition, it is constructed as a result of policy and therefore is not arbitrary, or given by nature; this level was chosen and is enshrined in law.

I heard 0.23μSv/hr creep into everyday use in acts of comparison as a model benchmark-comparator outside the realms of decontamination activity. The following two excerpts typify how 0.23μSv/hr (or often shortened to simply, '0.23') was used in conversation:

Member of a citizen radiation monitoring group: But the 0.23 has become a bible – it has become a fear line. And it's really interesting when you spend time with people and local people, and [there is] quite a variety in terms of how much they know about the measurement and how active they are. We'll see many people, it'll be like 0.3, and they'll say, "Oh wow! Its high!" …..[And I'll think]

Yeah – it's high for <u>you</u>! Higher than they want to live in. And I can totally accept that. But high compared to what? You know? (Fieldnotes, 16 July 2018)

Participant (Municipality decontamination official): [T]here are still some citizens who are still really worried about contamination. […S]ometimes we receive this kind of phone call from the citizens. Our staff visit them to do monitoring. […] They show the number to the person and they explain about the number too..

LE: How do they do this?

Participant: So we have different spots for measuring and we provide the results of the spot.

LE: And how does that help explain?

Participant: We just show them a number…Do you mean telling them whether the number is high or low?

LE: Well, […] they rang you and you can give them a number, but they might not understand what that means.

Participant: So, they know the number – the standard of decontamination, like 0.23μSv, so if it is lower than that number they can feel safe.

LE: Is it normally the case that they don't know the number and that is why they are worried? Or they know the number but they have a problem with 0.23?

Participant: Because they don't know the rate of the air dose. So most of the citizens –we think that most of the citizens know the number 0.23, so for the citizens who feel anxiety, they do not know the rate of their house. So they feel anxious. (Formal interview, 8 August 2018)

In the first example, the speaker highlights that knowing how to respond to a radiation measurement is an act of judgement. In order to 'know' that radiation levels are 'high' one has to already have a stand-in for what high might mean. '0.23' became one particular benchmark for 'high' in Fukushima. Being concerned in Fukushima frequently boiled down to being worried if something was above 0.23, rather than needing to hold multiple different points of comparison. It became a kind of heuristic for being concerned or not, a shorthand, whilst also subtly hiding the complexity of the calculation that underpins its generation. He suggests that 0.23[μSv/hr] has become that byword, that 'bible' by which the judgement is made, rather than by comparing the measurement to another case in time and place. The speaker also draws attention to the fact that the people using 0.23 had varying degrees of knowledge and understanding about radiation. From our conversations I knew that some of the people he was referring to could be considered very well read on the subject of radiation monitoring.

In the second example above, the officials' position that if a citizen's own number is lower than 0.23, they only have to know 0.23 in order to feel relaxed. For these government officials, the presence of the threshold 0.23 negates the need to further explain whether the reading is high or low – the citizens do that work themselves and they can feel 'safe' for themselves. But this is only if those residents have the same view of 0.23 as the officials. In my data, this idea of 'lower than 0.23 is safe' was a common one, however it not universal amongst the individuals I spoke to. Somewhere along the way, in the minds of *some* government officials and *some* residents, 0.23 has become synonymous with the concept of safety. It has become iconic, a fixed marker between safety or danger, anchored around a constant entity, rather than just another number or just another measurement. This is exemplified by the fact that many people using it frequently omitted the [superfluous] unit of measurement, because there were no other 0.23s to confuse it with.

0.23 also links the relatively near future (a reading by the hour) to the medium-term future (a measurement for the year). This is because MoE's decontamination protocols which are provided in measurements by the hour (0.23μSv/hr) are linked to the ICRP recommended maximum annual effective dose, which is provided in measurements by the year (1mSv/yr). Using 0.23μSv/hr puts the measurement in question in relation to an annual figure, a forward look, a projection into a 'safer' future implied by following an international standard. Using the threshold could be a way for some comparators to actively link government policy in Japan (the establishment of 0.23μSv/hr for decontamination work), directly to international guidelines for radiological protection set by the ICRP and established outside Japan..

5.3 Discussion

Thresholds therefore do different kinds of work in any given comparison. Thresholds can function as a ready-made off-the-shelf case against which another case can be compared. Thresholds can also act to calibrate the social-science-comparator by influencing the assemblage constructing the comparison. Thinking through how thresholds work helps explain why I heard 0.23 in conversation so frequently, and why it had become so iconic.

First of all, thresholds and standards are known ready-made cases that require little further explanation for why they are being used. Their usefulness has already been established over a period of time and is justified in places like government policy and guidance documents. They are easily understood within the assemblage-comparator, because they act as a ready-made benchmark. Every time 0.23 is used as a benchmark-comparator, the assemblage-comparator is recalibrated, and the usefulness of 0.23 is reinforced, making it a more attractive benchmark in future comparisons.

Secondly, thresholds and standards are easy to deploy, despite the complexity of their construction. Beckoning a threshold into a comparison is relatively simple. The iconic simplicity of stating '0.23', '100Bq' or 'ND' avoids needing to explain the complexity of their histories and how they came to be set at those levels. The complexity of benchmark-comparators is masked, making them easy to use by assemblage-comparators. Some assemblage-comparators may make explicit the complexity behind the threshold, others may not. Thresholds therefore hold an amount of elasticity in how they might be used in comparisons, depending on the assemblage-comparator.

Finally, thresholds and standards provide stability and durability for judgements made on the basis of comparisons they are employed in. Durability can be described as material, in that 'some materials last longer than others' (Law, 2008:148). The material physical elements of 0.23μSv/hr are provided by guidance documents and measuring devices machines that support decontamination plan deployment and which will remain long after the threshold is no longer used to assign decontamination plan responsibilities to different government bodies. Of course, this material durability does not reside in the materials themselves but is the result of webs of socio-material things coming together. The physical embodiment of 0.23 is present in plans, in designations, in decontamination practices etc. The decontamination guidance which establishes 0.23 also works to provide '*strategic durability'* (Law, 2008: 148) – the same calculation and threshold was being used across all parts of Japan affected by contamination to designate decontamination responsibilities. Using 0.23 across all the affected parts of Japan meant that it provided strategic durability to judgements based on comparisons with 0.23. Comparing radiation levels to 0.23 was just as effective in Iitate village as it was in Namie village or Koriyama City. The strategic durability held across time as well. 0.23μSv/hr for example has been a constant since it was adopted in 2012. As a result, 0.23μSv/hr is easier for the assemblage-comparator to remember and incorporate, in contrast to needing to know local background radiation rates in different villages in Fukushima, or elsewhere in the world, if another comparative case were used. Benchmark-comparisons used time and again are more likely to produce the same outcome, e.g. they make the comparative act repeatable and reproducible.

These findings support and provide an explanation for several observations made by the Radiation Council of Japan (2018) about the various standards imposed in Japan for radiation protection purposes. Namely, that:

> [N]umerical values were used beyond the originally intended use of them. (p. 2).
>
> [A] situation has occurred as "Use of the criteria can go around independently out of context", that is, only the numerical values are spread widely without proper understanding of their backgrounds and meanings. (p. 3)
>
> In some cases, the meaning or the position of the numerical standards has not been properly conveyed. (p.3)

The wording of the Radiation Council document suggests the use of such thresholds can (or at least ought to) be tightly controlled in ways which fit specific 'proper' ways of doing things. My data shows this mode of thinking is perhaps flawed because once 'released' thresholds have agency of their own and are active nonhuman agents within infinite diverse and uncoordinated assemblages.

Figure 38: An artist works with a physicist to make autoradiographs of things he or others have sourced from contaminated places in Fukushima –in this case a comparison of bees. In the picture top right, you can see lined up on a shelf other visualisations of radiation in the making. The more radioactive they are the less time is required for the radiation to affect the plates. The bees will stay on the shelf for a few months before the plates are read in the machine.

5.4 Conclusion

This chapter set out to explore comparison in the context of making sense of information about radiation in Fukushima. I demonstrated that the concept of assemblage-comparators as outlined by Deville, Guggenheim and Hrdličková (2016a), was a useful way of working through the examples of comparison that I had in my own data. The comparisons I found in my data were made by complex assemblages, deployed for various reasons, built on long-standing justifications, reaching back to carefully crafted infrastructures (Jensen & Morita, 2017).

Staying with devices and assemblages introduced in chapter 4, we can start to see comparisons as being a device for radiation knowledge making, and other associated practices such as decontamination, categorisation, and food preparation. The device is a socio-material assemblage made up of both human and nonhuman entities that does things. I argued that the alternative notion of *comparator* (Deville et al., 2016a) – a complex assemblage that creates, does and is shifted by comparison – is useful because it explained the multiplicity and fluidity of comparisons, as well as a way of exploring the agency of the human and more importantly nonhuman actors in the assemblage. I established that I understand all assemblage-comparators undergo a process for 'assembling a comparator' (Deville et al., 2016a), but that the assemblage and process of assembly will be at a different pace and calibrated according to different standards, values and justifications, depending on the assemblage and the audience for its comparison. Maintaining the 'assembling the comparator' process across all kinds of comparisons means acknowledging the socio-material assemblages that form all comparators.

A radiation knowledge producing assemblage that is doing comparison could include humans (residents, scientists, engineers, business people, policy makers), as well as nonhumans (technical tools for data collection and processing, tables of information, thresholds and so on). The make-up of any single comparison-making assemblage is constantly shifting and in the making. Such comparators are fed by data about spinach, ambient air, sea water, human bodies, and are calibrated through the process of defining the cases that are put into relation with each other. Common grounds for establishing commensurability between radiation-related cases is achieved by defining and focusing on elements of their entity, temporality and spatiality. Thresholds and standards have enduring agency across multiple comparisons and do different kinds of work in comparisons as special kinds of comparative cases. In my ethnographic data thresholds such as 100Bq/kg or 0.23μSv/hr have a dual role, functioning both as benchmark-comparators as well as calibrating parts of the assemblage-comparator. As ready-made off-the-shelf cases thresholds can be deployed quickly and easily without needing to be explained and they also act to calibrate the assemblage-comparator by influencing and shifting the comparator's sense of what is 'high/low', 'safe/not safe' etc.

Whilst chapter 4 established the need to explore a wider network of entities that are active in the creation of knowledge about radiation contamination, this chapter develops this further. The socio-material assemblages of radiation knowledge production are active and full of human and nonhuman elements that are doing work to order and produce knowledge and understanding. In this chapter I concentrated mostly on nonhuman entities within radiation assemblages of comparison. In the following chapter I focus instead on human actors within the assemblage. I use and extend a concept called *qualculation* to explain the different roles human actors play within knowledge making processes and the implications this has on knowledge production after disasters.

6 Qualculation

6.1 Introduction

In the previous chapter I examined acts of comparison in my data and used the concept of *assembling the comparator* to further refine my STS-inspired reading of radiation devices and assemblages. That chapter focused primarily on nonhuman actors in the assemblage, in the particular form of thresholds, rather than foregrounding the human aspects of comparison. In contrast, in this chapter I begin with human actors in qualculative assemblages, before reintroducing humans alongside nonhuman actors in the latter half.

Comparing is one specific way of working with radiation assemblages to make a judgement or decision. I now move away from the specifics of comparison and use another STS concept to probe the general process of making calculations with radiation data. *Qualculation* is a term that has been used in social science to rethink what we often think about as *calculation* (Cochoy, 2008, Callon & Muniesa 2005, Callon & Law, 2005). The process of *qualculation* is open to incorporating both qualitative and quantitative resources and continues to acknowledge the socio-material assemblages at work within the process. I use qualculation to interrogate my data on the making of judgements about radiation.

The first part of the chapter engages with qualculation and applies it to my own data as a means by which to explain how radiation data is generated and then translated – through different spatial and temporal locations – into knowledges and understandings. I springboard off the 'assembling the comparator' process outlined in the previous chapter to augment the existing conceptualisation of qualculations by suggesting a more in-depth assessment of 'assembling the qualculator'. In doing so I highlight four roles within the qualculation process that are undertaken by the various human actors in the assemblage.

I then examine *nonqualculation* – the instances and mechanisms by which qualculation is not achieved (Callon & Law, 2005). They suggest two mechanisms for achieving nonqualculation; the first is *rarefaction*, whereby all qualculative resources are removed, and the second is *proliferation* in which qualculation becomes impossible through an overload of qualculative resources. I test Callon and Law's ideas about nonqualculation against examples from my own data and offer an enrichment of (non)qualculation, by proposing how to conceptualise the ebb and flow of non/qualculation over time in response to an emergency. Finally, I link the possibility of achieving a non/qualculation to the arrangement and functions of the qualculator and describe different temporal and material implications of this.

Both extensions to the concept – the notion of *qualculator* and the evolution of qualculation in emergencies – will be of use to those trying to understand how different people and organisations go about knowing and understanding information in evolving situations like emergencies and contamination events. This chapter continues to respond to the two research questions: 'What kinds of calculative work takes place in creating radiation knowledge?' As well as: 'How and when do radiation knowledge assemblages produce knowledge and meaning from radiation data?' It demonstrates that the production of knowing and understanding about radiation contamination is not limited to one device, one method, or one time and space; it is not controlled or even controllable from a central position.

6.1.1 The qualculation process

The production and deployment of radiation data in knowledge making appears superficially, at least, to be the archetypal site of calculative knowledge production given the scientific practices, technical devices and numerical data involved. However, in my own data from Fukushima I could also see that judgements and decision-making about the radiological situation were not just about numbers that were being produced (c.f. Infant Feeding in Emergencies Core Group, 2022). Quantitative data is the product of construction by socio-material assemblages as discussed in both the Devices and Comparisons chapters. Decisions and actions about the radiological situation were determined by incorporating views about how those numbers were generated (who produced the data, which devices they used and what their methods were), alongside other political, social and cultural reasons for making the decision (e.g. current thresholds circulating, the status of different policy schemes, such as whether decontamination and or compensation was still available, as well as family or economic influences), and also the availability and accessibility of the data. Decisions and judgements involving radiological information are therefore the result of complex assemblages coming together.

Working not with radiation data, but with economic market data, Callon & Muniesa (2005: 1230), investigated the specific organisations of entities that allows 'markets' to 'make a calculated exchange possible'. They recognised that *economic* accounts made calculation the result of 'disembodied agents […] their preferences and calculative competencies', whilst *sociological* accounts of market calculations showed that economic calculations are complex, but tend to suggest that very little arithmetic calculation takes place at all (e.g. Miller, 1998; Knorr Cetina & Bruegger, 2002). Their starting position – and one that I adopt in this chapter – is that '[c]alculation starts by establishing distinctions between things or states of the world, and by imagining and estimating courses of action associated with those things or with those states as well as their consequences' (Callon & Muniesa, 2005: 1231). Calculation was neither *all* arithmetic nor *all* non-numerical judgement. They adopt Cochoy's term *qualculation* (2002) to suggest that *all* kinds of calculation involve socio-material objects manipulating resources in a single spatiotemporal frame with distributive agency (2005). Supported by Latour's notion of 'centres of calculation' (1987) and the idea that calculative agency does not only reside in humans, but 'is distributed among humans and nonhumans', Callon and Muniesa (2005: 1236) work with the idea of collected assemblages of human and nonhuman things doing calculative (or rather, qualculative) work. Qualculation, like comparison, is therefore another socio-material set of practices and another pointer towards the impact of the material world on the way that we come to see the radiological world.

Figure 39: In a radiation monitoring lab in Tokyo, air filters from air monitors in Fukushima are tested and interpreted to determine radiological contamination levels.

Qualculation is a useful concept by which to investigate the process of making judgements after contamination events. This is because it is agnostic as to the kind of data or resources that make it into the qualculative space (in terms of their qualitative or quantitative attributes) but directs attention towards the selection of things that make it into such spaces, as well as who participates in these activities and how the ordering and manipulating gets done. The most important boundary is therefore 'no longer between judgement and calculation, but between arrangements that allow qualculation and those that make it impossible' (Callon & Law, 2005: 720). Qualculation can show how radiation knowledge production is constructed and then integrated into wider processes for making judgements and decisions.

Callon and Muniesa (2005) articulate a three-stage process for performing a calculation and note that the process applies equally well to what Cochoy described as *qualculation* (2002). Callon and Law (2005) continue to work with this three-stage process as qualculation in order to examine instances of *nonqualculation*, which I address a little later on. First, they point out that 'relevant entities are sorted out, detached, and displayed within a single space' (p.719). Not everything makes it into the space – things have to qualify to enter (hence the 'qual' of qualculation). Second, those entities are manipulated, transformed and are ordered within the space – relations are created between the entities. The third part of the process is that, 'a result is extracted. A new entity is produced. A ranking, a sum, a decision. A judgment. A calculation' (Ibid). This new entity might for example be a judgement, such as – I can live here, I have a particular kind of illness, radiation is high in this location, this fish cannot be sold, or you may leave this area without your shoes needing to be decontaminated. The qualculation process needs material things like pens, paper, excel spreadsheets and in the case of radiation information, things like *radiation monitoring tools, databases, maps, cars, and human bodies* in order to take place.

There are three important things to note about thinking qualculatively (Callon & Law, 2005). The first is that the outcome is nothing other than the outcome of the relations and manipulations performed along the way. Second, that objects made in the space-temporal frame do not pre-exist – they are made by it. And third, that there are innumerable ways of arraying and manipulating entities in that space in order to generate an outcome. These points are important in relation to knowings about radiation, because they suggest a) there are innumerable other arrangements and arrays by which we might make radiation knowledge, now and in the future, b) that understandings of radiation generated through radiation monitoring practices and quantitative data are instances of the many ways by which we can make decisions and judgements about radiation and c) that radiation knowledge does not pre-exist before we call it into being with our processes of knowing about it.

6.1.2 The silent generator, doers and receivers of qualculations

As highlighted in the previous section, the 'qual' of qualculation relates to the idea of a 'qualified' calculation and that '[t]hings have to qualify before they can enter a process of qualculation' (Callon and Law, 2005: 719). Thinking in more detail about which entities make it into the process of qualculation, and who or what controls this access is of great interest and importance. Qualification defines and controls the boundaries of the space in which qualculation takes place and the kinds of possible qualculations. This raises questions about who has power and authority to determine what resources qualify to make it into qualculations, as well as who qualifies to access such qualculative resources, who qualifies to make a qualculation (and who does not), and also who controls where and how qualculations are displayed and disseminated.

Qualculation involves socio-material assemblages coming together. However, Callon, Muniesa, Cochoy and Law have little specifically to say about the human actors involved in different stages of the qualculation process. The implication is loosely that the same individuals perform all three steps in the process; that the maker and user of the qualculation are one and the same. Sometimes, the person generating the qualculation is assumed to be the specific end-user – as in Cochoy's 2008 example, the pusher of the shopping trolley and any associated present or virtual shoppers that they are representing during the shopping experience. But the end-user might not have participated in putting the qualculative resources together in that single space (e.g. the supermarket staff making decisions about the products to stock, thus bounding the shopper's choices or the employees putting stock out onto shelves), nor were they always able to influence or change how they are manipulated in that space. Cochoy's work also highlights that other humans (shoppers at the end of a phone) and other nonhumans (the shopping trolley) also play a part in the eventual purchasing decisions made.

I suggest it is necessary to be more explicit about differentiating between the different roles for humans in a qualculation assemblage. To show why, I offer an example from a former nuclear regulator in the UK. They discussed trying to establish a need for an evacuation of UK citizens in the days after the disaster. They were also trying to establish what was considered to be the right distances for the evacuations if they were needed.

Data for the UK's assessment was gathered from various sources and entered an ad hoc process for modelling isotope release (given particular weather conditions) in order to provide an answer:

> [W]e spent those first few days just gathering up as much monitoring information […] just trying to work out what we call the 'Source term'. You know what was actually in the reactor? […]
>
> If it was a UK event, then we've got arrangements with the site, we understand our reactors, we know what's in there and we can do the modelling from there. But we'd never dealt with an overseas event, so we didn't really know [….W]e had to try and find out what was in the reactor and there was very little information coming through, because of the situation [in Japan]. We had to pull our various intel from the different countries [we were working with] to try and understand…..what we were assuming, where was information coming from and we had to find information that was credible.
>
> It started off with us agreeing what we call the Source Term – how much material might be released. We'll look at how much is in the reactor and then the release mechanisms. How can that material get out? What could actually happen to the reactor and then how much can be released? […]
>
> We then told the Met Office that these are the isotopes that are going to be released of this amount and then they put it through their weather modelling and then that tells them how far it's going to distribute, how far the plume's going to go, and then PHE [Public Health England] were then at the back end to say, OK, this much lands on the ground in this area, then this is the dose, they then calculate the dose to members of the public. So, we all agreed, this is the sequence of information, this is how it can flow and then that advice would be given to government. So that's kind of what happened [in March 2011]. (Formal interview, 15 July 2022)

The example is in line with Cochoy's point that qualculation can be distributed. In the example, different human actors are performing different roles. The ultimate decision maker in this qualculation was the UK government. However, their decision was influenced by the UK nuclear regulator, the Office for Nuclear Regulation (ONR) who established an agreed sequence of information that produced their advice to government about what to do. Different agencies with different responsibilities and specialisms were involved in providing information and resources that fed into that decision – ONR provided information about radiological source terms and reactor design, the Met Office provided information about weather patterns and plume distribution and PHE provided information about health protection. The individuals who had the potential to be affected by this decision – UK nationals in Japan – were not part of the three step qualculative process (as articulated by Callon & Muniesa). Nonetheless, they were obliged to act in response to the judgement if located within suggested evacuation zones.

As I demonstrate, it matters whether the person(s) making a judgement at the end of the process was the same as the person(s) creating the qualculative resources, or the person(s) putting the specific qualculative space together. Not everyone is able to perform the maker of qualculative judgements, not everyone is obliged to act as a response to the judgement and not everyone has the ability to dismiss a judgement made by a third party. This observation is relevant in contamination emergencies (indeed any kind of emergency) as there may be legal requirements for or expectations of government organisations (or members of the public) to make (or accept) qualculations and judgements on behalf of (or by) others. This includes for example, using qualculative resources to determine where evacuation zones are, to mandate evacuations, to set requirements for food monitoring and control. Where to live, work and what to eat are things that, under most normal circumstances, are broadly within the control of individual citizens, rather than state or other agencies. Emergencies establish different working relationships and expectations about who is responsible for making decisions. Emergencies can confer organisations with power and authority (or just the expectation) to make qualculations on behalf of others in a way that they may not under normal circumstances, or have consequences for which human actors have access and funding for the technical tools for making data that feeds into decision making.

6.1.3 *Abstainers of qualculation*

Several participants informed me that after having produced radiation data they explicitly removed themselves from making decisions on behalf of others. In one example, a university scientist, Professor Hayakawa[23], published data and some of the earliest publicly accessible maps on Fukushima radiation deposition which were downloadable as pdfs to view online, could be printed off in large format using 7-11 convenience store printers and were available in pre-print format from local community groups. He told me that his message to residents was:

> Go! Go or stay. Eat or don't eat. Please decide [for] yourself. I give you [a] risk assessment by science, but you make the decision. I do not make the decision. (Formal interview, 9 July 2018)

On his maps he also repeats this message again (see Figure 40):

> 'Eat, don't eat. Go, don't go. Escape, don't escape. Do, don't do. Stop, don't stop. Decide for yourself. There is no right or wrong answer to measures against radiation contamination. How to cope with radiation depends on personal circumstances.' (Hayakawa Radiation Map, 2012[24])

Figure 40: The top of Professor Hayakawa's map shows his avatar (a volcano) telling people 'Eat, don't eat', 'Go, don't go' ....

He makes a particular point of doing the work of bringing the data and information into one single space – his map – but steps away to allow each individual to make decisions. Making each personal qualculation involves the individual bringing in other qualculative resources including information about their age, lifestyle, family and economic concerns and personal preferences. Similarly the citizen-run health clinic I mentioned earlier noted that it was not possible for their staff to arbitrate over what was safe or not on behalf of the users of the clinic because of the personal situation of the individual concerned. 'This clinic cannot judge if it is safe or not. Because it depends on the people's age and situation since the disaster. So, they provide this kind of information to help this kind of decision making' (Formal interview, 8 August 2018).

The clinic generate data through whole body counter tests, thyroid scans, food, beach water testing, and urine testing, and disseminate it to interested individuals as personal test results or collated community results published in booklets and online. However, they relinquish responsibility for determining meaning back to the citizen. One founding member of another radiation monitoring group reported similarly, 'We're not interested in arguing about what the data means, we're arguing that you should have the data, so that <u>you</u> can figure out what it means' (Formal interview, 9 July 2018, emphasis in original).

The scientist, clinic and radiation monitoring group acknowledge they can bring together the qualculative resources into one space (such as a map, table of results or online portal), but they actively refrain from determining what this means. Delineating between the different roles within qualculations – creating qualculative resources, making qualculations and using qualculations – helps identify the consequences of being able to perform some roles but not others, at some but not other times, in some but not other spaces.

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[23] He explicitly asked me not to anonymise his identity.
[24] Translation of this text is from EXSKF (2012).

The creators of qualculative resources might also control what makes it into the qualculations and might also be the same as the people using them (or obliged to act on them). But this is not always the case. This is relevant because it matters who has access to technical devices to create data, who has the power and authority to get to places and people in order to create data which might be needed for qualculation or who has power, authority and access to data sets already in existence. Not all individuals or groups trying to make a judgement can do so – they may only be in a position to be a 'user' of someone else's qualculation. It is important to think about which individuals and groups can be part of designing and steering the production of radiation knowledge and decisions because such knowledge and decision making can affect individual lives, by determining for them where they can go, what they can do, what they can eat and so on.

In the following section I suggest that thinking like a social-science comparator (introduced in the previous chapter), might be productive in articulating the different roles in radiation knowledge qualculations.

6.2 Thinking like a comparator

The qualculative process is similar to the comparator assembling process, as outlined by Deville et al. (2016) and discussed in the previous chapter. This is perhaps unsurprising given that qualculation describes a process for generic calculation, whilst comparison is one particular kind of *doing* qualculation. Just as a comparison is the product of an assemblage-comparator, a qualculation is the product of a social-material assemblage of parts working together. Qualculation is *doing* decision making and judging, rather than doing the making of comparisons. I suggest that thinking through *what 'assembling the qualculator'* could look like for radiation related qualculations could address gaps in the process articulated by Callon and Muniesa (2005), which only identifies how qualculations happen, but is less specific about the particular roles within that process. Such an extension offers a way of thinking about the inter-relations between the producers and consumers of the qualculative product and the construction of qualculative resources; it is also more explicit about how entities qualify to make it into the qualculation. These are important elements I observed which are not addressed by the qualculator model as it stands.

6.2.1 Assembling the qualculator

'*Assembling the qualculator'* acknowledges the multiple entities that come together to create qualculations. In relation to radiation qualculation, any one assemblage might include different types of human actors working individually and collectively together – governments, scientific institutions, funding bodies, citizens, businesses, families. These groupings can overlap, and it is possible for one individual to potentially be involved in the same qualculation but wearing different metaphorical hats. These different human actors, individuals and groups, perform different functions within the qualculation, including qualculative resource generation, gatekeeping, making and using. I now establish four distinct roles that human actors in the socio-material qualculative assemblages perform within the qualculation process:

1. **Generators**: Groups or individual(s) that make or generate entities (qualculative resources) which are incorporated into the qualculation (e.g. radiation data, technical devices such as radiation monitors and other tools, electronic platforms and systems used to store or manipulate the data etc). Qualculative resource Generators are reliant on access to other socio-material infrastructures in order to generate data and material resources needed for radiation data production.
2. **Gatekeepers**: Groups or individual(s) that control access of entities into the qualculative assemblage – they exert a lot of influence over what might qualify as a qualculative resource, who has access to the data or the systems or which infrastructures are used in the qualculation. Gatekeepers might include organisations responsible for setting thresholds or standards for radiation monitoring, organisations responsible for granting funds and providing resources that enable monitoring to take place, or that control access to populations or areas to be monitored. It also includes organisations that maintain, control or store previously captured data. Gatekeepers may not have generated the data themselves but are able to define many of the parameters by which it is generated and made available to others. The actions of qualculative gatekeepers influence the range of outcomes that can be achieved during the qualculation by controlling the range of entities that qualculators have access to.

3. **Qualculators:** This group or individual is responsible for determining the specific calculation or judgement at the end of the qualculation process. They carry out the qualculation according to the three steps articulated by Callon and Law – bringing together the qualculative resources, manipulating them in a specific place before coming to a conclusion – e.g. making a judgement about what the radiation data means. However, they cannot bring any and all resources together. The resources at their disposal will be defined or limited to those available at that time. The availability of qualculative resources depends on what the qualculative resource generator is able to generate. This is in turn, determined by Gatekeepers who have control over say technical instruments for measuring and monitoring, the provision of funding for measuring and monitoring, the setting of research agendas, the setting of policy etc.
4. **Qualculation users**: These organisations or individual(s) are the users of the final outcome produced by the qualculative process. They may also have been involved directly in the production of the data or the qualculation themselves. However, in cases involving data and outcomes produced by official sources (e.g. by government agencies or scientific/academic institutions), the users of the qualculation (e.g. businesses, residents, parents etc) may be obliged to accept a qualculation without being involved in its production. This is important because as noted by Callon and Law (2005:725) qualculation is heavily bound up with questions of trust. Trust is a relevant issue here because individuals who are obliged to accept a qualculation produced by another qualculator are more likely to accept that qualculation if they trust the qualculators producing it.

It is clear that these four roles might conceivably be performed by one and the same group or individual(s), however, I noted that there were times when distinct groups and individuals were associated with different parts of the qualculation process. In my data I saw that data generators and gatekeepers were more active in steps one (assembling qualculative resources in a time and space) and two (arranging and manipulating them). Qualculation makers and users are more closely associated with the third step, in which the outcome is generated and by implication made sense of. Having more precise descriptors for roles allows more precise understandings of the considerably varied ways humans can be enrolled in qualculative processes.

The ability to take up one of the four roles will change over time, with certain actors periodically excluded organisationally, infrastructurally or politically from performing the various roles. The issue of who gets to be a part of the groups that define and then answer questions in emergencies has been highlighted by the responses to COVID-19 (Iles and de Wit, 2021). This luxury is not afforded to everyone equally.

Thinking back to the list of different human actors that I mentioned at the start of this section (governments, scientific institutions, funding bodies, citizens, businesses, families), they have different capacities for influencing qualculative outcomes. The priorities, power, resources and influence of one individual citizen will differ from those of, say, a government ministry, a scientific institution or a municipality. By way of an example, I spoke with many people who wanted access to radiation level data in the early days or weeks but could not find it, or when they were given data were unsure how to make sense of the information provided. One farmer in Yamakiya told me he and his neighbours were able to read the radiation levels in their farms and 'knew' their land was contaminated. However, they were told not to evacuate by the local government and that everything was 'safe', because they were not in the official evacuation zone (which at that time was based around distance from the Daiichi site). Six weeks later in April 2011, the government amended the evacuation zones and the whole of Yamakiya village was asked to evacuate. In this example, the qualculations of the government took a while to catch up with the qualculations of the residents of the village. The qualculative potential of a farmer, and other local actors who had access to radiation detectors, were more agile than governmental actors trying to make sense of a much broader geographic area.

6.3 Nonqualculation

The second half of this chapter looks at *nonqualculation* (Callon & Law, 2005), where qualculation is not achiev-ed/able. It draws on human and nonhuman materialities in qualculative acts, as well as the temporalities of qualculation and how this might emerge over time. I briefly set out Callon and Law's descriptions of the two mechanisms for nonqualculation before drawing on two further examples from my own data. The first example deals with individual qualculations during a research tour of the most heavily contaminated parts of Fukushima, the second studies fixed radiation monitoring posts. I then look at both examples together, alongside the initial case at the start of the chapter (the setting of the evacuation zones for UK nationals). I consider what applying the lens of (non)qualculation to radiological contamination can say about making assessments and judgements in emergencies, and how in turn this can inform STS thinking about (non)qualculation. This leads me to make observations about the ebbs and flows of qualculative potentials over time.

Figure 41: On leaving the Red Zone' on 10 August 2018, (my first visit there) the vehicle's tyres were monitored for contamination as were the soles of our shoes. When I asked why we only had our shoes monitored and not our whole body or our hands (which was the case when I visited Chornobyl in 2015), the officials responded by monitoring me from head to toe by hand using an Aloka Hitachi survey meter. I think this was meant to be an additional performance of care to reassure me.

6.3.1 Rarefaction and proliferation

Qualculation requires disentangling the qualculative elements 'from wherever they were before' (Callon & Law, 2005:720). Qualculation stalls in situations where disentanglements are not possible. Callon and Law apply symmetrical arguments to both qualculation and nonqualculation. Just as making relations in *qualculations* takes work and is not natural, the same can be said about *non-qualculation*. To resist qualculation requires as much work as to become embroiled in it – letting go is an act that is both 'active and passive' (p721).

Callon and Law provide two mechanisms for non-qualculation: rarefaction and proliferation. Both impede the making of a qualculation, but they operate in opposite directions to do so. *Rarefaction* is achieved through removing 'all qualculative resources' (2005: 717), taking away all of the entities needed to generate an outcome. In one example of calculative rarefaction, Callon and Law describe the set of material and discursive practices that Quakers have for disentangling themselves. This involves material things such as a meeting space for worship, arrangements of chairs and also social protocols for how the meeting should proceed and how the attendees should behave. Actively resisting calculation or qualculation therefore requires specific tools, places and things to enable the resistance.

A second kind of non-qualculative mechanism is available: *proliferation*. Qualculation is rendered impossible because of an overload of the required resources, rather than not enough. Proliferation, Callon and Law argue, 'operates to generate subjects or subject positions that cannot qualculate [….] because they are too entangled with qualculation' (Callon & Law 2005 :726). Nonqualculation is achieved because the 'list' of qualculative entities to be ordered and manipulated is never closed and therefore no sense can be made (Callon & Muniesa, 2005). Callon and Law (2005) provide a train crash inquiry as an example of proliferation. The inquiry generated multiple accounts which were 'partially overlapping but also partially contradictory', and which 'made it impossible to account for the accident. [They p]ushed the events beyond the qualculable or the accountable' (p. 727). Nevertheless, at the end *there was one* single account, as provided in Lord Cullen's report into the crash, which suggests that a qualculation was achievable. Producing this one account meant making salient the links between some evidence and severing others, making judgements about what was important or irrelevant, then ignoring or paying attention to them accordingly. Things like legal systems, which control the inquiry process offer 'rather strict material and discursive framing which limits […] proliferation' (p. 728). The same can also be said of scientific journals and emergency instructions – they work to reframe a proliferating reality into one which is at the same time tractable and calculable. The tools of science and law work to make noncoherence look like coherence, something which I address in the Syncretism chapter in more detail. Thresholds, emergency instructions and centralised briefings also work towards a central narrative which act to limit proliferation and to make qualculation achievable in emergencies, because qualculations are needed to move things forward.

In the next section I trace three empirical examples of nonqualculation from my data and then discuss the implications and observations collectively at the end.

6.3.2 Intentional disentanglement and temporal validity

On 10 August 2018, I sat in the back seat of a car belonging to Mori-San. He had picked me up from Tomioka train station, and was giving me a tour around some of the restricted parts of Fukushima Prefecture. Tomioka station had only reopened the previous October having been destroyed by the tsunami in March 2011. We saw a strange mixture of buildings in every-day use and recently renovated, contrasting sharply with seven years of abandonment, ad hoc up-keep, animal and plant incursions and disrepair, or event in some cases, total demolition. Our tour meandered through the 'yellow' and 'red' zones, as Mori-san referred to them – colloquial terms for the areas being decontaminated and might reopen soon, and the evacuation zones named by the government as 'difficult to return to', respectively.

At the start of the tour Mori-san handed me a small personal dosimeter (a MyDose Mini) to wear, and at different stages throughout the day when we stopped to get out the car we got out various personal dosimeters and survey meters to see what the radiation levels were like. We compared the readings from our monitors to the ones we saw on the sides of the road, to fixed radiation monitoring posts in school yards (the schools were closed) and to each other. As we drove, one monitor stayed mounted on the dashboard of the car.

When we stopped at various points, Mori-san used a printed set of presentation slides containing data and information about the response to the disaster to provide us with different perspectives on the disaster. 'I want to show the facts. […] I found something important about the accident and I want to show this to people', he said. It was important to Mori-San that when I left, I would take away an understanding of how it was possible to live with risk in Fukushima; that it was neither impossible to live here, nor was it without daily adjustments for those who did already. I should know the 'safeness of living here as well as the risk'.

As we were driving back to Fukushima City, I asked Mori-San what he did with the data he got from his radiation monitors, including the one on the dashboard. He replied, 'I don't record the data from my journeys – I am not interested. My brother owns a construction company and he gets several millisieverts per week working on construction sites. One of these tours is about 5-10 microsieverts, so I'm not interested in recording the dose.'

Another time I spoke to him about radiation levels around both his and his 93-year-old father's homes:

> Right after, no, several months after the accident the radiation level is more than 10mSv per hour. And three years after the accident, it was still 3 or 4. But after the decontamination it was down to 0.3 or 5. And after that we stopped checking on the radiation. But it is still 0.3 and it is 0.7 in the back yard. Maybe it is 0.2 or something […] In my father's house. But we don't mind – I have not checked it. […] Maybe I have not checked the air radiation in our home. Maybe it is 0.3 or around. (Fieldnotes, 10 August 2018)

On both occasions, he spoke about not checking or recording current rates. Not checking involved being actively disengaged from the current potential qualculations, and at the same time remaining entangled in previous historical judgements about radiation levels. He actively sets aside the material aspects needed for qualculation – e.g. he ignored more current data from a radiation monitor and he based an assessment of the current levels on legacy resources. The radiation data from the monitor on the car dashboard effectively withered as he did nothing with it. This seemed to me to be a deliberate act of calculative rarefaction – the removal of qualculative resources which make qualculation not achievable.

It was also notable to me that though disengaging from qualculation for his own benefit, Mori-San was happy to facilitate qualculations on my part and he became part of my own qualculative assemblage. The MyDose Mini he gave me recorded my cumulative dose for the tour and he showed me how to display this on the device screen at the end of the day. This activity, in concert with his choices of where we went and what was included in the power point slides seemed to all form part of Mori-San's campaign to get visitors to the area to understand more about the events of 2011, as well as the current status of the area and the possibility of living there. In relation to his own qualculation he was performing all the four roles outlined above, in 'assembling the qualculator', while in the end sidestepping the qualculative process. Yet he also acted as a resource generator and qualculative gatekeeper for me, enabling me to achieve qualculation(s) of my own.

The way Mori-san engaged with previous qualculations also says something about the temporalities of qualculation. He was able to refer back to the typical cumulative dose expected for our tour of the evacuation

Figure 42: Multiple radiation monitors to hand in the cupholder or visible on the dashboard of the car on our drive through Fukushima

zones, about the contamination at his father's house and about his brother's dose. These assessments were still valid in the current spatio-temporal frame he was working in. This sentiment of, *I checked it before and it was fine, so I don't need to check it again now*, was a pattern I saw frequently. In one interview, a farmer shared he knew where on his farm to avoid spending lots of time because of the dose rates in that area. In another conversation a priest, mentioned to me:

> [N]owadays the farmers are not checking because it is below the threshold. […is] much lower […]. It's always been low. So farmers feel safe and they checked often, in 2012, 2013, 2014 and after that […]l…. It's annoying to check…. But I say it is necessary to test every time, *mainichi*…… we need to check *just in case*. (Fieldnotes, 15 May 2019)

The farmers wanted to accept the validity of previous judgements on an ongoing basis, whilst the priest needed a confirmation check every time – *mainichi* – every day, just in case. The just in case check extended the validity of the assessment into a point further ahead in the future. The validity of previous qualculative judgements therefore have a temporal aspect to them. However, it is not clear how long such calculations and judgements might hold for, or what might determine a reassessment of the situation or assemblage that created it. Nonqualculation can also be part of the disintegration of qualculative resources over time. They have a best before date.

6.3.3 Structural dismantling

The second example relates less to the human elements of the qualculative assemblage, instead pointing towards the physical and material infrastructures that underpin radiation knowledges and qualculations.

The Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) became responsible for aggregating information on general environmental monitoring (of soil, water, and atmosphere, etc.), in air space, sea areas, schools, and public facilities in August 2011 when the first Comprehensive Radiation Monitoring Plan was issued (Government of Japan – Monitoring Coordination Meeting, 2011, 2013, 2017, 2022). One of the most visible material elements of the MEXTs armoury of environmental monitoring tools was the installation of white pillar box shaped radiation monitoring posts mentioned earlier in the thesis and officially known as 'Real Time Radiation Monitors'. Within a few years they had sprung up like mushrooms all around the prefecture – around 3000 in total.

The priest I mentioned earlier described the radiation monitors as a 'lucky charm' which people liked to see. Not only are these fixed radiation monitoring posts part of the infrastructures that generate data about radiation which can be used in qualculations, but for residents in the immediate vicinity of the posts, they are also part of the material infrastructures that make radiation levels immediately visible (and therefore locally qualculable). They make radiation visible on three different levels. First, the monitors display local radiation levels on the monitors' screens, second, the readings are uploaded via network cable to a central database which feeds into an online map, and third, the presence of the monitors themselves is also an indication of data being collected and monitored, as well as the potential for radiation to be present. Radiation monitoring posts are part of multiple qualculative assemblages, at times part of data generation and display and at times part of a performance of qualculation.

In March 2018 the Nuclear Regulation Authority (NRA) announced plans to remove or move around 2400 of the 3000 monitoring posts that had been installed in Fukushima Prefecture by the end of the financial year 2020. Some posts would be removed entirely whilst others would be re-sited closer to the damaged reactor. The NRA argued that radiation levels in areas away from Fukushima NPP had been shown to be steadily decreasing and well below given thresholds for over a year (NRA, 2018). The NRA framing of the issue suggests they view the monitors' role as documenting the declining radiation levels. The monitors help create a physical link between the current situation in locations with the monitors, with a past historical event. A prefectural official also informed me that in some parts of Fukushima, the monitors were physical reminders of an incident which did not affect them from a contamination perspective. The presence of the monitors continued to indicate those passing by that there might have been contamination there before. Removing this visible token provides a break with that past contamination event and is a signal that there is no contamination here now.

When local government officials from affected communities in Fukushima Prefecture were asked to comment on the proposal, several stated that they did not want any posts to be removed until the contaminated waste in interim waste storage sites in their communities had been processed and taken away (NRA, 2018; Suzuki, 2019). This suggests that they linked the posts not just to the original contamination, but also to current material practices involved in managing it and the potential for a future contamination event during decommissioning of the Daiichi site. Without the posts, people would have to rely on what they were being told by the government or on smaller networks of knowing (e.g. community or individual monitoring activities). Removing the posts would have limited the number of qualculative possibilities, thus producing rarefied nonqualculation for those without alternative means of monitoring.

I heard of one gentleman who reportedly took a photo of the local monitoring post every evening to show his wife so she could know the local readings. However, as I moved around Fukushima, although I seemed to pay a lot of attention to radiation monitors (I frequently stopped to take photos of them or noted their readings), no one else appeared to match my enthusiasm for them. Nonetheless, several residents' groups campaigned to keep posts, so perhaps people were paying attention after all, but less overtly. Their value as indicators of contamination, as producers of radiation level readings or even as indicators of *non*-contamination, was elicited subtly. Perhaps just the presence of the posts was enough for some people, irrespective of the levels being displayed. Perhaps because someone else (in this case MEXT) was collecting, recording and monitoring the data, other potential qualculators (local residents) could switch off from making qualculations (or switch on nonqualculation) and actively paying attention to them themselves.

The proposed removal of the fixed radiation monitoring posts was never carried out after backlash against the suggestion (NHK, 2008; Suzuki, 2019). Had it proceeded it would have meant the intentional and active removal of infrastructural resources from the qualculative process. The physical and intangible links to contamination, to the past and to imagined futures would have been severed, making certain qualculative assemblages impossible. In addition, both this and the preceding example highlight the dual role of some materialities in the context of a longer-term view of radiological contamination incidents. The same materiality can be part of the assemblages that *allow* qualculation (for some qualculators) and that uphold *resistance* to qualculation (i.e. allow rarefaction for others).

Figure 43: Realtime fixed radiation monitor in a closed school in Iitate July 2013 (Credit: J Moross). One of my participants (personal correspondence) noted that the school was used by JAEA as a test site for decontamination methods. The trees in the background were not part of the testing but were accessible by children.

6.4 Discussion

Having looked at the cases individually, I now examine the two new cases (Mori-San's tour, and the fixed radiation monitoring posts) alongside the initial case provided at the start of the chapter (setting evacuation zones for UK citizens) for overarching observations about qualculations in terms of how and when they operate in radiation contamination emergencies.

This discussion addresses the following themes that emerged from looking at the very different cases collectively – the roles of (non) qualculation, the materiality of (non)qualculation, and the temporality of (non)qualculations. The cases suggest that alongside rarefaction and proliferation, opportunities for achieving nonqualculation also exist via the removal of the four roles in the qualculation process. The cases also highlight the material and temporal aspects of qualculations. Not all qualculations are possible all of the time and there seems to be a broad pattern of qualculative possibility after a contamination emergency. Parts of the qualculative assemblage, particularly the materially durable elements, can work to support or deny qualculation.

6.4.1 Roles and (non)qualculation

The four human roles in 'assembling the qualculator' that I outlined earlier in the chapter are active in the examples I cited: the resource generator, the qualculative gatekeeper, the qualculator and finally the user. No less important is the observation that removing any one of the four roles may lead to qualculation not being achieved. If there are no resources generated (no data, or no technical devices to generate data, no subjects or things from which to glean data) then a qualculation is not possible. If the qualculative gatekeeper restricts access to qualculative resources, for example by removing funding opportunities, limiting access to certain individuals or limiting access to datasets of gathered information or removing qualculative assets such as radiation monitoring posts, then a qualculation is not possible. If there is no one to do the qualifying, ordering, sorting or sense-making required for qualculations, then a qualculation will not be achieved.

Rarefaction relates mostly to the removal of the qualculative resource generator, but also to the work of the qualculative gatekeeper to restrict access by the qualculator to qualculative resources. For example, when the NRA proposed removing monitoring posts, they and other government agencies were in effect suggesting the reduction of qualculative resources. Mori-san, as a qualculator, makes himself available to help me make a qualculation about my dose on the trip, but avoids doing this for himself. He removes himself from the equation. It seems almost obvious to state, but if there is no one making qualculations, then they are not achieved. I demonstrated the same thing happening in the examples of the volcanologist I referred to earlier in the chapter who said, 'Go! Go or stay. Eat or don't eat. Please decide [for] yourself. I give you [a] risk assessment by science, but you make the decision. I do not make the decision' (Formal interview, 9 July 2018).

This as a kind of strategic rarefaction, a kind of nonqualculation not described by Callon and Law. Their version of rarefaction is about the removal of all of resources, rather than the qualculator strategically stepping away from making a judgement.

An individual who is able to or compelled to make a decision on their own (e.g. the decision about whether to return to an area where an evacuation order has been lifted), will incorporate in their qualculations about radiation other qualculative resources such as the consequences of any decision on their access to compensation, considerations about infrastructure and economic restoration and perspectives from their families. A return should not be taken as an acceptance of a judgement of safety but is the result of complex decision making beyond the radiological situation. Many have argued that residents have been compelled to return to Fukushima after evacuation orders have been lifted, because of removal of support mechanisms that would otherwise allow them to remain away from Fukushima given the choice (McCurry, 2015).

> Accurate information was essential for the evacuees to make informed decisions on whether to return or settle elsewhere. It was also critical to ensure their right to freely choose the most appropriate durable solution is not impeded by policies that make assistance conditional on return. (UN, 2022)

Other people have chosen to stay away not because of concerns about radiation directly, but in the intervening years, they have settled in other places and established new lives (Fujikura et al., 2022). The qualculations that these individuals make and act on draw understandably on different qualculative resources than government qualculations about when and where to lift evacuation orders. They are answering different questions and have different priorities.

6.4.2 Trust and (non)qualculation

At the start of any significant incident involving contamination there are many questions, unknowns and uncertainties, and it is likely the infrastructures and qualculative resources that are needed to respond to them do not yet exist. Initially, a citizen might have no option but to follow official instructions, because they are the only qualculations available as government organisations are more likely than residents to have access to specialist qualculative resources needed (in this case radiation monitors and people with specialist radiation knowledge and so on). This is relevant in emergencies because at different times, citizens are likely be legally or practically obliged (through limited access to qualculative resources of their own) to accept qualculations made on their behalf. Simultaneously, citizens may also have expectations of official organisations that these organisations will make qualculations on the citizens' behalf, and which these organisations are not able to meet. This quote reflects this mismatch between expectations and qualculative potential, and when they misalign:

> 'So the thing that became very clear immediately after 311 was that there was no publicly available radiation data to be able to access or make any sort of decisions about their own safety and this was a large concern because a lot of peoples' individual safety was put on them. There was not clear

> direction from the government about what people should do. There was a lot of grey area about ……well, *you could evacuate if you want to'* (Formal interview, 9 July 2018, my emphasis)

This highlights the importance of material arrangements producing data and access to these arrangements in order to make decisions. It also suggests that trust in qualculations and the assemblages (material and human) that make them is important. Being a user of a qualculations where other human actors are involved (as generators, gatekeepers, qualculators) implies a need to trust those other parties and their non-material counterparts. Further analysis of my data identified that there was a link between trust and the qualculative function, which these quotes from individuals involved in citizen radiation monitoring neatly summarise:

> Most ordinary people could not trust why the government set the food contamination limit of 500bq/kg in the first year of the accident […] and they changed to 100bq/kg from the next year. […M]ost people lost trust in the scientist of the governmental side, so they did not trust these data directly, so they wanted to check the contamination themselves. So, some people organised [food] measurement stations themselves. (Formal interview, 11 July 2018).

> You get a flow of information. This was based on personal trust and relationships. It got very liquid. It came down to – "You should read this, this guy's twitter feed or this blog" – and that sufficed. You might go through and critique the data and sometimes it held up. And some people helped by summarising […] helped make meaning from the data [showing] what you need to know. (Fieldnotes, 21 December 2021).

As a result of poor production and dissemination data by the government (NAIIC, 2012), which lead to a lack of trust in the government and the data that they did eventually share openly, many citizens chose to establish their own means of making qualculations. The ability of citizens to trust qualculations made by government scientists underpinned their ability to accept such qualculations unquestioningly. In this case some people chose to do their own monitoring and therefore performed all the qualculative roles themselves – they were not only the users of qualculations but could generate their own data and construct their own qualculations.

Figure 44: Two slightly different models radiation monitoring posts sit side by side on a disused parking area in Fukushima. One is covered with a screen saying that it is not working. Both are resting on metal frames, mounted on top of concrete slabs.

In the context of a radiation emergency, government statements along the lines of: ‘Fukushima rice is safe to eat’ or ‘You do not need to evacuate now because the radiation levels have reduced to a safe limit allowing you to return’, are examples of qualculations being made on behalf of someone else. Problems arise when there is no trust in the organisations producing the qualculative resources (e.g. data generation devices, monitoring networks of devices, data storage) or producing the resulting qualculations which citizens might be obliged to respond to as part of a government order. Where there is no trust in the qualculative resources or the end qualculations, citizens sometimes choose to ignore or set aside the qualculations made on their behalf.

6.4.3 Materialities and (non)qualculation

Alongside highlighting the functional roles within the qualculative process, the cases also acknowledge the material and methodological elements of qualculations. Callon and Law remind us that ‘calculation and noncalculation reside not primarily within human subjects but in material arrangements, systems of measurement, and methods of displacement or their absence’ (Callon & Law, 2005: 718).

The cases underpinned the notion that what is at stake relates not only to the human actors in the arrangements but equally to the material arrangements, the methods and tools for measuring radiation levels, and the systems in place for maintaining, storing and managing that data. Material arrangements can be the physical manifestation of strategic arrangements encoded in technical documents. Ulrike Felt for example highlighted the link between the technical representations of radiation on maps and how these were translated into materially present evacuation zones (2016). Material entities can continue to influence current and future qualculative outcomes as they are more likely to be durable. Fixed radiation monitoring posts were a material link to government concerns for public qualculations of contamination (or lack of it) near residents’ homes. The examples also showed that material parts of assemblages (e.g. radiation monitoring posts) can allow qualculation (for some qualculators) as well as providing material resistance to qualculation (i.e. allow rarefaction for others) at the same time or at a later point. Some materialities therefore have a dual purpose in supporting or denying qualculations in the context of a longer-term view of radiological contamination incidents.

Figure 45: What spaces and materialities are needed for making knowledge about radiation? A radiation monitoring laboratory in Fukushima Prefecture (August 2018)

A participant noted to me that the material devices of radiation measuring and monitoring also ‘facilitate’ other things. Generating data using things like D-Shuttles alongside diaries of what the wearers were doing, enabled more detailed and specific conversations to take place in radiation ‘counselling’ sessions, where citizens were given advice about how to reduce their exposure to radiation. Radiation counsellors could discuss specific action for a specific individual. This would not have been possible based on modelled data alone. Physical devices like the Safecast bGeigie also allowed citizens to measure radiation in places that were important to them. It liberated them from being dependent on other sources of data.

Qualculations require technical, organisational and communications (infra)structures to be found or built, which enable the qualculator to make a qualculation and for the qualculation to reach the intended 'audience' for it. At the start of an emergency incident the material elements of the qualculative process may not be readily available. The qualculator may not have access to the materialities that they require to – e.g. the right devices, access to data, access to participants, access to funding. For example, there may be few radiation monitors available at the start of the incident and supply chains can take time to come online. Additionally, access to materialities is also related to the qualculative gatekeepers, who control access to such resources. Funding opportunities (from major institutional donors like the Takagi Fund[25] who support many citizen science organisations in Japan, as well as from smaller individual donors), organisational support (e.g. scientists being released from their day jobs to provide their expertise on the situation) and access to the sites and subjects of resource generation (e.g. access to schools for monitoring, or to children for thyroid tests) – these are all things that can dwindle, be rescinded or removed. The social elements of qualculative assemblages also take time to pull together. Some of the organisational structures linking qualculative resource generators to gate keepers, qualculators and users may not be in place already and will need to be established or supported to develop.

Observations about the material and emergent nature of qualculative assemblages will not come as a surprise to those working in response to an emergency. However, it is worth paying attention to directly because those individuals might not have thought about the nature of qualculative assemblages or the impact of the different configurations on varied stakeholders.

Figure 46: Bottles of water inside boxes provided some shielding in citizen run labs and clinics. (l) Water shields detectors used for food monitoring, (r) water shields a Whole Body Counter

6.4.4 Spaces and (non)qualculation

Qualculation is not just limited to the production of knowledge in more traditionally recognised sites of knowledge-making such as university laboratories or even citizen science labs. Knowledges and understandings

[25] 'The mission of Takagi Fund is to foster and support independent Citizen Scientists who propose well-founded criticism and scientific counterarguments about problems and threats caused by present-day science and technology.' 'Our Mission' webpage, Takagi Fund website, http://www.takagifund.org/e/about/mission.html

about radiation are produced in many different spaces. Some spaces are tangible physical spaces such as hospitals, single emergency control rooms, residential homes, scientific institutions, businesses and government offices. Other spaces involved in qualculations could be seen instead as networked spaces – spaces that become linked in geographically distributed places (Mol & Law, 1994). I discuss the idea of the *spaces* of radiation knowledge making in more detail in the Syncretism chapter. Suffice to say that qualculative roles get performed in a variety of places, that these spaces change over time and that different human actors are enabled or prevented from operating in those spaces, sometimes by other human actors performing another qualculative role, in particular the gatekeeper role.

One of my participants, for example, mentioned attending a large symposium hosted by the Nippon Foundation where eagerly awaited Whole Body Counter data produced by Fukushima Prefecture was presented. Many people attending were keen to determine what the newly collated data might mean for the citizens of Fukushima and for future radiation protection actions. However, the data was presented in total units of Bq per body, without any information on bodyweight. Not weighing people prevented any calculations about body burden per kilogram generated, which is an essential comparative data point. My participant relayed his confusion about the missing weights and described a conversation with a well-known scientist:

> And we, [Dr X] and I discussed the data from the municipalities. I pointed out that they didn't weigh anybody. There's nothing in here for indicating the weight of the person. It would seem fundamental to me [to include that information]. I spoke to Dr [X] about this. And we discussed why this might be. "Why would they NOT have done that?". In the end we decided that in the mind of a bureaucrat it makes it easier if you take that out the equation; it is simpler and involves less in the calculation. (Fieldnotes, 21 December 2021).

My participant was effectively pointing out that generating data in that way facilitated a simpler calculation in one qualculative space, but that this simultaneously precluded other kinds of more complex qualculations involving the same data in other spaces. They were not thinking about how to produce usable data.

6.4.5 Temporalities and (non)qualculation

I have noted elsewhere that there is a broad pattern of 'radiation monitoring being used in exceptional decision-making *on behalf of* citizens, to every day decision making *by* citizens' (Elstow, 2022: 49). Qualculation provides an explanation for why and how that is the case by offering a way of conceptualising the entities active in a radiation knowledge making assemblage. Following this line of thinking, time becomes an important factor in the equation. Time is a key dimension of people's lives [and in radiation knowledge making assemblages] and can be considered using different timescapes (Adam, 2008). Time relates not just to the temporal validity of qualculative assessments that I noted before, but also influences the qualculative possibilities as assemblages of qualculation change and evolve over time.

Along with the observation made already that qualculative assemblages take time to come together and that they change over time, the examples also highlighted other temporal aspects of qualculation: their durability and frequency (durability was also touched on in relation to Comparisons in the previous chapter). The Mori-San example suggested that a previous qualculation satisfied his current needs for assessing the risk from radiation. He did not need to make another reading which might cause him to need to re-evaluate whether or not to be concerned about his dose. This raised questions about how long a radiation qualculation holds as 'true' for and what might cause qualculators to re-evaluate existing qualculative assessments. Can a qualculation about whether to be worried about exposure in Jan 2018 continue to be valid in Jan 2022? Are the material elements of qualculations more durable than the social? The priest mentioned earlier wanted farmers to continue to check food contamination levels 'just in case', whereas the farmers were content that what was OK in 2014/2015 would still be OK now. The proposed removal of the fixed radiation monitors implied that any final reading would have remained valid indefinitely if there were no ongoing newer readings to dislodge it from the qualculation.

Not only does it take time and effort to make (non)qualculations, it also takes time and effort to go through that process repeatedly. Remaking qualculations can help refine the judgement – for example my interviewee from the nuclear regulator said that they continued to recalculate and refine their data as new information about the situation in Japan came in – regarding the damage to the reactor, exactly what was in it, how the incident had evolved and what had been released. This increased their confidence in the assessments they were providing to the government. Conversely, extracting oneself from the exertion of continuing to make radiation qualculations might be a pragmatic response to living and working in a more or less contaminated area, as Mori-San does. Repetitive qualculation (constantly re-assembling the qualculative resources, re-ordering and manipulating them, re-making a decision) can be physically, mentally and financially draining. It is easy to imagine, that for some people who have chosen to go back to Fukushima, who have had to go back to Fukushima or who never left, it might be a pragmatic solution to make one or a handful of qualculative decisions relating to radiation and for that to continue as the default indefinitely. In an area still recovering from the impact not only of the nuclear disaster but also the tsunami and earthquake damage, there are other ongoing and equally pressing issues which might otherwise demand their time, effort and attention. Strategic rarefaction could easily be a coping mechanism.

6.4.6 Evolution of (non)qualculative possibilities in emergencies

Based on my data and examination of the literature, a pattern of qualculation can be traced in Fukushima that may apply to other contamination emergencies. I now trace three stages of an incident (early, middle and later, broadly defined). The framing of these stages is intentionally very loose (note my earlier discussion in 'Defining Disaster' about defining phases of an incident). These stages are based upon my empirical data and reading of literature. I acknowledge that my data – indeed no data – could ever definitively identify all of the qualculative acts in a space. I have however, identified these stages through my work (particularly in response to COVID) and they are helpful for thinking with because they reveal dynamics between roles and the longer-term temporality of incidents that are worth further consideration and investigation.

Initially, with limited qualculative resources available, very few qualculative assemblages are able to come together. Immediately after the 2011 Fukushima nuclear disaster, only limited qualculative resources were available, which meant that new infrastructures (social and material) to support qualculative resource generation needed to be constructed first. Very few citizens owned radiation monitors at the time of the disaster and numbers for those available to buy was soon outstripped by demand. Citizens had to rely on data and judgements coming from central government, who themselves either struggled to make their own assessments of the contamination due to damage to monitoring systems caused by the earthquake and tsunami (NAIIC, 2012; Hultquist & Cervone, 2017), or were in any case slow or reluctant to share this data externally (Onishi & Fackler, 2011; IAEA, 2015; Plantin, 2015; Yamaguchi, 2016; Sugawara & Jaraku, 2018).

Then over time, government guidance began to set out approved methods for generating data about radioactive contamination in bodies, in food and in the environment and these were incorporated into routinised ways of interpreting and ordering those qualculative resources to make different judgements – about where to live, what to eat, when to be concerned about a risk to health and so on. Fixed radiation monitoring posts and screens showing radiation readings were installed in public places. Alongside formal governmental systems and networks of measuring and monitoring, alternative systems and networks began to develop between citizens, local governments, NGOs and scientific institutions. Local food monitoring stations were established by local groups, and in time these were supplemented or replaced as government-run monitoring stations were established. Elsewhere new kinds of qualculations were needed. For example, nearly eleven years after the Fukushima Dai'ichi disaster, discussions and intense debate continue about what to do with waste water recovered from the site contaminated with tritium (see Mabon & Kawabe, 2022) for a useful summary of current debates). This is a reminder that contamination events have long recovery temporalities and that there remains work to be done to ensure that the voices of those impacted by the products of scientific measuring and monitoring are included within the assemblages helping to define and create that knowledge.

As relationships develop between the qualculative roles (resource generators, gatekeepers, qualculators and users), processes for making judgements become systematised and ritualised, qualculations become more routine. In Fukushima there were screens, readings, tables, charts and information about radiation in multiple places. Radiation measurements could be seen on the street, in the supermarket, on the bus, online. Opportunities for making different qualculations were nearly endless and overwhelming. But this was not to continue forever. I saw radiation monitors starting to fail, I saw websites displaying blank readings and with dead links, I noted databases of different kinds of data merging as government organisational structures changed. So as time moved on, qualculative resources began to overwhelm and then to fall away, and the infrastructures and resources needed for qualculation begin to disintegrate and change. They were either actively dismantled, amended or disintegrated over time.

The table below (Figure 47: Table of qualculative temporalities) summarises the broad trends that I noted. There is an opportunity for future work to address this in more detail.

Stage of incident response	**Type of qualculation**	**Kinds of qualculative acts**
Early stages of an incident	**Pre-qualculation** This is not rarefaction, because the resources have not been removed – they just don't exist yet. Generators work hard to start to generate resources.	Questions focus on what actually happened, who is being impacted and what by. It is not yet clear what kind of questions need to be asked. Qualculations, limited to existing and normally inadequate material and social infrastructures of knowing. Limited access to existing qualculative resources. Current infrastructures are not adequate to deal with the range of new questions being asked, decisions that need to be made and judgements sought. Hasty work to create qualculative resources to answer the big questions applicable to large populations/groups.
Middle stages of an incident – being brought under control – narratives being solidified	**Qualculations** Qualculative resources are plentiful, but not overwhelming **Rarefaction:** Gatekeepers control access to qualculative resources	More qualculations are possible. Gatekeepers control access qualculative resources – the kinds of things that get funded and the direction of research and policy questions that will be answered first. Although there are a variety of qualculative resources available (technical tools, ways of generating data, ways of sorting and understanding and ascribing meaning etc), more are still in development and coming online. New data generators come online and are perhaps outside official structures. Different groups become associated with specific kinds of knowing and specific kinds of answers. As knowledge expands, so to do the kinds of questions being asked. Questions asked and judgements are more specific and nuanced to individual situations.
	Proliferation: there are a potentially overwhelming number of qualculative resources available. **Rarefaction**: Active disengagement from qualculative resources by qualculators or users.	Basic facts and narratives have solidified and have stabilised. Remaining questions are far more nuanced and often more personal/specific than collective. Many more qualculative resources are now available meaning that gatekeepers have less influence and control. At times an almost overwhelming number of qualculative resources to consider. Older qualculative resources are removed or start to dissolve. Some people may actively disengage from qualculative acts, either as users of others' qualculations or as qualculators themselves.
Later on in the incident	**Rarefaction**: Active deconstruction of qualculative resources by gatekeepers	The maintenance of qualculative resources (e.g. monitoring post networks, volunteer citizen radiation monitoring groups, Whole Body Counter (WBC) screening, personal dosimetry data collection) becomes a sustainability issue – how will these infrastructures continue to exist – who will fund them, who will manage them, what is their purpose? Gradually rarefaction results as a result of the breakdown of qualculative resources over time.

Figure 47: Table of qualculative temporalities

6.5 Conclusion

In this chapter I have continued to work with and expand the accounting for what is needed to create knowledge and understanding about radiation in emergencies. I used and then extend the concept of *qualculation* to work more broadly with the making of judgements in emergencies. My suggestion was to adopt an *assembling the qualculator* approach and across my cases to attend specifically to the different human roles with the qualculation process and assemblage. I used these human roles to think about how they apply over time alongside material elements within radiation knowledge making assemblages and suggested a pattern of qualculative opportunities, both over time and also for different human entities. Identifying the potential multiplicity of the human actors in qualculative assemblages goes some way to understanding the complexity of the links between these different stakeholders and why qualculative assemblages take time to come together. In a contamination emergency not all stakeholders will be have the agency to able to, want to or be expected by others to perform certain roles and therefore to make or control qualculations.

The chapter also engaged with the materiality and temporality of (non)qualculations, linking these to the roles of qualculation. Thinking about radiation knowledge making in emergencies through the lens of (non)qualculation is beneficial, as it explains why there might be tensions between different stakeholders who might have drastically different agency to influence the construction of a qualculation – what should be included in it, what to pay attention to, what is important and so on. Differing priorities and ideas held about what is important between the various stakeholders mean that the assemblages they are part of will include or exclude different entities. Some stakeholders are prevented from being part of assembling the qualculator, and are obliged to act in response to other qualculations made on their behalf. This is important to note in emergencies where legal instruments, formal guidance documents and policies can define the boundaries of what is permitted or acceptable in certain settings/spaces and at certain times/phases (as defined in those documents). These documents, instruments and policies (themselves material parts of wider emergency management assemblages) can define the roles and spaces and temporalities of other radiation knowledge making assemblages, but their creation is often only possible once the specifics of the incident are available (Petersen et al, 2017: 313). I address more of the implications of this for professionals responsible for planning and responding to contamination emergencies within the final discussion and conclusion chapter of the thesis.

Having examined the technical devices of radiation knowledge production in more detail in Assemblages, the role of the nonhuman in Comparisons and focusing on the role of humans in this chapter, in Syncretism and Coherence, my last empirical chapter I take up practices of radiation knowledge production.

7 Syncretism and (Non)Coherence

7.1 Introduction

In the previous two empirical chapters I highlighted the multiplicity of assemblages and knowledge practices at work in Fukushima. The Comparisons and Qualculations chapters focused on nonhuman and human roles within radiation knowledge making respectively. In this chapter I use the concept of syncretism and (non)coherence (Law et al., 2013) to explore the idea that radiation knowledge production practices circulate within and interact with each other in wider networks of practices and assemblages. Syncretism asks what happens when radiation knowledge production practices and assemblages rub up against each other? How do they relate to each other? What kinds of logics are being enacted by different stakeholders when different modes of syncretism take place? I argue that the nature of the relationship between practitioners, as well as the organisational structures, formal frameworks in place, and also the times and spaces of syncretism all influence the kinds of syncretism exhibited.

Since the 2011 Fukushima nuclear disaster, researchers have explored knowledge practices, considering how different groups interrelate. Joke Kenens and colleagues (2022), for example, suggest citizen radiation monitoring efforts work alongside but separate to that of local government officials operating in structurally discrete domains. Kenens investigates citizen to local government relationships, precisely because local government radiation measurement activities are often overlooked in academic research. The focus is more often on the relationships between citizens engaged in radiation monitoring and national or regional government agencies. These relationships have been shown to be characterised by disappointment, power and gender inequalities, and mutual distrust (Moriss-Suzuki 2014; Abe 2014, 2015; Brown et al. 2016; Kuchinskaya 2019; Kenens 2020; Kenens et al. 2022a, 2022b; Berti Suman 2020, 2021; Berti Suman et al. 2020; Cousins, 2021).

Kenens et al. (2022) conclude that citizens and local governments are 'living apart together' and that 'CRMOs and local governments have established themselves as separate infrastructures, living and operating in the same environment, yet apart in the majority of cases' (p. 166). Although they collaborate together, the radiation monitoring activities of local governments and CRMOs are strategically held separate from each other, by operating in different spaces and searching for answers to different questions. Kenens et al. explore how and why this separation has occurred.

One of the mechanisms for holding the activities apart relates to the framing of the purpose of radiation monitoring and two Japanese words that both translate to the English '*safety'* – *anzen* and *anshin*. In the eyes of local government officials, CRMO data addresses *anshin* concerns whilst their own data is constructed as *anzen*. Whilst anzen is seen as more a scientific, more objective and technical means of describing safety, *anshin* is viewed as a more subjective notion of safety (Sternsdorff-Cisterna, 2015). One of my participants noted that the best translation was 'peace of mind', i.e. not worried. By framing CRMO activities as achieving *anshin*, local government officials hold CRMO radiation monitoring apart from their own *anzen*-driven activities. This delineation means that CRMO activities can be taken less seriously – any concerns raised through CRMO activities can be more easily dismissed as they are not seen to relate to an objective technically defined harm, but rather a feeling.

CRMOs were also separated from local government radiation monitoring activities by the places they operated in and the things they monitored. Both CRMOs and local governments performed measurements in *public spaces* such school yards. However, CRMOs first had to negotiate permission, for example from the principal and the local school board. It was difficult for CRMOs to collect soil samples from public spaces for testing in a lab, as this was considered theft, or to test school meals because it is not permitted to take school food off the premises (Kenens et al. 2022). Conversely, CRMOs had better access to *private* residences because they were frequently invited in by residents to come and do monitoring in these spaces, something less common for government officers. The practices of local government officials operate in different places and spaces to those of citizen science groups and the data being produced through those activities are shown to travel and move in different circles. This allows them to operate simultaneously but not to come into conflict with each other.

Rather than concentrate on the just two types of actors as Kenens does (CRMOs and local governments), I investigate what happens when a variety of practices and practitioners come together – farmers, teachers, parents, education boards, lawyers and decontamination teams. Kenens at al. identify separation at work but using the concept of syncretism I identify that there are multiple alternative modes of working together. By exploring the potential of bringing academic concepts to practice (e.g. what happens when you think about syncretism through the lens of disaster planning), I am also able to address how and where different radiation knowledge making practices work together. I am doing this ultimately to identify what the opportunities or implications might be for forms of professional expertise, because I am interested in what happens when these plans encounter localized contexts. Thinking about disaster planning (and response) through the lens of syncretism highlights the potential benefits of realising that there are multiple ways in which practices can interact together, and that this multiplicity matters. However, it is also about being realistic about the practical and pragmatic reasons why certain syncretic modes might be easily achieved in certain situations, or by certain socio-material assemblages, but not others.

I begin by introducing the notion of syncretism and its six modes, before examining cases from my ethnographic field data and then finally discussing implications for those responsible for making plans for monitoring contamination in emergencies.

7.2 Modes of Syncretism

In religious studies *syncretism* describes 'the process of combining practices taken from different religious traditions' (Law et al., 2013: 175), but more broadly it can be taken as the 'negotiation and interaction of new elements into a particular group or domain that stem from "essentially" different groups or domains' (Leopold & Jensen, 2004: 3). It is a word that has been used to describe what happens when two or more different religions are found to be trying to operate in the same spaces e.g. Christianity and Paganism in the UK, Brazilian traditions brough from West African via the slave trade (Law et al. 2013), or Shintoism and Buddhism in Japan today for example.

Syncretism is a way of thinking about apparent coherence, and also noncoherence. It has been used to think through things such as the hodgepodge of different companies that were brought together as London Transport in 1929 and eventually became Transport for London as it is known today (Law et al., 2013). The messiness of the underlying practices of the different organisations brought together is hidden by an overlay of purity, manifested by common signs and symbols and the famous styling of the London Underground map. London Transport was both coherent and *not* coherent. Acknowledging the apparent purity yet concomitant messiness of practices (in particular those generating scientific knowledge and understanding) has been the subject of many classic STS texts grounded in empirical cases. These texts looked, under the apparently pure overlay, for the details and situated complexity of knowledge creation and how practices emerge, for example in hospitals (Mol, 2002) and in scientific laboratories (Latour & Woolgar, 1986).

Syncretism describes thinking about combinations of practices, how differences or tensions are constituted, and what different logics and definitions of 'good' might be involved. Law and colleagues propose that 'practices that do not cohere might fit together in good ways if consistency and coherence were less important than they have been' (Law et al., 2013:177). My understanding is that *consistency* here implies that there are patterns across the different practices, and *coherence* suggests that practices make sense in relation to each other and are aligned in terms of logics. Law et al use the word *noncoherent* rather than *in*-coherent in their text to describe a practice which is not coherent from a particular perspective. While 'incoherent' has a connotation of negativity (i.e. one practice needing to be fixed because it doesn't fit or isn't how it should be in relation to others), 'noncoherent' reserves judgement by noting but not evaluating that difference.

Coherence can be useful – it helps passengers on complex transport networks navigate their way around by simplifying ticketing systems, coordinating interchanges and having the same visual clues about where to go. But it can also reduce diversity in a system and obscure or ignore local needs by making them conform with an overarching approach that does not quite fit. Law at al. frame their argument in relation to progress and modernity. Noncoherence is often erased in the mobilisation of discourse and processes around progress and modernity. My approach is to identify empirically what I see in my data in terms of syncretism and then work through how that relates to different types of practices which relate to key emergency management practices after a radiological contamination event (protective actions such as food control, evacuations, decontamination and monitoring) in which noncoherence might not be seen as a good.

In times of emergencies there is a tendency for the authorities to want to limit the idea of uncertainty and to frame an emergency response as being coordinated and controlled (Easthope, 2018, 2022) and based on a unified version of 'the science' (Tanaka, 2015). In several countries, including the UK and the US, 'following the science' became a government mantra during the response to COVID-19 (Coleman et al., 2021: 2). However, recent STS research has demonstrated that in emergencies, not only is 'technical knowledge […] subject to interpretation and experts rarely speak with one voice' but that '[i]n many countries, conflicting expert advice is the norm not the exception' (Jasanoff et al., 2021: 11). Given that in contamination events, there are likely to be a lot of unanswered questions about what is going on and what the next steps should or could be, it is realistic to think that there might be multiple scientific practices generating answers to those questions. Equally it is realistic to expect that some of the answers might be multiple, might emerge from institutional and extra-institutional settings and might involve multiple emergent groups coming together to find novel social and technical answers to such questions (Coleman et al., 2021; da Silva et al., 2021).

I therefore explore for the possibility of a less consistent, coherent or 'unified' version of 'the science' (Meek, 2020; McKee, 2022) being expected or planned for in contamination and monitoring activities, and to think about the logics that might underpin this. Are the scientific questions (and their answers) that are framed as coherent in contamination events underpinned by modes of syncretism? And if so, do these allow for noncoherence? How could practices more readily accommodate different ways of knowing?

Law and colleagues suggest six different styles of (non)coherence, which they call *modes of syncretism*:

- First **denial**. Denial is 'insistent' (Law et al., 2013: 177) on coherence between practices, meaning that one of the practices is effectively ignored as if it did not exist or were not relevant. The underlying messiness of multiple practices is glossed over and noncoherence is not allowed.
- The second mode of syncretism is **domestication,** in which one practice is incorporated into another, by implication more dominant, practice. Coherence is achieved by 'homogenizing' (p177) one into the other. Domestication purifies and tames one practice through so that by the end it looks like another.
- A third option is **conflict** and it asks whether it is even possible for two practices to come together? Conflict is only possible if the modes of practice operate in the same space – ie. conflict happens somewhere. Conflict hints at a desire for purity, and also for domestication or denial, but suggests that neither have been achieved. So, in conflict, coherence is an undesirable state for one or other party.
- **Separation** is about division, because practices can only be noncoherent if they are in the same space. Law et al. note that syncretism 'does not get realized until, in some location or other, different practices are put together and noncoherence becomes an issue. […It] often takes effort to hold practices apart.' (p.180). Separation is active rather than passive. There is a potential for the practices to appear to not be coherent in relation to each other, but only *if* brought together in the same space. Keeping them apart means that both practices can continue without questions of coherence arising. *Temporal distribution* holds practices apart by undertaking tasks at different times, whereas in *spatial distribution* the locations of the tasks is different, and finally in *social distribution* tasks are allocated to different people. By way of an example, atherosclerosis is practiced and enacted in different ways by pathologists than it is by vascular surgeons (Mol, 2002). *Social distribution* means tasks were undertaken either by surgeons or by pathologists, and *temporal distribution* means surgeons see live patients in front of them whilst pathologists typically encounter pieces of the body detached from a living person after surgery or death, and the work of surgeons and pathologists is *spatially distributed* in different parts of the hospital.
- A fifth option of syncretism is that the two practices combined into a new hybrid version. In **collapse**, purity is not required and 'things are being pushed together in an unproblematic combination' (Law et al. 2013:186). Although this looks messy from the outside, internally it makes sense.
- The final mode is **care**. In care, as in collapse, both practices are visible, but rather than just combining the two, they run alongside each other with constant tweaks, interventions and tinkering in the event of imbalance or noncoherence. With care, it takes ongoing work and adjustments to (re)balance the system.

Balance is only temporary and works by 'searching for a fix that works, […] recognizing that things may change, and a different fix may be needed in due course' (p. 183).

There are some additional points that can be made about these six modes and how they might also relate to one another. Collapse and care both result in the relatively harmonious conjoining of two practices in the same space. Separation on the other hand is the only apparently harmonious situation in which both practices remain unchanged, although the active work of separation prevents any of the practices coming together in the same place, which may or may not be desired by some of the actors involved. Three forms of syncretism (denial, domestication and separation) require the erasure in one way or other, of one of the practices from the place where the practices have come together. This is only the case because these modes seek coherence.

In order to tease out the implications for what thinking syncretically and about (non)coherence might mean in relation to practices of radiation knowings, I now examine cases from my ethnographic fieldwork in Japan.

7.3 (Non)coherence in Japan

In the following paragraphs, I present four cases from my data that showcase syncretism in action. These examples were chosen because they represent a range of different actors coming together around the practices of managing radiation contamination. I demonstrate the complexity of relationships between the different actors present, including farmers, decontamination workers, school principals, concerned parents, government agencies, international organisations and employees. The multiplicity of stakeholders involved in radiation knowledge practices is tied to the kinds of places where practices meet, the rationalities that are at play and the kinds of syncretism that are achieved. It would be impossible to establish a review of every instance where data practices around radiation knowledge production came into contact with each other, but the examples given here are particularly revealing in considering the ecological dimensions of data practices coming together.

7.3.1 On the farm and at the soil museum

On Nishimura-san's farm just outside Iitate in Fukushima Prefecture, we navigate a path that circles around her property in an anticlockwise direction. In the middle of the circle is a central agricultural field where she grows wild garlic, and around the central field in a kind of backwards C arrangement are other areas of cultivated land on which she is growing various plants including wild mountain hostas and fern scrolls (Figure 48). Other plants, including a Japanese pink pepper tree, poisonous plants and cedar trees, are also pointed out to me.

Figure 48: On the left – a hand points out where we are on Nishimura-san's hand drawn map of her farm, on the right –looking across the central fields back towards the farmhouse

Discussing farming practices with Nishimura-san, I observe that the farm constitutes a particular border between decontaminated and contaminated created by the practices that come together in this space. Alongside farming practices are also decontamination practices and food regulation practices. They need to work together in order for Nishimura-san to continue to grow and be able to sell her produce.

Some parts of the farm have been decontaminated by various processes including scraping the top level of 'contaminated' soil off and replacing it with fresh 'clean' soil. The outer sections of farmland immediately adjacent to the forested hills and mountains that surround Iitate have not been decontaminated. They were becoming less radioactive over time through weathering patterns and isotope decay only. The pathway is almost a physical marker of where contamination is and is not, and it is also a place where decontamination practices and farming practices come together.

> The area to the left of the river bank is relatively cleared of trees and has been decontaminated. Nishimura-san negotiated with the government to only take off the top layer of soil down. Instead of taking off 10cm as they would do in paddy fields or flatter agricultural fields, they just scraped off the top 5cm. 'We knew that it did not need to be decontaminated as much.' How did you know? I ask. 'Of course we know! Through the history and knowledge we know! These plants only have short roots' (Fieldnotes,16 May 2019)

> Farmland soil has unique characteristics in that it has been cultivated through years of farming activities by farmers and has diverse aspects that include preservation of the ecosystem. Accordingly, when decontaminating farmland, it is important to restore the conditions that enable agricultural activities to be resumed and safe crops to be provided once again by reducing the concentration of radioactive materials in the soil, in addition to reducing the radiation dose reaching surrounding residents. To achieve this in the process of farmland decontamination, [farmland] is expected to lose its fertilizer components and organic characteristics, [decontamination should be] followed by application of the necessary amount of soil from elsewhere, along with fertilizer, organic materials, or soil conditioners. (MoE, 2013: 2-94)

Nishimura-san was able to negotiate with the decontamination workers sent to her farm so that the practices of decontamination were adjusted to accommodate her knowledge of farming. Whilst the removal of topsoil reduces the levels of contamination, it also removes the nutrient rich soil that produced the kinds of fruits and vegetables Fukushima was known for around Japan. Because the roots of the plants were so shallow, her plants would not reach down into the contaminated soil below, but could still benefit from the nutrients in it. The Decontamination Guidelines also allow for this negotiation. They state, '[a]ccording to conventional wisdom it

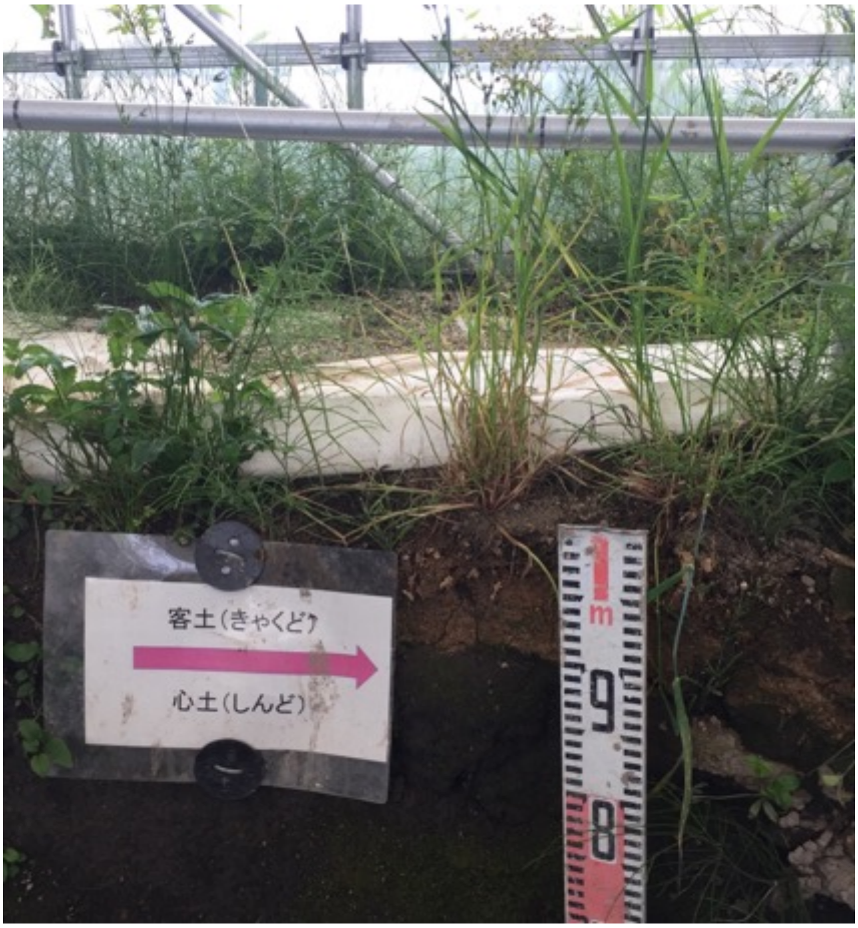

Figure 49: At the Soil Museum –the less fertile replacement soil is visible to a depth of 10cm on top of the darker older soil

is believed that adequate results can be achieved by scraping away at most about 5 cm of the soil surface' (p2-87) and that '[w]hen scraping away the topsoil, it is necessary to confirm in advance the depth of the contamination from the surface layer and establish the optimal depth to be scraped away in advance' (p2-93).

This can be seen as a kind of ***caring*** mode of syncretism – both farming and decontamination practices continued in the space but there was adjustment and tinkering needed for a balance to be found. Nishimura-san was in the position to put her case forward and to make sure that her farming practices were accounted for in decontamination practices, but equally these were allowed for in the documentation, which made that negotiation easier. Coincidentally, limiting the amount of soil that was removed is also beneficial for the government because it 'avoid[s] generating too much removed soil' (MoE – Government of Japan, 2013: 2-87), which needs has to be managed elsewhere in the system and which also has to be substituted by fresh soil.

Caring was not always the dominant mode of syncretism when farming and decontamination practices came

Figure 50: At the Matsuzuka Soil Museum, new clay pipes await installation in paddy fields after the heavy machinery used for decontamination work damaged the existing pipes

together. At the Matsuzuka Soil Museum, I saw that other fields were decontaminated down to 10cm, and that the heavy machinery used in process of decontamination often damaged the networks of clay pipes that were underneath the rice fields and which were necessary for flooding the rice paddies (see Figure 50). My hosts on that visit also pointed out the futility of decontaminating the soil in the rice paddies, but not the earth 'frames', the dykes around the edge that keep the irrigated water in the fields to maintain the waterlogged paddy. This meant that the contamination remained around the edges of the fields – contamination framing 'clean soil'. The reality of the contaminated frames around the nominally 'clean' paddy fields and the fragile clay pipes underneath them, was in such cases ignored or ***denied*** by the very decontamination system that sought to 'ensure the conditions that enable resumption of agricultural production [to be] restored' (MoE – Government of Japan, 2013: 2-94).

Back in Iitate, I asked Nishimura-san about the plants that she grows and how she is able to sell them.

> The wild garlic that is sold is only harvested from a specific area on the map (the only place in the centre with 4 measurements on it). In order to be able to sell the wild garlic, someone from the Prefecture has to come and pick some of the plants and monitor it. Nishimura-san then gets a permit if the plants are under the 100Bq/Kg contamination limit. The officer is however looking for ND [Not Detected]. He advised for fertiliser to be added to the soil. This was not to enrich the soil, but because it has potassium in it and this will inhibit caesium uptake in the plant. Nishimura-san said she did not want to do this as it affects the taste in the mountain vegetables. "Wild veg should be wild!"
>
> They got their first permit last March at the start of the wild garlic season [without applying fertiliser]. She challenged the officer – "Come and test it. You'll see!" At testing their produce came out at 29Bq/Kg.
>
> If three local farmers can all demonstrate that their produce (of a specific kind) is under the level, then the permit is indefinite. Nishimura-san is one of only two farmers to sell wild garlic in her area, so instead they have to get a permit and be tested every year. However, early in the season when they did

> the testing the plants are small and the radioactive contamination is more concentrated in the small plants, which Nishimura-san is unhappy about. (Fieldnotes, 16 May 2019)

Again, Nishimura-san negotiates different practices coming together on her farm. On this occasion she is coming up against the practices of prefectural government officers seeking to regulate the entry of potentially contaminated food reaching the marketplace. She declines the recommended fertiliser because she noted a mismatch between the advice and her knowledge of the affect this would have on the taste of her produce. But there is a further challenge. The coherence of the Fukushima vegetable market is achieved through regular testing to establish food safety. Most farmers only have to undergo this every three years, but because of the small number of farmers selling wild garlic, Nishimura-san's produce must undergo annual testing. This testing takes place early in the growing season, and she fears that contamination levels per kilogram are likely to be higher. The practice of farming uncommon crops, like wild garlic, is not accommodated within the three-year testing regime, and a different process is needed to substantiate a claim of 'uncontaminated produce'. Wild garlic farming is only possible via a process of ***domestication*** into a different annual regime. As a result, she has to negotiate the hurdle of testing and risking higher levels being detected more frequently than farmers growing more common products.

Nishimura is able to decline the recommendation for the use of fertiliser but remains bound by the timescales of the annual testing regime. So individually the two events were examples of ***denial*** by Nishimura-san in the first instance and ***denial*** by the prefectural officer in the second, and ***domestication*** of prefectural ways of doing things by Nishimura-san in relation to testing timescales – her farming practices were homogenised into meeting their permit regime requirements. Seen as part of a longer-term ongoing negotiation between the practices of the two parties however, ***care*** is also prevalent in the acts of negotiation and tinkering.

A final point to make is that coherence is also bound to places and times. We can see here that in order to get a permit for sale, Nishimura-san submits her vegetables for annual testing and the coherence of the notion of uncontaminated vegetables not only has to hold at the time of testing, but it has to hold in different spaces – in the farm, at the testing centre and in the office of the permit issuer. It might not hold for a would-be wild-garlic-buyer. Nishimura-san's wild garlic was for sale at a local service station in the village where villagers could bring food for testing free of charge. The coherence of the wild garlic as an uncontaminated foodstuff could at any point have been challenged again and required testing. The logics of one or other mode of syncretism may not necessarily hold in other spaces or other times.

7.3.2 Coherence in courts and compensation

Away from the farm other kinds of syncretism are at work. In Iwaki City, a coastal town affected by the both contamination from Fukushima Daiichi, as well as significant tsunami damage, a CRMO showed me their chair-based Whole Body Counter, which anyone can use for a small fee. Staff at the CRMO described to me that in recent years the main users of the chair were workers at the nuclear site involved in clean-up activities. They needed to have a WBC measurement to show their employers in order to be able to continue working on site. Any time they needed a new test they could pay to get retested to meet requirements set by employers. Citizen generated data about internal contamination levels of employees was successfully incorporated into the employment practices of local employers.

I also noted that upon paying the fee and receiving my own reading, a note on one of the forms advised me that my CRMO WBC readings could not be used in court. This highlighted that CRMO measuring practices were sometimes not coherent with legal practices. Courts and legal processes are instruments for holding practices apart needed to maintain ***separation***. So, whilst CRMO WBC readings were able to coexist alongside certain employment practices, they were held apart from other legal ones.

In other instances the practices of CRMOs could work alongside legal practices. For example, one CRMO member (Formal interview, 4 July 2018) discussed the compensation system set up after Fukushima with me:

> *A: There are some people who want to know, even after 7 years, whether radioactive materials remain in their houses. Some people want to know this information so that is why we measure the contamination in vacuum cleaner dust bags.*

B: The vacuum cleaner dust bag can be used as evidence for compensation from TEPCO [Tokyo Electric Power Company]. There is ADR [Alternative Dispute Resolution], a mediation before a trial. It is about figuring out reconciliation. It is not about a formal trial but …… […]

A: There is a case in Minamisoma where they did ADR with the group and they used the garbage pack as evidence and TEPCO also accepted that as evidence.

LE: Of contamination for that particular family?

A: Yes – for each family who collects the garbage. They use this as evidence of the contamination.

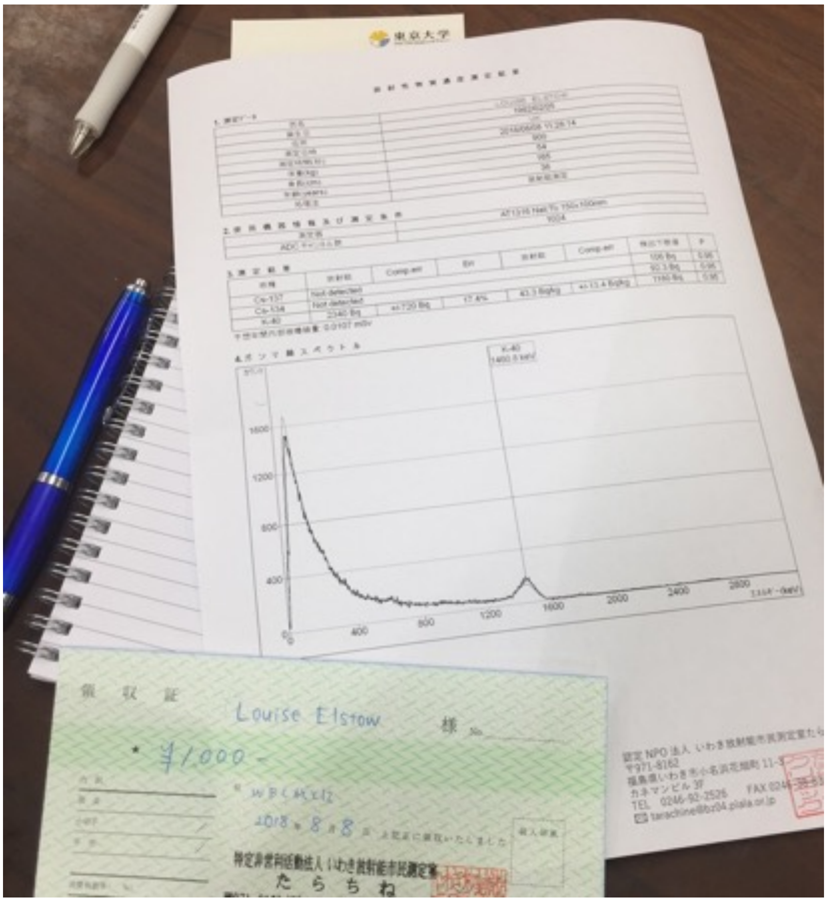

Figure 51: My own internal dose reading and receipt for 100Yen payment (August 2018)

In the example above, the families involved in this particular ADR process as part of the Minamisoma group were able to argue successfully that their vacuum cleaner dust was valid evidence for their case for compensation. This is in part because of the way that the ADR process works and the intent behind its design. ADR is based on mediation provided in a system designed to accommodate different practices and to find coherence through negotiation:

> Individuals whose harms were caused by the nuclear meltdown can seek compensation in three ways. The first, called the 'direct' route to compensation, is shaped by guidelines issued by the Dispute Reconciliation Committee for Nuclear Damage Compensation and is meant to address the bulk of losses caused by the nuclear accident. The second, alternative dispute resolution ("ADR"), was set up under the auspices of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), and focuses on compensating categories of people not included in the guidelines, including children, the disabled, and pregnant women. The third is litigation. (Feldman, 2015: 135)

ADR is particularly designed for those who 'do not fit neatly', for those who 'are not happy' with the payments so far or for those who 'do not want to engage with TEPCO in any way' (Feldman, 2015: 142). So it is about dealing with the non-coherence of different ways of doing claims for compensation. It is possible to see multiple modes of syncretism operating here. Being successful (i.e. achieving coherence on what is an appropriate amount of compensation) via the direct route comes as a result of fitting in with the multitude of processes defined by TEPCO and a committee of legal experts.

> Under these direct compensation procedures, a victim fills in the claim forms provided by TEPCO and sends them back with receipts to TEPCO; TEPCO assesses the damages based on its compensation standards that are almost the same as the guidelines set by the Dispute Reconciliation Committee; and if the victim agrees on the award proposed by TEPCO, they reach the settlement. (Osaka, 2019: 8)

Evidence which does not meet the standards of those processes is ignored by it. Coherence is achieved by TEPCO ***denying*** certain forms of evidence or by the claimant ***domesticating*** forms of evidence to make them fit what the standards require. One of the things that does not 'fit' easily into compensation claims (particularly the direct route) are radiation measurements – claims for compensation cannot be made on the basis of radiation measurements. A fishing business for example cannot use data about the levels of contamination in their catch to establish a basis of contamination. However, they can use the declined sales and prices per kilo as evidence of 'harm'. Lawyers working in a coastal town in Fukushima prefecture and who managed a lot of cases on behalf of claimants for compensation told me:

> So some people assessed [radiation levels in their land and furniture] – those outside the exclusion zone went to [a CRMO in their city] and other similar places in Fukushima City. They assess their furniture and [other personal items] and sometimes the exposure is really high. Using those readings they go to TEPCO and try to claim compensation. But all of those things are refused because TEPCO is compensating not for radiation exposure but denied access. (Formal interview, 7 May 2019)

The ADR process on the other hand is designed to account for practices and cases that ***could not be domesticated*** into or were ***denied*** by the main route for compensation via the 'Direct' route, a system based on conforming within rules, forms and paperwork, administered by thousands of people in a system being run by TEPCO (Feldman 2015). The ADR process is also for those who did not wish to engage directly in the third

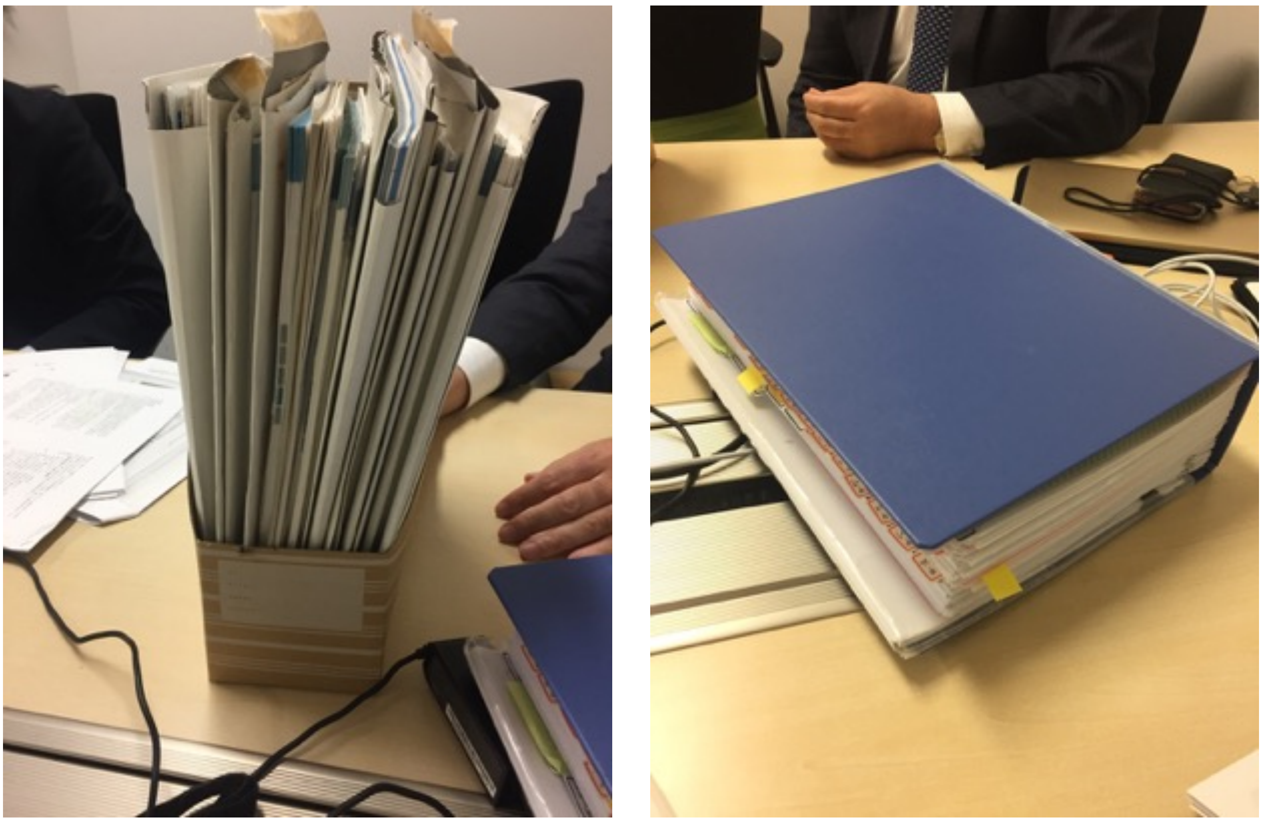

Figure 52: Legal case files for a single company attempting to gain compensation for damages through the ADR process

option for compensation, which is adversarial by its very nature – litigation. Litigation holds ***conflicting*** practices in the same space. Some individuals did not want to engage directly with TEPCO either through the direct route (where coherence is desired) or through the litigation route (where coherence of both is not achieved). Nevertheless, the investigators and mediators facilitating the ADR process are lawyers (Osaka 2019). ADR is operating both via ***care***, in terms of the mediation process, which allows different forms of evidence to be presented that might not make it into the forms of the 'Direct' route, and also ***separation*** – the claimants and their practices for knowing harm are held apart from TEPCO and their practices of acknowledging harm.

What is interesting is that the compensation system as a whole accommodates multiple modes of syncretism operating at any one time – the direct route favours domestication, ADR care and to a degree separation, and litigation functions via conflict. As a whole, the compensation system in Japan is an ecosystem of practices that strive for coherence, but in different spaces, at different times and via different modes of syncretism.

7.3.3 Non/Coherence and categorisation standardisation

Citizens' Collective Data (CCD) is a citizen run organisation which collates data from citizen radiation measuring labs across Japan and publishes them on a central website. The number of labs that have contributed data to CCD has fluctuated since it was established. It started off with 8, increased as more labs were keen to work together but has waned in recent years[26]. One of the CCD coordinators involved in the initial set up of the website described the ***domestication*** of the individual labs' practices by design. In order to be a single place for residents to be able to use, the data needed to exhibit coherence and to look comparable.

Practices from individual labs were ***domesticated*** into CCD practices so that the labs could contribute data and so that that data was accessible to citizens using the website. The coordinator explained what happened in relation to soil monitoring and the bringing together of data from different labs into one website.

> We decided not to show the data of soil because officially we have to measure the soil under 5 cm from the surface, but in reality the labs measured in different ways, like in different depths. The other labs measured in different ways. And also we measured data from hotspots. So, the data is not consistent, and it is not really possible to put it into a single database (Formal interview, 7 August 2018)

The messiness and inconsistency of data practices between the various labs meant coherence could not be achieved initially, but it was clear that coherence was intended and that domestication was the goal (and was achieved in the end). A participant from another citizen radiation monitoring group reported to me that they had been in discussion with CCD about using CCD collated data on their own website, but that the soil data was just 'not in a shareable format'. The design of the CCD data made it noncoherent across other formats.

CCD website practices worked to align the practices of participating organisations and were themselves aligned to practices of other key data producers. For example, CCD chose to categorise the different things that they held data about along the same lines as the Japanese Ministry of Agriculture (MoA), where possible:

> Regarding the category of products, we looked up how the Ministry of Agriculture categorised them. For example, for carrots, we categorised them as a root vegetable[..]. (Formal interview, 7 August 2018)

The participant from the other citizen group described to me that in 2013-15 they had been helping CCD with their website and suggested that they use the scientific Latin categorisation, based on an FAO categorisation of vegetables for their site because they used '*scientific (binomial) nomenclature'*. This would mean that the data would be more easily incorporated into official data sets.

> I suggested to [CCD] that if they used the scientific (Linnean)names, then their data was more likely to be useable to researchers at UNSCEAR, IAEA, etc., i.e., there would be more basis for including it, or at least noting it. Their reply was basically that they were primarily concerned with making it easy for Japanese people to navigate the database, by using only the most familiar names of food items. But the fact is, they hadn't even thought about making their data more broadly useable scientifically. (Personal communication, August 2022)

Although CCD could have chosen a categorisation system that made their data comparable (via commensurate terms) with other formal datasets, CCD told my participant their concern was to make it easy for Japanese

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[26] Some of the reasons I was given for this included lack of funds, waning interest of volunteers, a dwindling demand for their services from residents, other government monitoring improving etc. The sustainability (or not) of CRMO activity is worthy of further attention, but was not within scope of this project.

people to navigate, rather than more universal applicability. Coherence, as a stand-in for commensurability can therefore enable comparison. Thinking back to Chapter 5, I noted that cases are put into conversation with one another by establishing common grounds between the cases. Comparability in this sense can also be facilitated through not only legislation, as highlighted in the previous example, but also through the production of common standards between practitioners. Common standards for doing things helps make data and knowledge commensurate. It would also have been possible to include both names in the dataset, thus making the data commensurate for Japanese and alongside 'official' datasets.

At the same time as domesticating their categorisation process with that of the MoA, some of CCD practices were not coherent with MoA practices because they involved monitoring different kinds of products. Whilst the MoA were interested in testing soil and food products, as well as monitoring these, CCD also tested clothes and air conditioner filters, because '*this is closer to daily life'* (interview with one of CCD participant labs, July 2018). The practices did not have to look coherent because they inhabited different spaces and envisioned different priorities for daily life than those envisaged by the government data.

> [We monitor] food products and also clothes and air conditioner filters[…] This is because residents put the laundry outside to dry, and there are several labs that measure the laundry, so we decided to include the data.[…] We publish the data about laundry and air conditioning because the government does not show the data on their website. (Formal interview, 7 August 2018)

In this case there was no need for coherence between radiation monitoring practices of the CRMO and the government because they appeared to hold different notions of the kinds of information that was important to citizens. But there was also a bit of syncretic denial going on here. Back to my participant from another group – who explained that:

> Their database also includes a few entries for tatami. I pointed out that those items should be in an entirely separate database, so that they are not counted in any statistical output regarding the percentage of items over the 100bq/kg limit for food, etc, or any values intended to help estimate internal contamination risk. They were like, "Nah, it's easier this way." (Personal communication, August 2022)

So, the data about the percentage of food over the 100Bq/Kg threshold was potentially being 'contaminated' by the nonedible tatami mat data.

One of the tools that influences the kinds of syncretism that takes place includes the 'system of unified monitoring and measurement' established by the Government in legal frameworks (Government of Japan, 2011)[27]. According to the Comprehensive Radiation Monitoring Plan which establishes the practical basis of this 'unified' system, different government departments were responsible for monitoring radiation in different spaces or things (Government of Japan –Monitoring Coordination Meeting, 2011, 2013, 2017, 2022). The monitoring plan includes details about how and where measurements are carried out including specifics about the types of devices used and their methods of use. This document both acts to facilitate coherence in the form of standardised practices whilst also providing separate spaces the practices of different government organisations can inhabit.

In many cases the CRMOs I engaged with attempted in some way to mimic the practices set out in government guidance, as this could potentially support their arguments for action (e.g. for more decontamination to be carried out, or for claims for compensation) within existing formal structures for making things happen and affecting change (e.g. with decontamination teams, within the compensation system, or in dialogue with educational committees and school principals). Legal frameworks and formal guidance documents can therefore make powerful tools for the fragmentation as well as the unification of practices between government departments, which in turn can affect how these systems interact with other assemblages of radiation knowledge production.

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[27] For example, the *'Act on Special Measures concerning the Handling of Environment Pollution by Radioactive Materials Discharged by the NPS Accident Associated with the Tohoku District –Off the Pacific Ocean Earthquake That Occurred on March 11, 2011'.*

This example shows that domestication is not something that is necessarily a bad thing enforced by one dominant practitioner on another. It can also be a strategy for working more closely together in ways that are mutually coherent between both parties as well as to external stakeholders (e.g. by residents or by other organisations using data). Having larger apparently coherent datasets could for example provide more heft than multiple smaller datasets using slightly different methods. The example also shows that certain tools, such as the legal frameworks for decontamination work and also the Comprehensive Radiation Monitoring Plan provide anchor points around which domestication practices form.

7.3.4 Layers of care and denial in the school yard

In my final example I turn to the school yards of Fukushima. I spoke with Matsumura-san, the leader of a group of parents who had been campaigning locally for better radiation monitoring and more robust protection of children. She explained their radiation monitoring activities in school yards, a space in which they also came up against radiation monitoring by government decontamination workers. Government decontamination workers typically monitor school yards in one central place and then in the four outer corners of the yard to create the five points of measurement required according to government guidelines (MoE 2013). This monitoring was at 50cm height for elementary schools, and the standard 1m height for schools for older children using devices to measure ambient air dose rates (MoE 2013:1-20). As noted by Kenens et al. (2022),

Figure 53: Government fixed radiation monitoring post at a school with a Safecast radiation measurement sticker on the pole. (Credit: Joe Moross)

citizen groups have to get permission to monitor in schools. Matsumura-san's organisation was the only group to gain permission to go into schools in her town. In contrast to government workers, her group measured in multiple places (sometimes hundreds) around the yard and also in between buildings, behind buildings and next to fence lines. She told me that if they found an area with 'high' levels of ambient dose they would also look at the soil, a practice not routinely done by decontamination workers:

> As you know the government set the standard 0.23 at 1m height from the soil and at the Kindergarten and [elementary] schools, it is the same number but 50cm from the ground. However, the reason why the

government does not measure the soil dose is that the government says that there is a coefficient between air dose and the soil dose. However, when [our] organisation measure the data, we found out that it is not really true. So we set a higher standard. For us 0.15 is recognised as a slightly high air dose, which means that we then measure the surface of the soil. (Formal interview, 9 August 2018)

She also mentioned that in March 2016 her group found one area of soil that read 130,000 bq/kg in an educational facility with both an elementary school and a junior high school. The soil was in 'a little space next to the gym facility and children can really easily access that place,' she told me. Initial inspections suggested

Figure 54: A special device made by one CRMO allows three simultaneous radiation readings –at 10cm, 50cm and 1m off the ground

that debris from the forest had collected in the gutters on the roof the gym building, so they suspected that contamination from the forest was making its way into the school premises, but no one was able to say for sure why the reading was so high. Prior to the contaminated soil being found the school had undergone government decontamination, but according to Matsumura-san:

> The government only did a really limited area of decontamination in the playground. And because this place was really at the back of the gym building, the government did not recognise this place here as a place where children can get into. So they ignored it. (Formal interview, 9 August 2018)

Matsumura-san's organisation produced reports of any findings about hotspots and sent them to the City's local education committee, the City's Decontamination Department and the City's Children and Future Department.

It often took months or years before anything was done about the contamination Matsumura's group found. When I spoke to Decontamination workers from the city, they told me that decontamination work in the city had been 'finished' in November 2017, with applications for more being accepted up to March 2018 (Formal interview, 8 August 2018). I asked Matsumura-san what she was hoping for, given the decontamination department were no longer proactively doing decontamination. She mentioned that specific requests would still be acted upon, but that this was not necessarily straightforward:

> The government set a certain rule that said that you cannot do the same decontamination method in the same place. […] If there is a higher level of contamination, but the area has already undergone the decontamination process [by soil removal], they cannot remove the contaminated soil again. However, they can use another excuse to remove the soil. For example, if they have to build a new fence, so they have to remove the soil.
>
> […] Sometimes there are people in City Hall who understand [our group's] activity. Those people try really hard to help me to find ways around. I don't want to have conflict with the [local] government –I want to build trust and have a relationship with them. So, if it is impossible to do the second decontamination, I ask the government at least use a rope, to make it easier to understand that it has radiation. Put the signage up so that the children can understand immediately that there is a dangerous place. We have been doing negotiations and finally […]. They have now got a budget for the rope and the signage. (Formal interview, 9 August 2018)

In this example Matsumura-san had explicitly tried to avoid **conflict** and confrontation by appealing to the relationships that she had with local government officials to find another way through. They found another way through, but were confounded by another problem in that:

> So the local education committee gets the budget. However, the principal of the school does not want to do it. He does not want to put up the rope and the signage. So the City said you can use the budget for the rope and the signage and said to the school, please let us know if you need the sign. However, no school has requested the signs.[…T]he City will suggest, but cannot advise the school to do it, because the way decision making is done, the principal of the school has the right to make the decision, and the City cannot interfere with governance. (Formal interview, 9 August 2018)

During the second round of monitoring at the district's 200 schools, the group returned to monitor a different school where they had previously found higher radiation levels and where additional decontamination had been requested. Matsumura-san showed me pictures of a playground with an unintelligible sign hung on a fence. Several children sit underneath the sign ignorant of the raised radiation levels immediately around them.

> Matsumura-san: The school principals put up the signage, right? It says 'stay away from this place'….
>
> LE: And there are children right next to it.
>
> Matsumura-san: The rain washed away the letters.
>
> LE: So you did the first measurement and the principal put up a sign saying 'don't play here', and now you can't read the sign either.
>
> Matsumura-san: Yeah. So we requested decontamination again. And decontamination was carried out in 2016 in February. So in 5 years, they didn't do anything. (Formal interview, 9 August 2018)

In this example syncretism gets materialized through a sign, however no decontamination takes place and over time the sign fades. It is a materialization that there are different logics at work here. The principal's enactment of the logics of caring for the community of students here is also likely to be balanced against making visible something that might also be causing them harm and that has been there for years. This is despite government teams having declared the school 'decontaminated'. The decontamination system works in concert with the actions of the principal to enact a certain denial of these attempts by citizens to make contamination known and ultimately reduced in the places children inhabit. The ***care*** that was there at the time when the sign went up becomes ***denial*** over time as no further action materializes and the sign fades.

It is possible to see a range of modes of syncretism at work in relation to Matsumura-san's group's work. Whilst the activities of Matsumura-san's group are ignored (***denial***) by the decontamination policies set out by the Ministry of Environment, or ***separated*** (their monitoring of school yards pays attention to different spaces of potential contamination than the decontamination teams), her group appear to have good relationships with local government officials who try to accommodate their concerns and data, and make adjustments accordingly (***care***). In doing so she actively sought to avoid ***conflict***. However, their activities are ultimately ***denied*** by some school principals of who either ignored the request to rope off the area and put up a sign or failed to ensure either decontamination took place or that the sign was adequately maintained.

7.4 Discussion

In this section I take as a starting point that 'all practices are syncretic' (Law et al. 2013: 176), and that in post-Fukushima Japan, there is a plethora of interacting [radiation knowledge production] assemblages (Stengers, 2005) at work. The word 'ecology' is potentially useful here because it shifts attention from what is happening within one single assemblage to what is happening in the 'emergent web of relationships among constitutive and constituting parts' (Choy, 2011: 11) of the ecosystem – i.e. in between the different assemblages. Different assemblages 'coexist and are connected with one another in complexes […]in relation to each other like species in an ecosystem' (Kemmis et al., 2012: 36).

In my four cases I have shown empirically how some of the ways and modes in which an ecology of practices, all relating to living with contamination, have played out in Fukushima. As summarised in Table 7 below, radiation knowledge making practices are not only brought into relation with other radiation knowledge making practices, but also other adjacent practices such as getting compensation, providing a safe space for education, and producing food, and so on. Whilst my examples clearly cannot provide an exhaustive list of practices which might take place after a contamination incident, it does account for some of the most common protective measures including food control, decontamination and monitoring (of bodies and the environment).

Case	At the farm	Employment / legal spaces	On the website	At school
The actors	• The farmer • The decontamination teams • The local government official	• CRMO • Claimant / citizen / worker • The employer • The compensation system (lawyers, TEPCO and government committee)	• Individual CRMO labs • The central CRMO website • Other CS groups with data • Government ministry	• CRMO • The school principal • The decontamination teams • The local education boards / local gov
The practices	• The growing of vegetables for sale • The assurance of those vegetables as safe for consumption • The decontamination of farmland where food is produced	• The production of radiation knowledge as evidence • The practice of employment in a hazardous environment • Compensation practices (direct / ADR / litigation)	• The production of data • The collation and visualisation of data	• The identification of high radiation levels • The reduction of contamination • The provision of a (safe) space for children to be educated
The modes	• Farming and decontamination practices exist as **caring** and **denial** • Farming and food sale regulation practices exist as **caring** and **domestication** of farming into regulation	• Citizen radiation knowledge production and employment – coherence • Citizen radiation knowledge production and compensation o ADR – **caring** or **domestication** o Direct – **denial** or **domestication** o Litigation – **conflict** and then **denial** at the end for a resolution o As a whole – **separation** of practices	• Lab practices are eventually **domesticated** into website practices, which are themselves **domesticated** with MoA practices • Website practices are at times **separated** from government practices • CRMO practices are **denied** by government website practices and the comprehensive monitoring plan	• CRMO avoids conflict with local government – adopt a mode of **care** • The practices of the Mothers CRMO and the school principal – **between care and denial.** • Mothers CRMO and decontamination practices – **denial and then domestication**

Table 7: Summary of cases described and their modes of syncretism

7.4.1 Syncretism and technologies of [planning and] recovery

My data supports the idea that there is a bias towards the appearance of purity and coherence (Law et al., 2013) in the responses to a contamination emergency. The tools that are typically used to manage such responses –the 'technologies of recovery', include not only 'templates, checklists and guidance documents' (Easthope & Mort, 2014: 138), but also other inscription devices such as legislation and standards. Emergency plans and post disaster reports have also been described as 'fantasy documents' (Clarke,1999, Birkland, 2009, Deville, 2021, Easthope 2018). This is because they are created and disseminated for rhetorical purposes – to give the appearance of having done something, so perhaps it might be possible to speak of 'fantasy coherence', underpinned by nuance and situatedness.

The creation of technologies of (planning and) recovery fosters the appearance of coherence in a situation which is simultaneously <u>non</u>coherent, messy and uncertain. Remembering that neither coherence nor noncoherence is objectively a good or a bad outcome, it is possible to see that there is a certain logic to the tendency to want to achieve coherence in emergency management. Such technologies 'work within a wider context of disaster planning aimed at bringing order where much is uncertain, reactive and dependent on emerging relations between people, things and spaces' (Easthope & Mort, 2014: 135). Contamination events are messy and uncertain, but the tools that are most often employed to manage them deploy a desire for purity because this makes things look less complicated, clearer and therefore manageable.

> The work done when creating recovery plans and undertaking the 'recovery planning process' is important. The doing of gathering information, co-ordinating resources, exploring problems is useful. It generates technologies that may last more effectively than localised, perishable examples. However, the official technologies of recovery are often informed and directed by only one of many narratives. Both this absolutist narrative and the resulting reduced products are derivative; the product of one distilled account which crowds out many other knowledges and renders some narratives invisible. This is deliberate and is done so that the resulting tools and checklists can be applied to anywhere in the UK and to 'any' emergency planner. (Easthope, 2018: 236)

Generic document templates and standardised ways of doing things possess a certain normative good in that in theory at least these documents and their associated practices are designed to be applicable in multiple places meaning that they can travel easily – this is a useful property for strategic and overarching plans and arrangements that need to cover a variety of spaces and places. The denial of impurity is built systemically into certain processes (such as the compensation and decontamination processes, which include standards relating to methods, devices and actors of practices) and objects (e.g. legal instruments[28], emergency plans, guidance documents etc) and there are structural and procedural instruments and technologies that influence whether the mode of syncretism is harmonious or contentious.

A key practical point is that hyper-localised documents might be extremely useful in one situation or place but 'perishable' elsewhere, whilst very generic documents might travel well but don't really fit in anywhere immediately without tinkering. Stringent adherence to a generic plan or to a predefined format (for example the direct route to compensation) immediately points towards denial and / or domestication – other practices just do not fit into these systems and therefore their noncoherence is either ignored or they are required to be domesticated into the system and subsumed by it. So different kinds of syncretism seem to operate on different scales, with denial, domestication working on a larger scale, but undergirded by localised acts of care and collapse.

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[28] To provide a relatively recent example from my own professional experience during the response to COVID, I spent many hours on different days trying to fathom whether in the updated public health legislation that had just been enacted in England, a trolley service on a train was classed as a 'take-away' meal, and also how to accommodate the non-coherence of the laws and guidance of England, Scotland and Wales in relation to a train crossing borders in respect of mask wearing, how distant 'socially distanced' was, whether food could be served and so on. Accounting for non-coherence is not straight forward. The positions of Scotland, Wales and England were all individually at least nominally coherent and made sense. Incoherence was not the issue, but addressing the mutual non-coherence of the responses to COVID between the different nations *was*. In many cases the end result was often denial for example by picking the requirements of the nation where the train spent most time, or the most restrictive position, knowing that the less restrictive position would be accommodated within that.

7.4.2 Multiplicity, caring and syncretism

My cases showed that multiple modes of syncretism frequently operate at the same time (or sequentially) and in the same space between the different actors present. For example, whilst practices of governmental and organisational structures, enacted through emergency plans, legal instruments and guidance documents frequently work to foster coherence by ignoring or domesticating noncoherent practices, this was often underpinned at a local level by acts of care and tinkering to make things work in practice in that space. However, it was sometimes difficult for me to pinpoint exactly which mode of syncretism was at work. This highlighted to me that these labels, in particular 'care,' can strain a little. For example, is it really possible to call the ADR (Alternative Dispute Resolution) compensation process caring?

There are three different routes to compensation. It is possible to see that is a space for people to be in conflict, to say, 'I don't agree with you' via the normal litigation route. There is also an opportunity to go through a sort of sanitized process via the normal claims route. In this, compensation only follows if you domesticate your evidence into the prescribed sanitized and bureaucratic process. And then there's ADR, which is more of a negotiation and involves mediators. I suggested this was syncretism in *care mode* – there is space to manoeuvre because there are mediators, which suggests adjusting things and working for both parties, and also there is flexibility in the kinds of evidence that can be presented. However, the entire process (all three routes, not just ADR) is premised on an imbalance of who gets to be in those spaces and who defines what goes on in those spaces (see next section for more on this). ADR is still controlled by those with legal training and practices, and it is likely that some individuals in those spaces will be much more familiar and comfortable in them than others. There is a long lineage of thinking about care in STS. This work engages with critical questions about what doing care is about, the ethics behind it and who does it (de la Bellacasa, 2011, see also Mol, 2006 and Murphy, 2015). Care is therefore a tricky label to assign.

Care in syncretism suggests parity between the parties concerned – both work to gradually make adjustments that keep things in balance – this could ultimately be risky though because it might not be clear who is responsible for the end outcome of the practices working together. Care takes work because decisions have to be made again and again to maintain that balance, whereas denial and domestication smooth things out, limit the numbers of decisions needing to be made and make work 'easier' in the long run to a certain extent because things are not only temporarily in balance. In this light then ADR is not an example of care at all, because although there is some tinkering and tweaking and balancing going on, there seems to be an imbalance of agency between the parties present. So, what does or could care in disaster management actually look like? Is it about attending to local contingencies and situatedness in plans? And can it ever really do that in sufficient detail whilst still adhering to overarching organisational structures and plans?

It was clear that actors at a local level (e.g. the local government officials coordinating decontamination teams and food regulation permits), sometimes attempted to account for local deviation and non-coherence with the generic practices outlined in the documentation and guidance. For example, at the school there was an attempt to find other means of preventing children from entering a space, which according to one practice was 'decontaminated' and according to another was 'contaminated'. The work around involved removing the soil to install a fence meant that both positions were held simultaneously. The area was both formally checked off as decontaminated by the decontamination process, and it was also clear of contaminated soils once the new fence was in. It is notable that flexibility and making affordances are made easier if acknowledged in guidance documents. This was evidenced in the negotiations that took place on the farm in relation to the depth of soil being removed and the use of fertiliser, which are areas up for discussion according to the guidance itself.

My data also characterises how modes of syncretism can also flow into each other and happen together. The cases highlight transitions, overlaps and the coexistence of multiple modes. This means that these are not necessarily mutually exclusive, they coexist in spaces in a way that's materialised but not necessarily systematised. For example, in the case from the one school, the fact that there now is rope and signs, but that they have not been put up is material evidence of the fact that there is a tension between multiple modes and that care and denial are still sitting amongst each other. In the case of the school where a sign had been put up we can see care sliding into denial before the contamination data generated by the CRMO was finally domesticated into the decontamination system. In the case of the compensation system, nearly all modes are visible within the system as a whole. Even in the initial example provided by Kenens et al. (2022), what she describes as 'separation', could also be seen as continually changing and shifting modes of syncretism, negotiated between citizen science groups and local government officers. This is interesting because it shows the possibility for a more collaborative approach which provides a space for different knowledge practices.

In my examples, however, I also saw that a drive for coherence amongst practices was also visible amongst CRMOs and other citizen activity, and not just government organisations or more formal institutions or teams. Despite initial challenges to data collation arising from the non-coherence of data practices in each of the labs, they and the CCD website worked together to make their data production and collation and display practices coherent with each other and also with data categorisation practices from the MoA, in turn informed by those from the FAO. This domestication and alignment of practices was ultimately necessary to meet their goal to enable Japanese citizens to be able to readily access the data from multiple labs without having to go to multiple websites. Likewise, domesticating farming practices to accommodate the requirements of the local government permit process was necessary because it achieved the end goal and allowed Nishimura-san to sell her wild garlic.

7.4.3 Spaces and syncretism

The desire for coherence and purity (Law et al., 2013) is important and this desire can also be linked to the space(s) of practice. Spaces are important actors in assemblages. They influence which mode of syncretism transpires and who gets to be part of the syncretic process. As well as examining syncretism from the perspective of the actors or practitioners who might/ might not desire coherence, further attention should be paid to the spaces of radiation knowledge making. As seen in the examples, the coming together of practices might be in a tangible space or 'region' such as in a school, court or farm, or it might be in a less tangible space such as a website or other 'network' of things that are geographically dispersed (Mol & Law, 1994). Each of the laboratories contributing to the CCD website for example is a region in itself, but then also part of a network of disparate labs from across Japan. Space is important because different actors have different levels of authority about what goes on in those spaces. For example, a citizen is more likely (although not always) to have authority about the practices which take place in their own home than they are to be able to influence the practices that take place in say a courtroom or in a national government ministry. A citizen's group can control what they put on their website but is unlikely to be able to influence other organisations' websites.

Ulrike Felt's description of spaces as something that is 'being brought into being through relations and practices', draws attention to how spaces might define practices and vice versa (2017: 5). Her position makes use of Henri Lefèbvre's work, which highlights three dimensions of spaces – the material and physical qualities of the actual space, their discursive representation and the lived experience of spaces (1991) – as well as four characteristics of spatial practices, two of which are most relevant for this discussion. The 'appropriation of space' is concerned with how spaces can be or are used or occupied by certain people and objects and speaks to how spaces allow some activities to happen but exclude others. Another characteristic is the 'domination of space' which relates to who is able to determine how the space is used or occupied.

This is productive line of thought in regards to syncretism. It makes clear that some stakeholders have the power to determine who or what occupies a given space and what happens in it. This has implications for the different spaces of radiation knowledge making. For example, Nishimura-san is the owner of the farm in the first example, and she was able to assert her agency in relation to her farm and her farming knowledge about the growing habits of the plants she cultivated, to convincingly confront the practices of the decontamination workers. This resulted in less of the fertile top soil being removed which was better for her plants. She was also able to challenge and then deny the use of fertiliser on her farm because it would have spoiled the taste of her vegetables. However, she was obliged to be domesticated into the timings of the vegetable testing regimes because that was a requirement of getting a new permit, despite the non-coherence of this with her plant tasting practice. Nishimura-san was able to exert her authority in this space in a way that might not be possible elsewhere. It is important to point out here though that whilst Nishimura-san's practices are relatively confined to her farm, and where she sells her product, she has to domesticate it into the work of the permit provider which is taking place in multiple locations.

In contrast, Matsumura-san had very little authority in the schools that she was monitoring in. First she had to seek permission to be there from the local school board, then she negotiated with the local decontamination team about which areas required further decontamination work. Most of the authority to welcome or deny practices in school grounds lies with the principal of the school who denies both the CRMO monitoring practices as well as the decontamination practices of the local government officials. And whilst Matsumura-san, the city decontamination teams and the school boards are practicing in a network of schools, the actions of the principal are concerned with just one place – their individual school. However, it could be that it is easier to allow flexibility in some contexts, let's say in an individual negotiation with an individual farmer as compared to a school, where with teachers, school boards, parents and children to work with. It's a more complex situation. There are more actors that would need to be considered in order to allow for that flexibility.

The school example highlights that multiple interest groups and practices can be linked to the same space. In contamination events, different actors will be concurrently performing their practices in various places at the same time – for example in control rooms, in evacuation centres and in peoples' homes. The syncretism that is achieved when practices come together in those spaces is not just about coherence in those specific places at that specific time, but is also linked to wider coherence with practices in other regional or networked spaces.

The final determination of what mode of syncretism happens 'in practice' will be determined by those performing practices in those spaces, whether the practitioners desire coherence or not, whether they are part of determining which mode prevails, whether they agree on the outcome, and whether they have any agency to challenge it in the case of disagreement. The material 'things' of the practice can also act; think for example about the behaviour of Nishimura-san's short-rooted plants that don't reach down into the uncontaminated soil, or the website that guides data entry administrators to standardise data production. Here again legal instruments and guidance documents heavily systematise which voices are heard. This is because they can establish responsibilities in particular spaces and rights and obligations for particular individuals (e.g. which organisations are responsible for which monitoring, or who is responsible for what kind of decontamination).

For countries like the UK and Japan, which have signed up to the Århus Convention, there is an obligation on the part of the state to monitor and make available information about environmental hazards (including radiation), and there is also a right for citizens to monitor for themselves (and for that data to be taken seriously) if they believe the state is not meeting their obligations to do so (Berti-Suman, 2021). Those formally responding to emergencies are part of existing structures which have power and influence in certain spaces. In the UK for example, existing legislation, disaster response structures and ways of working already harmonise the practices of emergency responders to a certain degree – although this is an active and ongoing process in itself. The tools that foster coherence at a strategic level include, for example, the Civil Contingencies Act (2004) which requires certain named organisations to work together, JESIP (the Joint Emergency Services Interoperability Principles[29]), which outlines a set of principles that certain blue light responders are expected work to and the Civil Contingencies Lexicon, which provides a glossary of terms and the ways that they should be used for consistency. Without dissecting each of these objects in detail, it suffices to say that these tools for consistency and coherence of practice work within different spaces and apply to different agencies in different ways. Coherence between different entities can make a difference to 'how communities interact and find value in each other's actions' (Petersen et al., 2017: 312). The socio-materialities of these entities (laws, guidelines, principles, shared lexicons and so on) informs the potentials kinds of syncretism which are more (or less) likely to occur amongst those stakeholders and in the places of emergency response practice.

7.5 Conclusion

These observations point towards the potential for more than one way of doing syncretism and the fact that doing radiation knowledge production in emergencies will involve multiple practices and therefore multiple opportunities for syncretism(s). Syncretism depends on the practices, the practitioners, the spaces, and the authorities or agency of actors within those spaces to act in different ways. Readers familiar with common themes in STS literature will not be surprised about this as the suggestion that there are multiple ways of doing things, that things are always a bit messy and less coherent than they are presented. The difficulty is then marrying up what this might look like to practitioners of emergency management, public health and radiation protection (and similar allied professions) working to put in place the response to a contamination event, the impacts of which might be felt for months, years or generations. This has implications for thinking about how official knowledge making practices might work or not alongside other practices.

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[29] https://www.jesip.org.uk/joint-doctrine/principles-for-joint-working/

There is a tension here. How might those with a professional interest in making arrangements for the assemblages associated with a contamination event be open to noncoherence and impurity (the messiness), but still try to have a plan to control it in a way that makes sense and is actionable? Although denial and domestication seem to dominate the inscription devices of disaster planning and response, perhaps there might still be room to develop these plans, documents and arrangements more *care*-fully.

One of the ways that becomes clear is whether there might be a way for professionals to make space for and support the efforts by other groups (particularly in the volunteer sector, and citizen scientists / radiation monitoring groups) to domesticate their practices. I had several examples in my data (not just that presented here) of groups willing to domesticate their data practices into those performed by other organisations, but the domestication potential being ignored. Conversely at least one group intentionally wanted to keep separate their data practices from those undertaken by the government because that way they felt able to hold other formal institutions to account. It is possible, as Kenens at al. note, to 'live together apart' but living together, in (non)coherence might be possible too.

A second and more obvious point is that this has implications for thinking about how both to build the potential for coherence into response arrangements during the planning phase (e.g. before an incident), whilst also building into plans and guidance documents opportunities for 'care' which might account for different practices and situated knowledges. This means making space for different ways of knowing things, different cultures, different formats and so on. The flexibility that was built into the decontamination system benefited both the government officials in charge of disposing of and replacing contaminated soil, as well as Nishimura-san who was able to maintain as much fertile substrate as possible. Had there been a hard and fast rule about always removing at least Xcm of soil, it is easy to imagine that a 'care' might not have been present in that interaction. This highlights the importance and agency of different people (even those working for different governmental organisations) that have agency to be part of moments of care and caring, even if ultimately working as part of a system that is domesticating or denying at other times. Some stakeholders have more agency than others to influence the mode(s) of syncretism that occur(s), to have a voice in those spaces or to work collaboratively with others in the same spaces.

The following quote from a citizen group leader summarises some of the issues and potentials for closer working arrangements between stakeholders (and not just the typical citizen – government relationships often addressed in literature), as well as some of the limitations of driving collaborations from a top-down direction:

> The big issue is that the government feels like it is under no obligation to try to reach out to CRMOs – they [the government] feel like they [CRMOs] have no acknowledged utility or that they have requirement to do that [acknowledge CRMOs in their plans]. But it happens on the periphery. [...]Fukushima Dialogue[30] makes an interesting case. This was one of the stronger instances where the citizen's viewpoint is brought into alignment [alongside other organisations] and as a result government might make changes. But this was not really independent. It was driven by the ICRP. It was a strange bastard process. (Personal communication, August 2022)

Key questions emerge for professionals involved in the response to contamination events, such as: How can you create space for moments of care to sit alongside moments playing by the rules? How can you support community endeavours to domesticate their knowledge into the formal structures of emergency management, radiation protection and public health in a way that meets their (community) defined needs? Is coherence across practices always necessary – could you allow the messiness of different practices to be acknowledged? Those involved in formal structures and organisations are perhaps more likely to be articulated within the technologies of recovery and therefore might have more agency (individually and collectively) than the communities they represent. All kinds of involved parties (institutional or community-based) may however make positive changes that celebrate the messiness or pave the way for collective coherence when consistency is required. The question thus remains: How might existing formal structures of emergency management include a more diverse range of practices by design?

[30] Fukushima Dialogue web pages on ICRP website: https://www.icrp.org/page.asp?id=189

PART THREE: MAKING SENSE

8 Conclusions and implications

8.1 Introduction

I begin this conclusion by recapping the salient points from each of the empirical chapters. The written nature of a thesis has demanded that the account of this work has been presented in a linear form, even though, after the thesis' groundwork was set with Assemblages, the three main empirical chapters could have come in almost any order: they all relate back to the notion of socio-material assemblages and also to each other. The necessity of having to tackle each concept sequentially in neat chapters simplifies the relationality, complexity and multiplicity at the heart of the subject matter as a whole. This enables me, in the second section, to bring the consequences of my analysis much more explicitly into dialogue with professional practice and to draw out the implications of the thesis for those involved professionally in the planning and response to contamination events. I follow this with selected examples from the UK response to the COVID-19 pandemic.

This thesis therefore also operates on a practical level by providing contributions to how those charged with managing such events and their ongoing aftermaths conceive of the making and use of scientific information in contamination emergencies in their plans and practices. The central concern of this second section is to consider how STS concepts I have engaged with (primarily assemblages, compar-isons/-ators, qualculation and syncretism) can help disaster management, public health and radiation protection professionals to think differently about and work differently with devices for making and using science in contamination emergencies.

8.2 Chapter Review

Chapter 4, ***Assemblages*** sets out an STS account of how to think about the devices and assemblages that make contamination knowledge. It begins to ask, how are assemblages of radiation knowledge created, defined and negotiated?

During fieldwork, my interlocutors tended to use the term 'device' to talk purely in terms of a technical artifact, a neutral and objective tool which establishes critical data about radiation. I use STS theory to examine these devices. Rather than thinking of technologies of radiation measuring and monitoring as non-human technical tools that objectively represent radiation as it is 'out there', I argue that we might think instead about them as being part of a wider network (assemblage) of heterogeneous socio-material human and non-human entities that come together in patterns and arrangements to produce particular kinds of radiation knowledge, that suit particular needs and purposes in particular places and at particular times. These arrangements can be political – there have been choices about what to include and exclude from the arrangement and therefore what is allowed to matter. These arrangements are never finite though – they are always in the process of becoming because of the ways in which they interact with other assemblages and practices in a bigger network of circling and related assemblages.

Situating the technical tools of knowledge construction in emergencies within these STS concepts prompts us to ask questions about where the boundaries are drawn around radiation monitoring devices, who or what might define, compile or stabilise these boundaries, the nature of the relations between the entities in, the kinds of (often calculative) work done by them, and how time and place act in the practices of radiation knowledge construction. This is helpful because the responses to emergencies and crises involve many different technologies (tools that facilitate detecting, measuring, monitoring, mapping, communicating, representing and so on). The socio-material aspects of such technologies are rarely acknowledged in the professional discourses of incident management that I have worked in. An ANT-sensitive/assemblage approach directly acknowledges the socio-material arrangements, relations and practices of technical tools. This can be useful for practitioners in government (in particular those working in resilience, public health and radiation protection), because it gives insight into *how* particular devices and measuring and monitoring arrangements have come into being and what else is included beyond the technical. This can be used as explanation for what exists, for thinking ahead to how assemblages may be shaped in the future and whether this could be done more purposefully.

Devices-as-assemblages operate in different spaces and are often part of networks of knowing which extend outside the bounds of a physical space. As well as being discussed in Chapter 4, the notion of space is also picked up in the later chapter Syncretism and Coherence; the sites and spaces of radiation knowledge making are important; radiation knowledge making is done in specific locations and this has implications for who has access to those spaces and what makes it into the assemblage.

Resilience and emergency management work involves imagining futures in different ways. For example, potential futures make it into the design of emergency plans, the development of apparently plausible and challenging exercise scenarios and the set-up of physical spaces of emergency management, such as control rooms, or multi-agency workspaces. These could all be enriched by socio-material assemblages thinking.

Chapters 5 (***Comparisons***) and 6 (***Qualculation***) collectively address two questions. First, what kinds of calculative work takes place in creating radiation knowledge? And second, how and when do radiation knowledge assemblages produce knowledge and meaning from radiation data?

Comparisons focuses on nonhuman elements of radiation comparison assemblages. Radiation knowledge production is swaddled in numbers and calculations. Numbers need to be put to work in order to make sense. Making sense of numbers is about ascribing some kind of meaning to them and understanding the active part that they play in knowledge making assemblages. Comparisons are a common way of presenting radiation numbers to do just that. Comparisons are present everywhere in radiation knowledge production. I even argue that it is impossible to make sense of the situation in Fukushima at all without comparing to other cases, to thresholds or to trend data over time.

I use Deville et al.'s notion of *comparator* to explore comparisons in my data (Deville et al., 2016). This kind of comparator is a particular kind of complex assemblage that creates, does and is shifted by comparison. The conventional use of the term is used to describe something fixed and stable, to which something is compared. I use the term **benchmark-comparator** for this kind of stable comparator, and **assemblage-comparator** for the more dynamic comparator described by Deville et al. Examining my radiological contamination data via assemblage-comparators helped articulate what goes into creating comparisons. It highlighted the agency of both human and nonhuman actors in the assemblage and the dynamic tension between comparators making and being shifted by the comparisons they make. A radiation knowledge assemblage-comparator might include humans, such as residents, science communicators, business people, and policy makers, as well as nonhumans, such as technical devices, funding schemes, access to the data subject, collection methods, data gathering tools and visualisation tools. Assemblage-comparators are then fed by data about spinach, ambient air, sea water, human bodies, and are finally calibrated through the process of defining the cases that are put into relation with each other.

In an act of 'noticing' (Tsing et al., 2017) something seemingly mundane in Japan, I closely examine the construction and use of 0.23μSv/hr, a common threshold and point of comparison in relation to radiation in Fukushima.0.23μSv/hr is used both in relation to decontamination work and also to make sense of ambient radiation levels more generally. The key argument in this chapter is that thresholds perform dual roles in acts of comparison. First, they act as part of the assemblage-comparator, i.e. they are part of the assemblage of entities that is drawn into making the comparison. They also act as benchmarks within the comparison – ready made off-the-shelf cases. They operate as a fixed case against which to make a comparison, because they are easy to deploy and require relatively little explanation. In short, I assert that thresholds function as complex but important stabilisers of [radiation] knowledge production (often beyond their original intended purpose), because they work inform both what is being compared and how comparison is done.

Qualculation offered a way of examining more generally the process of how judgements and conclusions are arrived at. Qualculation is the process of extracting qualculative resources from where they are normally found and putting them together into a single space, where they can be manipulated and ordered, resulting in a result or conclusion (Callon & Law, 2005: Cochoy, 2008). I used qualculation to work with three cases from my data in terms of the process of translating (Callon, 1986; Latour, 1988) something out there but intangible to the human body, into what is happening during the process for making scientific knowledge about radiation contamination emergencies.

Thinking about radiation knowledge making as the result of a process of qualculation enabled me first to closely examine human actors within qualculation assemblages, the roles that they perform within the qualculation process, and how these evolve. My contribution here is to suggest four different functions performed by human actors in the qualculative process and assemblage: resource generators, gatekeepers, qualculators and qualculation users. My assertion is that different stakeholders able or excluded from being able to participate in any one of those four roles at any given time. Certain individuals and organisations emerge as more or less likely or able to become resource generators, gatekeepers or makers of qualculations and their abilities to take on any of the four functions changes over time. Typically, citizens are only able to perform the role of qualculation user in the initial response to an incident, whilst actors embedded in formal structures of emergency management are more likely to have greater access to making, accessing or using qualculative resources needed to make a judgement. As time passes the ability of any one stakeholder to participate in any of those roles is subject to change.

I then examined nonqualculation – when a qualculation is not achieved. Nonqualculation occurs as a result of the removal of qualculative resources (rarefaction) or else the overwhelming bombardment of such resources (proliferation), both of which result in qualculation not being achievable (Law & Ruppert, 2013). I proposed that both rarefaction and proliferation start from a place where qualculation is already achievable, which is not always the case in an emergency. My point is that emergencies and crises are characterised by unresolved uncertainty and novel questions; the possibility of achieving qualculation is not a given at the start of a contamination emergency, but rather fluctuates across time, space and between stakeholders. Qualculative resources are limited at the start of any kind of emergency, therefore the social and material infrastructures required to support data generation need to be constructed first. Probing the construction of scientific knowledge in response to an emergency with qualculation, highlights that different stakeholders are more (or less) able to achieve qualculations in different spaces and times. Thinking qualculatively about radiation knowledge production is useful in that it frames the making of understandings about radiation contamination not necessarily as providing a static view of an objective way of knowing or thinking about radiation, but as the product of a process involving negotiation, relationships, priorities, access, pre-existing structures, trust and expectations. The spatial and temporal aspects of the making scientific knowledge by both human and nonhuman entities is brought to the fore.

Chapter 7, ***Syncretism and (Non)Coherence*** unpacked how and where different radiation knowledge making practices work together using the concept of syncretism outlined by Law et al. (2013). My data showed that multiple layers of syncretism can happen simultaneously or chronologically, i.e. that there is no single way of combining practices in a given space. Both human and nonhuman actors in the radiation knowledge producing assemblage can influence the kinds of syncretism exhibited. This directs us to attend to which actors (human and nonhuman) have agency in the syncretic configurations that come about, which kinds of syncretism might come about in particular spaces, and which actors are able to resist forms of syncretism where their practices and knowledges might otherwise be marginalised, or prioritised at the expense of another form of knowing. Again, spaces and their materiality are important in determining which mode of syncretism transpires and who gets to be part of the syncretic process. Syncretism therefore depends on the social practices and practitioners, but also the spaces of practice, and the authorities or agency of human and nonhuman actors within those spaces to act.

In any network of practices, relations are always syncretic (Law et al. 2013). In my varied examples practices were driven by different aims, were made of different constituent parts and different things were at stake. There are multiple ways of *doing* 'knowing' about radiation and about responding to and potentially recovering from a contamination event unfold. However, these practices do not exist in isolation – they relate to each other. My data showed that different radiation knowledge making practices not only relate to each other, but also to other practices, such as getting compensation, providing a safe space for education, and producing food, and so on. This resonates with Petryna's (2013) biological citizens in post-Chornobyl Ukraine and Belarus who lean on their biological political status to gain access to medical care, compensation and employment opportunities.

My key argument in this chapter is that that [radiation] knowledge producing assemblages and their associated practices exist alongside multiple other knowledge making assemblages and practices, and that there is no single logic that defines how these interactions have to be resolved. Individuals and communities of knowledge production working within official response structures can influence how such assemblages accommodate (or not) other practices they might encounter. There is an opportunity for professionals of emergency management to make space for and support the needs and efforts by other groups to domesticate their own practices into official practices, and also to act with care in relation to these different practices. Might practitioners of official emergency responses be able to build potential for different kinds of syncretism (e.g. different ways in which different practices can come together) into response arrangements during the planning phase (e.g. before an incident)? Such thinking should also address how to build into plans and guidance documents flexibility which might account for different emergency practices being enacted, the specifics of which cannot be anticipated in advance. The questions then are around how to create space for moments of care alongside moments of playing by the rules, how to support community endeavours to domesticate their knowledge into the formal structures in a way that meets their (community) defined needs, and whether coherence across practices is always necessary. And if not, how might we embrace the mess?

There is a tension between the ways in which people handle the messiness of multiple noncoherent emergency management activities which are created in practice, and the simplified versions of emergencies that make their ways into emergency plans and response arrangements. I asked whether it is possible (or even desirable) for practitioners of emergency management, public health and radiation protection to acknowledge the noncoherence and messiness of science knowledge production in emergencies, whilst outlining actionable arrangements for responding. A homogenised imagined future contained in an emergency plan is unlikely to reflect the complexity of life when that plan is enacted, nor is it likely to reflect local complexities anticipated by local practitioners. Thinking about messier futures can give a voice to actors with different priorities to those officially working in response and also reflects the messy and situated character of any emergency. More work is needed to establish how social scientific future-thinking and emergency management practice might productively (and perhaps syncretically) come together.

8.3 What does this mean for me?

Emergencies present particular times and spaces characterised by uncertainty and for which novel knowledge producing assemblages are required. Whilst each chapter uses a concept as a lens by which to consider knowledge making in emergencies from a particular perspective, they build on each other to highlight a complex ecology of factors that influence for example, which entities and practices generate knowledge, the how, where and when of making it, and finally how it is operationalised alongside other knowledges and practices. Taken together, I argue that in any event characterised by uncertainty socio-material assemblages of human and non-human entities operate in particular spaces and times to produce particular kinds of knowledge, which address particular concerns or questions. Second, that thresholds function as complex stabilisers of knowledge production by informing both what is being compared as well as how comparison is done. Third, that human and nonhuman actors can perform different roles within the knowledge making process, but opportunities for actors are not equally available for all actors, at all times and in all spaces. And finally, that knowledge producing assemblages and their associated practices exist alongside multiple other knowledge making assemblages and practices, and that there is no single logic that defines how these interactions have to be resolved. These arguments speak not only to the direct case about making radiation knowledge in Fukushima since 2011, but also speak to wider debates about the complexities of knowledge construction, the makers of science, the tools and technologies of scientific knowledge production and practice.

The empirical chapters summarised in the paragraphs above describe (of course always partial and always situated) stories about life and living in Fukushima, that contribute to the broader empirical recording of the impact of the disaster on the affected communities in Japan after the radiological events of 2011. The thesis has also contributed theoretically to STS the conceptual frameworks I worked with. I have argued for and set out how Qualculations, Comparators and Syncretism could be refined or extended.

I now set out how these arguments work together, what that means beyond Fukushima and what this might mean for me.

The thesis has implications for organisations, institutions and individuals charged with planning for or responding to contamination events (which can include chemical, radiological or biological contaminants). I consider how they might take on board the consequences of using theoretical concepts alongside data from Japan. My final research question asks: how might disaster management, public health and radiation protection professionals take on board an STS sensitivity to the making and use of science in contamination emergencies? This follows in the footsteps of similar projects concerned with the application of STS lessons for management practice (Duret et al., 2000) and for scientific research (Valve & McNally, 2012). As the world emerges from the COVID-19 pandemic, I suggest that now is a timely moment to do the same for emergency management. How can, should or might emergency management (itself a socio-material assemblage of humans and nonhumans) reconfigure the way scientific knowledge is understood to be produced in emergencies?

8.3.1 Human and nonhuman actors

I have established complexity and diversity within the assemblages of radiation knowledge making (and more broadly science knowledge making in emergencies). When we look at a handheld radiation monitor in our palm or a fixed radiation monitoring post on the side of a street next to a rice paddy, it becomes possible to see what might have been previously occluded or obscure – the links connecting this technical tool to its designers and users, to maintenance budgets and acts of upkeep, to ways of doing data generation and analysis, to networks of data collation, to different stakeholders (government agencies, citizens, parents, farmers, decontaminators, scientists, journalists etc) performing different qualculative roles (resource generators, gate keepers, qualculators and qualculation users), to the tools of dissemination including websites, maps, pamphlets and lectures, and to decisions about what is important to measure and monitor in the first place (unruly children, spinach, alleyways at the sides of buildings, bamboo shoots, laundry and air conditioner filters).

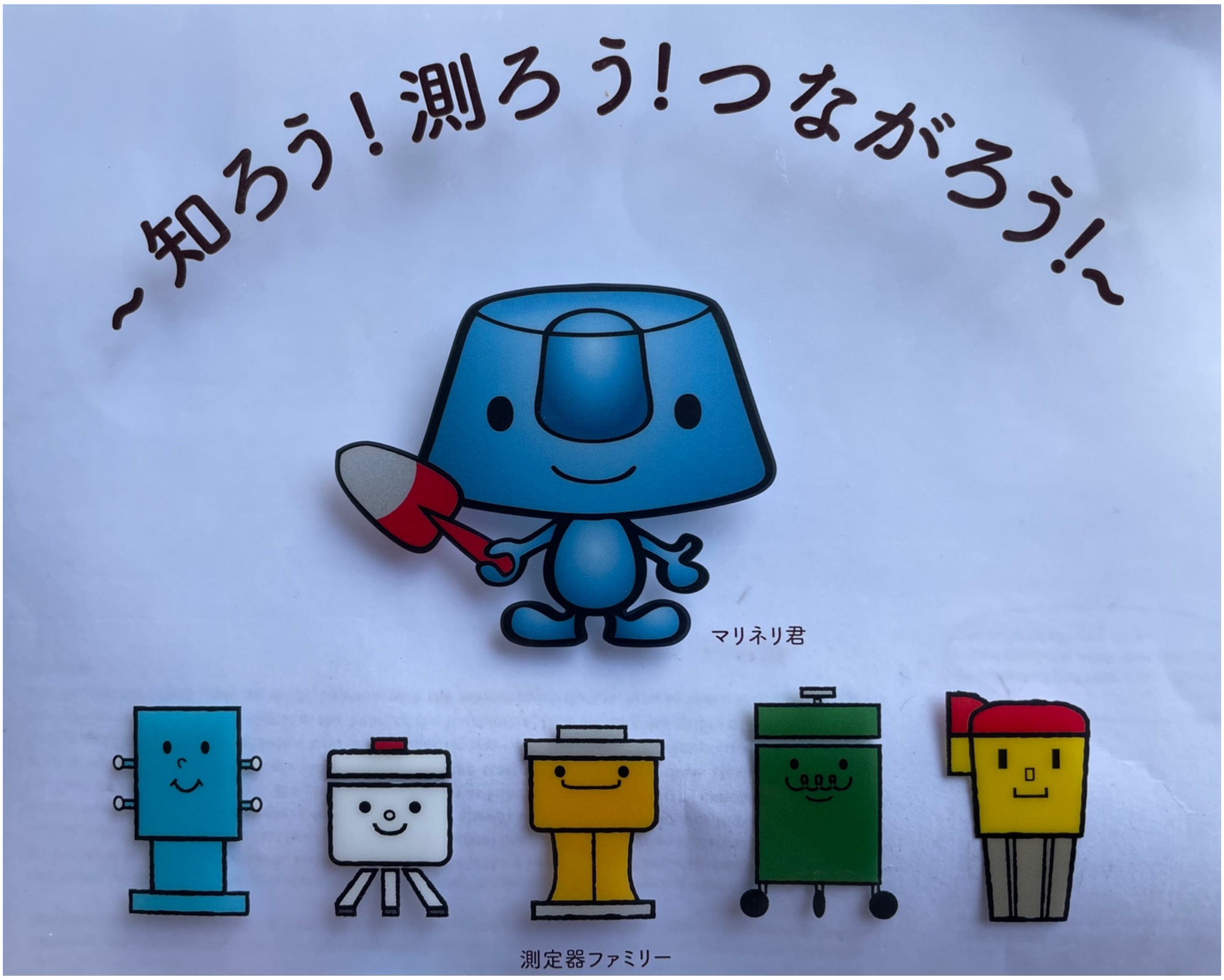

Figure 55: The Japanese propensity for anthropomorphising inanimate objects highlights the liveliness of nonhuman things like these different models of radiation detectors. The main character, Marinelli says, "Let's know! Let's measure! Let's connect!".

I set out with a commitment to symmetry in this thesis. I have tried where possible to provide a diverse range of cases in this study. This decision has a practical and theoretical basis, and is also relevant to the overall contribution of the project in terms of rethinking who and what makes science in emergencies. I wanted to bring symmetry to my research, not just by acknowledging the nonhuman within assemblages (which I discuss below), but also by trying to avoid privileging the stories and perspectives of any one kind of human actor.

In part this was because there were so many different individuals and groups making and doing radiation knowledge that to highlight the perspectives of just one or two of them would been very reductionist and a poor reflection of the variety of stakeholders I encountered in the production of radiation knowledge in Fukushima. The second reason for doing this is also linked to the broader concepts that I used to inspect and think through my data. The notions of assemblages and comparators for example highlights the multiplicity of the actors (human and nonhuman) that enter the heterogeneous assemblages and networks of radiation knowledge production and sense-making. To concentrate on one particular kind of actor would obscure that multiplicity or hide certain kinds of human actors.

Although I use terms such as 'professionals' and 'citizen groups' or CRMOs, I do so very cautiously (and on a practical note, these terms should be read as being very broad ends of a more complex spectrum of actors) and acknowledging that in doing so I am drawing boundaries around what this means and who might or might not be included. Drawing those boundaries too severely had the potential to portray the situation after the Fukushima nuclear disaster (and also other disasters) as an overly simplified depiction of the public vs. the government, 'proper' scientists vs 'citizen' scientists etc. In contrast, I found that things were rarely clear cut and that each of these broad groups is made up of infinite subgroups, departments and varieties, and that individuals are also more complex. Scientists, government officials, and medical professionals regularly work with local individuals and groups to produce radiation knowledge. There is no clear line between two defined groups – it is more of a tangled web of assemblages working to produce radiation knowledge in different ways and with different people involved. Sometimes assemblage entities overlap – sometimes they are wholly separate. The empirical reality I observed in Japan included people with multiple layers to their 'identity': father-salaried scientist-weekend radiation monitoring volunteer, parent-weekday citizen scientist, retiree-former paid scientist-now radiation science enthusiast, father-foreign national-financial expert-radiation monitoring group founder, farmer-science collaborator-Fukushima enthusiast. I therefore would have found it both practically and theoretically challenging to draw the lines that such a dichotomous approach would require. Although the complexity of the different activities that might count as coming under the banner of the contested term 'citizen science' has been discussed elsewhere (e.g. Kenens 2021), I tried where possible to avoid using this term, lest there be confusion or assumptions about what I was including or excluding from it. My first point is then to stress the broad range of *human* actors involved in assemblages producing radiation contamination knowledge.

I also want to draw attention to the lively and active part that *nonhuman* entities within radiation knowledge making assemblages have in the production of radiation knowledge (and other scientific knowings about contamination) – see Figure 55. I have shown that things like the choice of technical tools we use, whether materially tangible (like radiation monitoring posts) or not (such as thresholds and standards, policies and legislation) have a direct impact on the radiation that is found, how that is understood and whether or not it is acted on. I invite those with a professional interest in emergency management to consider which nonhumans are active in their own professional work and the work that they do in for example categorising things into 'safe' or 'not safe', 'clean' or 'dirty', requiring remedial work or not, determining who does or is responsible for taking action.

The assemblages we as emergency planning professionals (who might also be mothers, fathers, academics, scientists, community activists, school governors, farmers and so on) are part of have a role in defining the boundaries of the responses to contamination events, who is impacted by them and how.

8.3.2 Multiple sciences

In emergency situations subject matter expertise is incorporated into formal emergency management organisational structures, documents and arrangements in order to generate scientific knowledge to support the formal emergency response. My analysis provided an explanation for why formal assemblages of emergency might management seek coherence, between organisations, documents and policy. One such reason is that it helps translate (although does not always produce) a plan conceived in one place into a similar plan enacted in another. This is evident in practices such as the production of joint 'top lines' briefs in emergencies. Top lines are a set of responses 'lines' for communications teams in different organisations to adhere to in relation to a given emergency and are produced jointly so that the information given out by the emergency management community sound coherent and consistent.

Another example of coherence being sought comes from a document describing the framework for an emergency response to a CBRN (Chemical, Biological, Radiological or Nuclear) or hazmat incident in part of the UK that I have seen in the course of my work. The framework outlines the lead government department's priorities after a CBRN incident and in one section it describes what Government Ministers would like or need to know about different aspects of a CBRN emergency. In relation to technology and science it is suggested that a single or unified version of scientific truth should be made available. But is a single version of the truth around science ever an achievable, or even desirable, goal?

Social sciences have frequently pointed out that 'a view of scientific knowledge as hard and fast, evidence-based, objective fact is flawed' (Büscher, 2013). There are multiple, sometimes competing and sometimes collaborative assemblages making 'sciences' in major contamination events. My data has made clear that radiation measuring and monitoring is not the same thing every time and in every place, and it is not *doing* the same thing in every situation. Although there may be political or management reasons for doing so, striving for uniformity and coherence between *all* versions of science is not always logical, because it assumes that all stakeholders are driven by the same priorities, are asking the same questions and answering them in the same way. Each assemblage is answering a situated question determined by the qualculative assemblage itself. Some assemblages emerge from within the formal structures of emergency management, others from outside.

Acknowledging this set of observations immediately highlights the challenge of seeking a unified answer. The scientific knowledge that is created is dependent on the questions that are asked, by whom they are asked and how they are answered. Even when the same questions are being asked, the answers might be defined using different parameters.

There is not an arbiter of the 'right way' of doing science that applies to all situations. Although in many official arenas, 'science' may be held up to be more rigorous (or just specific standards of what is acceptable – whether these are cultural decisions is another matter) – science is *done* in many different arenas, not just in officially sanctioned spaces by officially sanctioned assemblages. Scientific knowledges produced by different assemblages are subject to different logics for what counts as 'right', what matters the most and how accuracy is defined. There is no objectively 'right' way of doing radiation knowledge production that is demonstrably the 'best' way of doing things in every occasion and for every stakeholder.

8.3.3 Defining the problem and the answer

I now make a point about the ability of certain assemblages to operate in certain spaces and alongside other assemblages to make a qualculation. Iles and De Wit recently observed that who gets to define what the problem is informs the kinds of science underpinning the solution. They asked, '[w]ho has the power to identify 'the COVID-19 problem,' and for whom? Who has the ability to define solutions and judge pandemic trends? To say when it is 'safe enough' to return to factories and begin gathering in restaurants?' (2021: 659). I move their argument on by suggesting that it is not just a question of 'who' (i.e. human actors), but what (nonhuman actors) is part of the assemblage, and where that assemblage is able to operate. Different assemblages are able to identify both the problem and the solution, but within particular places and at particular times. This links back to section 7.4.3, which discusses how spaces can be or are used or occupied by certain people and objects, how spaces allow some activities to happen but exclude others and who is able to determine how the space is used or occupied. I contend that the spaces in which emergency management activities take place, the logics and practices that are undertaken, and therefore where certain kinds of assemblages producing knowledge come together, allow or deny other human and nonhuman entities from being part of the assemblage.

I propose that when an 'official' assemblage (Assemblage A) of emergency planners and responders (and their nonhuman counterparts) comes into contact with any other assemblage (Assemblage B – also constituted of stakeholders, technical devices, methods for doing science, institutional support and so on), there is an implicit (and even sometimes explicit) assessment of whether that Assemblage B is coherent enough for Assemblage A to take it seriously. And vice versa. This informs the mode(s) of syncretism they engage in. This has implications for who (which human actors in the assemblage) or what (which assemblage as a whole) is able (has agency, is allowed) in an emergency to: determine the kinds of questions asked of science, provide a response to those questions posed of science, and perform the four qualculative roles required to generate a judgement or decision. Some science making assemblages are accepted in some places, at some times and by some audiences, and not in other spaces, times or by other audiences. This is important in an emergency management context because some assemblages are given space and agency to operate (and produce certain forms of officially sanctioned) science. Alternative forms of science may be created by other assemblages, but these assemblages may be obliged to operate in different places and address different questions.

This is relevant to *how* and *when* the general public (or other specific communities) are expected or not (or expect or not) to make decisions relevant to their own lives and in which situations particular sciences count. In a broader sense I am talking about paying attention to which assemblages are able to operate to make qualculations, in which spaces and on behalf of whom. Early on in an emergency, decisions may be made by authorities on behalf of citizens and relating to spaces occupied by citizens – for example evacuating parts of Fukushima after the nuclear accident and displacing people from their homes, or conversely requiring whole populations to go into 'lockdown' to prevent the spread of COVID-19 and obliging citizens to stay in them. In both these situations governments took on the role of qualculator and citizens were obliged to follow the instructions provided. Later on in both situations, autonomy over the decision to stay of leave one's home was also (in theory at least) eventually handed back to citizens. Citizens created or were part of their own assemblages which incorporated scientific (and other) information to determine whether they returned to or left their homes.

The implication of this for emergency planning professionals is that there might be more room for thinking about which kinds of decisions might need to be taken on behalf of citizens (if at all), when citizens might be expected to (be able to) make decisions on their own, how citizens can be enabled to take decisions for themselves, and whether citizens feel like they have the tools to be able to do this. It also encourages us (at a local and national level) to confront not only the spaces in which influential assemblages *operate*, but also the spaces and domains that they have agency or influence over.

The production of any output in a disaster, whether that is knowledge about radiation, or a new bit of equipment, revised plan, new law or guidance note, is the result of complex assemblages including multiple technical tools, practices and practitioners coming together. As is readily acknowledged, culturally and organisationally, within the profession of emergency planners and responders, any response to a major emergency is a multi-agency effort. Therefore, this thesis invites us (I include myself in this) to recognise that there is already syncretism at play in emergency response. However, the way these assemblages come together and how they interact and relate to one another becomes 'institutionalized' (Valve & McNally, 2012: 471; also Easthope, 2022) in some places, through cultural practices and at times through legal requirements. This can create 'systemic incapacities' (ibid) for dealing with surprises (Stengers, 2000) and things that do not fit (Callon, 2007). In the UK for example, the Civil Contingencies Act (2004) mandates certain responders to collaborate with other responders at a local level, via Local Resilience Forums. Coherence is being fostered between some organisations and individuals, but not between others which do not 'fit' the institutionalised mechanisms seeking coherence. A recent review of the CCA highlights that voluntary organisations are not mandated to act under the Act, and Government departments ought to have a role in information sharing to improve '*alignment'* between national and local planners (Cabinet Office – UK Government, 2022: 20, my emphasis). Different modes of syncretism are therefore likely to be needed between organisations inside or outside those institutionalised boundaries.

Sheila Jasanoff invites us to acknowledge 'the partiality of scientific knowledge and to act under irredeemable uncertainty' and with 'humility' (2007:33). Technologies of humility, she notes, are:

> [M]ethods, or better yet institutionalized habits of thought, that try to come to grips with the ragged fringes of human understanding – the unknown, the uncertain, the ambiguous, and the uncontrollable. Acknowledging the limits of prediction and control, technologies of humility confront 'head-on' the normative implications of our lack of perfect foresight. They call for different expert capabilities and different forms of engagement between experts, decision-makers, and the public than were considered needful in the governance structures of high modernity. They require not only the formal mechanisms of participation but also an intellectual environment in which citizens are encouraged to bring their knowledge and skills to bear on the resolution of common problems. (Jasanoff, 2003: 227)

How might we as emergency management professionals act with 'humility'? One answer is to think about the kinds of assemblages for scientific knowledge making, boundary making, and decision making that we are part of and to play close attention to what is included and excluded from them. In which times and spaces do they operate and how to they interact with other similar assemblages? How might organisational structures and physical spaces of emergency management impact upon the kinds of science being made and what happens when there are multiple versions of science in circulation? How are the technical tools that foster coherence between some organisations and communities (e.g. tools for interoperability and information sharing (c.f Petersen et al., 2017)) preventing other groups communities from being recognised?

In short, what is the process for negotiating decision making in such unavoidable scientific multiplicity?

8.3.4 Dismantling

I now want to make some points about dismantling assemblages. My thesis showed that a significant amount of work goes into constructing assemblages of radiation knowledge (e.g. 0.23Sv/hr, the food monitoring stations or the networks of fixed radiation monitoring posts). They act as hubs for understandings and help frame the ways that people come to make sense of their potentially contaminated environments, bodies and foods. Having been established, however, there are three options for the future; these assemblages can either be actively maintained, actively dismantled or alternatively allowed to fall apart and decay.

Having previously removed from citizens the ability to participate in certain decision-making assemblages (e.g. the determination that designated parts of the prefecture would be subject to mandatory evacuation orders or decontamination) because of the health risks arising from contamination, authorities are obliged then to decide how and when to hand back decision-making to citizens. The removal of mandatory instruments for managing the emergency suggests, amongst other things, that citizens are ready, willing and able to make decisions on their own. If this is to happen, citizens need access to qualculative resources by which to make decisions and may need support to enable them to make qualculations on their own and on their own terms. The ability to make a judgement about radiation risk might now be tied up with other things when it is reinstated. For example, in Fukushima, a decision to return to one's hometown after the evacuation orders were lifted might also be influenced by access to ongoing financial support to live elsewhere, family attitudes towards returning, the cost of giving up a new life established since the disaster, and the availability of health, economic and social infrastructures in their old hometown, as much as or more than scientific knowledge about the radiological risk of returning. It makes sense then that decisions are no longer just about whether it is *safe* to return.

When I spoke to the local government decontamination team of the coastal city in Fukushima in June 2018, the infrastructures for decontamination (e.g. the tools involved, the teams carrying them out, the managers coordinating them, the officers giving educational lectures to residents) were in the process of being decommissioned. The assemblages were being actively dismantled, despite the manifest presence of contamination in various locations – contamination in places such as forests and mountains is directly ignored by the decontamination process itself, and elsewhere contamination remained, obscured by the very assemblages of knowledge creation that would otherwise identify them (thinking back to the contamination in school playgrounds or down the side of buildings).

Those professionally responsible for the management of contamination emergencies ought to think more closely not just about the active construction of key radiation knowledge assemblages, but also to consider how they might be appropriately maintained, when is the right time to start to dismantle them, how dismantling (or decommissioning) might take place and who is affected by the consequences of removing them. Such considerations will also need to apply to the maintenance and dismantling of assemblages outside formally constructed assemblages, such as those generated by citizen-driven initiatives, business and academia. Such considerations are of strategic, practical and social importance, particularly in radiological contamination events, where the risk and threat of harm posed by the contaminant can persist for years if not decades or more. Given that acts of calculation and sense-making often require comparative data, we might need the data and qualculative resources to be created now in order to be able to answer questions we might have in the future. How long should we need to maintain an ability to monitor and create knowledge about radiation, are our assemblages for doing so aligned to this and what is in those assemblages?

8.3.5 In concert

In this thesis I used concepts such as assemblages, qualculations, comparisons, and syncretism to provide a multidimensional, layered way of thinking about the making and use of scientific knowledge in contamination emergencies. I demonstrated that multiple heterogeneous socio-material entities come together to construct radiation knowledge in different places, times and for different purposes. I contended that human and nonhuman actors are active in the process of radiation knowledge creation, performing different roles and functions in the assemblage. I argued that these actors influence what is in these assemblages, where and when they operate, and what happens when they come into contact with alternative assemblages operating in the same spaces and times. However, I stressed that this agency is not afforded to all actors equally. I exposed tensions between different knowledge-making communities – the questions they seek to answer, the resources they have access to, and the extent to which they want or need to align their practices with others. Furthermore, establish that the that nonhuman actors, such as emergency plans, legislation, standards, thresholds and guidance documents simultaneously do stabilizing work within knowledge making practices. I explained that stabilization occurs spatially (defining where knowledge making occurs), temporally (defining when different knowledge making is possible) and practically (defining who or what is involved or excluded from the process and how practice occurs).

As well as contributing to social science debates about the social and materiality of collective knowledge making practices in general, my findings are directly relevant to professionals charged with planning for and responding to contamination events. I make clear that knowledge making in emergencies involves a multiplicity of knowledge making assemblages, their opportunities and limits in different places and times, and how they operate alongside other knowledges and practices. Building on from these observations I argue that certain responders and responding agencies are more likely than other knowledge communities to have ready access to resources for making judgements and knowledge about radiation. They are likely to be directly involved in the construction of stabilizing nonhuman actors (such as legislation, guidance and thresholds etc.), and are also likely to be involved in the de/construction of infrastructures of knowing. Professionals working in these arenas therefore have an opportunity to recognise the agency they have in determining the kinds of knowledges we have about emergencies and who and what else is involved or is denied access to those processes and resources.

8.4 A COVID-19 example

The nature of doing research and immersing yourself in data and theoretical concepts is that you start to see examples of theory happening outside your data. I was no exception to this. I was, as a consequence of my research, perhaps bound to start paying more attention to the assemblages, comparisons, qualculation and syncretism in everyday life and in my own work. Latour and Law had already made this clear theoretically at least, but as well as seeing these concepts emerge in how I related to others, and in how I started to make decisions and judgements, I was also able to apply these concepts very clearly to the understanding of another disaster; COVID-19, a public health emergency[31] involving a biological contaminant. In late February 2020 I found myself drafted in to support the response by UK rail operators to the pandemic. This was a job which involved trying to understand how hastily written public health legislation applied in stations and on trains, and to different bodies. I spent hours reading legislation and guidance to determine whether trolley service counted as a 'takeaway' service, and trying to decipher where boundaries for face mask use were defined (and by whom).[32]

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[31] As highlighted in section 0, defining disaster/emergency is difficult. In using the term 'public health emergency' and drawing attention to the biological contamination present in the COVID pandemic, I am aware that it frames the pandemic in health terms only and ignores other impacts of the pandemic that I could readily also highlight. The COVID pandemic has also been described in many other ways, including as an economic, political, educational and environmental disaster (e.g. World Bank, 2020; OECD, 2021; Adolph et al., 2021; The Economist, 2022).

[32] At one point even uttering the word 'facemask' would lead to sighs and eye rolls. It was nigh on impossible to determine a single way through the new legislation and guidance being applied in different parts of the UK. Trains and train passengers have an annoying habit of moving through different spaces and jurisdictions along a single route.

I offer the following points about COVID to demonstrate how working with these STS concepts in a disaster management context might highlight new ways of thinking or to pay attention to overlooked or hidden aspects of scientific knowledge making. I will concentrate on three points from the UK's response.

Multiplicity in asking and answering. Multiple assemblages tackled the same issues differently. In the UK since 2009 formal emergency management structures have included access to scientific advice and guidance from social and natural scientists through two primary routes. At a local level, local resilience forums (LRFs) access scientific and technical advice (usually gleaned from subject matter experts within the local responder community) via the Science and Technical Advice Cell (STAC). The Scientific Advisory Group for Emergencies (SAGE) fulfils a similar role at a national level (SAGE, 2022a). In response to the COVID-19 pandemic SAGE sought expertise from a diverse pool, including academia, public sector, industrial and commercial communities. The term 'SAGE' became a household name during COVID, not least because of controversies about who was in SAGE, the evidence they were considering – or not (SAGE, 2022b) and to what extent government decisions and guidance related to that evidence. Outside these formal structures, an 'Independent SAGE' was established by an alternative group of scientists 'to provide independent scientific advice to the UK government and public on how to minimise deaths and support Britain's recovery from the COVID-19 crisis' (Independent SAGE, 2022). This was because there were disagreements about the questions being asked of science, who was providing an answer, the methods being used to answer them and what was happening with the responses to those questions. The SAGE vs. Independent SAGE debate[33] is a good example showing that science in emergencies is not always 'unified' and that certain assemblages are able to operate in certain spaces and others are not. The qualculations produced by SAGE and by Independent SAGE were taken seriously in different places and at different times.

The potential for multiplicity existed not only in being able to define the questions being asked, but also in terms of agreeing how 'the answer' was arrived at. This became very clear during COVID when countries were trying to establish how many deaths had been caused by the disease. A COVID death in the UK was not the same as a COVID death in Germany. This is because each of those answers incorporated different factors in order for the death to 'count', such as whether a positive test was required, whether a clinical diagnosis was sufficient, whether the death occurred in a hospital, or whether any death in relation to a positive case was counted (WHO, 2020). This made comparisons between different statistics complicated.

Influential assemblages. Many devices were developed for tracking and monitoring the spread of the disease within the UK population. One device that many people are now familiar with is the ubiquitous Lateral Flow Device (LFD) test (sometimes referred to as LFTs). At its most simple an LFD test is a device for making visible COVID's presence in a human body when it might otherwise remain undetected, or it confirms COVID's presence when symptoms suggest it is resident. The Lateral Flow Device itself cannot do this alone – alongside a white lateral flow device (the bit of the kit we most eagerly watched for signs of the right lines to emerge) test kits using LFDs also involve solutions for mixing, swabs for inserting into nostrils and or the backs of throats, and leaflets detailing both the specific way in which the manufacturer wanted the user to perform the test as well as instructions on what should happen to the results generated by the test. LFD tests sit within an ever-changing array of networks of tools for making the virus visible in and to an individual human, as well as monitoring levels of viral transmission in a community or a population as a whole. These networks and assemblages include supply chains linking the end user with the manufacturer, a person being tested, a method of taking the test, places and spaces for testing – e.g. walk and drive-in testing centres, appointment booking systems, contact tracers, guidance on who should have access to LFDs (or PCRs) tests – when and under what circumstances, distribution networks getting LFD test kits out to members of the public (or key workers), QR code check-in systems at venues, and COVID apps that 'ping' you. As time progressed, the configurations of the

[33] On 4 May 2020 Sir David King, a former UK Chief Scientific Advisor to both Prime Ministers Tony Blair and Gordon Brown, set up an 'independent' group of scientists to scrutinise and develop scientific positions on the COVID-19 pandemic response in the UK. This came in response to concerns about transparency about who attended the 'official' SAGE meetings and what their political, as opposed to scientific motivations might be. There were concerns raised by attendees that the attendance at SAGE by Dominic Cummings, Boris Johnson's Chief Political Advisor was *inappropriate,* given his political position. At the time membership of SAGE was not publicly divulged, although this has since changed. King is quoted as saying, "I am not at all critical of the scientists who are putting advice before the Government ... but because there is no transparency, the government can say they are following scientific advice but we don't know that they are." (Stone, 2020).

networks of tools for making COVID visible have started to reduce and the qualculative resources available for judgements about COVID have changed. In the England for example, LFD kits ceased being provided for free to most members of the public from 1 April 2022 as part of the ‘Living with COVID Plan’ (Department of Health and Social Care, UK Government, 2022), and the NHS reporting system does not accept results from privately bought LFD test kits (BBC, 2022). The LFD kits available are no longer connected to an NHS reporting system, contact tracers, QR codes or Government rules about reporting the results or even whether to stay at home in the event of a positive result.

Dismantling assemblages for creating scientific knowledge about contamination. Since LFD test kits ceased to be provided free of charge to members of the public in England on 1 April 2022, in Scotland on 18 April 2022 (Scottish Government, 2022), and in Wales on 31 July 2022 (Welsh Government, 2022), networks of knowing about COVID in the UK are parts of a smaller assemblage of a devices and practices, one which is more personalised to the individual. Individuals can of course still opt to use an LFT at home, but this is no longer part of a larger networked monitoring system controlled by government. Living in England, I can either use one of my old free NHS COVID tests, or buy one from a pharmacy, but the knowledge that is produced now sits in a smaller knot of assemblages, relevant to a very limited number of people (essentially me and my immediate friends, family and neighbours), or limited situations (e.g. my ability to meet travel requirements still in place in other countries, or because I am visiting someone who is still vulnerable to COVID). This example shows that the materialities of networks of knowing can be quite durable even when the social entities in the same assemblages fall away and also that the assemblages of knowledge production evolve over time to address

Figure 56: The residues of COVID assemblages in a Gloucestershire village

different questions. There are still roundel stickers on the floors of publicly accessible buildings, and signs on doors asking me to ‘keep 2m away’ or telling me it is mandatory to wear a face mask, long after any legal requirement to do so has fallen away in the UK. The door of my village football clubhouse still asks for those entering to scan a QR code so that they are traceable by a system no longer there, the village hall still has a 2m line painted onto the pavement outside to assist with distancing (see Figure 56). These are the residues of old assemblages of knowledge making in emergencies, something which Anna Tsing and colleagues might refer to as ghosts or ‘the traces of more-than-human histories through which ecologies are made and unmade’ (Tsing et al, 2017: G1).

8.5 Persistence

Social scientists in Japan have been called on to commit to undertaking 'urgent ethnograph[ies]' of disaster (Gill, 2014: 152). This thesis' ethnography in contrast, has taken time and effort to manage over 6 years. I argue that it is important to capture the responses to disasters as they happen in the initial days, weeks and months, whilst also continuing to persist in being attentive to what is going on, ten, twenty or thirty years later. In a radiological disaster such as Fukushima the bulk of contaminants have a half-life of over 30 years, so there is room also for taking things more slowly and working with the consequences of this temporality.

'*Madei'* is a local expression from the village of Iitate where I visited during my fieldwork. It has been translated as 'politely' (Mizoguchi, 2019: 180) or 'with sincerity' (Kanno, 2016: 64) and 'refers to time and effort that go into agriculture' (Budgen, 2021). To me, calling something *Madei* indicates care and attentiveness, and that things can't always be rushed. Some of my observations, particularly those which account for the temporal aspects of radiation knowledge creation and use, only become visible or captured because they are not part of a hurried research project completed soon after the disaster begins to unfold. This thesis is therefore an offer of *Madei* ethnography, or slow ethnography, one that provides an empirical (always partial and situated) record of the response to, and ongoing recovery from the nuclear disaster that began in Fukushima, Japan in March 2011 and continues to be experienced in different ways to this day. The subtitle of the concluding paragraphs – '*Persistence'* – speaks in part to my own tenacity over the past 6 years in continuing with this project and my hope that some of my arguments 'stick', but also to the persistence of radiological contamination and the assemblages we have for making it visible.

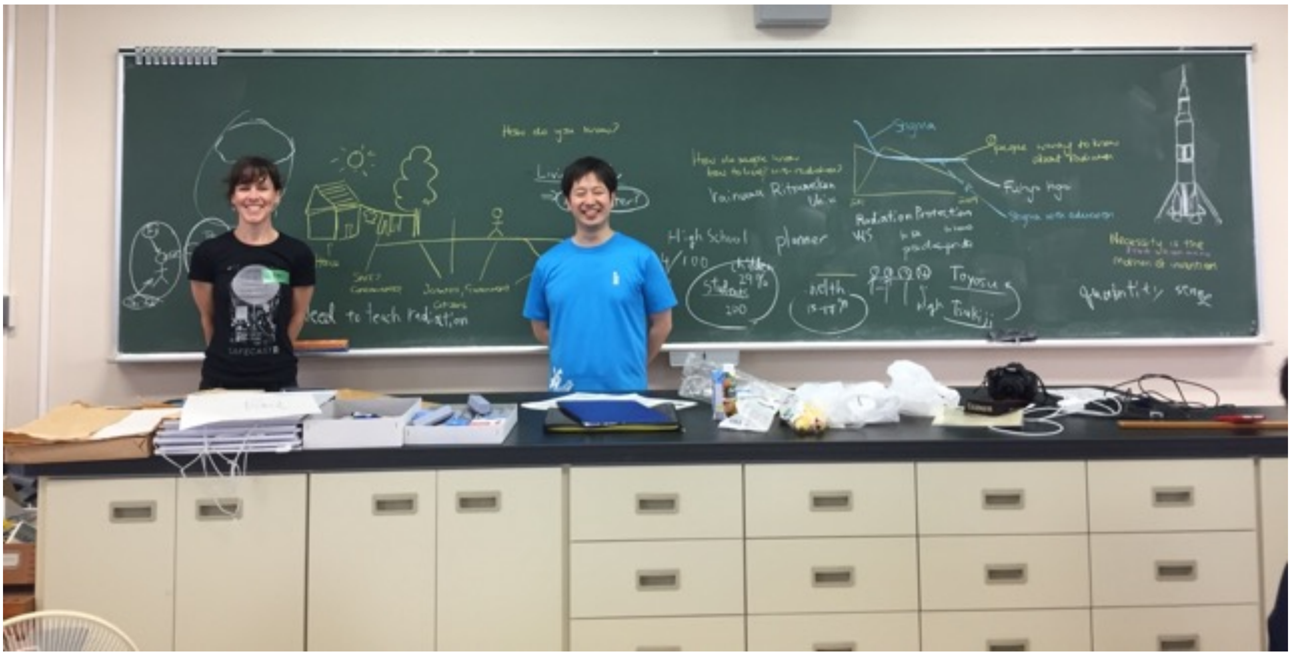

Figure 57: Talking about my research with a High School teacher in Fukushima

One of my participants noted once: *'We're monitoring radiation and Louise is monitoring us!'* I hope my own monitorings and the things that I chose to note, pay attention to and follow (or to ignore or exclude), provide a novel way of telling a story about the production of radiation knowledge in Japan since March 2011. There is so much more I could have said and so many more stories I could have retold – about the choices of colours on radiation maps, about leaving my radiation monitor on a bus and it continuing to record data for me the whole time until it was returned by a physicist involved in the Hiroshima bombings, about being left in charge of the Safecast car for two days in Fukushima and driving through the backroads near Namie past boarded up houses, about flying drones over the ziggurats of contaminated waste bags, about the paradoxes of doing 'citizen science' and hiding in plain sight, about opening up and poking about inside radiation monitors, about the dangers of bears, poisonous plants and the police when collecting samples for testing, or even the issue of how to get a very deceased and very flat dry cat into a radiation monitor. These stories did not make the cut not because they did not have something valid to say about the making of scientific information in contamination events but because crafting a compelling and readable narrative meant making decisions about which stories were the most important to the points I was making.

I will however end with one short vignette relayed to me by one of my key participants. We had spent many hours together travelling and in the office. Our conversations were always illuminating and often very funny too. I am not sure what he would make of all this STS theory – it will almost certainly not sit well with him as a technically-minded radiation monitoring specialist. But he described the following anecdote to me in the car:

> In July 2011 he brought some shiso which was growing wild in his garden, into his groups' office space, which shared an office with another separate organisation. Shiso is a bitter plant that looks a bit like nettle leaves and is widely used in making pickled plums and decorating bento boxes. His house is in Ichikawa close to an area of Tokyo which on 19th March 2011 was subject to notable levels of radiation contamination. In order to test the shiso, he wanted to dry it off so put it in the microwave in the kitchen of the office. 'No! You can't do that; it's radioactive!' cried one of the volunteers. 'We're going to use this for food later!' To which he replied – 'But it is food!' (Fieldnotes, 2 May 2019)

Just the act of preparing something to be tested to determine if it was contaminated was enough to render the shiso leaves as no longer food, but radioactive. At what point or how does something become radioactive and not food?

8.5.1 Concluding Remarks

STS scholars frequently highlight the complexity embedded in the seemingly simple. My intention has always been to challenge professional thinking on the making and use of scientific 'things' (evidence, advice, practices, tools) in emergencies and it matters to me that even if there is not an objectively 'right' way of doing things, then there might at least be opportunities for making things better, more inclusive of the multiplicity that I saw. Disaster managers, public health specialists and radiation protection advisors (to name just a few) have difficult and often invisible jobs (see Easthope, (2022) for a very frank reflection on the professional landscape they work in). I do not wish to overburden them by just making a claim that 'things are more complex than your plans suggest', not least because this would come as no surprise to them. Instead, I would like to call for adjustments in how we think and reflect on the ways in which disaster management is done and how the making of science in response to contamination emergencies is conceptualised in minds, plans, arrangements, exercises, training, tools and equipment. This thesis offers various questions throughout, by which to provoke and challenge some of the black and white statements in emergency plans and guidance. Who is that data for? What is it doing? Who or what is excluded or included from participating in asking questions or determining the answer? Where is 'science' being done in emergencies? Where are the impacts of this doing being felt? What other practices does contamination science relate to, enable or prevent?

It is my sincere desire to use these findings to make a difference to how we (speaking as a someone with a professional and personal interest in responding well to emergencies) work together in response to contamination events. I hope that it enables a greater appreciation of what to expect not just in the short- or medium-term response to a contamination disaster, which unfolds over months and years, but over a more sustained period of time – over decades. I hope it prompts some questions for which there may be no easy answers. Emergency planners like clarity in what is expected of them. We like post incident recommendations reports which make it clear what we need to do. I push back on that here with more questions than answers. I hope, in short, that it unsettles.

In a time where confidence and trust in the use of science in emergencies has been particularly bruised, it is an opportune moment to think about how doing science in emergencies might be done otherwise, how we can get more comfortable with uncertainty and (non)coherence, how our organisational structures and spaces affect the socio-materialities of government-led responses to emergencies, and how assemblages might be created, cared for or dismantled in the future.

Figure 58: When science escapes the lab. Top: scientists examining different conditions leading to wildly different contamination levels in the same plant and at the same farm, (bottom left) me collecting samples of wild garlic to take to the food monitoring station, (middle right) the bag of wild garlic is monitored and below the 100Bq/kg limit, so can be sold and is otherwise deemed safe for consumption, (bottom right) I and the scientists negotiate who gets what of the 'safe wild garlic and swap recipes, (middle left) a chef at my hotel is excited to create me a wild garlic meal with my fresh 'scientific' vegetables.

Appendices

Appendix A: References and citations

A

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Appendix B: Research Activities

The following table details the various research activities that I undertook as part of this project and it also provides a reference for my data in relation to quoted material in the main body of the text.

Date	Details	Kind of activity
2018.06.22	Initial meeting with Fukushima journalist, resident and gatekeeper for trips to Fukushima	Informal meeting –fieldnotes
2018.06.26	Informal meeting with another STS researcher at Waseda University	Informal meeting –fieldnotes
2018.06.27	Initial informal meeting with scientists from the Department of Environmental Health at the National Institute of Public Health	Informal meeting –fieldnotes
2018.06.27	Informal meeting with STS researcher form Komazawa University who has done similar research	Informal meeting –fieldnotes
2018.07.02	Attendance at Citizen Science Lab –Low Dose Radiation Team Monthly meeting –other attendees from different scientific organisations in public and private sector	Fieldnotes
2018.07.03	Initial meeting with members of a citizen science group based in Tokyo –visit to their office and informal discussion	Informal meeting –fieldnotes
2018.07.04	Interview with events organiser at Fukushima Prefectural Centre for Environmental Protection, tour of the centre, radiation monitoring lesson for school children and informal chat with school children	Formal interview and fieldnotes
2018.07.04	Interview with two citizen science organisers at a non-profit organisation in Fukushima City	Formal interview
2018.07.04	Visit to public exhibition at the Environmental Regeneration Plaza- with information provided by one of the members of staff present	Fieldnotes
2018.07.05	Interview with director of a citizen science laboratory and non-profit organisation near Fukushima City	Formal interview
2018.07.05	Visit to food detection laboratory at a local farmers market in Fukushima, informal discussion about food monitoring, watched food monitoring activity.	Informal meeting –fieldnotes
2018.07.05	Interview with author of a book on SPEEDI (governmental radiation monitoring network prior to Fukushima)	Formal interview
2018.07.06	Informal meeting with British university lecturer who has researched evacuation economics in Tokyo	Informal meeting –fieldnotes
2018.07.07-08	Attended conference as audience member. Conference at Meiji Gakiun University, Yokohama. Fukushima Nuclear Evacuees: Researchers' Findings and the Voices of the Victims. International Symposium with evacuees and informants present and speaking alongside the researchers	Fieldnotes
2018.07.09	Interview with founder director of a citizen radiation data gathering non-profit organisation in Tokyo	Formal interview
2018.07.09	Interview with director of a citizen science laboratory in Tokyo and tour of lab and WBC test	Formal interview and fieldnotes
2018.07.09	Interview with university professor in Gunma and maker of a publicly available map on radiation contamination	Formal interview
2018.07.10	Interview with a 'Local mediator' for Date City and other areas in Fukushima –first interview	Formal interview
2018.07.11	Interview with director of a non-profit in Tokyo made up of academics and scientist specialists looking at different facets of science and society	Formal interview
2018.07.16	Interview with a 'Local mediator' for Date City and other areas in Fukushima –second interview	Formal interview

2018.07.16	Founder director of a citizen science data gathering NPO in Tokyo – second meeting informally, discussing maps and data	Informal meeting –fieldnotes
2018.07.27	Interview with two scientists making maps and research on environmental contamination for JAEA and NRA	Formal interview
2018.08.04	Helped set up and participated in a children's radiation monitoring Summer Camp in Tokyo organised by citizen radiation monitoring group	Fieldnotes
2018.08.05	Informal chat in car with citizen radiation monitoring group regarding a joint project with a national post service	Fieldnotes
2018.08.05	Helped set up and facilitated a Radiation Protection Workshop in Fukushima with children from Fukushima and France present	Fieldnotes
2018.08.06	Interview with academic who set up a science media centre in Japan	Formal interview
2018.08.07	Interview with main coordinator of a lab collective in Fukushima-gathering data from multiple citizen run radiation monitoring labs in Japan	Formal interview
2018.08.08	Interview with PR Manager of a citizen monitoring lab and clinic in Iwaki City and tour of lab	Formal interview and fieldnotes
2018.08.08	Interview with municipality officials from decontamination department at a Fukushima City	Formal interview
2018.08.09	Interview with founder of mothers group that works on school monitoring	Formal interview
2018.08.10	First organised tour of the exclusion zone and evacuated areas of Fukushima	Fieldnotes
2018.08.10	Informal chat in car on way back from tour about access to data in the early stages of the incident	Informal meeting –fieldnotes
2018.08.10	Informal meeting with owner of a reopened traditional inn and participant in local monitoring and mapping in Futaba, Fukushima	Informal meeting –fieldnotes
2018.08.15	Interview with founder director of a citizen science data gathering organisation in Tokyo	Formal interview
2018.08.15	Made own Geiger counter and assisted in the update of steps for the instruction manual of the kit	Fieldnotes
2018.08.17	Interview with previous member of the Science Council of Japan and STS author	Formal interview
2018.08.17	Interview with scientist and artist working on visualisation of radiation using autoradiograph techniques and tour of their lab	Formal interview
2019.04.08	Revisiting contacts/colleagues/informants at a citizen science group in Tokyo	Fieldnotes
2019.04.09	Informal chat with ocean radiation specialist from US about ocean radiation monitoring	Informal meeting –fieldnotes
2019.04.11	Attended a talk by Michael Schellenberger on nuclear weapons and nuclear power. After talk was able to go to dinner with the host, the speaker and other academics.	Fieldnotes
2019.04.15-17	HeARD event in Fukushima (Health and Resilience in Disasters) – collaboration between Edinburgh and Fukushima Medical University (FMU). Hosted at Minamisoma General Hospital and FMU. British and Japanese researchers looking at health and resilience in disasters. I presented as well as participating in numerous facilitated discussions.	Fieldnotes
2019.04.17	Second organised tour of the exclusion zone and evacuated areas – some elements same as last visit and others new. Visited another CRMO in Minamisoma, Fukushima.	Fieldnotes
2019.05.03	Visit to the Tokyo Rinkai Disaster Prevention Park.	Fieldnotes

2019.05.05-06	Participated in community farming event in Yamakiya, Fukushima – foraging, monitoring, farming skills, learning about Fukushima and BBQ. Event attended by various scientists and their families as well as informal discussions with local farmers.	Fieldnotes
2019.05.06	Interview with a local farmer about radiation monitoring on the farm	Formal interview
2019.05.07	Interview with Fukushima-based lawyers about contamination, measuring and compensation process	Formal interview
2019.05.14	Interview with citizen monitoring group leader and Inn owner in previously evacuated village, Fukushima	Formal interview
2019.05.14-15	Visit to Fukushima –flying drones over the coastline near Daichi to monitor contaminated waste sites, hearing more about the Lush Cosmetics Project –using products from contaminated areas to make cosmetics.	Fieldnotes
2019.05.15	Informal discussion (in Odaka, Fukushima) with radiation monitor specialist and citizen science group leader,from Tokyo	Informal meeting –fieldnotes
2019.05.15	Interview with a Zen Priest at his temple just outside Fukushima City – he has been monitoring radiation in the area since before Fukushima incident and has very early data from Fukushima.	Formal interview
2019.05.16	Informal interview with farmers of 'wild mountain vegetables' in Iitate, Fukushima	Fieldnotes
2019.05.16	Informal chats in the car with scientists about radiation monitoring and their work as we travelled to the fieldsite.	Informal meeting –fieldnotes
2019.05.16	Accompanied scientists from a national institute on a fieldtrip to Iitate (village in Fukushima) –working with local farmers to understand variation in measurements across the same crop and a second activity was to compare airborne data with ground-based data to see why discrepancies.	Fieldnotes
2019.05.21	Interview with a senior scientist from a US institute about radiation monitoring in the ocean	Formal interview
2019.05.31	Interview with citizen science radiation monitoring group member –in charge of design of mapping tool and data archiving	Formal interview
2019.06.03	Interview with two scientists about their radiation monitoring work at a national institute and D-Shuttles.	Formal interview
2019.06.03	Visit to national institute and tour of a radiation monitor calibration suite to see calibration of radiation monitors.	Fieldnotes
2019.06.13	Interview with Chief of Ionizing Standards Group at a national institute –also a member of the ICRP group on standards –interview about standards and measurement.	Formal interview
2019.06.27	Short interview with medical doctor at FMU about their role in setting up the Fukushima Health Management Survey	Formal interview plus fieldnotes
2019.06.27	Interview with president of a citizen science radiation monitoring and community regeneration group in Iitate.	Formal interview
2019.06.27-28	Tour of Iitate village (Fukushima) –included 3/11 key sites as well as other lovely spots. Saw old schools, new village community centre, abandoned farms, new farming practices, soil museum, holiday park, mountain quarry etc.	Fieldnotes
2019.07.16	Informal chat over dinner and a drink with journalist and academics.	Fieldnotes
2019.07.21	Helped the set up of and facilitation of a workshop for school children in Fukushima –learning how to make radiation monitors and spoke with high school teacher about my research.	Fieldnotes
2019.07.22	Interview with prefectural director at Prefectural offices, about radiation monitoring and evacuation etc.	Formal interview

2019.07.23	Interview with citizen science group leader in southern Fukushima – links to ICRP.	Formal interview
2019.07.24	Attended talk at Tokyo University by Daniel P. Aldrich on his book Black Wave.	Fieldnotes
2021.03.11	Part of organising committee and also host of the European section of Safecast 10 a 10-year anniversary event about radiation monitoring in Fukushima. 16 hour live-screened event –including discussions with various stakeholders in radiation monitoring –in Japan and internationally	Fieldnotes
2021.10.28	Organised and hosted Nuclear Futures Creative writing and psychosocial geography event –in person	Fieldnotes
2021.12.21	Informal chat with member of CRMO in Tokyo	Fieldnotes
2021.12.22	Interview with the lead developer behind the D-Shuttle	Formal interview
2022.04.11-23	Organised and hosted Nuclear Futures exhibition at the Storey in Lancaster	Fieldnotes
2022.05.03	Hosted online discussion about Nuclear Futures and the NW of England	Fieldnotes
2022.06.28	Informal conversation with Nuclear specialist formerly from UK regulator	Informal meeting –fieldnotes
2022.07.15	Formal interview with nuclear specialist formerly head of UK Regulator nuclear incident team	Formal interview

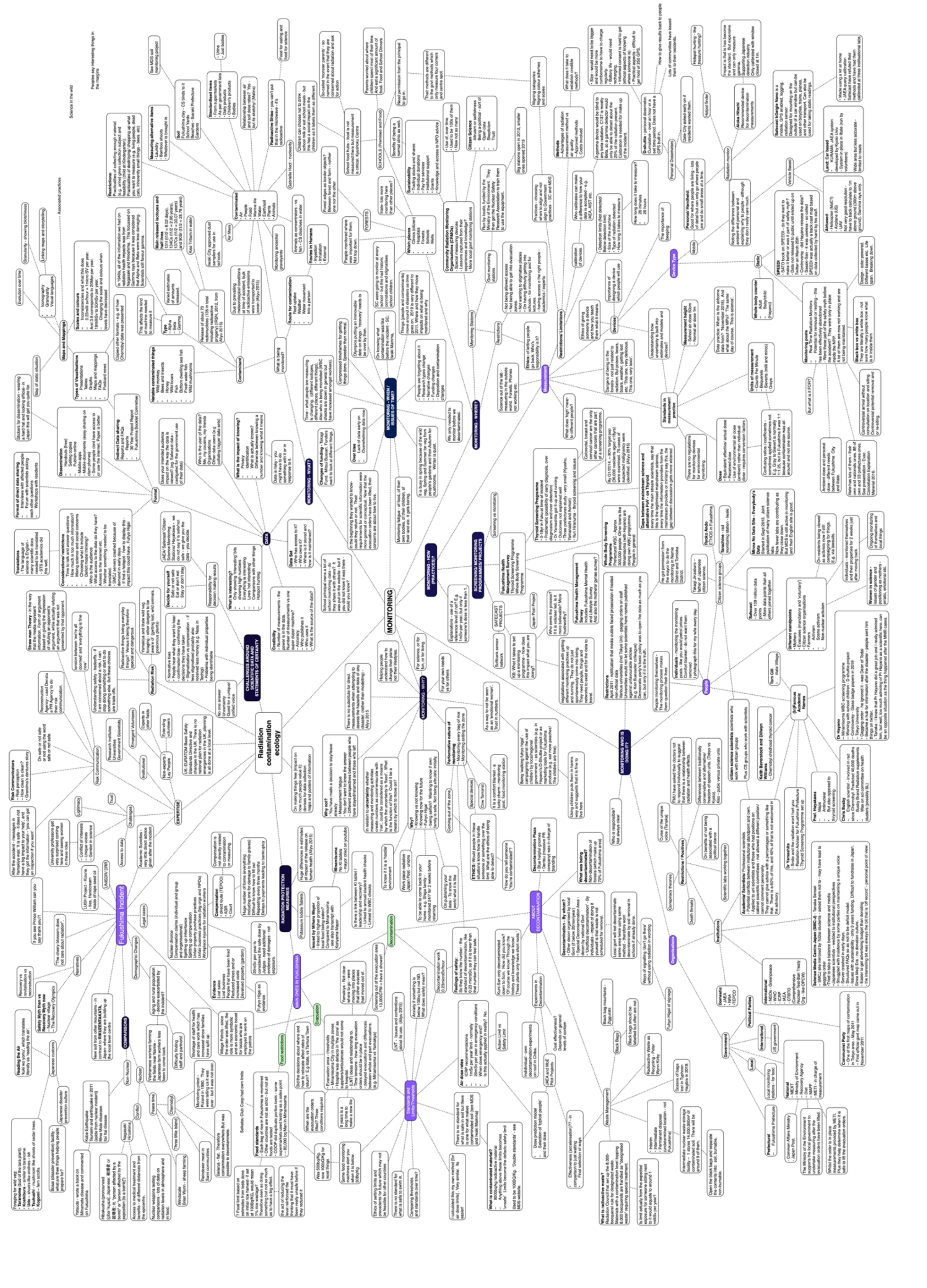
Appendix C: Conferences papers and posters

The following details the conferences I presented at whilst developing my argument for this thesis.

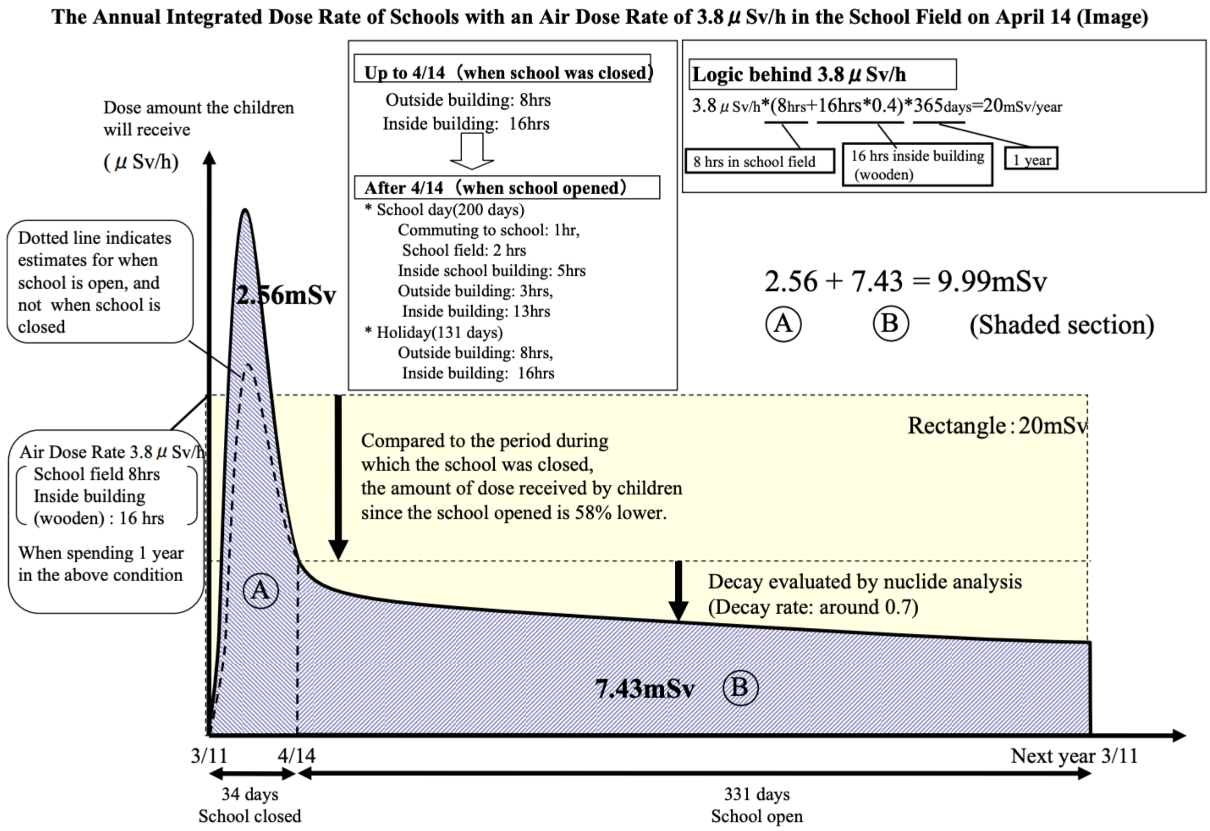
Date	Details
2022.05.10-12	*0.23microsieverts: Fear line, bible or policy. Comparisons and thresholds in post-Fukushima Japan* [Paper presentation]. Ricomet (part of NORM-X) 2022. Utrecht, Netherlands. Winner of prize for extending theory.
2022.03.11	*Individual Dose Measurement: Personal Dosimetry Systems and the Fukushima Nuclear Disaster* [Paper presentation]. Symposium –Health and the 2011 Great East Japan Earthquake and Tsunami: Risk, Disaster and Resilience, and Working as a Risk Assessment, Health and Environment. Online.
2021.10.6-9	*Finding the Right Pole and Hiding in Plain Sight. Citizen Radiation Monitoring Methods* [Paper presentation]. 4S Annual Meeting 2021. Toronto, Canada and worldwide.
2021.03.04	*Making contamination knowable: The tools and practices of radiation monitoring in Fukushima* [Poster presentation]. Fukushima Dai-ichi and the Ocean: 10 Years of Study and Insight. Online
2020.12.02	*Radiation monitoring after Fukushima: Citizen Science* [Paper presentation]. Office for Nuclear Regulation Protection Team Study Day. Online.
2020.08.18-21	*Monitoring Radiation in Fukushima: (Re)Constructing the Genba [Paper presentation].* EASST 2021. Prague, Czech Republic [online format].
2020.01.29	*Radiation and Time: Half-lives –My Own and that of Radioactive Isotopes* [Paper presentation]. Qualitative Research Symposium 2020. Bath, UK.
2019.12.12-13	*Contamination, Public Health and the Olympics: [De]Constructing 'safety' in Japan's Reconstruction Olympics* [Paper presentation]. Health and Resilience in Disasters (HeaRD) Symposium. Edinburgh, UK.
2019.09.26	*Contamination: What it means to me. Experiences and Comparisons – Fukushima and* ……..? [Paper presentation]. Emergency Planning Society (EPS) CBRN Working Group. Chris Abbott Memorial Lecture 2019. Bury St Edmonds, UK.
2019.09.09-10	*Colouring by numbers, or 'the map is not the radiation'*[Paper presentation]. AsSIST-UK Conference 2019 [Paper presentation]. Manchester, UK.
2019.09.11	*Dystopian Futures: Emergency Planning in 2030. A 'Years and Years' Themed Panel and series of short presentations: 'Measuring and Monitoring Contamination'* [Paper presentation]. Emergency Planning Society (EPS) Study Day 2019.
2018.04.15-17	*Measuring and Monitoring Contamination. The practices of radiation monitoring and representation* [Paper presentation]. Health, Risk Disaster (HeaRD) UK-Japan Network Symposium.
2018.09.09-10	*The Social Life of Contamination: A Science and Technology Studies approach using Fukushima as a case study* [Poster presentation]. British Association of Japan Studies (BAJS) 2018. Sheffield, UK. Winner of poster competition.

Appendix D: Initial mind map of data

This image is not intended to be legible, but to demonstrate the complexity of the data I worked with.



Appendix E: The calculation behind the threshold set for the reopening of schools in Fukushima



Source: MoE 2011. Trial Calculation of Actual Integrated Exposure Dose of Students, under assumption of a Living Patterns of Students of Schools, etc. with 3.8μSv/hr Air Dose Rates in Schoolyard, etc. https://www.mext.go.jp/component/english/__icsFiles/afieldfile/2011/05/27/1306601_0512_5.pdf

Appendix F: List of figures

Appendix G: List of Tables

In memory of Chris Bullen 1982–2022.

He would have enjoyed the numbers and almost certainly hated comic sans.

It's fair to say that I got mildly obsessed by the network of fixed radiation monitoring posts in Fukushima